

First NASA Aerospace Pyrotechnic Systems Workshop

(NASA-CP-3169) THE FIRST NASA
AEROSPACE PYROTECHNIC SYSTEMS
WORKSHOP (NASA) ~~417 p~~

N93-20132
--THRU--
N93-20153
Unclas

492947

4380

H1/28 0146951

*Proceedings of a workshop held at
Lyndon B. Johnson Space Center
Houston, Texas
June 9-10, 1992*

NASA

First NASA Aerospace Pyrotechnic Systems Workshop

*Compiled by
William W. St. Cyr
John C. Stennis Space Center
Stennis Space Center, Mississippi*

Proceedings of a workshop sponsored by the
Pyrotechnically Actuated Systems Program,
Office of Safety and Mission Quality,
National Aeronautics and Space Administration,
Washington, D. C., and held at
Lyndon B. Johnson Space Center
Houston, Texas
June 9–10, 1992



National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Program

1993

Workshop Management

NASA Pyrotechnically Actuated Systems Program

Norman R. Schulze, NASA Headquarters - Program Manager

Host Representative

Barry C. Wittschen - NASA, Lyndon B. Johnson Space Center

Workshop Coordinator

William W. St. Cyr - NASA, John C. Stennis Space Center

Workshop Program Committee

Norman R. Schulze
National Aeronautics and Space Administration
Code QE
Washington, DC 20546

James Gageby
The Aerospace Corporation
P. O. Box 92957
Los Angeles, CA 90009

Laurence J. Bement
National Aeronautics and Space Administration
Langley Research Center
Code 433
Hampton, VA 23665

Anthony Agajanian
Jet Propulsion Laboratory
Code 158-224
4800 Oak Grove Drive
Pasadena, CA 91109

William W. St. Cyr
National Aeronautics and Space Administration
John C. Stennis Space Center
Code HA20 - Building 1100
Stennis Space Center, MS 39529

Table of Contents

WELCOMING ADDRESS	vii
<i>Henry Pohl, NASA, Johnson Space Center</i>	
KEYNOTE ADDRESS	ix
<i>Dr. Daniel Mulville, NASA, Washington DC</i>	
 SESSION 1 - Pyrotechnically Actuated Systems	
NASA Pyrotechnically Actuated Systems Program	1
<i>Norman R. Schulze, NASA, Washington DC</i>	
Determination of Pyrotechnic Functional Margin	33
<i>Laurence J. Bement, NASA Langley Research Center, Hampton VA</i> <i>Morry L. Schimmel, Schimmel Co., St. Louis MO</i>	
Development of the NASA Standard Gas Generator (NSGG)	51
<i>Laurence J. Bement, NASA Langley Research Center, Hampton VA</i> <i>Harold Karp, Hi-Shear Technology Corp., Torrance CA</i> <i>Morry L. Schimmel, Schimmel Co., St. Louis MO</i>	
Pyrotechnically Actuated System Database and Applications Catalog (Talk Only)	83
<i>Paul Steffes and Floyd Smith, Analex Corporation, Brookpark OH</i>	
A Semiconductor Bridge Ignited Hot Gas Piston Ejector	93
<i>M.C. Grubelich and R.W. Bickes, Jr., Sandia National Laboratories,</i> <i>Albuquerque NM</i>	
 SESSION 2 - Laser Initiation	
Small ICBM Laser Firing Unit (LFU)	123
<i>Jim Aloise and Larry Snarr, Santa Barbara Research Center, Goleta CA</i>	
Laser-Initiated Ordnance for Air-to-Air Missiles	137
<i>David R. Sumpter, McDonnell Douglas Missile Systems Co., St. Louis MO</i>	
Laser Diode Ordnance Design (Talk Only with Video)	149
<i>Arthur D. Rhea, Ensign Bickford Aerospace Co., Simsbury CT</i>	
Introduction of Laser Initiation for the 48-inch Advanced Solid Rocket Motor (ASRM) Test Motors at Marshall Space Flight Center (MSFC) (with Video)	157
<i>C.J. Zimmermann, Aerojet - ASRM Division, and</i> <i>G.E. Litzinger, Aerojet - APD Division, Orangeville CA</i>	

Table of Contents (continued)

SESSION 2 - Laser Initiation (continued)

Laser Diode Ignition Activities at Sandia National Laboratories	179
<i>J.A. Merson, F.J. Salas, W.W. Chow, J.W. Clements and W.J. Kass,</i> Sandia National Laboratories, Albuquerque NM	
Laser-Based Firing Systems for Prompt Initiation of Secondary Explosives (Talk Only) . .	197
<i>Kent D. Meeks and Robert E. Setchell,</i> Sandia National Laboratories, Albuquerque NM	
Proposed System Qualification and Test Requirements for the Microlaser Ordnance System (Talk Only)	199
<i>D.F. Waldo and B.A. Soltz,</i> McDonnell Douglas Electronic Systems Co., St. Louis MO	
Description of a Thirty-two (32) Output Laser Firing Unit Being Developed for the Phillips Laboratory (Video Only)	201
<i>Richard G. Hallmark,</i> Lockheed Missiles & Space Co., Sunnyvale CA (Presented by Jerry Callaghan)	
Proposed System Safety Design and Test Requirements for the Microlaser Ordnance System (Talk Only)	203
<i>B.A. Soltz and D.F. Waldo,</i> McDonnell Douglas Electronic Systems Co., St. Louis MO	
Laser Diode Ignition Characteristics of Zirconium Potassium Perchlorate (ZPP)	215
<i>Jerry Callaghan and Scot Tindol,</i> Hi-Shear Technology Corp., Torrance CA	
Advances in Laser Diodes for Pyrotechnic Applications	223
<i>Richard R. Craig,</i> Spectra Diode Laboratories, Inc., San Jose CA	

Table of Contents (continued)

SESSION 3 - Modeling and Analysis

Laser Diode Initiated Detonators for Space Applications	247
<i>D. W. Ewick, J. A. Graham and J. D. Hawley, Ensign Bickford Aerospace Co., Simsbury CT</i>	
Portable Fiber Optic Coupled Doppler Interferometer System for Detonation and Shock Wave Diagnostics	257
<i>Kevin J. Fleming, Sandia National Laboratories, Albuquerque NM</i>	
Development and Testing of Hermetic, Laser Ignited Pyrotechnic and Explosive Components	275
<i>D.P. Kramer, T.M. Beckman, E.M. Spangler, A.C. Munger, and C.M. Woods, EG&G Mound Applied Technologies, Miamisburg OH</i>	
Application of the MESA Reactive Hydrocode to Space Vehicle Explosive Ordnance Systems	287
<i>Selma Goldstein, The Aerospace Corporation, Los Angeles CA</i>	
Precision Linear Shaped Charge Severance of Graphite-Epoxy Materials	329
<i>Manuel G. Vigil, Sandia National Laboratories, Albuquerque NM</i>	
Explosive Component Acceptance Tester Using Laser Interferometer Technology	375
<i>Richard D. Wickstrom and William W. Tarbell, Sandia National Laboratories, Albuquerque NM</i>	
Pyrotechnic Modeling for the NASA Standard Initiator and Pin Puller	397
<i>Joseph M. Powers and Keith A. Gonthier, University of Notre Dame, Notre Dame IN</i>	
First Deployment of the Shuttle Drag Chute (Video Only)	
<i>Keith E. Van Tassel, NASA Johnson Space Center, Houston TX</i>	

Table of Contents (continued)

SESSION 4 - Panel Discussion/Open Forum

Moderator: Norman R. Schulze, Program Manager, NASA Pyrotechnic Actuated System Program and Chairman, NASA/DoD/DoE Pyrotechnic Steering Committee

Panel Members: Jim Gageby, The Aerospace Corporation
Larry Bement, NASA Langley Research Center
Mark Gotfraind, USAF/30th Space Wing
Jere G. Harlan, Sandia National Laboratories
Gerald Laib, Naval Surface Warfare Center
Art Rhea, Ensign Bickford Aerospace Company

Discussion Topics:

1. Comments on pyrotechnic technology coordination.
2. What additional pyrotechnic technology areas should be addressed by:
 - NASA/DOD/DOE Steering Committee
 - Future Workshops
 - the Pyrotechnic Program
3. Can solid state laser safe-and-arm systems meet range safety requirements?
4. Affiliation with AIAA
 - Advance Ordnance Committee
 - Training.
5. Technology transfer between Government and Industry.
6. Open forum among all workshop participants.

Note: The panel discussion and open forum comments were not transcribed are not included in this conference publication.

APPENDIX A - List of Participants

APPENDIX B - Written Questions and Answers

FIRST NASA AEROSPACE PYROTECHNIC SYSTEMS WORKSHOP

WELCOMING ADDRESS:

Mr. Henry Pohl

Director of Engineering

Lyndon B. Johnson Space Center

Houston, Texas

Henry Pohl is the Director of Engineering at JSC. All pyrotechnic activities at JSC fall under his directorate. Prior to becoming the director of engineering, he was Chief, Propulsion and Power Division, and before that was Chief of the Auxiliary Propulsion and Pyrotechnics Branch. His association with pyrotechnics spans over 20 years of service at JSC.

Good morning. On behalf of Aaron Cohen and P. J. Weitz it's my honor and privilege to welcome you to the Johnson Space Center and to the first ever Aerospace Pyrotechnics System Conference. I hope you found your accommodations good last night, found your way down here and you didn't have too much difficulty finding this building this morning. I hope you arrived here early enough to find a parking place. It seems like all of our parking places are out in the back forty but with as much space as we have around here we still don't have enough parking. This is Building 30 and right across the hall over here is the Mission Control Center. The Mission Control Center is the place that put NASA on the map with the statement to Houston that the Eagle has landed back during the Apollo days. It's also the area that you see most often when flights are going on. You either see the Kennedy Space Flight Center with the Shuttle lifting off, or Edward's AFB when

it's landing, or Mission Control in between. That's just a very small part of NASA. NASA is made up of other centers that are not quite as visible. But this is the part that you see in front of the public most of the time. It is a real pleasure to have you here. I hope the weather will hold out for you. I think it will.

There are some things I don't ever fully understand. This is the first Pyrotechnic conference that I am aware of, yet I would say that in the past year we probably had twenty conferences on software, and probably another twenty conferences on avionics. Both of these are multi-billion dollar industries in this day and time. We could take the entire NASA budget put it in software or avionics and it probably would not affect the direction of this very much in this day and time. Yet there's nothing that's more critical or more important to the Aerospace community than pyrotechnics. Back

when I first started out in this business, when we thought of pyrotechnics, we thought in terms of fail safe, and a fail safe device was one of those devices that 50% of the time it didn't work when you wanted it to work. You can have a 30 caliber round in a machine gun, if it duded, you just pulled it out and threw in another one. It's really not until the Apollo program that we started thinking in terms of fail safe, fail operational; the device has to work when you need it to work and it could not operate prematurely. A lot of activity went into developing what I'd call safe functional systems in the 60's. We then kind of got out of that business and went through a kind of stale mate for a long time. It's really invigorating to see today that we are beginning to put some activity and some resources into looking at laser initiated devices, looking at new techniques, innovative new ideas - some of which take advantage of

the latest avionics or solid state technologies.

So it is with a pleasure that I have this opportunity to welcome you here. I hope you have a successful and productive two days. If we can be of any assistance to you in any way, please don't hesitate to call on us. I know Barry will be more than happy to show you around. We do have some beautiful facilities here for those of you who haven't had the opportunity to visit them. Spend a little time and go through Mission Control. We have a self guided tour. Unfortunately most of our displays are being moved out of the visitor's center and being moved into the Space Center Houston, our antique shop as some people call it, which is scheduled to open in October. So with that I thank you and have a good day.

FIRST NASA AEROSPACE PYROTECHNIC SYSTEMS WORKSHOP

KEY NOTE ADDRESS:

Dr. Daniel Mulville
Technical Standards Division
NASA Headquarters
Washington, D. C.

Dr. Daniel Mulville is the Director of the Technical Standards Division in the Office of Safety and Mission Quality at NASA Headquarters. He was formerly the Deputy Director of the Headquarters Materials and Structures Division and responsible for NASA's Composite Technology Program.

Prior to coming to NASA, Dr. Mulville was the Program Manager for Aircraft and Missile Structures Technology at the Naval Air Systems Command and was an engineer at the Naval Research Laboratory responsible for failure analysis of structural components and materials.

Good Morning. It's a pleasure to have the opportunity to address the First NASA Aerospace Pyrotechnic Systems Workshop. As Henry Pohl mentioned, NASA has a major investment in software and avionics systems; yet it is important for us to consider hardware issues as well, and that's one of the reasons why we are here today.

The speaker who was originally scheduled to give the keynote address was Mr. George Rodney. He has been the Associate Administrator for Safety and Mission Quality since 1986; and, unfortunately, he was unable to make it, so I am here as his representative. As you may know, George is retiring from the Agency. The new Associate Administrator for the Office of Safety and Mission Quality is Colonel Fred Gregory, an astronaut from JSC. So we look forward to having a close

association with JSC in the future. Because of his experience with the shuttle vehicle and being a pilot, Col. Gregory is keenly aware of and sensitive to the true benefits and the necessity to support pyrotechnic systems.

One of the responsibilities that we have in the Technical Standard Division at NASA Headquarters - in addition to working with technical standards and the process for implementing them within the Agency - is the development of applied technologies. The Technical Standards Division is the organization in the Agency that supports bridge technologies to transition research and development activities into actual flight applications. We have a number of programs with this objective which are similar in many respects to the Pyrotechnics Actuated Systems activity. We are supporting the development

and qualification of a solid state gyroscope, a fiber optic rotation sensor as a replacement for the mechanical gyros which have caused a number of problems in the past. We are also working on advanced batteries as replacements for the nickel-cadmium systems in use today, including super Ni-Cd batteries and advanced nickel hydrogen batteries for improved reliability in space systems. We have a program on electronic packaging, for surface mount technology and multi-chip modules to improve and transition new packaging technology into applications.

The objective of the Pyrotechnic Actuated Systems Program is to develop new technologies and to integrate them into flight system applications. As Henry Pohl mentioned, one of our major program efforts is focused on the test and evaluation of laser initiated ordnance for flight systems. Our new Pyrotechnic Program is focused on developing opportunities to enhance safety and reliability by integrating new technology into these systems. This is an opportunity for us to work across the Agency to bring together not only the Johnson Space Center, but Langley, Lewis, Marshall, and other NASA centers that have an interest in pyrotechnics and to work with the other government agencies, particularly the Department of Defense and the Department of Energy. We have been successful in putting into place the NASA-DOD-DOE Aerospace Pyrotechnic Systems Steering Committee which is composed of representatives from those agencies to advise us in the development of our program.

Our recently initiated Pyrotechnic Actuated Systems Program is a new activity which was started last year. The Committee was instrumental in its initiation and later provided support through their comments and reviews of proposed tasks. We see this workshop as another opportunity to obtain feedback from industry, as well as the user community, to identify what we should be doing to enhance the safety and reliability of our systems.

I see three major goals of this workshop. First, this workshop is an opportunity for you to review the NASA Pyrotechnic Program and to give us your honest opinion of the program goals and direction. Tell us if we're focused in the right areas. Give us your direction and guidance in terms of what we should be doing to improve and enhance the safety of these systems and to integrate new technologies into applications. The second goal, is to provide an opportunity for technical interchange, and the third goal is to provide an opportunity for you to work with us and to identify activities to form a partnership with NASA. In partnership, industry and NASA can bring forth new pyrotechnic devices and systems and integrate them into all of our spacecraft applications.

We have had a good track record and have been very successful in the past in the application of pyrotechnic systems. Truly we would not be where we are today if we did not have safe, reliable pyrotechnic systems, and we would certainly never be able to complete some of the major goals and missions of the future - the space station activities or the exploration missions - without safe,

reliable pyrotechnic systems. These systems are perhaps not as obvious as other hardware devices. They may not get quite the visibility or the technical focus that many other hardware systems do, but they clearly are important and certainly are essential to the entire flight process.

This workshop is a very good mechanism in the program for bringing forth new technologies and state-of-the-art capabilities. There is a full schedule. You will have a busy two days, and it will be a good opportunity to compare the processes and techniques in development, test, and qualification of pyrotechnic systems, to look at the new developments that are coming on the horizon and opportunities to integrate new technology into our spacecraft systems.

So I welcome your participation in this workshop. I encourage your involvement and look forward to your comments and recommendations. I also look forward to working with you and with the entire community in trying to strengthen the NASA program, to enhance our overall activities, and to your forming a partnership with us in the future.

I challenge you to come forth and give us an assessment and appraisal of where we are today and to work with us to go forward together in the future.

Thank you.

This page intentionally left blank.

FIRST NASA AEROSPACE PYROTECHNIC SYSTEMS
WORKSHOP

NASA PYROTECHNICALLY ACTUATED SYSTEMS PROGRAM

Norman R. Schulze
Program Manager, NASA Aerospace Pyrotechnically Actuated Systems Program
Chairman, NASA-DoD-DoE Aerospace Pyrotechnic Systems Steering Committee
NASA, Headquarters
Washington, DC

ABSTRACT

The Office of Safety and Mission Quality initiated a Pyrotechnically Actuated Systems (PAS) Program in FY 92 to address problems experienced with pyrotechnically actuated systems and devices used both on the ground and in flight. The PAS Program will provide the technical basis for NASA's projects to incorporate new technological developments in operational systems. The program will accomplish that objective by developing/testing current and new hardware designs for flight applications and by providing a pyrotechnic data base. This marks the first applied pyrotechnic technology program funded by NASA to address pyrotechnic issues. The PAS Program has been structured to address the results of a survey of pyrotechnic device and system problems with the goal of alleviating or minimizing their risks. Major program initiatives include the development of a Laser Initiated Ordnance System, a pyrotechnic systems data base, NASA Standard Initiator model, a NASA Standard Linear Separation System, and a NASA Standard Gas Generator. The PAS Program sponsors annual aerospace pyrotechnic systems workshops.

I. BACKGROUND ON INITIATION OF THE PROGRAM

The purpose of this paper is to discuss NASA's Pyrotechnically Actuated Systems (PAS) Program, the primary goal of which is to enhance the safety and mission success of NASA's programs. One significant objective is to provide the pyrotechnic technology with firm principles of science and engineering design and test.

to the safety of those individuals whose lives may depend upon the device's proper function as well as those who handle the devices (Fig. 1).

Situation. Pyrotechnic devices must accomplish mechanical functions that are critical to both the success of aerospace programs and

Pyrotechnic devices are usually considered by users, e.g., program managers, to be immediately and readily available as off-the-shelf components. Consequently, little or no pyrotechnic engineering effort is expected from, nor committed by, program offices, that is, until problems develop. Since the technology is

Approved for public release; distribution is unlimited.

“mature,” no pyrotechnic research program exists. Further, no pyrotechnic technology developmental program exists.

the explosive device and any hardware which interfaces with pyrotechnic devices, but to the ignition system and circuitry as well.

Although pyrotechnic components/– devices/systems are frequently required to demonstrate near perfect reliability in both human and robotic vehicle applications, serious problems on the ground and failures in flight have occurred. The only technology efforts performed have been limited to responses applied to address specific program problems. That

contrasts with the preferred managerial approach of understanding device function to prevent problems using sound design and test principles. We can accomplish the necessary understanding through an applied pyrotechnic technology program. Technical understanding is clearly preferred to the “design and shoot” approach. The “design and shoot” approach has resulted in increased program cost for redesign, and in many instances, requalification, at even greater expense. The pyrotechnic technology has lacked a management advocate to rectify this situation.

Before proceeding, an explanation of the term, “pyrotechnic,” is important in order to understand the nature and scope of our activity. By “pyrotechnic” we refer to those devices which are operated by the explosive release of chemical energy to carry out a function (Fig. 2).

These functions include linear shaped charges, explosive transfer lines, functional components in systems such as separation bolts, cable cutters, pin pullers, normally open or closed valves, escape systems, safe & arm devices, initiation of a larger device such as a rocket motor, etc. By “system” we refer to not only

of these problems. Funding for the PAS Program was first provided in FY-91. The Program was initiated with the fundamental purpose in mind of enhancing the technology by applying management attention to pyrotechnically actuated devices and the systems in which they are required to operate. The PAS Program will be of direct assistance to NASA’s mainline programs by providing well defined, standard hardware design approaches and by maintaining the technology in a state of currency.

Program need. A significant need, therefore, exists in the discipline to significantly enhance the technical understanding of pyrotechnically actuated systems and to provide engineering tools, such as, standard design approaches, specifications, guidelines, analytical models, and manufacturing process criteria to prevent the recurrence

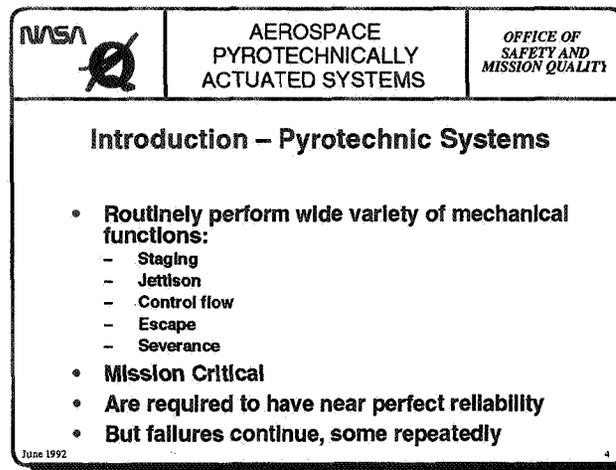


Fig. 1. Introduction to aerospace pyrotechnic systems applications.

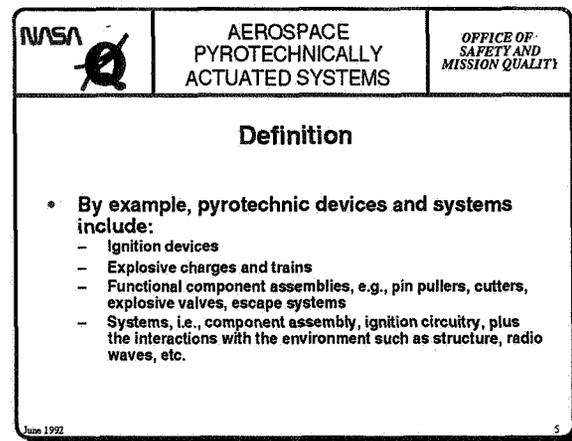


Fig. 2. Definition of pyrotechnics.

The program beginning can be traced to 1986 when the author in the NASA Headquarters Office of the Chief Engineer requested Mr. Swain, Director, Systems Engineering and Operations, Langley Research Center, Hampton, VA, to investigate pyrotechnically related problems across NASA (Fig. 3).

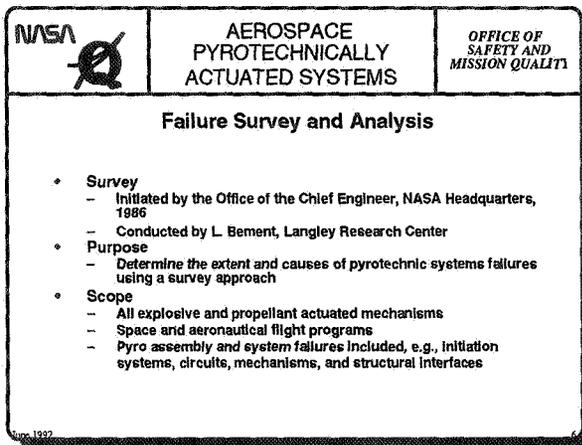


Fig. 3. NASA survey of pyrotechnic failures and analysis.

The investigation was performed by Mr. Laurence Bement using a survey technique since no automated pyrotechnic data base existed (ref. 1). As a major resource, the members of the NASA-DoD Aerospace Pyrotechnic Systems Steering Committee¹ were polled for information. By using that process the Department of Defense's (DoD) pyrotechnic data was also included. The Steering Committee was also instrumental in reviewing the results of the survey and assisting in the establishment of the program. Survey results are published in *Pyrotechnic System Failures: Causes and Prevention*, (ref. 2) (Fig. 4).

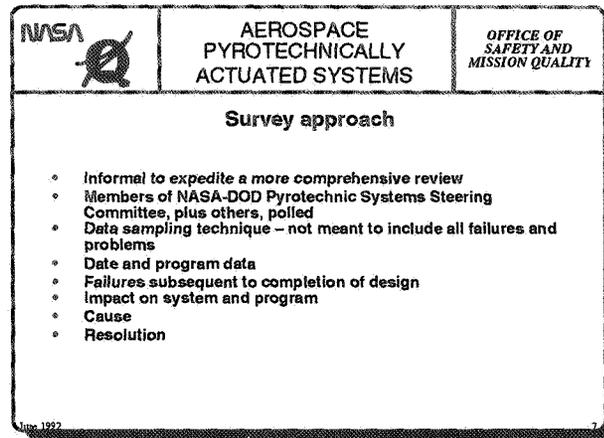


Fig. 4. Pyrotechnic survey approach.

Problem survey. An examination of the results, in brief, is instructive to determine how the PAS Program has been organized. In summary, the survey, which covered a time frame of 23 years for both NASA's and DoD's programs, revealed 84 significant failures, including 12 flight failures. In addition, from the safety perspective, 3 deaths were attributed to the accidental ignition of a solid rocket motor (Fig. 5).

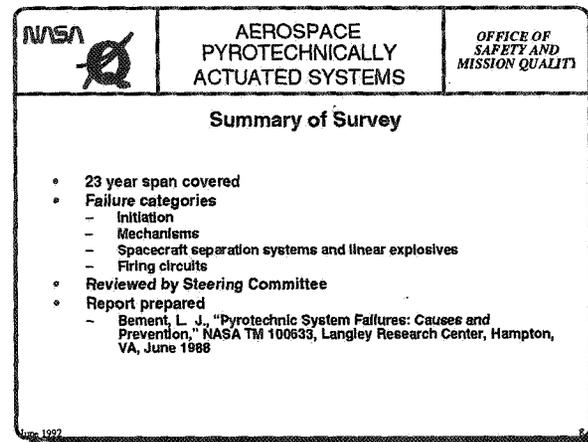


Fig. 5. Summary of survey.

The underlying cause of those failures was attributed to the lack of a technological base. In Fig. 6 the number of failures is presented for each phase of the device's life cycle. We find that a large number of problems escape the lot

acceptance testing. That result is indicative that acceptance test approaches need to be improved for acceptance testing to become the dependable filter of defects of pyrotechnic quality which we require to be consistent with the high reliability expectations discussed earlier. That is clearly an issue which we wish to rectify.

Failures were found in the Langley survey (ref. 2), more specifically, to occur from a multitude of causes:

- a lack of technical understanding of pyrotechnically actuated mechanisms,
- a deficiency in designs, specifications, quality control, and procedures,
- a lack of standardization,
- an inadequate technology base for the pyrotechnic technology, including no technical data base,
- a lack of resources for pyrotechnic technology funding, personnel, and facilities and,
- poor communications among centers.

The failure distribution by cause is presented in Fig. 7.

For convenience, we categorized the failure causes into four groups:

- design approach
- pyrotechnic technology and documentation
- communications
- resources.

The results of the deficient areas, as determined

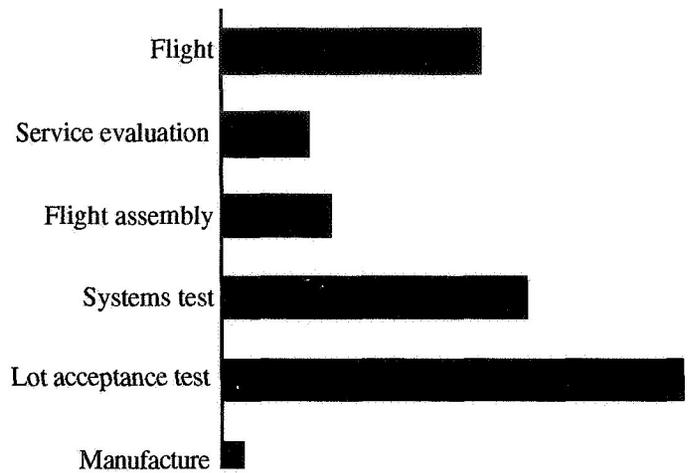


Fig. 6. Failures experienced during pyrotechnic life cycles.

from the survey, and the recommendations to rectify the situation are summarized in Fig. 8. The findings of the survey for each of the above four groups are discussed below.

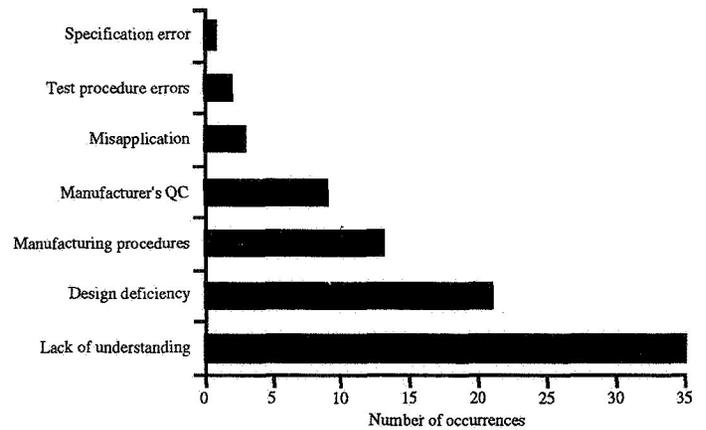


Fig. 7. Distribution of failures by cause.

Assessment of Survey Results

Deficient Areas	Recommended Tasks
<ul style="list-style-type: none"> • Design Approaches <ul style="list-style-type: none"> - generic specification - standard devices 	<ul style="list-style-type: none"> • Design Approaches <ul style="list-style-type: none"> - prepare NASA specification handbook - select/verify existing hardware types
<ul style="list-style-type: none"> • Pyrotechnic Technology <ul style="list-style-type: none"> - research/development technology base - recognized engineering discipline - training/education - test methodology/capabilities - new standard hardware 	<ul style="list-style-type: none"> • Pyrotechnic Technology <ul style="list-style-type: none"> - endorse and fund plan's technology tasks - fund training and academic efforts - R&D for new measurement techniques - develop new h/w for standard applications
<ul style="list-style-type: none"> • Communications <ul style="list-style-type: none"> - technology exchange - data bank & lessons learned - intercenter program support 	<ul style="list-style-type: none"> • Communications <ul style="list-style-type: none"> - continue Steering Committee meetings - initiate symposia - establish pyro reporting requirements for NASA PRACA - perform as a Steering Committee function
<ul style="list-style-type: none"> • Resources <ul style="list-style-type: none"> - funds - research/development staff and facilities 	<ul style="list-style-type: none"> • Resources <ul style="list-style-type: none"> - implement pyrotechnic program plan

Fig. 8. Deficient areas and recommended tasks.

12

Design Approach

The greatest cause of pyrotechnic failure was attributed to the lack of a technical understanding of pyrotechnically-powered mechanisms. However, a NASA or Air Force technology developmental and advancement program for the pyrotechnics discipline that could pursue device understandings was nonexistent. Individual pyrotechnically actuated devices are funded only to meet specific program needs. If any research and development activities are accomplished, they are geared to the narrow bounds of program requirements, to the program schedule, and, of course, to the program's budget priorities. There is little opportunity for thorough investigations of functional mechanisms or for the development of a basic understanding of operational parameters. The lack of technically proven, standardized test methodology was determined to be a frequent limiting factor in resolving problems or developing new designs as well as in problem prevention. Pyrotechnic modeling has not been developed for aerospace

pyrotechnic mechanisms; but modeling could be a key factor in reducing costs, understanding design margins, and enhancing safety and reliability. Not only has NASA been so limited, but so have the contractors.

That situation is resolved by the initiation of an applied technology program to focus on pyrotechnic device and system technology.

Pyrotechnic Technology

There was very limited pyrotechnic technology research and development programs that would permit the preparation of guidelines and specifications for pyrotechnic design, hardware development, qualification, production, acceptance testing, and system testing. Only some generalized military standards exist in DoD. For example, guidelines are not available that properly address: the selection of pyrotechnic approaches - including: the use of previously qualified hardware, the best means to accommodate structural interfaces, how to achieve true redundancy, how to conduct proper testing, and how to achieve true reliability. The design of pyrotechnics has been and continues

to be approached more as an art rather than as a science. Empirical relationships between design, operation, and manufacturing controls have not been established. Flight programs cannot rely on meaningful statistically derived component test performance data through repetitive testing because costs of test programs become prohibitive. Good modeling approaches have not been developed to take advantage of new analytical tools. There are no well defined and widely accepted standards for demonstration of functional margin. Hence, considerable developmental work that will be necessary to establish a solid foundation for the development of meaningful specifications.

A NASA generic pyrotechnic specification that provides guidance for all of these considerations benefits programs through expert guidance. More standardized components with well-characterized functional performance characteristics reduce design efforts and design problems since the standardized hardware designs incorporate lessons learned and provide a wide data base. The wide data base from standard hardware provides better understanding of design margins, a key factor for enhanced safety, reliability, and performance assurance. A need exists to: identify key hardware which require enabling and enhancing pyrotechnic technology, to develop the identified critical technology, and, where feasible, to implement use of that technology by NASA's programs. This need is a subject that the PAS Program will continue to study since pyrotechnic requirements change as programs change.

One major program goal is to make the design of pyrotechnically actuated systems a science. That goal will be aided by the advent and progress of modeling technology which has occurred in recent years. The demonstration of functional margins through an understanding of the relative importance of system variables is important to a cost effective means of characterizing device performance sensitivities. Prediction of the effects of manufacturing changes on performance has not been possible. The effects of tolerance stack-up from variables

within the system can be anticipated to result in unreliable devices. Modeling can become a key tool in resolving those deficiencies.

Communications

Intercenter communication, cooperation and support have been inadequate. Most pyrotechnic efforts are performed independently with little intercenter cooperation or sharing of technical gains, resolution of problems and failures, and lessons learned. Thus, NASA's programs suffer from a lack of exchanging and application of current pyrotechnic technology developments. There are no libraries or central sources for information on this aerospace technology, particularly no data base of design information, test data, past problems, and failures. Indeed, the failure survey was necessarily conducted by polling the memory of senior, experienced individuals. Few papers on pyrotechnic failures are published; and few programs thoroughly document design information, functional performance properties, and physical characteristics in a format permitting engineers to conduct trade studies for subsequent programs. Furthermore, there have been no consistent, high-quality symposia, tailored to present data in a manner that meets the overall NASA needs. Thus, the pyrotechnic work has always been highly individualistic, program related, rather than a discipline oriented technology.

Resources

To improve the existing pyrotechnic devices, as well as to meet future program technical requirements, NASA needs more "hands-on," technology-oriented engineering personnel and adequate test facilities. Design and problem solving are accomplished mainly by subcontractors under the management of specific individual program offices as needed. In the end the technology is weakened when strong oversight and technical management by the government staff cannot be provided. Very little formal pyrotechnic training or academic involvement is available. Thus, without the

opportunity to gain experience in technology oriented facilities, government pyrotechnic personnel, of necessity, have placed a strong dependence on the manufacturer's expertise. The result is an inability to gain a valuable independent second technical judgment. Similar funding constraints in industry and product price competition have prevented industry from conducting applied pyrotechnic technology programs.

Not only is the government lacking good technical understandings of PAS; but, in a highly competitive business world, the manufacturer also cannot afford to understand and characterize hardware commensurate with the high reliability demands placed upon it. Hence, the lack of that understanding is reflected in specifications.

The consequence is, the government has lost oversight; the manufacturer has lost insight; and the program risk is increased.

Management Review

On April 13, 1988, the Committee carried its concerns forward to Mr. George A. Rodney, Associate Administrator for Safety, Reliability, Maintainability, and Quality Assurance (now the Office of Safety and Mission Quality) at NASA Headquarters, Code Q. Mr. Rodney requested that the Committee's recommended Program Plan be finalized and endorsed by all participating centers. That was accomplished. In addition to the problems that the survey revealed, Mr. Rodney also expressed concern over the problems that have been experienced with safe and arm devices which had not been included as part of the scope of the original survey. On June 25, 1990 the Code QE Technical Standards Division was approved by the NASA Administrator as an office to address both applied technology and technical standards. The pyrotechnic issues and failures and the program plan to resolve those issues were reviewed with the Division Director, Dr. Daniel Mulville, on January 18, 1991, and the program was subsequently

launched. The *NASA PAS Program Plan* was updated from the 1988 draft to reflect new technology developments, budget changes, and new program interests. The *NASA PAS Program Plan* (ref. 3) was approved by Dr. Mulville on February 28, 1992.

¹ The NASA-DoD Aerospace Pyrotechnic Systems Steering Committee is comprised of government pyrotechnic staff with representatives from each of the NASA centers plus the Air Force, as represented by the Aerospace Corporation, and the Navy by the Naval Surface Warfare Center. The Committee was organized in 1985 to assure channels of communication among the users of aerospace pyrotechnic technology. In 1991 the membership was expanded to include the DoE as represented by the Sandia National Laboratory, Albuquerque. The Committee is chaired by NASA Headquarters. It serves in an advisory role to the NASA Pyrotechnic Program.

II. PAS PROGRAM PLAN

The *PAS Program Plan* presented in this section reflects the results of the survey and the Steering Committee's suggestions. The PAS Plan responds to NASA's most pressing requirements for pyrotechnic hardware development.

Goals

This Program's basic goals are to:

- reduce program risk due to pyrotechnically initiated systems and
- improve NASA's aerospace pyrotechnic systems technology.

We proceed to reduce risk by performing those activities that will increase mission success, enhance personnel safety, and improve equipment safety. To increase the mission success posture of NASA's aerospace pyrotechnic systems technology, the Program includes projects that will provide NASA with pyrotechnically actuated devices that are well characterized and which have higher mass specific performance. The characterization is to be reflected in the development of strengthened specifications. The relationship of the Program goals to the Program products is depicted in Fig. 9.

These goals will be accomplished by structuring the PAS technology to produce the following program products:

1. Engineering Tools. Provide the engineering tools needed by the NASA pyrotechnic engineering staff to perform sound, updated, and advanced technical design approaches to meet pyrotechnic system requirements of NASA's mainline programs.
2. Standard PAS. Develop standard pyrotechnic devices having well defined operational characteristics that have been controlled through proper technical specifications.
3. Design Standards and Specifications. Develop well characterized pyrotechnic system design standards to provide assurance that consistent, high quality practices are employed throughout NASA.
4. Operational Guidelines. Provide operational guidance that will incorporate lessons learned and which will be applied during ground processing. Incorporate guidance that will apply from the beginning to the conclusion of the pyrotechnic device's life cycle.
5. Modeling. Assist manufacturers by better characterizing the effects of variables associated with manufacturing processes, thereby helping to assure that hardware meets desired performance specifications.
6. Experienced Staff. Foster intercenter collaboration and provide for a well trained, experienced hands-on pyrotechnic technology engineering staff.

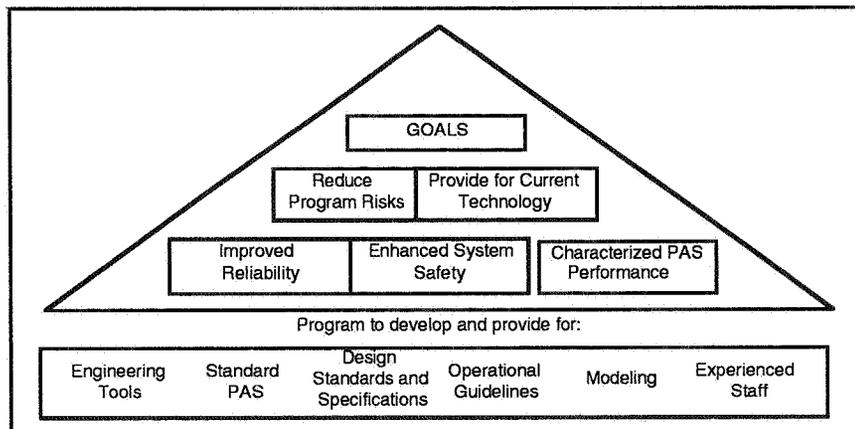


Fig. 9. Program goals and products.

Objectives

This Program provides NASA with a focused pyrotechnic systems activity to:

- develop improved design methods, standards, specification, and approaches for pyrotechnically actuated systems,
- make policy recommendations regarding their use, and
- enhance NASA's technical capability in the application of the technology.

Quality is achieved by the application of strong standard designs that have been well authenticated by analysis and verified by qualification testing to the maximum anticipated operational level with a well defined and understood design margin. Quality is also achieved by designing in margins commensurate with intrinsic sensitivities of device performance to manufacturing tolerances. The attainment of high quality devices requires an understanding of those sensitivities to the manufacturing processes and tolerances. Program goals are met, too, when confidence is high that the product acceptance test procedures will adequately validate that the

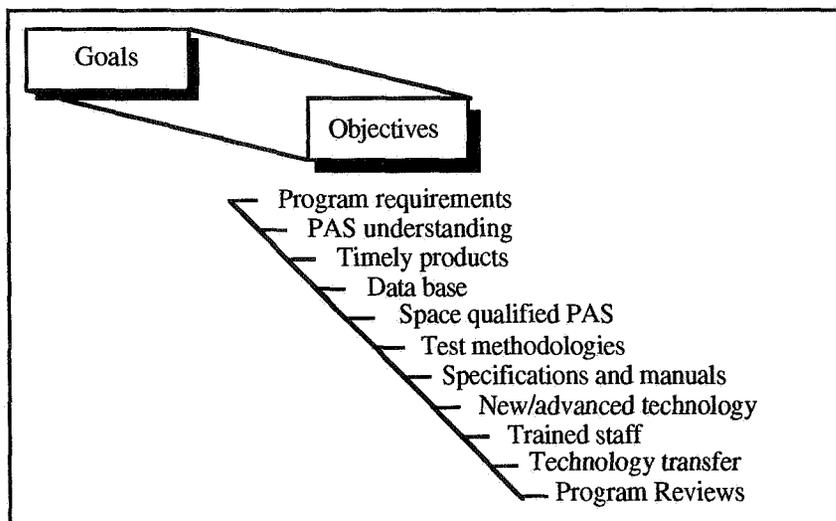


Fig. 10. PAS Program objectives.

PAS technology must be developed into a well-understood science to provide NASA with the desired high quality capabilities in this technical field. In addition, resources must be soundly established in terms of staff, equipment, and funding.

The Program accomplishes its goals by increasing pyrotechnic device and systems reliability through quality improvements.

manufactured hardware is built per design. The Program's objectives are presented in Fig. 10.

This Program contains a comprehensive set of specific objectives to achieve its goals. These objectives are to:

1. Program Requirements. Analyze NASA's future program needs in this technology to allow the conduct of a well planned, properly focused program.
2. PAS Understanding. Assist programs

by assuring that dependable pyrotechnically actuated components and systems have been developed, characterized, and demonstrated for use with a minimum of risk, i.e., the Program will undertake projects that:

- a. provide for standardization of components and assemblies,
 - b. improve current designs through better understanding of device internal functions,
 - c. obtain an understanding of manufacturing processes and quantify the influence of key process parameters on device performance,
 - d. conduct device modeling to reduce faults from design and manufacturing processes, and
 - e. determine how to properly incorporate margins and/or redundancy into device designs and how to verify margin and redundancy.
3. Timely Products. Make well characterized, reliable advanced pyrotechnic technology hardware designs available on a timely basis for the benefit of future NASA programs.
4. Data Base. Develop and maintain a PAS data base for design and operational aids and to identify areas in need of technology support.
5. Space Qualified. Develop techniques and testing with the required level of rigor to assure availability of the means to have proper product control and to provide the best possible qualification test techniques.
6. Test Methodologies. Improve specifications and test methodologies as a means to verify device performance upon design completion and to verify its quality conformance to the design upon manufacture.
7. Specifications and Manuals. Provide new and updated specifications and manuals to assist programs in the implementation of sound pyrotechnic technology.
8. New/advanced Technology. Develop

new and advanced technologies to support programs.

9. Trained Staff. Ensure that NASA has a well-trained, functional hands-on capability using the latest technology for design tools, test equipment, and technical approaches to:
- a. attain and maintain the technical expertise for properly managing technical requirements in NASA's contracts, an essential role for safety and mission success,
 - b. serve in an independent oversight function, and
 - c. ensure that objective, independent validation testing can be performed using hands-on capabilities.
10. Technology Transfer. Interact with industry to provide and transfer updated technical information.
11. Program Reviews. Conduct analyses and perform or sponsor independent technical reviews of pyrotechnic systems installed on flight and ground programs.

Program Plan Overview

The *NASA Aerospace Pyrotechnically Actuated Systems Program Plan* responds to NASA's anticipated needs for high-performance systems as well as for safe and reliable pyrotechnically actuated systems, both for the current program applications and for future program uses. PAS Program management reviews will be accomplished periodically to evaluate status. These reviews will serve to ensure that the stated goals and objectives are achieved on a timely basis, to coordinate interrelated PAS Program efforts, and to enhance technical communication among the affected governmental organizations.

The projects in this Plan insure the development of key PAS technologies and utilization of the Program's products. The plan by which this is to be accomplished is shown in Fig. 11.

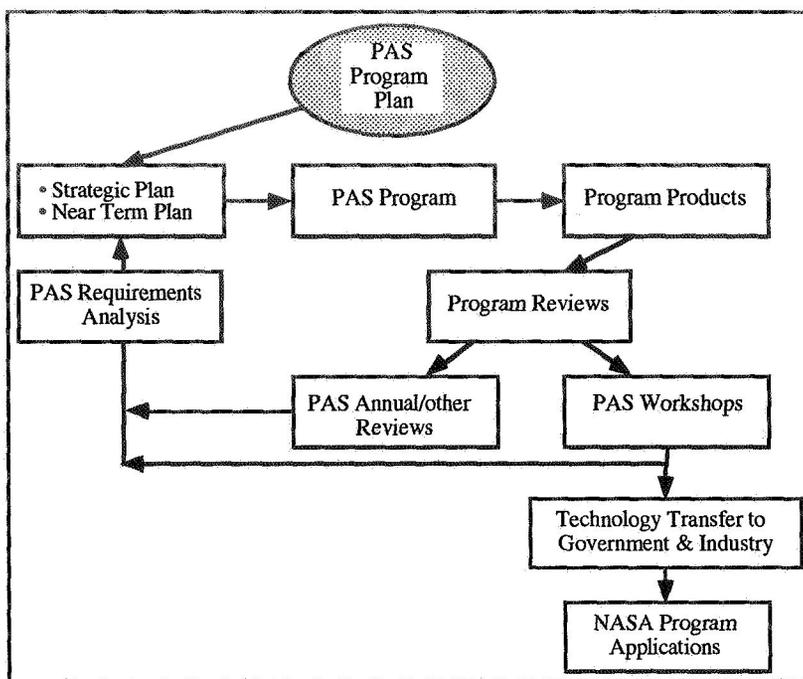


Fig. 11. Plan to assure use of PAS Program products.

The Program Plan is, therefore, formally structured to develop strategic courses of action and to address near term needs:

A. Strategic Plan

1. Assess NASA's overall program requirements for PAS.
2. Increase the number of well-characterized, standardized devices.
3. Improve guidelines and specifications for all aspects of system design, development, qualification testing, check-out testing, and acceptance testing.
4. Plan and implement PAS technology to meet future requirements of NASA's mainline programs.
5. Improve technical communications.
6. Expand and maintain an applied technology and experience base.
7. Provide a training and educational base, including hands-on experience.
8. Assure use of the technology developed.

B. Near Term Plan

1. Identify NASA's future program requirements for PAS.
2. Complete the Program Implementation Plan.
3. Initiate work on the most technically beneficial/high leverage hardware.
4. Develop critical policies and specifications.
5. Establish a data base, including:
 - current pyrotechnic designs,
 - applications,
 - results of usage.
6. Emphasize interagency cooperation in sharing technology.
7. Transfer technology to other government agencies and to industry.

The interrelationships of this Program and its projects with the survey results, the NASA Program offices, and Code Q are shown in Fig. 12, the Pyrotechnically Actuated Systems Program master flow chart.

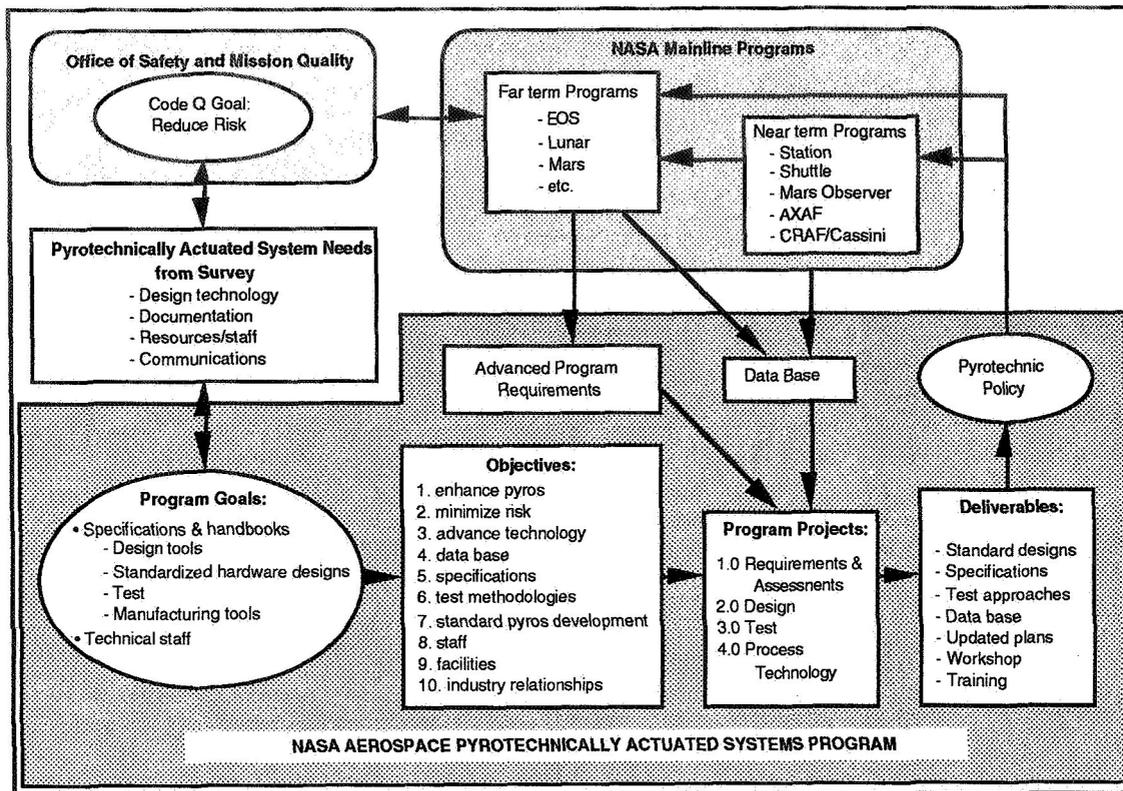


Fig. 12. Pyrotechnically Actuated Systems Program master flow chart.

The figure also presents the plan to ensure that the Program Plan is integrated with NASA's mainline program applications and that those programs will influence the PAS Program in an iterative process.

Program Content

The Program is divided into four major Program Elements, each of which provides appropriate projects to accomplish the Program objectives (Fig. 13).

PYROTECHNICALLY ACTUATED SYSTEMS PROGRAM ELEMENTS	
1.0	Program Requirements and Assessments
2.0	Design Methodology
3.0	Test Techniques
4.0	Process Technology

Fig. 13. Program Elements, NASA Aerospace Pyrotechnically Actuated Systems Program.

The projects described below are designed to improve both the near and long term pyrotechnic technology base—including components and systems — and to work toward the resolution of the problems summarized above.

The Plan focuses upon the following specific remedies: design improvements, new and/or improved specifications, hardware standardization, an improved and expanded technology base, and enhancement of communications in the pyrotechnic community. Fig. 14 provides an overview of the Program content. The figure shows how the Program supports Code Q's functional role in NASA relative to design, test, and manufacturing.

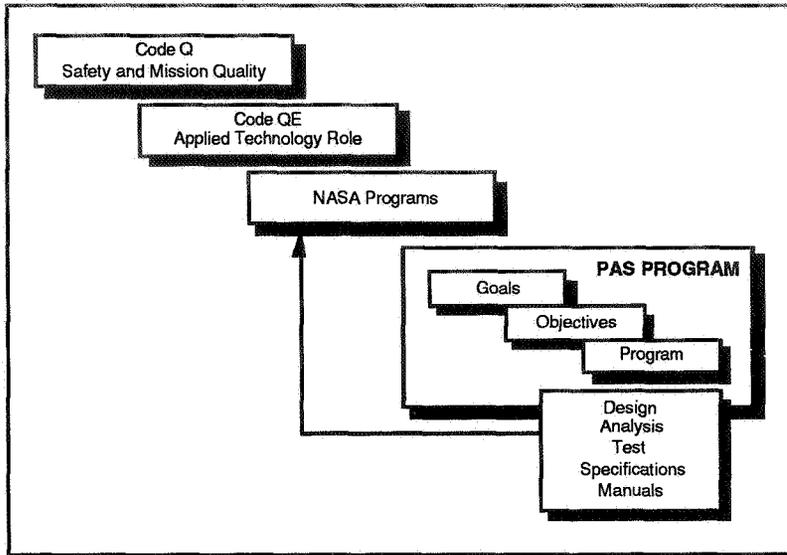


Fig. 14. Relationship of PAS Program to Code Q, QE, and NASA program roles.

Table 1 lists projects recommended by the Steering Committee. The text following the table describes in broad terms the function of each project and the products.

Funding levels limited the specific projects that the Program will be able to undertake initially. The programs which fall within the NASA approved budget are identified below. Program reviews will subsequently establish the

funding of new projects and those projects that are identified herein but which are currently unfunded. Projects have been defined which will be implemented contingent upon funding approval: Training, Hardware System Reviews, NASA Standard Detonator testing, NSD Performance, NSGG Model Development, NSD Model Development, and Standard System Model Developments. An annual PAS Program review and report will be prepared.

Table 1. Pyrotechnically Actuated Systems Program Elements and objects.

PROGRAM ELEMENT	PAS PROJECTS
1.0 Program Requirements & Assessments	1.1 Future Pyrotechnic Requirements 1.2 Pyrotechnic Policy Preparation 1.3 PAS Technical Specification 1.4 PAS Data Base 1.5 Annual Program Review and Report 1.6 Program Implementation Plan 1.7 NASA PAS Manual 1.8 PAS Workshop 1.9 Training 1.10 Hardware System Reviews
2.0 Design Methodology	2.1 NASA Standard Gas Generator 2.2 Standard System Designs 2.3 NASA Standard Detonator 2.4 NASA Standard Laser Safe and Arm 2.5 Advanced PAS
3.0 Test Techniques	3.1 NSGG Performance 3.2 Standard Systems 3.3 NSD Performance 3.4 Safe and Arm Performance 3.5 Advanced PAS Performance 3.6 Service Life Aging Evaluations
4.0 Process Technology	4.1 NSGG Model Development 4.2 NASA Standard Initiator Model Development 4.3 NSD Model Development 4.4 Standard System Model Development

A general description of the projects in this follows. The organization of the program is program element and the major products presented in Fig. 15.

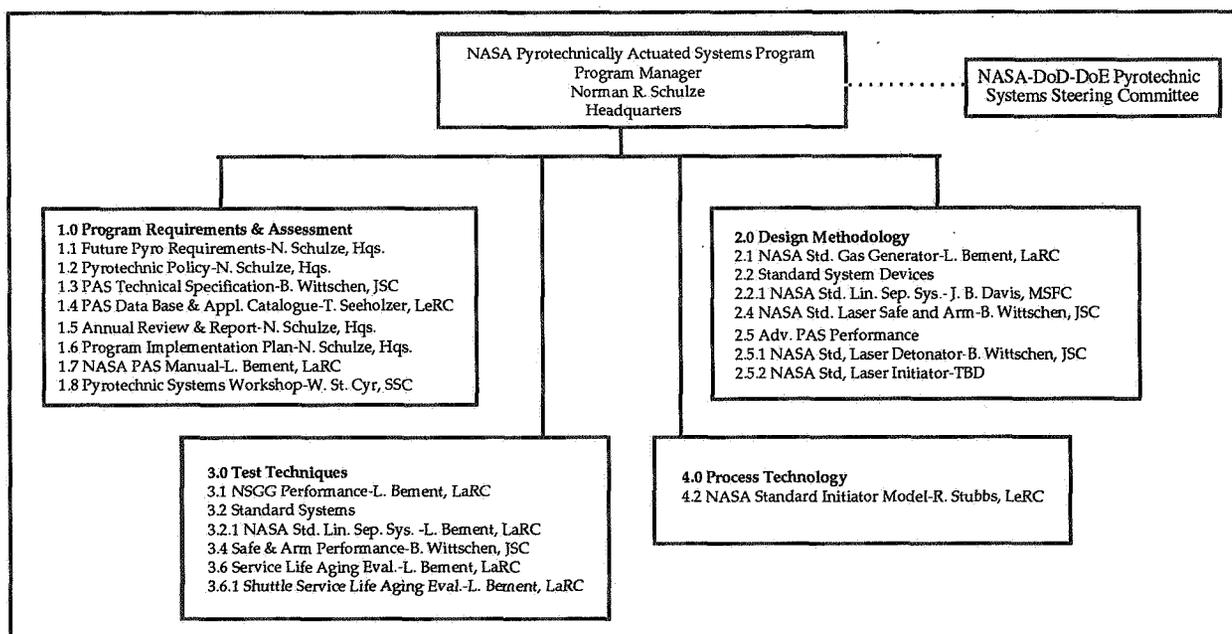


Fig. 15. PAS program organization.

Program Requirements and Assessments Program Element

This program element implements those projects that are necessary to address the management aspects of the Program's objectives. In this element we particularly emphasize documentation and communications (Fig. 16).

	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
1.0 Program Requirements and Assessments Element		
<ul style="list-style-type: none"> • Implement projects necessary to address management aspects of the Program's objectives • Emphasize documentation and communications • Prepare policy and planning documents to ensure products used • Analyze NASA's future program requirements and current problems • Provide computerized data base • Produce documentation related to reviews, proceedings, analyses, etc. 		
June 1992		18

Fig. 16. Project 1.0, Program Requirements and Assessments Element.

Policy and planning documents, for example, are prepared to ensure that the products of the Program will be used. The policy document will be in the format of a NASA Management Instruction that addresses PAS in a broad sense. Analyses of NASA's future program requirements and of current problems will enable appropriate revisions to the Program Implementation Plan. Problems, and the analyses thereof, will also be the subjects for final reports and the computer data base that will be developed. The Program Element includes analysis and design efforts needed to address the overall systems aspects of the Program and the documentation work that produces the reports and presentations associated with reviews, proceedings, analyses, etc.

1.1 Future Pyrotechnic Requirements - N. Schulze, Headquarters

New pyrotechnic technology requirements necessary for future missions will be studied. Programs are expected to require new pyrotechnic mechanisms to meet more demanding environments and to extend service requirements further than previously accomplished. Functional understanding and new computational modeling capabilities will enhance PAS performance capabilities. The objective of the advanced planning is to define the efforts needed to improve and to verify the improvements in PAS quality. New diagnostic techniques, for example, will be evaluated (Fig. 17).

A report on an analysis of future requirements will be provided. The future requirements document will be used by the PAS Program's management to make revisions in the Program Implementation Plan or in the Program Plan. The PAS requirements report will be updated every two years.

	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
1.1 Future Pyrotechnic Requirements		
Project Mgr: N. Schulze, Headquarters		
<ul style="list-style-type: none"> • Determine new pyrotechnic technology requirements • Define efforts to: <ul style="list-style-type: none"> - Improve PAS quality - Meet more demanding environments - Extend service requirements • Evaluate new diagnostic techniques • Provide efforts to provide for functional understanding using computational modeling capabilities - enhance specifications • Product: <ul style="list-style-type: none"> - Report on analysis of future requirements 		
June 1992		19

Fig. 17. Project 1.1, Future Pyrotechnic Requirements.

1.3 PAS Technical Specification - B. Wittschen, JSC

A technical specification applicable to pyrotechnic design, development, demonstration, environmental qualification, lot acceptance testing, and documentation will be prepared (Fig. 18).

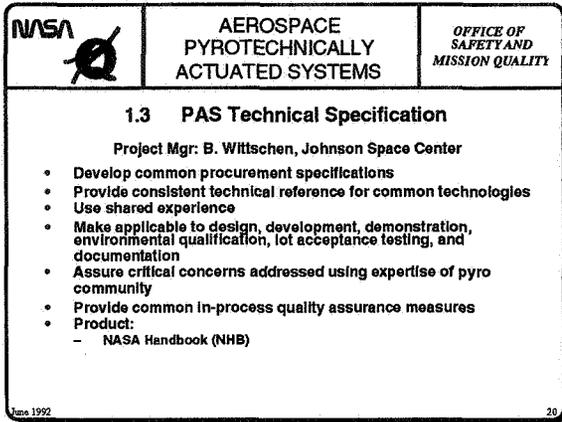


Fig. 18. PAS Technical Specification.

The specification will include improvements on the means for defining and demonstrating PAS functional margin. The specification will fulfill a void and will serve as a contractual reference document.

The specification will be prepared as a NASA technical standard.

1.4 Pyrotechnically Actuated Systems Data Base - T. Seeholzer, LeRC

This Project will develop and document the past and current PAS programs in terms of system requirements, designs developed, performance achieved, lessons learned, and qualification status with sufficient detail to provide guidance for users (Fig. 19).

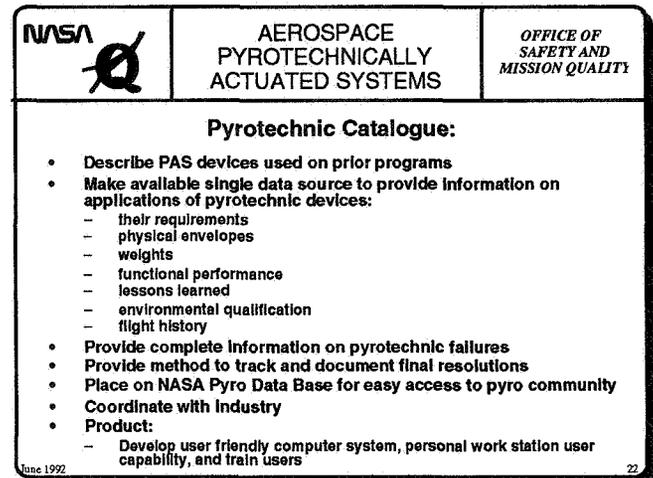
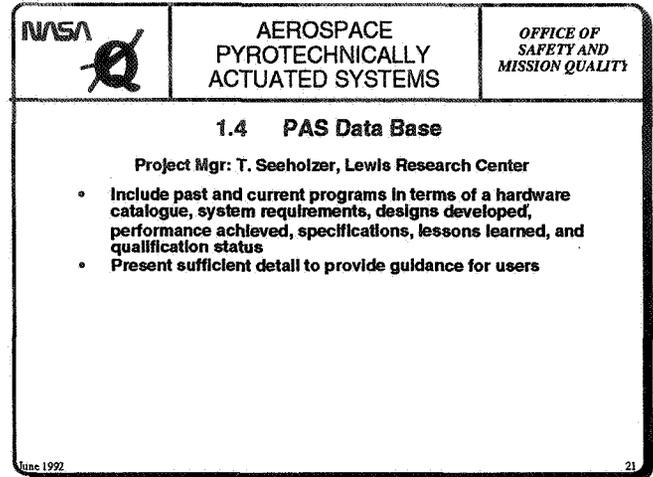


Fig. 19 a, b. Pyrotechnically Actuated Systems Data Base.

The data base structure and a user friendly interface will also be established. Documentation requirements which will support the data base will be identified as part of a proposed NASA Pyrotechnic Policy document that the Program will prepare for review by the Steering Committee and ultimate implementation by NASA. These requirements will also be incorporated into device specifications. The data base content includes data, reports, specifications, documents, etc. The catalog will list all past and presently available pyrotechnic devices. This project requires project management to interact cooperatively with other NASA Centers, various DoD and DoE

organizations, and private industry. Funding in later years will maintain the data base.

The data base requirements will be established and published, a computer system selected, a user-friendly program developed, entries made, and training provided for users of the system. The catalog portion of the data base will be prepared as a NASA Handbook to provide designers with options in a single up-to-date reference document. This is to be a turn-key effort.

1.7 NASA PAS Manual - L. Bement, LaRC

A detailed "how-to" document will be prepared providing guidance on all aspects of design, development, demonstration, qualification (environmental), acceptance testing, and margin demonstrations of pyrotechnically actuated devices and systems (Fig. 20).

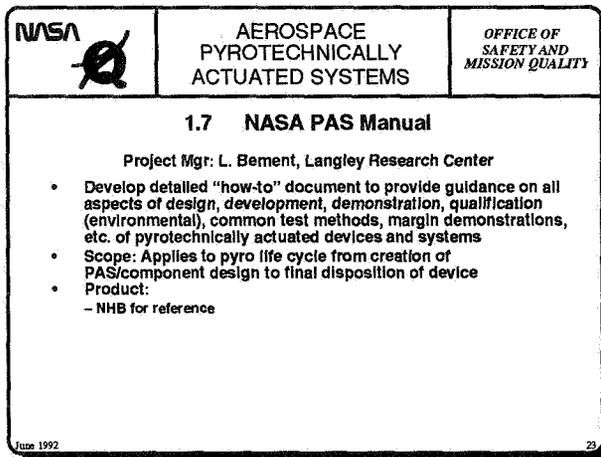


Fig. 20. NASA PAS Manual

The manual's scope will be from the creation of the PAS/component design to final disposition of the device to take environmental and safety issues into account.

This manual will be prepared as a NASA guidelines document that will be used for reference.

1.8 Pyrotechnically Actuated Systems Workshop - W. St.Cyr, SSC

Technology exchanges at the national level will be achieved through the creation of a separate pyrotechnic dedicated workshop (Fig. 21).

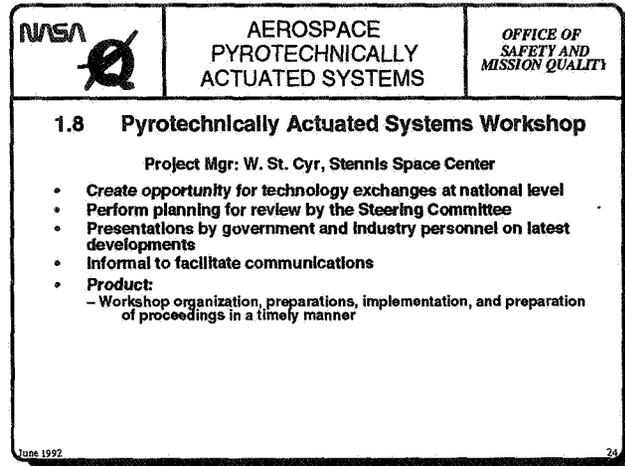


Fig. 21. NASA Pyrotechnically Actuated Systems Workshop.

Presentations by government and industry personnel are planned as appropriate. Planning of the workshop is reviewed by the Steering Committee.

The workshop organization, preparations, implementation, and the preparation of the proceedings in a timely manner are all part of the responsibilities and products of this Project.

2.0 Design Methodology Program Element

The Design Methodology Program Element addresses those design deficiencies noted in the survey where the need was expressed to further understand current design limitations and to apply advanced design approaches. This element develops designs, tests hardware, and documents results. The primary Design Program Element's deliverables consist of

design specifications or standards (Fig. 22).

The projects performed here will develop the hardware that advances basic research conducted on PAS into operationally demonstrated technologies for performance characterization and for flight hardware applications. They will, therefore, more accurately define the device's ability to function under anticipated operational

environments as well as operations in off-nominal conditions. Design limits of the device are to be determined. Recommendations for new applied technology projects will be provided by the Program staff for approval by the Director of the Technical Standards Division, Code QE. In the Design Methodology Program Element, hardware will be designed, manufactured, acceptance tested, and specifications prepared. Designs developed under Element 2.0 are tested under Element 3.0. This approach addresses the resolution of a major problem area revealed in the survey, provides emphasis on the importance of both design and test, and identifies separate budgets for work breakdown structure purposes.

Emphasis is placed on design standards and analytical techniques. From the work in this element, the PAS Program provides the fundamental data required to generate the guidelines, handbooks, and specifications for the design and development of pyrotechnic components and systems as required for the Program to accomplish its hardware focused goals and objectives. The technical content for the appropriate documents will be developed for all aspects of pyrotechnic component and systems applications. The Program will conduct the applied technology necessary for supporting document preparation including

verification of the accuracy of the specification values.

These projects are highly beneficial to NASA's programs because flight hardware characterization and applied technology developments will decrease the chance of failure of new hardware design approaches or of proven hardware applied to new operational regimes.

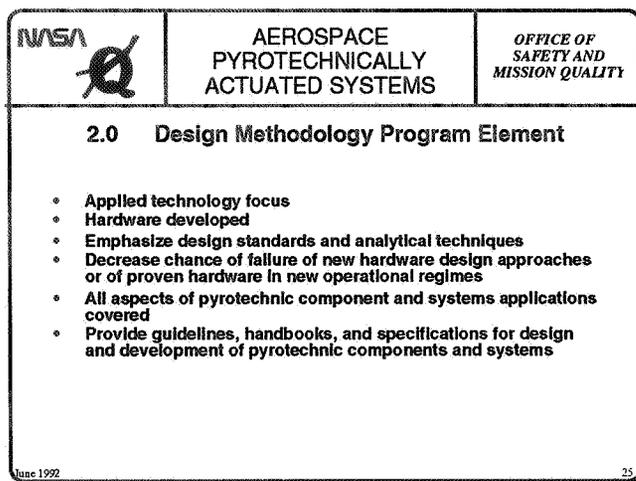


Fig. 22. Design Methodology Program Element.

2.1 NASA Standard Gas Generator (NSGG) - L. Bement, LaRC

The NASA Standard Gas Generator will be among the first hardware developed. The NASA Standard Initiator (NSI) has been applied universally to serve both as an initiator and a gas generator. This has been found to contribute to functional failures. The number of applications of the NSI as a gas generator well exceeds that as an initiator. The NSGG will be flight qualified, but its reliability will not be numerically proven due to the large number of samples required. The development of a NSGG has been assigned a high hardware priority since it has the widest pyrotechnic application. It is important to safety and mission success (Fig. 23).

A qualified NSGG will be provided. A design specification will be developed as a NASA technical standard from data provided by the project. Test reports will be written.

NASA	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
<p>2.1 NASA Standard Gas Generator (NSGG)</p> <p>Project Mgr: L. Bement, Langley Research Center</p> <ul style="list-style-type: none"> • Develop where the use of gas output is needed to perform a function rather than serving as ignitor: <ul style="list-style-type: none"> - Separation nuts, valves, cutters, switches, pin pullers, thrusters, mortars, bolts, etc. • Common NASA GG <ul style="list-style-type: none"> - Based on NSI (NASA Standard Initiator) to provide pedigree - Important for safety - Saves \$, NSI - Wide variety of cartridges - lack "pedigree" inherent with a "Standard" • Develop sizes to meet wide range of performance requirements • Products: <ul style="list-style-type: none"> - Qualified NSGG - Design specification (NHB) - Test reports <p>June 1992 26</p>		

Fig. 23. NASA Standard Gas Generator.

2.2 Standard System Designs

Improved, more reliable, high performance hardware is needed. Extensive background and operational experience will be evaluated preceding selections of candidates for NASA standard hardware designs. Functional performance, the effects of system variables, and scaling will be characterized. Process controls will be specified in detail to assure consistency and reliability for all manufacturing lots. The systems to be studied include linear separation systems, pin pullers, etc. Qualified NASA standard system designs and design specifications will be developed as NASA technical standards from data provided by the project. Test reports will be written.

2.2.1 NASA Standard Linear Separation System (NSLSS) - Joe B. Davis, MSFC

NASA	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
<p>2.2.1 NASA Standard Linear Separation System (NSLSS)</p> <p>Project Mgr: Joe B. Davis, Marshall Space Flight Center</p> <ul style="list-style-type: none"> • Develop standard linear separation system <ul style="list-style-type: none"> - Improved, more reliable, high performance hardware - Lower cost • Characterize functional performance, effects of system variables, including scaling • Specify process controls to assure consistency and reliability • Qual test for flight • Establish operational functional margin • Solicit design approaches from industry <ul style="list-style-type: none"> - Prepare NASA-wide technical specification <p>June 1992 27</p>		

Fig. 24. NASA Standard Linear Separation System.

The development of a NASA Standard Linear Separation System (NSLSS) has been assigned a high system development priority since these systems are expensive and have wide, safety/reliability-critical applications. This project undertakes the development of a standard linear separation system to provide improved, more reliable, high performance hard-

ware which can be produced at a lower cost (Fig. 24).

Current NASA and industry separation designs will be considered to serve as an effective standard. Functional performance, as well as the effects of system variables, including scaling, will be characterized. Process controls will be specified in detail to assure consistency

and reliability for all manufacturing lots. The separation system will be flight qualified and its operational functional margin will be established. Demonstration of margins is a key goal of this project. However, its reliability will not be numerically proven within the funding constraints.

A qualified NASA Standard Linear Separation System, including the design specification and general procurement specification, will be developed from data provided by the project. The specification will be prepared as a NASA-wide technical specification, published by NASA Headquarters. Test reports will be written. The goal is to qualify more than one supplier to build the system.

2.4 NASA Standard Laser Diode Safe and Arm - B. Wittschen, JSC

A wide variety of complex mechanisms currently exist to assure the inadvertent initiation of pyrotechnically actuated systems, particularly for flight termination systems. Standardized solid state approaches for safe and arm hardware and their interfaces are anticipated to reduce risk considerably while enhancing functional reliability (Fig. 25).

This project undertakes the qualification of a solid state laser safe and arm for demonstration on the Pegasus launch vehicle. The design, integration, and operation aspects is being funded as a cooperative venture with the Small Launch Vehicle Program Office at NASA Headquarters.

The Project will develop, qualify, and demonstrate in flight a standardizable solid state laser safe and arm system. Significant improvements are expected in size reduction, operational performance, power, and explosive containment. The latter will reduce hazards from debris. The results of this effort will

be a flight performance demonstration and guidelines on how design features from this work can be incorporated into flight units. A design specification for a NASA standard laser safe and arm will be generated. Test reports will be written.

2.5 Advanced Pyrotechnically Actuated Systems (PAS)

This project will define and pursue those advanced design concepts that are needed to bring NASA programs up to the state-of-the-art in pyrotechnic technology and to maintain a state of currency (Fig. 26).

	<p align="center">AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS</p>	<p align="center">OFFICE OF SAFETY AND MISSION QUALITY</p>
<p align="center">2.4 NASA Standard Laser Diode Safe and Arm Project Mgr: B. Wittschen, Johnson Space Center</p> <ul style="list-style-type: none"> • Develop, qualify, and demonstrate in flight a standardizable solid state laser safe and arm system <ul style="list-style-type: none"> - Flight demonstration - TBD - Joint HQS. activity with JSC • Determine criteria for what constitutes an acceptable S&A <ul style="list-style-type: none"> - Closely involve range safety in the design and testing - Place operational considerations up front in the design • Enhance safety and reduce risk <ul style="list-style-type: none"> - Enhance functional reliability - Simplify design - Eliminate problems with current electromechanical designs • Reduce power, explosive containment, and costs • Make design more easy to manufacture/checkout • Products: <ul style="list-style-type: none"> - Flight performance demonstration-TBD - Guidelines for incorporating features into flight units - Design specification for standard safe/arm devices 		

Fig. 25. NASA Standard Laser Diode Safe and Arm.



Fig. 26. Advanced Pyrotechnically Actuated Systems.

The first such activity concerns the development of a NASA Standard Laser Detonator (partially funded). The second activity will be the development and qualification of a NASA Standard Laser Initiator (partially funded). New, flight qualified, standard hardware will be built. Specifications will be prepared as NASA technical standards. Test reports will be written.

2.5.1 NASA Standard Laser Detonator, Phase I - Developmental Investigations - B. Wittschen, JSC

This project will investigate advancing NASA pyrotechnic technology by developing and conducting tests of laser detonators, Phase I. This project will also support Project 2.4, *NASA Standard Laser Diode Safe and Arm*, by the conduct of off-limits testing of developmental hardware. If successful, Phase II will proceed with the qualification of a NASA Standard Laser Detonator and subsequently the development and qualification of a NASA Standard Laser Initiator (NSLI), Task 2.5.2. (Fig. 27)

The rationale for the development of the Laser Standard Detonator is similar to that for the NSI. The current NASA Standard Initiator (NSI) was developed during Apollo and became a standard pyrotechnic device for Shuttle. Although it is extremely reliable, the NSI is susceptible to electromagnetic interference and is not suitable for efficient, automated manufacturing. While it is believed that enhancements will occur in initiator safety and reliability, the greatest gain from laser initiated devices is anticipated to be in cost savings from more efficient operational hardware and vehicle processing. It is,

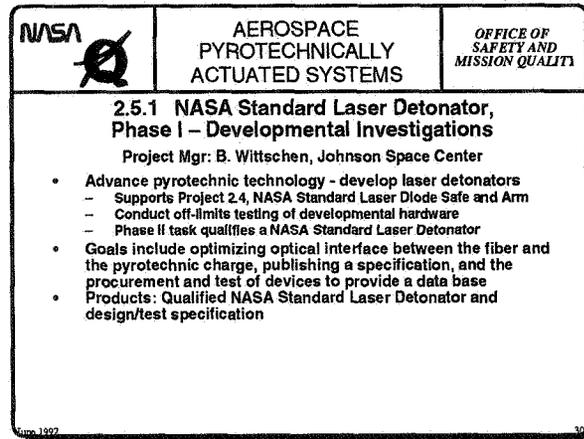


Fig. 27. NASA Standard Laser Initiator (NSLI).

therefore, highly desirable to develop a simplified initiator using a non-electric energy source of pyrotechnic charge ignition, such as a laser pulse. Laser initiators would become the initiation source for many pyrotechnic systems currently using the NSI. While the principle of laser ignition was demonstrated about 25 years ago and some devices have been produced, no progress is being made toward a standard device. The concept of laser initiated ordinance appears very attractive, but there is a need for data to develop confidence that this technology can perform as expected. The goals of this project are to optimize the optical interface between the fiber and the pyrotechnic charge, to publish a device specification, and to procure and test devices to initiate a data base. If the data appear sufficiently attractive, then a project

plan will be developed for Phase II—the qualification a NSLD.

A qualified NASA Standard Laser Detonator design and specification will be developed from data provided by this project. Test reports will be written.

2.5.2 NASA Standard Laser Initiator - TBD

This project will advance NASA pyrotechnic technology by developing and qualifying a NASA Standard Laser Initiator (NSLI). It will be supported through the experience gained by Project 2.4, NASA Standard Laser Diode Safe and Arm, through the conduct of off-limits testing of developmental hardware and firing circuits, and by the NSLD Task 2.5.1. (Fig.28)

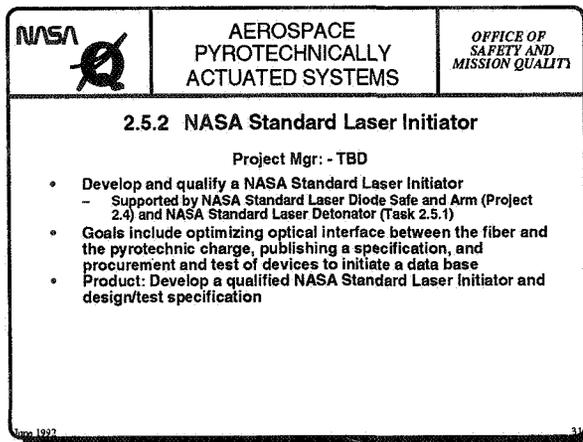


Fig. 28. NASA Standard Laser Initiator.

A qualified NASA Standard Laser Initiator design and specification will be developed from data provided by this project. Test reports will be written.

3.0 Test Techniques Program Element

This program element addresses all aspects of testing: manufacturing, lot acceptance, qualification, margin validation, accelerated life, ground checkout, and in-flight checkout. Deficiencies will be addressed as noted in the

survey where a need to improve upon pyrotechnic test methods was indicated and where it was considered necessary to develop test approaches that better characterize component and system performance (Fig. 29).

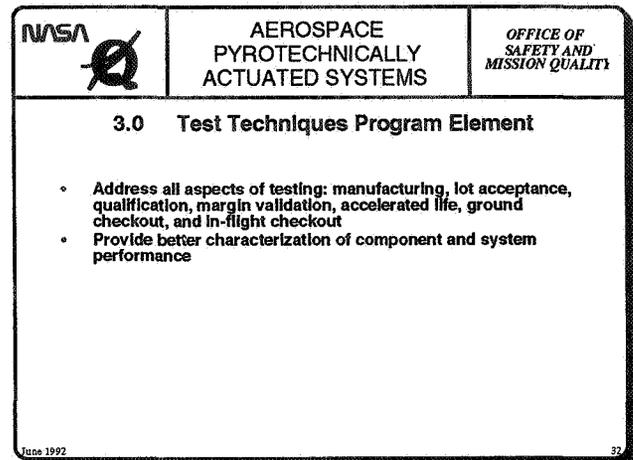


Fig. 29. Test Techniques Program Element.

Under these projects, the Program will test the hardware produced in Element 2.0. This Program Element will also develop new, improved, and appropriate test techniques to assure that the requirements imposed upon pyrotechnic devices are producing the specified performance required by NASA’s programs. Of particular concern is the provision for sound technical approaches that verify the device’s energy output and energy output rate. This element must provide the means to show that operational hardware can consistently meet specified design margins in a manner that is consistent with the manufacturing and process tolerances allowed by the specified manufacturing control documentation.

Guidelines, handbooks, manuals, and specifications will be produced for proper design practices, development, qualification, production (manufacture), and acceptance testing of pyrotechnic components and systems. The above will be developed for all aspects of pyrotechnic component and system applications. This Program Element will emphasize experimental and analytical developments to demonstrate functional margins. The technology needed to support the

accurate preparation of appropriate documents will be developed.

3.1 NSGG Performance - L. Bement, LaRC

This Project will qualify the NSGG for flight. It will also develop test procedures for the NSGG that confirm its intended operation and quantify performance relative to the design specification (Fig. 30).

The results of the analysis will be published and incorporated into the Program planning activity. System designs will be flight qualified, and test reports will be prepared. Process controls will be specified in a detailed technical specification to assure consistency and reliability for all manufacturing lots. The initial system to be qualified will be a linear separation system (Project 2.2.1).
 3.2.1 NSLSS Performance - L Bement, LaRC and J. B. Davis, MSFC

	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
3.1 NSGG Performance Project Mgr: L. Bement, Langley Research Center <ul style="list-style-type: none"> • Test to demonstrate NSGG for flight • Develop test procedures • Quantify performance • Qualify NSGG • Prepare design and test specifications • Products: <ul style="list-style-type: none"> - Design and test specification - NSGG qualification test report 		
June 1992		33

This Project will demonstrate functional performance of the NSLSS developed in Project 2.2.1. Functional performance margins, as well as the effects of system variables, including scaling, will be demonstrated. It will also develop test procedures for the NSLSS that confirm its intended operation and quantify performance relative to the design specification, Project 2.2.1. Test data will be obtained to qualify the NSLSS for flight. The data will also be used to update design specifications and for publishing test specifications. (Fig. 32)

Fig. 30. NSGG Performance.

Test data will be obtained to demonstrate the NSGG for flight. The data will also be used to update design specifications and for publishing test specifications.

The results of the testing will be published as a test specification for use by programs. It is anticipated that new NASA standards will be developed as a result. A NSGG qualification test report will be prepared.

3.2 Standard System Performance

Extensive background and operational experience will be obtained during qualification of standard designs selected for development in Project 2.2. Functional performance and the effects of system variables, including scaling, will be characterized (Fig. 31).

	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
3.2 Standard System Designs <ul style="list-style-type: none"> • Provide improved, more reliable, high performance standard hardware designs • Establish functional performance, effects of system variables, scaling • Prioritized selection of candidate hardware to become "standards" • Products: <ul style="list-style-type: none"> - System designs flight qualified and reports - Process controls specified in a technical specification 		
June 1992		34

Fig. 31. Project 3.2, Standard Systems Designs.

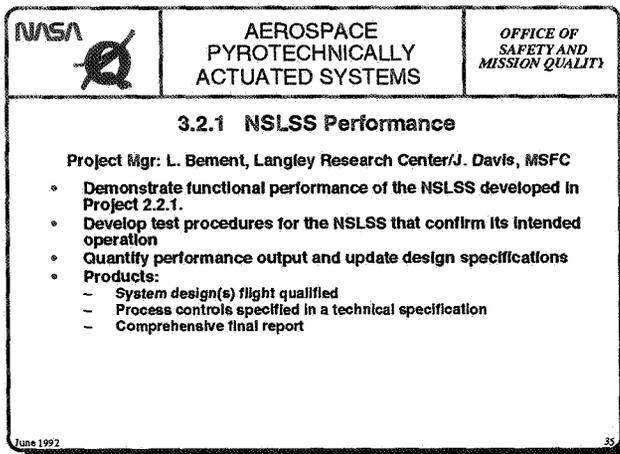


Fig. 32. Project 3.2.1, NSLSS Performance.

A comprehensive final report on the results will be published. System designs will be flight qualified and individual test reports prepared as testing is completed. Critical process controls will be identified in detail to permit preparations of a NSLSS technical specification. That specification will provide the information necessary to assure NSLSS consistency and reliability for all manufacturing lots.

3.4 Laser Diode Safe and Arm Performance - B. Wittschen, JSC

Test procedures for the safe and arm devices will be developed that confirm intended operation and quantify performance relative to the design specification (Fig. 33).

Test data will be produced to demonstrate range safety aspects required of safe and arm devices for flight use. The data will also be used to update design specifications and for test specifications.

Test reports will be prepared. Test results will be entered into the PAS Data Base and will be incorporated into the safe and arm design and test specifications.

3.5 Advanced PAS Performance

This project will test the performance of

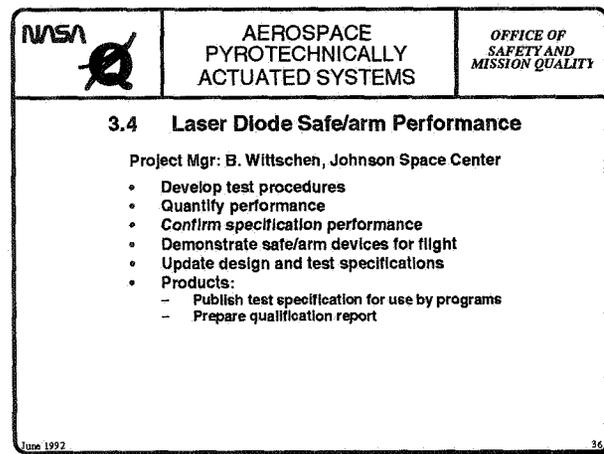


Fig. 33. Laser Diode Safe and Arm Performance.

advanced pyrotechnic devices and systems. Highly relevant measurement approaches will be used to define device outputs and system functions. The data will also be used to update device specifications and to prepare manufacturing test specifications.

The results of the testing accomplished will be published as a test specification for use by programs. New NASA standards will be developed. Qualification reports will be prepared.

3.6 Service Life Aging Evaluations

The effects of aging on pyrotechnic devices and any degradation incurred as a result of storage and service in the intended operational

environments will be evaluated (Fig. 34).

Relationships between storage environments and device shelf life will be determined. Approaches to accelerated life testing will be evaluated to find performance characteristics that can be measured during qualification to ensure that function and margins are not impaired by long periods of storage and service. The first activity under this project will use Space Transportation System (STS) pyrotechnic devices removed during major overhaul of Columbia.

Guidelines will be provided for estimating device service life capability based on data obtained from test methods that measure performance after actual or accelerated storage conditions. Test reports will be prepared.

3.6.1 Service Life Evaluations – Shuttle Flight Hardware, L. Bement, LaRC

Using current LaRC developed techniques, this project will determine effects of aging on Shuttle pyrotechnic devices, and any degradation incurred as a result of exposure to the operational environments. Relationships between service environments and device shelf life will be determined. Accelerated life testing will be evaluated to ensure that function and margins are not impaired by long periods of storage. The project will provide the technical data for permitting the extension of Shuttle pyrotechnic devices, thereby potentially saving NASA millions of dollars and other savings that will result from more efficient operations. The Shuttle hardware offers the first opportunity to compare actual space flight hardware with older hardware that has remained on the ground under

controlled conditions. (Fig. 35)

A comparison of the effects on device performance that can be attributed to the combined effects of ground processing, space launch/entry/landing dynamics, and in-space flight operational exposures can be determined.

The effects of service life will be

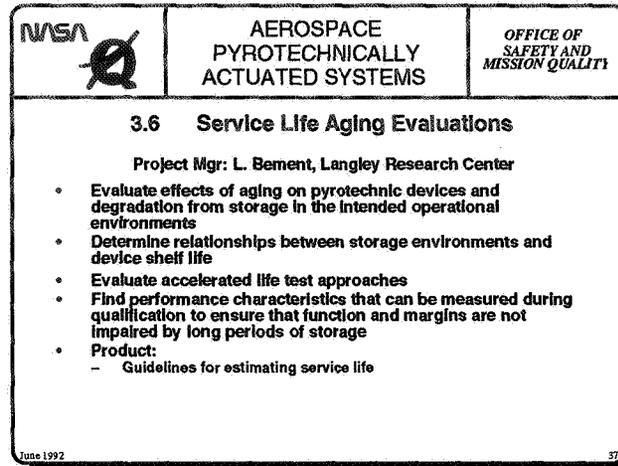


Fig. 34. Service life aging evaluations.

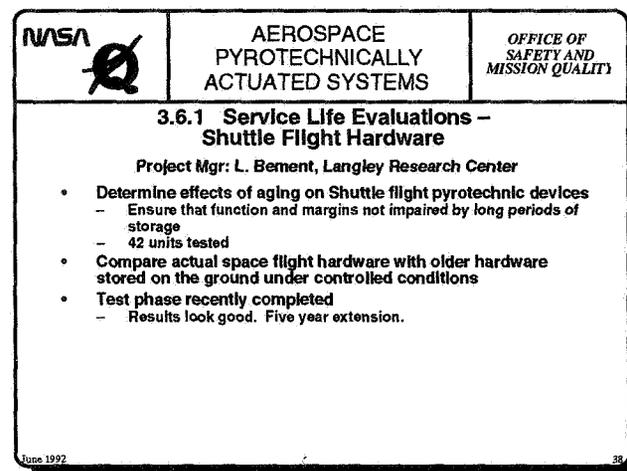


Fig. 35. Service Life Evaluation of Shuttle hardware.

determined for Shuttle TBI (Through Bulkhead Initiator) – 4 units, FCDC (Flexible Confined Detonating Cord) – 12 units, window cutting assemblies – 2 units and SMDC (Shielded Mild Detonating Cord) – 24 units. Service extensions will be based on data obtained using proven test methods that measure performance after exposure of the actual flight hardware exposed to flight operational environments. The test phase of this project has been recently completed.

developing approaches for analytically characterizing device performance sensitivities to manufacturing tolerances and “faults,” or deviations, in component ingredients (Fig. 36).

Emphasis will be placed on process understanding and controls needed to assure that specified hardware performance is realized

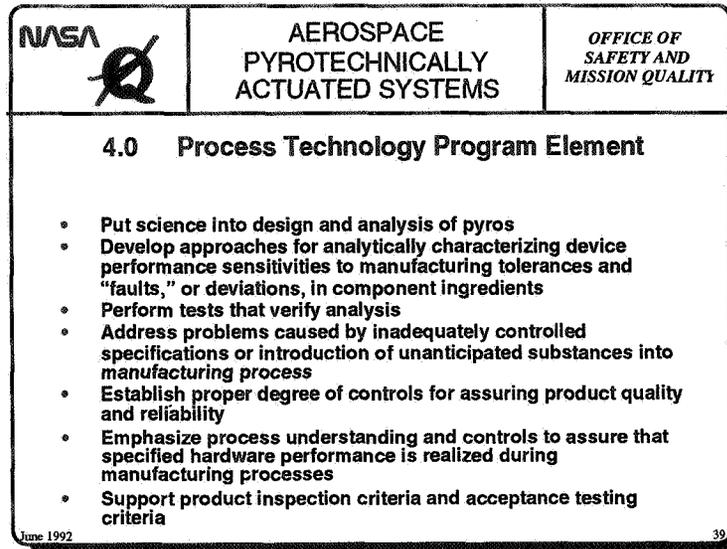


Fig. 36. Modeling - Process Technology Program Element.

It is necessary to develop test techniques that verify the analysis (Element 3.0). This program element will address the problems caused by inadequately controlled specifications or by the unexpected introduction of substances into the manufacturing process. This element is expected to establish the proper degree of controls for assuring product quality and reliability.

during manufacturing processes. The Program will conduct the necessary technology developments that support manufacturing processes. The means to validate that the critical manufacturing steps are all in place (product inspection) and that the delivered product performs per specification (acceptance testing) is of equal importance to understanding and adequately controlling processes. This relationship is shown in Fig. 37:

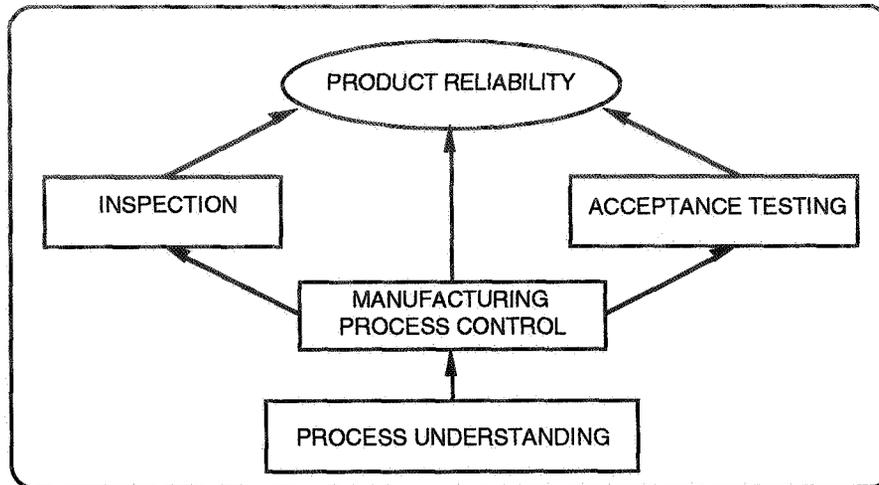


Fig. 37. Interrelationships between PAS Program and product reliability.

Guidelines, handbooks, and specifications will be provided for production (manufacture), and acceptance of pyrotechnic components and systems as required for the pyrotechnic discipline to accomplish its goals. The appropriate guidelines, handbooks, and specifications will be developed for all aspects of pyrotechnic component and systems manufacturing.

Schedule

A five-year program schedule, showing the overall intent and scope of the planning activity, is provided in Fig. 39. Detailed program schedules are presented in the PAS Program Implementation Plan.

4.2 NSI Model Development - R. Stubbs, LeRC

This project will provide a better understanding of the effects of process variables on the NSI's performance. It will be accomplished through the development of a model, the fidelity of which will be verified by testing. This Project will present the technical details needed to control the device's function to a consistently high reliability level of performance (Fig. 38).

A user friendly NSI model will be developed, and a report will be published describing the modeling in specification format for use by programs.

	AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS	OFFICE OF SAFETY AND MISSION QUALITY
<p style="text-align: center;">4.2 NSI Model Development</p> <p style="text-align: center;">Project Mgr: R. Stubbs, Lewis Research Center</p> <ul style="list-style-type: none"> • Provide better understanding of NSI's sensitivities to the effects of process variables on performance • Develop model <ul style="list-style-type: none"> - Contract with Dr. J. Powers and Dr. K. Gonthier, University of Notre Dame • Verify by testing • Present necessary technical details to control device's function providing consistently high reliability level of performance • Products: <ul style="list-style-type: none"> - Validated model - Report describing model in specification format <p style="font-size: small;">June 1992 40</p>		

Fig. 38. Project 4.2, NSI Model Development.

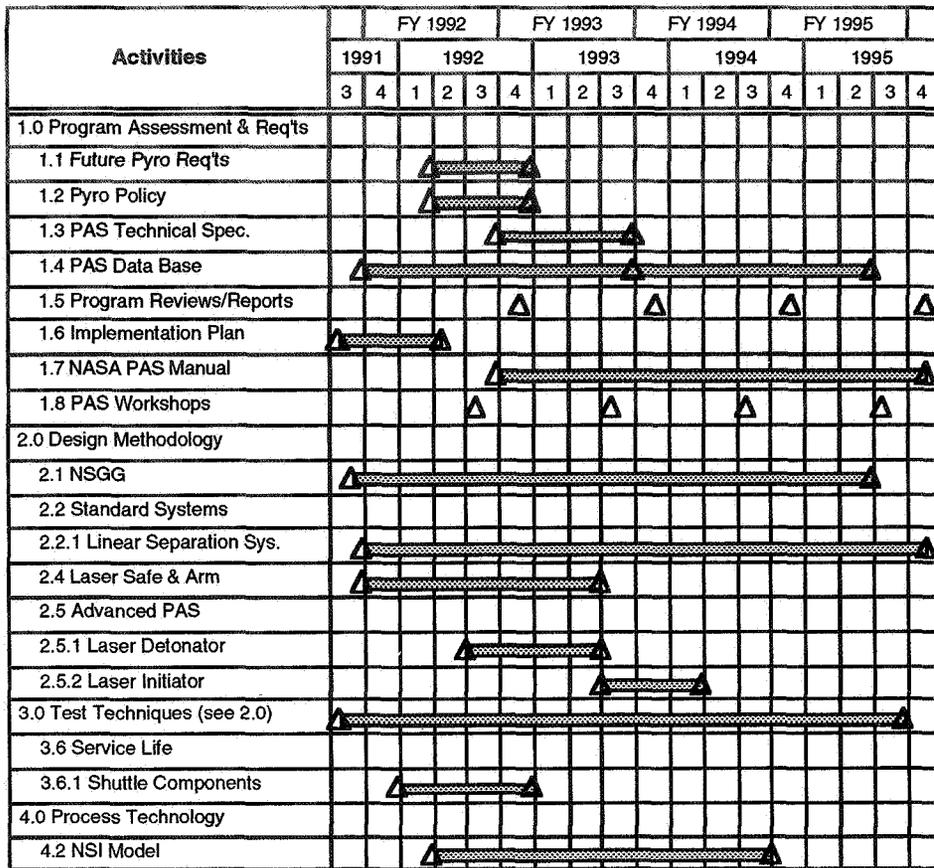
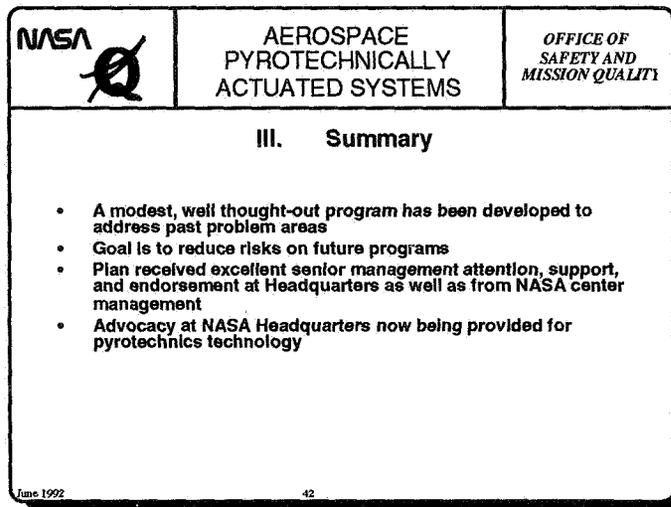


Fig. 39. PAS Program schedule.

III. SUMMARY

The NASA Aerospace Pyrotechnically Actuated Systems (PAS) Program, a focused technology program, has been initiated to enhance the reliability, safety, and performance of pyrotechnically actuated systems. This Program has been planned to help resolve concerns raised by the NASA-DoD Aerospace Pyrotechnic Steering Committee and by senior NASA management. This Plan reflects key efforts needed in PAS technology (Fig. 40).

The Plan identifies the goals and the detailed objectives which define how those goals are to be accomplished. The Program will improve NASA's capabilities to design, develop, manufacture, and test pyrotechnically actuated systems for NASA's programs. Program benefits include the following:



- Improved safety and mission success for NASA's flight programs,
- Advanced pyrotechnic systems technology developed for NASA programs,
- Hands-on pyrotechnic systems expertise,
- Quick response capability to investigate and resolve pyrotechnic problems,
- Enhanced communications and intercenter support among the technical staff, and
- Government-industry PAS technical interchange.

Fig. 40. PAS Program Summary.

DEFINITIONS

Goal

The top level purpose of the program.

Near term

Activities having the highest urgency plus those required as a foundation for the strategic elements. This period of time is ~ 2-3 years.

Objective

Detailed focused activities to support the accomplishment of the program's goals.

Pyrotechnically Actuated System (PAS)

Includes pyrotechnic devices and interfacing elements that could cause the pyrotechnic device itself to malfunction or for the pyrotechnics to influence an otherwise unwanted effect.

Pyrotechnic device

Comprises explosive and propellant-actuated mechanisms excluding propulsion systems.

Qualification testing

Testing conducted to verify that factory manufactured hardware, when built to specification drawings and control documents, will meet specified performance requirements in the intended operational environment. The number of units tested will be sufficient to provide a representative sampling of the manufactured hardware.

Reliability testing

Testing conducted on the number of samples that is required in order to verify that factory manufactured hardware, when built to specification drawings and control documents, will meet specified failure rate requirements and performance requirements in the intended operational environment.

Specific performance

A higher level of output per unit input. In the case of pyrotechnics, it is the energy produced per unit mass.

Strategic

Long, 10-year, general purpose program plan to provide guidance for the properly directed development of the program in the future.

ACRONYMS

DoD	Department of Defense
DoE	Department of Energy
FCDC	Flexible Confined Detonating Cord
LaRC	Langley Research Center
LeRC	Lewis Research Center
MSFC	Marshall Space Flight Center
NSD	NASA Standard Detonator
NSGG	NASA Standard Gas Generator
NSI	NASA Standard Initiator
NSLD	NASA Standard Laser Detonator
NSLI	NASA Standard Laser Initiator
NSLSS	NASA Standard Linear Separation System
PAS	Pyrotechnically Actuated Systems
PIP	Program Implementation Plan
SMDC	Shielded Mild Detonating Cord
SSC	Stennis Space Center
TBI	Through Bulkhead Initiator

REFERENCES

1. NASA survey entitled, "Solicitation of Interest in a Coordinated Pyrotechnic Technology Effort Among Centers," performed by the Langley Research Center, May 15, 1986.
2. Bement, L. J., "Pyrotechnic System Failures: Causes and Prevention," NASA TM-100633, Langley Research Center, Hampton, VA, June 1988.
3. "NASA Pyrotechnically Actuated Systems Program," prepared by Norman R. Schulze, approved by Daniel Mulville, NASA Headquarters, Washington, DC, February 1992.

This page intentionally left blank.

DETERMINATION OF PYROTECHNIC FUNCTIONAL MARGIN

by

Laurence J. Bement
NASA Langley Research Center
Hampton, VA

Morry L. Schimmel
Schimmel Company
St. Louis, MO

Approved for public release; distribution is unlimited.

3 3

PRECEDING PAGE BLANK NOT FILMED

DETERMINATION OF PYROTECHNIC FUNCTIONAL MARGIN

Laurence J. Bement
NASA Langley Research Center
Hampton, VA

Morry L. Schimmel
Schimmel Company
St. Louis, MO

SUMMARY

Following the failure of a previously qualified pyrotechnically actuated pin puller design, an investigation led to a redesign and requalification. The emphasis of the second qualification was placed on determining the functional margin of the pin puller by comparing the energy deliverable by the pyrotechnic cartridge to the energy required to accomplish the function. Also determined were the effects of functional variables. This paper describes the failure investigation, the test methods employed and the results of the evaluation, and provides a recommended approach to assure the successful functioning of pyrotechnic devices.

INTRODUCTION

Although pyrotechnic devices accomplish critical mechanical functions in aerospace systems, little effort has been applied to understand how well they perform (their functional margin). These devices are single-shot and costly, so the number of component tests (development, qualification and lot acceptance) and the number of system-level functional tests are minimized. Furthermore, there are few generally accepted margin tests to assist in enhancing this understanding. Consequently, many programs enter flight operations with only a "go/no-go" definition of pyrotechnic performance; that is, in testing the device the only data collected were that the device either did or did not function. This lack of testing and performance definition has led to costly failures on two current programs. The Hipparcos astronomy satellite utilized through-bulkhead initiators to ignite a rocket to achieve a circular orbit. Failures of the initiators left the satellite in an eccentric orbit, which reduced the effectiveness of the mission (references 1 and 2). The Tri-Services stealth missile utilizes pyrotechnic devices "to blow the cover off the radar-evading missile when it's dropped from a bomber, allowing its wings to unfold and its engine to start," (reference 3). These devices have contributed to three flight failures, and have delayed funding on the \$15 billion program, (references 3 and 4). The purpose of the effort described in this paper was to improve the of understanding how pyrotechnic devices work by demonstrating a method for measuring the performance margin of a pyrotechnically actuated pin puller for use on the NASA's Halogen Occultation Experiment (HALOE) instrument, which is on an orbital spacecraft.

Performance of cartridge-actuated devices, such as the pin puller, is influenced by a number of parameters. These include: composition of the gas-generating charge; the volume, shape and material into which the cartridge is fired; and the work to be accomplished within the device. As described in reference 5, designers have generally tried to use the peak pressure achieved by cartridges in a closed bomb, that simulates the initial volume in the device, as measure of performance. With this peak pressure and past experience, designers then use a "cut and try" approach to size the cartridge's charge for use in the actual device. When the device is fired, the usual approach is to document whether it did or did not accomplish the desired function.

This paper raises and addresses two very important questions:

1. How could devices that passed qualification fail to perform?
2. What can be done to minimize the risk of flight failures?

The approach for this paper was to follow the history of the HALOE pin puller to address these questions and describe how it: 1) was qualified for and successfully performed on a planetary landing mission, 2) experienced failures on a second intended application, 3) was subjected to an extensive failure analysis, and 4) was redesigned, functionally evaluated, including analysis of functional margin, and requalified for use on the HALOE instrument.

PIN PULLER DESCRIPTIONS

Two pin puller designs for different applications, as shown in figures 1 and 2, were evaluated in this effort. The Viking application was to release an antenna on the surface of Mars, and the HALOE application was to release a gimbal interface in Earth orbit. Both pin pullers had the same basic design: a 0.25-inch diameter pin was withdrawn just over a half inch, by firing either of two cartridges. The cartridge output vented through a 0.100-inch diameter opening out of the port to pressurize the pin side of the piston. The shear pin failed at approximately 80 pounds static force. Redundant o-rings were used on both the pin and the piston and lubricated with medium consistency silicone grease. A deep-drawn, 0.15-inch long, 0.010-inch wall thickness, 302 stainless steel energy-absorbing cup (labeled shock absorber in figure 1 and energy absorbing cup in figure 2) crushed on impact into the cap to remove the excess energy from the pin/piston and prevent rebound. The following describes the features that were unique to each pin puller.

Viking Pin Puller

The body and cap were manufactured from 6061-T6 aluminum as a weight consideration and to allow the cap to be welded to the body, (figure 1). The aluminum had a chemical chromate coating both internally and externally for oxidation protection. A molybdenum disulfide coating was applied to the pin as a dry lubricant. The energy absorbing cup had a height of 0.150 inch. The cartridge used, the Viking Standard Initiator (VSI), is a clone of the NASA Standard Initiator (NSI). The NSI was qualified for the Apollo and Space Shuttle programs. Both cartridges use 114 mg of zirconium/potassium perchlorate as the output charge.

HALOE Pin Puller

This body and cap were manufactured from 15-5 stainless steel; no coatings were required. The pin/piston used an electrodeposited nickel/Teflon coating as a dry lubricant. To assure lubrication of both the o-rings and the pin/piston bores, the o-rings were generously lubricated before installation and the pin/piston assembly was stroked six times through its limits in the body, followed by a force measurement to verify low friction levels. An o-ring was used to seal the cap to allow reusability. The units were disassembled and cleaned after each firing. The cap was extended to allow a larger volume to accommodate the potential for blowby and gaseous compression in the stroke of the piston. The energy absorbing cup height was increased to 0.250 inch to provide a greater energy absorbing capability than that in the Viking pin puller.

TEST APPARATUS

The pin puller was evaluated in three basic test configurations: tests to determine the energy required to stroke, tests to measure and compare NSI output, and functional tests.

Energy Required to Stroke

To determine the energy required to stroke, a drop test rig was employed to drop 1, 2 or 3-pound steel weights onto the vertically oriented pin puller. The total energy input was determined by multiplying the drop weight by the drop height to obtain a value in inch-pounds. The rebound height of the drop weight was monitored and found to be negligible, less than 2 percent. Small weights and large drop heights were selected to simulate the dynamics of an actual firing. Drop tests completed the stroke in 2 milliseconds, while an actual firing required 0.5 millisecond. The measured energies required to stroke the pin puller are conservative, because

impact losses were not considered.

Cartridge Output Comparisons

The pin puller was fabricated with a steel body and adapted to an energy sensor to measure cartridge output, as shown in figure 3. On functioning, the pin puller's piston/pin stroked against crushable honeycomb that was cut and calibrated to present about 300-pound force resistance throughout the stroke. The amount of stroke achieved during the firing, multiplied by the crush strength, provided an energy measurement in inch-pounds.

Functional Tests

Functional tests of the flight-configuration pin pullers were usually conducted in fixtures that induced no resistance to the stroke of the pin, (a non-system test). However, a number of tests were conducted, described later, using actual spaceflight hardware and interfaces, (a system test).

PROCEDURE

The approach used in this effort was to compile the history of this pin puller design from its application on the Viking program to Magellan failures, through a HALOE-sponsored failure investigation, to the HALOE redesign, functional evaluation, and requalification.

Viking History

The records for the Viking mission were studied to document the approach for development, including functional demonstration, qualification and system testing.

Magellan Selection/Failures

The records of the Magellan project's experience with the Viking pin puller design were compiled. Fortunately, the same prime contractor, Martin Marietta, developed both the Viking and Magellan spacecraft, allowing technical continuity to be maintained.

HALOE Failure Investigation

The HALOE project office had chosen to use residual Viking pin pullers from the original manufactured lot in their system. It was imperative that the Magellan failures be resolved, prior to incorporating the Viking pin puller into the HALOE instrument. The approach for this failure investigation was to examine pin pullers that had been functioned in past tests, determine the functional parameters that affected performance, and determine functional margin of

this design. The goals of the HALOE investigation were to determine if the Viking pin puller could be used, and if not, compile information to assist in the redesign.

Post-test examination - Four pin pullers previously used in LaRC HALOE system-level tests were x-rayed and dissected for visual inspection by removing the caps and cutting the bodies on their longitudinal axes on the centerline, perpendicular to the view shown in figure 1, to expose the piston and pin bores.

Evaluation of functional parameters - Evaluated were the effects of friction of the piston/pin o-ring interfaces, the performance of the energy absorbing cup, and the variation in output performance of the NSI. The drop test fixture was used to determine the energy required to overcome the shear pin and stroke the piston/pin with different levels of lubrication. Drop test energies were further increased to measure the crush characteristics of the energy absorbing cups. The honeycomb energy test fixture was used to determine the output performance of the VSI and two candidate NSI lots. Performance enhancement tests were conducted to improve combustion efficiency of cartridge loads, using VSIs with a 0.075-inch throat-diameter, epoxy nozzle (cast into the output cup of the VSI), and bonding 20 mg of BKN03 in the output cup of the VSI. A dual VSI firing was conducted to determine a maximum output energy production. (The normal mode of operation is to fire a single cartridge). A reusable, steel-bodied test unit, identical to the aluminum body, was manufactured for this series of tests, instead of using new aluminum bodies for each test. A Viking flight unit was also tested in the honeycomb energy test fixture.

HALOE Redesign/Functional Evaluation/Requalification

The goals for the redesign were: 1) that the energy deliverable by the NSI be at least three times that required to withdraw the pin, 2) that all functional parameters be controlled, 3) that the pin puller performance be evaluated in worst-case, system-level tests, and 4) that the environmental qualification effects on performance be minimal.

Once the design was selected, a total of 18 pin pullers were manufactured in a single lot. Of the total, 2 units were subjected to repeated test firings (refurbished after each) for functional evaluations, 10 units were subjected to an environmental qualification, and 6 units were set aside for system tests and flight. The 2 units were used to evaluate the energy required to stroke and to size the height of the energy absorbing cup, as well as providing data on the energy delivered by the NSI. On completion of all firings, the energy delivery data were analyzed to determine the pin puller's functional margin.

RESULTS

The results obtained in this effort are presented here in the same order as in the Procedures section.

Viking History

The Viking pin puller progressed through development, environmental qualification, and system demonstration.

The functional margin demonstration consisted of measuring and comparing the pressure in the working volume of the pin puller produced by fully loaded VSIs to the pressure produced by VSIs in which a percentage of the propellant load had been removed (off-loaded). Reference 6 specifies the requirements of using off-loaded cartridges to demonstrate functional margin. Since the pin puller was still able to function with half the expected peak pressure, a functional margin of two was assumed. System-level frictional tests were successfully conducted. Seven units successfully passed environmental qualification. All of the approximately 150 units tested in the Viking program successfully functioned. None of the units were subjected to a post-test dissection evaluation.

Magellan Selection/Failures

Based on the success of the Viking program, the Magellan program selected this pin puller to release the spacecraft's solar panels. At least two lots of pin pullers were manufactured by the original supplier and to the original drawings for the development effort. Two NSI lots were used during development; NSI lot XPJ was selected for flight.

Early in the program, a functional failure occurred, as reported in reference 7. The pin had stroked approximately half the required distance. The force required to push the pin to the end of its stroke was approximately 50 pounds. An inspection revealed that the NSI port had not been chemical chromate coated, as required by drawing. Additional firings of deliberately uncoated units, and properly coated units showed that coated units produced consistently higher peak pressures, so the failure was considered resolved.

Within three more firings a second failure occurred. In this failure the pin stroked less than 0.02 inch. The dissection revealed that the web (defined in figure 1) in the port into which the NSI was fired was deformed and had gripped and locked the piston into place. This pin puller design was then abandoned in favor of another previously qualified design. There was no failure resolution.

HALOE Failure Investigation

The objective of this effort was to inspect recently fired units and to evaluate the functional parameters of the Viking pin puller. These firings were made with NSI lot XPJ.

Post-test examination - An x-ray examination revealed that the pin puller bores on all the Viking units had been drilled off-center by as much as 0.009 inch, thus causing the webs to vary by that amount. On removing the caps from the bodies of three pin pullers that had been fired with a single NSI, two units had not fully stroked to contact the end cap, and the third had just contacted without appreciably deforming the energy absorbing cup to achieve the locking function. The fourth unit had been fired in a non-standard mode with two simultaneously initiated NSIs. The energy absorbing cup in this unit was completely flattened. The cylinder bores indicated no appreciable web deflection in the NSI port bottom, and only minor scuffing on the walls. There were no obvious indications of blowby around the o-ring seals.

Evaluation of functional parameters - This test series included input energy drop tests and honeycomb crush energy output tests.

Drop tests conducted with well-lubricated o-rings indicated that approximately 25 inch-pounds were required to fail the shear pin (5 inch-pounds), stroke the piston/pin (static friction forces of 3 to 5 pounds) and lock it by slightly deforming the energy absorbing cup. Tests without lubrication required over 100 inch-pounds to stroke (static friction forces of 50 pounds). The o-rings actually had rolled up on their axes and had chunks of material torn from their bodies.

The results of drop tests to determine the crush characteristics of the energy absorbing cups are summarized in figure 4. The amount of crush increased linearly with both the initial (I series) 0.150 and a new procurement of 0.250-inch deep cups (DC series).

The results of the cartridge output series are shown in table I (reference 8). The NSI lot XPJ produced the highest and most consistent energy output, averaging 127 inch-pounds, with a standard deviation of 20 inch-pounds. The VSI with 99 and 21 inch-pounds, respectively, was the second highest and consistent. However, the NSI lot XDB exhibited a low and highly erratic output; the average was 53 inch-pounds with a standard deviation of 49 inch-pounds. The maximum was 137 inch-pounds and the minimum was 19.

The performance enhancement tests, table II, indicate considerably improved performance. The epoxy nozzles produced a 100 inch-pound increase in energy output in both

the VSI and the NSI lot XDB. The BKNO3 charge produced an increase that was greater than 200 inch-pounds. The dual-VSI firing produced an increase that was greater than 200 inch-pounds.

Severe blowby was visually observed at all o-ring interfaces during the single firing of an NSI lot XPJ in a Viking pin puller. This unit had been previously drop-tested to measure its state of lubrication and reset to its original position. In the firing, the piston/pin stroked less than 0.020 inch and the web deformed and locked the piston, as had been experienced in the second Magellan failure. An examination revealed that a possible cause of the blowby was that the chemical chromate coating had rubbed off and adhered to the surface of the o-rings, preventing contact with the piston bore. The molybdenum disulfide coating had also likely wiped off of the pin and deposited on the pressure side of the pin's o-ring interface, preventing sealing. The previous drop test likely further aggravated these conditions.

In summary, the aluminum-bodied test series revealed that a considerable increase in energy required to stroke could be expected with less lubrication on o-ring interfaces. The chemical chromate and molybdenum disulfide coatings reduced the sealing reliability of o-ring interfaces. The aluminum body had a sensitivity to deformation. The steel-bodied test series revealed considerable output variation among VSI and NSI lots and that the combustion efficiency of all lots could be significantly enhanced by using an epoxy nozzle and an external BKNO3 booster charge. Also, the steel body exhibited none of the sensitivities to sealing or metal deformation. Finally, the use of a steel body met the requirement that the NSI energy output (127 inch-pounds for lot XPJ) was at least three times the energy required to stroke (25 inch-pounds).

HALOE Redesign/Functional Evaluation/Requalification

Based on the results of the failure investigation, the project office decision was to proceed with a steel-bodied configuration.

Energy required to stroke tests - Drop tests revealed that the 25 inch-pound energy requirement to stroke and lock the piston and the cup crush characteristics were the same between pin puller designs.

Energy delivered by the NSI tests - The energies measured in all functional tests of the HALOE pin puller are shown in table III. Energy delivery measurements were obtained in each firing by measuring the amount of crush occurring in the energy absorbing cups. The cup crush calibration of energy input versus cup crush (figure 4) was obtained from drop tests. Note that for tests 1 through 9, using the 0.154-inch

energy absorbing cup, the energy deliveries are greater than 120 inch-pounds. This is because all cups were fully crushed. This situation was not determined until late in the series, when in the dual cartridge firings (tests 8 and 9) the piston was deformed, even though the cup crush did not increase. Therefore, a 0.250-inch cup was selected. Accurate energy deliveries are shown in tests 10 through 15. The environmentally tested units, tests 16 through 25, produced comparable energy levels, excluding tests 17 and 18. A sympathetic initiation of the second cartridge (not an NSI) occurred in the opposite port in test 17. This second cartridge did not have sufficient thermal insulation to prevent such an initiation. Test 18 was a deliberate dual-NSI firing to determine the pin puller's pressure containment capability at +200 F under vacuum; the piston deformed as the cup bottomed out, but no venting occurred. The five pin pullers fired in the system tests produced significantly lower energy outputs than tests 10 through 25, which was attributed to pin loading.

Functional margin analysis - The functional margin for pyrotechnic devices is defined as follows:

$$\text{Functional Margin} = \frac{\text{Energy Deliverable} - \text{Energy Required}}{\text{Energy Required}}$$

Energy Deliverable is the average energy produced by the cartridge through firings under test conditions that are identical to the flight configuration.

Energy Required is the average energy required to function the device, measured through drop tests with flight hardware.

Therefore, Functional Margin is a ratio of the energy in excess of that required to accomplish the function to the energy required to accomplish the function. For the HALOE pin puller:

$$\text{Functional Margin} = \frac{165 - 25}{25} = 5.6$$

The average energy deliverable by the NSIs in the system tests was 165 inch-pounds. The energy required to stroke the piston was determined to be 25 inch-pounds in the drop tests.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations in regard to the two questions raised in the introduction are:

1. How could devices that passed qualification fail to perform?

For the Viking pin puller design, there was an inadequate demonstration of functional margin. That is, not enough information had been obtained on the influence of functional variables and how much energy was consumed by these variables in accomplishing the function. The Magellan failures occurred when production variables reduced the pin puller's performance below its functional threshold: 1) sliding friction increased, 2) o-rings seals were poor, 3) the combustion efficiency of the NSI was reduced, and 4) the aluminum housing deformed.

2. What can be done to minimize the risk of flight failures?

Functional margin should be determined, comparing "energy deliverable" by a cartridge to the "energy required" for the device to function. The "energy deliverable" by the cartridge should be measured by firings in the actual device. "Energy required" should be determined by drop tests on the actual device.

A further conclusion is that the changes made to the pin puller design, specifically using steel instead of aluminum and using a more durable dry coating on the pin, significantly improved functional performance.

REFERENCES

1. Europeans Tussle Over Motor Failure. Space News, June 11-17, 1990.
2. Hi-Shear Part Blamed for Hipparcos Failure. Space News, July 16-22, 1990.
3. Pasztor, Andy: Strategic Air Command to be Eliminated in Sweeping Reorganization of Air Force. Wall Street Journal, September 18, 1991.
4. USAF Warns Northrop on Problems with Standoff Missile. Aviation Week & Space Technology/September 23, 1991.
5. Bement, Laurence J. and Schimmel, Morry L.: Cartridge Output Testing: Methods to Overcome Closed-Bomb Shortcomings. Presented at the 1990 SAFE Symposium, San Antonio, TX, December 11 to 13, 1990.
6. NSTS 08060, Space Shuttle System Pyrotechnic Specification, Revision F, March 21, 1988. Paragraph 3.6.18.1C specifies functional margin demonstration.
7. GIDEP ALERT F3-A-86-11; Explosives, Pyrotechnic Pin Puller, February 1987.
8. GIDEP ALERT H5-A-89-01; Explosives, Pyrotechnic Pin Puller, Initiator, March 1989.

TABLE I - ENERGY OUTPUT COMPARISONS OF VSI AND TWO NSI LOTS
IN STEEL TEST PIN PULLER ENERGY SENSOR
CONFIGURATION.

<u>Ser. No.</u>	<u>Energy</u> <u>in-lb</u>
Viking Standard Initiator, Lot No 13-32275, Mfd in 1972	
0500391	85
0500372	95
0300141	119
0300088	92
0500452	89
0500665	110
0500732	104
0500716	74
0500683	78
<u>0500745</u>	<u>143</u>
	Average = 99
	Std Dev = 21
	Percent of Avg = 21%

NASA Standard Initiator, Lot XPJ, Mfd in 1985	
0384	107
0385	135
0398	143
0393	113
0392	122
0400	121
0414	165
<u>0394</u>	<u>110</u>
	Average = 127
	Std Dev = 20
	Percent of Avg = 16%

NASA Standard Initiator, Lot XDB, Mfd in 1988	
0147	26
0144	19
0150	137
0149	31
<u>0138</u>	<u>54</u>
	Average = 53
	Std Dev = 49
	Percent of Avg = 92%

**TABLE II - PERFORMANCE ENHANCEMENT TESTS IN STEEL TEST PIN
PULLER ENERGY SENSOR CONFIGURATION.**

<u>Ser. No.</u>	<u>Energy</u> <u>in-lb</u>	<u>Test Configuration</u>
VSI with epoxy nozzle		
0500695	207	
0500380	271	
0500727	189	
0500755	210	
0500690	<u>202</u>	
Avg	216	
Std Dev	32	
% of Avg	15	
NSI lot XDB with epoxy nozzle		
0121	111	
0154	257	
0152	128	
0118	192	
0148	<u>144</u>	
Avg	166	
Std Dev	59	
% of Avg	36	
BKNO3 charge bonded to VSI output closure		
0300009	>270	40.5 milligrams
0300139	>280	19.3
0500685	310	20.1 Two honeycomb cubes
0500750	370	20.1 stacked to double the
0500389	392	20.0 measuring capability;
0500398	359	20.1 o-rings still vented
0500698	320	20.0 due to inadequate length
0500693	190	10.0 of piston bore.
Dual VSI firing		
0500684	>360	Simultaneous initiation with
0500718		420 pound-strength honeycomb

TABLE III - HALOE PIN PULLER FIRING TEST DATA (NSIs, LOT XPJ)

Test No.	NSI Ser. No.	Crush inch	Energy Delivery inch-pounds
----------	--------------	------------	-----------------------------

Energy Absorbing Cup Size - 0.154 Inch

In tests 1 through 9 the cups were fully crushed, producing energies that were greater than 120 inch-pounds.

Energy Absorbing Cup Size - 0.250 Inch
(Non-System Tests)

10	0448	.124	189
11	0720	.138	210
12	0476	.126	192
13	0489	.123	188
14	0479	.130	198
15	0480	.118	<u>180</u>
			Avg = 193
			Std Dev = 10
			% of Avg = 5

Energy Absorbing Cup Size - 0.250 Inch
(Environmentally Exposed Pin Pullers, Non-System Tests)

16	0454	.102	156
17	0447/symp.*	.167	>254
18	0444/0446	.183	>278
19	0450	.120	183
20	0453	.117	179
21	0449	.128	195
22	0455	.138	210
23	0451	.110	168
24	0448	.107	164
25	0452	.135	206
			**Avg = 183
			Std Dev = 22
			percent of Avg = 12

Energy Absorbing Cup Size - 0.250 Inch
(System Tests)

26	0491	.115	176
27	0456	.096	147
28	0445	.089	136
29	0396	.115	176
30	0390	.124	<u>189</u>
			Avg = 165
			Std Dev = 22
			percent of avg = 13

*Wrong second cartridge installed. **Excluding tests 17, 18.

Viking PYRO OPERATED PIN PULLER - 1/4"

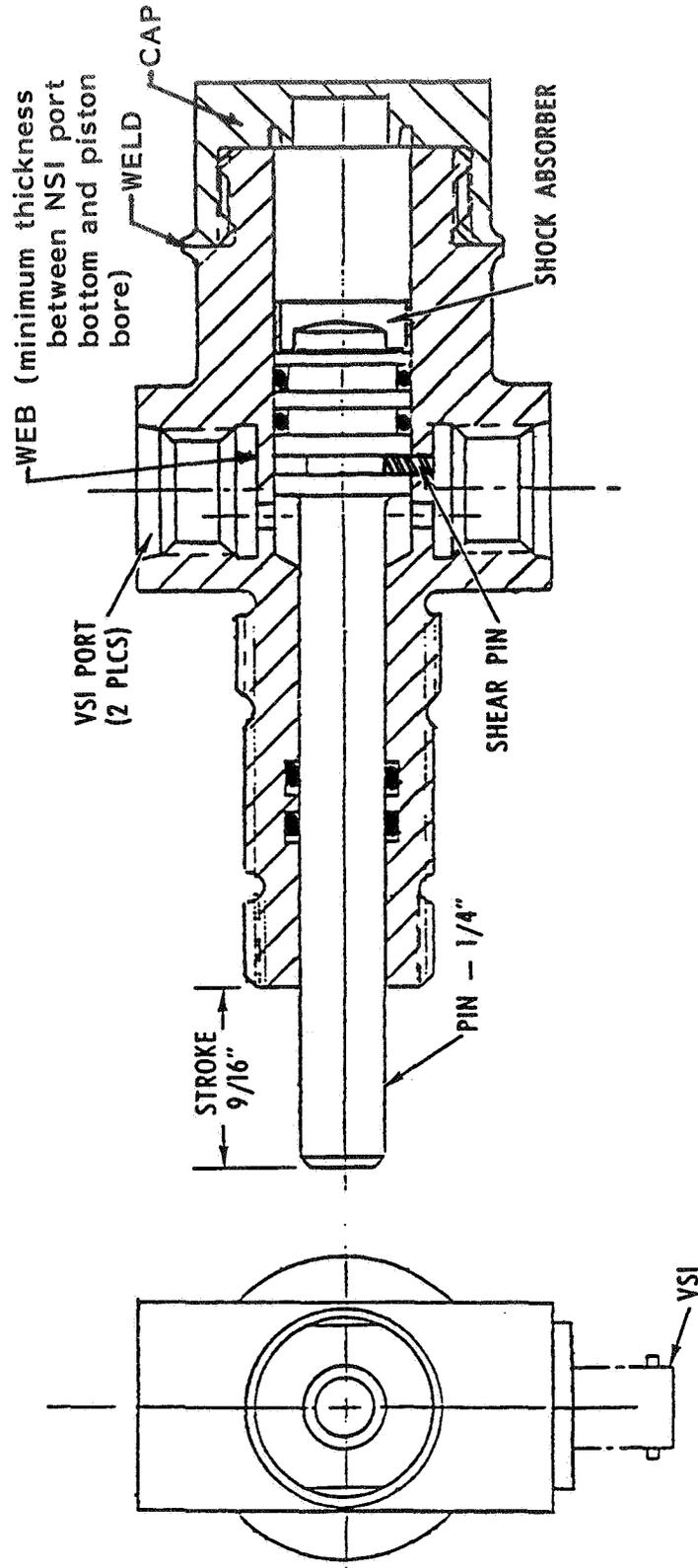


Figure 1.- Cross sectional view of aluminum-bodied Viking pin puller.

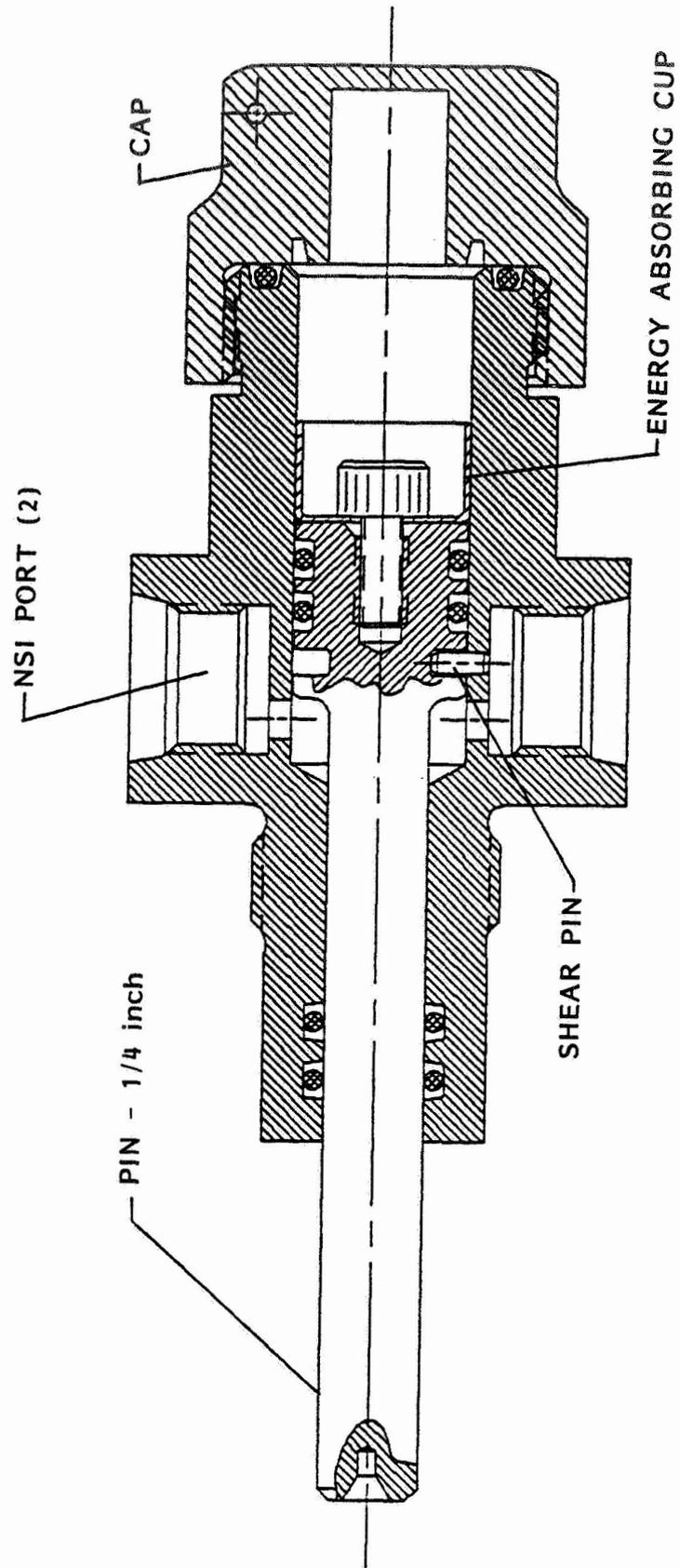


Figure 2.- Cross sectional view of steel-bodied HALOE pin puller.

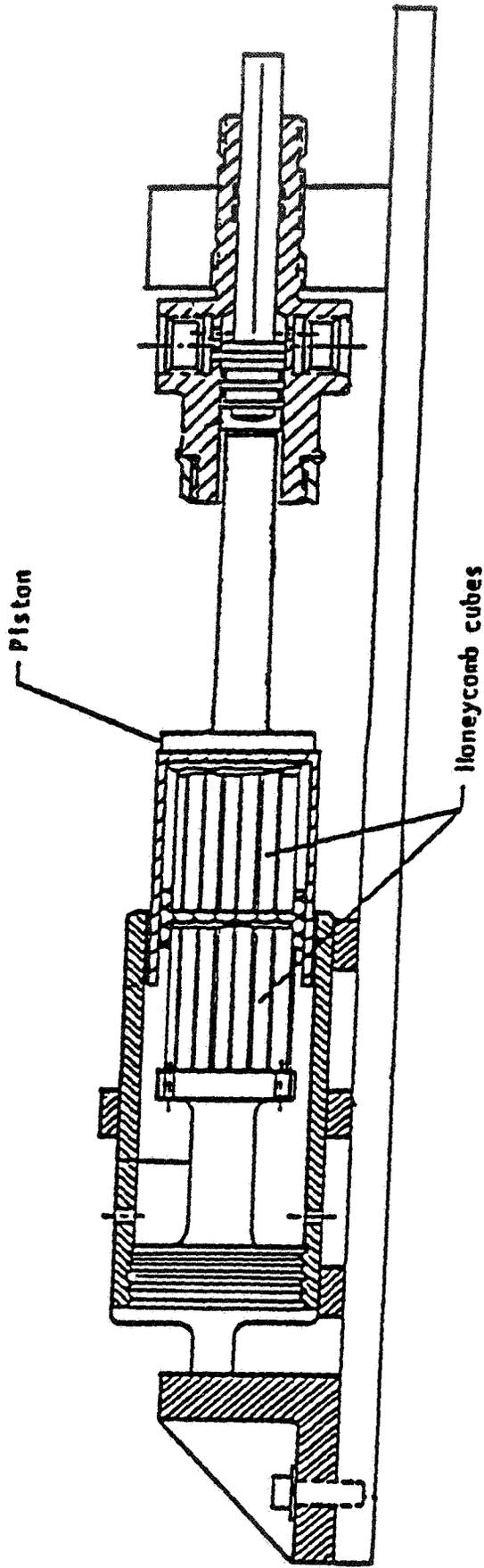


Figure 3:- Cross sectional view of energy sensor adapted to pin puller.

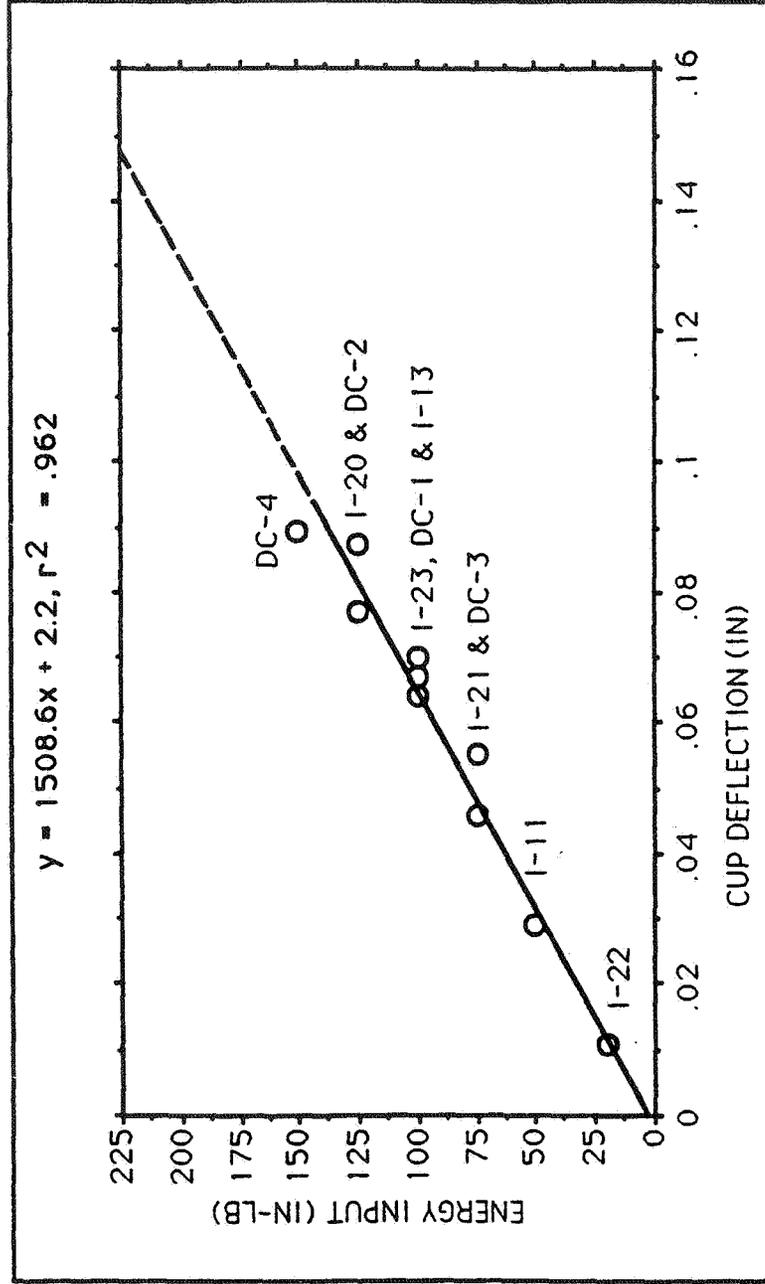


Figure 4.- Crush characteristics of the energy absorbing cups obtained by drop tests.

DEVELOPMENT OF A NASA STANDARD GAS GENERATOR

BY

LAURENCE J. BEMENT
NASA LANGLEY RESEARCH CENTER

HAROLD KARP
HI SHEAR TECHNOLOGY CORPORATION

MORRY L. SCHIMMEL
SCHIMMEL COMPANY

Approved for public release; distribution is unlimited.

1993010 17
493019
32P

N 9 3 - 2 0 1 3 5

DEVELOPMENT OF A NASA STANDARD GAS GENERATOR

- **GOALS**
- **BACKGROUND**
- **APPROACH**
- **FEASIBILITY STUDY RESULTS**
- **FEASIBILITY STUDY CONCLUSIONS**
- **FUTURE PLANS**

This shows the outline of the presentation.

NSGG GOALS

- **DESIGN, DEVELOP, AND QUALIFY A NASA STANDARD GAS GENERATOR**
 - **SAME ENVELOPE AS NASA STANDARD INITIATOR (NSI)**
 - **HIGH THERMAL, VACUUM AND AGE STABILITY**
 - **CONSISTENT, RAPID-DELIVERY, GAS PRODUCTION**
 - **CAPITALIZE ON NSI QUALIFICATION**

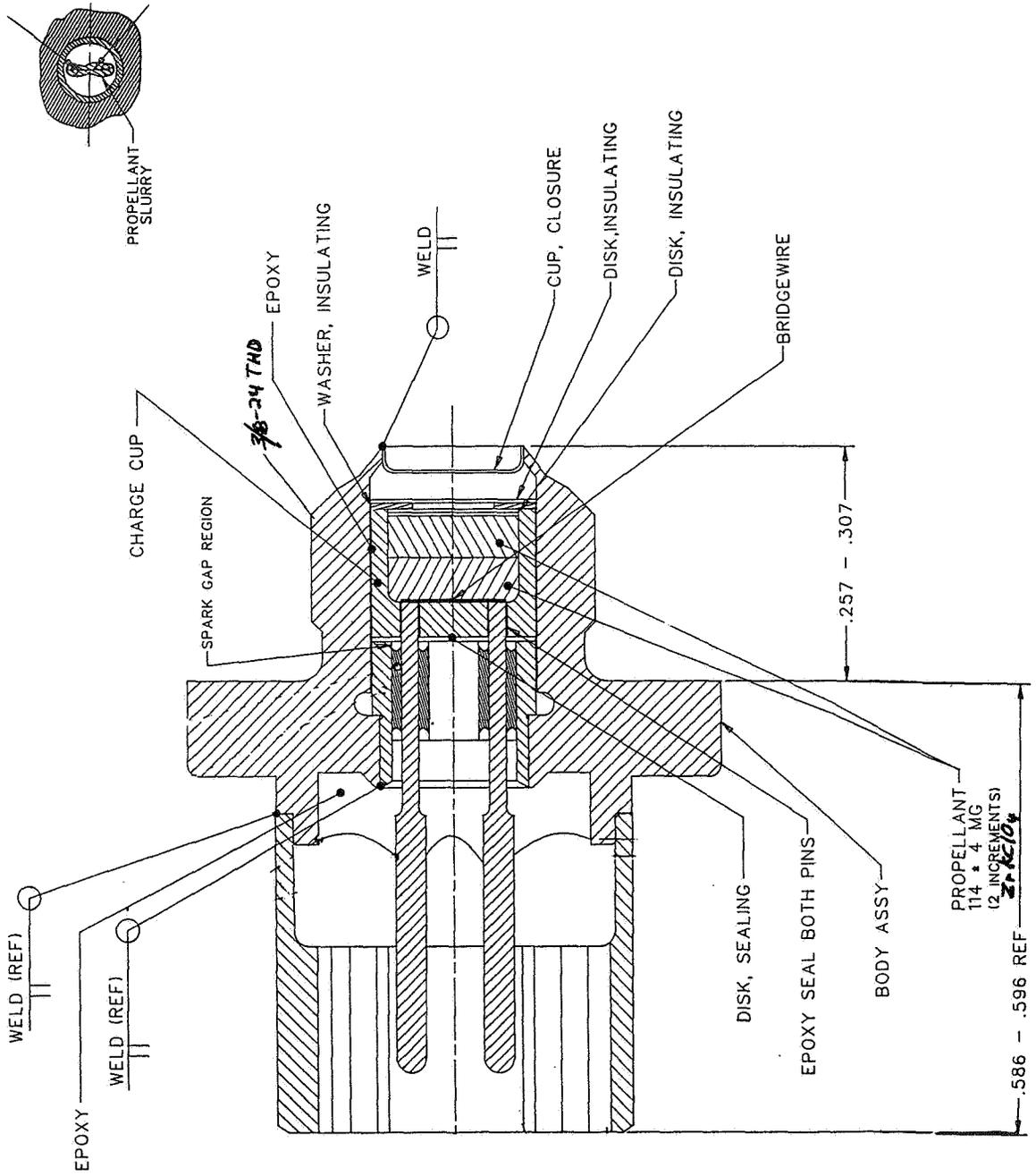
- + **MAINTAIN STRUCTURE AND ELECTRICAL IGNITION INTERFACE**
- + **MODIFY PYROTECHNIC LOAD**
- + **CONDUCT DELTA-QUALIFICATION**

- **CHARACTERIZE OUTPUT PERFORMANCE FOR A VARIETY OF APPLICATIONS**

- **MAKE NASA STANDARD GAS GENERATOR GFE, LIKE NSI**

The NSGG goals are to create a NASA standard gas generating cartridge, characterize its performance and make it readily available to users. A cartridge within the same envelope as the NASA Standard Initiator (NSI) has the greatest potential use, as described in subsequent viewgraphs. Due to long-term, deep-space operations, the materials selected must withstand temperatures of over 300 F at vacuum, while exhibiting long-term stability. Consistent performance in gas production is necessary in work applications, with rapid delivery rates to accommodate small pyrotechnic mechanisms. The qualified NSI will be minimally modified to maintain the existing structure and electrical ignition interface. The approach is to replace up to 50 % of the current NSI output charge with a gas generating material, which will require only a delta qualification, rather than a complete verification of performance and environmental exposure. The output of the NSGG will be measured and characterized with a variety of mechanical applications. Ultimately, the NSGG will be available as Government-furnished equipment, like the NSI.

NASA STANDARD INITIATOR (NSI)



This is a cross section of the NSI to show the structure and proposed change. Only the second increment of the main ZrKClO4 will be modified.

BACKGROUND

- **NSI HAS BEEN MISAPPLIED AS A GAS GENERATING CARTRIDGE**
- **DESIGNED AND INTENDED TO BE AN INITIATOR**
- **CONVENIENT SIZE/ENVELOPE**
- **QUALIFICATION STATUS**
- **NASA PREFERENCE; APPLICATION AS INITIATOR ON SHUTTLE PAYLOADS**
- **INADEQUATE DESIGN/DEVELOPMENT GUIDELINES FOR GAS GENERATOR APPLICATIONS**
- **COMBUSTION/GAS GENERATING SENSITIVITIES/ VARIATIONS**

Although the NSI was designed as an initiator, it has been misapplied as a gas generating cartridge. It's convenient, small size and envelope has allowed it to be installed in a variety of small pyrotechnic mechanisms. It's qualification status allows ready acceptance by spacecraft designers and the Government. In fact, the Shuttle payload document states that the NSI shall be used as the electrical ignition interface, or an alternate approach justified; an equivalent safety performance and qualification demonstration is expected.

Unfortunately, design/development guidelines for gas generating cartridge applications are inadequate in providing assurance of successful performance. Furthermore, the NSI gas generating output performance is sensitive to the conditions under which it is fired, such as initial volume and configuration, materials and volume change as in a stroking piston.

BACKGROUND (Continued)

- **SEARCHED FOR A QUALIFIED GAS GENERATING CARTRIDGE**
- **MANY CARTRIDGES CONTAINED THE SAME PYROTECHNIC COMPOSITION AS THE NSI**
- **THE MODIFIED CARTRIDGES DO NOT MEET NASA ENVIRONMENTAL REQUIREMENTS**
- **OUTPUT PERFORMANCES NOT ADEQUATELY CHARACTERIZED**
- **NO OTHER CARTRIDGE HAS NSI ACCEPTANCE AND HISTORY**

00

Industry was surveyed for a gas generating cartridge that met the above requirements. Many cartridges contained the same pyrotechnic composition as the NSI, and the modified cartridges did not meet the thermal/vacuum stability. Hercules Hi Temp was frequently used, which contains a high percentage of RDX that will sublime under vacuum. Again, the output performances of these cartridges were not characterized, so there was no need begin such an evaluation over an NSI-derived cartridge. Finally, no other cartridge has achieved the NSI recognition, acceptance and variety of applications.

APPROACH FOR NSGG DEVELOPMENT/QUALIFICATION

- **DEVELOP EVALUATION TEST METHODS**
- **CONDUCT FEASIBILITY STUDY**
- **CONDUCT PRELIMINARY DEVELOPMENT**
- **CONDUCT FINAL DEVELOPMENT**
- **CONDUCT DELTA-QUALIFICATION**

Our approach for NSGG development and qualification was planned to be conducted in several phases. Test methods were developed to evaluate output performance for a variety of potential applications. A feasibility study using modified NSIS was accomplished. Preliminary and final development will be conducted with a delta qualification to evaluate the effects of manufacturing lots and environments.

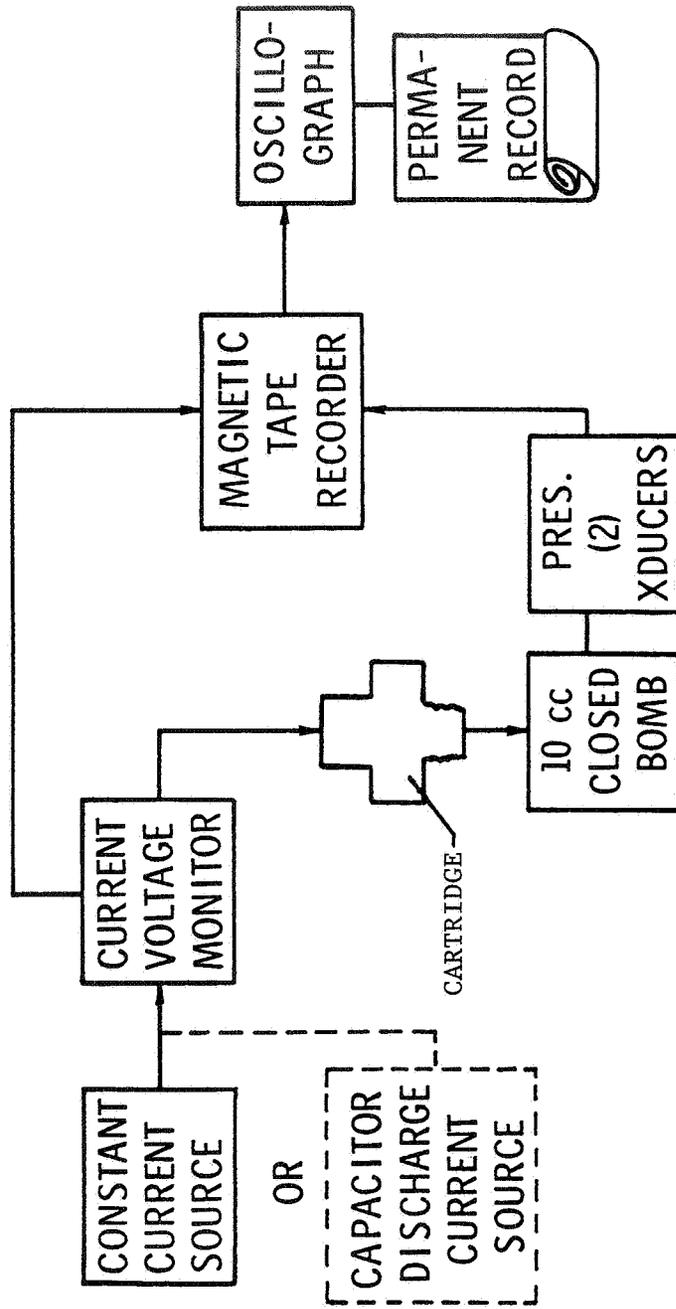
CHARACTERIZATION OF NSGG OUTPUT

- OUTPUT OF ANY PYROTECHNIC CARTRIDGE DEPENDS ON HOW IT IS APPLIED
- WHY FOUR OUTPUT TEST METHODS?
 - CLOSED BOMB (10 CC)
 - * UNIVERSALLY ACCEPTED STANDARD
 - * DOES NOT SIMULATE ANY PYROTECHNIC DEVICE
 - DYNAMIC TEST DEVICE
 - * SIMULATES AN EJECTOR
 - MCDONNELL ENERGY SENSOR
 - * SIMULATES THRUSTER ACTING AGAINST A CONSTANT RESISTANCE
 - HALOE PIN PULLER
 - * SIMULATES A RETRACTOR

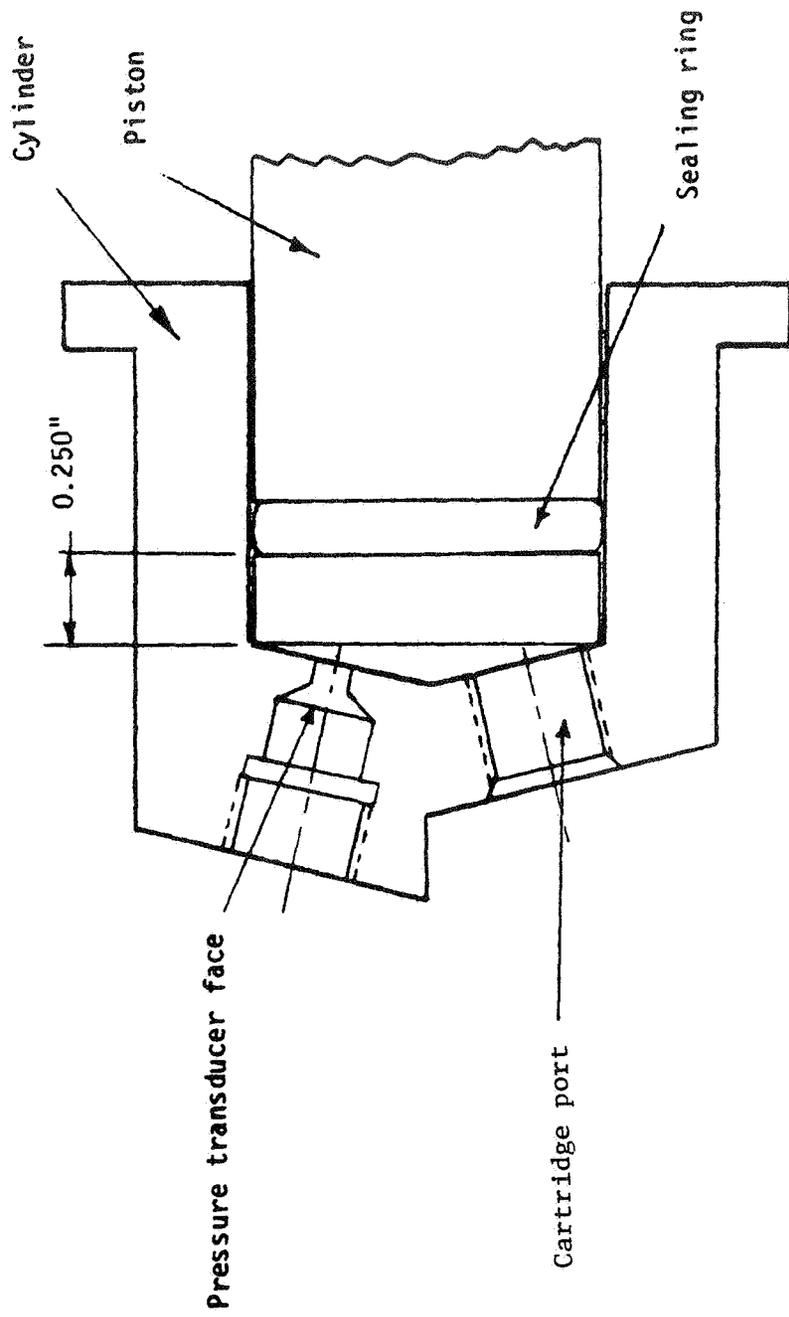
The output of any pyrotechnic cartridge depends on how it is applied. Therefore, the output of the NSGG should be evaluated with a variety of applications. Four test methods, fabricated of steel for reusability, were selected for functional evaluation for the following reasons. The 10 cc closed bomb, described in figure 8, is the universal performance standard for acceptance and design of cartridges and applications in devices. However, this test does not simulate any pyrotechnic device; a pressure trace achieved within a fixed volume has no meaning in what work a cartridge could accomplish in a mechanism. The Dynamic Test Device, shown in figure 9 is a one-inch diameter, one pound, one-inch stroke piston/cylinder device which simulates an ejector with a free mass. The energy delivered by the cartridge is obtained by measuring the final velocity of the mass ($1/2mv^2$). The McDonnell Energy Sensor (figure 10) has a half-inch diameter piston which strokes against a constant resistance force, provided by 300 pound-strength, crushable honeycomb, to simulate a thruster. The energy delivered by the cartridge is obtained by multiplying the stroke achieved in inches by the strength of the honeycomb in pounds force to obtain a value in inch-pounds. The HALOE pin puller, shown in figure 11, has a 0.4-inch diameter piston which strokes to withdraw a pin. Energy measurements are achieved by measuring the amount of crush of the energy absorbing cup at the end of the piston stroke. This cup crush has been calibrated in inch-pounds of energy through dynamic impact tests to drive the piston through its stroke.

Each of the energy measuring devices represents a unique mechanical aspect of pyrotechnic devices in terms of the mass moved, the resistive forces and the transfer of energy from the cartridge. The Dynamic Test Device has a very large surface area and mass of the stroking piston. The McDonnell Energy Sensor presents the minimum possible initial free volume and measures work on the axis of the cartridge, since the output of cartridges is directional. The HALOE pin puller presents a tortuous, energy-absorbing path for the gas output of the cartridge to vent through a 0.1-inch diameter opening to drive the small-mass piston. The NSGG data collected in these devices will provide guidelines for potential users. The user would compare his intended application mechanism to the above three test methods and have a starting point to begin his design. It must be emphasized that the user would have to demonstrate the performance of the NSGG in his application, rather than imply that the energy measured in the three test methods will assure successful performance.

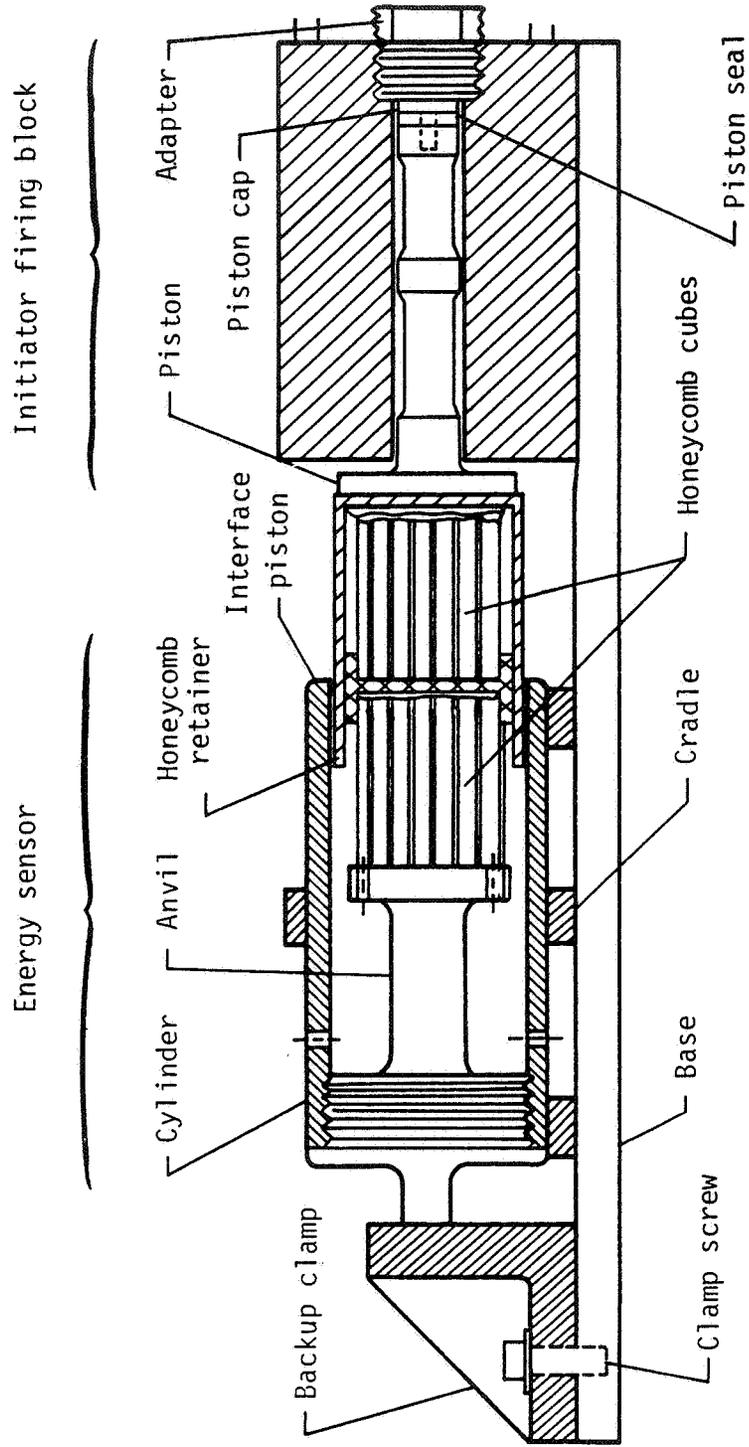
CLOSED BOMB FIRING AND MONITORING SYSTEM



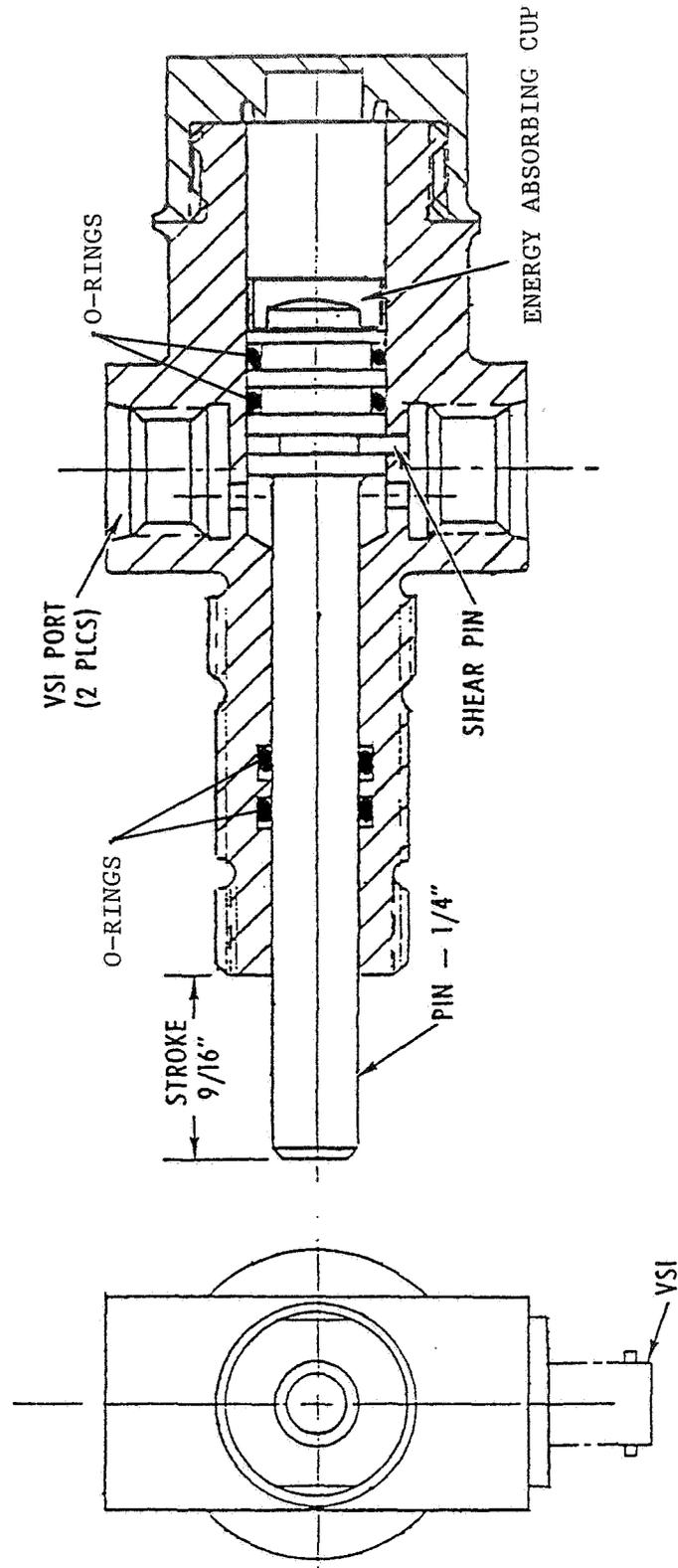
NASA LARC DYNAMIC TEST DEVICE



MCDONNELL ENERGY OUTPUT TEST FIXTURE



Viking PYRO OPERATED PIN PULLER - 1/4"



FEASIBILITY STUDY GOALS

- **EVALUATE TEST METHODS/PERFORMANCE CRITERIA**
- **DEMONSTRATE FEASIBILITY OF ENERGY PRODUCTION WITH MODIFIED NSI WHICH INCLUDES GAS GENERATING MATERIAL**

The goals of the feasibility study were to evaluate the proposed test methods, as well as to establish a performance criteria for what could be expected from an NSGG. Also, demonstrate the feasibility of modifying the NASA Standard Initiator with the addition of gas generating material. These goals have been demonstrated, as described in subsequent viewgraphs, to provide the confidence needed to proceed into development.

TEST METHODS DEMONSTRATION

- VIKING STANDARD INITIATOR (VSI)
- VSI WITH 20 MG BKNO₃, BONDED EXTERNALLY

GAS GENERATING MATERIALS EVALUATION

- NSI WITH STANDARD 114 MG MIX
- NSI WITH 85 MG STD. MIX AND 30 MG BKNO₃ (25 PERCENT)
- NSI WITH 85 MG STD. MIX AND 30 MG HI TEMP (25 PERCENT)
- NSI WITH 85 MG STD. MIX AND 30 MG HI SHEAR 006 (25 PERCENT)
- NSI WITH 57 MG STD. MIX AND 57 MG HI SHEAR 006 (50 PERCENT)

The feasibility study was divided into two areas, test method demonstration and gas generating materials evaluation.

Two different cartridge configurations were employed to evaluate the test methods. The Viking Standard Initiator (VSI) is a clone of the NSI, having the same housing, electrical interface and pyrotechnic charge. Past experience in adding 20 mg of boron, potassium nitrate (BKNO_3) to the output cup of the VSI has provided a considerable increase in output of the VSI in the pin puller, due to raising the internal pressure and achieving a more efficient combustion of the NSI mix. Actual data is shown in subsequent view graphs.

The gas generating materials evaluated were compared to the standard mix, which contains 114 mg of ZrKClO_4 . The following four combinations were assembled and tested. The standard 114 mg load was reduced by 30 mg (25 %) and very fine BKNO_3 was pressed into place. The process was repeated for 30 mg of Hercules Hi Temp, which is an RDX-based energetic material. Hi Temp is not a candidate material, since it sublimes under vacuum; it was evaluated here because it would provide the most energy for the 30 mg weight. The proprietary Hi Shear 006 mix was added with both a 30 and 57 mg load, which is 50 % of the weight of the standard NSI load.

FEASIBILITY STUDY TEST RESULTS

AVERAGED OUTPUT

CARTRIDGE	CLOSED BOMB PSI/MS TO PK	DYN TEST DEV INCH-LBS	PIN PULL HONEYCOMB INCH-LBS	PIN PULL CUPS INCH-LBS
VSI	646/.13	366	118	250
VSI/BKNO3 EXT.	909/.31	542	347	334
TEST METHODS DEMONSTRATION				
GAS GENERATING MATERIALS EVALUATION				
NSI	660/.23	346	100	270
NSI/BKNO3 (25 %)	692/.33	418	157	233
NSI/HI TEMP (25 %)	887/.36	543	282	399
NSI/006 (25 %)	815/.35	502	257	345
NSI/006 (50 %)	880/1.00	506	234	330

BEMENT/KARP/SCHIMMEL
6/9/92

This chart summarizes the feasibility study test results. Each data point is an averaged value of 1 to 4 test units. The test cartridges are listed in the first column, with the Closed Bomb, Dynamic Test Device, the HALOE Pin Puller against honeycomb (instead of using the McDonnell Energy Sensor), and the HALOE Pin Puller cup crush data in the remaining columns.

For the Closed Bomb, the VSI and NSI performed within the 650 +/- 125 psi specification. A significant increase in peak pressure was achieved in each of the gas generating test configurations. Also, the times to peak pressure significantly increased. For the 50 % load, the time to peak pressure quadrupled over the NSI.

For the Dynamic Test Device, the increase in energy does not correspond to the higher peak pressure values recorded in the Closed Bomb. Furthermore, a 50 % load of the 006 mix did not significantly increase the energy delivered over the 25 % load.

For the Pin Puller against honeycomb, the low energy production of the VSI and NSI are obvious. The addition of gas generating materials increases the output by 50 to 180 %.

For the Pin Puller/cup crush configuration, the variation in output is not as dramatic as in the honeycomb configuration.

FEASIBILITY STUDY CONCLUSIONS

- **SIGNIFICANTLY MORE ENERGY DELIVERABLE WITHIN NSI ENVELOPE**
- **TEST METHODS VALID, USE AS PROCUREMENT STANDARDS FOR NSGG**
- **TEST RESULTS PROVIDE A PERFORMANCE BASELINE FOR VARIETY OF FUTURE APPLICATIONS**

At least three conclusions can be drawn from the Feasibility Study. The addition of gas generating materials provides a significantly greater delivery of energy within the NSI envelope. The test methods yield reproducible values of pressure and energy deliverable, which can be used as procurement standards for the NSCG. The test results provide a clear demonstration of the different energies produced by the three mechanisms. These results will be useful for initial predictions of performance for new pyrotechnic mechanisms, matching the new mechanism to the closest corresponding test apparatus. It is important to clarify that these test results do not reduce the responsibility of the designer to conduct a thorough test evaluation of new devices.

CURRENT STATUS/PLANS

- **AWARDED CONTRACTS FOR PRELIMINARY DEVELOPMENTAL UNITS, QUALIFIED SOURCES OF NSI**
- **HI SHEAR**
- **UPCO**
- **CONDUCT FUNCTIONAL EVALUATION WITH 4 TEST METHODS**
- **RECOGNIZE AND CONTROL VARIABLES**

The current status and plans for the NSGG development are summarized in three steps. Development contracts have been awarded to each of the two qualified sources of the NSI, Hi Shear and UPCO. These two companies will manufacture NSGG units, using their proprietary mixes for evaluation with the four test methods at NASA Langley Research Center. Gas generating compositions will be varied to maximize performance of the NSGG, while recognizing and controlling production variables. For example, past evaluations at Langley have indicated that the particle size of the potassium perchlorate is very influential to the efficiency of combustion and the energy produced by the NSI in the HALOE pin puller.

FUTURE PLANS

- **SELECT SUPPLIER**
- **MANUFACTURE FINAL DEVELOPMENTAL UNITS TO DEMONSTRATE**
 - **CONSISTENCY**
 - **EFFECTS OF TEMPERATURE/ENVIRONMENT**
- **MANUFACTURE 750 PRODUCTION UNITS AND CONDUCT QUALIFICATION (DUPLICATE LAST NSI DELTA QUALIFICATION)**
 - **THREE LOTS, 250 UNITS EACH**
 - **ESTABLISH FUNCTIONAL PERFORMANCE STANDARDS**
 - **CONDUCT ENVIRONMENTAL EXPOSURES**
 - **FUNCTION AND COMPARE TO PERFORMANCE STANDARDS**

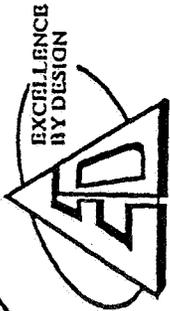
My future plans are to select at least one of the companies to produce Final Developmental and Qualification units. The Final Developmental units will be used to assure the consistency of performance and the effects of temperature and environments. The Qualification units will be used to duplicate the last NSI delta-qualification, which verified the NSI redesign met the -420 F functional requirement. Three lots of 250 units each will be functionally and environmentally evaluated. A portion of each group will be functioned in the four test methods "as-received" to establish a performance standard against which the environmentally exposed units will be compared.

RESUMES

Laurence J. Bement has been employed at NASA LaRC for 28 years and has been active in pyrotechnic research, applications and failure investigations. Highlights of his career include managing the first operational in-flight helicopter escape system, service life evaluation of pyrotechnic components for military aircraft escape, and the failure investigation/resolution of the Super*Zip separation system. He has over 50 publications, including 9 patents.

Harold Karp has been active in design and manufacture of pyrotechnic devices for 28 years. He is currently director of research at Hi Shear Technology Corporation.

Morry Schimmel has 36 years of research and engineering experience in design and development of explosive, propellant and pyrotechnic devices for aerospace vehicles. He now manages his own consulting company. From 1956 to 1984 he rose to the position of Senior Pyrotechnic Staff engineer at McDonnell Douglas Corporation. Highlights of his career include engineering support for the F-111 crew module, Gemini spacecraft, explosive transfer studies, NASA helicopter escape, B-1 seat escape system and the Super*Zip investigation. He has over 20 publications, including 11 patents.



ENGINEERING DIRECTORATE
4330/STRUCTURAL SYSTEMS BRANCH



Pyrotechnically Actuated Systems
Database and Applications Catalog

June 9, 1992

8 3

C-2

10p

1993010947

493023

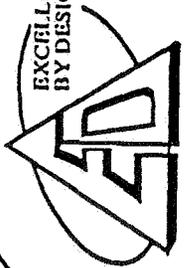
N 9 3 - 2 0 1 3 6

NASA Lewis Research Center
Cleveland, Ohio

Prepared by: Paul Steffes
Analex Corp.
(216) 977-0123

Approved for public release; distribution is unlimited.

EXCELLENCE
BY DESIGN

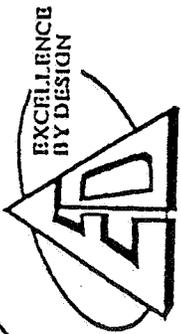


ENGINEERING DIRECTORATE
4330/STRUCTURAL SYSTEMS BRANCH

NASA
Lewis Research Center

PRESENTATION AGENDA

- Purpose of Database and Catalog
- Implementation Ground Rules
- Database Menu Format
- Deliverables



ENGINEERING DIRECTORATE 4330/STRUCTURAL SYSTEMS BRANCH



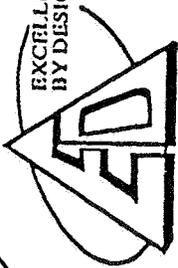
PURPOSE OF DATABASE AND CATALOG

Pyrotechnically Actuated Systems Database

The purpose of the Database is to store all pertinent design, test and certification data for all existing aerospace pyro devices into a standardized database accessible to all NASA/DOD/DOE agencies. The Database is intended to identify all information necessary to support conceptual design activity for pyrotechnically actuated systems.

Applications Catalog

The purpose of the Applications Catalog is to identify the pyrotechnic devices available, including basic performance and environmental parameters. The Catalog is intended to be a quick reference for users during selection of potential pyrotechnic devices and will consist of select information and sketches extracted from the database.

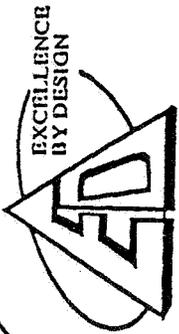


ENGINEERING DIRECTORATE
4330/STRUCTURAL SYSTEMS BRANCH



IMPLEMENTATION GROUND RULES

- The Database will be developed and operate on the Macintosh computer system.
- The Database & Catalog will include current and non-obsolete past pyro devices used on launch vehicles, spacecraft, and support systems.
- The Database and Catalog will compile information from all NASA/DOD/DOE Centers. Each center will be contacted for an inventory of pyrotechnics units. As necessary, LeRC personnel will arrange for visiting centers to assist in compiling such listings.
- The format for the Database and Catalog will include pertinent design and specification data.
- Suitable drawings and graphics will be requested for forming the figures of each device and system.



ENGINEERING DIRECTORATE
4330/STRUCTURAL SYSTEMS BRANCH



IMPLEMENTATION GROUND RULES (cont.)

- Tabulations of each center's devices will be recorded and an integral index will be formed from the individual lists.
- Cross reference indices by alphabetical listing and by type of device will be included in the Catalog.
- User instructions will be developed and provided for the Database.
- The Database and Catalog will be updated as required.

Search by:

Agency/Center....

Reference Number

Usage....

System Type....

Device Type....

Characteristics....

Keyword

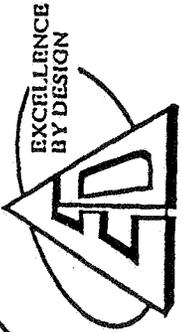
All

Help

Cancel

Find

Items selected:



EXCELLENCE
BY DESIGN

ENGINEERING DIRECTORATE

4330/STRUCTURAL SYSTEMS BRANCH



Pyrotechnic Database Format

Title Block

1. Title
2. Specification
3. NASA/DOD/DOE part number
4. Principal agency
5. Vendor/Contractor Name
6. Vendor/Contractor part number

Purpose

Describes the purpose of the device or system.

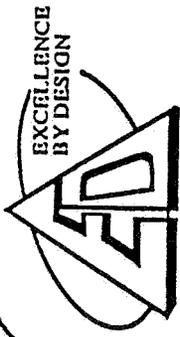
Describes the function of the device and it's usage.

Application

Briefly describes the applications of the device - including what systems it is used in and vehicle and spacecraft applications.

Physical Data (illus.)

Figure describing weight, material, and dimensions of part.



ENGINEERING DIRECTORATE

4330/STRUCTURAL SYSTEMS BRANCH



Performance Data (illus.)

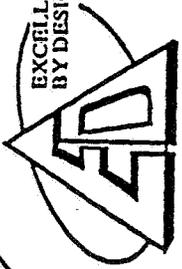
Figure describing performance characteristics - includes plot of pressure versus time.

Pyrotechnic Data

1. Type of initiation
2. Booster charge material
3. Main charge material

Environmental Capabilities

1. Operating temperature range
2. Non-operating temperature range
3. Temperature cycle
4. Storage temperature
5. Shelf life
6. Autoignition temperature
7. Humidity
8. Sun/solar radiation
9. Altitude
10. Fungus
11. Salt fog
12. Rain
13. Leakage
14. Sand dust
15. Drop (8 ft.)
16. Shock
17. Acceleration
18. Vibration - transient, random
19. Acoustic noise
20. Pressure cycling
21. Pressure - proof, burst



EXCELLENCE
BY DESIGN

ENGINEERING DIRECTORATE 4330/STRUCTURAL SYSTEMS BRANCH

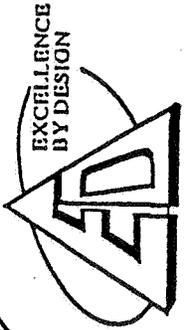


Electrical Characteristics

1. All-fire current
2. All-fire power
3. Bridgewire resistance
4. Checkout current
5. Electrostatic sensitivity
6. Leakage current
7. Electrical connector

Additional Data

1. Qualification report
2. Flight certification status
3. DOD Classifications
4. Applications
5. Demonstrated reliability
6. Functional margin demonstration
7. References and publications
8. Additional remarks



ENGINEERING DIRECTORATE
4330/STRUCTURAL SYSTEMS BRANCH



DELIVERABLES

After editing and finalization of the Database and Applications Catalog, the following items will be delivered to the Pyrotechnic Steering Committee in quantities as requested:

- Database printed hard copy
- Database computer software discs, tapes, cartridges, or network transfer
- Database User's Guide handbook
- Applications Catalog

30p 1993010748
493025

**A Semiconductor Bridge Ignited
Hot Gas Piston Ejector**

N 9 3 - 2 0 1 3 7



M. C. Grubelich and R. W. Bickes, Jr.

*Explosive Components Department 2513
Sandia National Laboratories
Albuquerque, New Mexico*

Presented by:

D. E. Mitchell

Explosive Components Department Manager

Approved for public release; distribution is unlimited.

RWB:2513:6/4/92



- **Concept**
- **Performance**
- **Development**
- **Application**

SEMICONDUCTOR BRIDGE TECHNOLOGY



- OBJECTIVE: Development of Very Low Energy Explosive Devices
- BENEFITS: Low Energy (Cost, Size, Weight Savings), Fast Function, Enhanced Explosive Safety, Digital Compatibility and Circuit Integration (Smart Device), Automated Manufacture
- APPLICATIONS: Valve Actuators, Rocket Igniters, Miniature Thrusters, DoD & DOE Devices, Air Bags, Delayed Detonators
- PROGRESS TO DATE: Low Energy, Safety, Digital Compatibility, and Integration Demonstrated
- FUTURE: Focal Point, Satellite Systems, Actuator Controlled Missiles, Anti-Tank Weapons, Phalanx, Universal Water Activated Recovery Systems, Multiple Air Bag Systems, Rock Blasting and Mining, Photo-Optic SCB Devices



- **SYSTEM DEVELOPMENT**
 - **Sensors**
 - **Smart Firing Sets**
 - **Digital Coupling (Wire and Optical)**
 - **Explosive Component**
 - **Smart SCB**

- **SCB INTEGRATION**
 - **Discrete**
 - **In-situ**

- **PARTNERING**
 - **Government Facilities**
 - **Private Industry**
 - **Universities**

Technology Transfer



SANDIA – R&D

Technology Transfer

Commercialization, Production and Sales

Government Applications
SCB Technologies
Thiokol
Bulova
Hercules

License
Private Enterprise
SCB Technologies
Thiokol
BAI

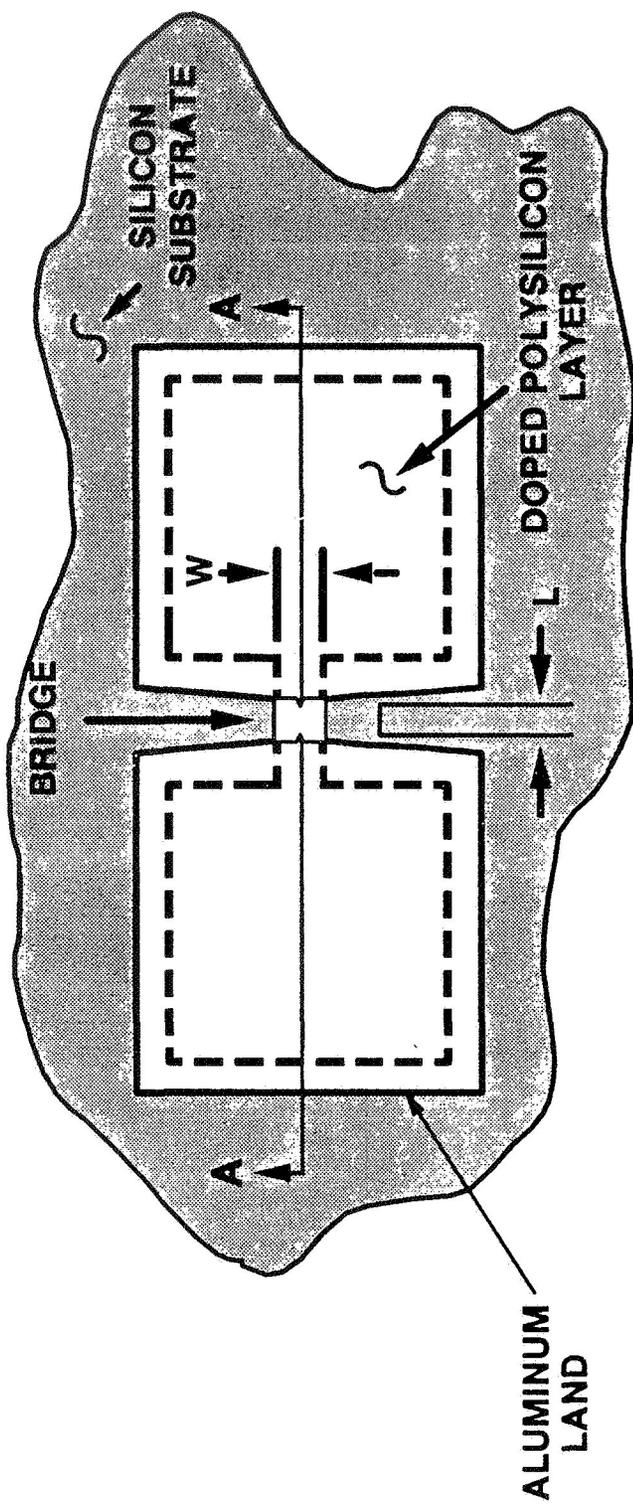
Products

Attitude Control Motors
RAP
UWARS

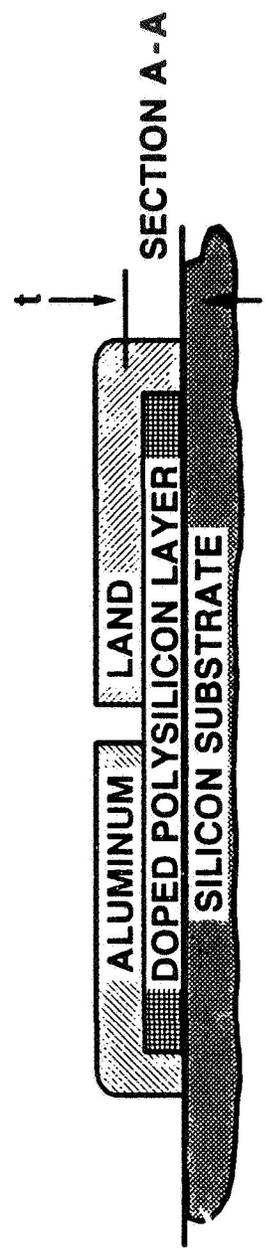
Air Bags
Blasting

CRADA
WFO
MIPR

SIMPLIFIED SKETCH OF SEMICONDUCTOR BRIDGE (SCB)



NOT TO SCALE

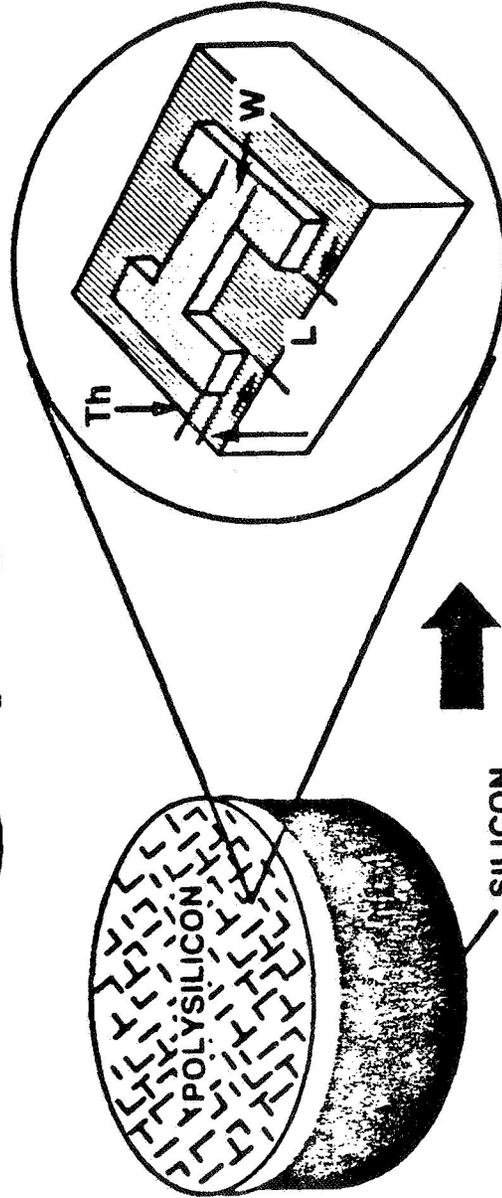


88F2000.18

SCB PROCESSING

PHOSPHOROUS DOPING
 OXIDE LAYER GROWTH
 PHOTORESIST & MASK
 WASH & ETCH

PVD ALUMINUM LAYER
 PHOTORESIST & MASK
 WASH & ETCH



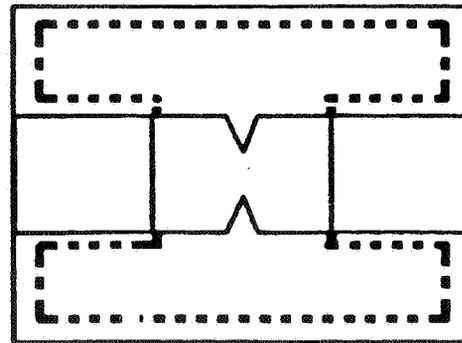
POLYSILICON-ON-SILICON WAFER
 1-4 MICRON POLYSILICON LAYER
 0.022" SILICON
 SUBSTRATE

DOPED POLYSILICON
 LAYER DEFINED

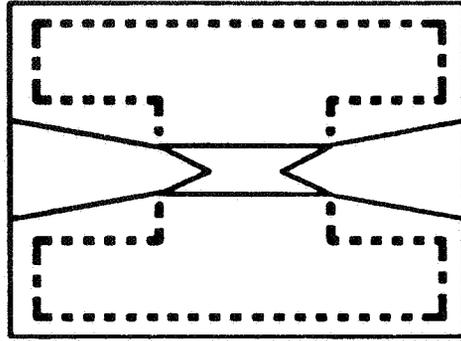
METAL LANDS
 DEFINE SCB
 (FINISHED BRIDGE)



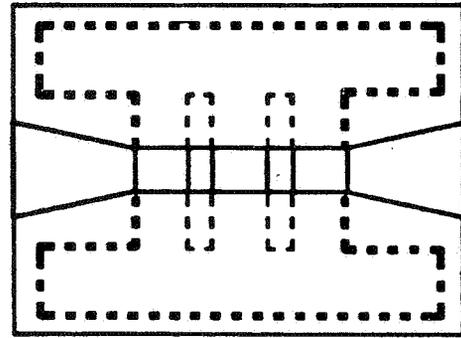
SCB DESIGNS



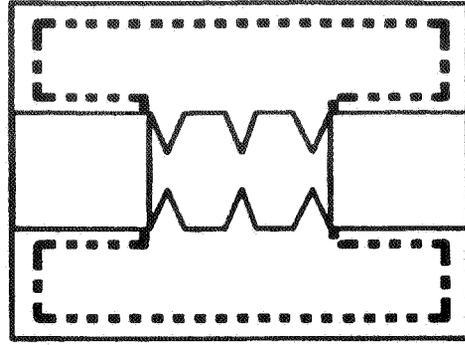
TYPE 12



TYPE 14



TYPE 11

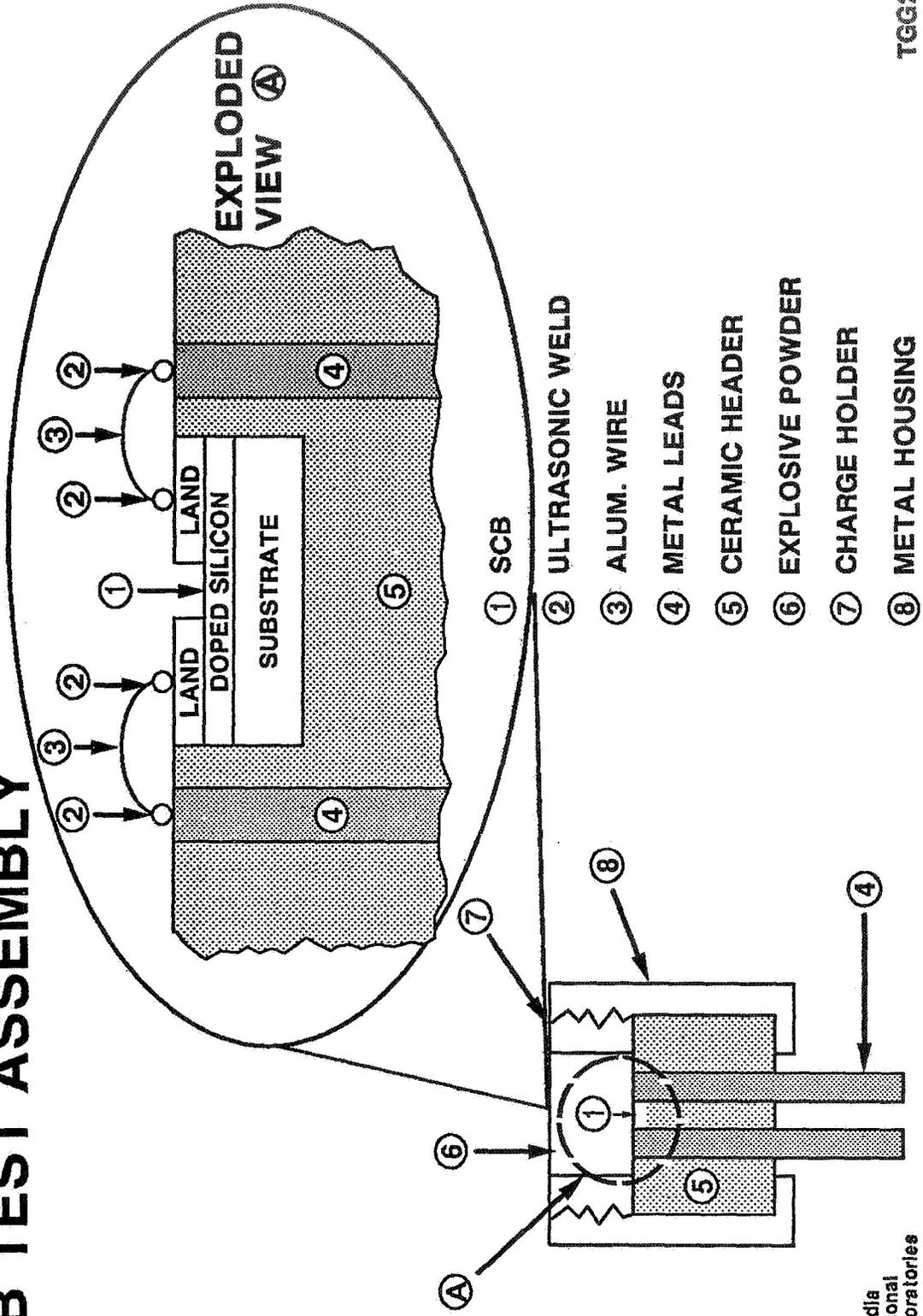


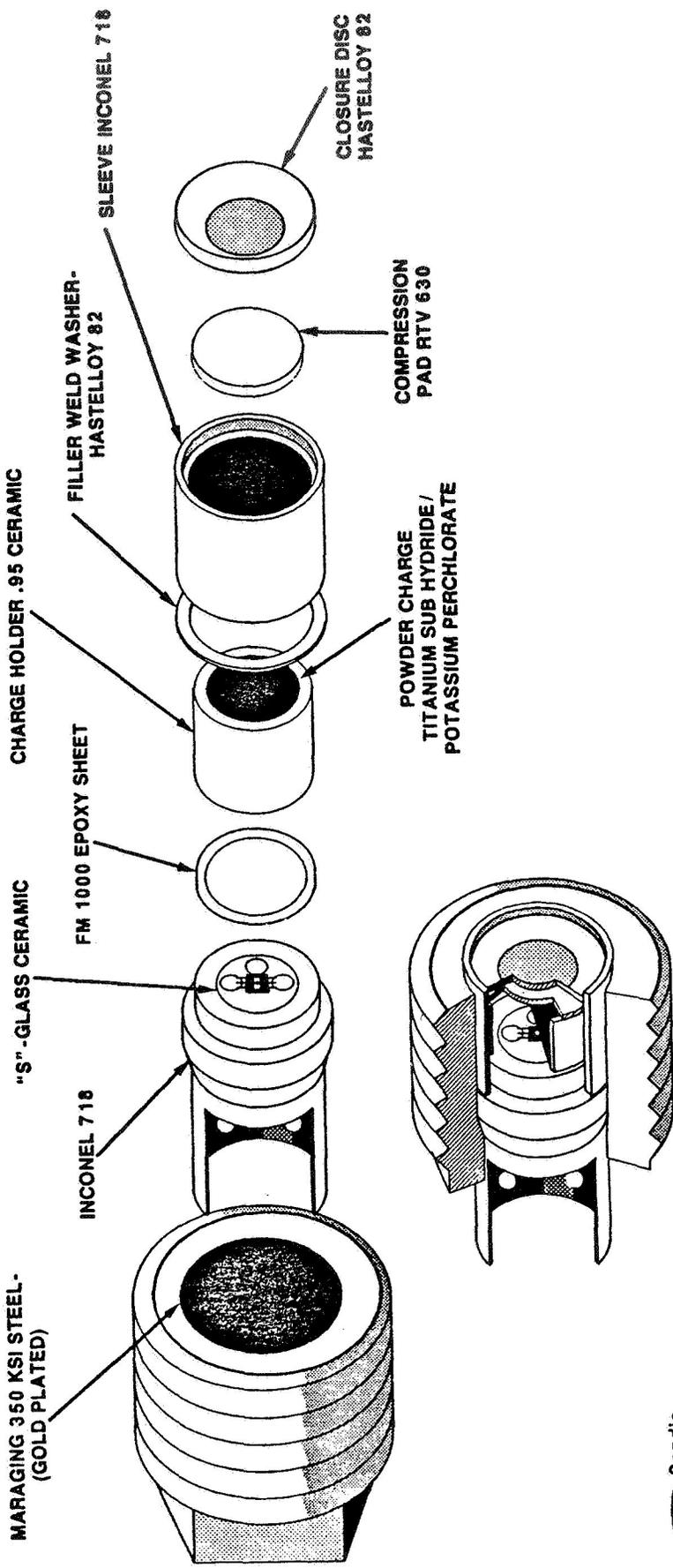
TYPE 13

TX2000.36

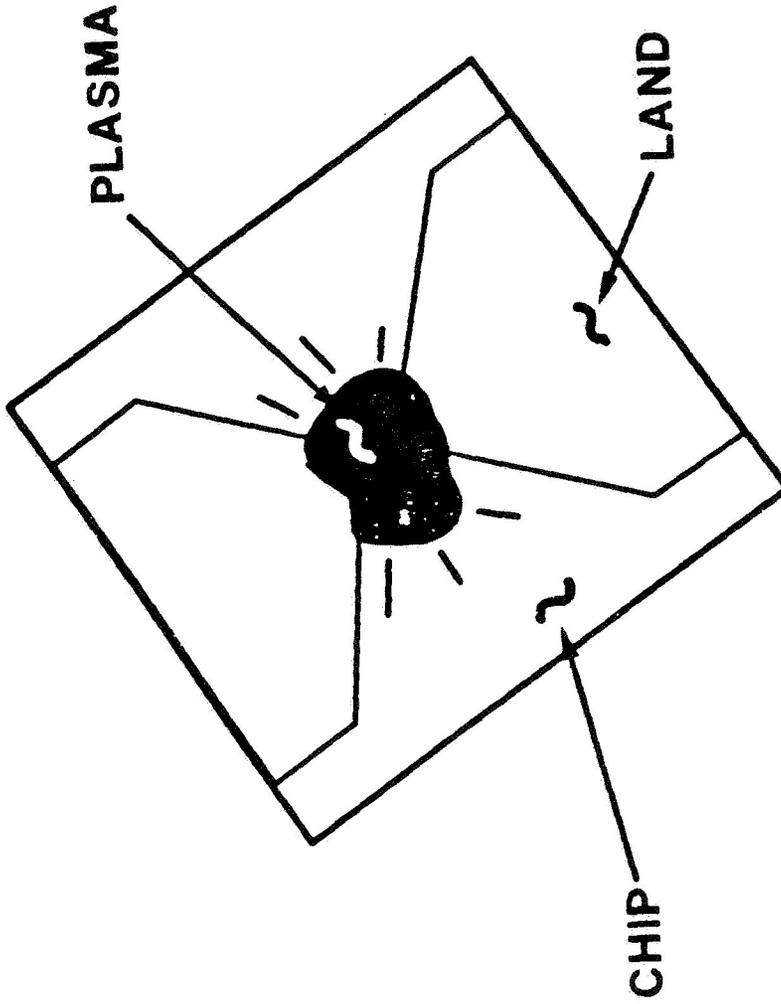


SCB TEST ASSEMBLY



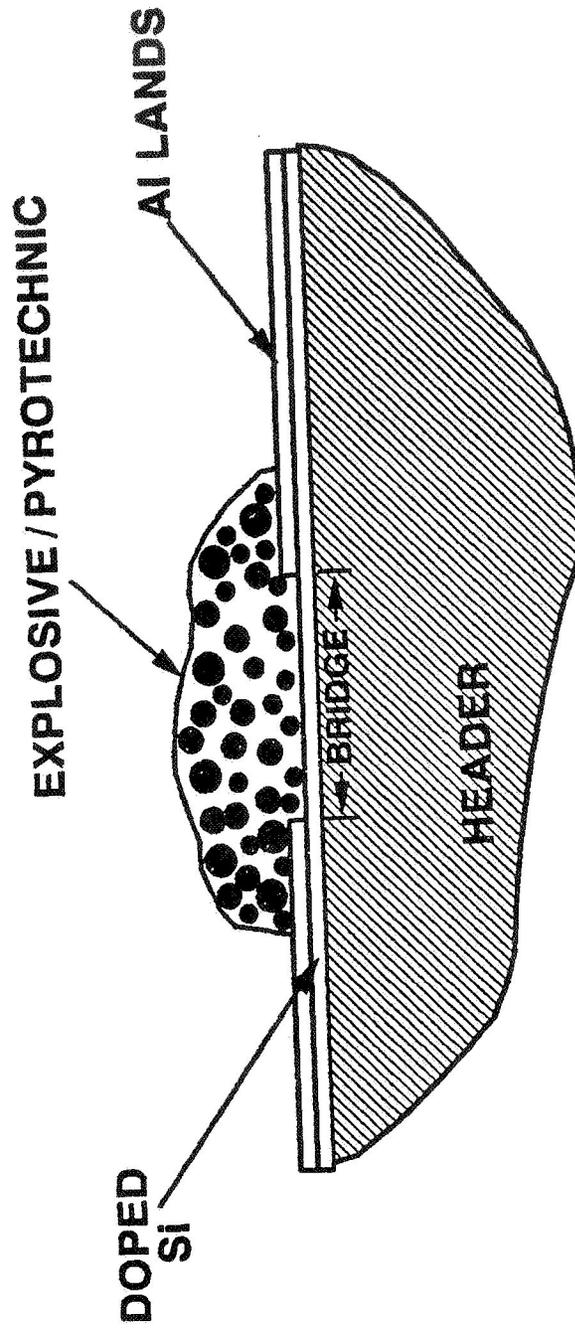


**5 mJ SCB BURST
BASED ON A POLAROID PHOTOGRAPH**



TV2000.38

MICRO-CONVECTIVE HEAT TRANSFER HYPOTHESIS



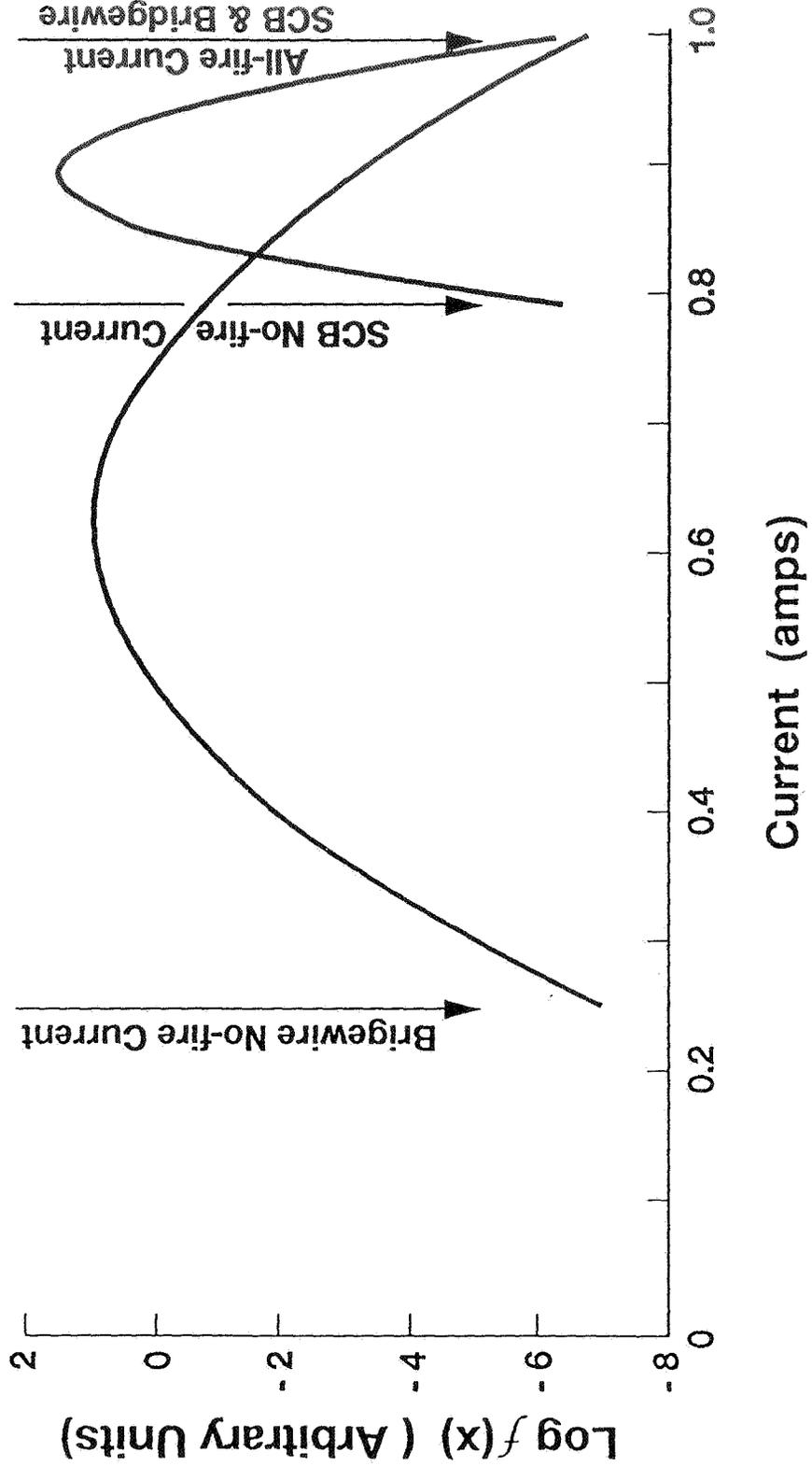
- THE BRIDGE IS VAPORIZED
- SI VAPOR IS ELECTRICALLY HEATED
- SI VAPOR PERMEATES THE ADJACENT EXPLOSIVE / PYROTECHNIC
- LOCAL CONVECTION AND CONDENSATION EFFICIENTLY HEATS THE PARTICLES



LOG OF NORMAL DISTRIBUTION

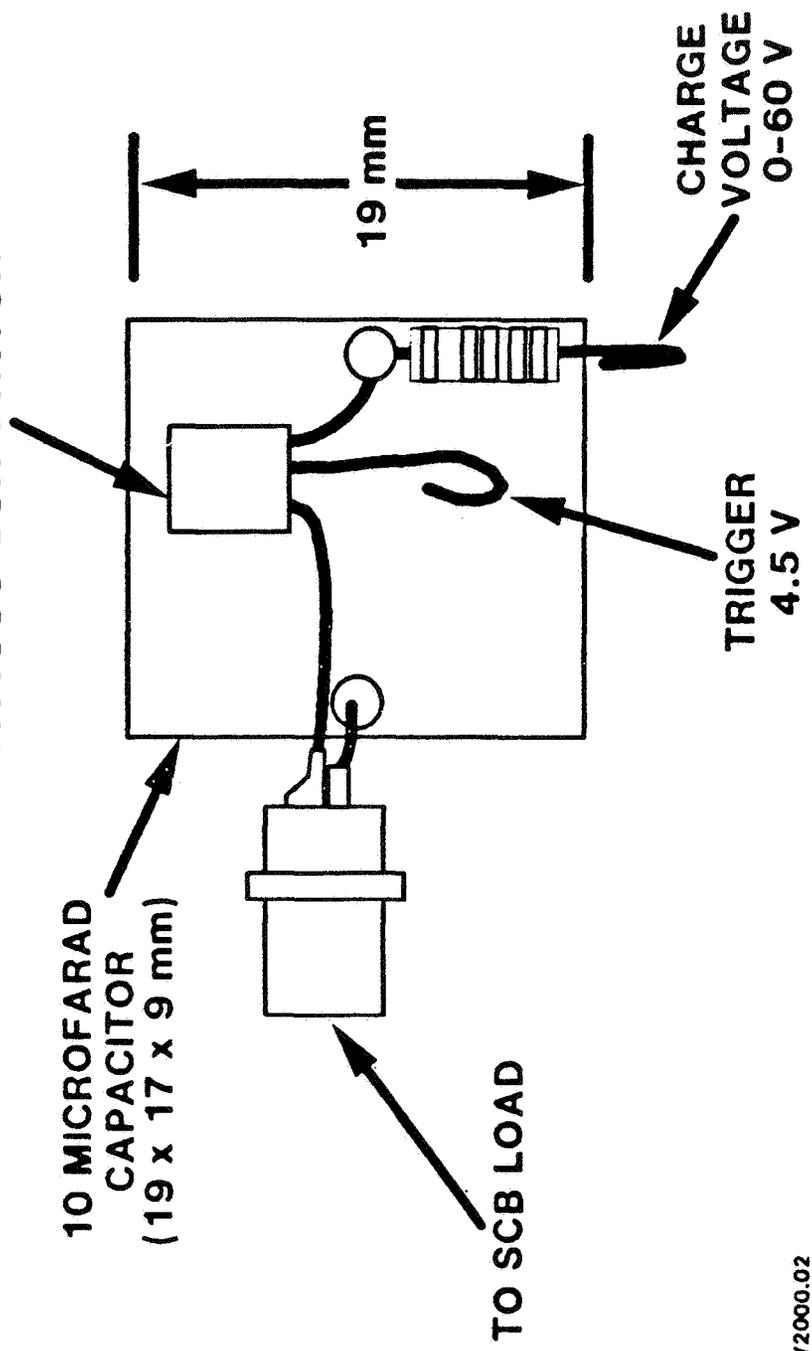
$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}}$$

AS A FUNCTION OF FIRING CURRENT



SCB FIRE SET

SA 1990 SCR SWITCH



TW2000.02

COMPARISON OF SCB AND HOT-WIRE ACTUATORS

	<u>HOT WIRE</u>	<u>TYPE 3-2</u>	<u>TYPE 15</u>
ALL-FIRE ENERGY (mJ)	32.6 ± 1.02 (AMBIENT)	2.72 ± .48 (-65 °F)	1.33 ± .03 (-65 °F)
NO-FIRE CURRENT (A)	1.1 (AMBIENT)	1.39 ± .03 (165 °F)	1.30 ± .12 (165 °F)
ESD TEST	PASSED	PASSED	PASSED
FUNCTION TIME (µs)	3400 (AMB.)	60 (AMB.)	60 (AMB.)

88G2000.45





- **Direct RF Injection**
 - **10 MHz - 20 W**
 - **200 MHz - 3 W**
 - **8.9 GHz - 20 W**
 - **10 Second Injection Times**

 - **Franklin Institute: "Grossly Insensitive"**

- **NSWC Ground Plane Facility**
 - **High Level RF Environments**
 - HF Communications Bands**
 - Radar Frequencies**

 - **Only One Unit Fired (Arc Conditions)**

SATELLITE FIRING SETS

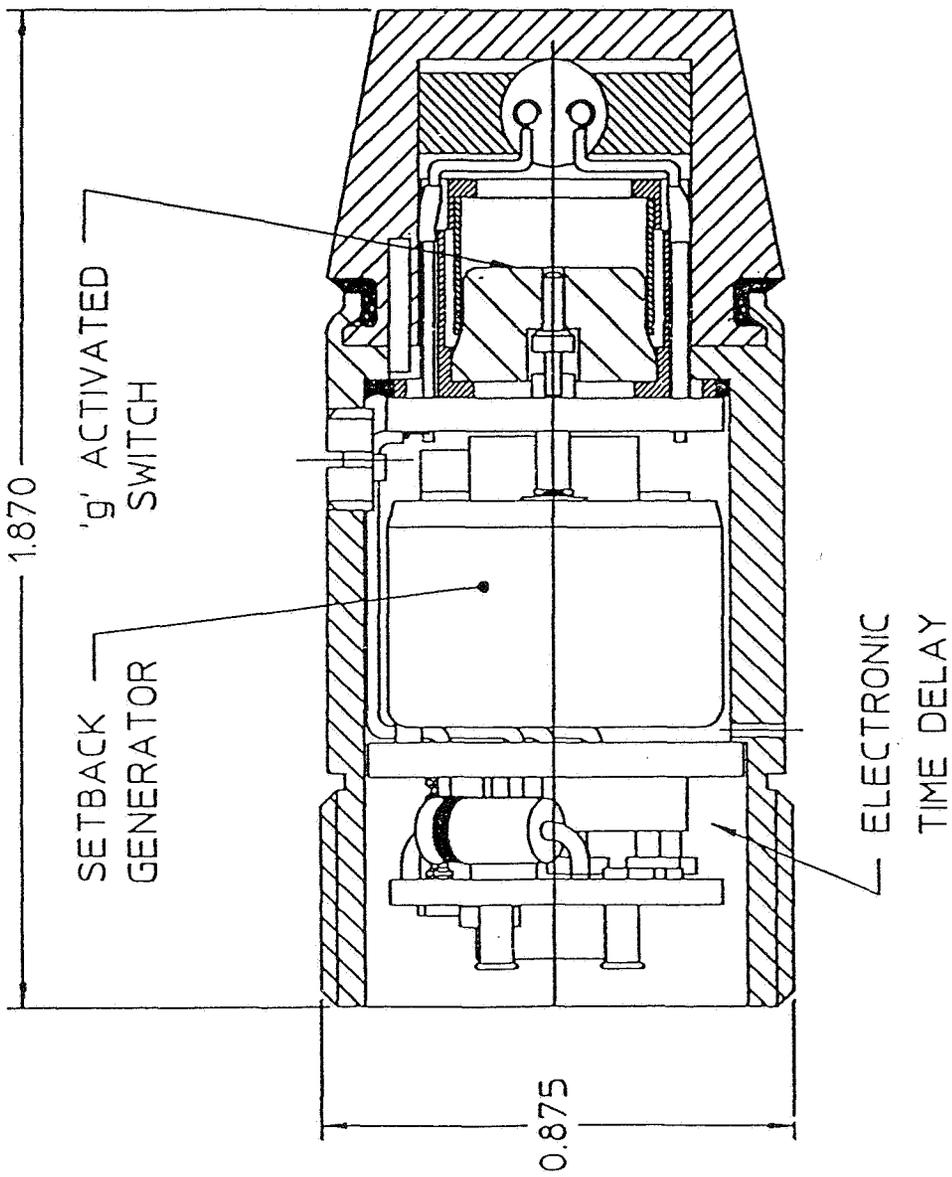


- **Multiple Fire**
 - **2200 micro-Farads**
 - **Charge = 27.4 V**
 - **Four Parallel Outputs**

 - **Bridge Burst Delta t = 5 microseconds**

- **Single Fire**
 - **300 micro-Farads**
 - **Charge 16 V**
 - **Series Resistance 0.4 Ohms**

 - **2.5 mJ**
 - **Function Time = 81 microseconds**



RD CORD

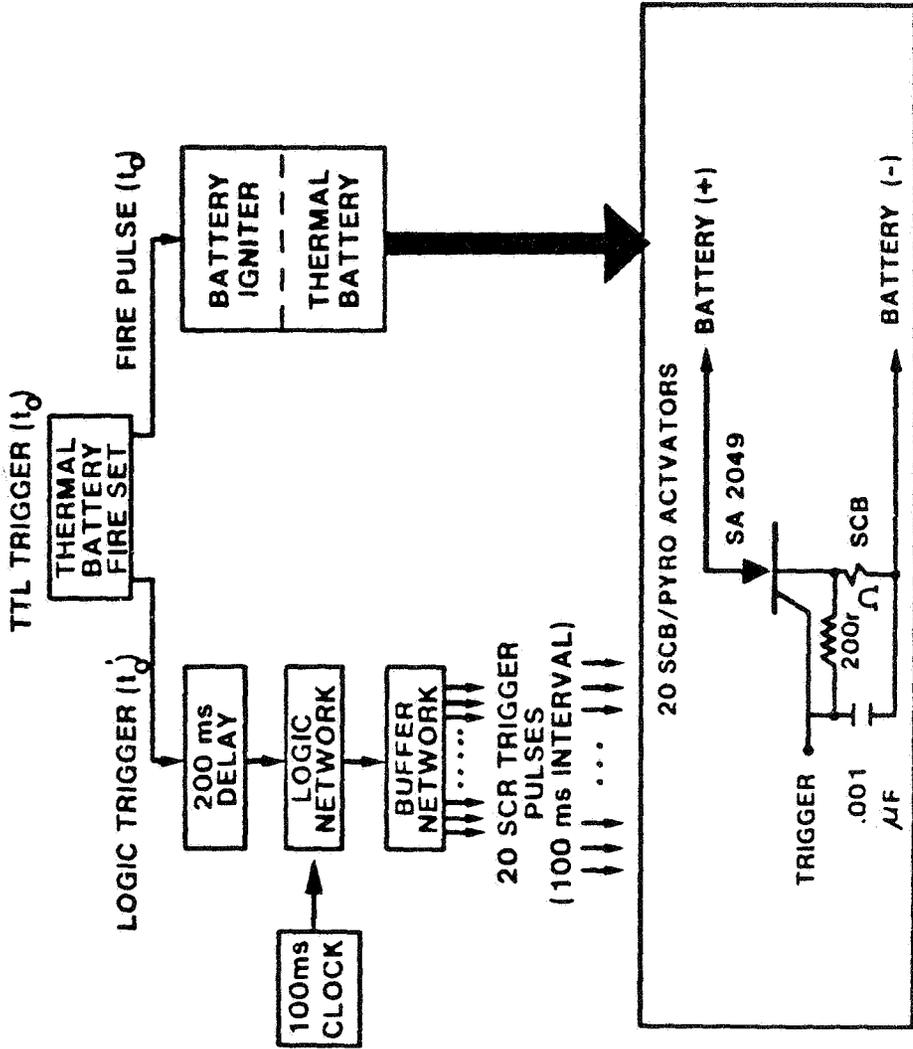
SCB SQUIB

SETBACK GENERATOR

'g' ACTIVATED SWITCH

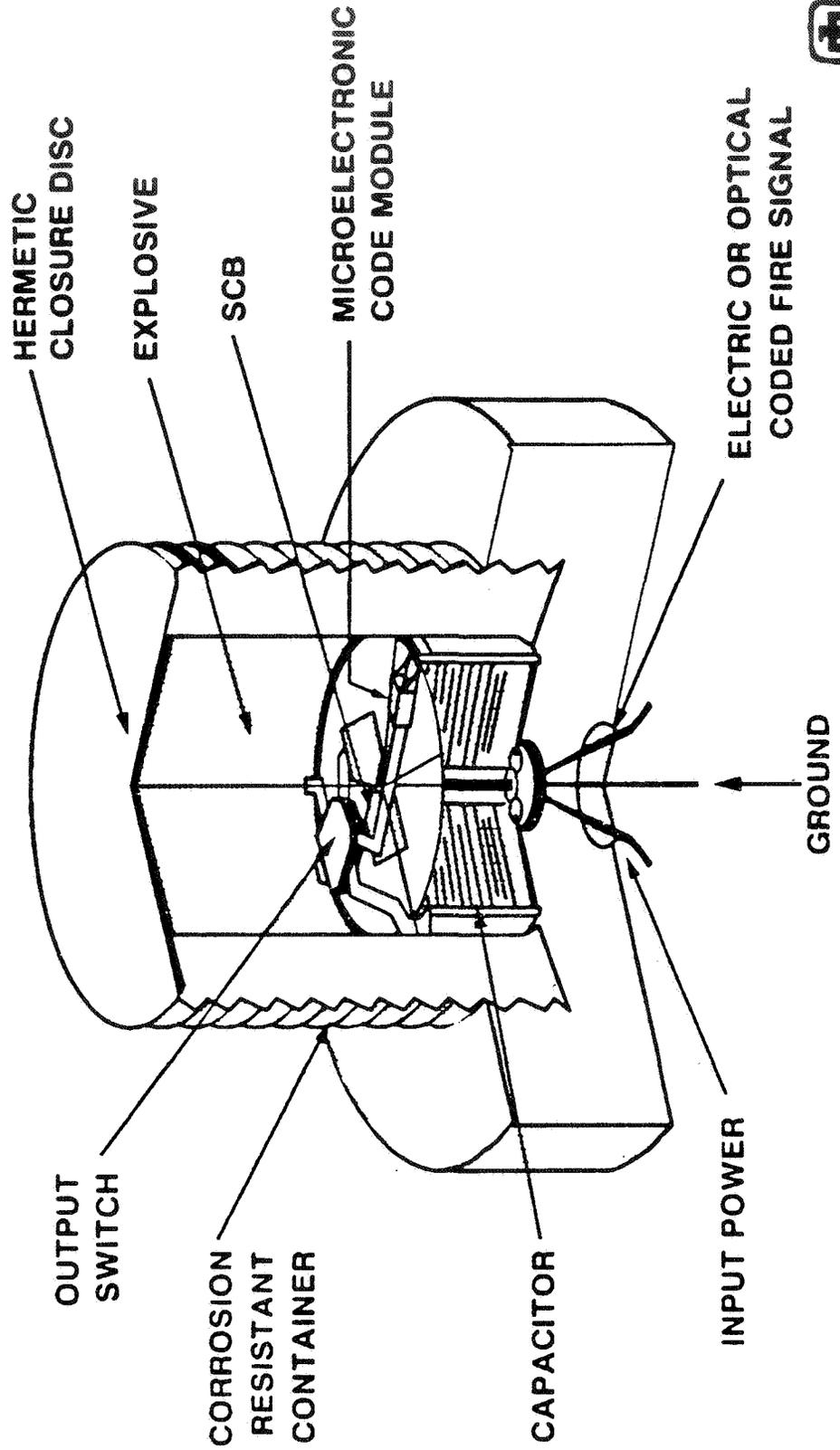
ELECTRONIC TIME DELAY

LOGIC FIRE SET



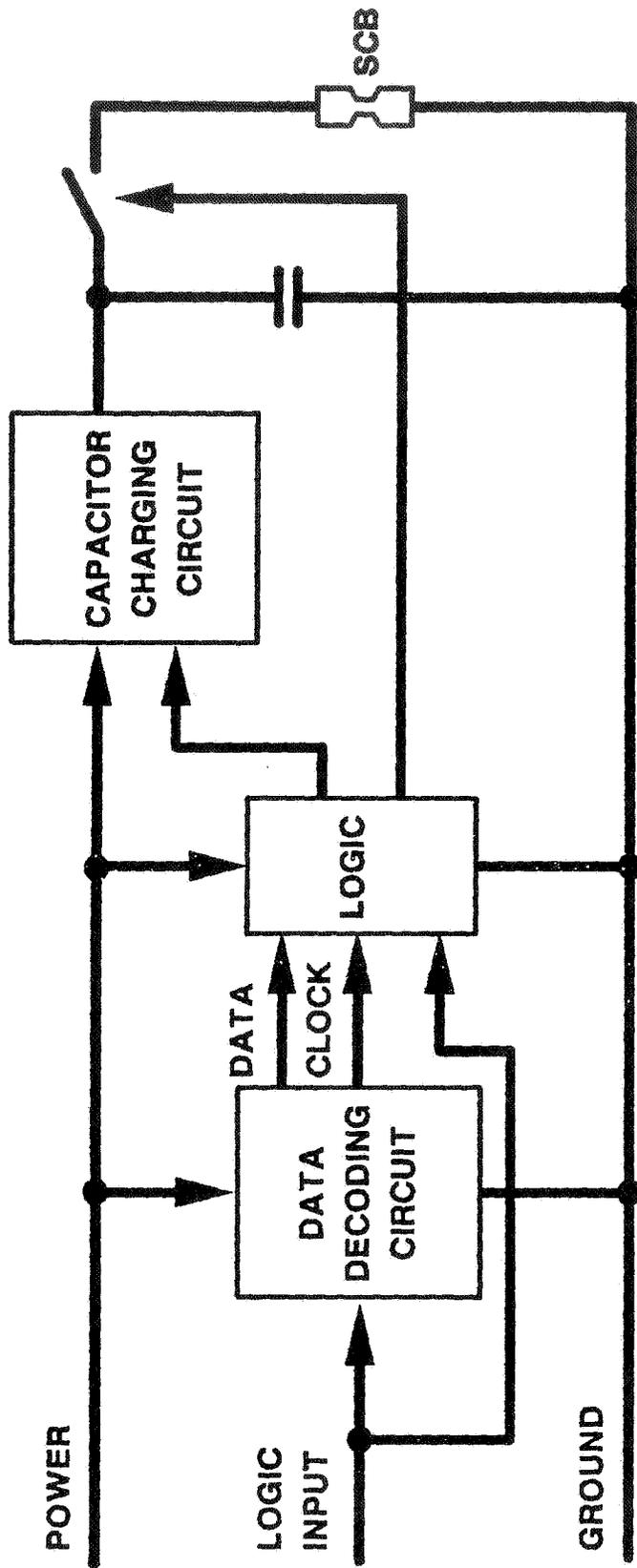
TV2000.40

SCB SMART COMPONENT



TX2000.35V

SCB SMART FIRING SET



SCB CONCEPT



SEMICONDUCTOR DESIGN CONSIDERATIONS

- THE SCB IS A RESISTOR NOT AN ACTIVE ELEMENT
 - Allows separation of SCB design and existing semiconductor design technology

- ULTIMATE DESIGN FLEXIBILITY
 - Resistor size and doping and integrated components can be independently varied to suit application

- ALLOWS USE OF EXISTING SCB INITIATING AND PYROTECHNIC DATA BASE

- LEAST INTRUSIVE TO STANDARD SEMICONDUCTOR DESIGN AND FOUNDRY PROCESS FLOWS

SPECIAL SEMICONDUCTOR DIVISION - 2175



- **Develop a Low Firing Energy Ejector**
- **Control Acceleration Profile**
- **Control Ejection Velocity**
- **Use a Single Pyro Device for All Applications**

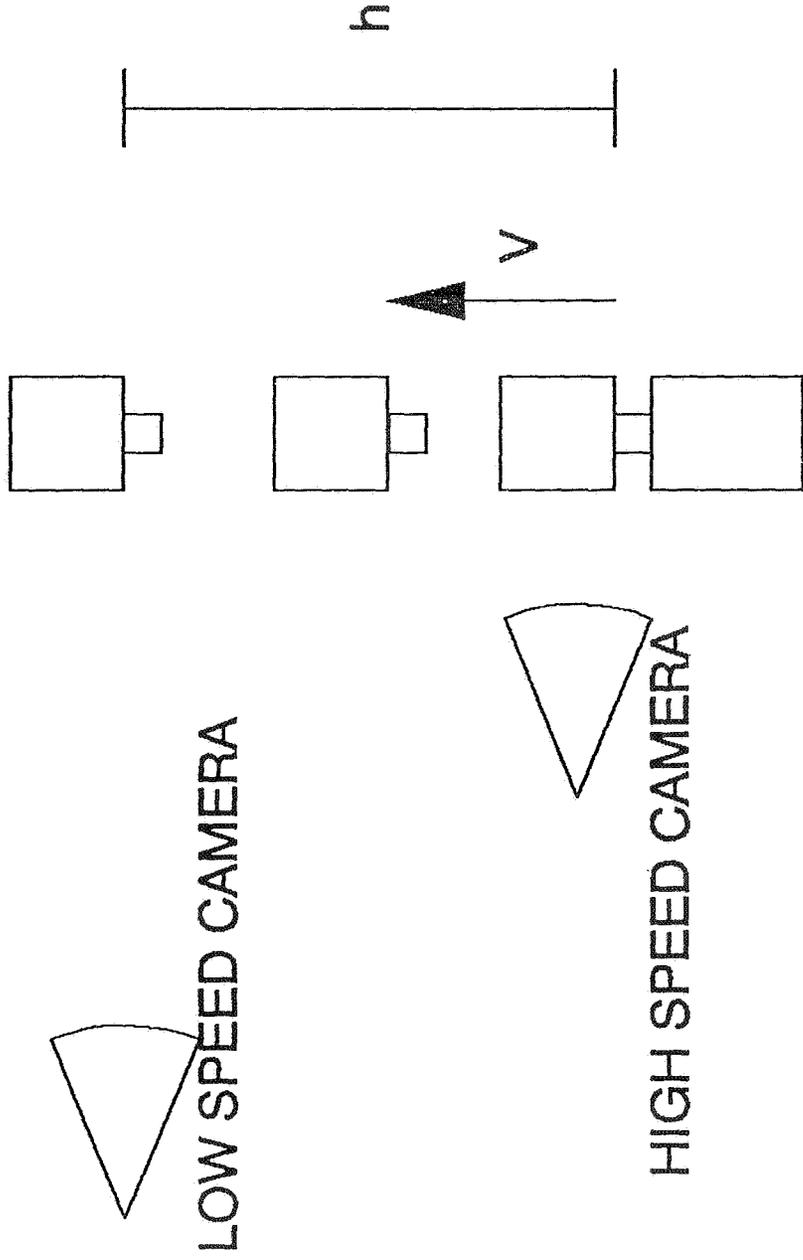
Why Use Pyro Actuators?



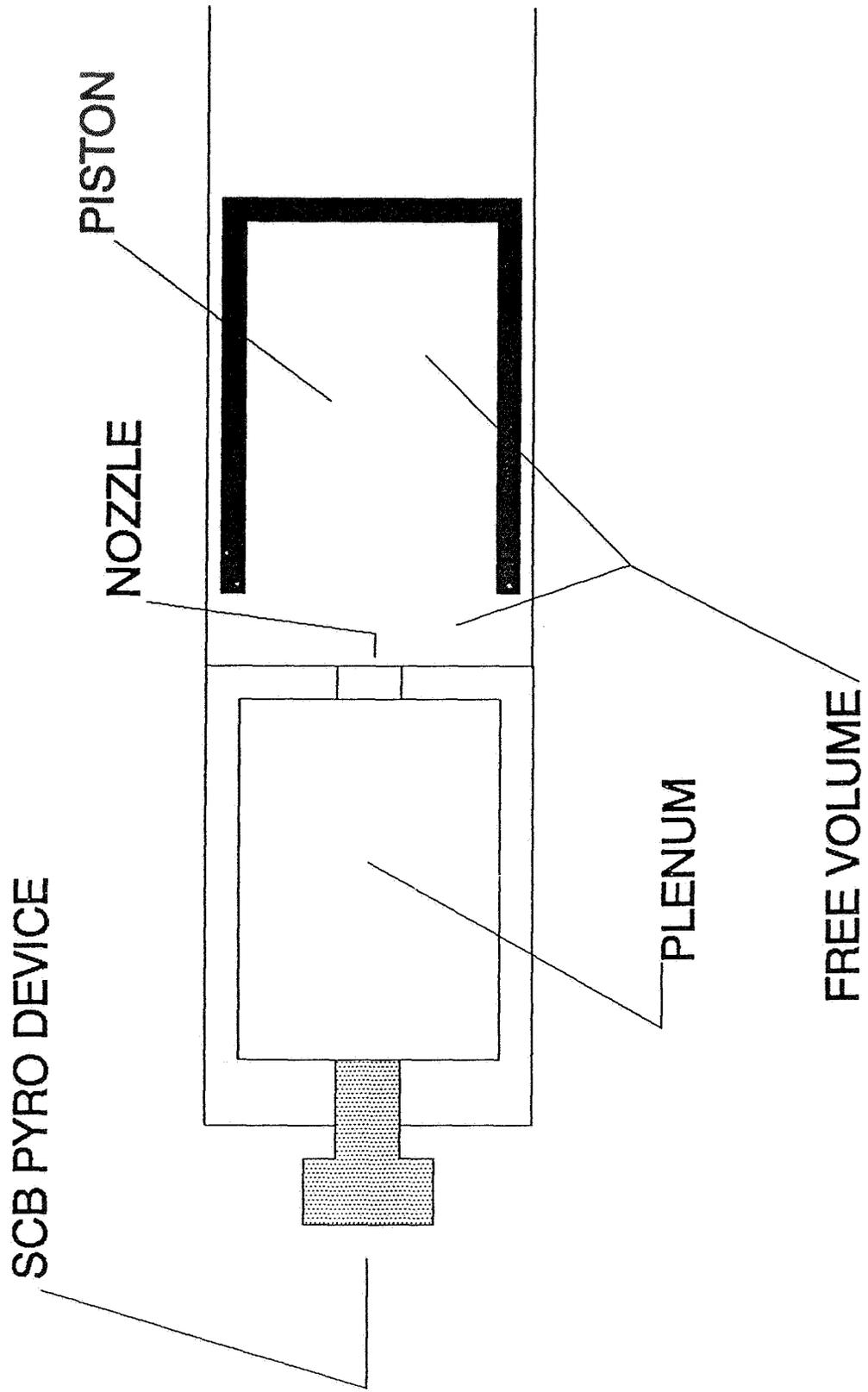
- **ENERGY DENSITY**
- **FUNCTION TIME**

TEST

$$\text{AVAILABLE PV ENERGY} = mgh = 1/2mv^2$$



"ADJUSTABLE" ACTUATOR SYSTEM



Results for THKP



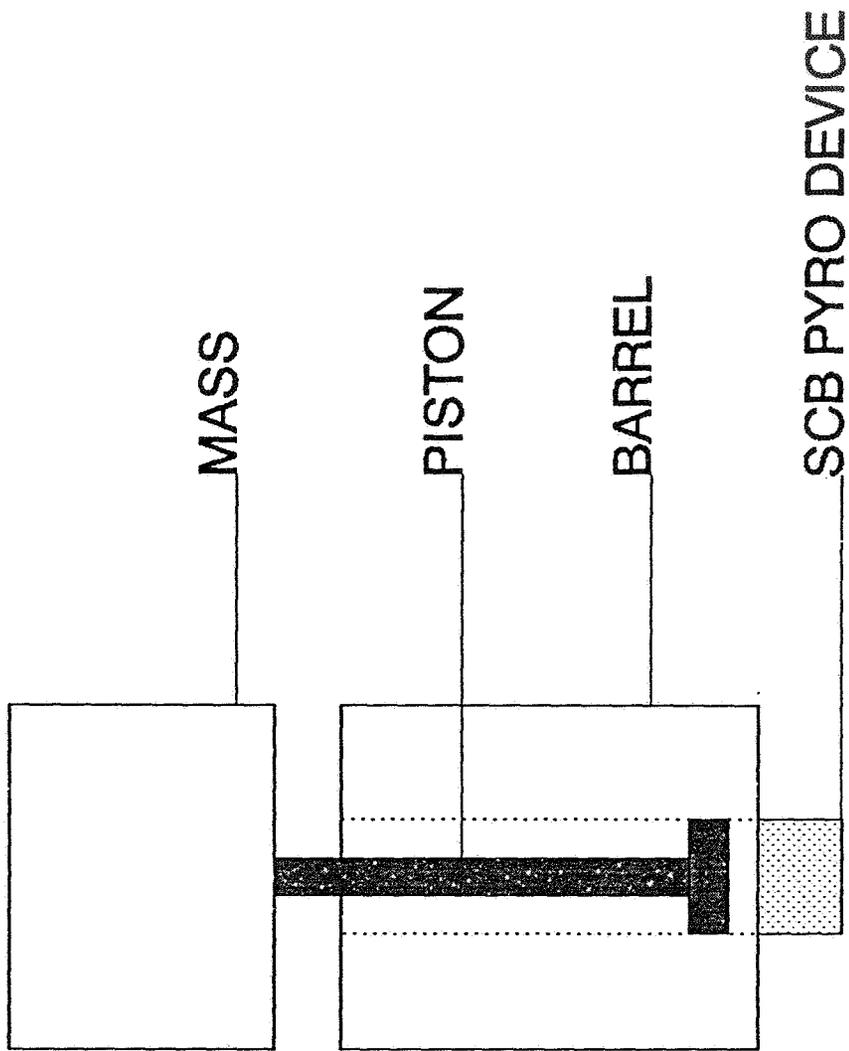
- **Recover 20% of Total Energy Available**
- **Losses - Condensed Species, Heat Transfer**

Summary



- **SCB – Safe Low Energy Igniter**
- **Ignite THKP with an SCB**
- **Use THKP to Pressurize Small Volume**
- **Vent Pressurized Volume to Eject Mass**
- **Control Velocity and Acceleration**
- **Simple Method to Determine Available Energy**

TEST FIXTURE



This page intentionally left blank.

1993010947

493028

148

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

N 9 3 - 2 0 1 3 8

Small ICBM Laser Firing Unit (LFU)

**By Jim Aloise
and
Larry Snarr
(LFU Program Manager)**

Approved for public release; distribution is unlimited.

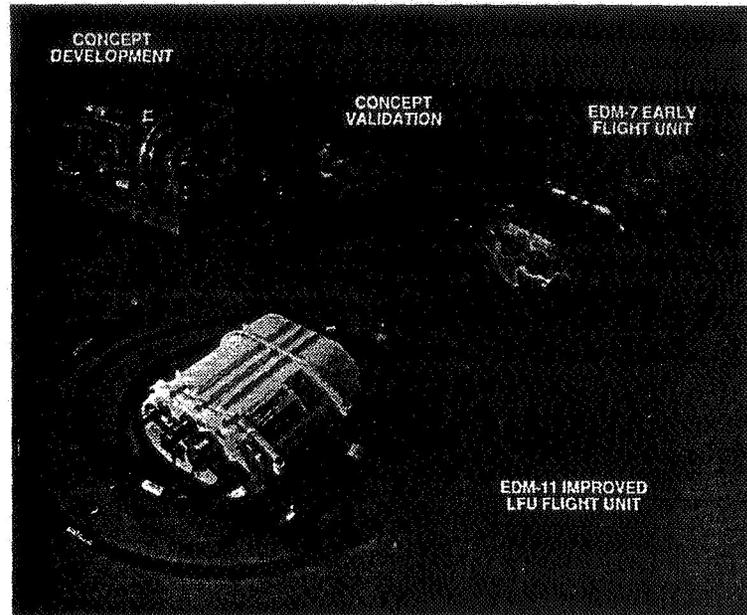
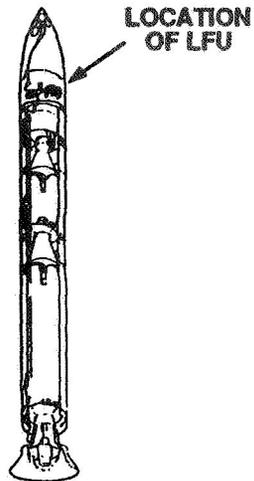
1 2 3

PRECEDING PAGE BLANK NOT FILMED

LFU DEVELOPMENT HARDWARE

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary



3

Pictured is the Small ICBM Laser firing unit hardware in various stages of development. Also shown is the location of the firing unit in the SICBM. It is located in the post boost vehicle (PBV) and has a fiber optic cable harness which extends down an internal raceway to the various ordnance locations along the missile.

SPECIFICATIONS /FEATURES

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

NUCLEAR HARDNESS AND SURVIVABILITY

ENVIRONMENT	OPERATING	NON-OPERATING
TEMPERATURE (°F)	45 TO 110	-37 TO 140
ACCELERATION	15 g	4 g
VIBRATION	18.7 g RMS	3.2 g RMS

MISSION RELIABILITY

>.999 REQUIRED >.99997 ACTUAL

BUILT IN TEST (BIT)

CONTINUITY OF OPTICAL PATH FROM LASER TO INITIATOR

TEST FIRE THE ORDNANCE LASER

4

The LFU was required to function during and after exposure to a nuclear environment. The system was tested to the temperature, acceleration vibration and shock environments shown in a series of evaluation and flight proof tests. Mission reliability was specified to be greater than .999 and was calculated to be greater than .99997. The calculation included a monthly built in test operation that verified proper output of the ordnance laser and continuity from the laser to each initiator.

SPECIFICATIONS /FEATURES (CONTD)

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

SEQUENCED OPERATION	11 SEQUENTIAL EVENTS (ORDER OF EVENTS FIXED)
SIZE	10" X 12" X 5" (APPROXIMATELY)
WEIGHT	30 LBS
SIMULTANEOUS INITIATIONS	2 (ELIMINATED IN LATER DESIGN)
MARGIN ABOVE ALL-FIRE	> 30X SINGLE EVENTS
	> 15X DUAL EVENTS

5

The LFU has 11 operational events that occurred in a known order and with a separation in time of no less than 1 second. Size and weight are as shown. There were 2 simultaneous initiations for some events. Simultaneity was accomplished using a single beamsplitter placed in the converging beam just in front of the optical fiber. All flight tests were conducted using this optical splitting approach. The optical splitting was later dropped during the producibility study.

Margin above all-fire level is approximately 30 times under best case conditions (no nuclear event) for a single event and 15 times for the deleted dual events. During a nuclear event margin drops significantly.

SPECIFICATIONS /FEATURES (CONT'D)

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

EVENTS PERFORMED

STAGE SEPARATION

VALVE ACTUATION

MOTOR IGNITION

LAUNCH EJECT

FLIGHT BATTERY

CABLE CUTTER

REDUNDANCY

**EACH EVENT - 2 INITIATORS, 2 FIBER OPTIC LINES, 2
LASERS, 1 LFU**

The LFU performed all operational functions of the missile except release and initiation of the warhead. A single LFU has two redundant sides which resulted in a single initiation event being actuated by 2 discrete lasers firing down 2 discrete optical fibers to 2 discrete initiators.

COMPONENTS

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

ORDNANCE LASER	FLASHLAMP-PUMPED Nd:GSGG
	400 MILLIJOULES
	180 MICROSECONDS
FIBER	400 MICRON POLYMER-CLAD GLASS
SEQUENCER	STEPPING SOLENOID ACTUATED RHOMBOID PRISM
INITIATOR	WAVELENGTH SENSITIVE COATED WINDOW
	SINGLE FIBER PIGTAIL
	CP
	10 MILLIJOULE ALL-FIRE
BIT SOURCE	LASER DIODE

7

The ordnance laser is a flashlamp pumped Neodymium doped Gadolinium Scandium Gallium Garnet crystal (Nd:GSGG) rod laser. It is a derivative of the M1 laser rangefinder laser which was also designed and built by Hughes. GSGG was chosen over a less expensive material such as Yttrium Aluminum Garnet (YAG) due mainly to nuclear hardness requirements. The laser operated about 400 millijoules in a 180 microsecond pulse. This is just over 2 kilowatts.

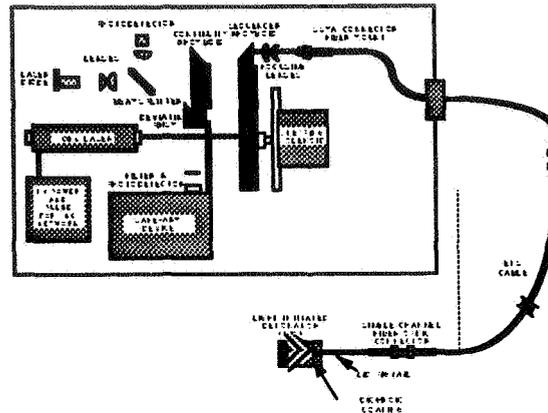
The fiber used was a 400 micron core polymer clad glass fiber. The sequencing mechanism was a stepping solenoid actuated rhomboid sequencer. The rhomboid was used because of its unique properties as an alignment tool. It displaces a collimated beam in translation only while retaining the input angle. An in depth discussion of this property was made at the workshop at Aerospace corporation in October 1990. Copies of the materials presented can be obtained from the author (J. Aloise).

The detonator was packed with CP and had a 10 millijoule all-fire level as determined by Bruceten testing. The interface was a fiber optic pigtail attached to a window with a wavelength sensitive coating.

OPTICAL LAYOUT-ARM

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary



8

The light from the ordnance laser enters the input facet of the sequencing rhomboid and after traversing the two internal facets, it exits at the same angle it entered. The beam is brought to focus by a lens whose focal plane is just beyond the fiber face. Placing the fiber slightly displaced from the focal plane reduces the energy density at the fiber face which reduces damage.

The light travels down the optical fiber to the initiator and travels uninhibited into the pyrotechnic material igniting it. The rhomboid sequencer is stepped to the next location and the laser is fired again at the appropriate moment in the timeline.

BUILT IN TEST

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

CONTINUITY TEST

SIMPLER THAN NARROW PULSE

RETURNED ENERGY FROM ALL REFLECTIONS INTEGRATED

**THRESHOLD DEPENDENT UPON NUMBER OF CONNECTORS AND
OTHER OPTICAL ELEMENTS**

**INCREASING NUMBER OF CONNECTORS INCREASES PROBABILITY
OF INCORRECT CONTINUITY EVALUATION**

**VARIATIONS DUE TO MANUFACTURING TOLERANCES AS WELL AS
CHANGES OVER LIFETIME MUST BE CONSIDERED**

10

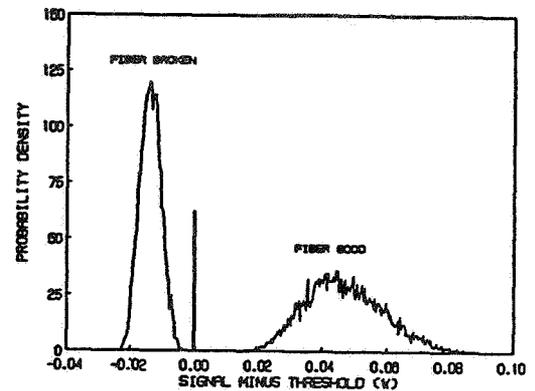
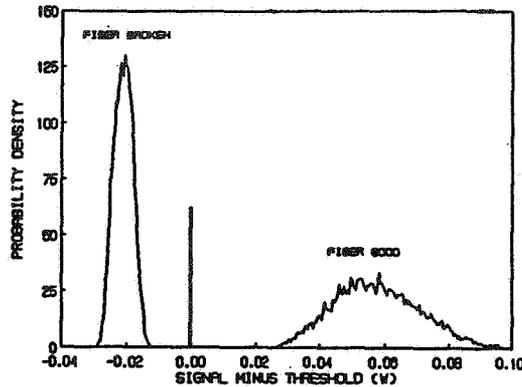
The continuity test uses a fairly short (approximately 20 nanoseconds) but not ultra-short laser pulse. A very short pulse could be used to detect individual surface reflections and the return from the initiator window. This optical time domain reflectometry-type operation is less susceptible to variations in number of connectors and other effects that get buried in the return with a longer pulse.

The longer pulse system is a bit simpler however. The integrated energy from all reflections is compared to a preset threshold for a go - no go decision. The optimum threshold is dependent on many factors including number of connectors and optical elements as well as circuit characteristics and mechanical tolerances. The most significant effect is adding a connector to the path. When analyzing the optimum threshold for good vs. bad fiber it is important to go beyond a simple analysis using nominal values. Also, variations due to degradation and drift over time and temperature must be considered.

BUILT IN TEST (CONT'D)

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary



12

The histograms show the probability density functions of the signal produced by a good fiber versus a bad fiber. The numbers are represented by a relative factor in that the difference between actual signal and threshold are plotted. The graphs show several phenomena. First, it can be seen that the relative width of the bad fiber density function is much smaller than that for a good fiber. This means that the optimum location for threshold in terms of simultaneously reducing the probability of judging a good fiber as bad or a bad fiber as good is somewhere other than the center of the peaks of the two curves. Second, it can be seen that the adding of an additional connector to an otherwise unchanged optical system moves the probability density functions closer requiring a new optimal threshold setting. Adding additional connectors moves the functions closer and closer until the overlap is unacceptable.

The graphs were obtained using a Monte Carlo analysis of the appropriate parameters of mechanical, optical and electronic elements. Each parameter was defined to have a nominal value with some allowable variation due to manufacturing tolerances, degradation and drift with time. The LFU was required to function for up to 15 years.

PRODUCIBILITY ISSUES

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

45 DAY PRODUCIBILITY STUDY

NO MAJOR DESIGN CHANGES RECOMMENDED

MANY MINOR CHANGES SUGGESTED

EXAMPLE

BEAMSPLITTER REQUIREMENTS

EXOTIC LIGHTWEIGHT MATERIALS

STANDARDIZE COMPONENTS

CAST VS MACHINE STRUCTURES

HANDLING FIXTURES

EFFECT

APPROXIMATELY 3 % INCREASE IN WEIGHT

APPROXIMATELY 20 % SAVINGS ON RECURRING COSTS

13

During the 45 day study in 1989 many aspects of the LFU were examined in the context of improving producibility. No major design changes were recommended. Many minor changes such as accessibility to certain locations or material changeouts were recommended. An example follows related to the ability of manufacturers to meet tolerances and schedules.

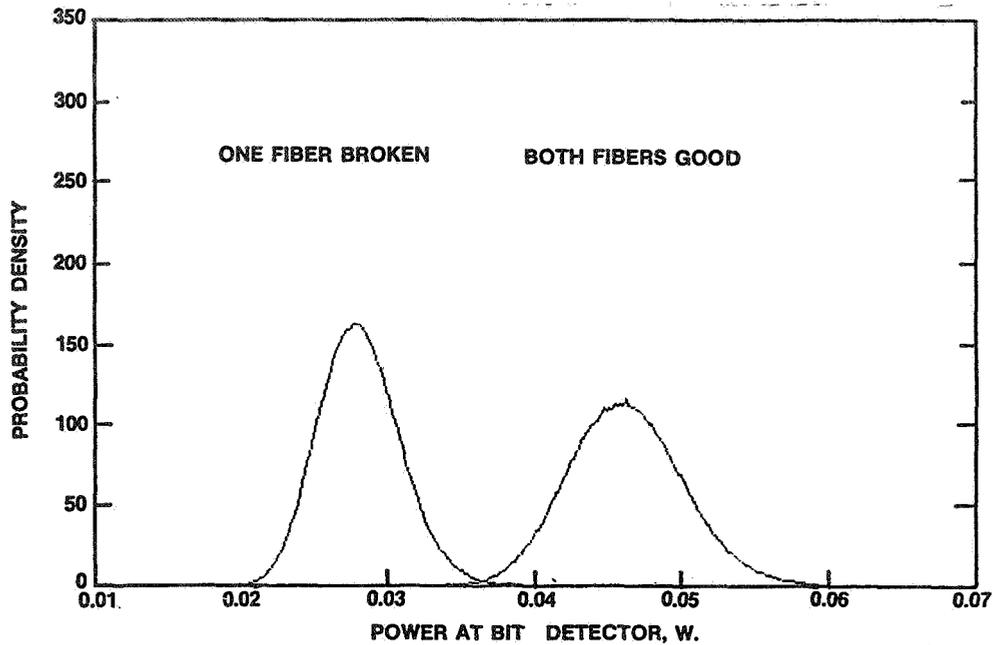
The use of an optical splitter to achieve simultaneous intillations was dropped due to qualified suppliers inability to meet a high enough production rate with the tight tolerances specified. The beamsplitters had reflectance requirements that were related to both wavelength and polarization. Although it was not necessary to determine which of the two paths were bad (only if one or both were), it was necessary to isolate the return signal from one versus the return signal from the other. This was accomplished by using BIT lasers with orthogonal polarizations. The beamsplitter would send one polarization down one path and the other polarization down the other path. The result was a beamsplitter that was 50 % reflective and not polarization sensitive at 1.06 microns and highly reflective in one polarization and highly transmissive in the other at .85 microns. In addition the coating is required to meet a high laser damage threshold. The resulting beamsplitter design was sensitive to moisture, requiring special handling during unit assembly and supplier yields were less than 30%.

Incorporating the suggested changes resulted in a 3% increase in weight and a 20% reduction in cost.

PRODUCIBILITY ISSUES (cont'd)

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary



14

The graph shows the type of results that occurred when all variables were modeled to their full tolerance distribution expectations in a dual channel path. It can be seen that a dual event path presented an unacceptably high probability of rejecting a good fiber as bad or finding a bad fiber to be good. The model included additional polarization sensitive elements such as quarter wave plates and compensators.

By simply matching continuity test hybrids to a particular beamsplitter, for example, the types of well separated distributions shown on the earlier slide can be achieved. Addressed from a producibility standpoint, the recommendation was made to eliminate optical splitting rather than proceed with matching components.

1993010 730
493031
128

N98-20139

**LASER-INITIATED ORDNANCE
FOR
AIR-TO-AIR MISSILES**

**Presented by: David R. Sumpter
McDonnell Douglas Missile Systems Company**

Approved for public release; distribution is unlimited.

LASER-INITIATED ORDNANCE FOR AIR-TO-AIR MISSILES

Abstract

McDonnell Douglas Missile Systems Company (MDMSC) has developed a Laser Ignition Subsystem (LIS) for Air-to-Air missile applications. The MDMSC subsystem is designed to activate batteries, unlock fins, and sequence propulsion system events. The subsystem includes Pyro Zirconium Pump (PZP) lasers, mechanical Safe & Arm, fiber-optic distribution system, and optically activated pyrotechnic devices (initiators, detonators and thermal batteries). The LIS design has incorporated testability features for the laser modules, drive electronics, fiber-optics, and pyrotechnics. Several of the LIS have been fabricated; and have supported thermal battery testing, integral rocket ramjet testing, and have been integrated into integral rocket ramjet flight test vehicles as part of the flight control subsystem.

Introduction

McDonnell Douglas Missile Systems Company, with Hercules/Allegany Ballistics Laboratory, SAFT America, and Hi Shear has demonstrated the use of laser-initiated pyrotechnics to sequence events in the Advanced Air-to-Air Missile (AAAM) D&V program. The Laser Ignition Subsystem (LIS) uses six Pyro-Zirconium Pump (PZP) lasers to initiate the thirteen pyrotechnics, controlling the activation of the Fin Unlock, Battery Activate, and Integral Rocket Ramjet functions. Two distinct initiators and a detonator were developed for the LIS, along with a unique activation train within the thermal batteries. The lasers and associated control and test functions were housed within two modules, which are form/fit compatible with the AAAM application. Each of the six laser modules require Arm and Fire signals for activation, and feature a mechanical Safe/Arm device to preclude inadvertent firing of the lasers and pyrotechnics. The fiber optic harness incorporates multiple strands of 200 μm and 400 μm fibers routed to each pyrotechnic. Built-In Test features of the system include optical integrity checks from laser rod to pyrotechnic, lamp module status (fired/unfired), and fire function monitor.

The LIS has proven to be reliable, and has been successfully used in the development of the thermal batteries, booster and ramjet sustainer. It has been subjected to strenuous environmental tests and retained operational capability. Several have been installed the the AAAM Air Vehicles in preparation for flight demonstration.

I. Integral Rocket Ramjet System

The Integral Rocket Ramjet (IRR) system concept applied to the AAAM program is outlined in Figure 1. The Flight Controls regulates all activity in the system. It transmits Arm and Fire commands to the LIS to activate the thermal batteries, unlock the fins, and sequence the booster and sustainer functions. The Flight Controls also commands fin position and manages the fuel flow to control vehicle flight.

There are six laser modules in the LIS, which are fired in response to commands from the Flight Controls. The first event is the activation of the two thermal batteries, which is performed using aircraft power prior to launch. The second laser is

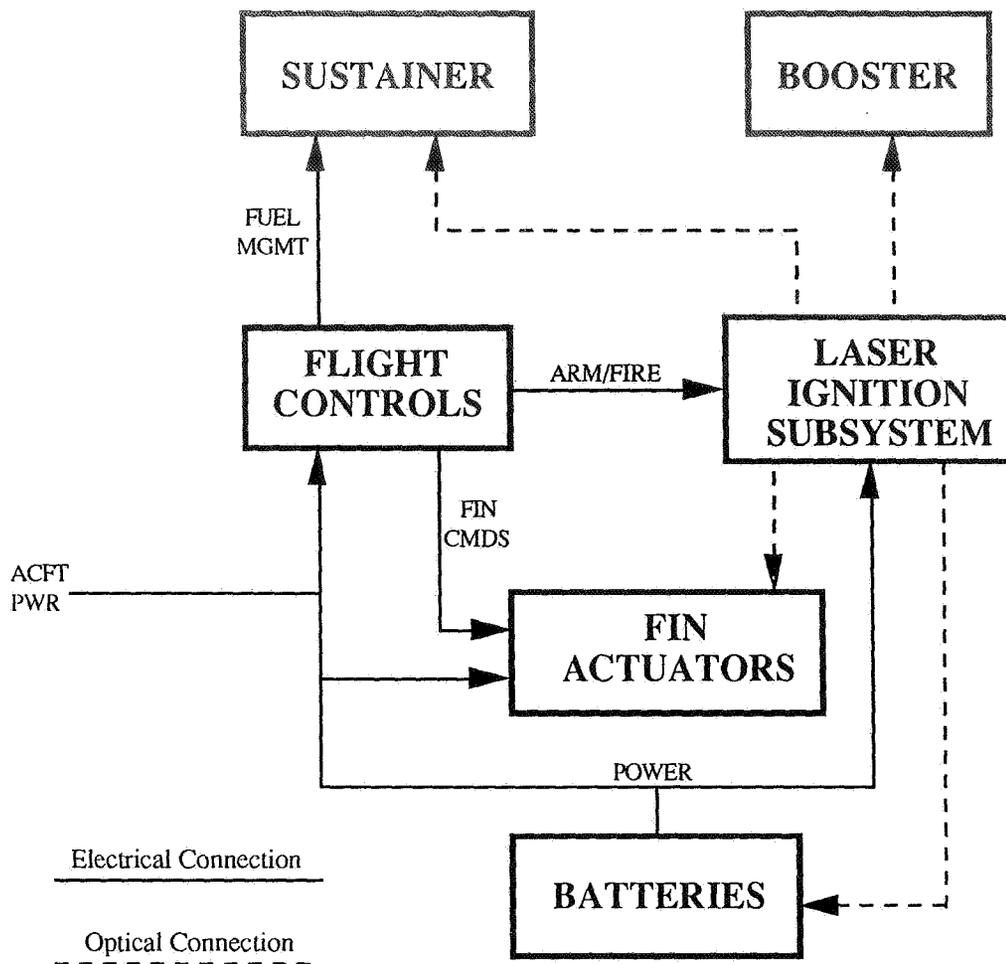


FIGURE 1. Integral Rocket Ramjet System Concept

used to unlock the four fins simultaneously. The remaining four lasers are used to sequence the propulsion events, which use a total of seven pyrotechnic devices. Each of the six lasers is fired only once, activating a total of 13 pyrotechnics.

II. The LIS Control Assemblies

The lasers, Safe/Arm devices, and associated electronics are packaged in two housings, as shown in Figure 2. The port assembly consists of the laser modules for the Battery Activate and Fin Unlock, and has the Optical BIT detector circuitry for all laser functions. The starboard assembly contains the laser modules for the propulsion events.

The segregation of the events in this manner is not merely for convenience. Only the battery power is routed to the starboard control assembly, significantly reducing the risk of an inadvertent firing before launch. The port assembly requires a single Arm command to arm both lasers, and a distinct fire command to activate the specific lasers. For safety purposes, the starboard assembly requires two Arm commands to arm all four lasers, and then the distinct fire commands to activate the specific lasers. Neither starboard Arm command is shared by the port assembly, and

the two commands are generated by separate sources to further preclude a failure-induced ignition.

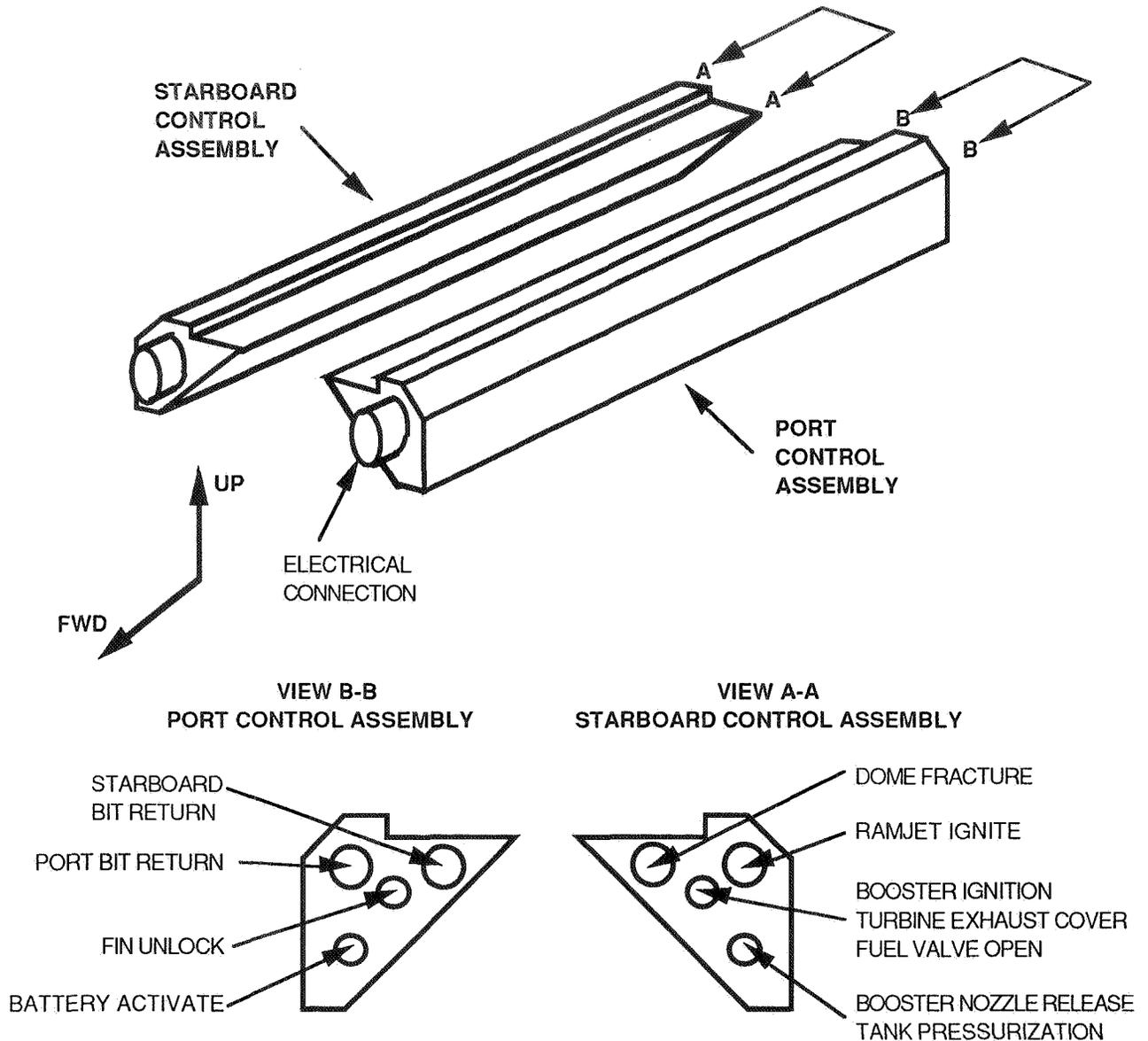


FIGURE 2. Laser Ignition Subsystem (LIS) Control Assemblies

The laser sources are based on a PZP system. Five flashlamps are used to excite the Neodymium-Glass laser rod, which generates a 2 Joule pulse at 1060 nm. As shown in Figure 3, this energy passes through a focusing lens to reduce the beam size for the fiber optic cable. In the Safe mode, a shutter interrupts the optical path, using a dichroic-coated window to block the laser energy. When Armed, the window is mechanically removed from the beam path, permitting the laser energy to pass into the fiber optics. A short length of 1000 μm fiber is used as an environmental seal for the control assemblies. When the fiber optic cable is connected, the laser energy is transmitted through the cable to the pyrotechnic device.

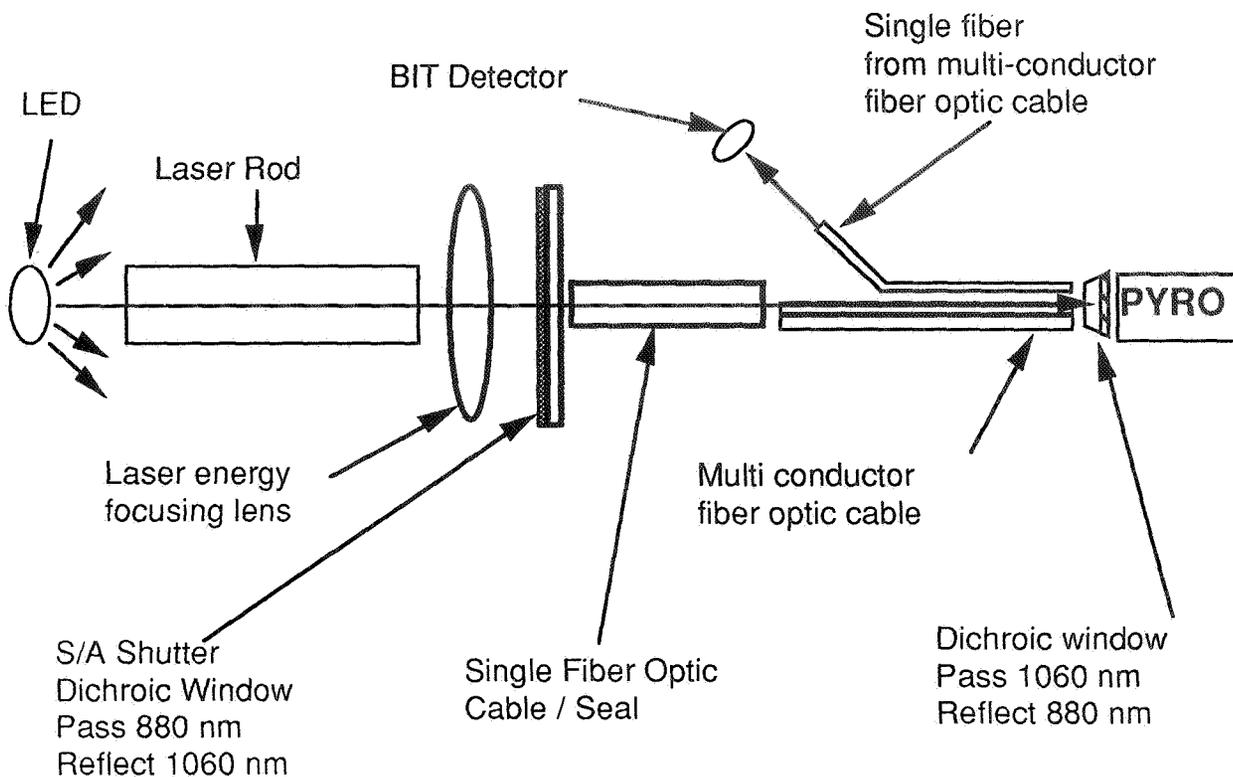


FIGURE 3. Optical Path for Laser and BIT Energy

The laser modules are grouped in pairs, and share a rotary solenoid for the Safe/Arm function. In the Safe mode, the rotary solenoid shorts the flashlamps to ground, and positions the shutter to interrupt the optical path. When armed, the flashlamps are connected to the fire circuit, and the shutter is removed from the optical path. Figure 4 shows a pair of laser modules with the common Safe/Arm device.

There are three Built-In Test (BIT) functions in the LIS. The first uses a metalized film wrapped around the flashlamps to determine flashlamp integrity. When the flashlamps are fired, the metalized film melts, changing a low-impedance path to high impedance. Sensing the impedance flags expended laser modules. The second test checks the fire circuitry. When the fire circuit is activated, the Optical BIT function is inhibited. A failed Optical BIT during a fire command, when preceded and succeeded by a passing Optical BIT, verifies the performance of the fire circuits.

The third BIT function is Optical BIT. The integrity of the optical path, from laser rod to pyrotechnic is verified by this function. The Optical BIT concept is shown in Figure 3. An LED is positioned behind the laser rod. The 880 nanometer radiation propagates through the laser rod and focusing lens. The position of the shutter does not seriously impact the function, since the dichroic passes greater than 90% of the BIT energy, and is out of the path when armed. The BIT energy passes out of the control assemblies, through the fiber optic cables, to the pyrotechnics. The dichroic element

in the pyrotechnic is reflective to the 880 nm energy. A single fiber, dedicated to Optical BIT, originating at the pyrotechnic termination, collects the reflected BIT energy and transmits it back to a detector in the control assembly. The detectors are monitored to assess the status of the optical path.

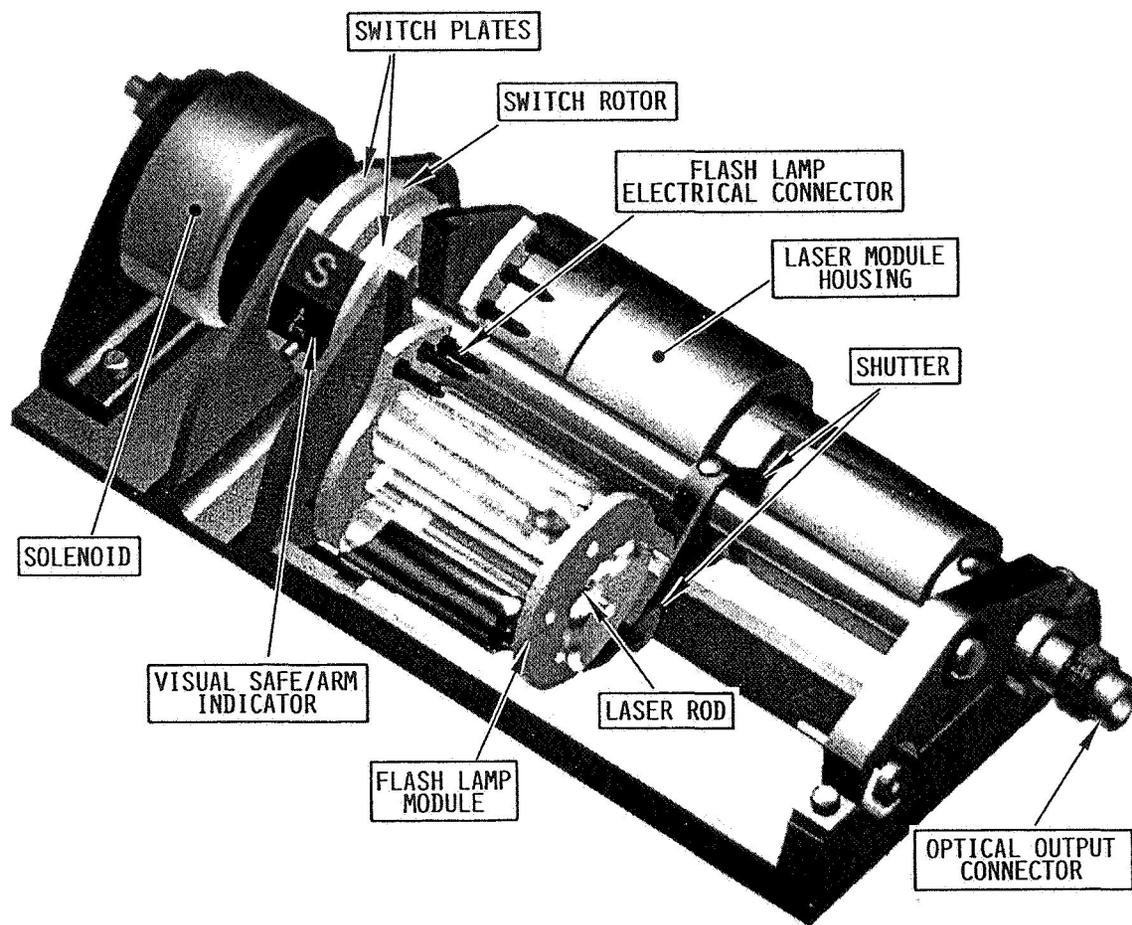


FIGURE 4. A Two-Pulse Laser Assembly

III. Initiators and Detonators

The LIS uses six initiator and and detonator designs for the Integral Rocket Ramjet concept. The basic, or "standard" initiator, is shown in Figure 5. The fiber optic termination uses a conventional SMA connector. The pin seats on the outer rim of the receptacle, and is polished to a tightly controlled length to maintain a minimal air gap between the pin and the window. The glass window is tapered to provide a seating surface, and has a dichroic coating on the inner surface (adjacent to the propellant). This dichroic coating passes the laser energy, but reflects the Optical BIT energy back into the fiber optic for detection. The propellant consists of a Zirconium Potassium Perchlorate (ZPP) donor charge, and BKNO_3 as the primary propellant. A spacer occupies the extra volume, holding the propellant in position.

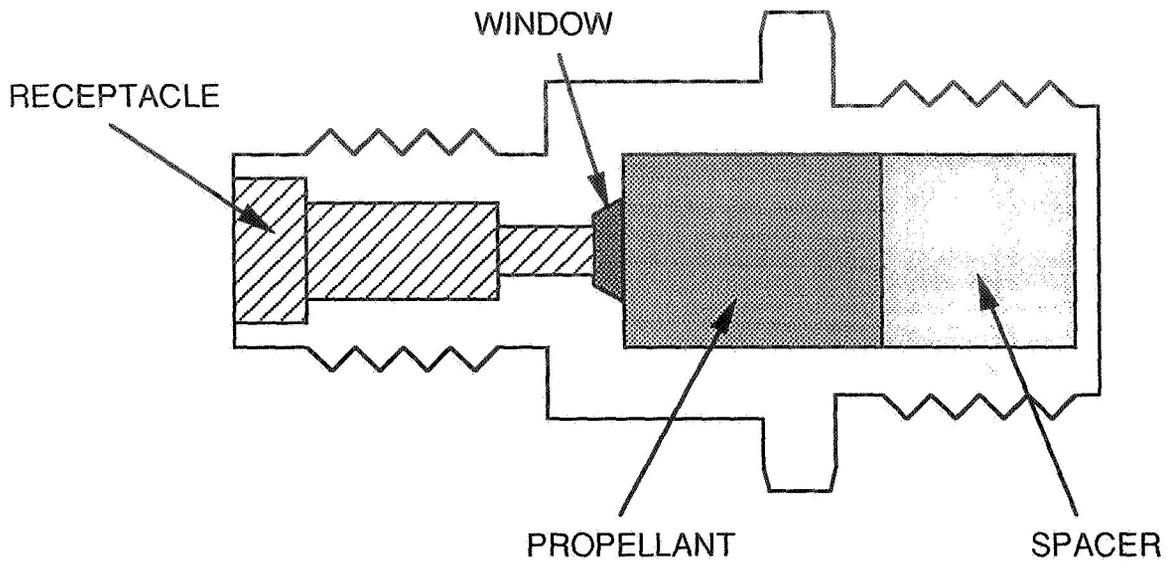


FIGURE 5. Standard Initiator Configuration

There are three variations of this initiator. Two differ only in the amount of propellant, since two different output pressures were needed. The third does not use the SMA optical interface. This third device is the Fin Unlock Initiator, which is installed in the removable fins. The fiber optic is terminated in the fin control actuator, and is spring-loaded to maintain contact with the initiator when a fin is installed. The Fin Unlock Initiator looks like the standard initiator with the SMA connection removed, as shown in Figure 6. To accept the blind mate of the fiber optic pin to the initiator, the receptacle is chamfered.

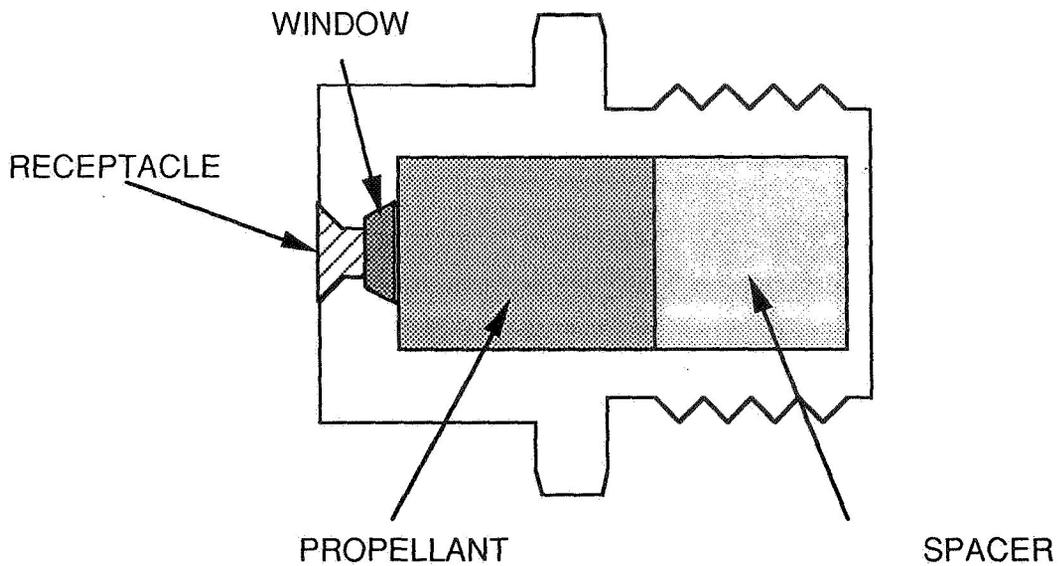


FIGURE 6. Fin Unlock Initiator Configuration

The detonator design is also very similar to the standard initiator. The optical interface is the same, however the charge is different. A small amount of ZPP is used to accept the laser energy. Instead of directly igniting the propellant of the initiator, the ZPP in the detonator ignites a donor charge of PETN, which in turn ignites the primary PETN explosive charge. The detonator does not need the spacer, since the entire charge cavity is utilized.

The remaining two initiators are unique devices. The first is used to ignite the booster. The booster igniter must operate radially in the booster port, instead of an axial output like the standard initiator. The approach used was a bag of BKNO_3 pellets embedded in the booster port. The initiator is placed in the bag of pellets, which is then installed in the booster port and foamed in place. Since this device is installed as part of the booster manufacturing and is not directly accessible, a fiber optic lead is required as part of the delivered booster. Figure 7 shows the configuration of the booster initiator.

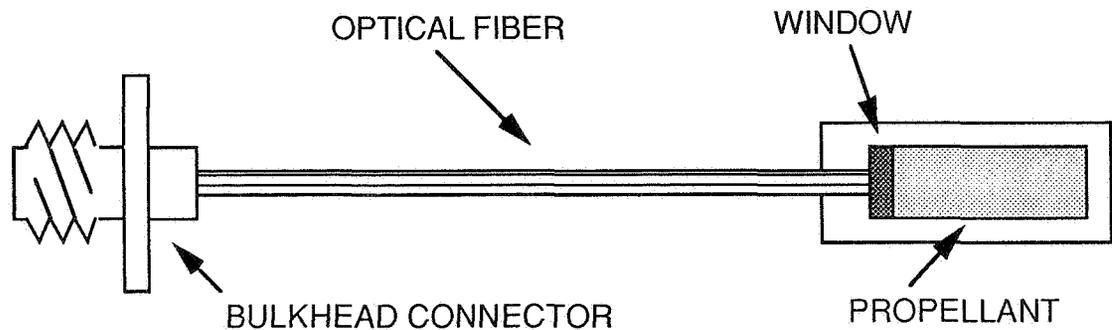


FIGURE 7. Booster Initiator Configuration

The bulkhead connector interface is the standard SMA contact. The bundle of optical fibers lead from the bulkhead connector to the initiator, and are terminated at the glass window. Like the other devices, the window has a dichroic on the second surface to reflect the Optical BIT energy, and pass the laser energy. The propellant consists of a small donor charge of ZPP, with a primary charge of BKNO_3 . The body of the initiator is nylon which is sealed with epoxy, permitting the propellant to rupture it easily to activate the booster igniter.

The final initiator type is built into the thermal batteries. The configuration is illustrated in Figure 8. The receptacle is a standard SMA connection, and the glass window is the same as that used for the standard initiator, including the dichroic coating. The donor charge is again ZPP. The ZPP ignites the fuze, which extends through the core of the battery. The fuze then activates the cells in the battery stack.

Note that the dichroic window on each of the devices is on the inside of the device. This was done for two reasons. First, it provides a gap between the polished pin and the reflective surface, which is needed to scatter the Optical BIT energy from the transmit fibers to the single return fiber. Second, it is burned off when the device is activated, which will cause Optical BIT to fail, flagging an expended device.

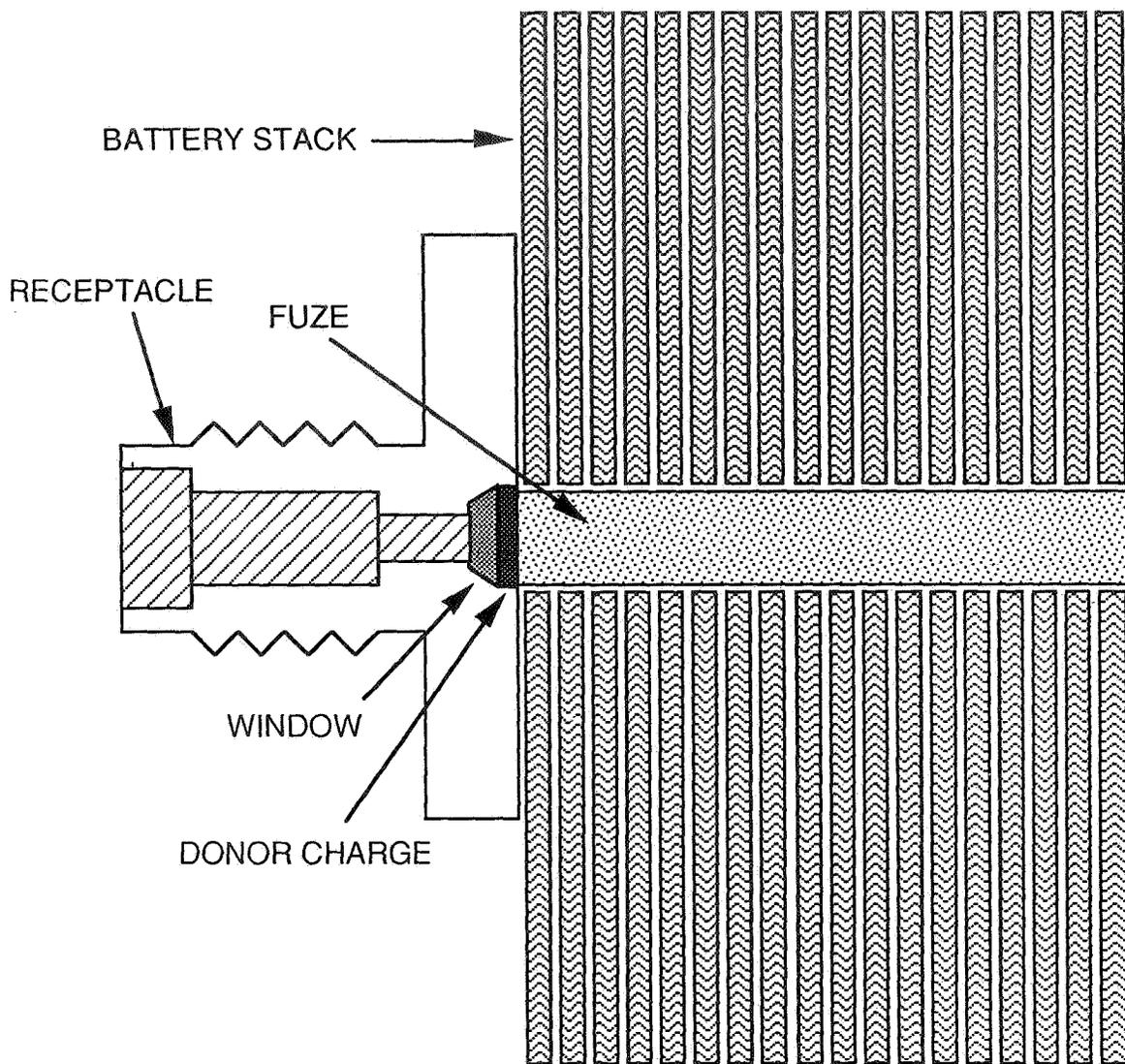


FIGURE 8. Battery Initiator Configuration

IV. Fiber Optics

The fiber optics are used to transmit the Optical BIT and laser energy to the pyrotechnic devices, and return the reflected Optical BIT energy to the detectors. Each fiber optic has multiple transmit fibers and a single return fiber routed to each pyrotechnic device. The most complicated is the Fin Unlock, which is shown in Figure 9.

The Fin Unlock fiber optic cable starts at the Control Assembly with nineteen fibers. The number nineteen is significant because it produces a stable pattern, with one in the center, an inner ring of six, and an outer ring of twelve fibers. These nineteen fibers are divided between the four fin unlocks. The primary consideration is the power density of the laser beam, which is highest in the center, and falls off rapidly at the outside of the beam. The four groups of fibers are selected such that each fin unlock will receive approximately the same laser power.

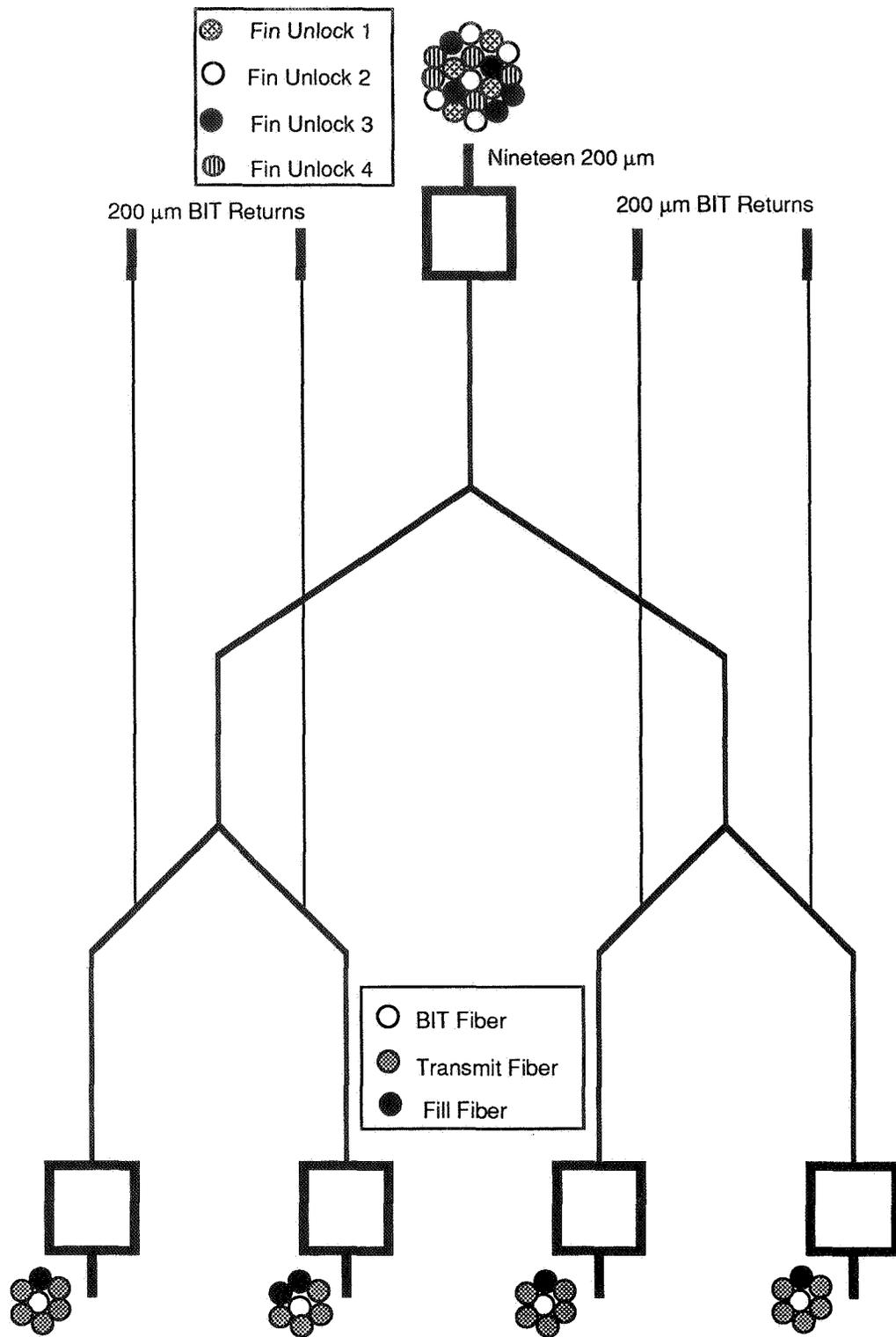


FIGURE 9. Fin Unlock Fiber Optic

The four groups of fibers are separated into individual cable branches, and routed to the four fin unlocks. Note that three of the fin unlocks have five transmit fibers, the other has only four. At the fin unlock terminations, the stable pattern size is now seven: the center fiber and the ring of six surrounding it. The center fiber is always the Optical BIT return fiber, so that it can collect scattered BIT energy from all adjacent fibers. Since none of the four fin unlock terminations has all seven fibers assigned, fill fibers are inserted to complete the stable pattern. These fibers are cut off in the cable just outside of the pin, and serve no purpose other than filling the gaps.

The individual Optical BIT return fibers are routed to the port control assembly, where all the BIT detectors are located. The port control assembly has two connectors of seven pins (one pin is unused) for the BIT returns. Each pin is inserted into the assigned position, then all are held in place with an insert and nut.

The five remaining fiber optic cables are designed using the same considerations. The cables which activate two or less devices use 400 micron fiber for the transmit fibers instead of the 200 micron, since fewer 400 micron fibers can carry the same energy, and the energy division problem is simpler. When the 400 micron fiber is used, the stable patterns used are seven and four fiber bundles.

V. Test Results

The LIS has been subjected to thermal, vibration and shock testing using the AAAM environments. The dynamic environments are reasonably severe. Operation has been demonstrated during and after 19 Grms vibration, and after 42 G shock. The temperature environments are not as severe; operation has been demonstrated during and after +160°F and -65°F soaks.

The LIS has also been used to develop other systems for the Integral Rocket Ramjet. The thermal batteries, fin unlocks, booster and ramjet sustainer functions have all been demonstrated. This testing has shown the fiber optics to be unreliable after repeated use. When firing the laser through the fiber optic bundles, some of the laser energy is absorbed by the epoxy between the fibers. This localized heating causes the epoxy to boil, which results in contamination being spattered on the polished fiber optic surface. Attempt to re-use the fiber optic, without additional polishing to clean the surface, results in attenuation which can be severe enough that the energy reaching the pyrotechnic is below the all-fire level. This condition is detectable by Optical BIT, however BIT was not used for the development tests. Also note that this condition does not impact a deployed system, where the fiber optics are only used once.

VI. Summary

A laser ignition system has been developed and demonstrated for the Integral Rocket Ramjet concept applicable to Air-to-Air missiles. The design has been used to support development and testing of other subsystems. Several of the LIS have been installed in air vehicles.

This page intentionally left blank.

LASER DIODE ORDNANCE DESIGN

for the

**NASA AEROSPACE
PYROTECHNIC SYSTEMS WORKSHOP**

JUNE 9 & 10, 1992

Arthur D. Rhea

Approved for public release; distribution is unlimited.

88

1993010751

493036

N93-20140

LASER DIODE ORDNANCE DESIGN

INTRODUCTION:

- **Technologies are now available to optimize vehicle ordnance performance, weight, safety, reliability and cost**
- **Maximum benefits achieved only through comprehensive ordnance to vehicle integration - Technology vs Requirements**
- **Laser Diode Ordnance provides one solution to meet the requirements for multiple aerospace applications**

LASER DIODE ORDNANCE DESIGN

CHARACTERISTICS:

- **Simple Electronic Controls and Safing**
 - **Adapts to multiple control and sequencing options**
 - **Hardened to stringent environments**
 - **Can be miniaturized**

- **Low Voltage System**
 - **No high voltage components**
 - **Prompt timing**

- **Inert Fiber Optics**
 - **Safe from electrical interference**
 - **Low light power for reduced impact on connector interface**

- **Insensitive Initiators**
 - **Secondary explosives**
 - **Fiber interface for electrical safety**

LASER DIODE ORDNANCE DESIGN

SYSTEM DESCRIPTION:

- Laser Firing Unit, Fiber Optic Cables and Initiators
 - Receives Command Control Signals and Power
 - Routing of Single or Multiple Fiber Cables
 - Explosive or Pyrotechnic Initiators

Issues:

- Centralized vs Distributed Design
- Number of Firing Units and Optical Connectors
- System vs. Component requirements
- System Reliability vs Component Margins
- Requirements Definition - Specification Intents
 - Barriers or Inhibits
 - BIT or Testability

LASER DIODE ORDNANCE DESIGN

LASER FIRING UNIT:

- **Single or Multiple Laser Diode Outputs**
 - **Single Quantum Well Laser Diode, 850 nanometer wavelength**
 - **2.5 watt output with 200 micron fiber**
- **Single Discrete Commands, 28 VDC power**
- **Single Fault Tolerant**
- **Independent and Verifiable Inhibits**
- **Weight and Volume, 1.5 lbs, 40 cubic inches for up to 6 outputs**

Issues:

- **Electrical and Mechanical Interface**
- **Laser Power**
- **Safing Design**
- **Built In-Test**

LASER DIODE ORDNANCE DESIGN

FIBER OPTIC CABLES:

- **Hard Clad or Glass-on-Glass Fibers**
 - **Diameters range from 100 microns to 400 microns**
 - **MIL-C-38999 connectors**
 - **Bend Radius - 0.5 inch for 200 micron fiber**
 - **Proof test up to 500,000 psi**

Issues:

- **Cable and Connectors Requirements**
- **Connector Losses**
 - **Contamination Characterization**

LASER DIODE ORDNANCE DESIGN

INITIATORS:

- **Performance Duplicates Existing Devices (Detonators & Squibs)**
 - **Insensitive Explosives or Pyrotechnics**
 - **Hermetic (< 1 X 10⁻⁶ cc/sec He leak rate)**
 - **Fiber or Window Seal**
 - **Dichroic Coating**

Issues

- **Acceptable Explosive Materials**
- **No-Fire Levels**
- **Inadvertent Events and Levels**
- **BIT Level**

LASER DIODE ORDNANCE DESIGN

CONCLUSIONS:

- **Launch vehicles, Satellites, Tactical Missiles, Strategic Missiles and Aircraft Ordnance Systems can be optimized for specific requirements**
- **Laser Diode Ordnance is a low risk solution for multiple applications**
- **Vehicle specifications for ordnance must be flexible to alternative technologies to achieve "Best Fit" design**

17730141

493038

22P

N 9 3 - 2 0 1 4 1

**INTRODUCTION OF LASER INITIATION
FOR THE 48-INCH ADVANCED SOLID ROCKET
MOTOR (ASRM) TEST MOTORS AT MARSHALL
SPACE FLIGHT CENTER (MSFC)**

**C.J. Zimmerman
Aerojet-ASRM Division**

**G.E. Litzinger
Aerojet-APD Division**

9 June 1992

Approved for public release; distribution is unlimited.

I. Pyrotechnic Ignition System

The Advanced Solid Rocket Motor is a new design for the Space Shuttle Solid Rocket Boosters. The new design will provide more thrust and thus more payload capability, as well as incorporating many design improvements in all facets of the design and manufacturing process. A 48-inch (diameter) test motor program is part of the ASRM development program. This program has multiple purposes for testing of propellant, insulation, nozzle characteristics, etc. Ignition of this motor is the subject of this paper.

This paper overviews the evolution of the 48-Inch ASRM test motor ignition system which culminated with the implementation of a laser ignition system. The laser system requirements, development, and operational configuration will be reviewed in detail.

The igniter for the 48-inch test motor is a fairly simplistic style of design, known in the igniter field as a "Bag Igniter". The bag connotation refers to arrangement of propellant in a loosely controlled structure and contained in a flexible and/or consumable container. The objective of this style of igniter is to provide a specific energy flux or pulse without controlling the direction of the energy output.

Figure 1 depicts the original design for the bag igniter. The design is as follows:

- 1) An ignition cord (ITLX) is looped inside a velostat bag which encases Boron Potassium Nitrate (BPN) granules.
- 2) The components of #1 are encased in a second velostat bag which contains BPN pellets.
- 3) The components of #2 are encased in a third velostat bag which contains propellant.

Figure 2 is a schematic of the ignition train. The ignition sequence begins with the Safe and Arm which initiates the nonel shock cord. The shock cord transfers pyrotechnic energy to the ignition cord. The ignition cord ignites the granules, which ignites the pellets, which ignites the propellant.

Initial development testing revealed that energy transfer to the ignition cord was not reliable. The design was revised that which is depicted in figure 3. The ignition cord was removed. A cellulose acetate tube was added and inserted into the bag of BPN granules. BPN powder (IP-10) was added into the tube and the nonel shock cord was inserted into the powder. This system was tested several times without failure. A demonstration of the igniter initiating a test motor was successfully performed at MSFC.

After the successful firing of the test motor at MSFC, production of 2 lots of igniters was commenced. During this build it was discovered that the revised ignition system output was not 100% reproducible. It was then decided to completely redesign the ignition system. A laser ignition system was chosen as the best option to interface into the complete system requirements of the 48-inch test motor. The laser ignition option met safety and remote operation requirements, fulfilled pyrotechnic output requirements, and easily integrated into the sequencing operations of the test control facility at MSFC.

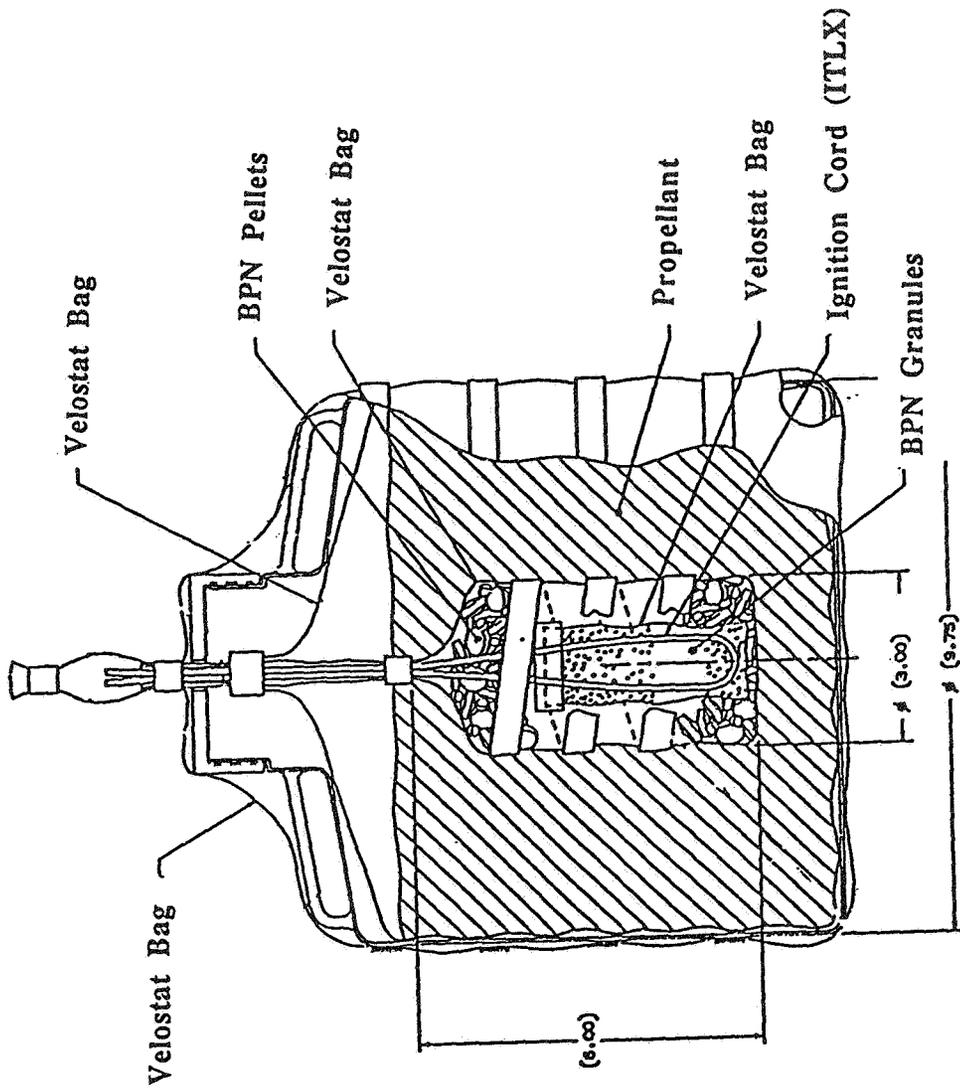
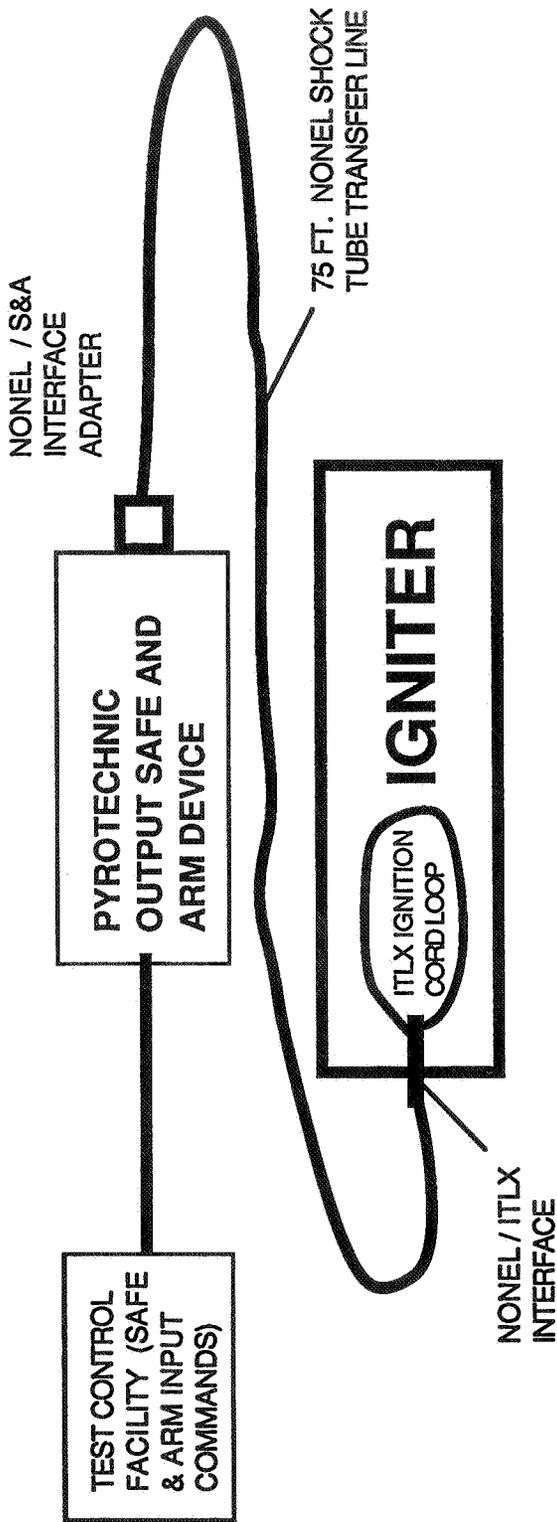


Figure 1
Original Design



- PYROTECHNIC OUTPUT FROM SAFE AND ARM DEVICE
- PYROTECHNIC NONEL SHOCK TUBE TRANSFER LINE
- NONEL SHOCK TUBE TRANSFER TO ITLX IGNITION CORD WHICH INITIATES THE IGNITER BAG CONSISTING OF BPN GRANULARS AND BPN PELLETS

FIGURE 2: ORIGINAL PYROTECHNIC INITIATION SYSTEM

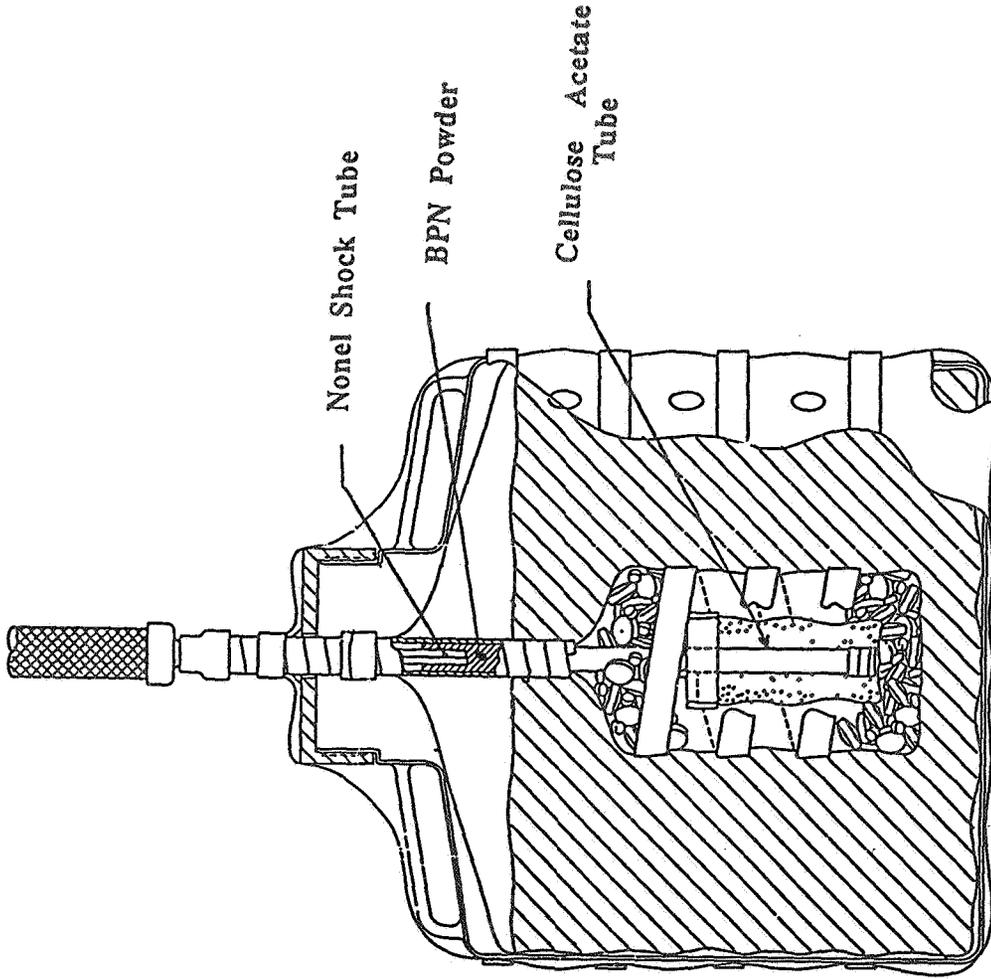


Figure 3
Modified Original Design

II. Laser Initiated Ordnance System.(LIOS)

The LIOS consists of a remotely operated portable laser diode firing unit, fiber optic cables with optical connectors, and a laser initiated squib. Additionally, a laser energy sensor meter is used for laser system checkout prior to connection of the pyrotechnics. This system is designed and manufactured to comply with all CDHR (United States Department of Health, Education, and Welfare Center for Devices and Radiological Health) requirements. Figures 4 & 5 show schematics of the laser system, and the test facility schematic. Figure 6 lists the test facility requirements on the system.

Portable Laser Diode Firing Unit. (PLDFU)

System Overview

The PLDFU is designed to operate in a remote mode only. The user has control of the Arm & Fire commands from a remote location. A local and remote voltage feedback is provided to monitor the capacitor network internal to the unit. The front panel power indicator will function in remote mode and is also useful for voltage monitoring purposes.

PLDFU Front Panel

The PLDFU front panel contains a key switch interlock, interlocking remote power and an LED indicator to identify PLDFU power. The front panel is described below. Refer to Figure 7 for reference.

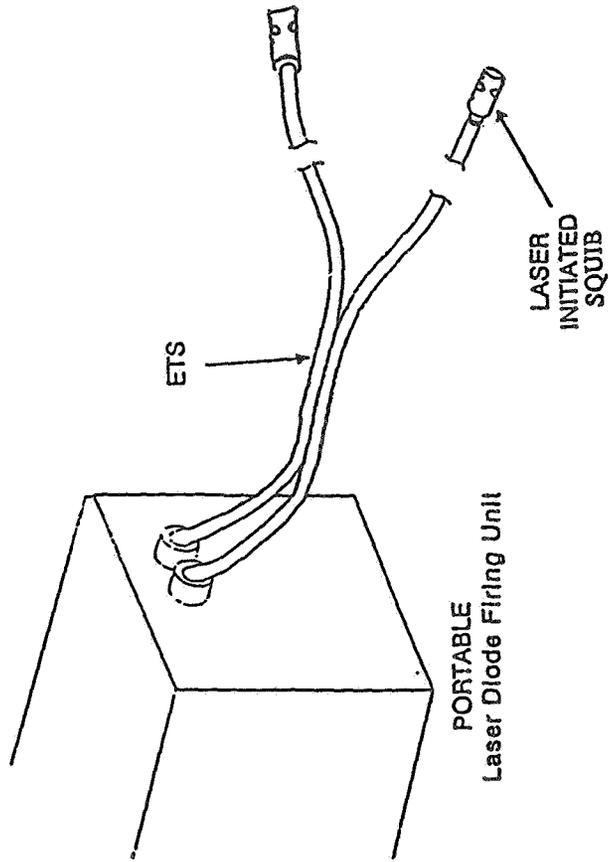
Enable Key Switch -- The enable key switch is used to control external primary DC power to the PLDFU. Two positions are available: OFF and ON. In the OFF position (vertical), external DC power is disconnected from internal circuitry. In the ON position (horizontal), DC power is enabled. The ON position is the normal position when the system is in operation. In preparation to turning the system ON, the user must turn the key switch from the OFF position to the ON position. The correct method of powering down the system is to turn the key switch from the ON position to the OFF position. The key can only be removed in the OFF position.

Power Lamp -- The power lamp will illuminate when external power has been provided and the interlock key switch is in the on position.

PLDFU Back Panel

The PLDFU back panel contains dual laser diode outputs, a power connector, voltage monitor output and remote interface connector. Refer to figure 7 for reference.

J2, Power Input -- External power must be provided to this input. The required level is +24VDC +/- 2VDC. Also provided on this connector is voltage feedback used for remote voltage monitoring.



ASRM SYSTEM

Figure 4

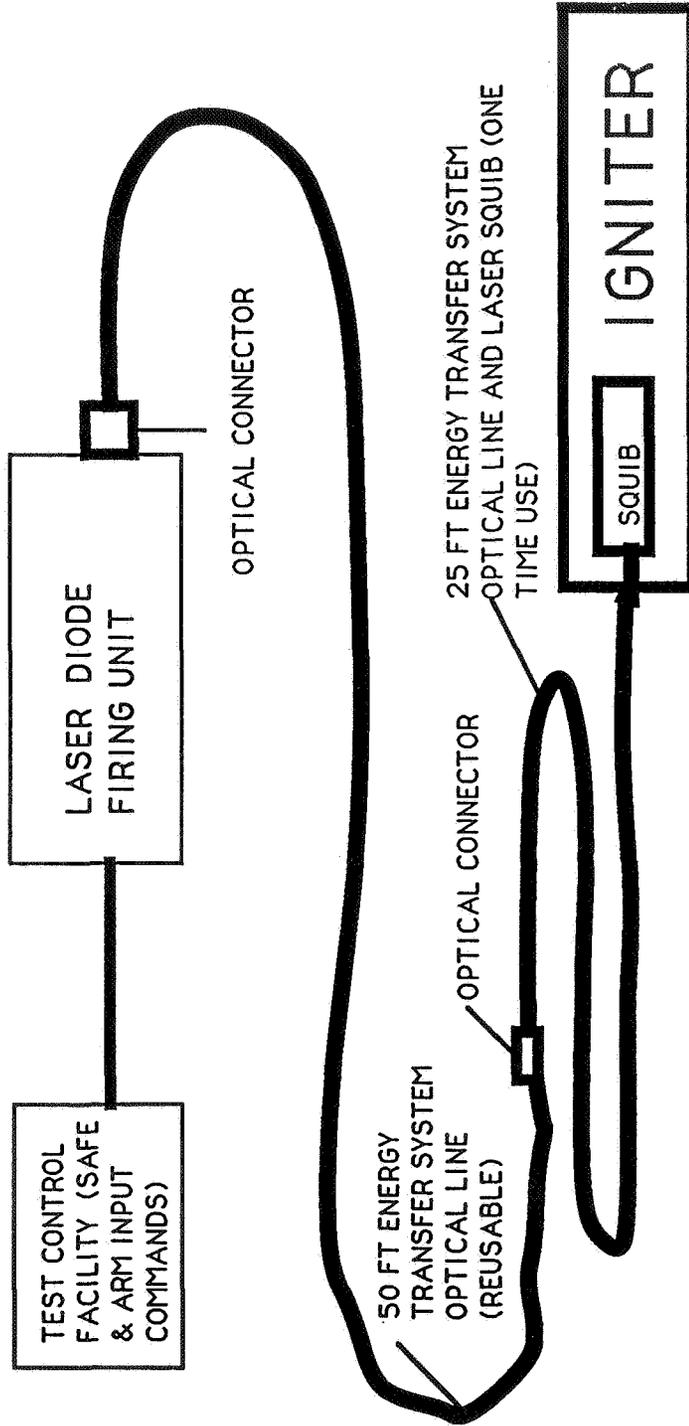
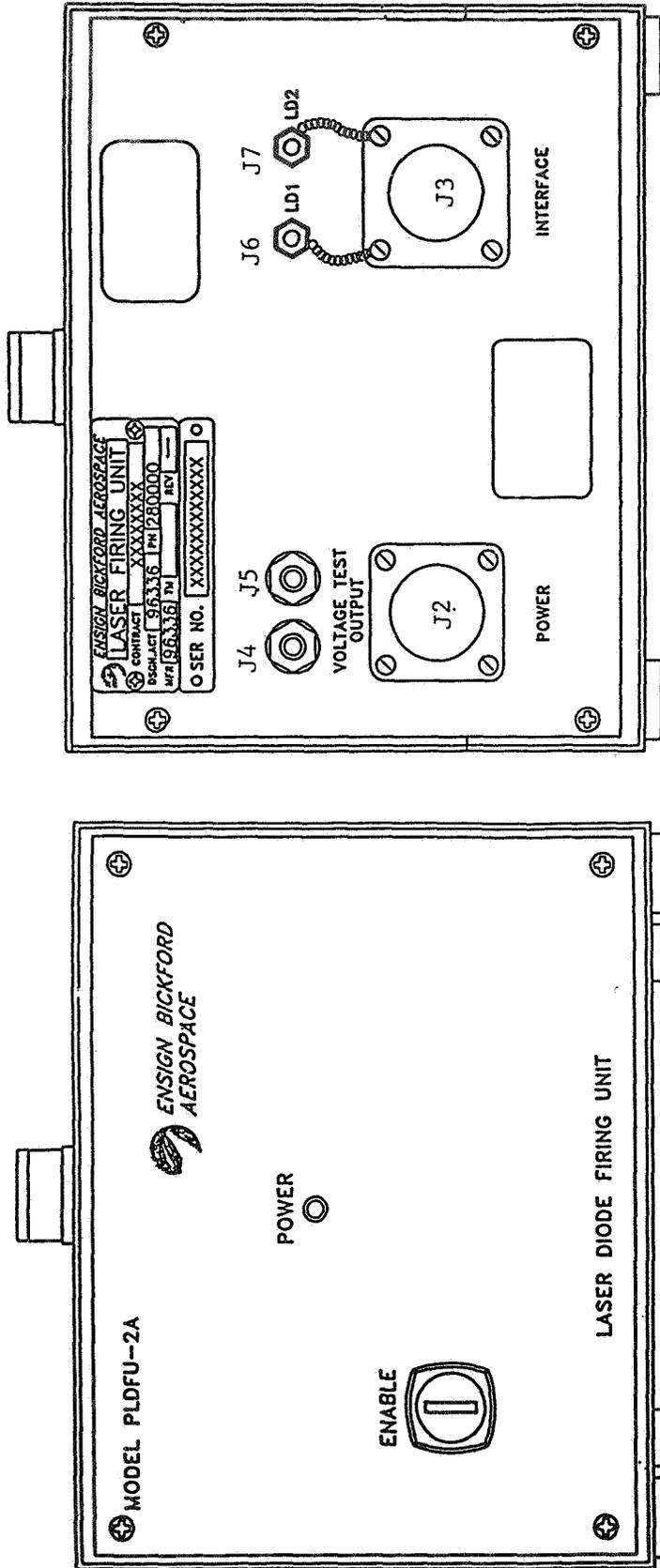


Figure 5: Test Facility Schematic

- REMOTE POWER SUPPLIED BY TEST FACILITY
 - STRAY VOLTAGE VERIFICATION INCORPORATED INTO DESIGN
- REMOTE MONITORING OF TRIGGER CIRCUIT
 - EVALUATE TIME PROFILE FROM FIRE COMMAND TO MOTOR IGNITION
- REMOTE ARM STATUS MONITORING
- REMOTE FIRE STATUS MONITORING
- COMPLETE VERIFICATION OF UNIT ACCOMPLISHED OFF-LINE, PRIOR TO MOTOR FIRING TEST SET-UP
 - STRAY VOLTAGE TEST
 - TEST FIRING OF LASER DIODES (LASER ENERGY METER)
 - VERIFICATION OF "SAFE" CONDITION PRIOR TO HOOK UP

Figure 6: Test Facility Requirements



PLDFU FRONT PANEL

PLDFU BACK PANEL

Figure 7

J3, Remote Interface Connector -- The remote interface enables the user to control PLDFU's arming and firing in remote locations. Also, discrete outputs are available to inform the user of armed and firing status and trigger output. The trigger output is an electrical output enabling the user to monitor the actual internal fire pulse generated by the PLDFU. It can be used as a trigger source when measuring system delay times.

J4,5, Local Voltage Feedback -- The internal capacitor bank voltage is provided at these connectors.

J6, Laser Diode Output 1, LD1 -- Laser diode output 1 provides the laser output used for event initiation. The Energy Transfer System (ETS) connects to this output.

J7, Laser Diode Output 2, LD2 -- Laser diode output 2 provides the laser output used for event initiation. The Energy Transfer System (ETS) connects to this output.

Energy Transfer System. (ETS)

The ETS is an optical harness that transfers laser power from the PLDFU to the igniter squib. The components of the ETS are:

- 1) Reinforced fiber optic lines
- 2) PLDFU and squib harness optic connectors

The ETS interfaces to the PLDFU with a MIL -C-38999 Series IV connector. The squib is assembled directly to the reinforced fiber optic lines as a subassembly.

Fiber Optic Connectors

The fiber optic connector is a MIL -C-38999 Series IV connector that utilizes fiber optic contacts. The contact used to terminate the fiber optic core is based on 16 gauge electrical contact. The fiber optic contact, like its electrical counterpart, is removable from the rear of the connector. The fiber optic core is assembled into the connector using a crimp, epoxy

and polish process that holds the optic losses to less than 1dB per interface. The fiber optic contact can be placed in any standard insert that accepts 16 gauge electrical contacts. Figure 8 is a schematic of a fiber optic connector.

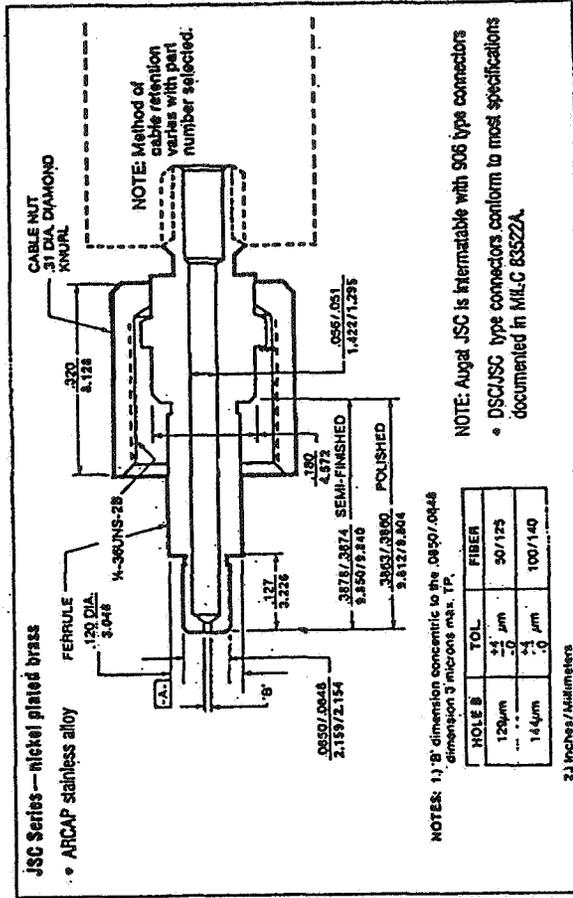


Figure 8

Fiber Optic Connector

Fiber Optic Line

The fiber optic line (see figure 9) is a 400 um HCS fiber manufactured by the Ensign Bickford Optics Company. The fiber has a core of high purity silica, and a hard polymer outer cladding. The hard cladding is a hydrophobic material which offers high resistance to moisture penetration. The hard clad is applied during manufacture to the pristine surface of the core just after the drawing operation. It provides an intimate protective coating by chemically bonding to the silica, and increases the tensile strength of the fiber to in excess of 750,000 psi. The structure of the fiber optics line includes an extrusion of Tefzel over the cladding, a Kevlar reinforcement layer over the Tefzel, and a final polyurethane jacket. The fiber optic line weighs less than 2.5 grains per foot and the energy loss is less than 6 dB per kilometer at 800 nm wavelength.

Laser Initiated Squib. (LIS)

The LIS assembly is shown in Figure 10. The initiator body is 0.25 inches in diameter and 1.25 inches long. The body material is polycarbonate. Two 0.35 inch diameter bushings are bonded to the body to center it within the tube in the igniter assembly. The body is configured with four equally spaced holes to provide radial pyrotechnic output. A polycarbonate plug is threaded into the end of the body to prevent axial pyrotechnic output. The body contains a cavity for two pyrotechnic charges- 25 milligrams of boron/red lead as the first fire mix and 45 milligrams of zirconium/potassium perchlorate as the output mix. The first fire mix is pressed directly against the face of the 400 micron diameter optical fiber which is secured within a polycarbonate fiber ferrule threaded and epoxied into the initiator body. The output mix is pressed directly on top of the first fire charge. The optical fiber pigtail is 25 feet long and is terminated on the input end by a SMA-type optical fiber connector.

III. Laser Initiator Development

The initiator was designed to interface with the Aerojet P/N 3802019 Igniter Assembly - 48 Inch Motor. All major components of the initiator are machined from polycarbonate to ensure their consumption during the motor firing. The initiator was designed to be functioned by a Laser Diode Firing Unit and has .999/95% all-fire and no-fire powers of 472 and 145 milliwatts respectively. Adequate system margin is assured as the anticipated power received from the Laser Diode Firing Unit will be approximately 2.5 times the all-fire.

Fiber Optic Schematic

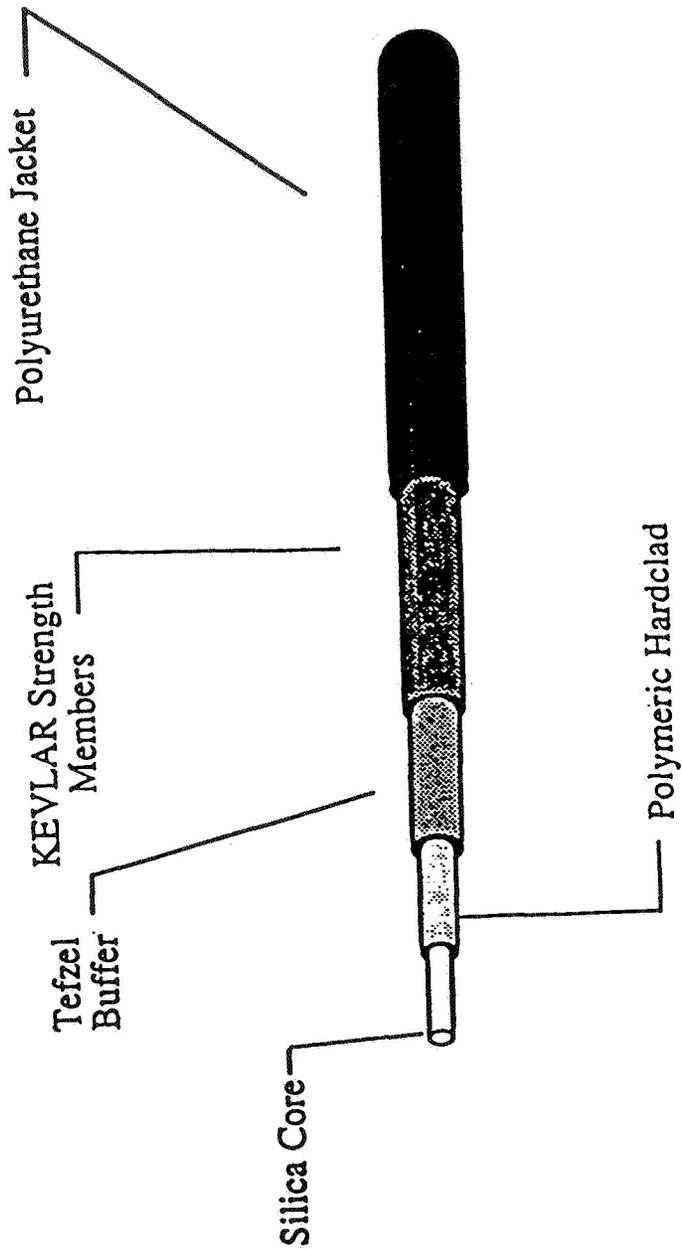


Figure 9

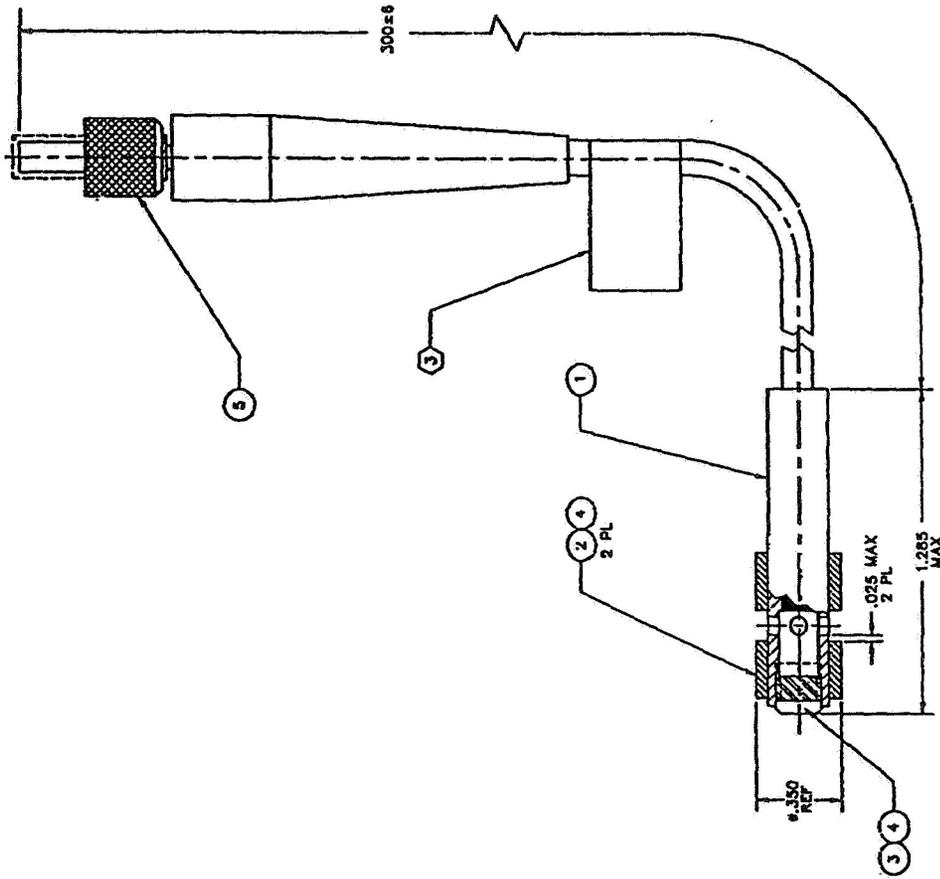


Figure 10
Laser Initiator

Test Summary

The Laser Initiator design was based upon two devices that were developed for similar applications. Boron/red lead was evaluated several years ago as a first fire mix for a diode initiated squib. The zirconium/potassium perchlorate output mix has been used in a variety of squibs and the selected charge weight of 45 mg was used in a prior design to initiate boron/potassium nitrate pellets in a solid rocket motor igniter.

However, as these baseline devices utilized 200 micron diameter optical fiber, development testing had to be conducted with this new device to determine its all-fire and no-fire power and thus ensure that there was sufficient power margin in the system for reliable functioning.

Two series of six firings each were conducted with generic design plastic housings to obtain baseline data on the all-fire power of boron/red lead when mated to a 400 micron fiber. Results of this limited testing indicated that the 50% power (1/2 fire, 1/2 no-fire) was in the area of 400 milliwatts. As improvement on this number was expected when the actual hardware was utilized and more data was generated in a formal test, work proceeded on the basic design.

A prototype lot of fifteen initiators was manufactured to preliminary processing documentation. The purpose of this lot was twofold. It served to provide units for formal development testing and also checked out the preliminary manufacturing and inspection procedures. Ten assemblies were expended in a formal Langlie analysis for all-fire and no-fire powder level determination. The raw test data is shown in figure 11. With a normal distribution assumed, the calculated all-fire power at .999 reliability and 95% confidence was 472 milliwatts. The calculated no-fire power at identical reliability and confidence levels was 145 milliwatts. Radial output was achieved in all instances and no fragmenting of the initiator occurred. The function time curve of Figure 12 is based upon limited timing data that was obtained during the Langlie test. At the anticipate system power input, a function time of under 4 milliseconds should be achieved.

One assembly from this lot was rejected on x-ray and was functioned in a test to demonstrate the radial output. In this firing, the initiator was centered within a 1 inch diameter cardboard tube. When fired with a laser diode, the initiator's radial output left four equally spaced signatures on the inside diameter of the tube.

One assembly from this lot was fired to determine if its output was sufficient to rupture the cellulose acetate buterate tube in the P/N 3802019 igniter. When this requirement became known, the initiator design was modified to incorporate the two bushings on the outside of the body to both center it within the tube and to direct and confine the radial output against the tube wall. When functioned in this test, the initiator output was sufficient to rupture the wall of the tube.

Test	Test S/N	Calculated Energy Level (mw)	Actual Energy Level (mw)	Result X=Fire 0=No Fire	Function Time (ms)	Destruct Energy Level (mw)	Destruct function Time (ms)	Desired Current (amps)	Actual Current (amps)
1	2	375	376	X				1.31	1.27
2	15	188	187	0		675	4.44	0.81	0.80
3	1	281	279	0		-	48.07	1.05	1.02
4	3	516	519	X	5.7			1.65	1.588
5	4	399	401	X	10.7			1.36	1.314
6	5	293	292	X	17.7			1.08	1.054
7	6	146	145	0		675	3.02	0.72	0.714
8	7	220	221	0		675	2.54	0.90	0.882
9	9	309	310	0		675	6.39	1.12	1.090
10	10	413	414	X	14.0			1.39	1.340

FIGURE 11. Laser Initiator Development Test Raw Data

FUNCTION TIME VS LASER DIODE INPUT POWER
P/N 239141 LASER INITIATOR

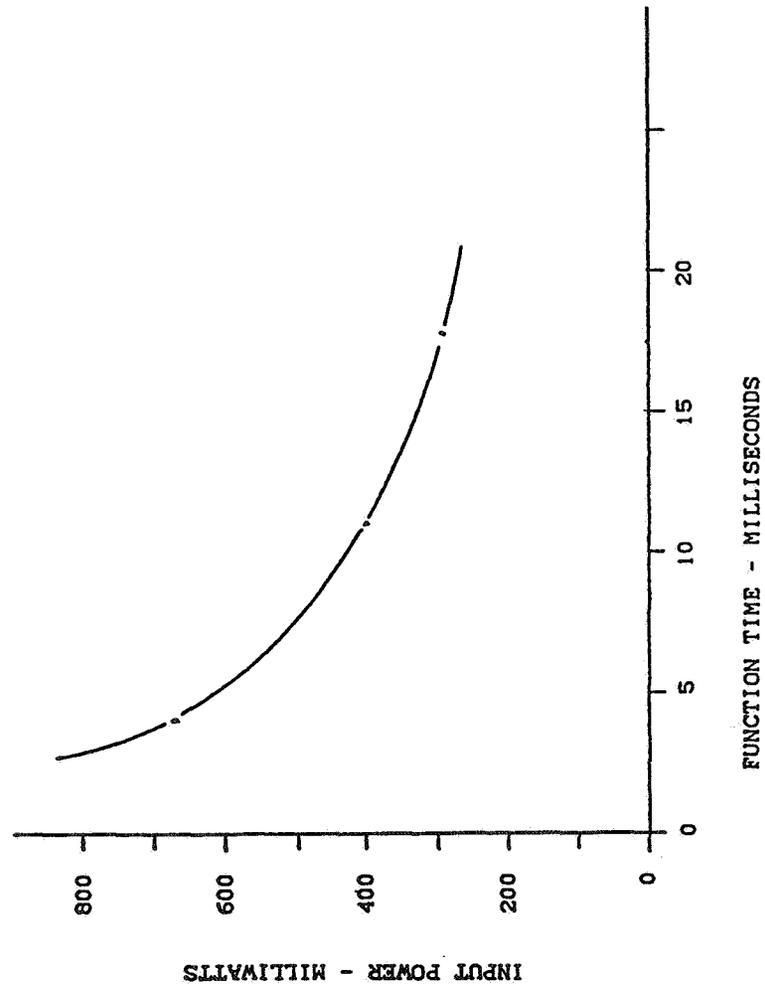


Figure 12

Two initiators were functioned to demonstrate that they could directly initiate boron/potassium nitrate (BPN) granules. The set-up was similar to that to be employed in the P/N 3802019 Igniter except that only 5 grams of BPN granules were loaded into the velostat bag. The functional set-up comprised a laser diode firing unit, a fifty foot optical fiber trunkline, and the igniter subassembly with its twenty-five foot fiber pigtail. The firing unit provided 690 milliwatts of power at the output of the fifty foot trunkline. Testing was conducted at an outdoor test site; the ambient temperature was approximately 20 degrees Fahrenheit. The laser initiator in the first set-up failed to function when the diode powder was applied. This initiator was replaced with a spare and was subsequently successfully functioned as was the second igniter set-up. In both instances the initiator ignited the BPN pellets through the cellulose acetate buterate tubing.

Failure Analysis

The following preliminary failure modes were established at the time of the functional failure:

- 1) Insufficient or no output from the firing unit
- 2) Frozen condensation at the optical fiber interface resulting in high loss and insufficient power to the initiator
- 3) Initiator defect (broken fiber, foreign material at fiber/pyrotechnic interface)

The firing unit was checked out immediately following the failure and prior to resuming testing. The output was found to be at the required level. Subsequent examination revealed no defects in the firing unit, i.e., loose wires, etc. The firing unit was eliminated as the cause of the failure.

In the first test, the optical fiber connection between the initiator and trunkline was made outdoors. In addition, the connector ends were cleaned with methanol outdoors immediately before the connection was made. It was thought that water in the methanol might have frozen in the cold temperature and subsequently attenuated the power at the connector interface. Examination of the methanol used showed that less than 0.05% water was present. This was eliminated as a failure cause.

As further test of the above two failure modes, the failed initiator was set up for firing under controlled laboratory conditions. It again failed to fire.

The failed initiator was re-x-rayed to determine if any internal defects were present. None were found. It was then subjected to a teardown analysis. The body was cut at the radial output holes to expose the inner seal over the powder charge. The rear bushing was then removed. Both charges could be seen through the clear body and had been loaded in the correct locations. The output end of the body was soaked in acetone to soften it and the epoxy seal. The seal was then removed, exposing the output charge. Both charges were then removed via an ultrasonically-activated water soak; all residual material was saved. When all pyrotechnic was removed, the optical fiber was checked for loss. Originally at 0.45 Db, it was found to be at 0.59 dB which showed it to be intact. This minor increase is reasonable as no attempt at special cleaning was made to remove any residue. It should be noted that the acceptance criteria was 0.7 dB maximum. A broken fiber was thus eliminated as a cause of the failure. The residual material from the cleaning operation was then examined. Foreign material was found. This object, 388 microns in diameter, appeared to be either a thin film of epoxy or flake of polycarbonate with boron/red lead

embedded on its surface. Either could have been present with the epoxy coming from the gluing of the fiber ferrule to the body and the polycarbonate from the body machining operation. With this lot of assemblies, the fiber face was not examined just prior to loading, so it is not possible to prove/disprove this theory. Loss testing with a thin film of epoxy over the fiber face showed an increase from 0.54 dB to 2.16 dB on a sample fiber; this would have brought the power at the fiber/pyrotechnic interface to 80% of the all-fire level. A higher loss would be anticipated with a flake of polycarbonate at that interface.

During the manufacture of the deliverable units, operators noticed that flakes of polycarbonate were present within the initiator body and in fact were adhering to the fiber ferrule when it was inserted. These flakes were due to the machining operation and had not been removed by two water washes.

It was concluded that the most likely cause of failure was the presence of a polycarbonate shaving at the fiber/pyrotechnic interface which prevented full power from reaching the first fire charge. The following corrective actions were instituted for the manufacture of the deliverable units;

- 1) All plastic parts were cleaned with compressed air to remove residual plastic shavings.
- 2) A QC visual inspection point was added to the manufacturing lot traveler to check for contamination at the fiber face just prior to loading.
- 3) A second fiber loss check was included at the subassembly level after the housing and fiber ferrule were mated.

IV. Laser Initiation Of the 48-Inch Test Motor

Laser Initiator Demonstration at Igniter Production facility.

The laser initiators were next integrated into the 48-inch motor test program. First it was demonstrated that the system worked by firing 1 squib by itself at the igniter production facility. The Bag Igniter was redesigned to accommodate the laser initiator as depicted in figure 13. Laser initiation of the bag igniter was demonstrated in an R&D firing. With the successful demonstration of the squibs and the bag igniter, full confidence in the system had been achieved and lot production of the igniter assemblies was reinstated. Two lots of Igniter assemblies with laser initiators were built and successfully completed Lot Acceptance Testing (LAT), including 4 igniter firings.

Laser Initiator System Checkout / First Firing at Test Facility (MSFC).

Detailed sequencing procedures for testing checkout and live operation at the test facility were prepared and reviewed. When the procedures were approved the PLDFU and ETS was installed at the test facility. The laser energy sensor meter was attached to the ETS. Full motor firing sequencing was demonstrated and verification of the laser system operation was accounted for by registering laser energy on the laser energy sensor meter. When proper set up and system operation had been verified, actual pyrotechnic operation was demonstrated by firing 3 laser initiators. Each firing was performed using full rocket motor firing procedures. On April 10, 1991 the first 48-inch rocket motor initiated by a laser ignition system was fired. This firing also has the distinction of being the first laser initiated large rocket motor firing at Marshall Space Flight Center.

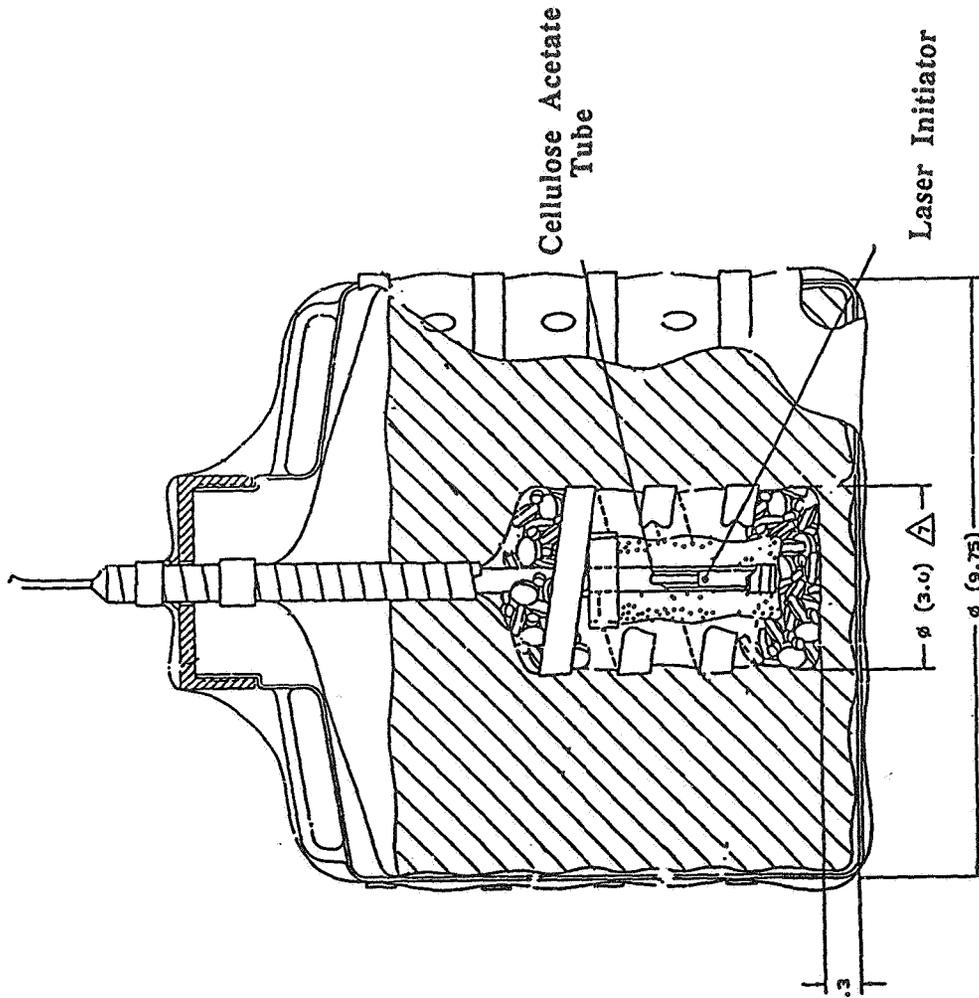


Figure 13

Laser Initiated Design

This page intentionally left blank.

18p
47507-
1993010953

**LASER DIODE IGNITION ACTIVITIES
AT SANDIA NATIONAL LABORATORIES**

**J. A. Merson, F. J. Salas, W. W. Chow
J. W. Clements, and W. J. Kass**

**Sandia National Laboratories
Albuquerque, NM 87185**

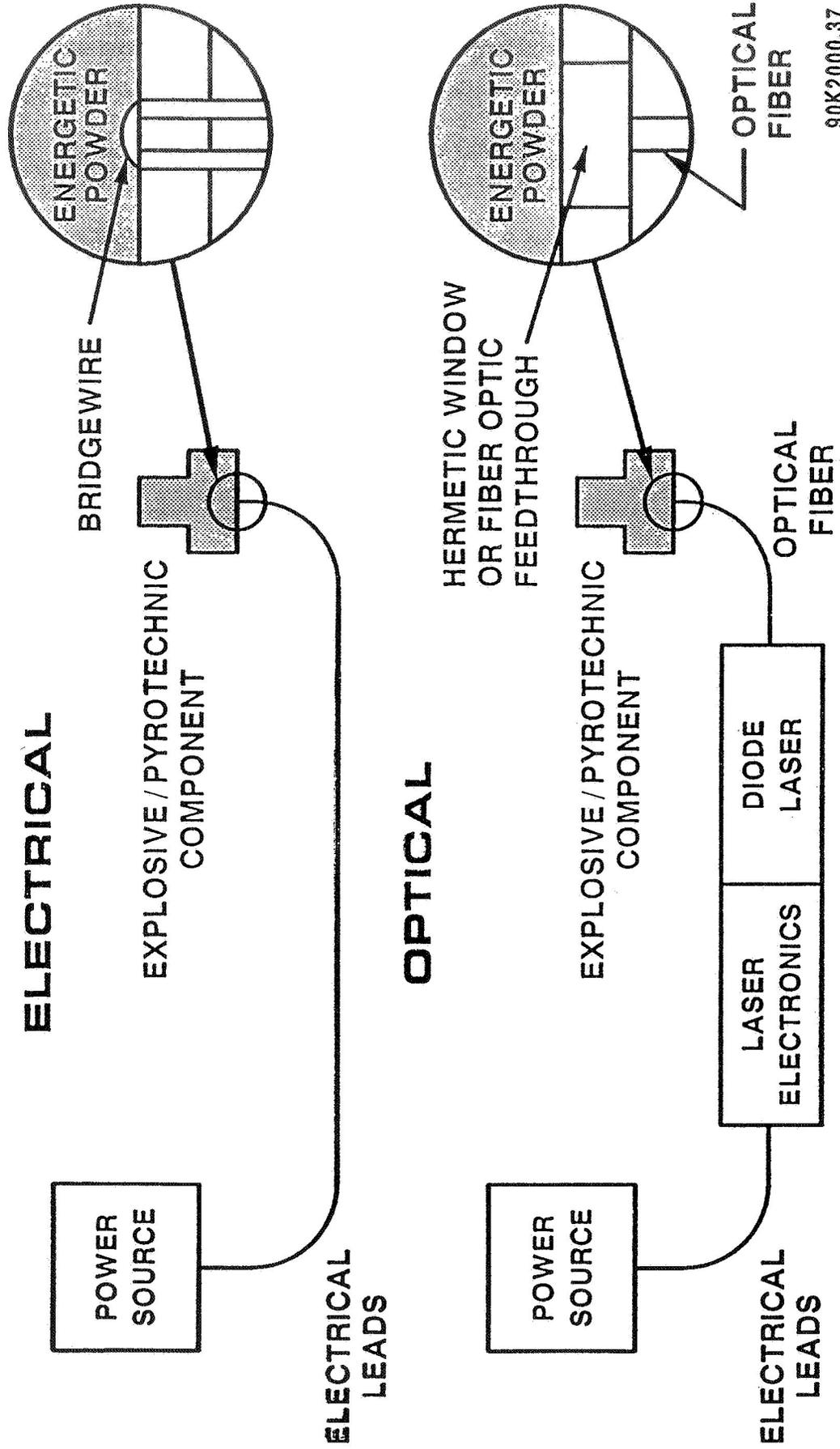
**Presented to
NASA/DOD/DOE Pyrotechnics Systems Workshop
June 9-10, 1992**



SANDIA NATIONAL LABORATORIES

Approved for public release; distribution is unlimited.

IGNITION SUBSYSTEMS



WHY?

ENHANCED SAFETY



SANDIA NATIONAL LABORATORIES



Optical Ordnance Power Densities in W/cm^2

	Laser Diode Ignition (LDI)	Pulsed Laser Ignition (PLI)	Direct Optical Initiation (DOI)
Threshold	10^3	10^5	10^9
Operational	10^4	10^6	10^{10}
		Thermal Ignition	Shock Initiation



LOW ENERGY OPTICAL ORDNANCE PROGRAM

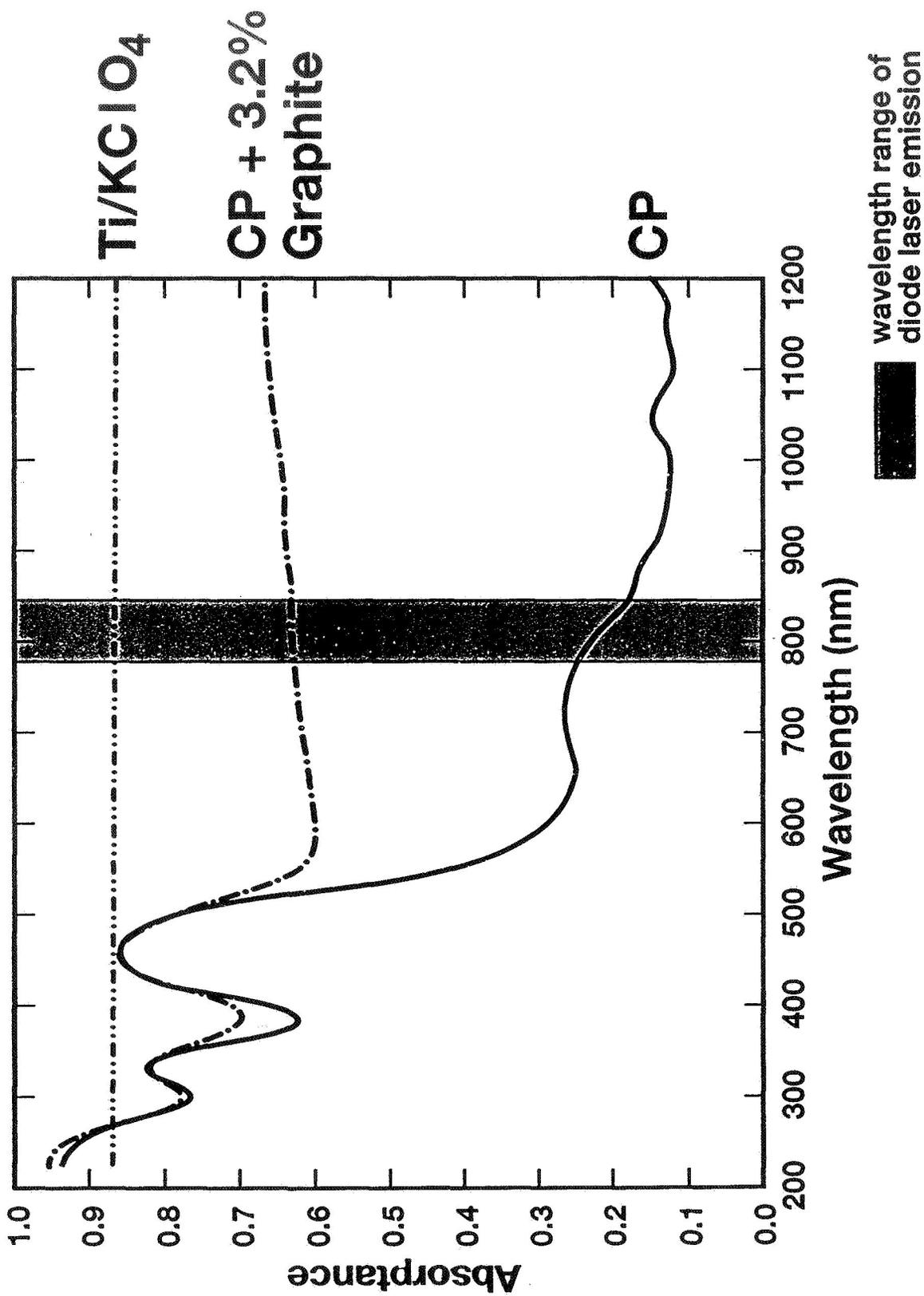
- OBJECTIVE:** Develop optically ignited devices to replace low energy, hot wire igniters, detonators, and actuators.
- CONCEPT:** Transmit optical energy from a laser source to an explosive or pyrotechnic via a fiber optic. The fiber is coupled to the powder through a hermetically sealed window, fiber feedthrough or a reimaging lens window system.
- ADVANTAGES:** The absence of a bridgewire and electrical leads eliminates powder/bridgewire interface decoupling and corrosion concerns. No fire, CAF, ESD, EMR, and IR concerns are reduced.
- Input energy required is comparable to hot wire devices.



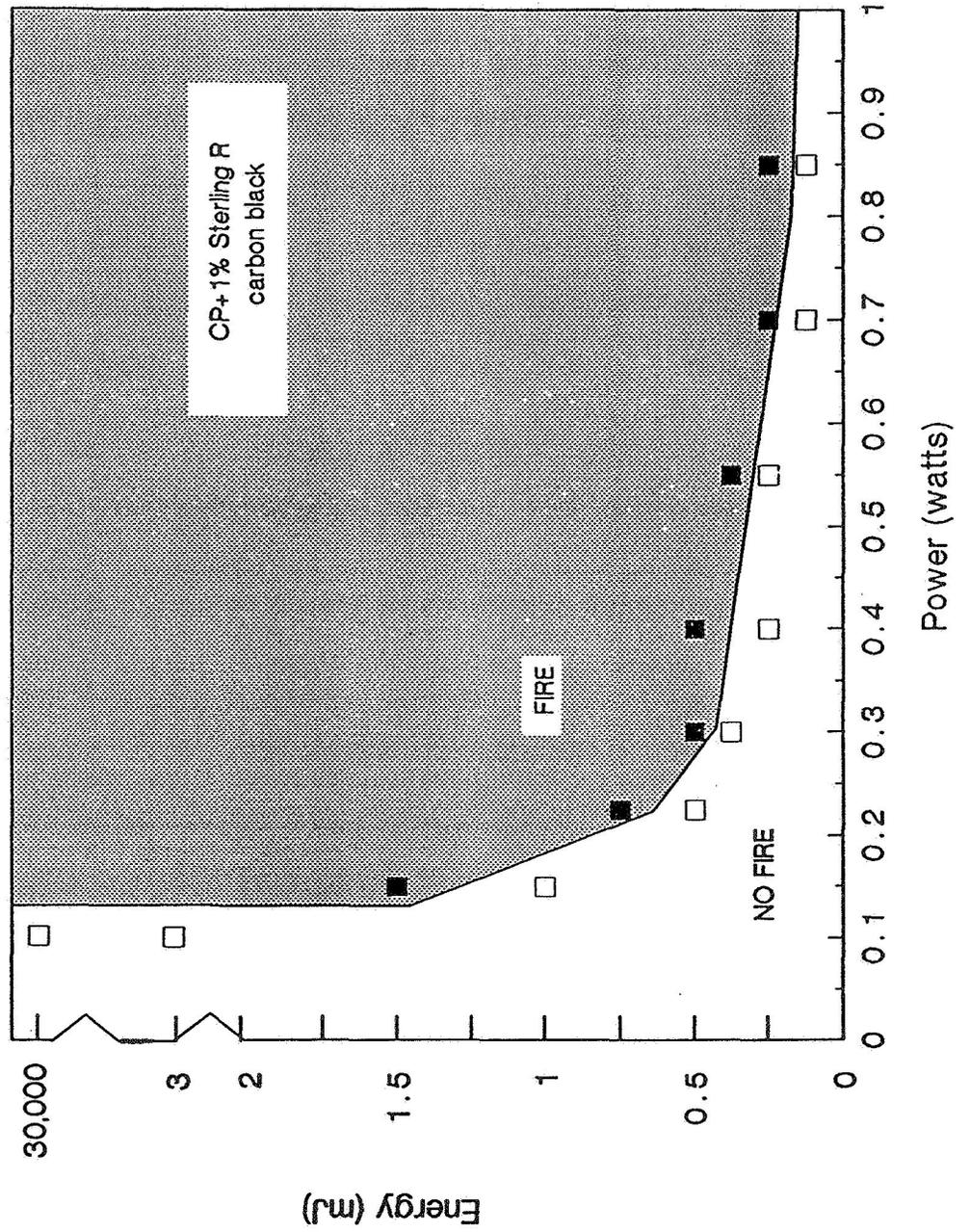
OPTICAL IGNITION FACTORS

- Energetic Material Characteristics:
 - Optical Absorptance at Laser Wavelength
 - Ignition Temperature
 - Thermal Conductivity
- Laser Energy Delivery:
 - Pulse Width and Height
 - Spot Size
 - Wavelength
- Optical Header Properties:
 - Thermal Conductivity
 - Beam Divergence
 - Powder Confinement

The absorbance of CP near 800 nm can be enhanced by adding dopants



LASER DIODE IGNITION PROJECT POWER DEPENDENCE OF DOPED CP



System Operational Electrical Requirements



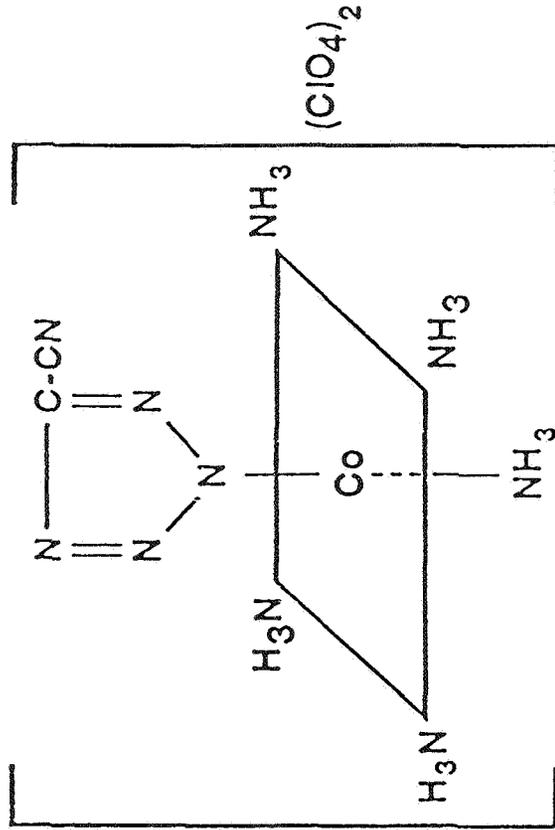
Device	Voltage (V)	Current (A)	Pulse Width (ms)	Energy (mJ)
SNL hot wire -- CP	3.5	3.5	1.75 ^a	21
SNL hot wire -- Ti/KClO ₄	3.5	3.5	1.75 ^a	21
SNL hot wire -- Barium Styphnate	2.5	0.56	4 ^a	5.6
LDI -- CP (doped)	3.0	3.0	0.88 ^b	7.9
LDI -- Ti/KClO ₄	3.0	3.0	1.76 ^b	16

^awire burn out time

^bthree times an ignition charge function time at 0.85 watts laser power



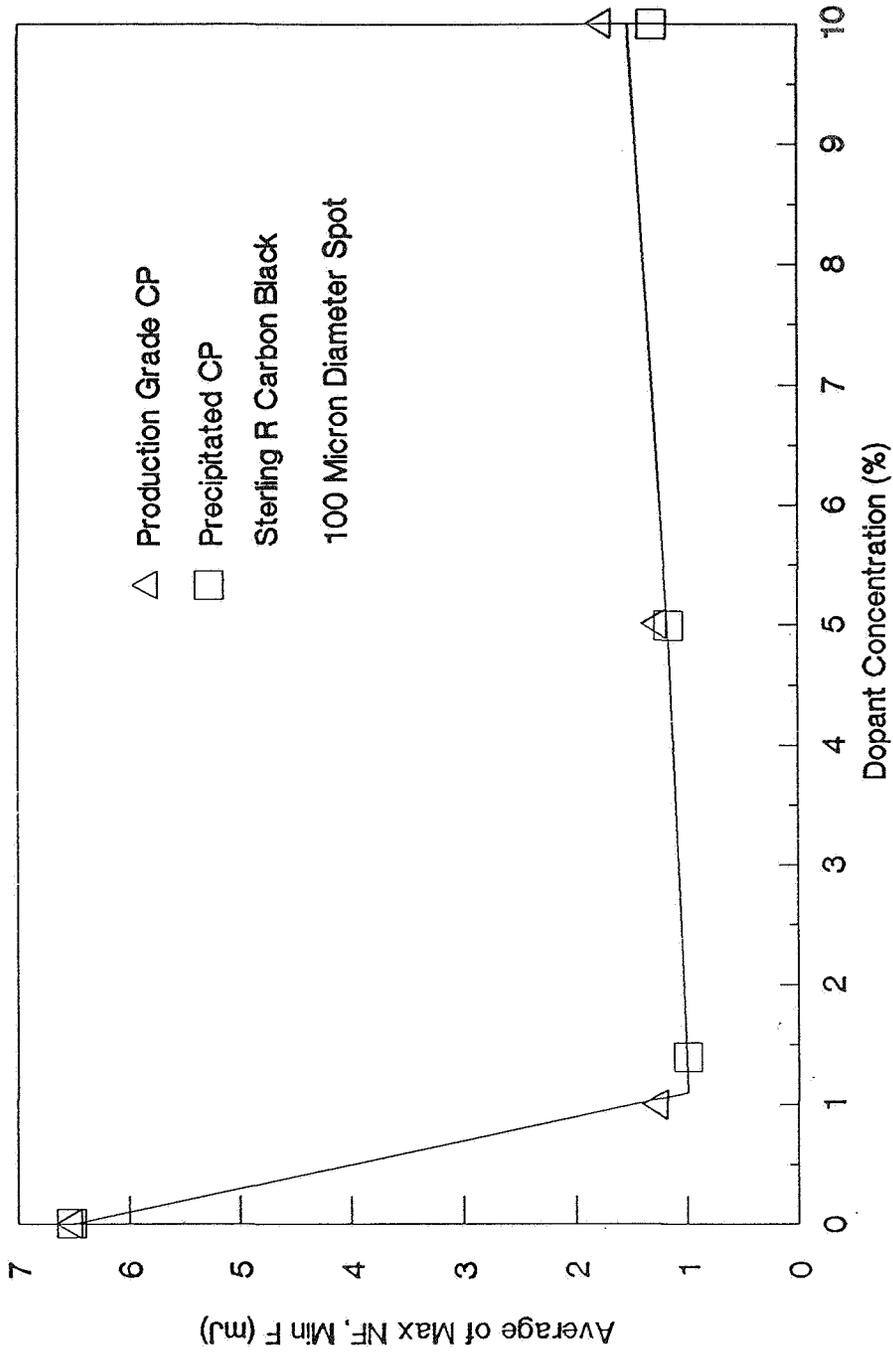
THE DDT EXPLOSIVE, CP



2-(5-cyanotetrazolato)pentaamminecobalt(III)
perchlorate (CP)

Particle size:
production grade 15 μm
precipitated 4-6 μm

DOPANT CONCENTRATION EFFECTS FOR DIFFERENT CP PARTICLE SIZES





Zr/KClO₄ Optical Ignition Thresholds

Thresholds

Ambient (20 C)	Liquid Nitrogen (~196 C)
Highest no-fire	Highest no-fire
Lowest fire	Lowest fire
3.0 mJ - 3.25 mJ	3.0 mJ - 5.0 mJ*

Density = 2.7g/cc (10 Kpsi loading pressure)

100 micron fiber

10 ms pulse width

* Limited number of units tested



LDI Liquid Nitrogen Test Results

Units fired at 77 K or -196 C

<u>Header Type</u>	<u>Energy Levels</u>	<u>Results</u>
Sealed Fiber Header	1.8/3.0 mJ	No Fire/Fire

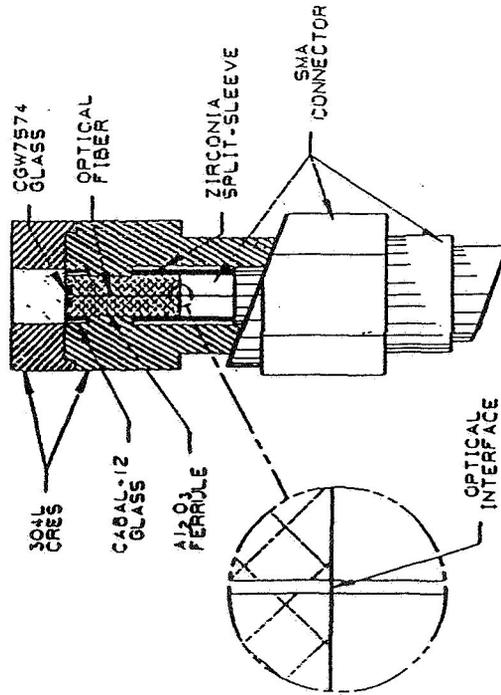
Powder--CP/1% Carbon Black

Typical Threshold at Ambient is 1.25 - 1.50 mJ



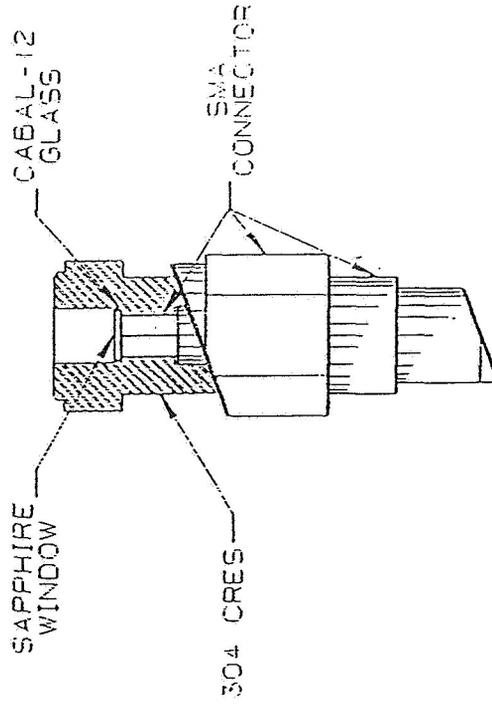
Electrostatic Discharge Testing

CONNECTOR-READY OPTICAL FIBER WINDOW SEAL



- 2 ea. CP
- 2 ea. Zr/KClO₄

CONNECTOR-READY SAPPHIRE WINDOW SEAL



- 2 ea. CP
- 2 ea. Zr/KClO₄

Both Header Types Survived The Sandia Severe Electrostatic Tester (Fischer Model)
With a 25 KV Input Pulse

SANDIA LOW ENERGY OPTICAL ORDNANCE PROGRAMS

MAST (Multiple Application Surety Technology)

Baseline LDI Subsystem

STEP (Stockpile Transition Enablement Program)

Family of LDI Components for Future Applications

FOCAL POINT

Baseline LDI Subsystems as part of Other Adv. Dev. Projects

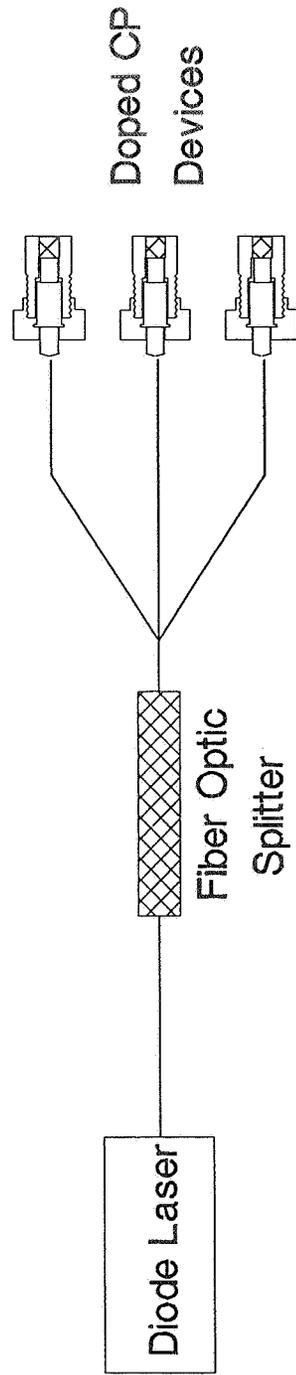
INTERNAL ADVANCED DEVELOPMENT



SANDIA NATIONAL LABORATORIES



Laser Diode Ignition of 3 ea. Devices

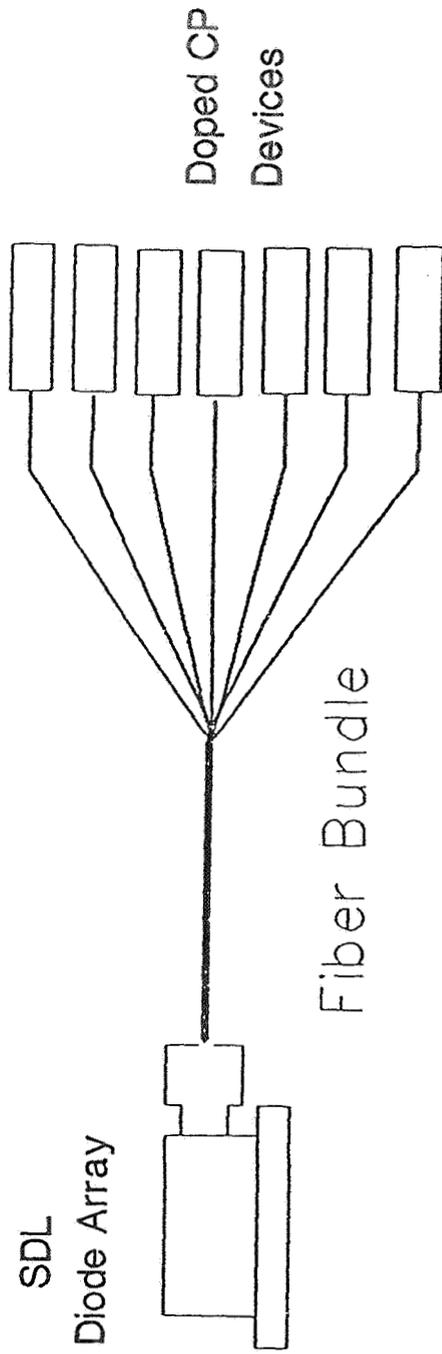


Leg	Energy Level (mj)	Function Time (ms)
1	2.13	1.63
2	2.08	1.80
3	2.03	.892

- 1 Watt, 10 ms pulse out of Diode Laser



Laser Diode Ignition of 7 ea. Devices



Leg	Energy Level (mj)	Function Time (ms)
1	2.74	3.00
2	3.16	2.10
3	2.79	2.40
4	2.59	3.26
5	3.10	1.81
6	3.80	1.73
7	2.85	2.11

SUMMARY

Low energy ignition represents an effective replacement for hotwire devices.

The removal of the bridgewire eliminates ESD and EMR concerns.

Multiple explosive functions have been demonstrated using both a single laser diode and a laser diode array.

Feasibility of low energy optical ordnance has been demonstrated and the technology is now ready for full scale engineering development.



SANDIA NATIONAL LABORATORIES

1993010954

493041

68

N 9 3 - 2 0 1 4 3

LASER-BASED FIRING SYSTEMS FOR PROMPT INITIATION OF SECONDARY EXPLOSIVES

Kent D. Meeks and Robert E. Setchell
Advanced Weapon Systems Department
Sandia National Laboratories
Albuquerque, New Mexico

ABSTRACT

Motivated by issues of weapon safety and security, laser-based firing systems for promptly initiating secondary explosives have been under active development at Sandia National Laboratories for more than four years. Such a firing system consists of miniaturized, Q-switched, solid-state laser, optical detonators, optical safety switches, and elements for splitting, coupling, and transmitting the laser output. Potential system applications pose significant challenges in terms of severe mechanical and thermal environments and packaging constraints, while requiring clear demonstration of safety enhancements. The Direct Optical Initiation (DOI) Program at Sandia is addressing these challenges through progressive development phases during which the design, fabrication, and testing of prototype hardware is aimed at more difficult application requirements. A brief history of the development program, and a summary of current and planned activities, will be presented.



LASER-BASED FIRING SYSTEMS FOR PROMPT INITIATION OF SECONDARY EXPLOSIVES

FOR FURTHER INFORMATION:

* OPTICAL DETONATOR DEVELOPMENT

SANDIA: STEVEN M. HARRIS, ORG. 2513, 505-844-0949

LANL: DENNIS L. PAISLEY, M-7/P950, 505-667-7837

P.O. BOX 1663, LOS ALAMOS, NM 87545

* LASER DEVELOPMENT

LOUIS S. WEICHMAN, ORG. 2574, 505-844-6500

* OTHER SYSTEM COMPONENTS; PROGRAM ISSUES

KENT D. MEEKS OR ROBERT E. SETCHELL

ORG. 5166, 505-844-1040 (MEEKS)

-3847 (SETCHELL)

SANDIA NATIONAL LABORATORIES
PO BOX 5800, ALBUQUERQUE, NM 87185

**Proposed
System Qualification and Test Requirements
for the
Microlaser Ordnance System**

McDonnell Douglas Electronic Systems Company
St. Louis, Mo 63166

B. A. Stoltz and D. F. Waldo

Laser ordnance systems are handicapped in the procurement cycle due to the lack of documented specifications and qualification requirements. However, the MDESC Microlaser System has been based on current specifications and qualification requirements.

System Level
Range Safety Manual 127-1 (various ranges)
Mil-Std-1576

Squib Level
DOD-83578A (JSC 8060.1)

Control Electronics
Mil-Std-461/462

Hybrid Electronics
Mil-Std-883C

The additional requirements are minimal and can be included in the subsystem specifications. These additions include:

- 1) Verification of power and energy margins at the squib.
- 2) Testing of optical losses within the fiber optic harness.
- 3) Derating criteria for laser diodes/systems.

For this presentation, we will address the applicable requirements from the above documents as well as additional requirements that may be necessary to fully qualify a laser ordnance system.

This page intentionally left blank.

Description of a Thirty-two (32) Output Laser Firing Unit Being Developed for the Phillips Laboratory

Richard G. Hallmark
Lockheed Missiles & Space Co.
Sunnyvale, CA

(Presented by Jerry Callaghan)

(Video Only)

This video presentation provided a description of a thirty-two (32) output laser firing unit being developed for the Phillips Laboratory at Edwards AFB. The unit is capable of initiating twelve single events and twenty simultaneous events. A full built-in test capability is included that measures the energy produced by the laser and verifies the transmissivity of each of the thirty-two fiber optic lines.

PRECEDING PAGE BLANK NOT FILMED

This page intentionally left blank.

UP 1993010955
493044

N 9 3 - 2 0 1 4 4

**Proposed
System Safety Design and Test Requirements
for the
Microlaser Ordnance System**

**McDonnell Douglas Electronic Systems Company
St. Louis, Mo 63166**

B. A. Stoltz and D. F. Waldo

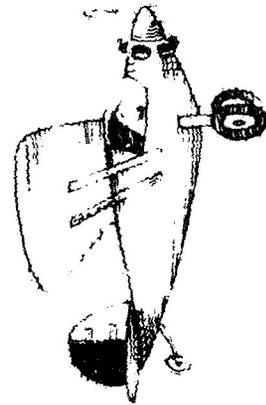
Safety for pyrotechnic ignition systems is becoming a major concern for military. In the past twenty years the stray electromagnetic fields have steadily increased during peacetime training missions and have dramatically increased for battlefield missions. Almost all of the ordnance systems in use today depend on an electrical bridgewire for ignition. Unfortunately the bridgewire is the cause of the majority of failure modes. The common failure modes include: broken bridgewires, transient RF power inducing bridgewire heating, and cold temperatures contracting the explosive mix away from the bridgewire. Finding solutions for these failure modes is driving the costs of pyrotechnic systems up. For example, analyses are performed to verify the system in the environment will not see more energy than 20dB below the "No-Fire" level. Range surveys are performed to determine the operational, storage and transportation RF environments. Cryogenic tests are performed to verify the bridgewire to mix interface. System requirements call for "last minute installation", "continuity checks after installation" and rotating safety devices to "interrupt the explosive train". As an alternative MDESC has developed a new approach based upon our enabling laser diode technology. We believe that Microlaser initiated ordnance offers a unique solution to the bridgewire safety concerns.

For this presentation, we will address, from a system safety viewpoint, the safety design and the test requirements for a Microlaser ordnance system. We will also review how this system could be compliant to MIL-STD-1576 & DOD-83578A, and what additional requirements are needed.

*NASA Aerospace
Pyrotechnic Systems
Workshop*

6/8/92

SYSTEM SAFETY



FLY

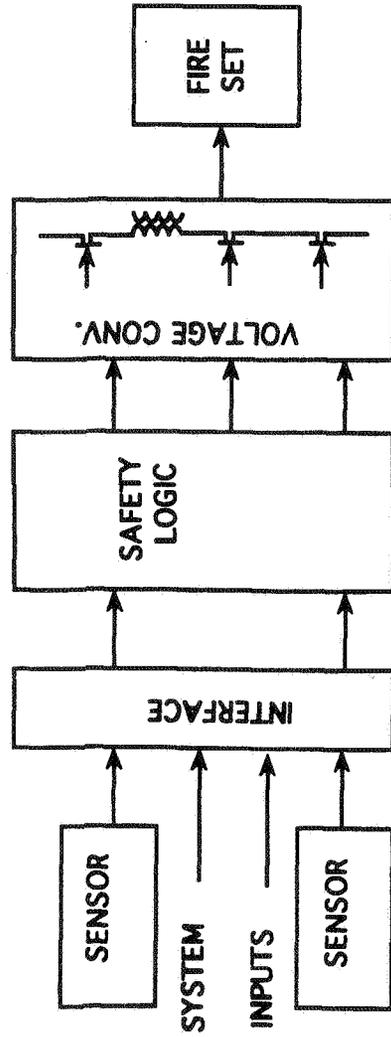


• **MIL-STD-1576, MIL-STD-1901**

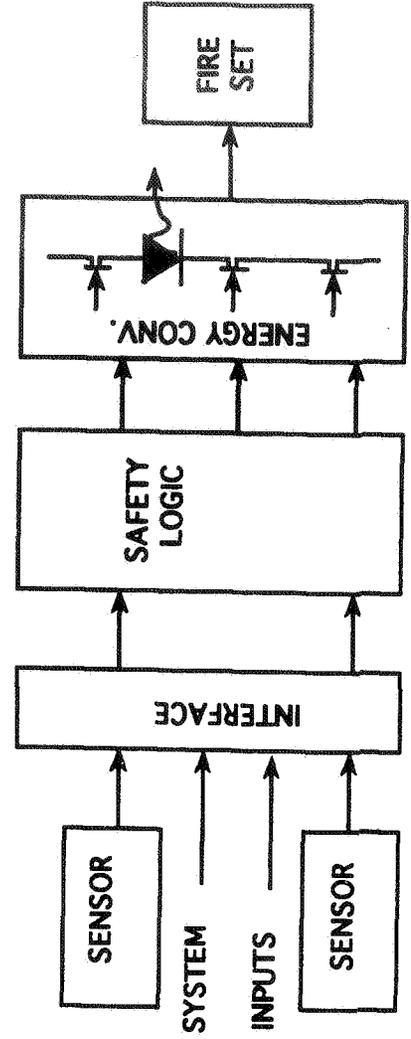
• **Top Level System Requirements**

- **Two independent energy control features**
- **Minimum fire energy not available to the initiator prior to arming**
- **One energy interrupter, controlled by at least two independent safety features to prevent the flow of energy to the initiator**
- **Positive indication of safe condition prior to arming**

Similarity to ESAD

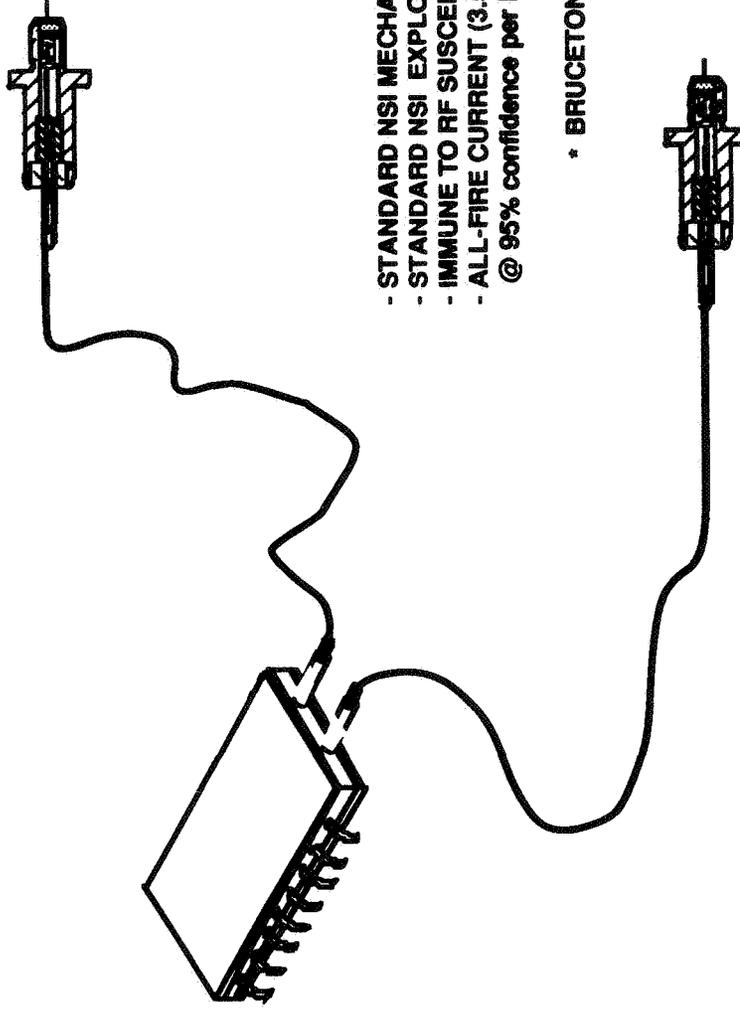


The ESAD
functional block diagram



The Microlaser Safe & Arm
functional block diagram

Simplified Microlaser Initiator System



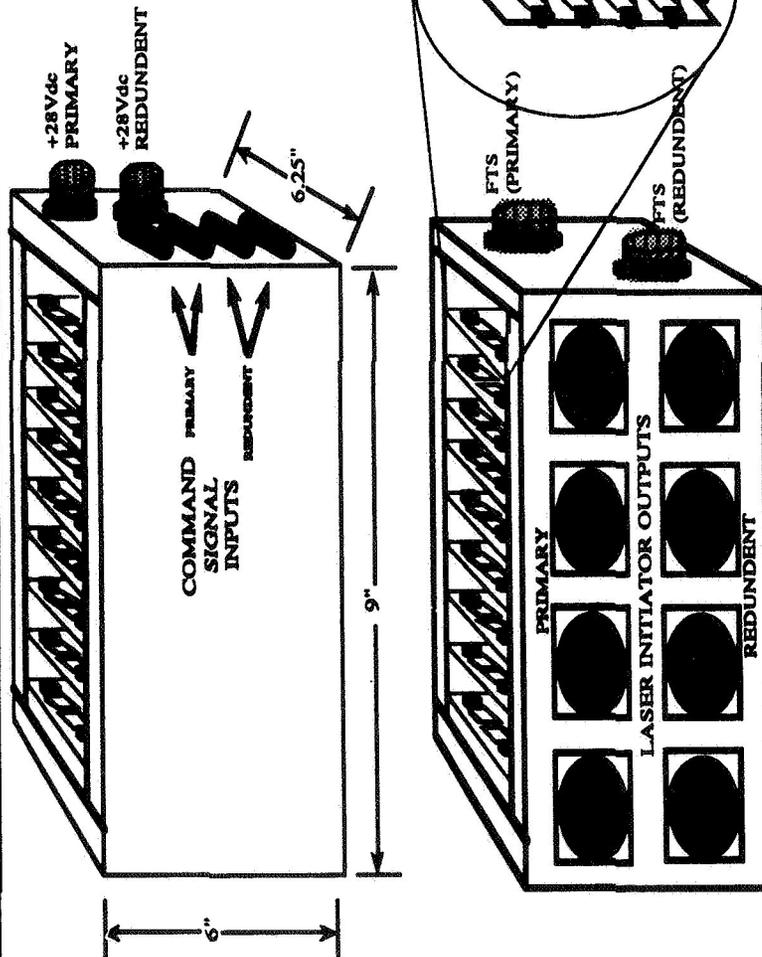
- STANDARD NSI MECHANICAL INTERFACES
- STANDARD NSI EXPLOSIVE MIX (Zr-KClO₄)
- IMMUNE TO RF SUSCEPTIBILITY
- ALL-FIRE CURRENT (3.5 Amps, 0.999 Reliability @ 95% confidence per DOD-E-83578) *

* BRUCETON TEST DATA

MCDONNELL DOUGLAS ELECTRONIC SYSTEMS COMPANY

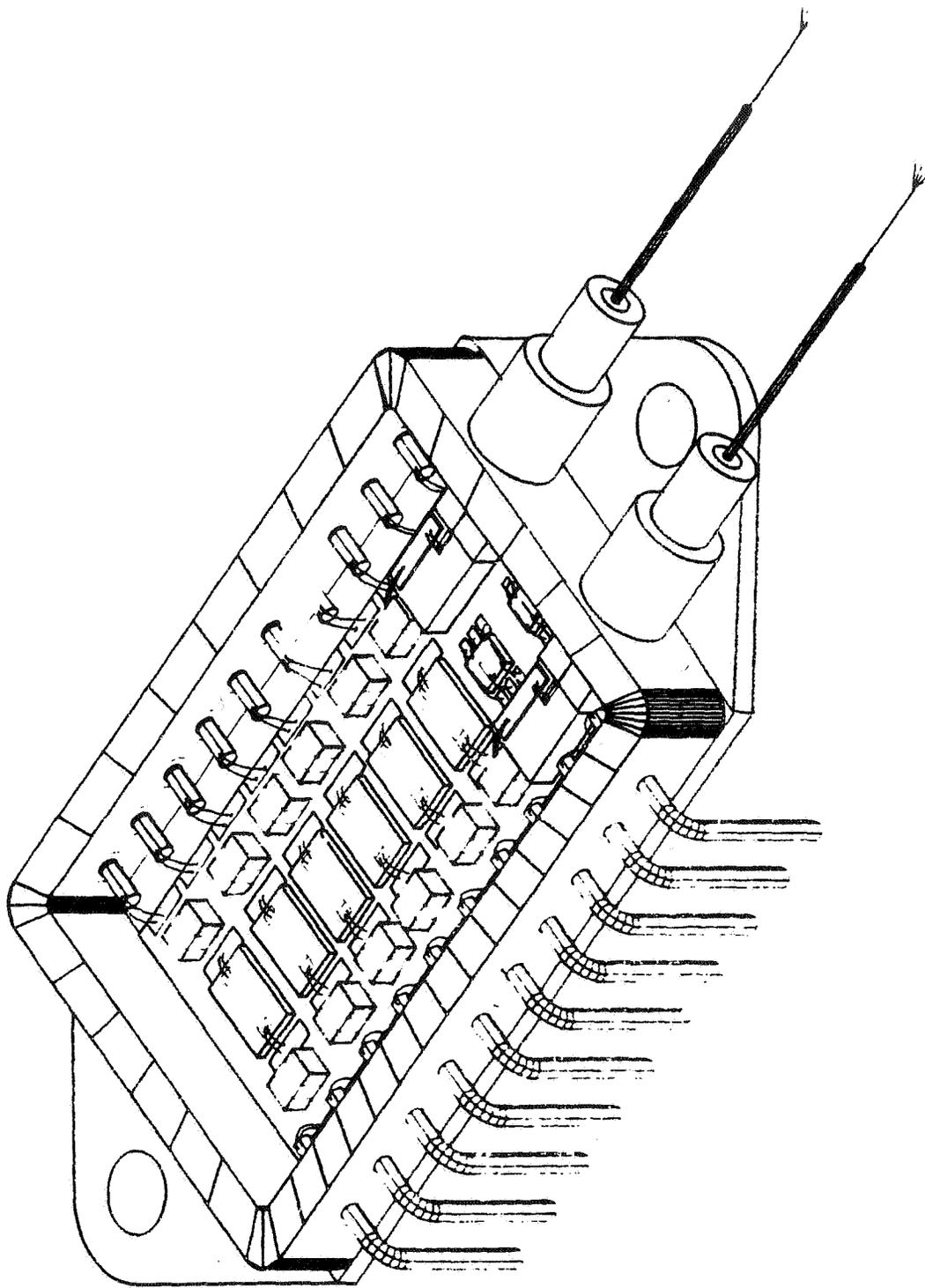
MICROLASER FIRING UNIT

MICROLASER FIRING UNIT
(144 LASER OUTPUTS)



WEIGHT 6.2 lbs

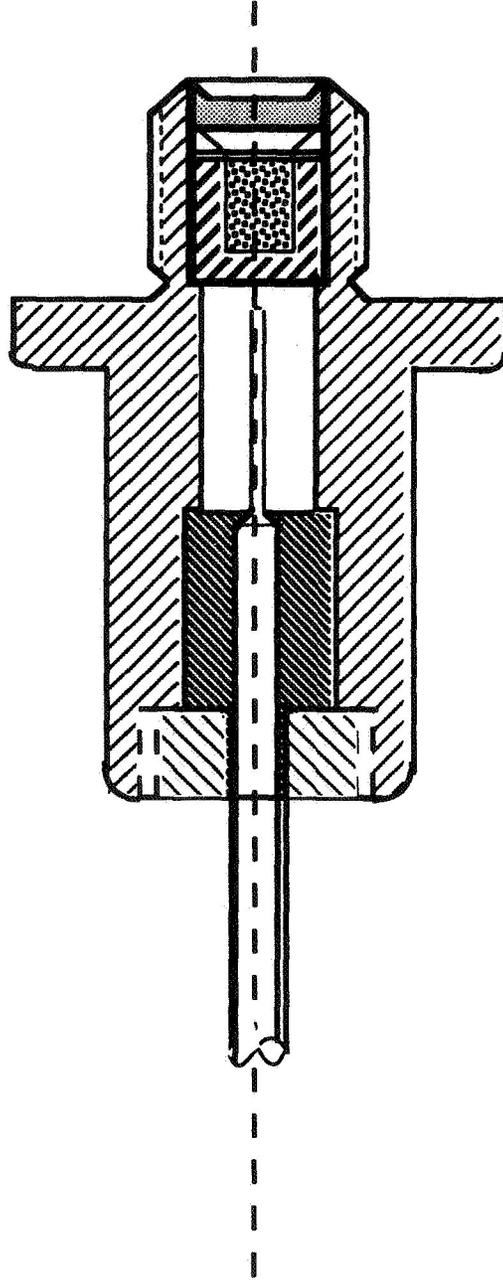
MCDONNELL DOUGLAS ELECTRONIC SYSTEMS COMPANY



Safety Analyses and Tests

- **Failure Modes and Effects Analyses**
 - Circuit Design**
 - Layout Design**
- **Qualification Tests**
 - Hybrid single point failure tests**
 - Environmental tests**
 - Bruceton tests (All-Fire, No-Fire)**
 - Functional Tests**
- **Acceptance Tests**
 - Functional Tests**
- **Field Tests**
 - Functional Tests (BIT only)**

LASER INITIATOR



- **Fiber or lens coupling of laser into mix**
- **One Laser diode per initiator**
- **Easily modified for detonating train**
- **Tailor laser diode emission for specified mix**

Initiator Safety Tests

- Derived from DOD-83578A

No-Fire and All-Fire Levels must be based on system operating characteristics (Bruceon Test Method only allows for the variation of a single variable - changing power, pulse width, and duty cycle would provide inaccurate results)

2 1 3

Tests not required

Qualification

Bridgewire Resistance

Insulation Resistance

Acceptance.

Bridgewire Resistance

Static Discharge

Insulation Resistance

Additional tests / inspections

Qualification

Glass to metal seal between the fiber and the initiator

Acceptance.

None

Summary

- **The Microlaser design approach provides an inherent safe design with reduced safety testing without a reduction in reliability or performance**
- **Plan to verify Microlaser Ordnance system cannot inadvertently cause premature arming**
- **Working with Special Devices Inc. (SDI) on Explosive / Detonation trains tailored to Microlaser characteristics**
- **Need to quantify detonation transfer reliability**



TORRANCE · CALIFORNIA

8P
493045

N 9 3 - 2 0 1 4 5

1993010956

Laser Diode Ignition Characteristics of Zirconium Potassium Perchlorate (ZPP)

By
Jerry Callaghan and Scot Tindol

ABSTRACT

Hi-Shear Technology, Corp. (HSTC) has designed and built a Laser equivalent NASA Standard Initiator (LNSI). Langlie tests with a laser diode output initiating ZPP have been conducted as a part of this effort. The test parameters include time to first pressure, laser power density requirements and ignition time. The data from these laser tests on ZPP are presented.

INTRODUCTION

This paper describes a part of an effort conducted by HSTC to design and build a Laser equivalent NASA Standard Initiator (LNSI). There is a need to establish a data base on the interaction between laser energy and pyrotechnic mixtures commonly used in aerospace applications. One of the standard pyrotechnic mixtures being initiated via a laser system is ZPP. The ZPP used in this study has been manufactured by HSTC (HSTC P/N 939321-003) since 1964 for use in the NSI.

There have been many efforts and studies using solid-state laser systems (Nd:glass, Nd:YAG, RUBY and others) as initiation sources. A steady increase in technology relating to high power laser diodes has resulted in the production of laser diodes with sufficient output power for initiation of explosive materials. One drawback in the technology of laser initiation is the lack of published data regarding experimental procedures and test results. Publication of this type of information in proper format would greatly help designers of new and existing systems in the selection and incorporation of lasers as an initiation source.

Laser initiation systems offer many desirable features not found in current ordnance systems. These features include the virtual elimination of inadvertent initiation by stray voltages, electromagnetic radiation (EMR) and electrostatic discharge (ESD). The inherent safety of a laser initiation system allows for the installation of the ordnance during the assembly of ordnance functioned devices resulting in less time required during installation or integration of the final assembly.

This paper will describe the experimental procedure used to obtain specific statistical data on laser diode initiation of ZPP. This testing was performed under laboratory conditions at HSTC and was funded under IR&D program number 970011.

Approved for public release; distribution is unlimited.



TORRANCE · CALIFORNIA

EXPERIMENTAL PROCEDURE

The laser diode used for these tests was manufactured by Laser Diode, Inc. This diode operates at 820nm nominal and has an output of 750mW into a 0.29 Numerical Aperture (NA), 100 micron core fiber optic. This fiber optic cable is a hermetic integral pigtail installed by the manufacturer. The fiber optic cable was terminated at HSTC with an ST-type connector. The laser diode output was controlled by a Spectra Diode Lab Model 822 laser diode driver. The test setup is shown in Figure 1.

As the primary objective of this testing is to provide specific data on the initiation of ZPP with a laser diode, the spot size must be a constant. This was accomplished by pressing the ZPP directly on the fiber optic which holds the spot size constant at 100 microns. This test method also allows for the energy output to be measured directly at the pyrotechnic interface. To preserve the laser diode pigtail from damage when the ZPP initiated and allow for easy loading of the test initiators, an interface fiber optic cable assembly was used. This interface cable was terminated on one end with an ST-type connector for mating with the laser diode and an SMA connector for attaching the test cartridge on the other. The test initiator is shown in Figure 2.

The ST-type connector is a precision fiber optic connector which minimizes the interconnect losses. Both the test initiator and the energy meter accept the SMA connector. An O-ring is included in the SMA to provide a pressure seal when the test initiator is functioned. The interface cables were labeled and calibrated before the Langlie was begun to insure the repeatability of the interconnect loss through several mate/de-mate cycles. The actual loss due to this interconnect was not a concern for this series of tests. The calibration of the interface cables was to insure the losses were repeatable (within measurement error) over multiple mate/de-mates with the laser diode pigtail.

As stated above, the ZPP was consolidated directly onto the fiber optic face. A nominal 120 milligrams of pyrotechnic was loaded into the cartridge in two equal increments. After several pre-test firings it was found the cartridge function characteristics were not affected by the deletion of a closure. The omission of the closure during loading allowed for quicker testing.

The energy levels were monitored by a Photodyne Model 66XLA optical power/energy meter with a Model 350 integrating detector head. This detector head has adapters to allow any style of fiber optic connector to be accurately placed into the head, including a bare, unterminated fiber optic. The values calculated during the Langlie testing were measured at the SMA connector before installation into the test initiator. The various output values were obtained by varying the current supplied to the laser diode. The test initiator was then attached to the SMA connector and the ZPP loaded.

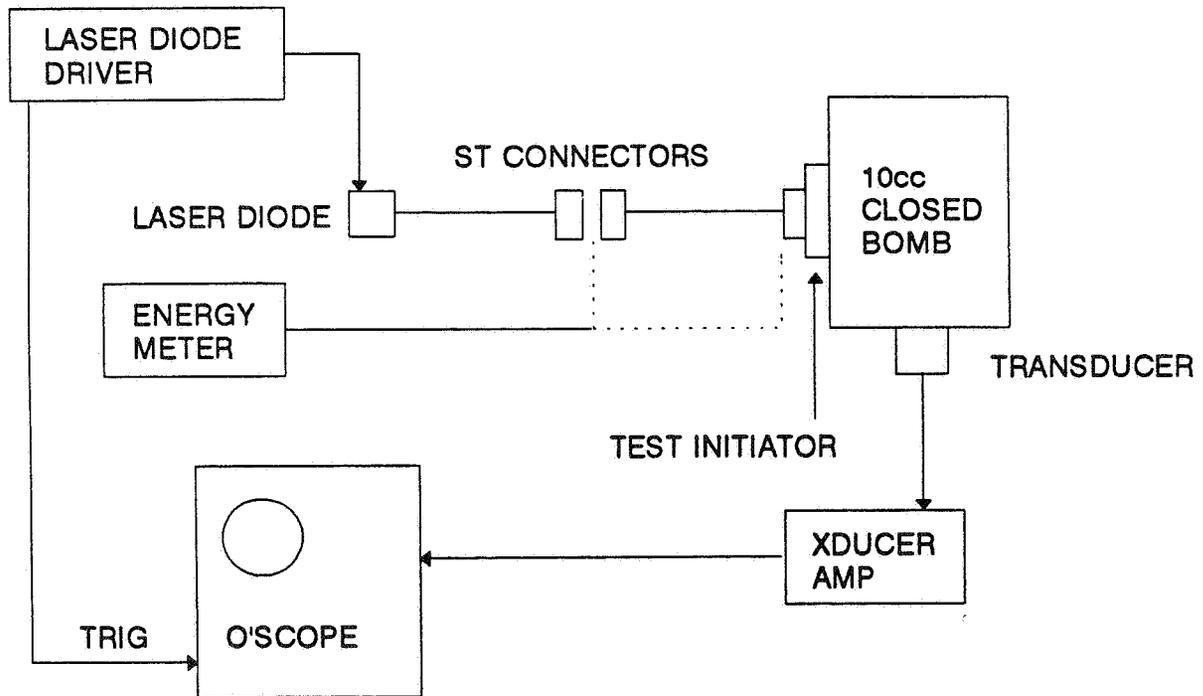


Figure 1
Test Set-up



TORRANCE · CALIFORNIA

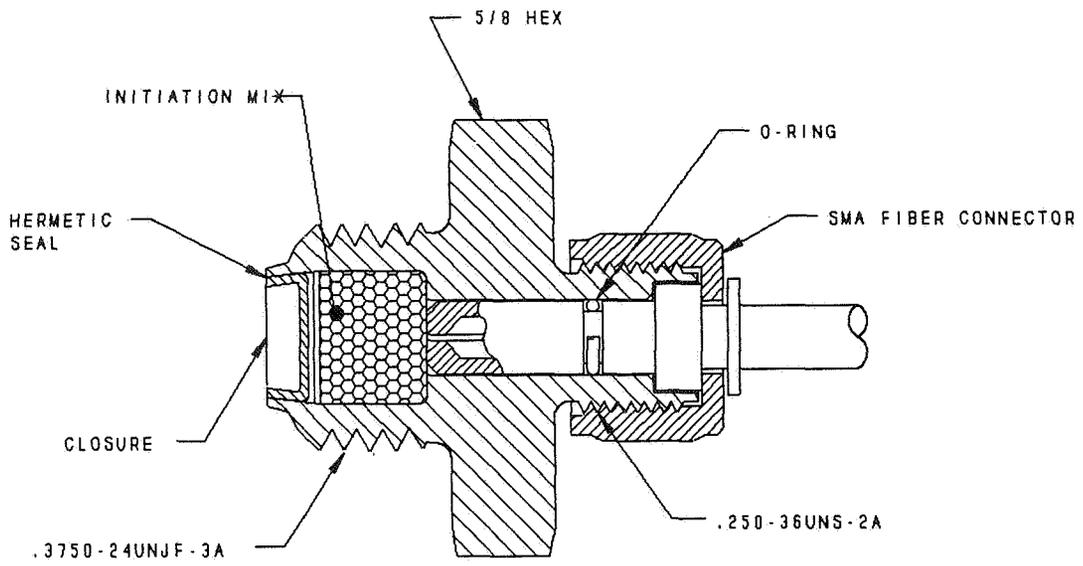


Figure 2

Laser Test Initiator



TORRANCE · CALIFORNIA

The test initiator was installed into a 10cc test bomb equipped with a pressure transducer to monitor pressure and function time. All tests were performed at room ambient temperature and humidity. A total of 30 trials were used in the test series. Of these 30 devices a total of 14 devices functioned. This even split between fire and no-fire indicates proper bracketing of the energy. A typical pressure verses time curve is shown in Figure 3. A typical NSI output is shown in Figure 4. The output monitor from the laser diode driver was used to trigger the O'scope and is used to find the function time.

TEST RESULTS

The Langlie statistical approach has an advantage over other test methods used in determining the function characteristics of ordnance devices. The Langlie method finds both the mean and standard deviation efficiently without requiring a detailed test procedure as does a Bruceton. An upper and lower limit of the mean firing point are chosen and the Langlie testing begins halfway between these two points. As the test continues the next level selected is calculated on the response of the previous firings - fire or no-fire. The statistical results from the Langlie test are shown in Table 1.

For information purposes the test initiators that did not function at the Langlie stimulus were fired at the calculated 99.9% at 95% confidence point. All 16 test initiators functioned.

The function time of an NSI when fired with 3.5 Amps constant current is 1.0 mSecond minimum and 6.0 mSeconds maximum. The maximum jitter in a test series is 3.5 mSeconds. The 1.0 mSecond minimum time is based on a NASA study which followed the function times of NSI lots over several years. No NSI's were found to function less than 1.0 mSecond when fired with 3.5 Amps. The LNSI function times ranged from 0.39 mSeconds to 2.5 mSeconds. This discrepancy in the minimum function time is not a true comparison to the NSI as the LNSI does not have a bridgewire.

CONCLUSIONS

The use of laser diodes as the ignition source of ZPP is a viable approach. Conventional testing of these devices produces repeatable results. The current laser diode technology can supply twice the all-fire energy into a 100 micron core fiber optic cable.

Additional studies planned by HSTC include the environmental dependance (temperature, shock and vibration) on the all-fire energy level. Other analysis includes a Taguchi test on the assembly process/procedures involved in the manufacture of the LNSI. Testing is planned on other pyrotechnic materials as well as secondary explosive materials.



TORRANCE · CALIFORNIA

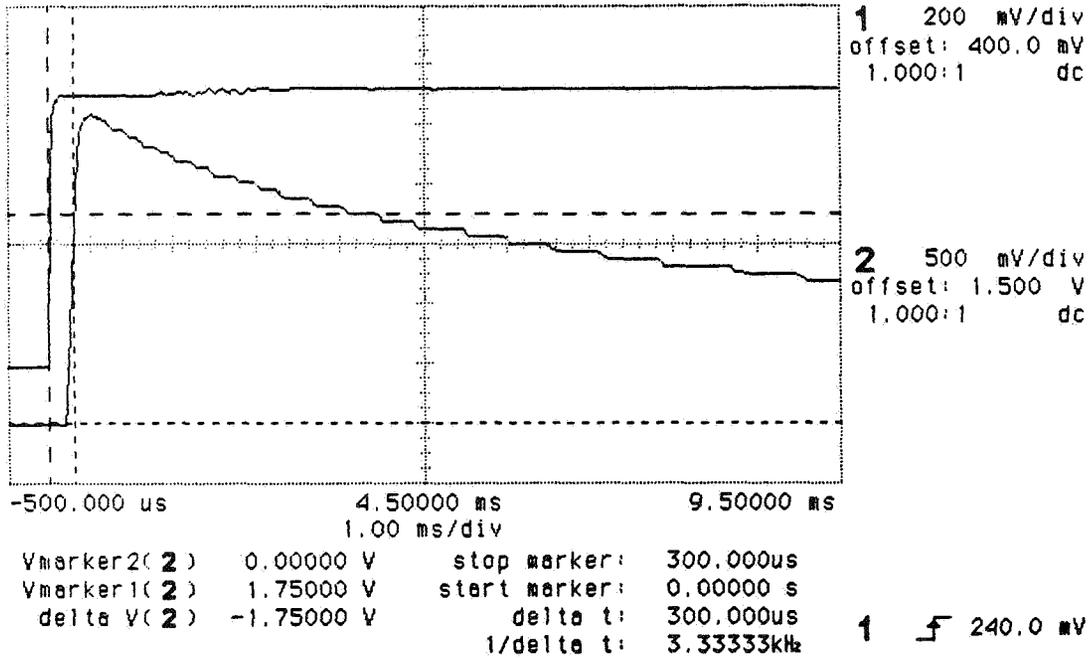


Figure 3
Typical LNSI Pressure Curve
Channel 2 Calibration 300 psig/Volt



TORRANCE · CALIFORNIA

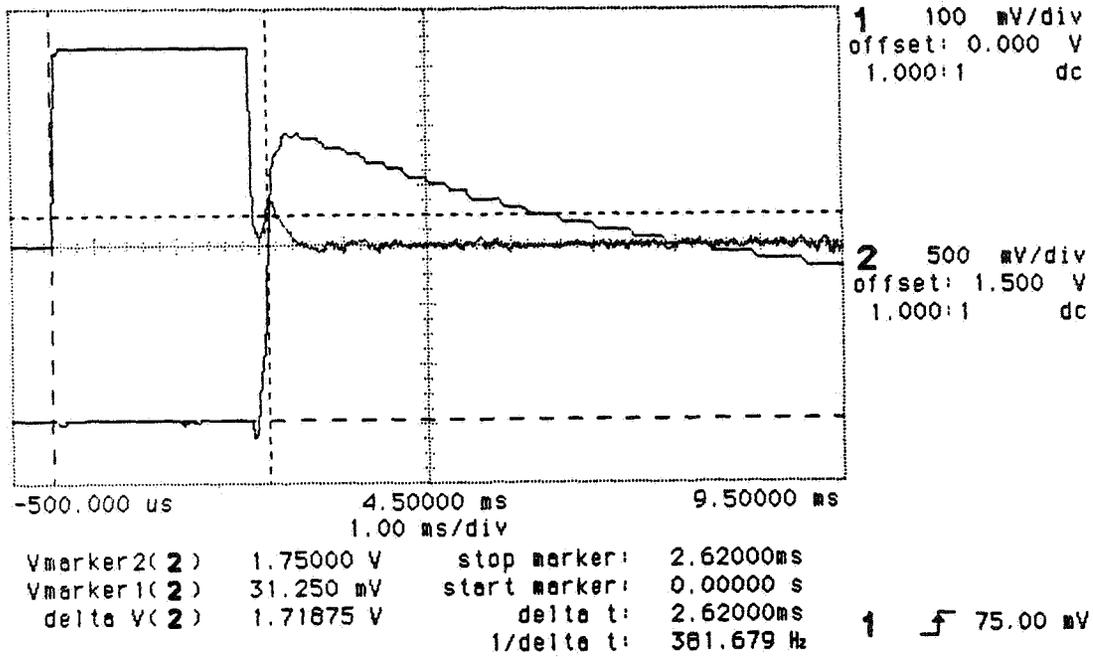


Figure 4
Typical NSI Pressure Curve

Channel 2 Calibration 300 psig/Volt



TORRANCE · CALIFORNIA

TABLE 1
LANGLIE TEST RESULTS

MEAN FIRE (50%)	1.24 mJoules
SIGMA	0.12mJoules
ENERGY DENSITY	15.75 J/CM2

NO-FIRE POINT	CONFIDENCE	ENERGY
0.1%	90%	0.27 mJoules
0.1%	95%	0.23 mJoules
0.1%	99%	0.18 mJoules

ALL-FIRE POINT	CONFIDENCE	ENERGY
99.9%	90%	5.65 mJoules
99.9%	95%	6.56 mJoules
99.9%	99%	8.65 mJoules

ADVANCES IN LASER DIODES
FOR
PYROTECHNIC APPLICATIONS

Richard R. Craig
Spectra Diode Laboratories

199300957
493054
24p

N93-20146

Approved for public release; distribution is unlimited.

OUTLINE

BACKGROUND ON LASER DIODES

DAMAGE LIMITS

TEMPERATURE STABILITY

FIBER COUPLING ISSUES

SMALL FIBER RESULTS (100 MICRON)

PACKAGE GEOMETRY

ELECTRO-OPTICAL PROPERTIES

TEMPERATURE STABILITY

LARGE FIBER RESULTS (400 MICRON)

LASER BAR PERFORMANCE

PACKAGE GEOMETRY

ELECTRO-OPTICAL PROPERTIES

POWER LIMITS FOR LASER DIODES

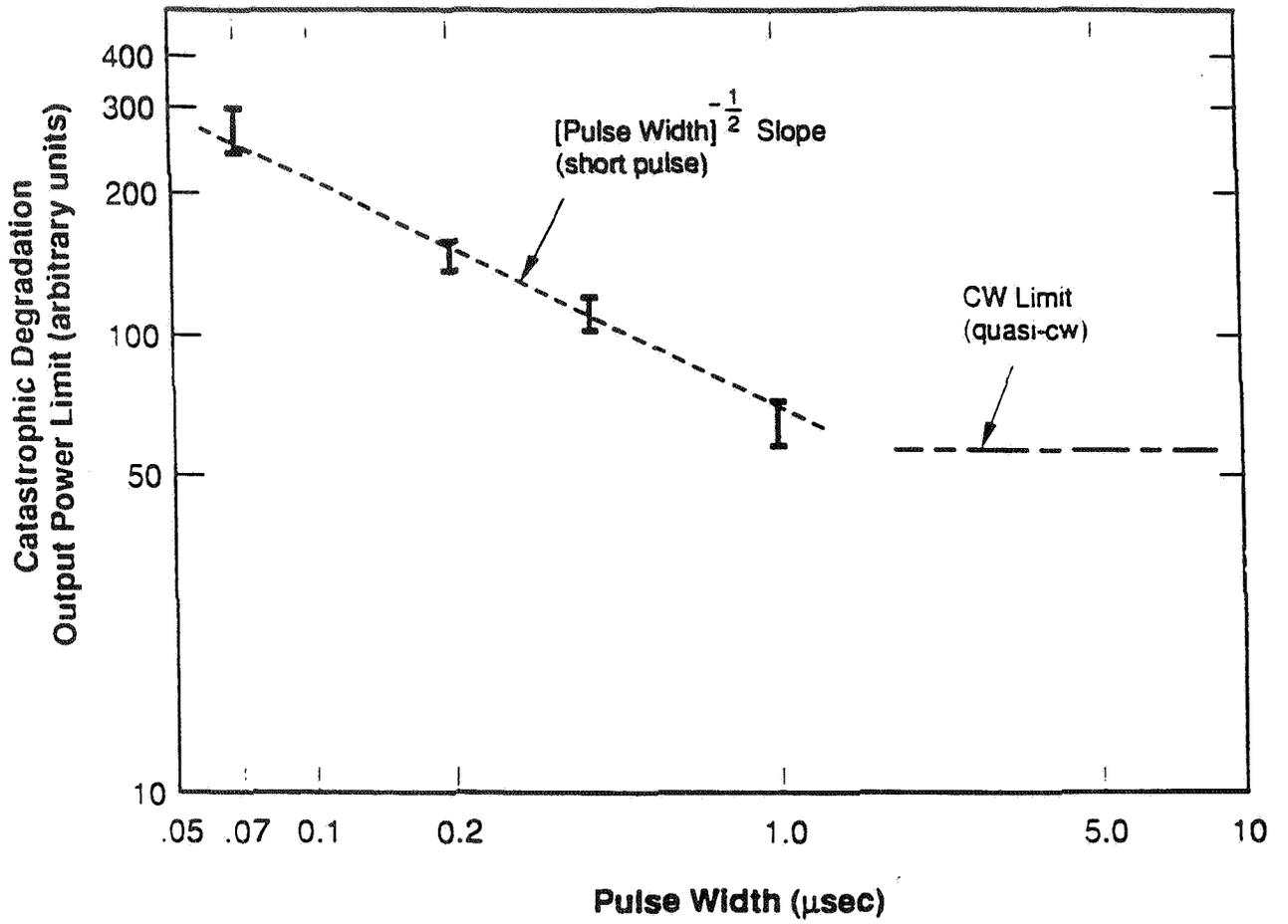
FOR OPTICAL PULSES LONGER THAN 1 MICROSECOND FACET DAMAGE DEPENDS ON OPTICAL POWER NOT OPTICAL ENERGY.

FOR WELL "PASSIVATED" LASERS DAMAGE LIMIT APPROXIMATELY 10 MW/cm .

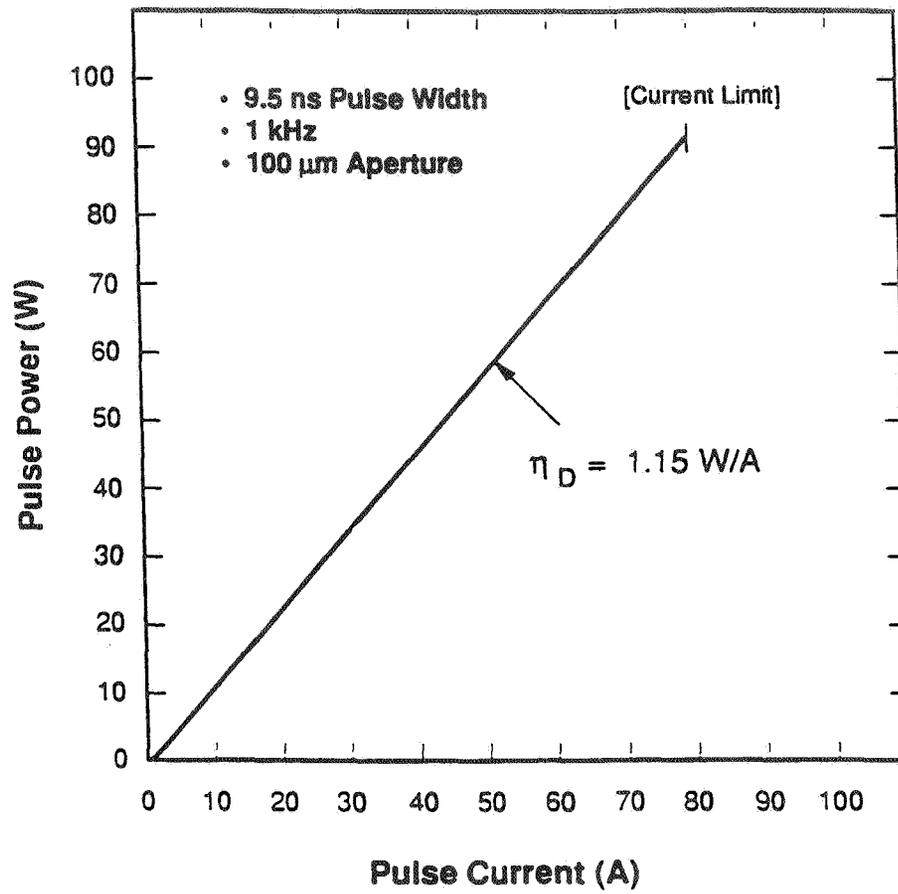
WELL "PASSIVATED" AlGaAs LASERS HAVE SAME DAMAGE LIMIT AS InGaAs LASERS.

LOW EFFICIENCY OR POOR HEATSINKING CAN CAUSE LASER TO "ROLL-OVER" BEFORE DAMAGE LIMIT IS REACHED.

Pulsed Laser

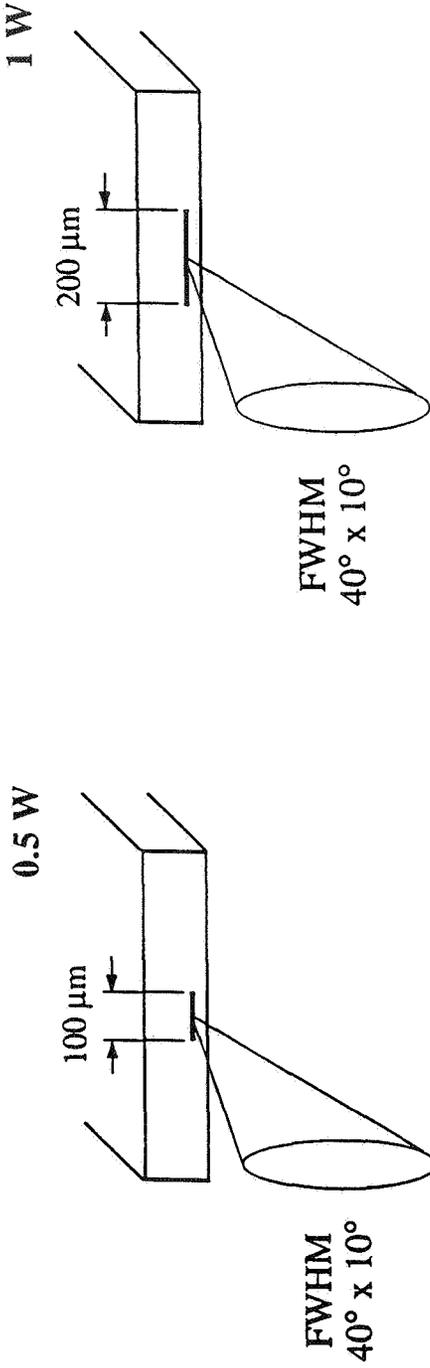


Short Pulse Power Curve

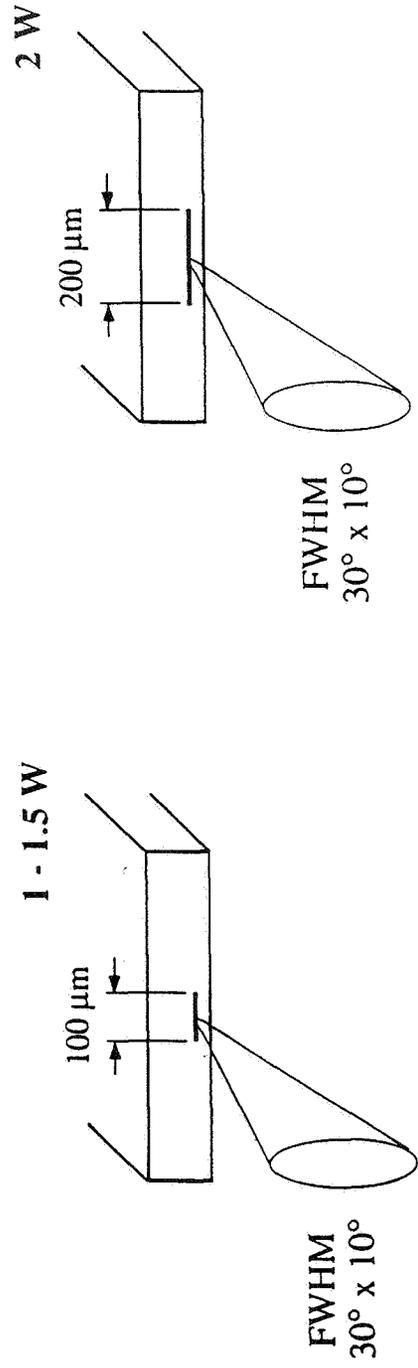


High Brightness Multimode Lasers

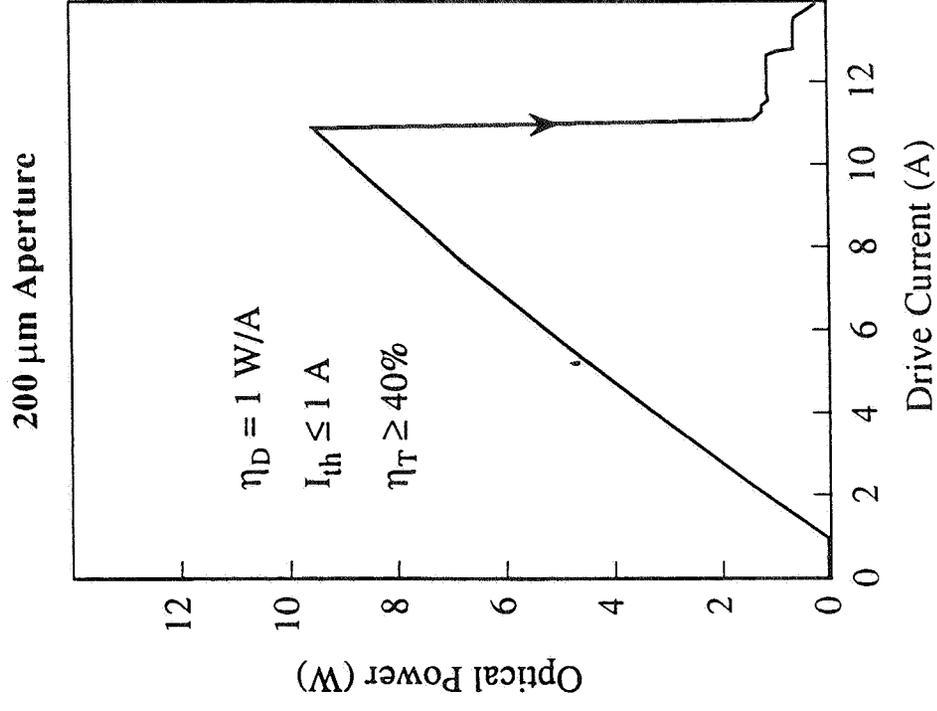
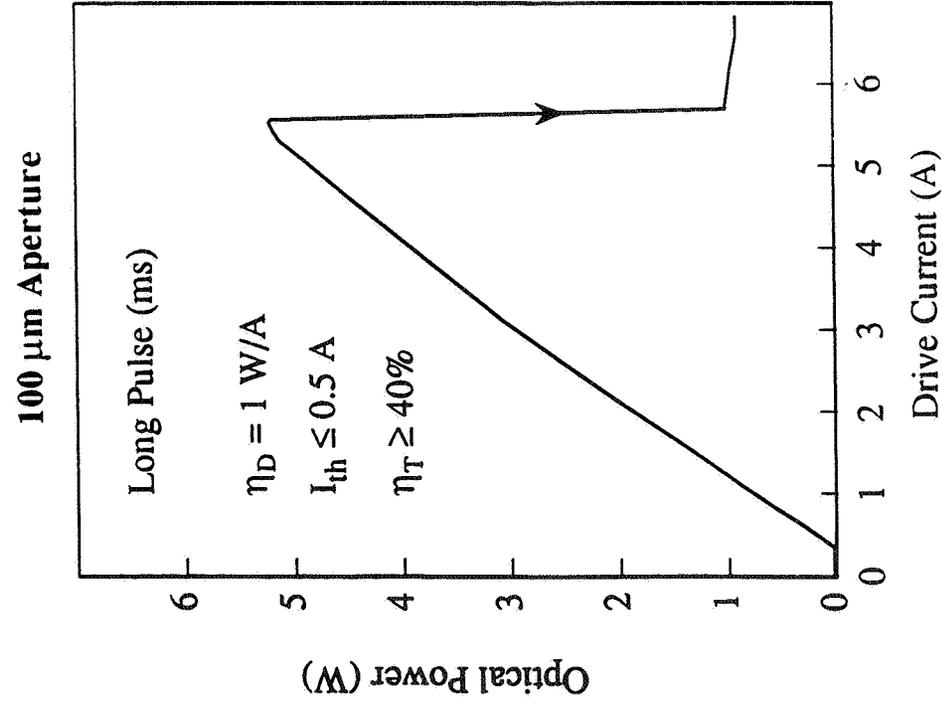
1987-1991 Commercial State-of-the-art



1991 New Technology



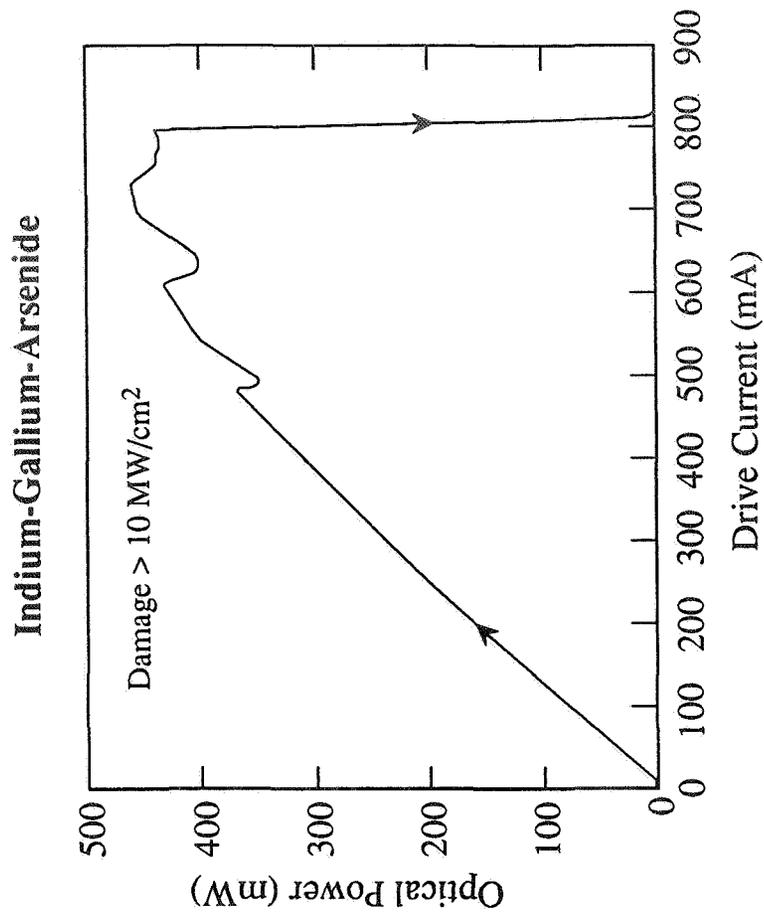
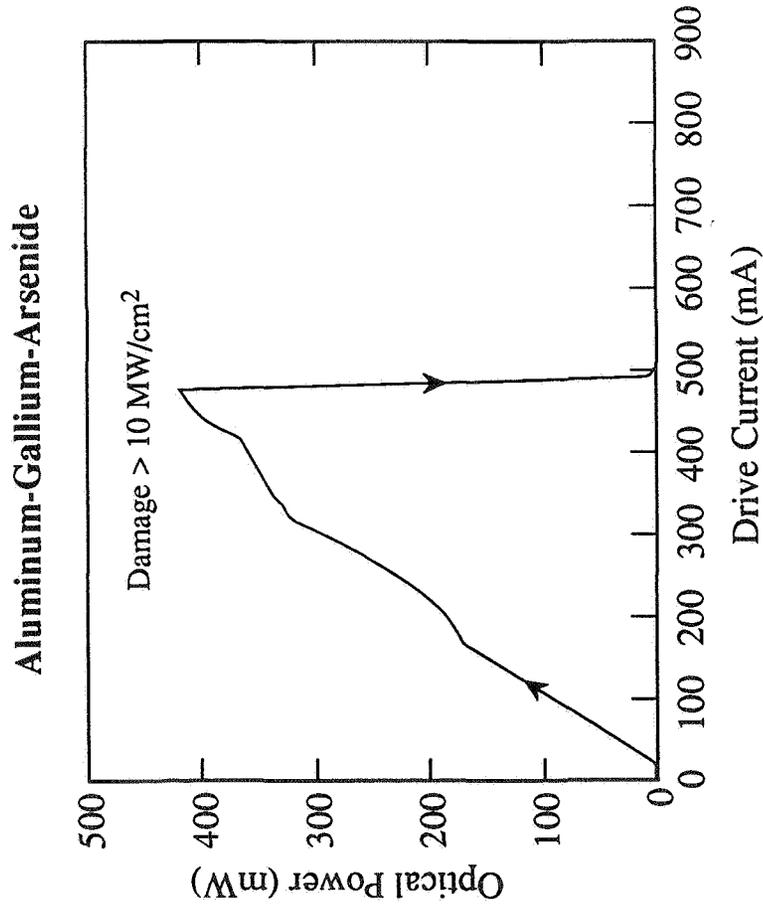
AlGaAs SQW Characteristics (795 - 860 nm)



Damage Limits of Diode Lasers

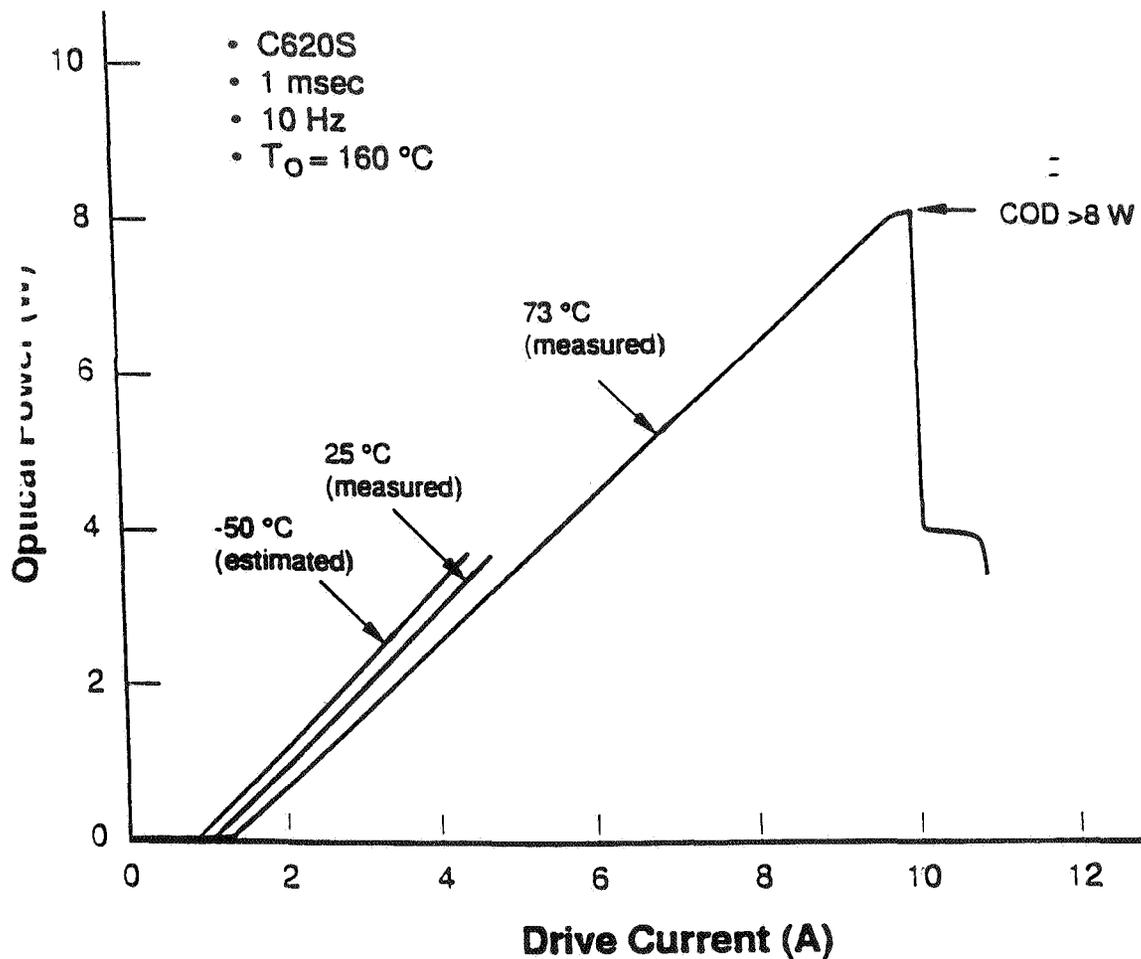
AlGaAs vs. InGaAs

(Both are single mode lasers of similar structure)



DAMAGE LEVEL NOT SIGNIFICANTLY DIFFERENT

High T_0 Quasi-cw 200 μm Aperture Laser

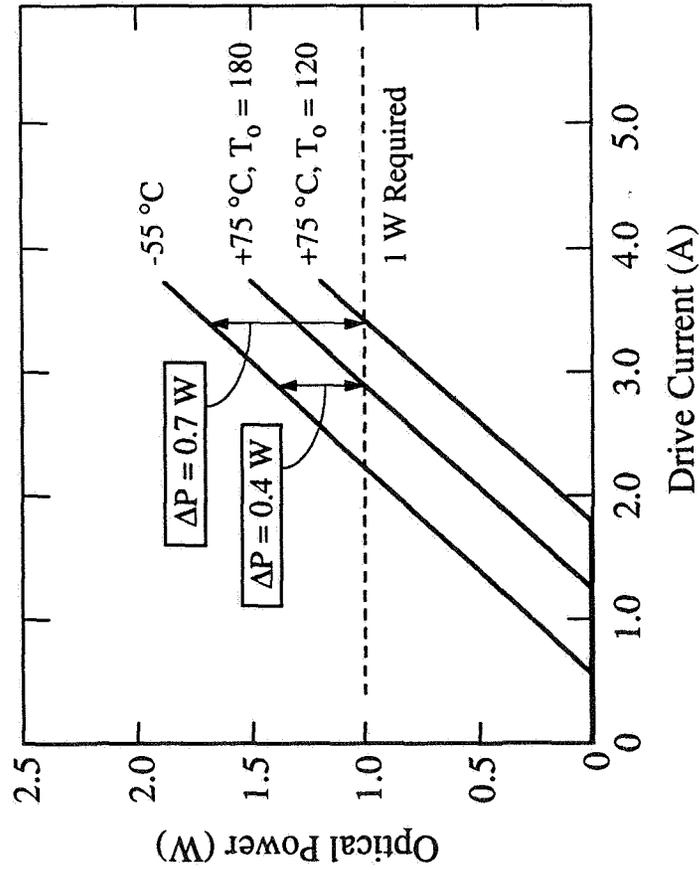


Temperature Dependence of Laser Threshold:

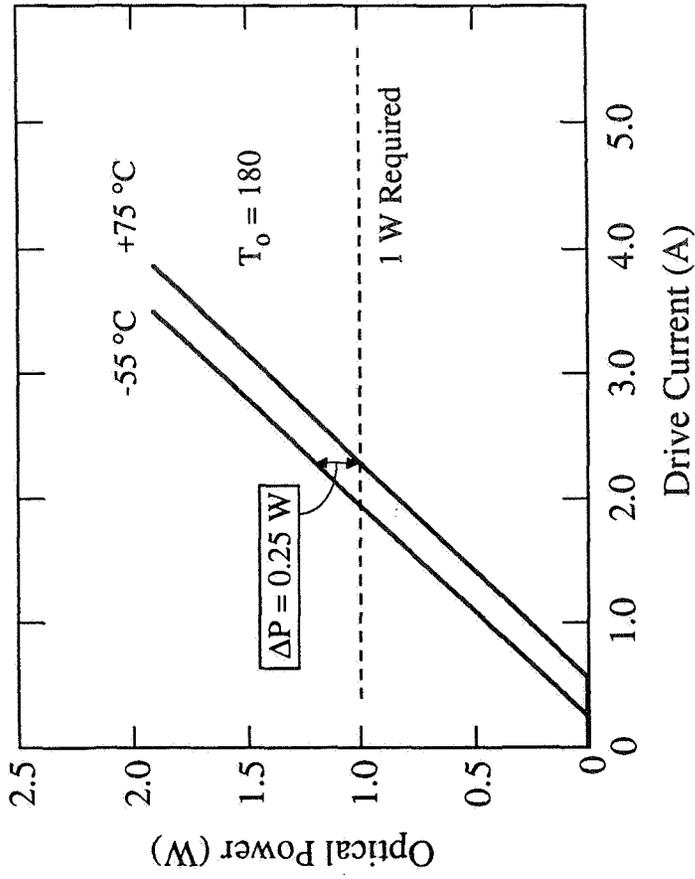
$$\frac{I_{TH1}}{I_{TH2}} = e^{(T_1 - T_2)/T_0}$$

Temperature Variations

Modeled 200 μm Aperture Laser



Modeled 100 μm Aperture Laser



FIBER COUPLING OF LASER DIODES

IN SIMPLE COUPLING SCHEMES THE LASER APERTURE IS SMALLER THAN THE FIBER DIAMETER.

TAPERED FIBERS OR OTHER LENS APPROACHES CAN ACHIEVE COUPLING OF LASERS WITH APERTURES GREATER THAN TWICE THE FIBER DIAMETER.

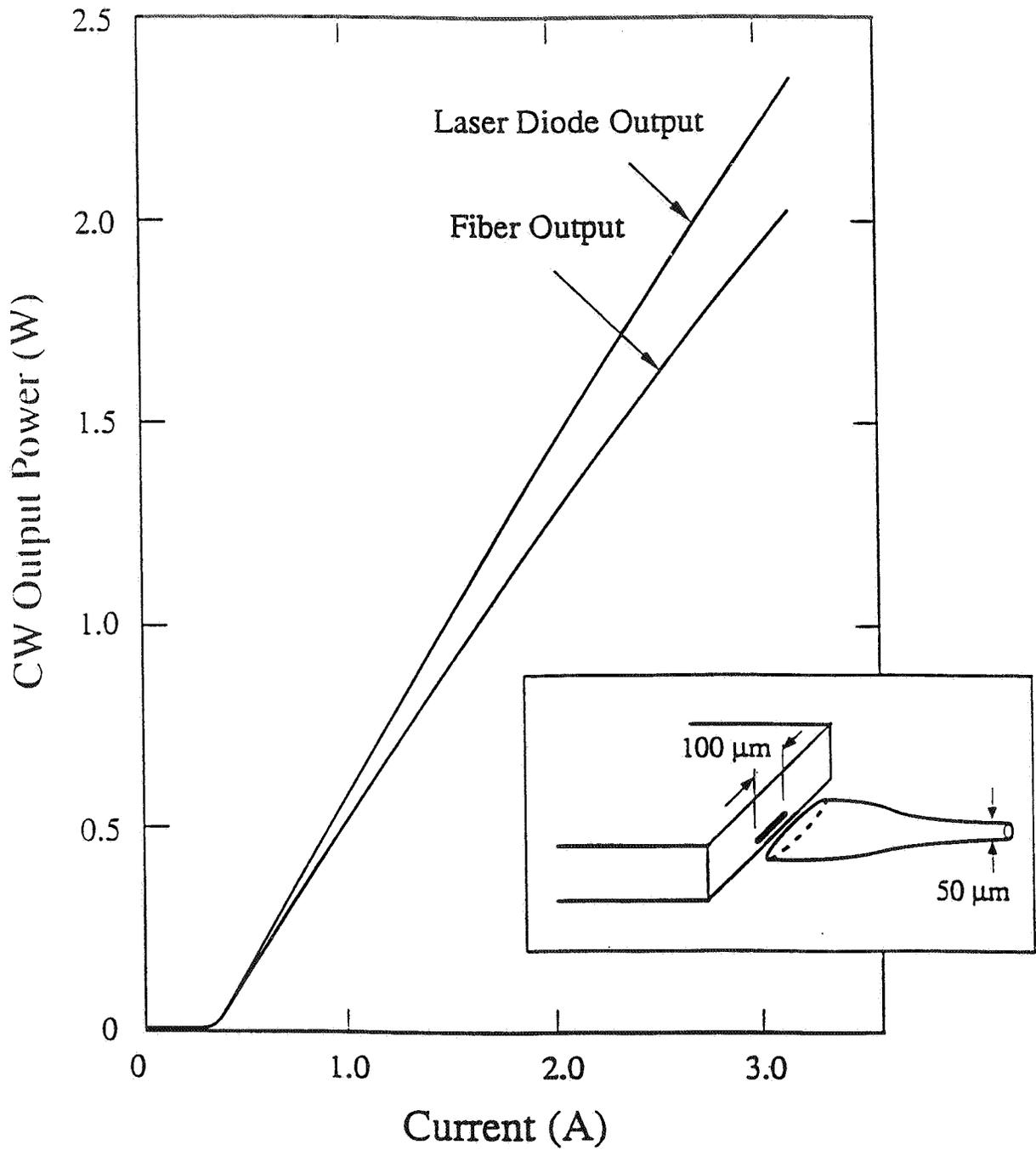
COMMON BASIS FOR COMPARISON OF LASER SYSTEM CAN BE BRIGHTNESS FROM THE FIBER

$$\text{BRIGHTNESS} = \text{POWER}/(\text{AREA} \times \text{SOLID ANGLE})$$

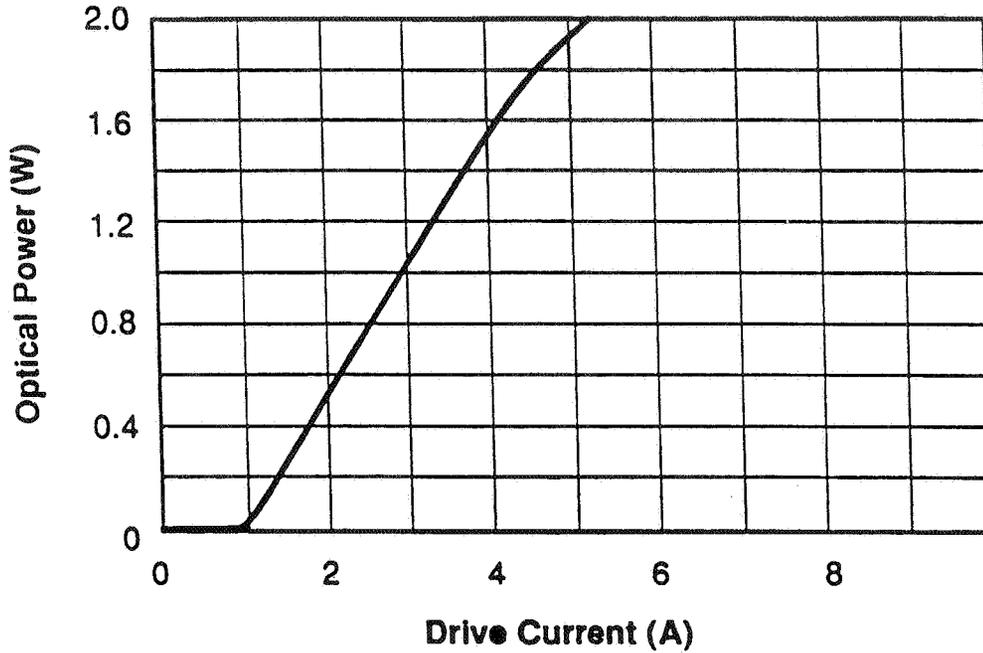
RELAXING BRIGHTNESS REQUIREMENT CAN REDUCE MANUFACTURING COSTS.

Tapered Fiber Couple

50 μm Diameter, 0.4 NA



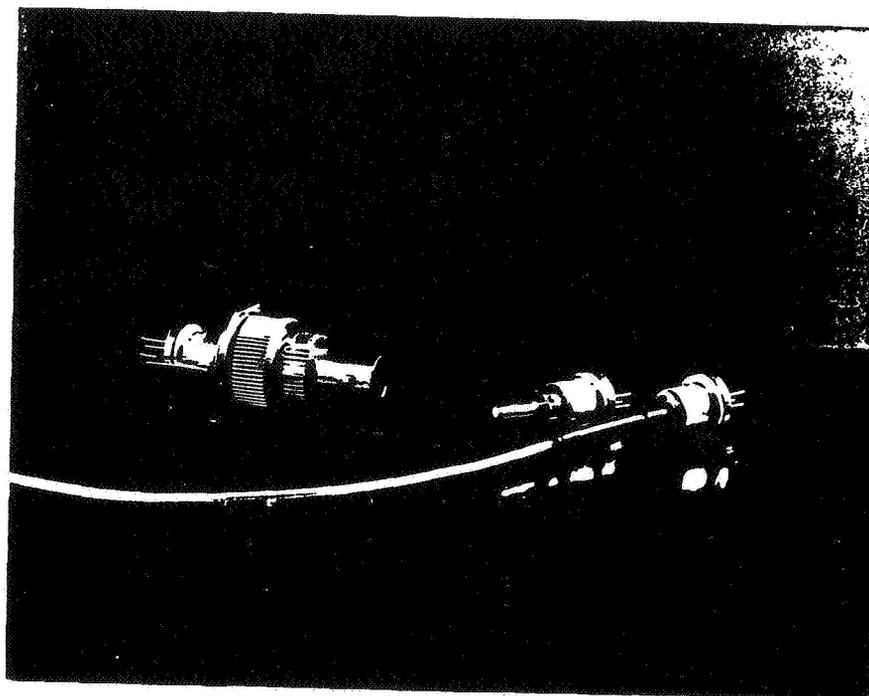
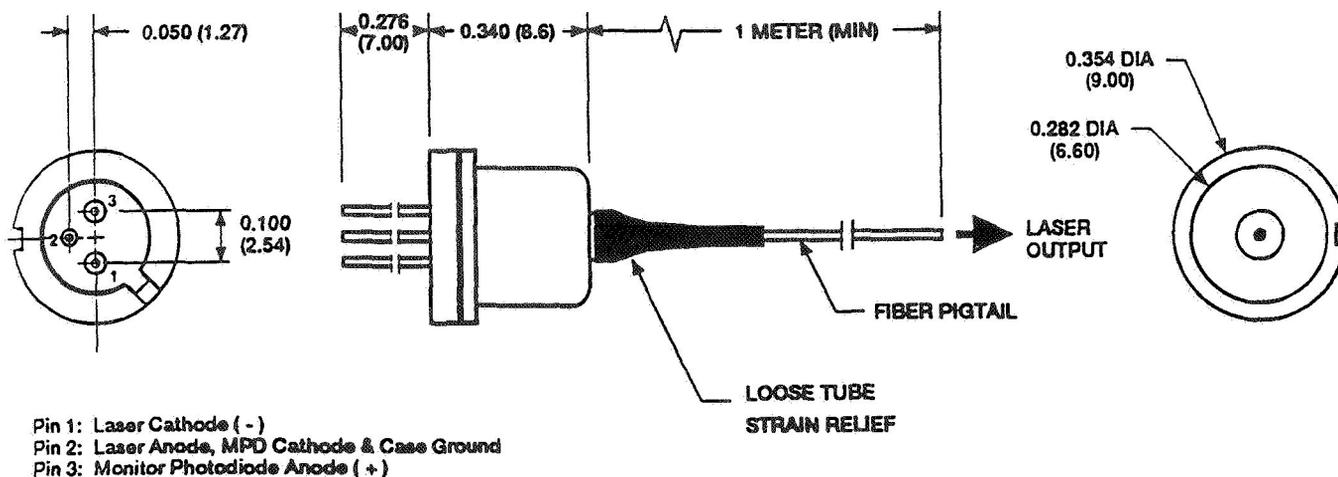
**2 Watt Quasi-cw (10 msec)
Fiber Coupled to 100 μm Fiber**



**1 Watt Quasi-cw from 100 μm Fiber
Meets Present Sandia Detonator Requirements**

Package Specifications [Dimensions in inches (mm)]

S9140 SOT-148 Fiber Pigtail Package



100 μm Fiber Results

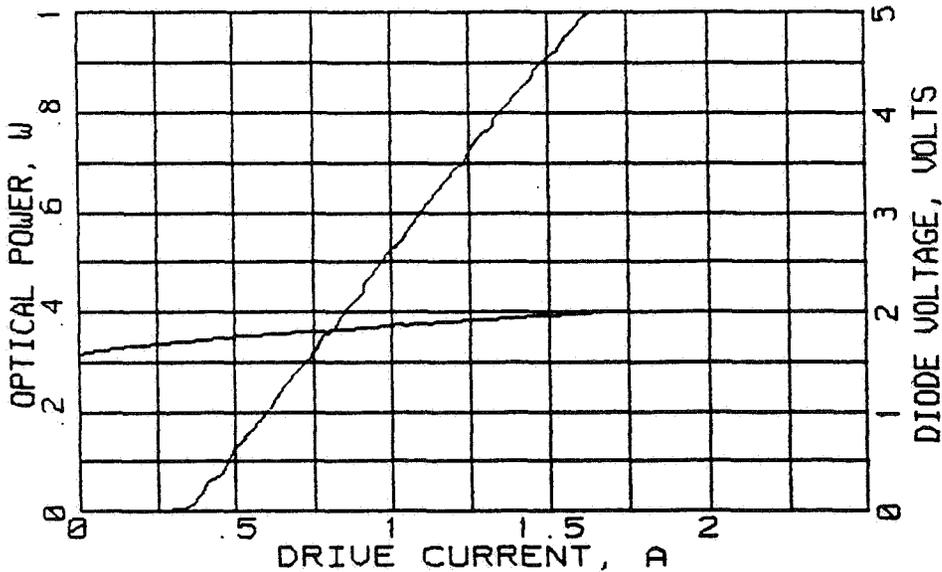
SPECTRA DIODE LABS, INC.

DEVICE TYPE: SDL59141-62
DATE: 1 APRIL 92

SERIAL NUMBER: RL499
TIME: 13:56

PARAMETER	PULSED	UNITS
THRESHOLD	.34	A
DIFF. Q. E.	51	%
SLOPE EFF.	.78	W/A
V AT 1 A	1.9	VOLTS
RESISTANCE	.216	OHMS
I AT 1.0 W	1.63	A
V AT 1.0 W	1.99	V

PULSE: WIDTH = 10000 usec, RATE = 10 Hz, TEST TEMP = 25 C
MONITOR GAIN: .6 mA/W

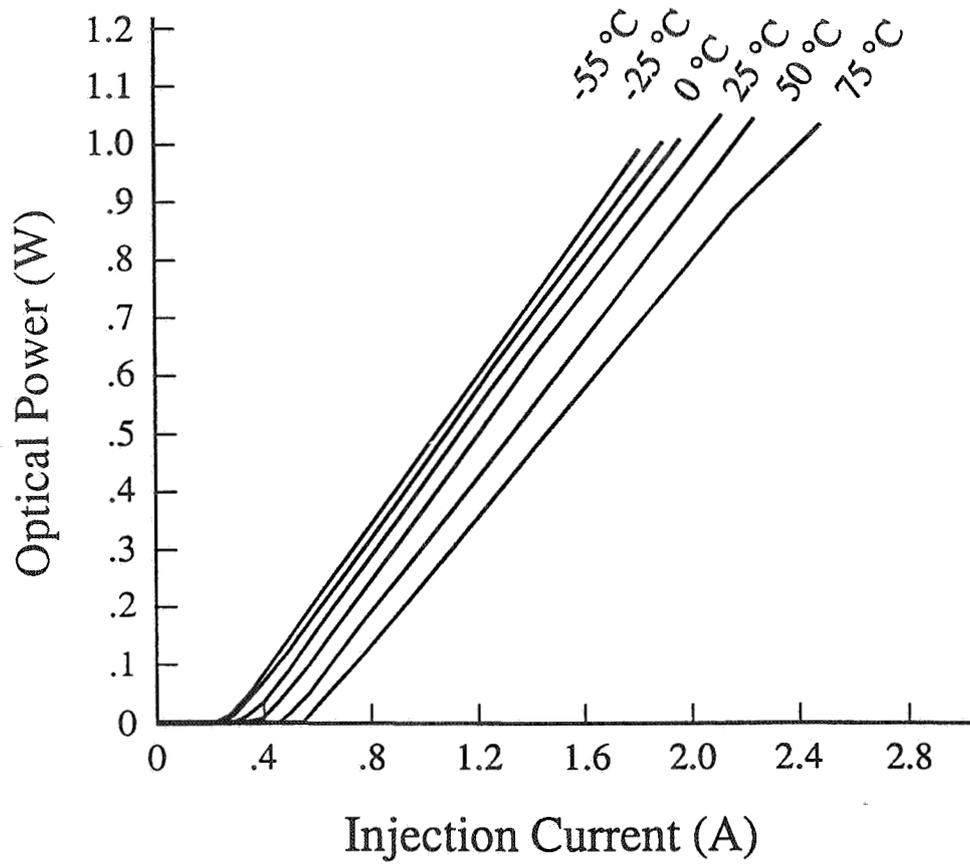


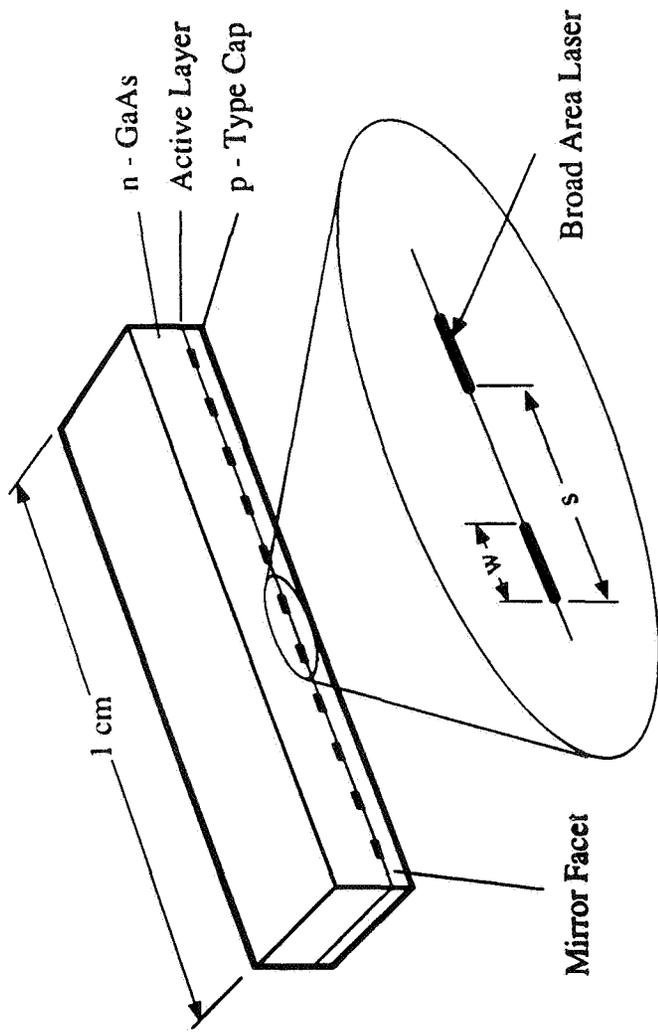
***** SHIPMENT CHECKLIST
LABELS: SDL, S/N * -???? (??)
SERIAL NUMBERS MATCH
OPERATOR'S MANUAL

CHECKED BY
-3138
WAVELENGTH MATCHES ORDER

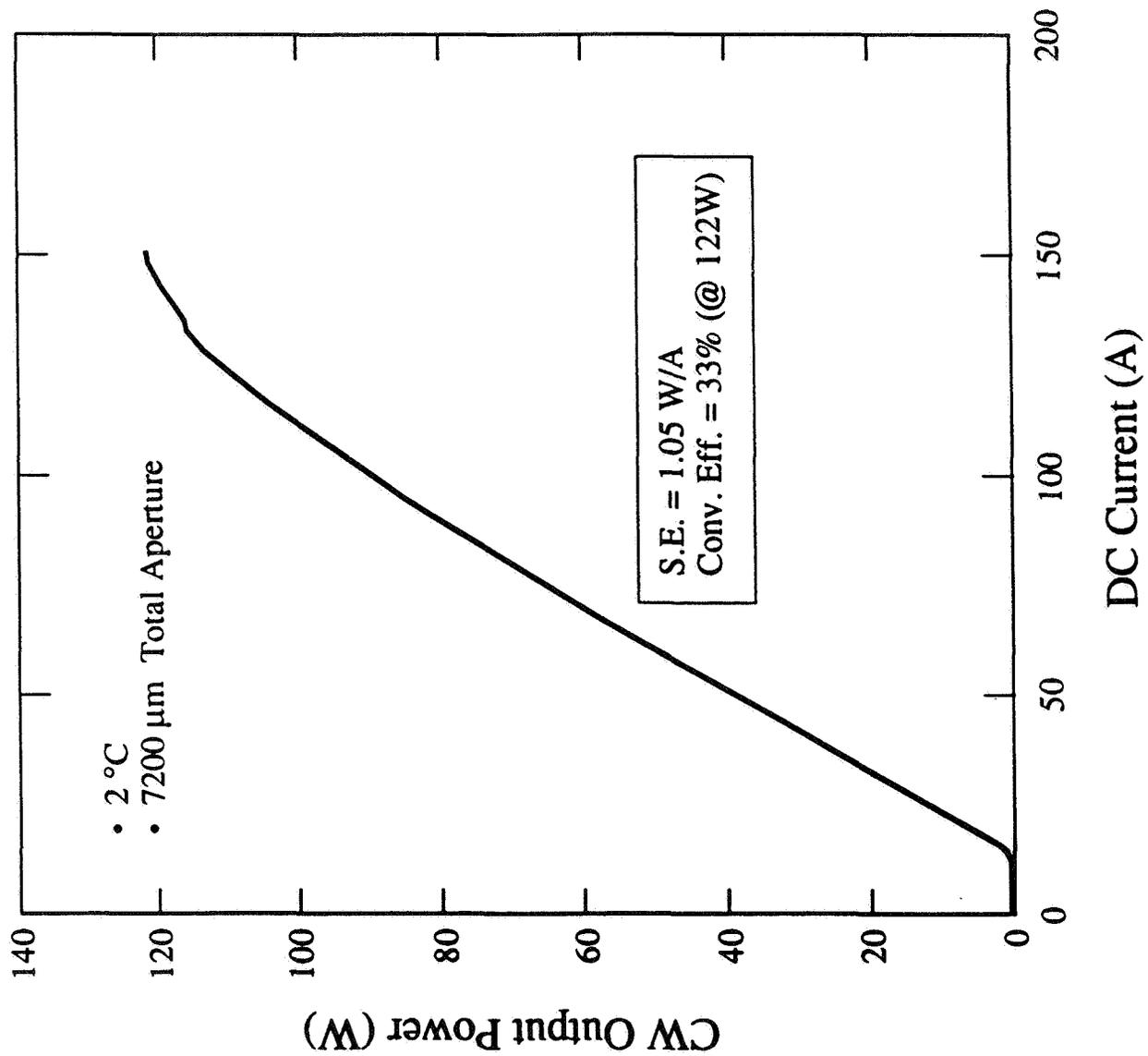


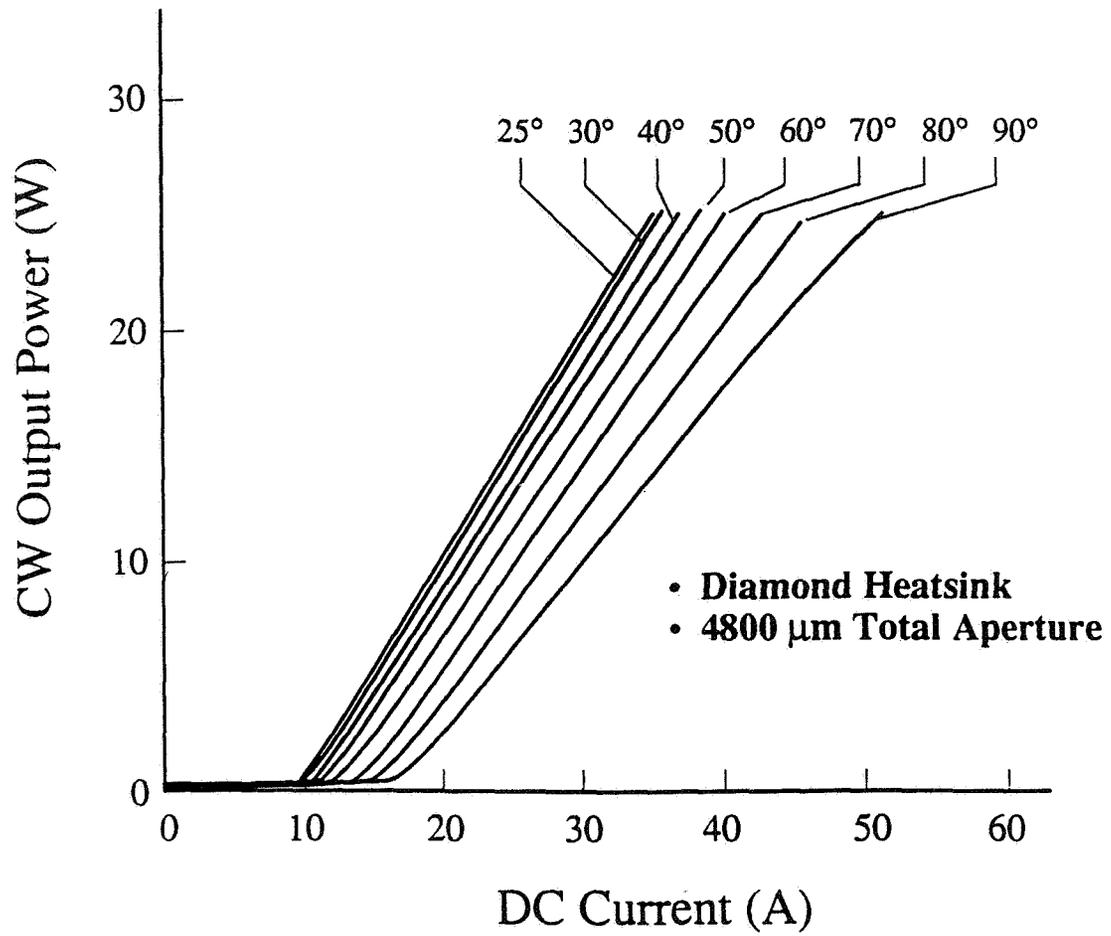
Power Characteristics of S9140



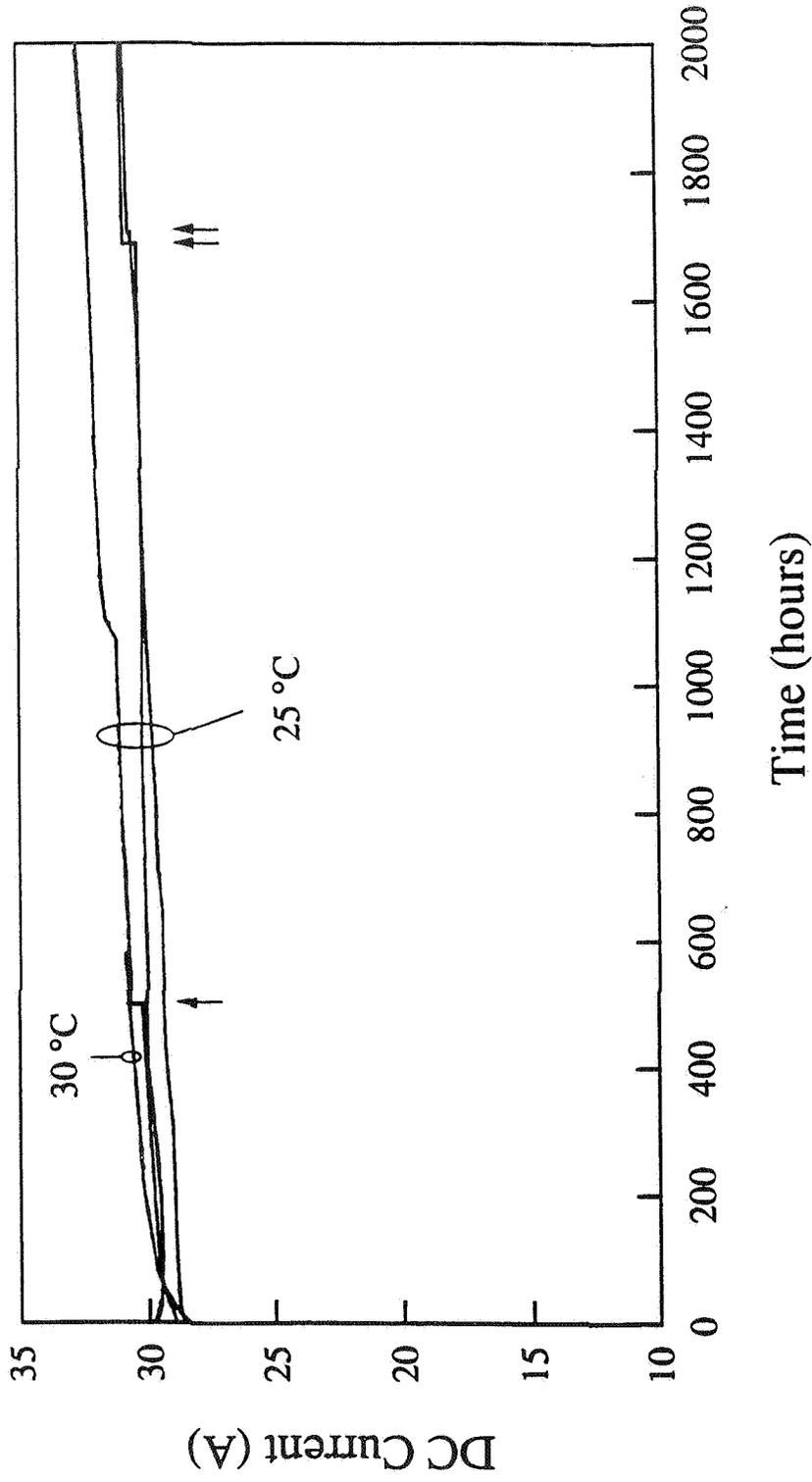


Total Width	w	s
2400 μm	170 μm	700 μm
4800 μm	100 μm	200 μm
6000 μm	80 μm	125 μm
7200 μm	96 μm	125 μm



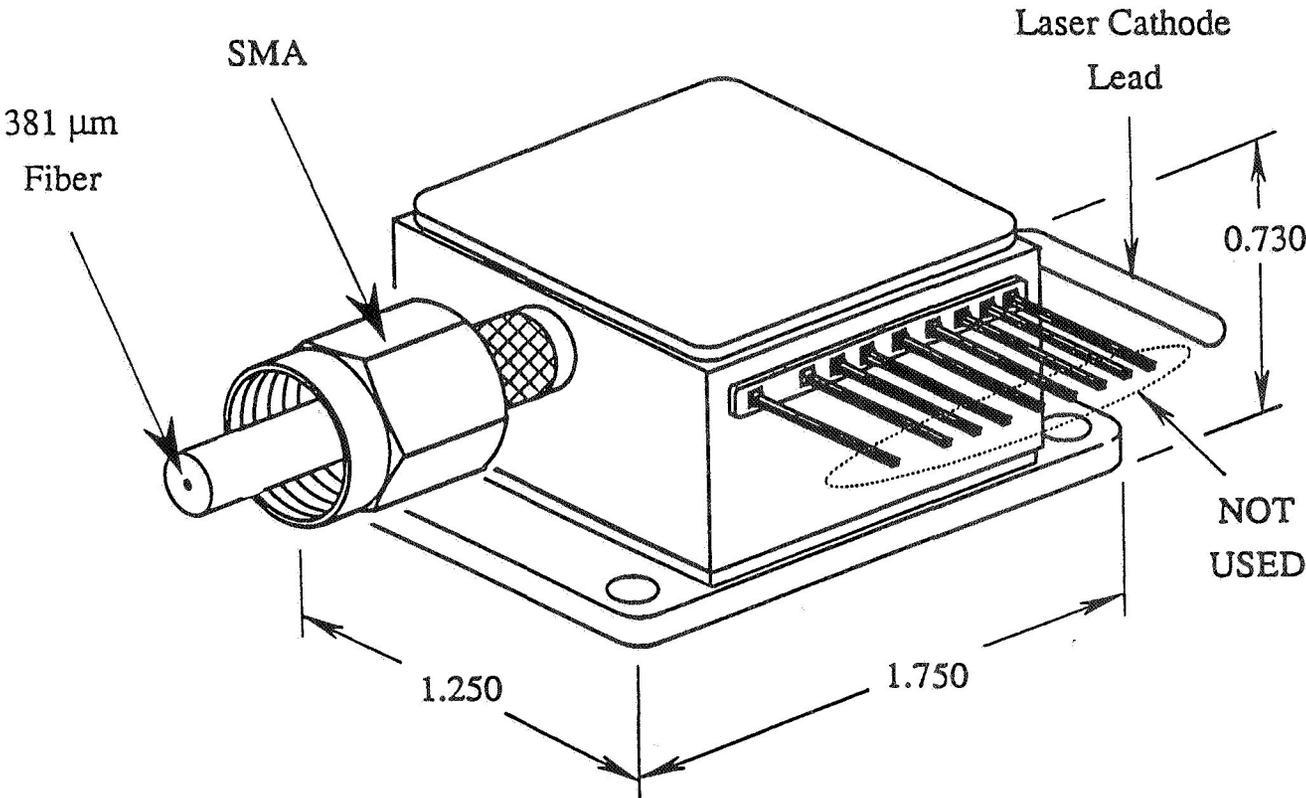


20 W CW (4800 μm Total Aperture)



Projected Lives of 4,000, 7000, and 15,000 hours @ 25 °C
(3 bars, 20% increase in operating current)

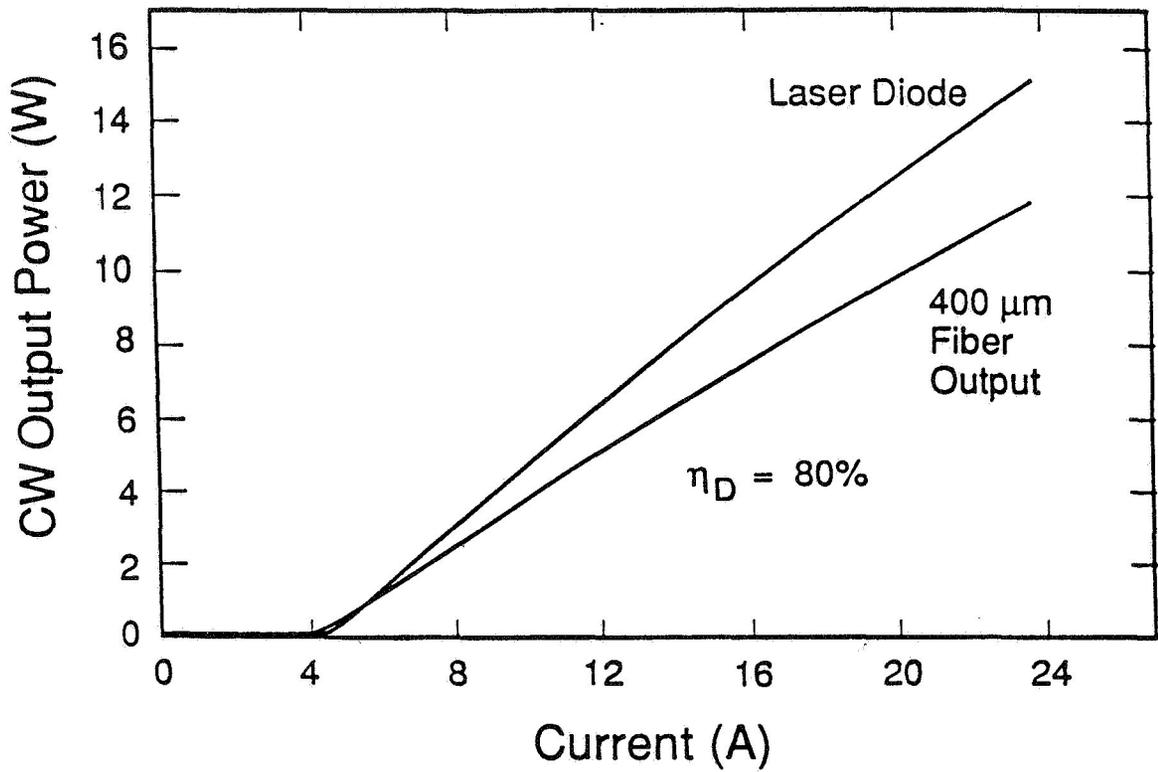
High Heat Load Fiber Coupled Package (P5)



PACKAGE IS ANODE

SDL-3450-P5

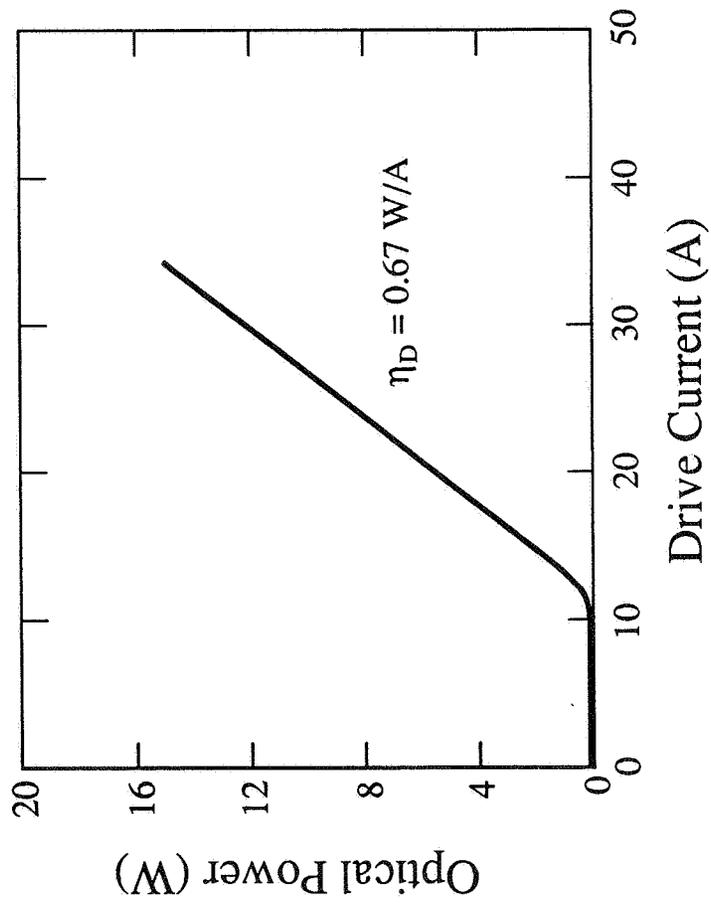
Light vs. Current



High Power Fiber Coupled Laser for Pyrotechnics

Test Conditions: 10 ms pulse, 10 Hz
20 °C

Fiber: 400 μm , 0.4 NA



This page intentionally left blank.

107 443058
19930/0958

N93-20147

LASER DIODE INITIATED DETONATORS FOR SPACE APPLICATIONS

D. W. Ewick, J. A. Graham, and J. D. Hawley
Ensign Bickford Aerospace Company
Simsbury, CT 06070

ABSTRACT

Ensign Bickford Aerospace Company (EBAC) has over ten years of experience in the design and development of laser ordnance systems. Recent efforts have focused on the development of laser diode ordnance systems for space applications. Because the laser initiated detonators contain only insensitive secondary explosives, a high degree of system safety is achieved. Typical performance characteristics of a laser diode initiated detonator are described in this paper, including all-fire level, no-fire level, function time, and output. A finite difference model used at EBAC to predict detonator performance, is described and calculated results are compared to experimental data. Finally, the use of statistically designed experiments to evaluate performance of laser initiated detonators is discussed.

INTRODUCTION

Work on all-secondary explosive laser initiated detonators began at Ensign Bickford Aerospace Company (EBAC) in the early 1980's. Although initial efforts were based on solid state (Nd:YAG) laser initiation, the more recent emphasis has been in the area of laser diode initiated detonators. The feasibility of laser diode initiation is due largely to dramatic improvements in diode output power and, to a lesser extent, improvements in powder blending technology for laser grade explosives.

Because they have relatively low autoignition temperatures, secondary explosives such as RDX and HMX are excellent candidates for laser diode initiation. Since the optical absorption of these materials at typical laser diode wavelengths is relatively poor (Ref. 1) additives such as graphite, carbon black, and boron are used to enhance powder absorptivity and, therefore, lower detonator

Approved for public release; distribution is unlimited.

2 4 7

all-fire level.

PETN has been found to be susceptible to temperature cycling induced effects and should not be considered for laser diode initiation applications. The temperature cycling problems with PETN are not unique to laser initiation, but have also been reported with other forms of thermal ignition, such as hot bridgewire (HBW) and semiconductor bridge (SCB) initiation.

Initial detonator designs at EBAC were based on the concept of flying plate initiation (Ref. 2). In this approach, a confined donor explosive charge is ignited by the laser pulse and burns until sufficient pressure has been built up to rupture a confinement disc. The ruptured disc, or flying plate, is then propelled down a barrel by the high pressure gases produced by the donor charge at a velocity in excess of 1 km/sec. The velocity of the flying plate is sufficient to shock initiate a secondary explosive acceptor charge at the end of the barrel.

More recent efforts relative to laser initiated detonators have been based on the principle of deflagration-to-detonation transition (DDT). As with the flying plate detonator, a confined secondary explosive donor charge is ignited by the laser pulse, causing it to deflagrate and rupture the confining disc. In this type of device, however, the "barrel" contains a relatively long column of secondary explosive termed the "transition charge". As the high pressure gases and the ruptured disc drive into the transition charge, the reaction transitions into a high order detonation.

Confinement is an extremely important parameter in all-secondary explosive laser initiated detonators. As a general rule of thumb, the more insensitive the explosive, the higher the degree of confinement needed for reliable function.

Important design requirements for laser diode initiated detonators include all-fire and no-fire levels, output, function time, and environmental ruggedness. Typical environmental requirements include hot and cold temperature function, as well as temperature cycling, thermal shock, vibration, and pyrotechnic shock. For DDT detonators, run-to-detonation distance is also an important parameter, since it directly related to detonator size and weight, as well as margin.

Performance of laser diode initiated DDT detonators can be predicted and optimized using tools such as computer modeling as advanced experimental design techniques. At EBAC, finite difference modeling has been used to predict ignition-related aspects of detonator performance, including all-fire and no-fire levels, and effects of temperature and laser diode pulse width. Advanced experimental design techniques have been used to optimize detonator design parameters, such as powder density, particle size, and column diameter.

PERFORMANCE CHARACTERISTICS

Important performance characteristics of laser diode ignited detonators include all-fire level, no-fire level, function time, and output. All-fire and no-fire levels are determined by performing sensitivity tests, such as Bruceton, Langlie, or Neyer (Ref. 3) and are conducted at a fixed laser diode pulse width. The data reported in this paper are based on a pulse width of 20 ms. Detonator all-fire and no-fire tests are normally conducted at "worst case" temperature levels, which are typically -54°C and 74°C, respectively.

Twenty (20) each all-secondary explosive laser diode initiated detonators were used to determine all-fire and no-fire levels. As was noted above, the laser diode pulse width was 20 ms. The detonators were coupled to the laser diodes via a 200 μm diameter optical fiber. The .999/95% all-fire level was found to be 478 mW at -54°C. The .001/95% no-fire level, at 74°C, was 116 mW. It should be noted that these tests were performed with a single SMA type fiber optic connector between the laser diode and detonator. The all-fire and no-fire level, therefore, are actually for the detonator plus one connector.

For electro-explosive devices (EED's) no-fire testing is normally conducted using a 5 minute duration constant current pulse as a worse case scenario rather than the actual firing pulse, which may be only tens of milliseconds in duration. This requirement stems from concerns relative to potential sources of RF energy in proximity to EED's, where the firing circuit can act as an antennae and induce an electrical current in the bridgewire. In general, a 5 minute no-fire requirement may not be applicable to laser initiated detonators, however, it certainly represents a conservative approach to no-fire testing.

Twenty additional laser diode initiated detonators were assembled and utilized in a 5 minute laser diode no-fire test. The laser diode was operated continuously (CW) for 5 minutes while performing this test. As before, a 200 μm diameter optical fiber was used to couple the laser diode to the detonator and the detonators were conditioned to 74°C. Data analysis yielded a .001/95% no-fire level of 98 mW. Again, this value includes one connector between the diode and detonator. Note that there is only a 15% decrease in the no-fire level between pulse widths of 20 ms and 5 minutes. This is attributable to the small spot size achieved by coupling the fiber directly to the powder, which minimizes the effective thermal mass.

As with all thermally ignited devices, function time of a laser diode initiated detonator varies inversely with the applied power. Twenty additional detonators were fabricated to assess the effect of laser diode power on detonator function time. Two detonators each were fired at levels from 300 mW to 1.2 watts, in increments of 100 mW. The tests were conducted at ambient temperature using a 20 ms laser diode pulse and a 200 μm diameter optical fiber. A graph of function time versus diode power is shown in Figure 1. The line drawn through the data points in Figure 1 is a least squares fit of the form $y=a+b/x^2$. As before, note that the data is based on a single SMA connector between the laser diode and detonator.

The final performance characteristic of laser diode initiated detonators to be discussed is output. Standard EBAC test detonators include a one grain HNS-IA output charge housed in a .005 inch thick stainless steel cup and pressed at 32,000 psi. In tests at ambient temperature with steel witness blocks, the average dent produced by the laser initiated detonators was .012 inches.

FINITE DIFFERENCE MODELING

Because of their axial symmetry, typical laser diode initiated detonators are excellent candidates for finite difference modeling techniques. In reference 4, the author presented a laser diode ignition model based on a one-dimensional finite difference solution of the governing time-dependent heat conduction equation. An improved two-dimensional model has since been developed and used to predict the performance of EBAC laser diode initiated detonators. The general heat conduction equation is shown in equation (1) below. Note that a cylindrical coordinate system has been chosen and that a heat generation term has been included.

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} + \frac{1}{r^2} \frac{\partial^2 T}{\partial \phi^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}}{k} = \frac{1}{a} \frac{\partial T}{\partial t} \quad (1)$$

where: T = temperature
 t = time
 z = axial coordinate
 r = radial coordinate
 ϕ = angular coordinate
 q = heat generation rate
 k = thermal conductivity
 a = thermal diffusivity

For an axially symmetric system, as is the case with typical laser diode initiated detonators, equation (1) reduces to:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}}{k} = \frac{1}{a} \frac{\partial T}{\partial t} \quad (2)$$

Optical absorption of the incident laser radiation by the donor charge is handled by the heat generation term, which may be written as follows:

$$q = \alpha \cdot p \quad (3)$$

where: α = absorptivity of first fire mix
 p = incident power density

As first order approximations, it may be assumed that thermal conductivity and heat capacity are constant and do not vary with temperature. Also, as a first order approximation, the model does not include a self-heating term for decomposition of the explosive material, but instead assumes a constant autoignition temperature.

Equation (2) may be solved using conventional finite difference techniques. Due to the large number of nodes needed to reasonably model a laser initiated detonator, a computer is needed to carry out the detailed calculations.

The finite difference model has been used to model the laser diode ignition characteristics of a fine particle HMX/Carbon Black blend. Figure 2 shows the predicted function time as a function of laser diode power assuming a 100 μm diameter spot size. Calculated results are shown for the two-dimensional model described by equation (2) and also for a one-dimensional (axial only) model. Also noted in Figure 2 for reference, are a pair of experimental data points for fine particle HMX/carbon black (Ref. 1).

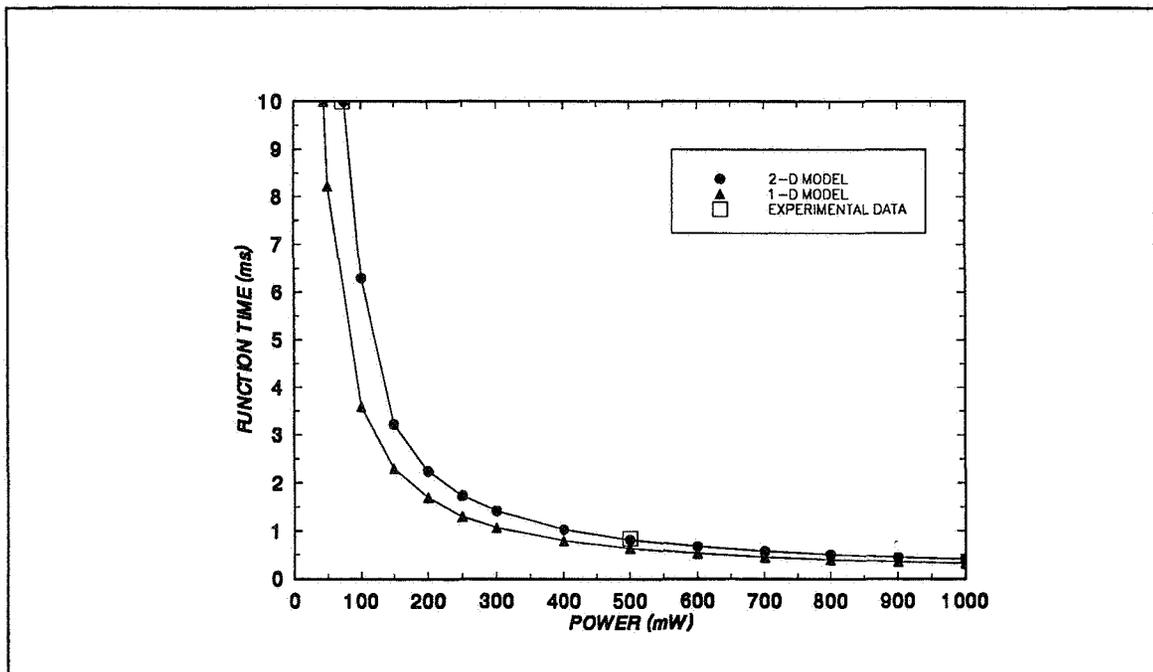


Figure 2
Comparison of 1-D and 2-D Finite Difference Calculations

Note that the two-dimensional model predictions are in excellent agreement with the experimental data points. In addition, note that the function times predicted by the one-dimensional and two-dimensional models converge as the diode power increases. At relatively high power levels, the one-dimensional results are also in reasonably good agreement with the experimental data, however, at lower power levels the one-dimensional model underestimates the diode power required for ignition because radial heat losses are not accounted for.

Another obvious limitation of the one-dimensional model is its inability to accurately predict spot size effects. The laser diode ignition threshold for HMX/carbon black has been found to scale as the diameter raised to the 1.4 power (Ref. 5). A one-dimensional model, however, inherently assumes that initiation is a function of power density. In other words, the one-dimensional model will predict that the ignition threshold varies as the diameter squared. The two-dimensional model is in much closer agreement with experimental data, predicting that ignition threshold scales with the diameter raised to the 1.6 power. The effect of varying the laser diode pulse duration has also been studied using the finite difference model. Figure 3 shows the predicted ignition threshold as a function of spot size for laser diode pulse widths of 10 and 20 ms.

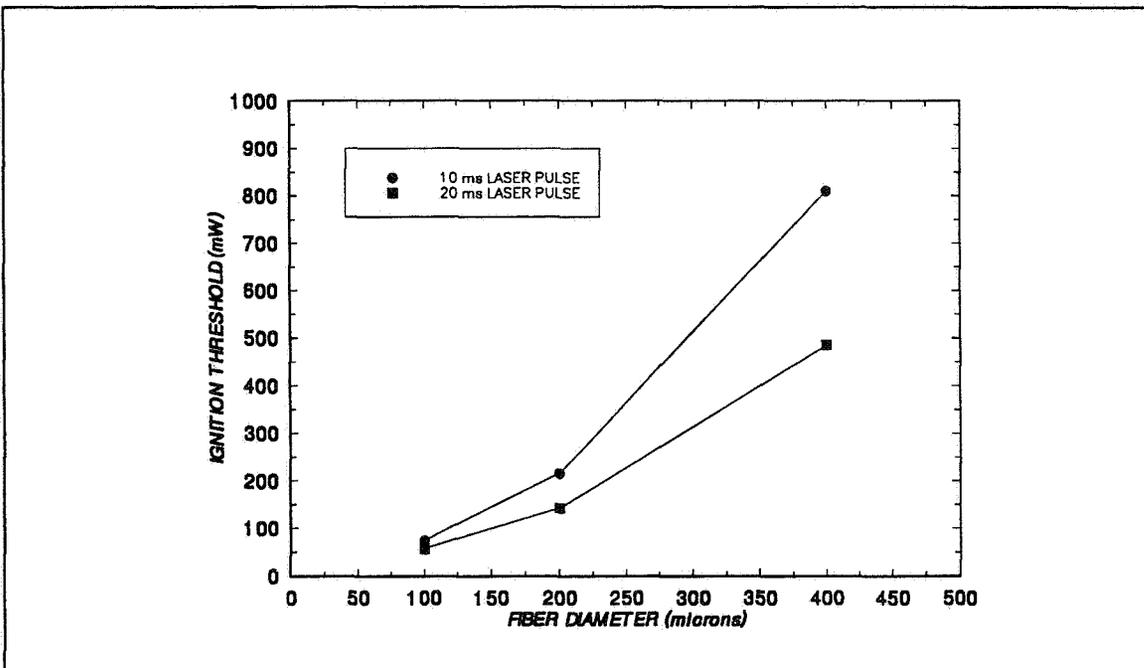


Figure 3
Effect of Laser Diode Pulse Width on Ignition Threshold

Due to the larger thermal mass associated with a larger spot size, the penalty of a higher ignition threshold is reduced by using a longer pulse duration.

Finally, the finite difference model has been used to predict the effect of temperature on ignition threshold. Figure 4 shows the predicted ignition threshold as a function of spot size for temperatures of -54°C, 22°C, and 74°C. A 20 ms laser diode pulse was used as the basis for these calculations.

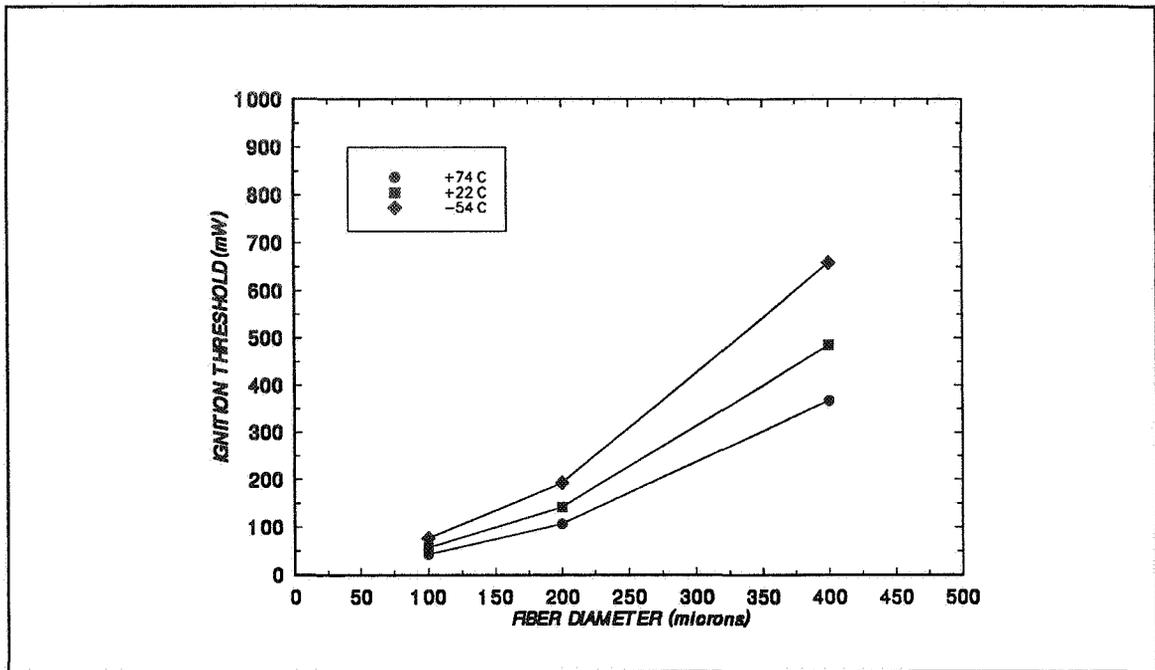


Figure 4
Effect of Temperature on Ignition Threshold

EXPERIMENTAL DESIGN TECHNIQUES

The finite difference modeling discussed above addressed only the ignition characteristics of laser diode initiated detonators. Design parameters affecting the ignition characteristics can be optimized with the aid of the heat transfer model, however, testing is obviously required in order to verify the model predictions.

In addition, the design of laser diode initiated deflagration-to-detonation transition (DDT) detonators also requires optimization of those parameters affecting the transition from burning to high order detonation.

At EBAC, advanced experimental design techniques have been used to investigate the effects of parameters such as transition charge diameter, loading density, specific surface area, and confinement disc thickness on the run distance to detonation and function time of laser initiated detonators. Although the tests were conducted using a pulsed Nd:YAG laser source, the run distance to detonation data is applicable to laser diode initiated detonators, as well. Although

EBAC considers the specific parameter values and test results to be company confidential information, a summary of the results is presented here.

For the transition charge designed experiment, a total of twenty-three tests were conducted. Three levels were considered for each of the four parameters studies, except confinement disc thickness, for which there were only two levels. From the results, an optimized design configuration was established via statistical analysis. In addition, a trend analyses was performed to evaluate the effect of each parameter on the run distance to detonation. Figure 5 shows the combined effect of charge density and specific surface area on run distance to detonation.

REFERENCES

1. Ewick, D. W., et al., "Ignition of HMX Using Low Energy Laser Diodes", Proceedings of the Fourteenth Symposium on Explosives and Pyrotechnics, San Francisco, California, February 13-15, 1990, 14 pp.
2. Dinegar, R. T., All-Secondary Explosive Hot-Wire Devices, LA-7897-MS, Los Alamos National Laboratory, Los Alamos, New Mexico (October 1979), 7 pp.
3. Neyer, B. T., More Efficient Sensitivity Testing, MLM-3609, EG&G Mound Applied Technologies, Miamisburg, Ohio (October 1989), 31 pp.
4. Ewick, D. W., "Finite Difference Modeling of Laser Diode Ignited Components", Proceedings of the Fifteenth International Pyrotechnics Seminar, Boulder, Colorado, July 9-13, 1990, pp. 277-296.

MARGIN
THICKNESS = 1.4, DIAMETER = .67

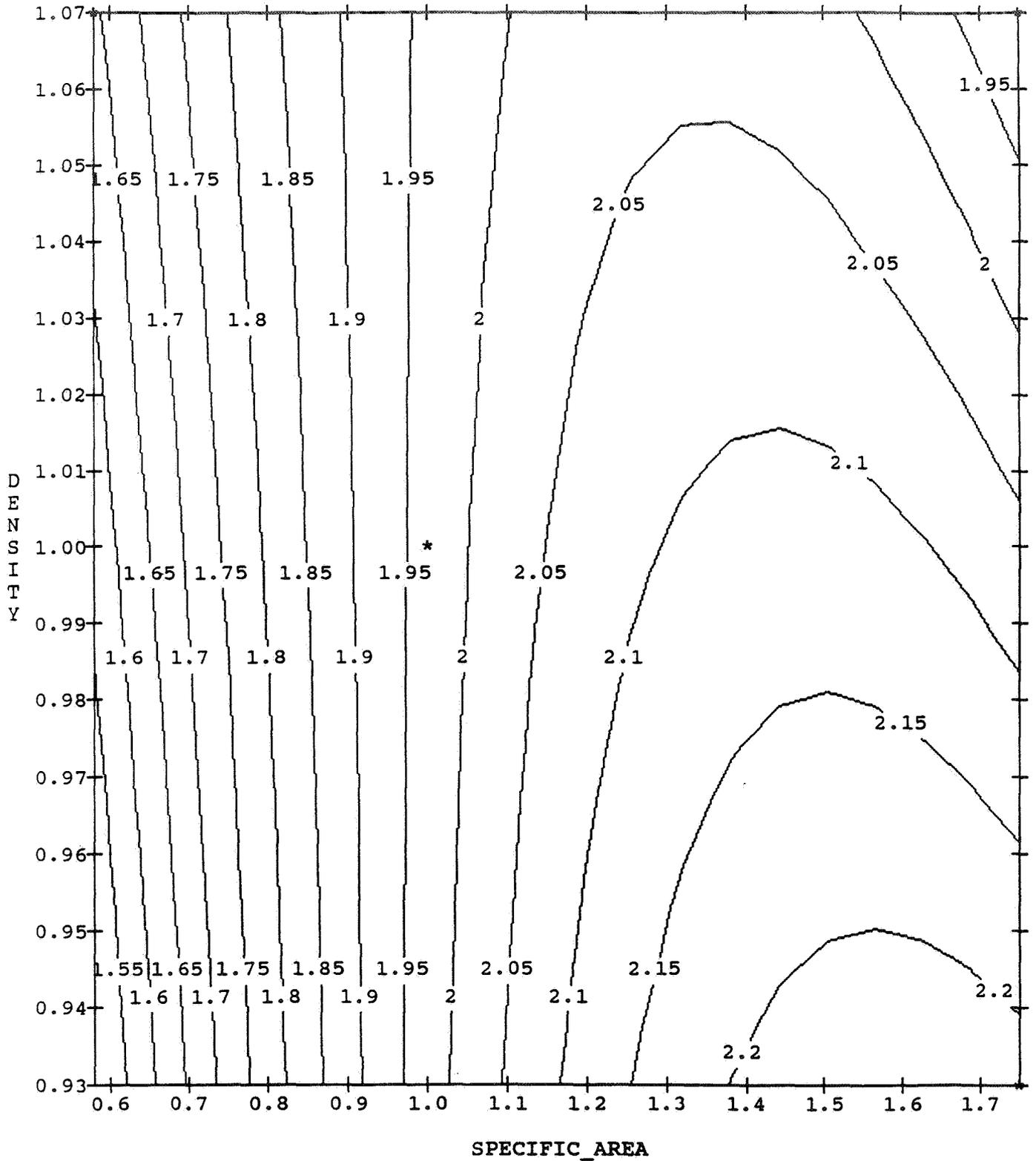


Figure 5
Combined Effect of Density and Specific Surface Area

188

1993010959

493061

SAND92-1359C

N93-20148

PORTABLE FIBER OPTIC COUPLED DOPPLER INTERFEROMETER
SYSTEM FOR DETONATION AND SHOCK WAVE DIAGNOSTICS

Kevin J. Fleming

Sandia National Laboratory
Division 2514
Explosive Projects and Diagnostics

Presented at:

NASA Aerospace Pyrotechnic Systems Workshop
June 9-10, 1992
Lyndon B. Johnson Space Center
Houston, Texas

ABSTRACT

Testing and analysis of shock wave characteristics such as detonators and ground shock propagation frequently require a method of measuring velocity and displacement of the surface of interest. One method of measurement is doppler interferometry. The VISAR (Velocity Interferometer System for Any Reflector) uses doppler interferometry and has gained wide acceptance as the preferred tool for shock measurement. An important asset of VISAR is that it measures velocity and displacement nonintrusively.

The conventional VISAR is not well suited for portability because of its sensitive components, large power and cooling requirements, and hazardous laser beam. A new VISAR using the latest technology in solid state lasers and detectors has been developed and tested. To further enhance this system's versatility, the unit is fiber optic coupled which allows remote testing, allowing the VISAR to be over a kilometer away from the target being measured. Since the laser light is contained in the fiber optic, operation of the system around personnel is far less hazardous. A software package for data reduction has been developed for use with a personal computer. These new advances have produced a very versatile system with full portability which can be totally powered by batteries or a small generator.

This paper describes the solid state VISAR and its peripheral components, fiber optic coupling methods and the fiber optic

Approved for public release; distribution is unlimited.

coupled sensors used for sending and receiving laser radiation.

VISAR OPERATION AND DESCRIPTION

The conventional VISAR consists of a single mode, single frequency laser (typically argon ion), interferometer cavity, peripheral optics, modulator, photomultiplier tubes (pmt's), amplifiers, digitizer(s) and computer (figure 1). In a typical VISAR setup in the "push-pull" configuration using the "fixed cavity", the laser beam is routed through a focusing lens placed in front of the surface that is to be measured (the surface is diffusely reflective). The lens focuses the light on the surface and the scattered return light is routed back to the interferometer cavity (figure 2). The interferometer is a modified Michaelson cavity. The return beam is split and routed through the cavity in which one beam goes through air (reference leg) and the other beam travels through glass (delay leg) and an eighth wave retarder with a mirrored coating on the rear surface. The two combined beams are split and sent to polarizing beamsplitting cubes (PBC). The beams interfere with each other producing either a bright or dark spot (constructive or destructive interference) that are converted to electrical signals by photomultiplier tubes (pmt). The polarizing beamsplitting cubes separate and linearly polarize the light containing the doppler information into their "S" and "P" components (figure 3). The S and P light possess the same doppler information but since the light passes through the 1/8 wave retarder twice, the phase is retarded by 90 degrees. The light (P component) that passes through the PBC is called DATA 2 and DATA 2' and light that is reflected (S component) is DATA 1 and DATA 1'. The two pairs of interfered light have identical phase-time information except that they are out of phase with each other by 180 degrees. DATA 1 is electronically inverted and added to DATA 1' as is DATA 2 and DATA 2'. The advantage of this method of inverting and adding the signals is that it cancels out self light and the signal amplitude is doubled. The stored data is then manipulated and converted to displacement and velocity using custom software (figure 4).

When the target is at rest, the wavelength in both legs of the interferometer cavity is equal and no change in the interference fringes pattern is observed (figure 5). The instant the target starts moving, a doppler shift of the light occurs (the optical equivalent of the changing pitch of a car engine as it passes by). Since the light in the glass portion of the interferometer cavity is delayed before it is recombined with the reference light, the interference fringe pattern moves. The velocity of the target correlates to the amount of fringes recorded and the amount of delay the interferometer induces to the light. Velocity per fringe (VPF) is related by the equation:

$$VPF = \lambda / 2\tau (1 + \Delta \frac{v}{\Delta})^{1/1+\gamma}$$

where: λ = laser wavelength

τ = delay time in the interferometer

$\Delta v/v$ = correction for window materials

γ = correction factor for refractive index vs wavelength

The fringe change (phase-time change) is captured by the optical detectors (pmt's) and the amount of fringe movement is correlated to the amount of delay in one leg of the interferometer cavity. The VISAR cavity can be configured with varying amounts of delay for the anticipated velocity range or multiple systems may be used to cover a wider range of velocities. The normal range of velocities VISAR normally covers is 100-8000 meters-per-second.

SOLID STATE VISAR

VISAR has been limited to the laboratory because of its large size, sensitivity to transportation, large electrical & heating requirements and setup complexity. Recently, a new VISAR (Fixed Cavity VISAR) has been developed which uses an interferometer cavity that is permanently cemented together (figure 3). Although this improvement reduces the size and complexity of the system and simplifies operation, the large size, power and cooling requirements restricts portability of the system. Also, fiber optic coupling is limited to short runs because of the high attenuation and low bandwidth for short (514nm) wavelengths that the argon-ion laser produces.

Two types of solid state VISARs have been successfully designed, built and tested. The design differences revolve around the laser and detectors. These systems use low power consumption and the components are rugged enough to be used in the field. The attenuation and bandwidth are substantially lower than visible lasers allowing long fiber optic runs with minimal losses.

DIODE LASER BASED VISAR

Single mode-single frequency diode lasers with a power output of 120 milliWatts operating at 830 nanometers wavelength are used for this system. The output beam is collimated using either GRIN lenses or aspherical lenses. The optical isolation of the laser to prevent mode hopping and damage to the laser is accomplished by installing an optical isolator. The Faraday effect is used to rotate the polarization of the laser light 45 degrees. Two polarizers are installed on either side of the Faraday rotator which cancels out any reflected light trying to re-enter the laser cavity. The transmitted light is then focused into a fiber optic and the light is routed to the experiment via an optical probe (figure 6). The light is focused on the target and the reflected light is picked up by a second fiber and transmitted to the interferometer cavity.

The detectors used to convert optical power to electrical power are solid state Schottky silicon photodetectors. Silicon based detectors are preferred because their sensitivity is peaked for the wavelength of the laser. Various alignments and beam manipulation is difficult with an invisible beam. A simple solution is using a fiber optic splitter in reverse. A visible diode laser (680 nm wavelength) is injected into the fiber optic and routed through the optics at the target area. Since the visible laser is routed through the same fiber optic as the VISAR laser and the wavelength is not appreciably different and the insertion loss is only .5 decibels (db) per laser. This system enables the user to do the alignment without the use of infra-red imaging devices.

DIODE PUMPED Nd:YLF LASER BASED VISAR

Although diode laser light has a fairly low loss in fiber optics, there are situations where minimal attenuation and maximum bandwidth are critical. Dispersion is a major concern in maximizing bandwidth. There is a point where dispersion approaches zero at a particular wavelength when light is propagating in a typical silica fiber optic (figure 7). A diode pumped Nd:YLF laser with an output wavelength of 1319 nanometers and output power of 160 milliWatts is used in conjunction with InGaAs based detectors. This VISAR is capable of operation with kilometer length fiber optics.

DESIGN CONSIDERATIONS

Although these two types of lasers are quite different in their lasing mechanisms, they share many of the same traits that must be considered when designing a solid state VISAR.

OPTICAL FEEDBACK

Optical isolation of the laser from any backreflected light is essential for proper mode structure and longevity of the laser. A diode laser operating in the single frequency-single longitudinal mode is especially sensitive to optical feedback and will hop modes or operate in a multimode structure with as little as .05% backreflected light returning to the cavity (Dakin & Culshaw(figure 8)). A greater than 38 db isolation using a TIGG crystal Faraday rotator is usually enough for most applications. Minimization of fiber optic connectors will also reduce the feedback due to Fresnel reflections at each connector surface. Wherever possible, connectors using index matching fluid should be used to virtually eliminate Fresnel backreflections.

Nd:YLF lasers are 30-100 times less sensitive to optical feedback than diode lasers. Also, the longer operating wavelength allows the use of BIG (bismuth iron garnet) deposited film isolators. Termed "aspirin tablet" isolators, they are well suited for compact design when size is important.

LIGHT INJECTION INTO FIBER OPTICS

Injecting light from a laser diode into fiber optics is more difficult than most lasers emitting a collimated beam because of the large beam divergence that is not uniform. Care must be taken to keep planar surfaces that are normal to the laser out of the optical design so optical feedback is reduced. Since the beam's divergence is too large for direct transmission through the optical isolator, it must be collimated first, meaning that there is no isolator protecting the laser from the fresnel reflections off of the lens. Two types of collimating lenses have been used successfully with the diode laser. A GRIN (GRADIENT INDEX) lens with a convex front surface and an angle polished rear surface both with anti-reflective coatings is an economical, compact method of collimating the light through the isolator. Recently, Corning Glass has been able to manufacture diffraction limited aspheric lenses that are also suitable for optimum collimation while minimizing aberrations.

These methods of collimation are not necessary for the Nd:YLF laser since the light is collimated well enough for transmission through the isolator. Selecting optics for injection of light into fiber optics is dependant on the diameter of the fiber optic core and its Numerical Aperture (NA). The ideal optical design for light injection is a diffraction limited lens with a focal length as short as possible with the working NA of the lens less than the NA of the fiber. (NA is the sine of the half angle of the cone of light exiting a lens. NA of a fiber optic is the sine of the maximum half angle that light is coupled and guided in a fiber and also the half angle of the exiting light.)

FIBER OPTIC SELECTION

Careful selection of fiber optics is essential for proper bandwidth and efficiency of the system. Multimode fiber optics are preferred because single mode fiber optics are difficult to inject light into, are sensitive to bending and exhibit nonlinearities such as Stimulated Brillouin Scattering and wavelength broadening. Normally light is sent to the target in a 50 um fiber optic and collected with the largest fiber that still has adequate bandwidth for the test. The small diameter of the sending fiber has a smaller exit aperture and is easier to image a small spot on the target. Conversely, the smaller spot is more efficiently imaged into the return fiber and thus signal strength is larger. Visible wavelength laser beams not only exhibit large attenuations in fibers but the bandwidth is also lower due to more coupled modes and higher dispersion. Although the diode laser has low attenuation and dispersion in fiber optics compared to the argon-ion laser, The Nd:YLF laser operating at 1319 nm wavelength has much lower attenuation than the diode laser and has the lowest dispersion of any laser operating outside the 1300 nm wavelength. This is due to several modes of dispersion cancelling out each other.

DETECTORS

For most uses, PIN, Schottky and APD are the three most common types of high speed solid state photodetectors. APD (avalanche photodiode) has an internal gain when biased near its threshold. Its disadvantages are that it must have a very well regulated high voltage power supply and they also have fairly long transit times for the hole carriers. PIN diodes have fairly high parasitic resistance which reduces the operating bandwidth. Schottky diodes are the preferred choice because they have low parasitic resistance allowing a high bandwidth while retaining a larger active area than APD or PIN photodiodes. Large active areas are essential for ease of alignment since the light must be focused completely into the active area of the detector (some high speed detectors have active areas of only 100um in diameter).

SUMMARY

The visible laser/photomultiplier tube VISAR with the open beam to the target is the simplest, most light efficient system and is preferred for laboratory conditions where only short, if any, distances of fiber optic transmission is required. If the user needs remote testing capabilities, low power requirements, portability, or foresees any condition where long lengths (>200

meters) of fiber optic cable is needed, the solid state fiber coupled VISAR may be the right system.

DEFINITION OF TERMS

- **VISAR - VELOCITY INTERFEROMETER SYSTEM FOR ANY REFLECTING SURFACE**
- **MONOCHROMATIC LIGHT - LIGHT COMPOSED OF A VERY NARROW BAND OF WAVELENGTHS**
- **DOPPLER SHIFT - THE CHANGE IN FREQUENCY OF LIGHT REFLECTED FROM A MOVING OBJECT**
- **INTERFERENCE PATTERN - THE RESULTING LIGHT LEVEL WHEN TWO OR MORE WAVELENGTHS ARE COMBINED**



SANDIA NATIONAL LABORATORIES

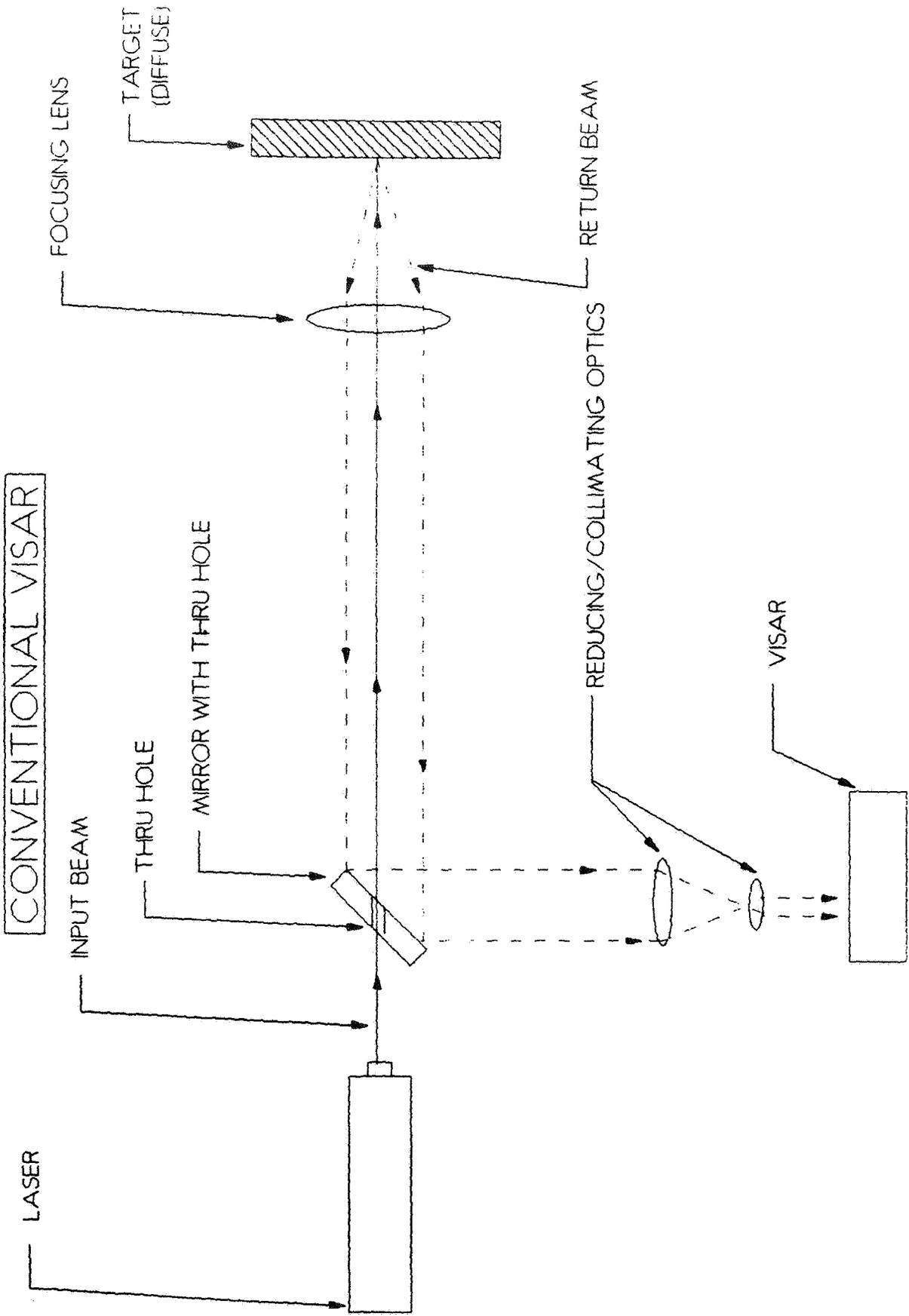
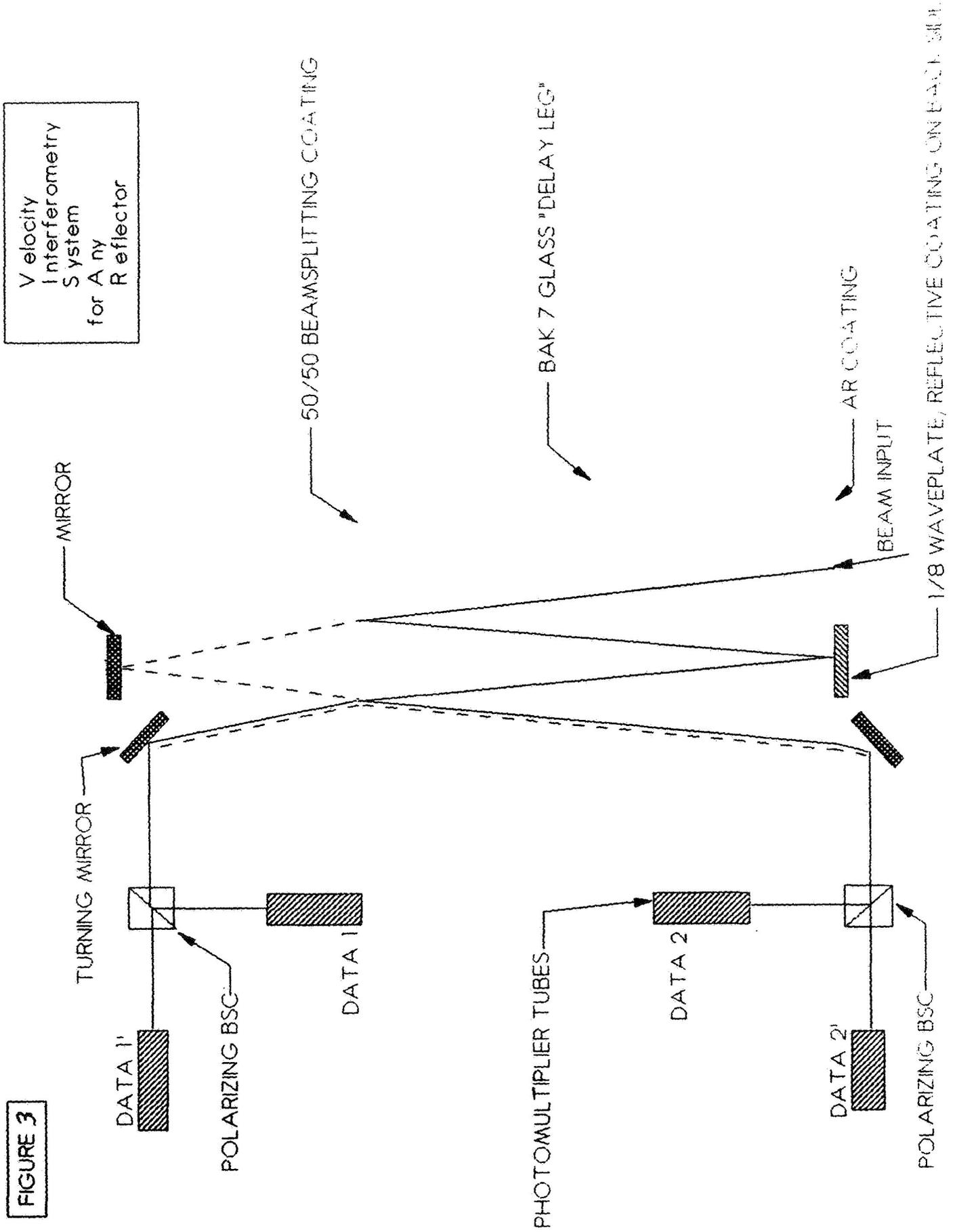
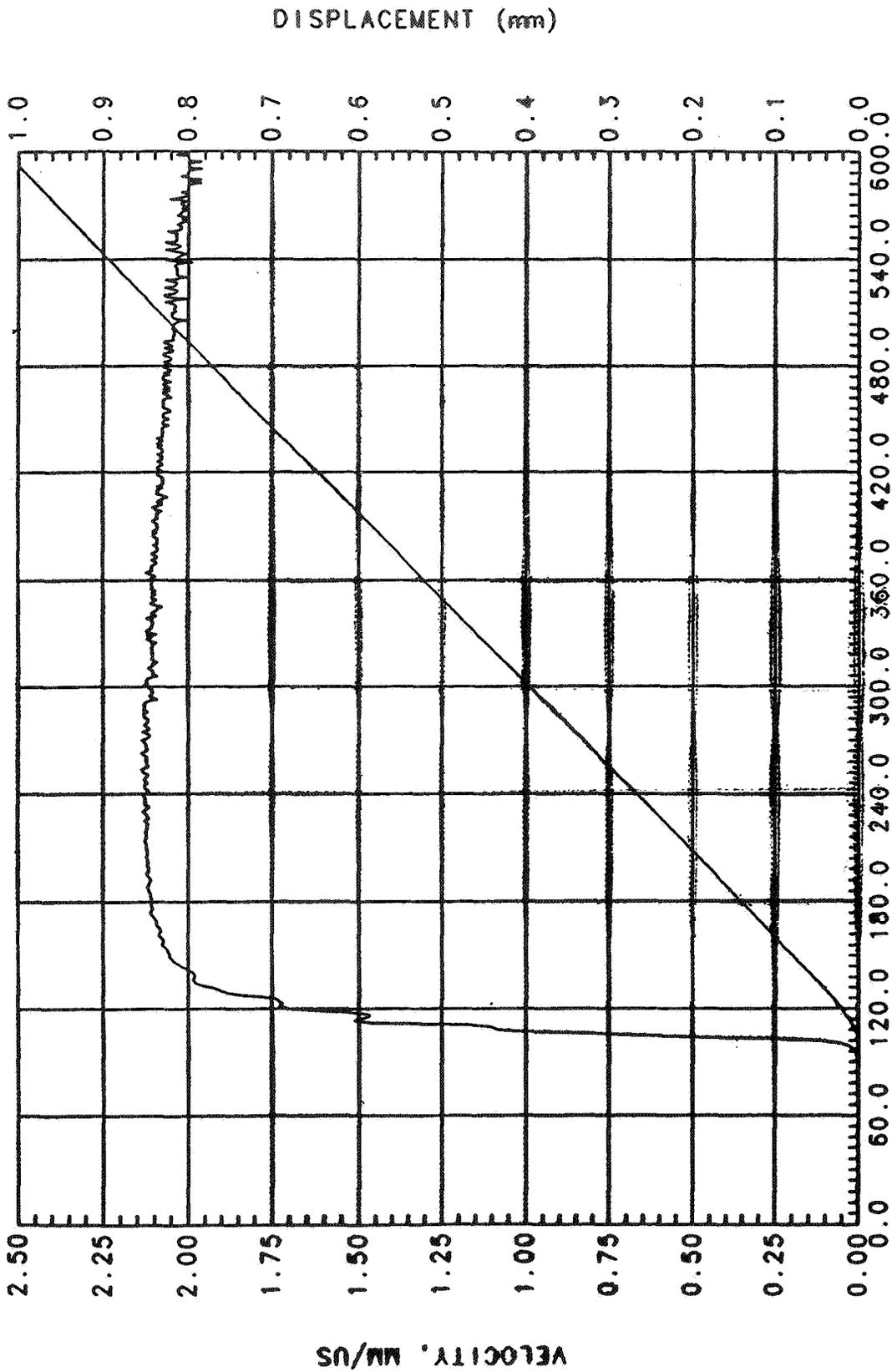


figure 2

FIGURE 3





TIME (n-sec)

dot:DOI1FP.V05

10-MAR-92
16:08:59

Figure 4

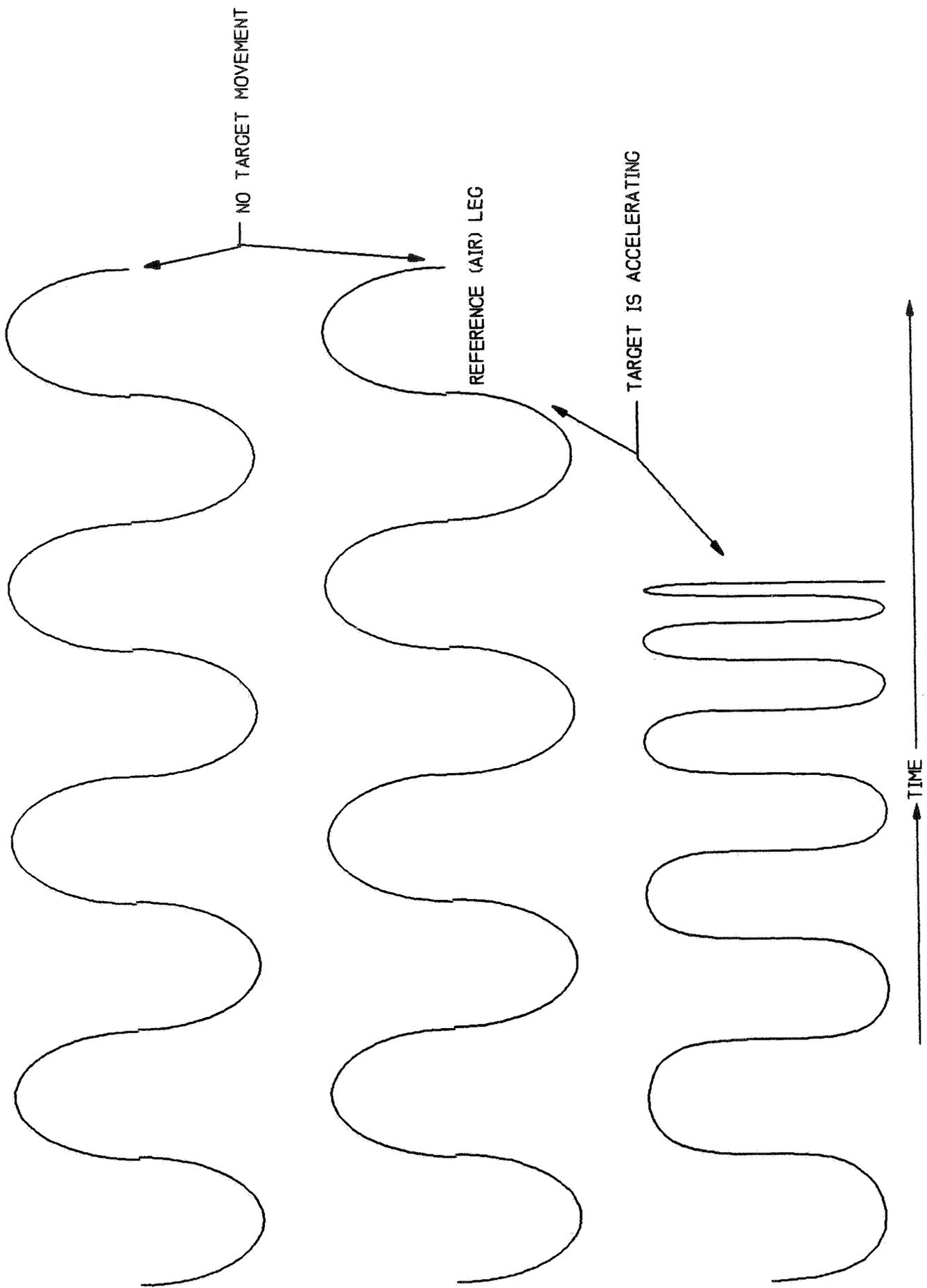
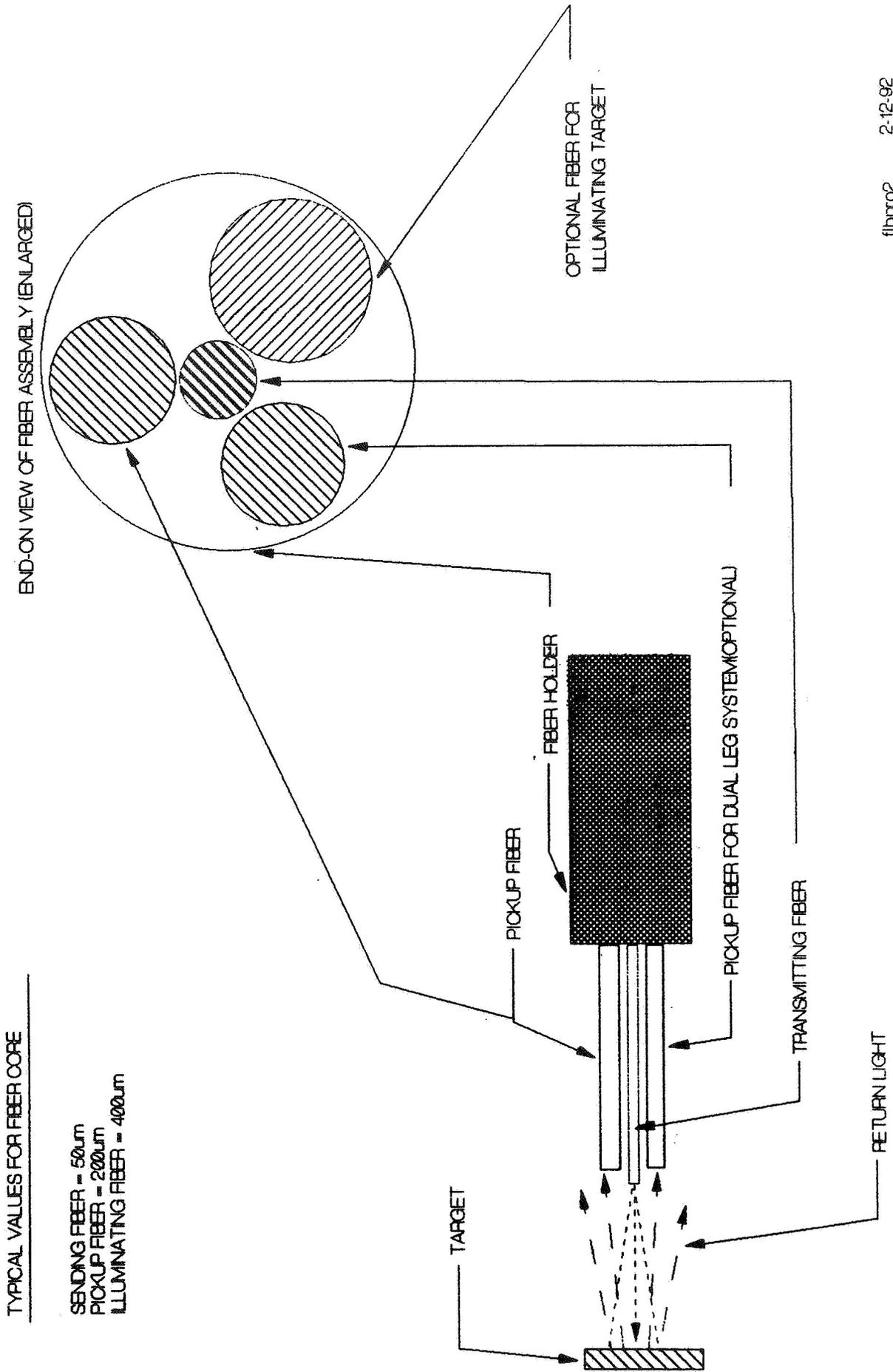


Figure 5

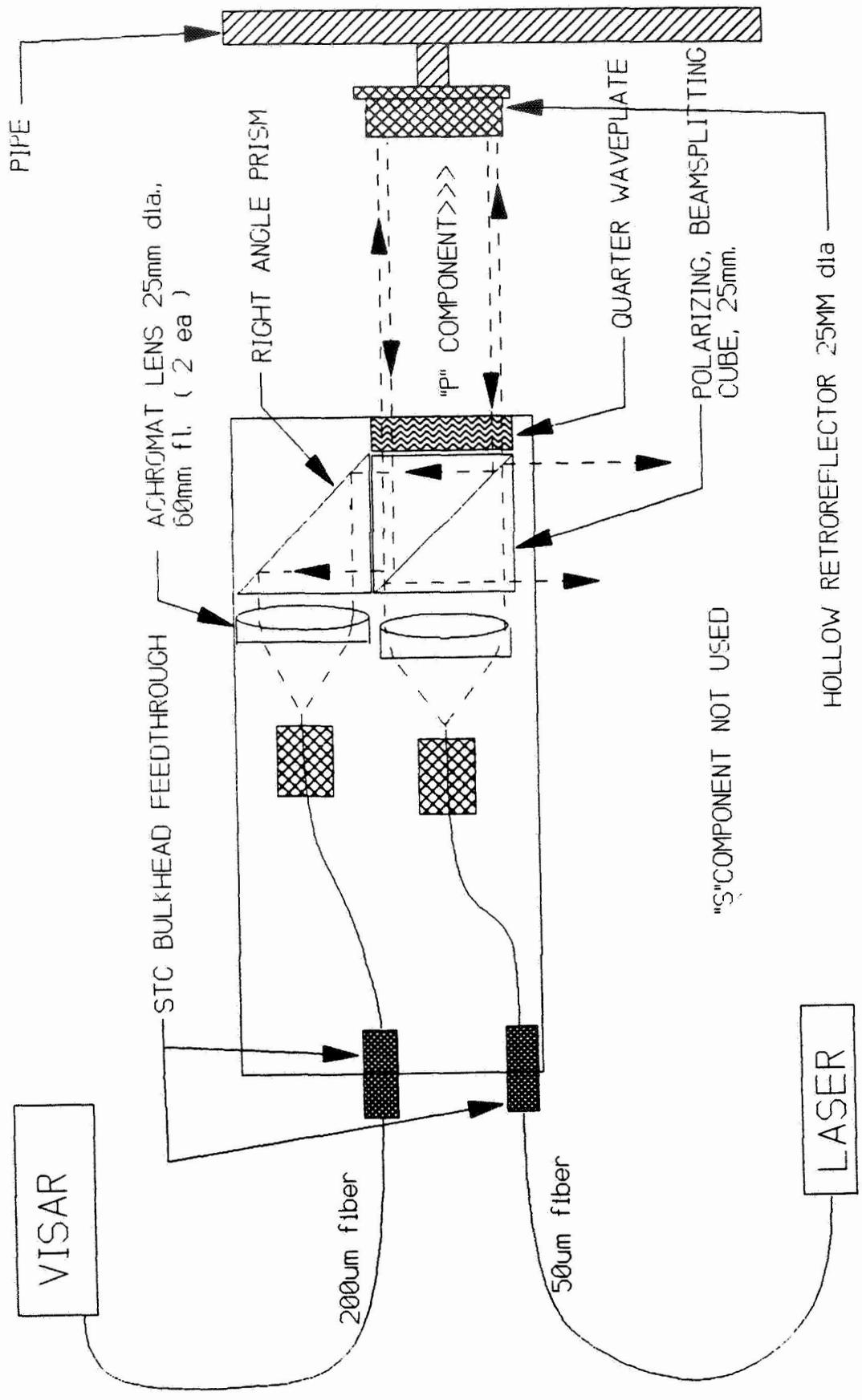
MULTI-FIBER PROBE



270
C-4

Figure 6

HUNTER'S TROPHY EXTENDED RANGE PROBE



I.F.H.T.P

Figure 6a

ATTENUATION IN FIBER OPTICS

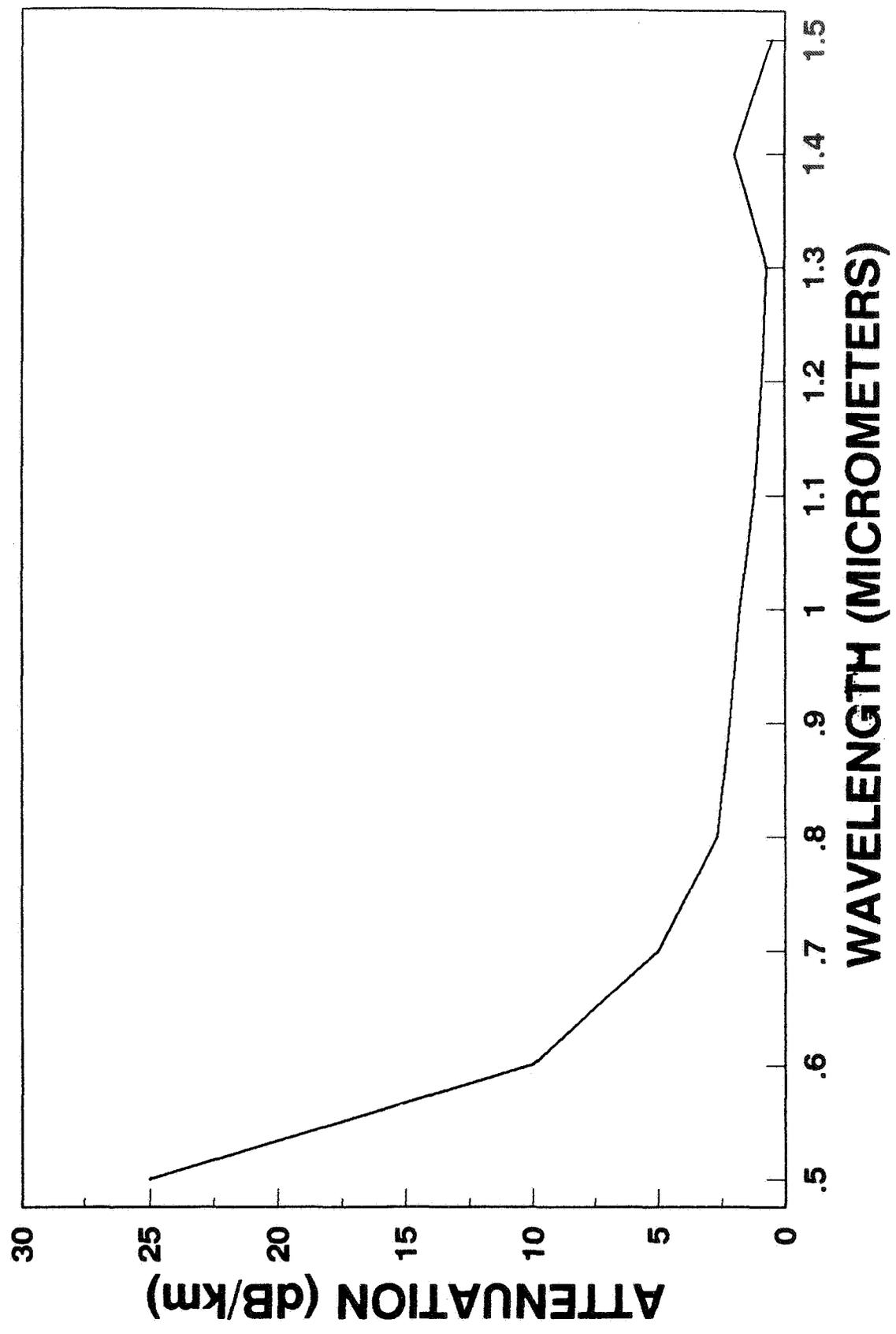


Figure 7

SPATIAL MODE STRUCTURE WITH VARYING OPTICAL FEEDBACK

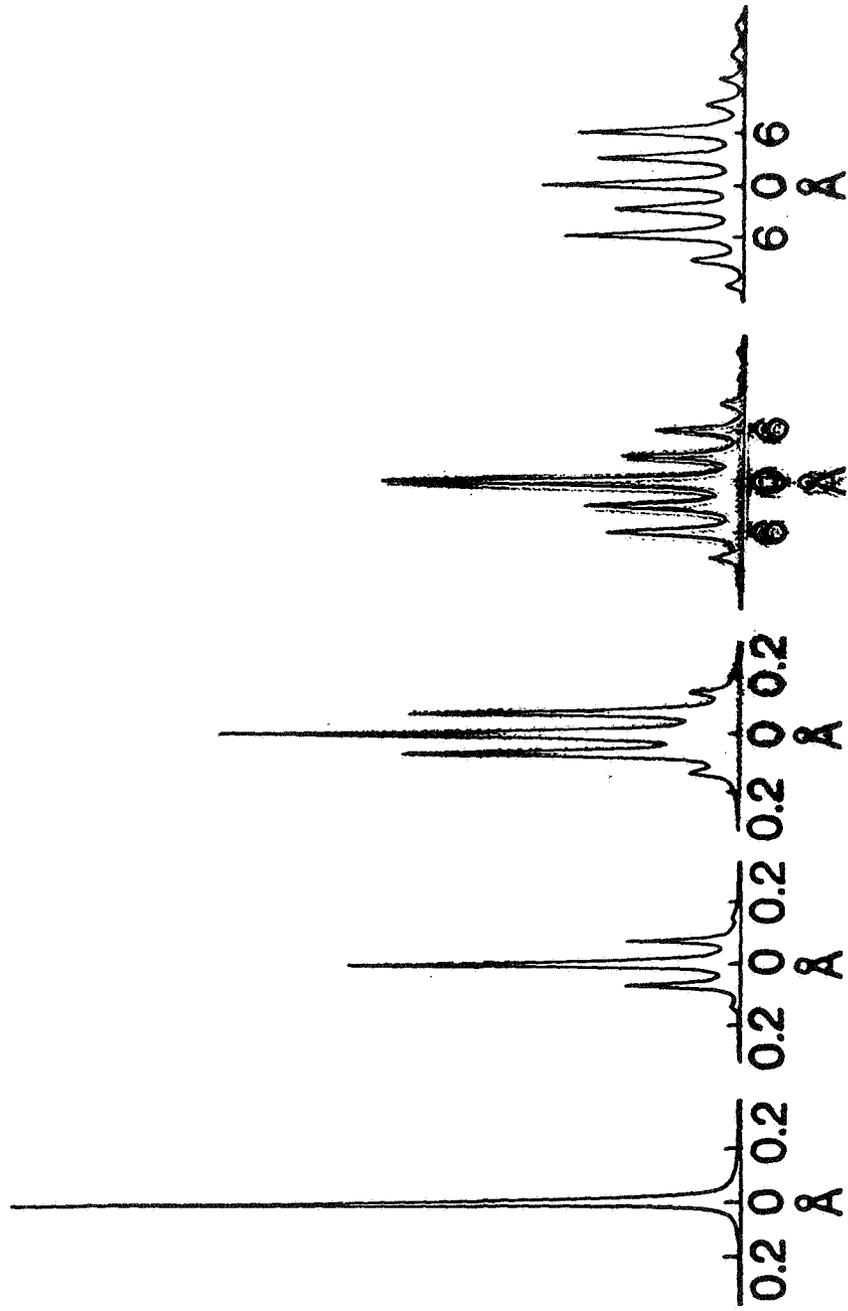


Figure 8

This page intentionally left blank.

Development and Testing of Hermetic, Laser-Ignited
Pyrotechnic and Explosive Components

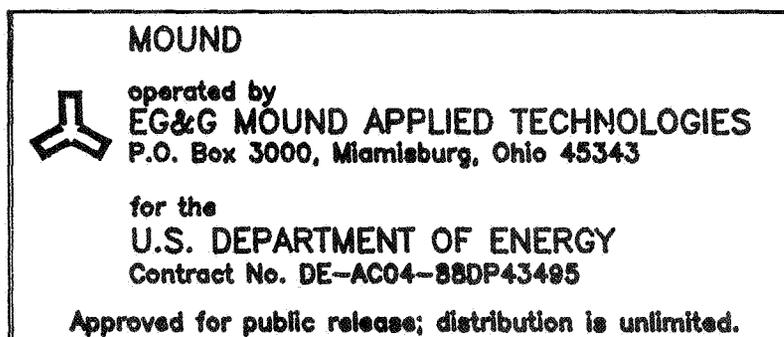
1993018960
493063
12P
N93-20149

D.P. Kramer, T.M. Beckman, E.M. Spangler,
A.C. Munger and C.M. Woods
EG&G Mound Applied Technologies

ABSTRACT

During the last decade there has been increasing interest in the use of lasers in place of electrical systems to ignite various pyrotechnic and explosive materials. The principal driving force for this work has been the requirement for safer energetic components which would be insensitive to electrostatic and electromagnetic radiation. In the last few years this research has accelerated since the basic concepts have been proven viable. At the present time it is appropriate to shift the research emphasis in laser initiation from the scientific arena or whether it can be done to the engineering realm or how it can be put into actual practice in the field.

Laser initiation research and development at EG&G Mound has been in three principal areas: 1) laser/energetic material interactions, 2) development of novel processing techniques for fabricating hermetic (helium leak rate of less than 1×10^{-8} cm³/s) laser components, and 3) evaluation and testing of laser-ignited components. Research in these three areas has resulted in the development of high quality, hermetic, laser initiated components. Examples are presented which demonstrate the practicality of fabricating hermetic, laser initiated explosive or pyrotechnic components that can be used in the next generation of ignitors, actuators, and detonators.



INTRODUCTION

Present-day explosive and pyrotechnic devices, which include detonators, ignitors, and actuators, are functioned by applying an electrical signal to one or several bridgewires [1,2]. This is accomplished by sending the signal through the metal pin(s) (which are electrically isolated from each other and the metal shell by an insulating material, usually a ceramic, glass, or glass-ceramic) to the bridgewire. The energy transferred via the bridgewire is used to ignite the energetic material. In order for the component to function successfully, the selected insulating material must form a high-quality seal with the pin(s) and with the shell [3-4]. In many applications, the seal must be leaktight or hermetic (helium leak rate of $<1 \times 10^{-6}$ cm³/s) and of sufficient strength to ensure successful functioning of the component.

Over the years bridgewire devices have been employed in systems despite having several inherent safety limitations. These safety concerns are based on the fact that the explosive or pyrotechnic material is not truly isolated from its surroundings, making these components susceptible to the effect of outside electromagnetic radiation. This safety consideration has been the driving force for the design of a new family of laser-ignited components that would be impervious to spurious levels of electromagnetic radiation. It is envisioned that laser components, which are insensitive to various high-risk environments, will eventually replace classical bridgewire components in many applications.

Past research on the laser initiation of energetic materials has centered primarily on understanding or measuring the interaction between lasers and these materials [5-8]. This work successfully demonstrated that laser ignition of energetic materials is feasible and, most importantly, reliable. Over the past few years research in this discipline has shifted from a scientific emphasis to one of engineering centered on the development of actual hermetic, laser-ignited components [9-14]. These components can be functioned by a variety of lasers, including laser diodes, which produce a sufficient output energy through an optical fiber to ignite the energetic material. These safer laser components require the fabrication of high-strength, hermetic seals with small-diameter optical fibers or transparent windows. The emphasis of this paper is to demonstrate the feasibility of fabricating hermetic, laser-ignited, explosive or pyrotechnic devices that could be used in the next generation of ignitors, actuators, and detonators.

DESIGN AND TESTING OF HERMETIC, LASER INITIATED COMPONENTS

Three principal design configurations (Figure 1) are under development for fabricating laser initiated components: 1) Direct Fiber Placement, 2) Fiber Pin, and 3) Transparent Windows. Each of these approaches has certain identifiable strengths and weaknesses depending on the required application. This paper will present examples of each type of component and some illustrations of firing results which have been obtained.

Direct Fiber Placement Components

As shown in Figure 1, Direct Fiber Placement components contain a length of optical fiber hermetically sealed within the component. In these devices, one end of the optical fiber is located at the former "bridgewire surface," while the other end "pigtails" out of the device for several centimeters or meters which then could be used for connecting to a laser or to another connector. The principal advantages of this type of design are: 1) the number of connections between the component and the laser is reduced, which minimizes losses due to interfacial reflections, 2) the optical fiber is sealed within the device, thus eliminating alignment problems, and 3) close tolerances can be obtained since the fiber is in final position prior to sealing.

The principal difficulty in the fabrication of Direct Fiber Placement components has been in developing processing techniques which result in a hermetic glass seal between the optical fiber and

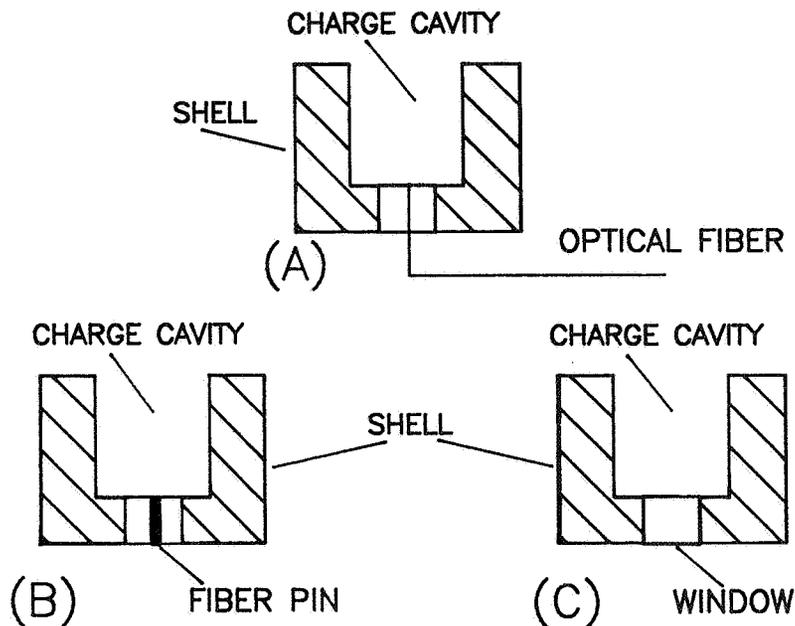


Figure 1 - Comparison of the three principal design configurations under consideration for laser-ignited components: (A) Direct Fiber Placement, (B) Fiber Pin, and (C) Transparent Window.

the sealing glass and between the sealing glass and the structural member or shell. This is difficult to accomplish without cracking the optical fiber due to the large coefficient of thermal expansion mismatch (α) between typical fused silica optical fibers ($\alpha \sim 8 \times 10^{-7}$ cm/cm/ $^{\circ}$ C, 25 to 400 $^{\circ}$ C) and the shell material such as a stainless steel ($\alpha \sim 170 \times 10^{-7}$ cm/cm/ $^{\circ}$ C, 25 to 400 $^{\circ}$ C). However, the Direct Fiber Placement component shown in Figure 2 was successfully fabricated using one of several Fiber Insertion Processing techniques which have been developed [15]. These components were fabricated using a SMA 906 alumina ferrule connector (obtained from Optical Fiber Technologies, Inc., Billerica, MA) as the shell material. The connector was modified to accept a glass preform, which was used to form the hermetic seal with a stepped index, 100-micron core optical fiber. After seal formation, a standard alumina ferrule SMA connector was glued to the unsealed end of the optical fiber and both connectors were polished using standard techniques.

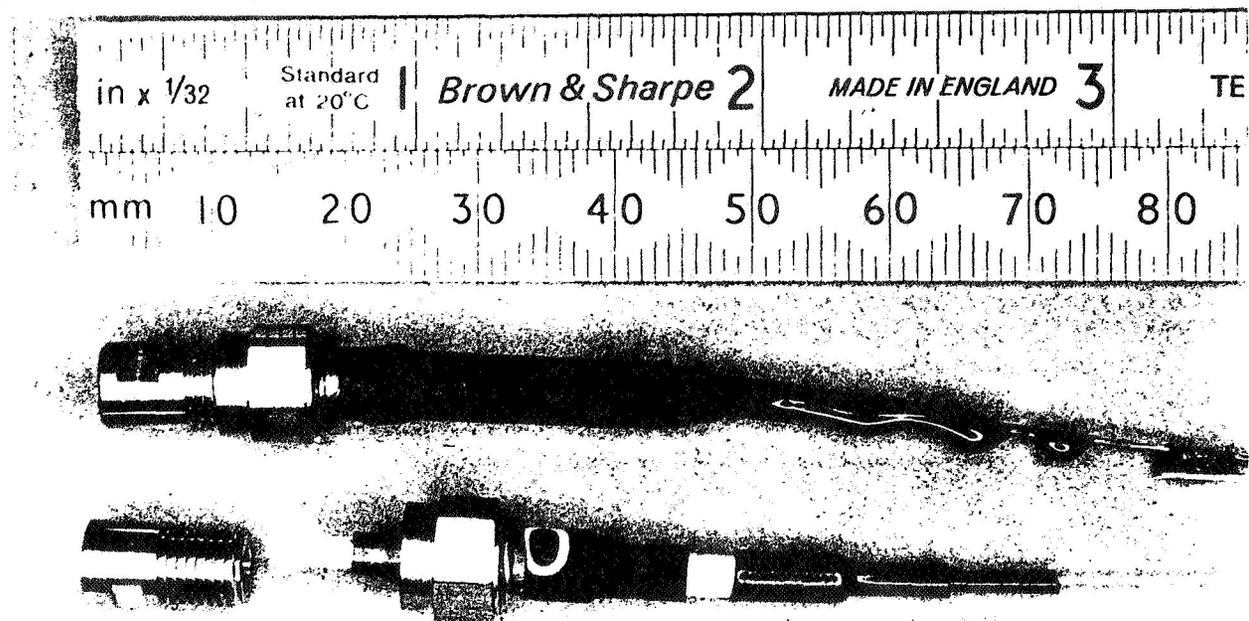


Figure 2 - An example of a "full-up" Direct Fiber Placement Device (top), assembled from a loaded shell (bottom left) and a sealed Direct Fiber Placement component (bottom right).

Several of the Direct Fiber Placement test components were loaded with either Ti/KClO₄ or CP (2-(5-cyanotetrazolato) pentaamine cobalt III perchlorate) doped with carbon black. The CP/carbon black units were loaded with 17.0 mg of powder pressed to a density of 1.7 g/cm³, while the Ti/KClO₄ units were loaded with 20.0 mg of powder to a density of 2.0 g/cm³. The components were ready for firing after a closure disc was welded onto the output end of the unit. Firing tests were performed using the test setup shown in Figure 3. The components were ignited using a 500-mW, 10-ms (5.0-mJ) laser diode pulse. All of the components functioned and the test results for two of these components are shown in Figure 4.

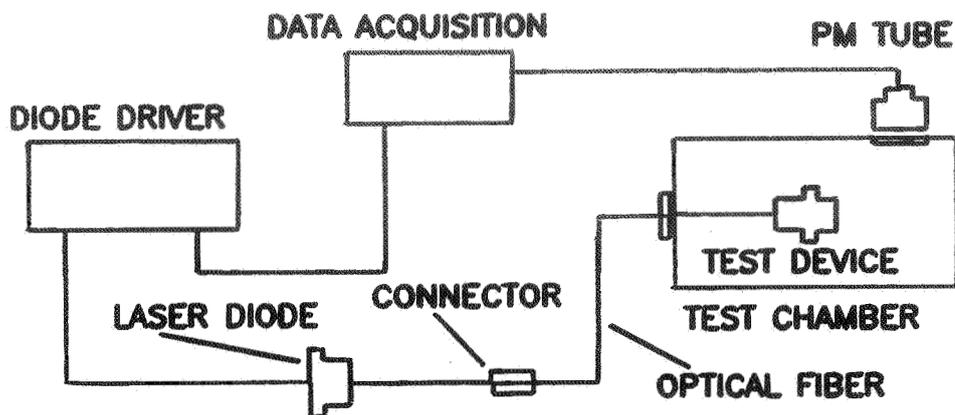


Figure 3 - Test setup used in determining the function times of the fabricated devices.

Figure 4(B) was obtained on a CP/carbon black loaded component, and shows a very short function time of $\sim 0.2-0.4$ ms. Figure 4(C) was obtained on a Ti/KClO_4 loaded device and it exhibited a longer function time of ~ 1 -ms. The results obtained on the components were encouraging since the units functioned during the initial part of the laser diode pulse. The difference between the function times obtained on these two components is related to CP/carbon black having a lower laser ignition threshold value than Ti/KClO_4 . An energetic material's laser ignition threshold value is a function of its heat capacity, thermal conductivity, and several other physical and chemical properties.

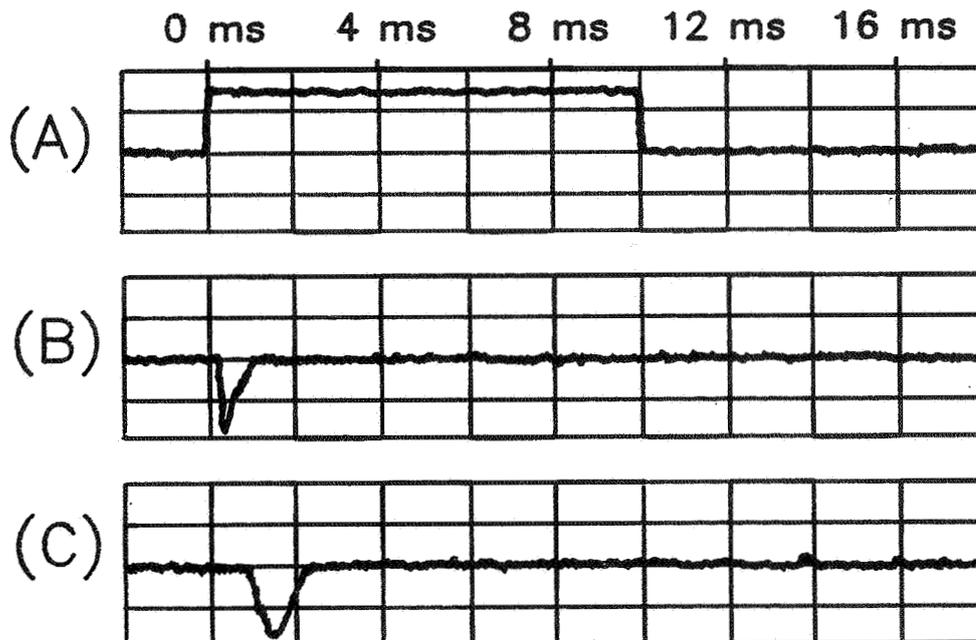


Figure 4 - Traces of the laser diode pulse (A), the photodetector signal obtained from a hermetic, CP/carbon black-loaded, Direct Fiber Placement component (B), and from a hermetic, Ti/KClO_4 -loaded, Direct Fiber Placement component (C).

Fiber Pin Components

Fiber Pin components (Figure 1) are fabricated using short lengths of optical fibers or "pin(s)," which are meant to function in the same general manner as the metal pins they replace. Some advantages of Fiber Pin devices are: 1) the "pin(s)" are optical fibers, which mean they act as waveguides, 2) there is no fiber pigtail that may be damaged during handling, and 3) these devices can be designed to withstand high pressures. The latter is true since the pressure spike applied to the "optical pin" during functioning is low due to the fiber's small cross-sectional area. The main disadvantage of these components is that they must be mated with an external connection to the energy source. This is not trivial since the alignment of two small diameter optical fibers (typically less than 200 microns) may be difficult, especially when one of the fibers is sealed within a device. Connections of this type also typically result in inherent signal losses due to angular and axial fiber misalignments and reflections.

An example of a high-strength Fiber Pin device is shown in Figure 5. This component was fabricated by first fixturing, a stainless steel shell, a glass preform, and an optical fiber. After fixturing, hermetic seals between the glass and the shell and between the glass and the optical fiber were formed by heating in a furnace to the appropriate temperature. The main difficulty in fabricating these components is obtaining crack-free, hermetic seals due to the large mismatch in the coefficients of thermal expansion between the stainless steel shell and the optical fiber. The formation of crack-free, leaktight seals is made possible only by the careful selection of the sealing glass and by the precise control of the time-temperature furnace parameters.

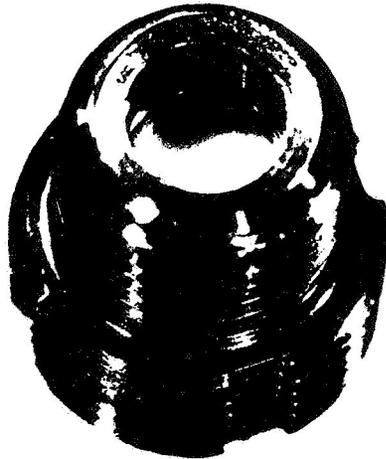


Figure 5 - Fiber Pin device (maximum O.D. ~1.27-mm) that was fabricated with a short length of optical fiber (small spot in the glass) instead of a metal pin.

Fiber Pin components have been prepared by loading with ~ 93 mg of $\text{TiH}_{1.65}/\text{KClO}_4$ powder pressed to a density of 2.2 g/cm^3 . These components were designed to be high-strength devices capable of withstanding the high pressures produced during the ignition of the pyrotechnic without self-destructing. This type of function testing has been designated as Zero Volume Firing. Zero Volume Firing is an extreme overtest performed by threading the component into a pressure block that contains a calibrated transducer. Figure 6 shows the test setup used in the Zero Volume Firing tests, which were performed by driving the laser diode output to ~ 700 - 800 mW for a pulse length of 10-ms (7-8 mJ). Figure 7 shows the results of a Zero Volume Firing test obtained on one of the loaded Fiber Pin components. The top trace in Figure 7 shows the time duration of the laser diode pulse (10-ms), while on the bottom is the pressure trace. The maximum pressure obtained with this

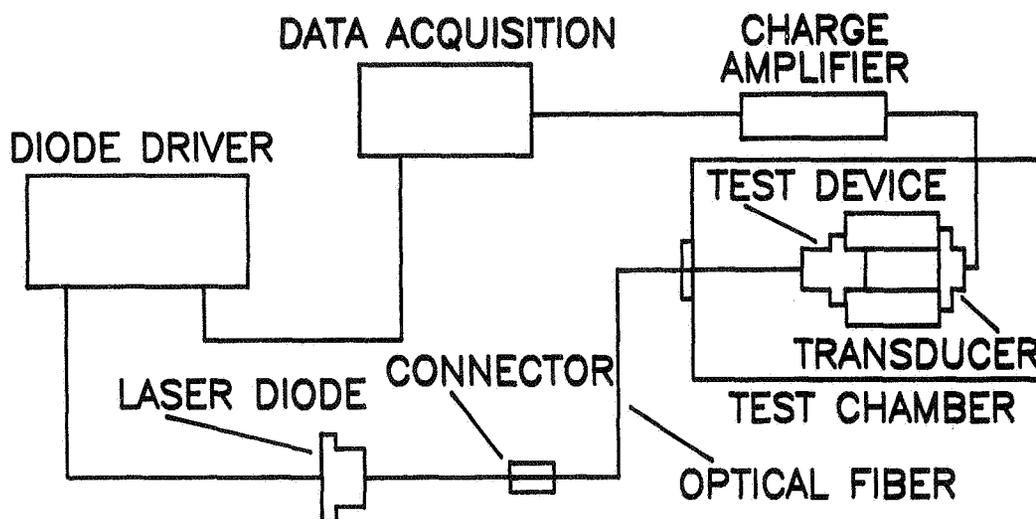


Figure 6 - Test setup used in determining the pressure output of fabricated high-strength test components.

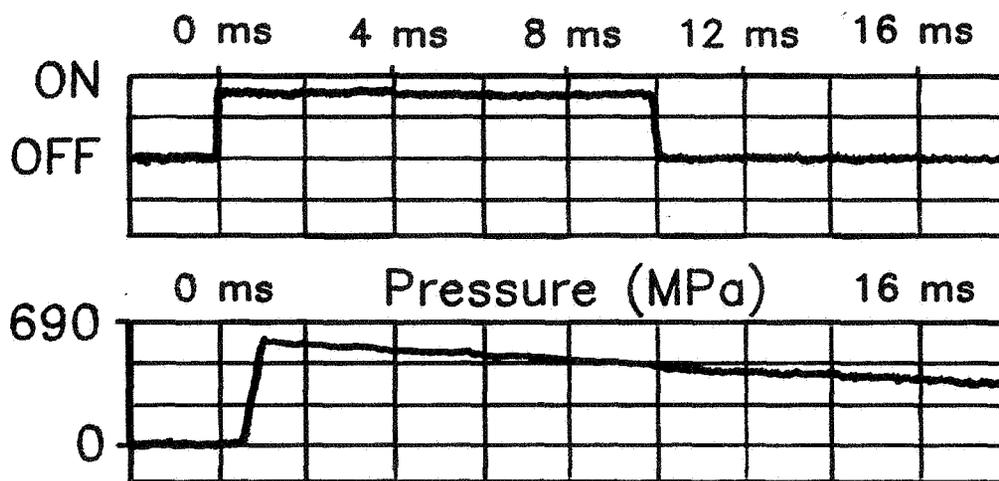


Figure 7 - Traces of the laser diode pulse (top) and of the transducer output (bottom) obtained on a $\text{TiH}_{1.65}/\text{KClO}_4$ loaded, hermetic, Fiber Pin device.

stainless steel device was ~ 550 MPa ($\sim 80,000$ psi). The trace shows that the component successfully held the pressure without failure. The slight decrease in the pressure trace as a function of time is due to the cooling of the reaction products and not due to any pressure release by the component.

Transparent Window Components

Transparent Window components (Figure 1) are classified as components that contain a transparent window sealed within the structural member or shell. The window has typically been fabricated out of either sapphire or glass. The selection of the window material is based on a number of considerations including: 1) the index of refraction of the window material, 2) the required strength of the component, and 3) the thermal expansion relationship between the window and the shell.

Window components have one very significant characteristic which makes them very attractive for application in laser-ignited components. This advantage is that the window diameter is many times larger than that of the connecting optical fiber. Therefore, there are minimal concerns about aligning the connecting optical fiber to the window. This eliminates signal losses due to misalignment. However, window components have basically the same limitations as Fiber Pin devices in that they have inherent losses due to reflections at the fiber-to-window interface. In addition, window components have the added disadvantage in that the window does not act as a waveguide; hence, the incident light will diverge as it travels through the thickness of the window. The magnitude of the divergence is a function of window thickness (which determines the strength of the window) and the window's index of refraction. Therefore, the design engineer must accept a trade-off between the amount of beam divergence that is acceptable to insure the functioning of the component and its required strength.

An example of a window component that has been developed jointly with the U.S. Navy is shown in Figure 8. This component is a hermetic, stand-alone, laser-ignited deflagration-to-detonation transition (DDT) detonator which was originally designed for use with the Navy's Laser Initiated Transfer Energy Subsystem (LITES) [16-18]. The detonator uses the secondary explosive HMX doped with 3% carbon black as the ignition charge and undoped HMX as the transition charge. In all of the development tests conducted the detonator has successfully functioned as designed and has remained completely intact after detonation. These tests were accomplished using a pulse from a Nd:YAG laser through a 1-mm optical fiber, even though other optical fiber/laser combinations could be utilized. As designed, the detonator has been determined to be capable of successfully effecting detonation transfer in a number of configurations after being initiated from a laser source.

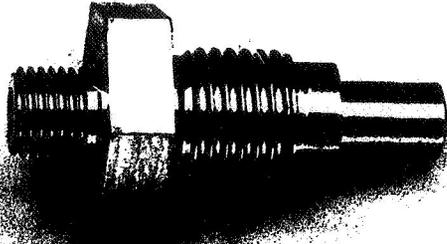
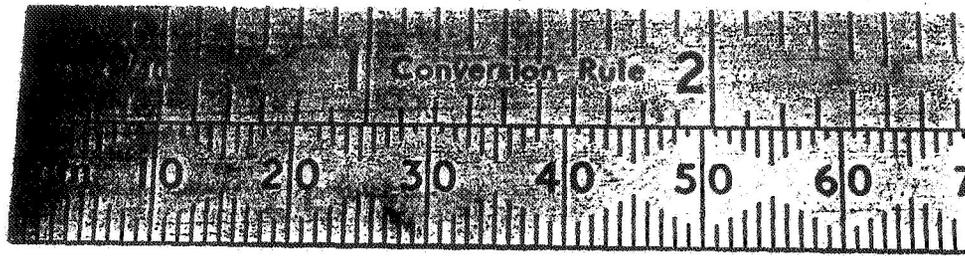


Figure 8 - Hermetic, window, laser-ignited all-HMX DDT detonator.

SUMMARY

It has been demonstrated that the fabrication of hermetic, laser ignited, pyrotechnic and explosive components is possible. This new technology based on a laser/optical fiber or window combination in place of bridgewire(s) and pin(s) can readily be adapted to various engineering requirements. Several novel processing techniques have been developed for fabricating these devices that have been shown to exhibit the required strength and hermeticity to ensure the successful functioning of the device. Examples of several types of laser-ignited devices have been fabricated and tested using a variety of pyrotechnic and explosive materials. These function tests have confirmed that reliable, high-strength devices can be produced. The results illustrate that there are no fundamental reasons why laser ignited components should not be considered for future designs of pyrotechnic and explosive components.

ACKNOWLEDGEMENTS

The authors would like to thank the many people at Mound in the Ceramic Machine Shop, the Welding Group, and the Nondestructive Evaluation Group whose support and assistance made this research possible. The authors would also like to thank Tom Blachowski, Naval Surface Warfare Center, Indian Head, for all of his support and assistance.

REFERENCES

- 1) K.O. Brauer, Explosive-Actuated Devices, pp. 39-80, in Handbook of Pyrotechnics, Chemical Publishing Co., Inc., New York, New York, 1974.
- 2) R.T. Barbour, Initiators, Detonators, and Primers, pp. 11-25, in Pyrotechnics in Industry, McGraw-Hill Book Company, New York, New York, 1981.
- 3) D.P. Kramer and R.T. Massey, "Design and Fabrication of Super High Strength Glass-Ceramic to Metal Seals," Ceramic Engineering and Science Proceedings, Vol. 5, No. 7-8, 739-751, 1984.
- 4) D.P. Kramer, W.E. Moddeman and M.D. Kelly, "Hot Isostatic Pressing of High Performance Glass-Ceramic to Metal Components," Ceramic Engineering and Science Proceedings, Vol. 12, no. 9-10, 2175-2189, 1991.
- 5) V.J. Menichelli and L.C. Yang, "Direct Laser Initiation of Insensitive Explosives," Proceedings of the Seventh Symposium on Explosives and Pyrotechnics, pp. III-2-1 to III-2-8, Philadelphia, PA, 1971.
- 6) L.C. Yang and V.J. Menichelli, "A High-Efficiency, Small, Solid-State Laser for Pyrotechnic Ignition," JPL Quarterly Technical Review, Vol.2, No. 4, pp. 29-37, Jet Propulsion Laboratory, Pasadena, CA, 1973.
- 7) J.A. Holy and T.C. Girmann, "The Effects of Pressure on the Laser Initiation of $TiH_x/KClO_4$ and Other Pyrotechnics," Proceedings of the Thirteenth International Pyrotechnics Seminar, The International Pyrotechnic Society, 449-468, Grand Junction, CO, 1988.
- 8) D.W. Ewick, T.M. Beckman, J.A. Holy and R. Thorpe, "Ignition of HMX Using Low Energy Laser Diodes," Proceedings of the 14th Symposium on Explosives and Pyrotechnics, Franklin Research Center, 2-1/2-17, 1990.
- 9) R.G. Jungst, F.J. Salas, R.D. Watkins and L. Kovacic, "Development of Diode Laser-Ignited Pyrotechnic and Explosive Components," Proceedings of the Fifteenth International Pyrotechnic Seminar, The International Pyrotechnic Society, 549-568, Boulder, CO, 1990.
- 10) D.P. Kramer, T.M. Beckman and D.W. Ewick, "Development and Evaluation of Laser Diode Ignited Pyrotechnic Components," Proceedings of the Fifteenth International Pyrotechnic Seminar, The International Pyrotechnic Society, 569-579, Boulder, CO, 1990.

- 11) S.C. Kunz and F.J. Salas, "Diode Laser Ignition of High Explosives and Pyrotechnics," Proceedings of the Thirteenth International Pyrotechnics Seminar, The International Pyrotechnic Society, 505-523, Grand Junction, CO, 1988.
- 12) D.W. Ewick, L.R. Dosser, S.R. McComb and L.P. Brodsky, "Feasibility of Laser Ignited Pyrotechnic Device," Proceedings of the Thirteenth International Pyrotechnic Seminar, The International Pyrotechnic Society, 263-277, Grand Junction, CO, 1988.
- 13) D.P. Kramer, D.W. Ewick and T.M. Beckman, "Development of Hermetic, Optical Fiber Laser Initiated Pyrotechnic Components," Ceramic Transactions Vol. 28: Solid State Optical Materials, edited by Allan Bruce and Basazaraj Hiremath, The American Ceramic Society, 1992.
- 14) A.C. Munger, T.M. Beckman and D.P. Kramer, "Hot Wire vs. Laser, Is There A Difference?," to be published in the Proceedings of the Eighteenth International Pyrotechnic Seminar, The International Pyrotechnic Society, Breckenridge, CO, 1992.
- 15) D.P. Kramer, "Hermetic Fiber Optic-To-Metal Connection Technique," Patent Pending.
- 16) T.J. Blachowski, "Development of a Flashlamp Pumped Laser and Fiber Optic Initiation Subsystem," Proceedings of the Thirteenth International Pyrotechnics Seminar, The International Pyrotechnic Society, 89-102, Grand Junction, CO, 1988.
- 17) D.W. Ewick, T.M. Beckman and D.P. Kramer, "Feasibility of a Laser-Ignited HMX Deflagration-to-Detonation Device for the U.S. Navy LITES Program," MLM-3691, EG&G Mound Applied Technologies, June 1991, 21 pp.
- 18) C.M. Woods, E.M. Spangler, T.M. Beckman and D.P. Kramer, "Development of a Laser Ignited All Secondary Explosive DDT Detonator," to be published in the Proceedings of the Eighteenth International Pyrotechnic Seminar, The International Pyrotechnic Society, Breckenridge, CO, 1992.

This page intentionally left blank.

**APPLICATION OF THE
MESA REACTIVE HYDROCODE
TO SPACE VEHICLE
EXPLOSIVE ORDNANCE DEVICES**

S. GOLDSTEIN

**NASA AEROSPACE PYROTECHNIC SYSTEMS WORKSHOP
JUNE 9-10, 1992**



THE AEROSPACE CORPORATION

Approved for public release; distribution is unlimited.

1993010961
493070
42p

N93-20150

PRECEDING PAGE BLANK NOT FILMED

This page intentionally left blank.

I AM GOING TO DISCUSS SOME OF THE WORK THAT I AND MY COLLEAGUES, JIM GAGEBY AND ROBERT CHIU, HAVE BEEN DOING AT AEROSPACE TO CONSTRUCT DETAILED COMPUTATIONAL MODELS OF THE DYNAMIC BEHAVIOR OF VARIOUS EXPLOSIVE ORDNANCE DEVICES USED ON SPACE VEHICLES.

This page intentionally left blank.

OUTLINE

- GOALS
- BASIC CONCEPTS
 - NUMERICAL METHODS
 - EXPLOSIVES AND DETONATIONS
- INTRODUCTION TO MESA
- MESA CAPABILITIES
 - EXAMPLES OF APPLICATIONS
- CONCLUSIONS



MY PRESENTATION WILL FIRST LOOK AT THE GOALS WE ARE PURSUING, AND THEN DISCUSS SOME OF THE BASIC PRINCIPLES BEHIND THIS KIND OF MATHEMATICAL MODELING, AND WHAT PHYSICS IS INCLUDED. I WILL GO ON TO DISCUSS THE MESA CODE THAT WE HAVE BEEN USING, ITS HISTORY, AND CAPABILITIES. THE MAJORITY OF MY TIME WILL BE SPENT SHOWING YOU THE RESULTS OF A SAMPLE CALCULATION. I WILL USE THE EXAMPLE TO ILLUSTRATE FEATURES OF THE CODE AND TO SHOW THE DIFFERENT TYPES OF PROBLEMS WE CAN ADDRESS. FINALLY, I WILL DISCUSS THE EFFECTIVENESS OF THIS MODELING, WHAT WE HAVE ACCOMPLISHED THUS FAR, AND WHERE I THINK WE ARE HEADING IN THE NEAR FUTURE.

GOALS

PROVIDE ANALYTICAL TOOLS FOR

- IMPROVEMENT OF EXPLOSIVE ORDNANCE DESIGN
 - UNDERSTAND DEVICE FUNCTION
 - PREDICT PERFORMANCE
- ASSISTANCE WITH FAILURE ANALYSIS
 - UNDERSTAND MECHANISMS
 - DIRECT CORRECTIVE ACTIONS



THE GOALS OF THE COMPUTATIONAL EFFORTS IN THE EXPLOSIVE ORDNANCE SECTION AT AEROSPACE ARE TO PROVIDE OUR INDUSTRY WITH ANALYTICAL TOOLS TO IMPROVE EXPLOSIVE ORDNANCE DESIGN BY BEING BETTER ABLE TO UNDERSTAND THE DEVICE FUNCTIONING AND TO BETTER PREDICT THE EFFECTS ON PERFORMANCE CHARACTERISTICS OF VARIOUS SPECIFIC DESIGN FEATURES.

THESE ANALYTICAL TECHNIQUES WILL ALSO ASSIST US IN FAILURE ANALYSIS BY HELPING TO UNDERSTAND AND IDENTIFY FAILURE MECHANISMS. THEY WILL ALSO MAKE EFFICIENT AND EFFECTIVE CORRECTIVE ACTIONS EASIER TO IDENTIFY AND SELECT.

THIS WORK IS FOCUSED ON BRINGING POWERFUL ANALYTIC AND COMPUTATIONAL TECHNIQUES FROM THE WEAPONS DEVELOPMENT INDUSTRY TO BEAR ON PROBLEMS INVOLVING THE EXPLOSIVE ORDNANCE SYSTEMS THAT ARE USED IN THE SPACE INDUSTRY. CONCEPTUALLY, THERE ARE MANY SIMILARITIES: BOTH KINDS OF SYSTEMS ARE MECHANICAL DEVICES THAT EMPLOY EXPLOSIVES TO DO WORK IN A PRECISE AND RELIABLE MANNER. THE MAJOR DISTINCTION IS IN THEIR SIZE, WHICH I WILL COME BACK TO LATER IN THE PRESENTATION.

BASIC MATHEMATICS

- PARTIAL DIFFERENTIAL EQUATIONS FOR COMPRESSIBLE FLUIDS

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \qquad \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} + \frac{\nabla P}{\rho} = 0 \qquad \frac{\partial s}{\partial t} + (\mathbf{v} \cdot \nabla) s = 0$$

- STRENGTH/STIFFNESS TERMS CAN BE ADDED

- JUMP CONDITIONS DEFINE DISCONTINUITIES IN STATE VARIABLES

$$[\rho(\mathbf{v}-D)]_1^2 = 0 \qquad [1/2(\mathbf{v}-D)^2 + h]_1^2 = 0 \qquad [P + \rho(\mathbf{v}-D)^2]_1^2 = 0$$

- ADIABATIC CONSTRAINT + JUMP CONDITIONS = HUGONIOT

$$e_1 - e_2 = 1/2(V_2 - V_1)(P_1 + P_2) \qquad h = e + PV \qquad V = \frac{1}{\rho}$$

- DEFINES LOCUS OF ATTAINABLE STATES FOR EACH MATERIAL

Explosive Ordnance Section

Environmental Criteria and Test Department

Structural Mechanics Subdivision



THE COMPUTER CODE THAT I WILL BE DISCUSSING IS A MEMBER OF A FAMILY OF COMPUTATIONAL FLUID DYNAMICS CODES THAT MAKE NO APPROXIMATIONS TO THE EQUATIONS OF MOTION THAT WOULD PREVENT THE EXISTENCE OF SHOCK WAVES. THESE PROGRAMS HAVE BEEN IN EXISTENCE SINCE THE 1950'S, BUT A NEW GENERATION OF PROGRAMS OVER THE LAST FEW YEARS HAS TAKEN ADVANTAGE OF PROGRESS IN MATERIALS AND NUMERICAL METHODS TO MAKE THE CODES MORE POWERFUL. OF COURSE, NEW COMPUTER HARDWARE HAS ALSO CONTRIBUTED TO ALLOWING THESE TECHNIQUES TO BE IMPLEMENTED.

THE EQUATIONS TO BE SOLVED ARE THE TIME DEPENDENT NONLINEAR EQUATIONS OF MOTION FOR COMPRESSIBLE FLUIDS. THE JUMP CONDITIONS ARE THE EQUATIONS FOR CONSERVATION OF MASS, ENERGY, AND MOMENTUM ACROSS MATERIAL INTERFACES, AND DEFINE SHOCK WAVES. THE ADDITIONAL CONSTRAINT OF ADIABATIC FLOW OVERDETERMINES THE SYSTEM AND ONLY A LIMITED SET OF THERMODYNAMIC STATES ARE ALLOWABLE FOR A SHOCKED MATERIAL. THE CURVE DEFINING THESE STATES IS CALLED THE HUGONOT CURVE.

BASIC NUMERICAL METHODS

- **SOLVE PARTIAL DIFFERENTIAL EQUATIONS FOR COMPRESSIBLE FLUIDS**
 - **TIME DEPENDENT, NONLINEAR**
 - **STRENGTH / STIFFNESS TERMS CAN BE ADDED AS CORRECTIONS**
- **FINITE DIFFERENCE ALGORITHM**
 - **SPACE DIVIDED INTO CELLS TO FORM A MESH**
 - **TIME DIVIDED INTO STEPS DETERMINED BY WAVE SPEEDS AND MESH**
- **LAGRANGIAN - COORDINATES IDENTIFIED WITH MASS ELEMENTS, MESH MOVES WITH MATERIAL**
 - **FASTER INTEGRATION**
- **EULERIAN - COORDINATES FIXED IN SPACE, MATERIAL FLOWS THRU**
 - **MORE ACCURATE FOR LARGE MOTIONS**



THE FLUID DYNAMICS EQUATIONS ARE SOLVED FOR THE ENTIRE SYSTEM BY EXPLICIT INTEGRATION IN A FINITE DIFFERENCE ALGORITHM. FINITE DIFFERENCE METHODS ARE SIMILAR TO FINITE ELEMENT FORMULATIONS OF STRUCTURAL PROBLEMS BUT HAVE SOME ADVANTAGES IN EFFICIENCY FOR TIME DEPENDENT PROBLEMS. IN THIS TECHNIQUE, SPACE IS DIVIDED INTO CELLS THAT FORM THE COMPUTATIONAL MESH, AND TIME IS DIVIDED INTO STEPS FOR INTEGRATION PURPOSES. THE TIME STEPS ARE DETERMINED BY THE SIZE OF THE STRUCTURE, THE MATERIAL PROPERTIES INVOLVED, PARTICULARLY SOUND SPEEDS. THE MESH CELL SIZES ALSO IN TURN AFFECT RESOLUTION AND ACCURACY OF THE RESULTS AND THE RUNNING TIME OF THE CALCULATION. THE SETUP OF A PROBLEM IS THEREFORE A COMPLEX PROCESS IN WHICH ALL OF THE PHYSICAL AND MATHEMATICAL ELEMENTS INTERRELATE.

DEALING WITH DETONATIONS

- **SHOCK WAVES FROM EXPLOSIVE DETONATION EXPLICITLY MODELED**
- **EQUATIONS OF STATE DETERMINED FROM
 - **EXPERIMENTAL DATA**
 - **CALCULATION FROM DENSITY, HEAT OF FORMATION AND CHEMICAL COMPOSITION****
- **WORK DONE BY SHOCK WAVE INTERACTIONS AND PRODUCT GAS MOTION**
- **DETONATION PRESSURES = 3 - 5 MILLION PSI**
- **DETONATION VELOCITIES = 15,000 - 25,000 FEET PER SEC**
- **AVERAGE SIZE STEP = 1 NANOSEC
 - **CALCULATION TIME = 10 -20 MICROSEC, CAN BE LONGER**
 - **TOTAL DEVICE FUNCTION TIME = 20 MILLISEC****



THE DISTINGUISHING FEATURE OF THE MODELS THAT WE WOULD LIKE TO BUILD, COMPARED WITH OTHER STRUCTURES OR MECHANISMS, IS THE PRESENCE OF THE EXPLOSIVE COMPONENTS IN THE DEVICES. THE FACT THAT WE ARE STARTING WITH A CODE THAT CAN TREAT SHOCK WAVES ALLOWS US TO EXPLICITLY MODEL THE DETONATION OF THE EXPLOSIVE, AND TO ALLOW THE SHOCKS TO PROPAGATE INTO THE OTHER MATERIALS IN THE SYSTEM. THE PRINCIPAL MEANS OF INITIATING MOTION IN A MECHANISM IS BOTH BY SHOCK AND BY PRODUCT GAS EXPANSION. THESE MODES INCLUDE BOTH ENERGY AND MOMENTUM TRANSFERS BETWEEN THE EXPLOSIVE DRIVER AND THE OTHER INERT COMPONENTS.

ONE OF THE IMPORTANT INPUTS TO THE CODE IS THEREFORE EQUATION OF STATE DESCRIPTIONS OF THE EXPLOSIVES IN BOTH THEIR UNREACTED AND REACTED FORMS. THIS INFORMATION IS CONTAINED IN A DATABASE FOR A VARIETY OF MATERIALS, BUT BY NO MEANS ALL THAT WE USE. FOR SOME THERE IS EXPERIMENTAL DATA THAT HAS BEEN DETERMINED DIRECTLY, AND FOR OTHERS THERE ARE CALCULATED PARAMETERS BASED ON KNOWN DENSITY, HEAT OF FORMATION, CHEMICAL COMPOSITIONS AND OTHER CHEMICAL AND THERMODYNAMIC PROPERTIES.

THE PRESENCE OF THE EXPLOSIVES MAKES THE CALCULATIONS PARTICULARLY SENSITIVE TO NUMERICAL DETAILS THAT MAY BE OF LESSER IMPORTANCE IN OTHER SYSTEMS. SHOCK PRESSURES BEHIND DETONATION FRONTS ARE ON THE ORDER OF 3-5 MILLION PSI, AND DETONATION SHOCK VELOCITIES ARE BETWEEN 15000 AND

25000 FPS. THESE FACTS LEAD TO NUMERICAL INTEGRATION SCHEMES THAT MUST ACCOMMODATE TIME STEPS OF APPROXIMATELY 1 NANOSEC. MESHES CONTAINING 40000 CELLS ARE ON THE SMALL SIDE FOR ACCEPTABLE ACCURACY, AND REASONABLE AMOUNTS OF COMPUTER TIME ACHIEVE TOTAL CALCULATION TIMES, OR SYSTEM MOTION, OVER ONLY A FEW TENS OF MICROSECONDS. NORMAL DEVICE FUNCTION TIMES ARE THAT SAME NUMBER OF MILLISEC., AND THE CALCULATIONS CAN BE FOLLOWED TO THESE TIMES, BUT RUN TIMES ARE VERY LONG, AND THE COMPUTATIONAL MESH MUST BE PERIODICALLY REDRAWN TO FOLLOW THE MATERIALS. THIS ALSO IS ONE OF THE FEATURES THAT MAKES IT NONTRIVIAL TO APPLY HYDROCODES LIKE MESA TO SPACE VEHICLE ORDNANCE DEVICES. THEIR SMALL SIZE CAN CAUSE NUMERICAL INSTABILITIES BECAUSE OF THE VERY SHORT WAVE TRANSIT TIMES ACROSS MESH CELLS.

This page intentionally left blank.

MESA REACTIVE HYDROCODE

- TWO DIMENSIONAL - PLANES, CYLINDERS
 - RUNS ON SUN WORKSTATION
- 3D CODE RUNS ON CRAY
 - IN USE AT PHILLIPS LAB

NEW FEATURES IN MESA

- IMPROVED MATERIAL RESPONSE
 - DETONATION MATH MODELS
 - FRACTURE ALGORITHMS
 - PHASE CHANGES FOR CERTAIN MATERIALS
- NEW INTERFACE RECONSTRUCTION ALGORITHM FOR LARGE DEFORMATIONS AND MIXED CELLS
 - GREATER NUMERICAL STABILITY

PRECEDING PAGE BLANK NOT FILMED

3 0 3



THE AEROSPACE CORPORATION

THE CODE THAT WE HAVE CHOSEN TO USE AT AEROSPACE IS MESA. MESA WAS WRITTEN AT LOS ALAMOS NATIONAL LABORATORY, ALTHOUGH THERE ARE OTHER SIMILAR CODES DEVELOPED AT LAWRENCE LIVERMORE LABORATORY AND SANDIA NATIONAL LABORATORIES. MESA WAS ORIGINALLY DEVELOPED TO ANALYZE WEAPONS AND ARMOR SYSTEMS. THERE ARE 2 AND 3 DIMENSIONAL VERSIONS OF THE PROGRAM. THE 2D CODE IS RUNNING ON AN IN-HOUSE SUN WORKSTATION. THE 3D CODE IS STILL ONLY DESIGNED FOR THE CRAY.

SO-CALLED REACTIVE HYDROCODES (HYDRODYNAMIC CODES THAT INCLUDE CHEMICALLY REACTIVE MATERIALS) HAVE BEEN IN EXISTENCE FOR ABOUT 30 YEARS. MESA IS ONE OF THE NEW GENERATION THAT TAKES ADVANTAGE OF NEW NUMERICAL METHODS IN ADDITION TO IMPROVED KNOWLEDGE ABOUT MATERIAL RESPONSES AT HIGH RATES OF STRAIN. IT CONTAINS THE MOST ACCURATE MATHEMATICAL MODELS OF DETONATION TO GOVERN THE ENERGY RELEASE MECHANISMS, AND INCLUDES ALGORITHMS THAT ALLOW FRACTURE AND CRACKING IN ADDITION TO SPALL. FOR A SMALL NUMBER OF MATERIALS, PHASE CHANGES CAN ALSO BE MODELED. THE PRINCIPLE MATHEMATICAL IMPROVEMENT IS AN INTERFACE RECONSTRUCTION ALGORITHM THAT MAKES THE CALCULATION MORE STABLE IN THE FACE OF VERY LARGE DEFORMATIONS AND MANY CELLS CONTAINING MORE THAN ONE MATERIAL SPECIES.

ONE OF THE DIFFICULTIES IN APPLYING A CODE LIKE MESA TO SPACE VEHICLE

EXPLOSIVE ORDNANCE DEVICES IS THEIR SIZE. THE WEAPONS SYSTEMS ARE MANY TIMES LARGER, MEANING THAT CELLS CAN BE LARGER WHILE STILL ACHIEVING SUFFICIENT RESOLUTION. GIVEN DETONATION VELOCITY MAGNITUDES, AS CELLS GET SMALLER, WAVE TRANSIT TIMES GET SMALLER, AND THE TIME STEPS NEED TO BE EVEN SMALLER TO GET REASONABLE RESOLUTION OF THE DYNAMICS. CONSTRUCTING AN OPTIMAL MESH THAT IS SUFFICIENTLY ACCURATE AND YET DOES NOT CREATE NUMERICAL PROBLEMS HAS BEEN ONE OF THE TRICKIER PARTS OF OUR TASK AT AEROSPACE. DESIGNING THE PROBLEM BECOMES OF CRITICAL IMPORTANCE IN ORDER TO BE ASSURED OF PHYSICALLY REASONABLE RESULTS AND TO CONTROL RUN TIMES.

ALSO, TESTING TO VERIFY THAT THE MODEL IS REALISTIC IS STILL AN IMPORTANT PART OF THE TASK, ALTHOUGH WE HOPE THAT IT CAN BECOME A SMALLER, LESS COSTLY EFFORT AS THE ANALYTIC METHODS BECOME MORE SOPHISTICATED.

This page intentionally left blank.

MESA RESULTS

- **OUTPUTS**

**POSITION
VELOCITY
DENSITY
PRESSURE
INTERNAL ENERGY
INTRINSIC SOUND SPEED
TEMPERATURE**

**STRAIN RATE
STRESS DEVIATORS
PLASTIC STRAIN
PLASTIC WORK
ELASTIC DEFORMATION
ELASTIC WORK**

- **GRAPHICAL DISPLAY OPTIONS**

**VECTORS - VELOCITY, PRINCIPAL STRESSES
CONTOURS - ALL VARIABLES
PROFILES - DENSITY, INTERNAL ENERGY, MOMENTUM, PRESSURE,
KINETIC ENERGY**

PRECEDING PAGE BLANK NOT FILMED



This page intentionally left blank.

MESA SAMPLE CALCULATION

- EXPANDING TUBE SEPARATION SYSTEM MODEL
 - GENERIC STRUCTURE
 - AXIAL SYMMETRY

PRECEDING PAGE BLANK NOT FILMED



WE HAVE APPLIED MESA TO SEVERAL PROBLEMS SINCE WE BEGAN USING IT ABOUT 8 MONTHS AGO. THE FIRST ONE AROSE FROM A PROBLEM WITH A GROUND TEST OF SUPER*ZIP, AND IS A SIMPLIFIED EXPANDING TUBE SEPARATION SYSTEM. THIS MODEL HAS THE MAJOR FEATURES OF, BUT IS SIMPLER THAN, THE SUPER*ZIP SYSTEM. EVEN THOUGH THERE ARE MANY STRUCTURAL DETAILS THAT HAVE NOT BEEN INCLUDED IN OUR MODEL, YOU WILL SEE THAT THE SEPARATION CONCEPT AND MAJOR FEATURES OF ITS FUNCTION CAN BE DESCRIBED.

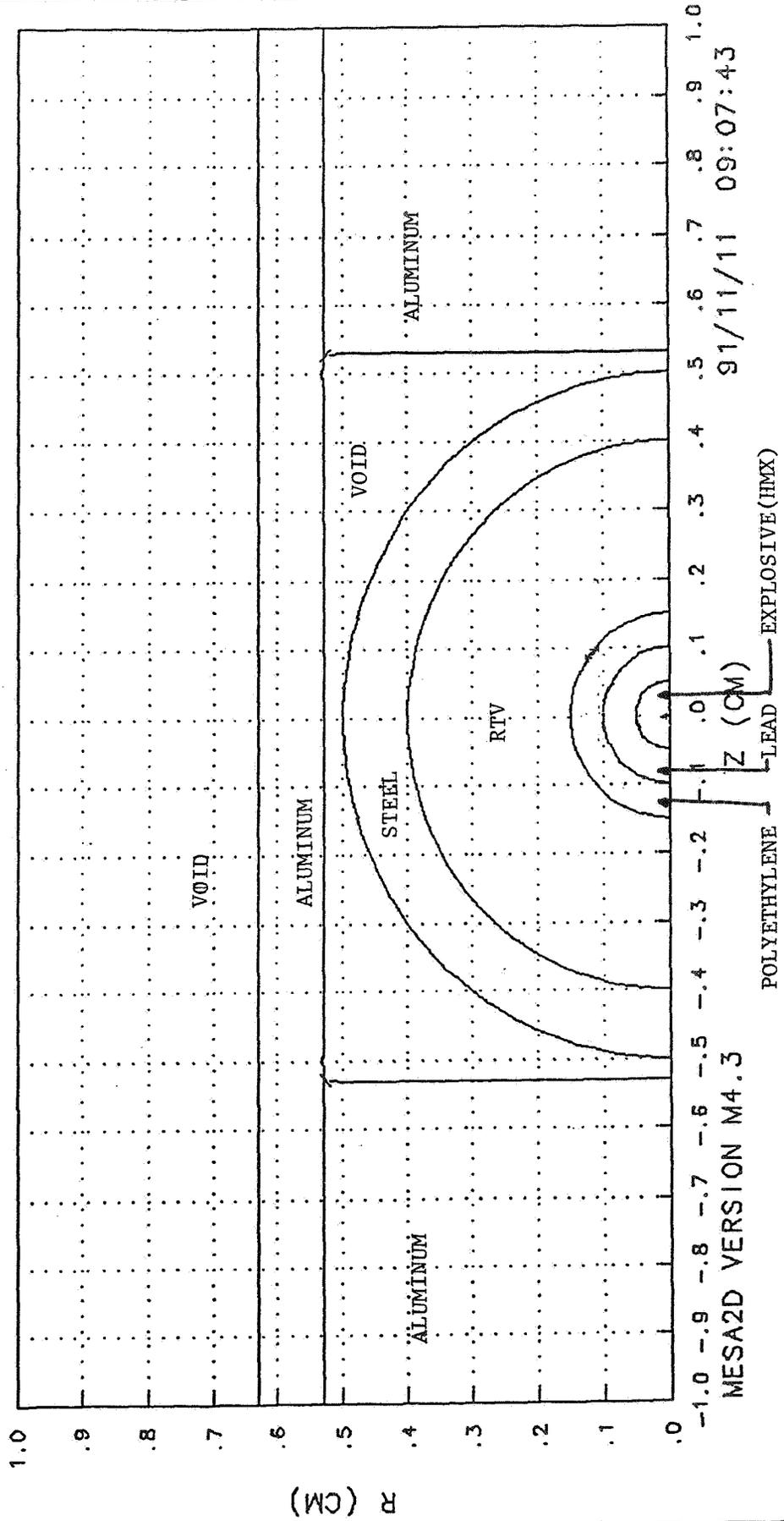
INTERFACES

GENERATOR INPUT FILE

TIME

E-P

.0000
MICROSECONDS



MESA2D VERSION M4.3

91/11/11 09:07:43

THIS IS THE CROSS-SECTION OF 1/2 AN EXPANDING TUBE SEPARATION SYSTEM. SUCH A SLICE WOULD REPRESENT A POINT IN THE MIDDLE OF THE TUBE, AWAY FROM END EFFECTS AND THE DETONATOR BLOCK. MATERIALS HAVE BEEN CHOSEN TO PARALLEL SUPER*ZIP, ALTHOUGH MANY OF THE FEATURES SPECIFIC TO THAT DEVICE ARE ABSENT FROM THIS MODEL. IN THE ORIENTATION OF THIS MODEL, THE DOUBLER TO BE FRACTURED IS AT THE TOP OF THE CHART. THE DETONATION CORD IS AT THE CENTER BOTTOM, AND THE CALCULATION WILL BE STARTED FROM THE POINT AT WHICH IT INITIATES. THE DETONATORS ARE NOT IN THIS CALCULATION.

PRESSURE (MBAR)

TIME

6.0415

MICROSECONDS

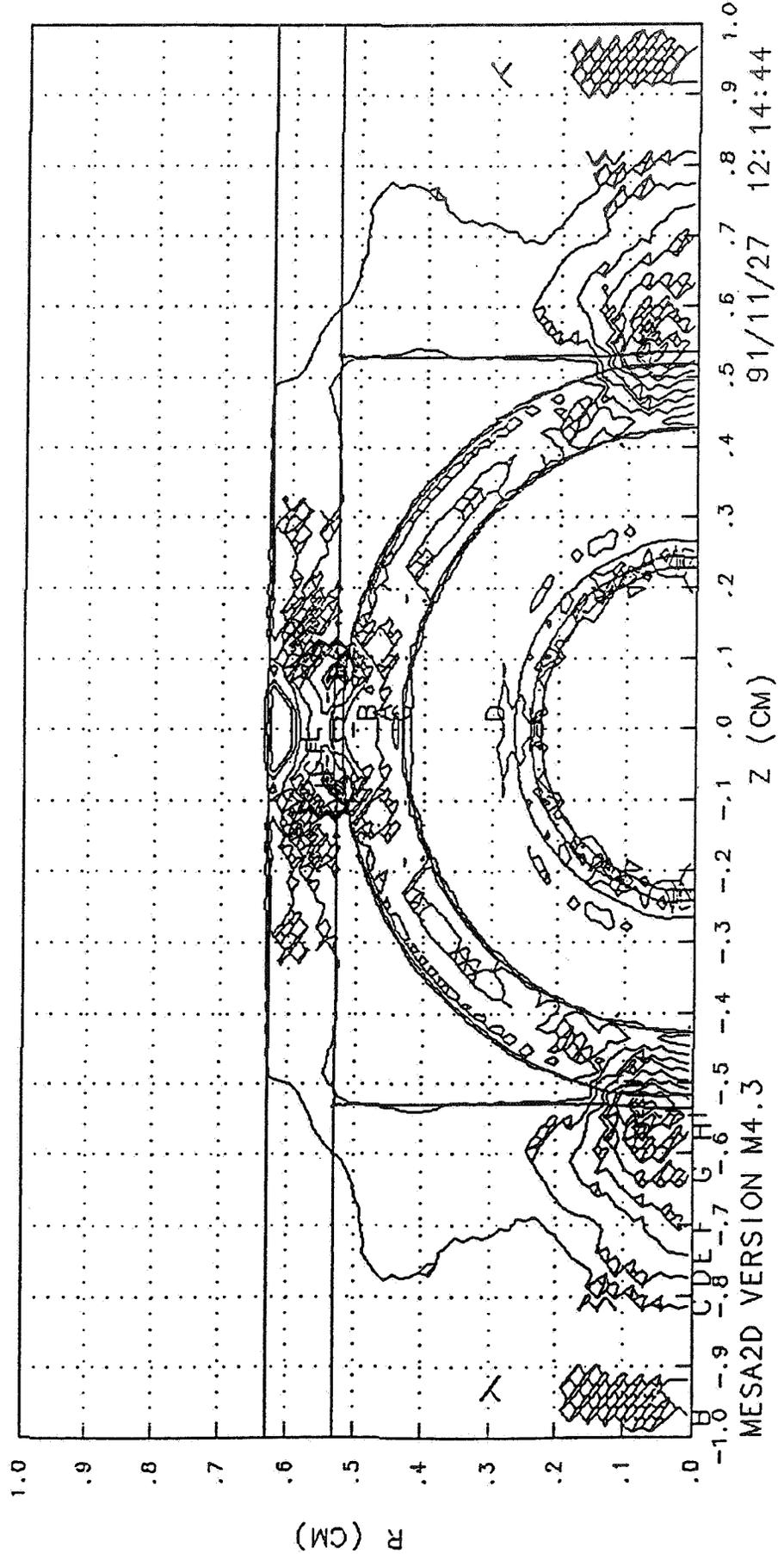
GENERATOR INPUT FILE

E-P

- A -1.251E-03
- B -4.425E-04
- C 3.664E-04
- D 1.175E-03
- E 1.984E-03
- F 2.793E-03
- G 3.602E-03
- H 4.411E-03
- I 5.220E-03
- J 6.029E-03

MINIMUM -2.060E-03

MAXIMUM 6.838E-03



MESAS2D VERSION M4.3

Z (CM)

91/11/27 12:14:44

AFTER THE HMX INITIATES, SHOCK WAVES PROPAGATE OUT RADially TO THE SURROUNDING MATERIALS. AT A TIME APPROXIMATELY 6 MICROSEC AFTER INITIATION OF THE CORD AT THIS POINT, THEY LOOK LIKE THIS. THESE CONTOURS ENCLOSE REGIONS IN WHICH THE PRESSURE IS GREATER THAN THE LEVEL OF THE CONTOUR. SOME REGIONS ARE ALREADY IN TENSION.

VECTOR VELOCITIES (CM/MICRO-SEC)

TIME 7.0347

MICROSECONDS

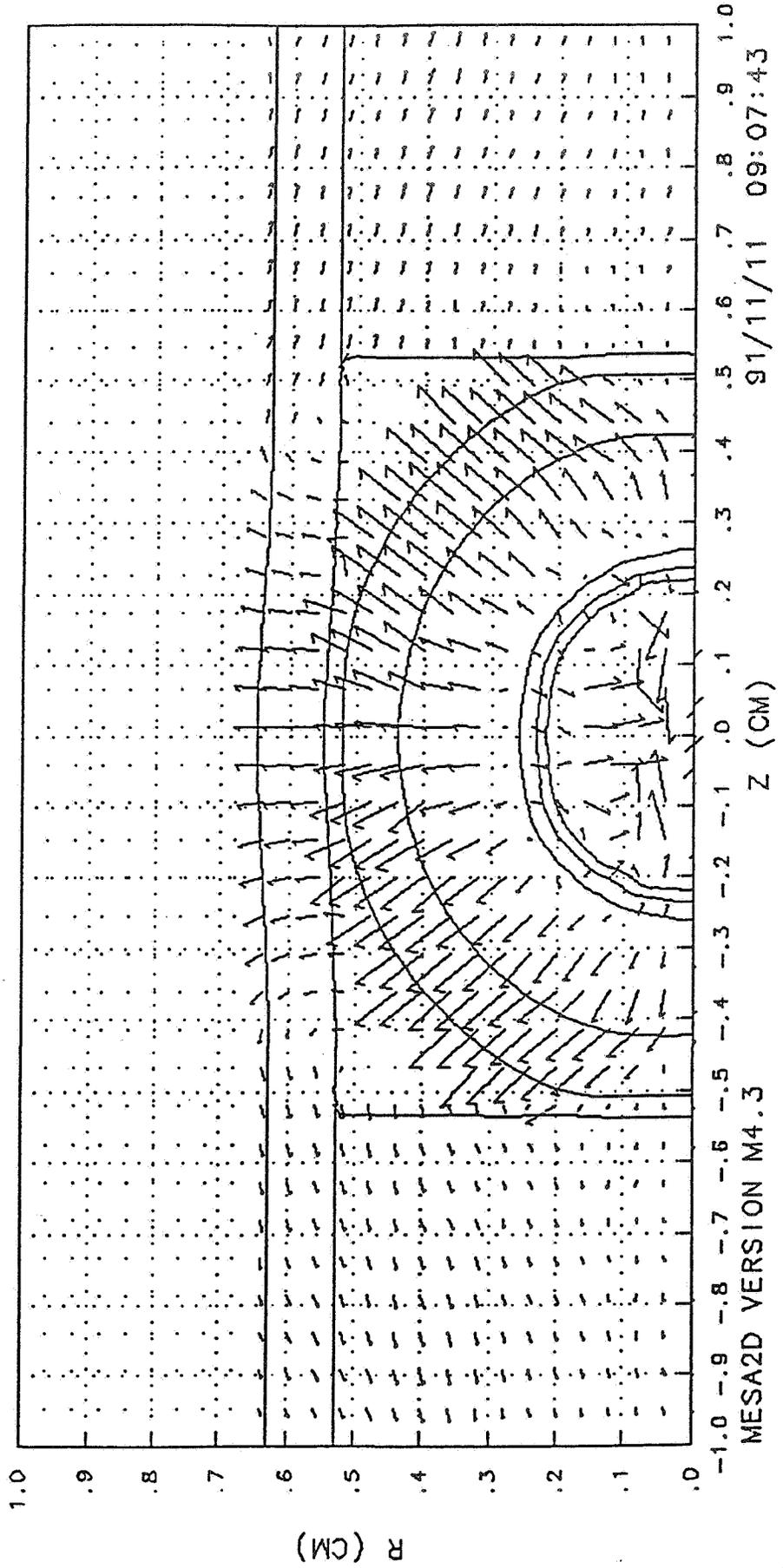
GENERATOR INPUT FILE

E-P

LOCAL MAX 1.716E-02

GLOBAL MAX 1.716E-02

SCALED VEC 1.716E-02



MESA2D VERSION M4.3

91/11/11 09:07:43

PARTICLE VELOCITIES FOR EACH MESH POINT SHOW RESULTANT MOTION OF MASS POINTS CAUSED BY THE EXPLOSIVE PRODUCT GASES EXPANDING AND BY THE PASSAGE OF THE SHOCK WAVES. MESA PLOTS ARROWS SHOWING A SCALED VELOCITY MAGNITUDE AND DIRECTION AT ALL OR A SELECTION OF MESH POINTS. BY THIS TIME, 7 MICROSEC, DEFORMATION OF THE CONTAINMENT TUBE AND OF THE DOUBLER IS BEGINNING TO APPEAR.

ELASTIC WORK

TIME

8.0343

MICROSECONDS

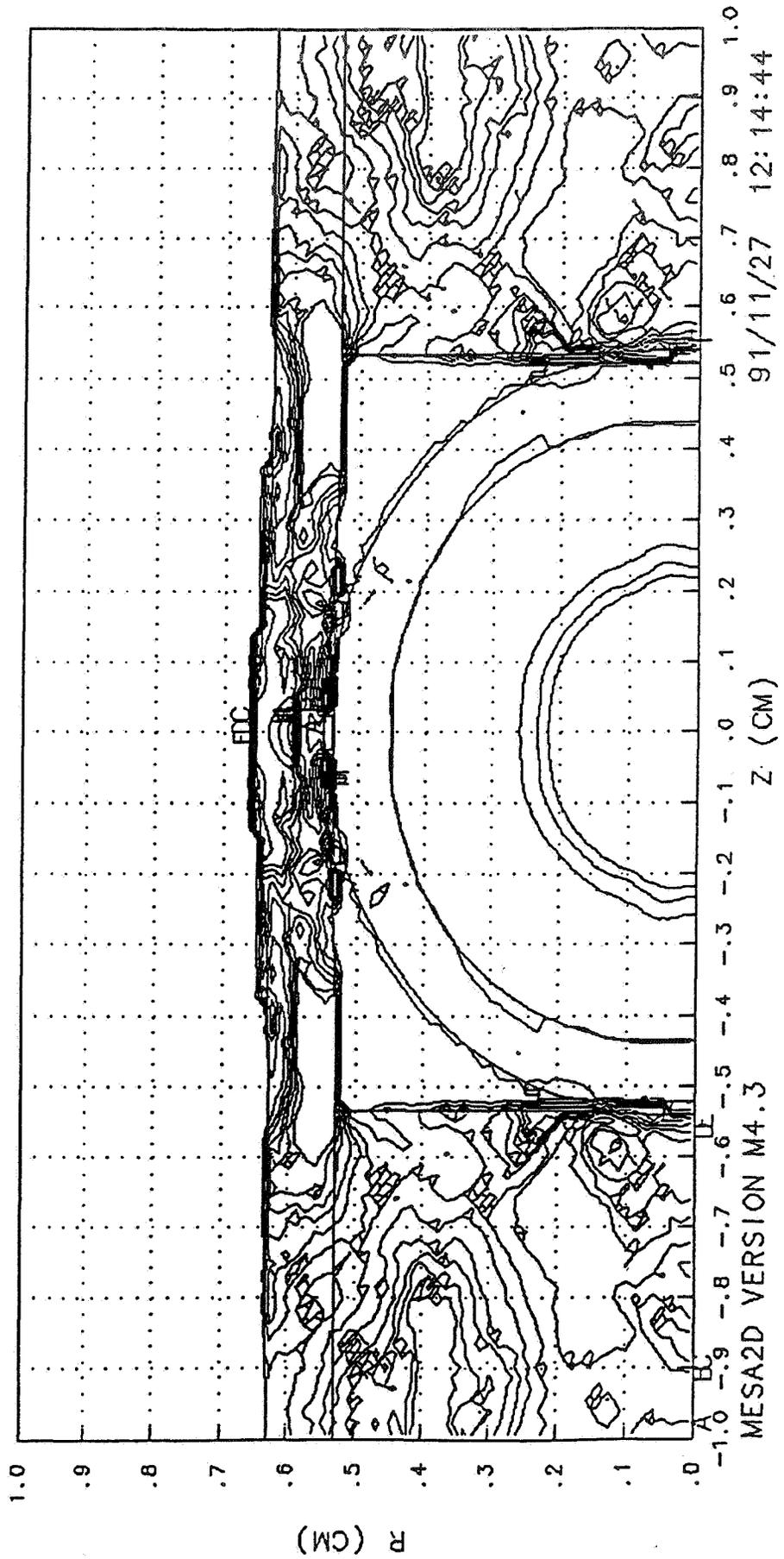
GENERATOR INPUT FILE

E-P

A 2.093E-07 F 1.412E-06
B 4.499E-07 G 1.653E-06
C 6.904E-07 H 1.893E-06
D 9.310E-07 I 2.134E-06
E 1.172E-06 J 2.375E-06

MINIMUM -3.130E-08

MAXIMUM 2.615E-06



THIS PLOT SHOWS THE ELASTIC WORK BEING DONE ON THE ALUMINUM STRUCTURES. THE AL AND STEEL ARE THE ONLY MATERIALS IN THIS MODEL THAT WERE GIVEN AN ELASTIC-PLASTIC CONSTITUTIVE RELATION. THE ELASTIC WORK IN THE STEEL IS VERY SMALL BECAUSE IT IS ALREADY IN THE PLASTIC REGIME. ALL THE OTHER MATERIALS ARE TREATED AS PURE FLUIDS BECAUSE THEIR PROXIMITY TO THE EXPLOSIVE AND THE STRONG SHOCKS MAKES THEIR STRENGTH NEGLIGIBLE.

PLASTIC WORK (MBAR-CC/GM)

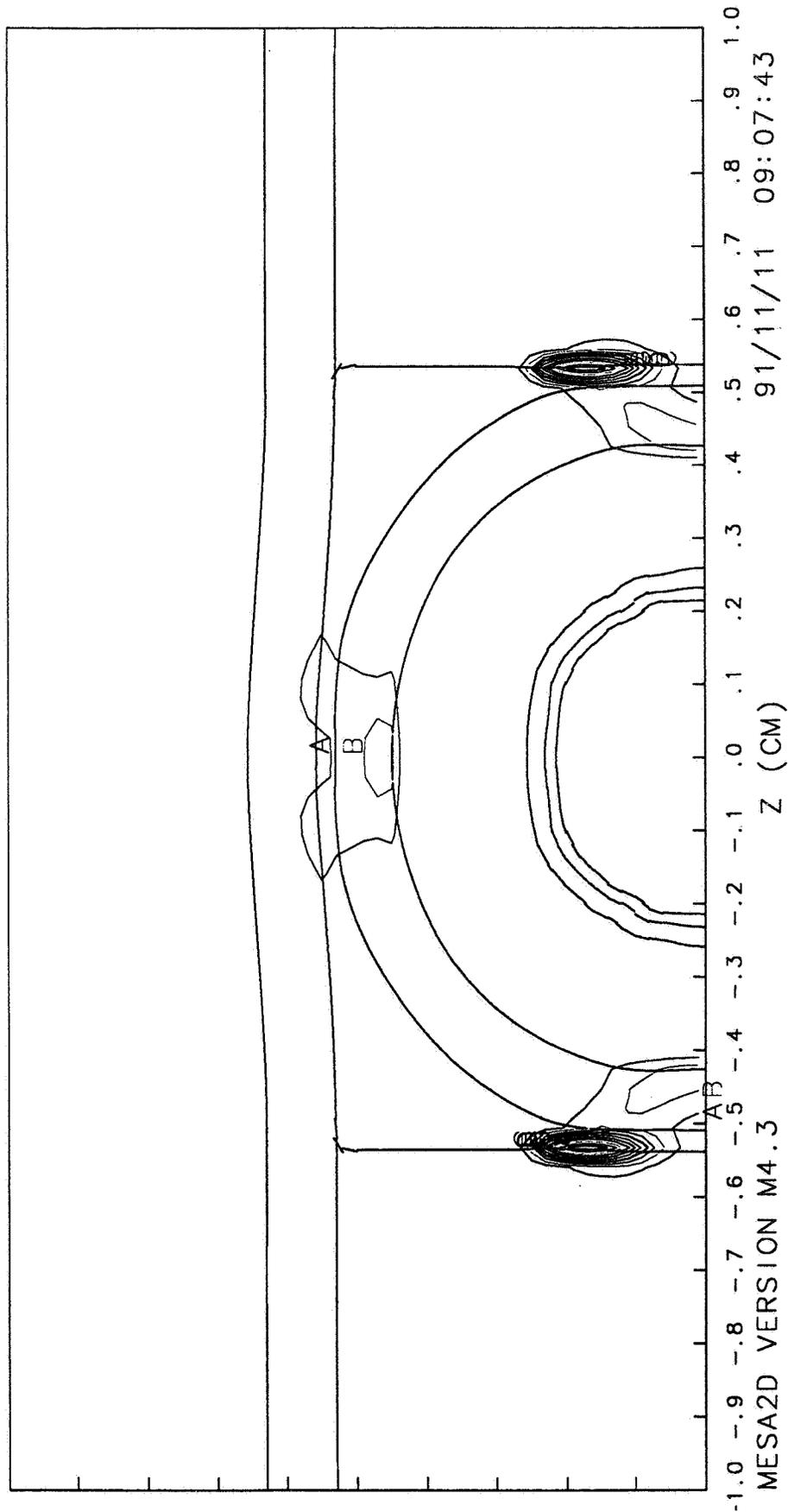
TIME 8.0632

GENERATOR INPUT FILE FOR SUPER*ZIP 1D, CORRECTED EOS, E-P STEEL

- A 5.529E-05 F 3.317E-04
- B 1.106E-04 G 3.870E-04
- C 1.659E-04 H 4.423E-04
- D 2.212E-04 I 4.976E-04
- E 2.765E-04 J 5.529E-04

MINIMUM 0.000E+00

MAXIMUM 6.082E-04



THE NEXT PLOTS SHOW PLASTIC WORK AND PLASTIC STRAIN. COMPARING THE MAGNITUDES OF ELASTIC AND PLASTIC WORK, IT IS SEEN THAT THE PLASTIC WORK IS TWO ORDERS OF MAGNITUDE GREATER THAN THE ELASTIC. THIS IS TYPICAL OF VERY HIGH STRAIN RATE PROCESSES, AND IN MANY CALCULATIONS THE ELASTIC COMPONENT IS NEGLECTED.

PLASTIC STRAIN

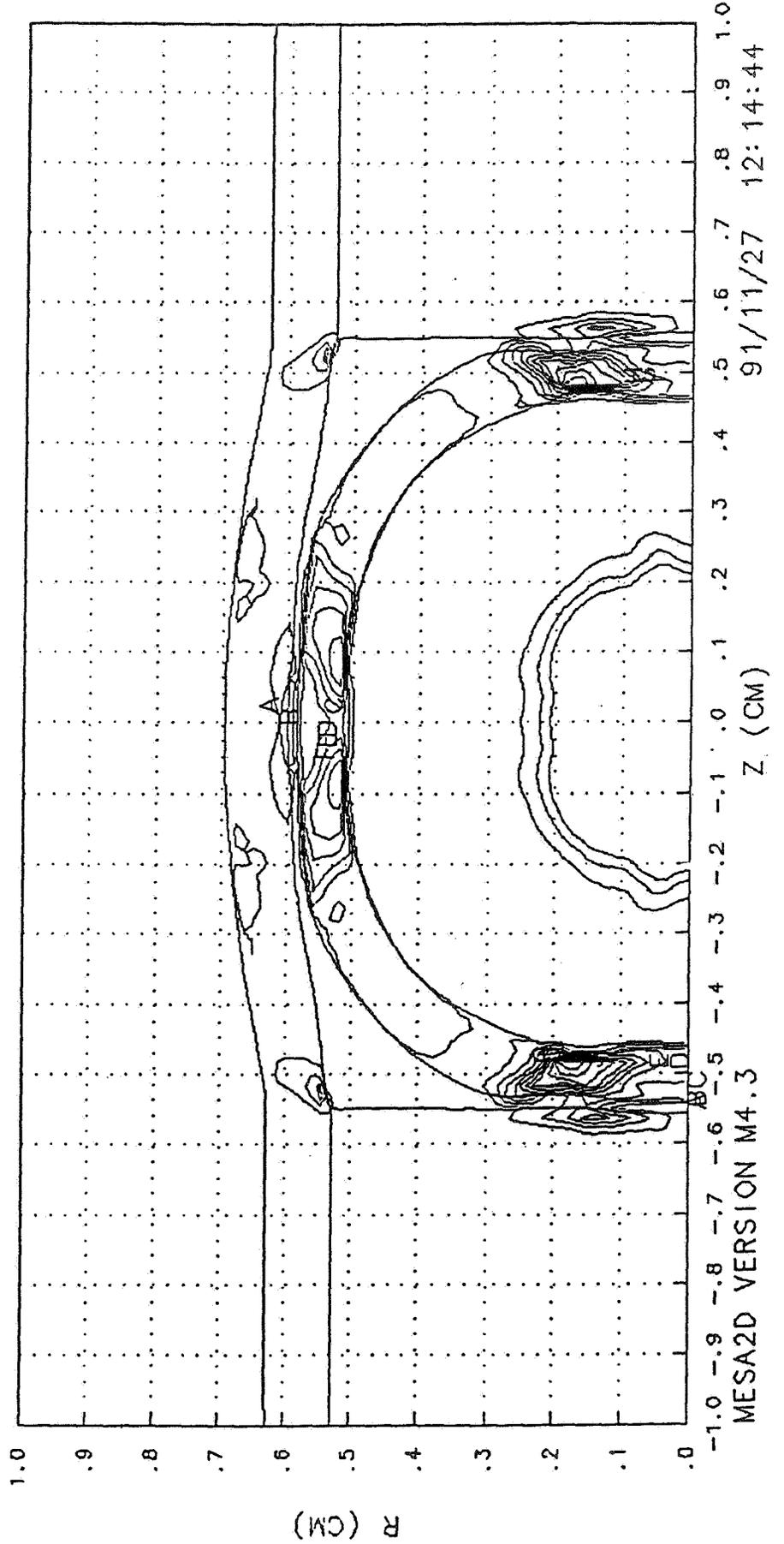
TIME 15.0120
MICROSECONDS
E-P

GENERATOR INPUT FILE

- A 8.284E-02 F 4.971E-01
- B 1.657E-01 G 5.799E-01
- C 2.485E-01 H 6.627E-01
- D 3.314E-01 I 7.456E-01
- E 4.142E-01 J 8.284E-01

MINIMUM 0.000E+00

MAXIMUM 9.113E-01

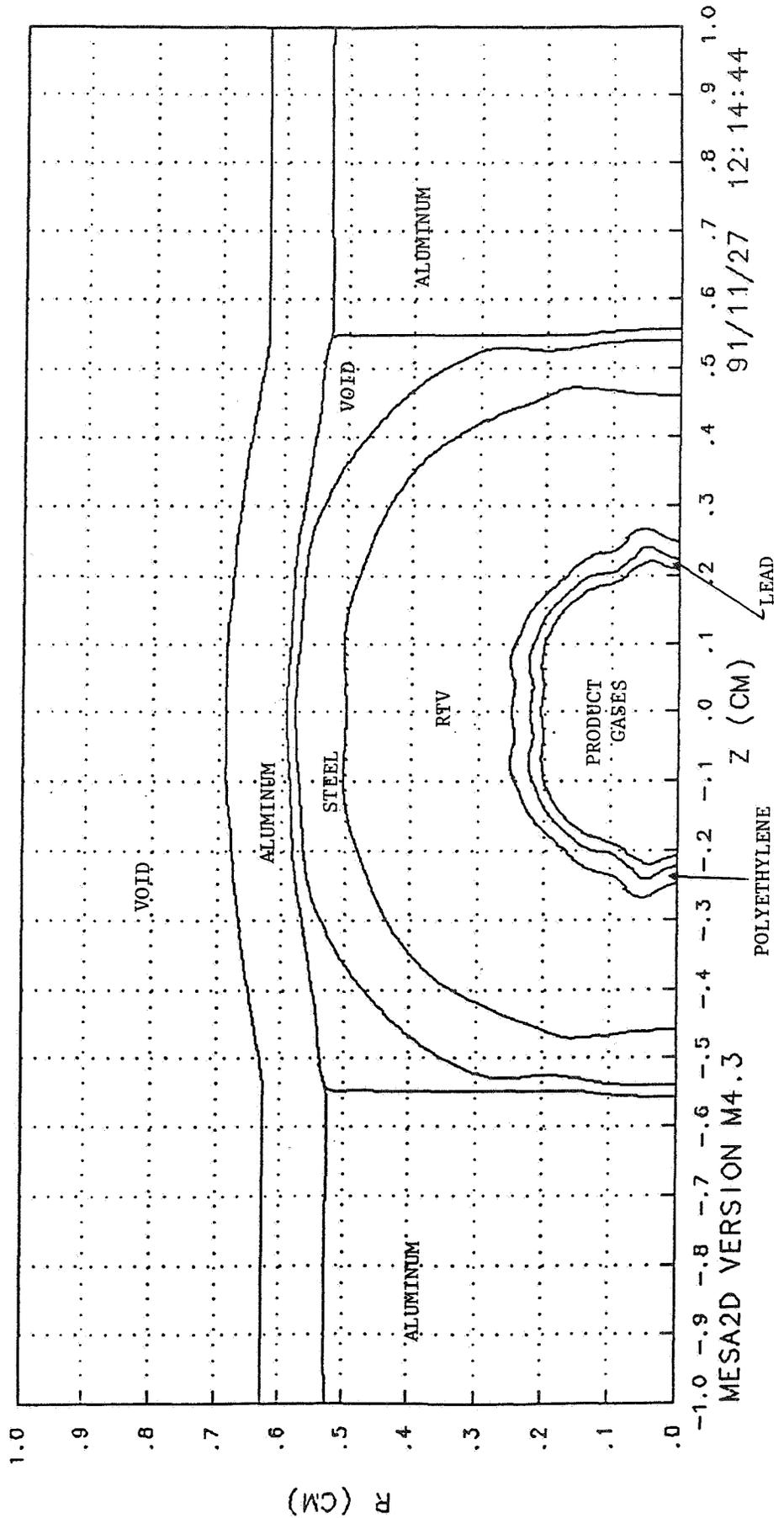


This page intentionally left blank.

INTERFACES

GENERATOR INPUT FILE

TIME 14.0458
MICROSECONDS
E-P



THIS IS THE CONFIGURATION OF THE SYSTEM AT THE FINAL TIME FOR THIS CALCULATION. THE THINNING OF THE CONTAINMENT TUBE WHERE IT CONTACTS THE STRUCTURE IS VERY APPARENT. THE DOUBLER IS BENT EVEN THOUGH THERE WAS NO NOTCH INCLUDED IN THE INITIAL MODEL. AN EXAMINATION OF THE TENSILE STRESSES IN THIS MATERIAL WOULD SHOW THAT IT FRACTURES, BUT THE MODEL DID NOT INCLUDE ANY FRACTURE CRITERIA SO THAT IS NOT SHOWN EXPLICITLY. IT WOULD BE POSSIBLE TO CARRY THE CALCULATION FURTHER IN TIME IF DESIRED. THIS EXAMPLE TOOK SEVERAL HOURS TO RUN ON THE WORKSTATION.

CONCLUSIONS

- REACTIVE HYDROCODES CAN BE APPLIED TO SPACE VEHICLE ORDNANCE DEVICES
 - QUALITATIVE AGREEMENT BETWEEN SIMPLE MODELS AND OBSERVED BEHAVIORS
 - NUMERICAL FORMULATION IMPORTANT FOR VALID RESULTS
 - MATERIALS RESPONSE DATABASE MUST BE EXPANDED

- USE OF ADDITIONAL CODE FEATURES WILL IMPROVE
 - AGREEMENT WITH TEST RESULTS
 - PREDICTIVE CAPABILITIES



WE HAVE ONLY BEEN WORKING AT THIS FOR LESS THAN A YEAR, AND ALREADY I BELIEVE WE HAVE MADE SIGNIFICANT PROGRESS AND ACHIEVED SOME VALUABLE RESULTS. WE CONCLUDE FROM THESE INITIAL CALCULATIONS THAT REACTIVE HYDROCODES LIKE MESA CAN SUCCESSFULLY BE APPLIED TO SPACE VEHICLE ORDNANCE DEVICES. EVEN SIMPLE CONCEPTUAL MODELS SHOW GOOD AGREEMENT WITH QUALITATIVE FEATURES OF OBSERVED BEHAVIOR. HOWEVER, RESULTS ARE DEPENDENT ON THE QUALITY OF THE NUMERICAL SIMULATION AND THE CALCULATIONS ARE ONLY AS GOOD AS THE MATERIALS DATA THAT GOES INTO THEM. IN ORDER TO FULLY EXPLOIT THE POTENTIAL OF THIS TYPE OF MODELING, ADDITIONAL EXPERIMENTAL WORK MUST BE DONE TO INCREASE THE MATERIALS RESPONSE DATABASE, ESPECIALLY FOR HIGH STRAIN RATES.

AS WE CONTINUE TO BECOME MORE ADEPT AT USING MESA AND TO TAKE ADVANTAGE OF ADDITIONAL FEATURES THAT WERE NOT EXERCISED IN THESE INITIAL EXAMPLES, THE AGREEMENT WITH TEST RESULTS IS EXPECTED TO IMPROVE AND THE PREDICTIVE CAPABILITIES OF THE TECHNIQUE TO BE MORE POWERFUL.

WE HAVE APPLIED MESA TO OTHER PROBLEMS IN ADDITION TO THE EXPANDING TUBE SEPARATION SYSTEMS. AMONG THESE ARE A PRESSURE CARTRIDGE AND LINEAR SHAPED CHARGES. REACTIVE HYDRODYNAMICS IS ESPECIALLY APPROPRIATE FOR SHAPED CHARGES BECAUSE THE TREATMENT OF THE SHEATH MATERIAL AS A MATHEMATICAL FLUID IS A VERY GOOD APPROXIMATION IN THIS CASE.

WE ARE ALSO IN THE PROCESS OF EXPANDING OUR REPERTOIRE OF COMPUTATIONAL TOOLS AT AEROSPACE BY INTEGRATING OTHER CODES INTO OUR APPROACH TO PROBLEMS. AMONG THESE IS SIN, A ONE-DIMENSIONAL HYDROCODE THAT HAS BEEN VERY USEFUL IN SCOPING PROBLEMS BEFORE USING MESA AND IN APPROXIMATING SIMPLE GEOMETRIES. WE HAVE RECENTLY OBTAINED, AND ARE IN THE PROCESS OF IMPLEMENTING, SCAP AND LESCA, TWO PROGRAMS FOR SHAPED CHARGE ANALYSIS DEVELOPED BY SANDIA.

THE NEXT MAJOR STEP IN OUR CAPABILITY WILL BE USING MESA-3D. IT IS RUNNING ON THE CRAY-2 AT PHILLIPS LABORATORY, AND WE ARE ABOUT TO BECOME USERS.

STATUS AND FUTURE DIRECTIONS

- OTHER SYSTEMS MODELED
 - PRESSURE CARTRIDGE
 - LINEAR SHAPED CHARGE PENETRATION
- PLANNING TO RUN 3D MESA AT PHILLIPS LAB
- INTEGRATING COMPLEMENTARY CODES
 - SIN
 - LESCA
 - SCAP



1993010762 493076
46
SAND92-0610C
Printed June 1992

N93-20151

**Precision Linear Shaped Charge Severance
of Graphite-Epoxy Materials**

Manuel G. Vigil

Sandia National Laboratories
Explosive Components Department
P.O. 5800
Albuquerque, New Mexico 87123

Paper presented at the 1st NASA Aerospace Pyrotechnic Systems
Conference on June 9 - 10, 1992 at the Lyndon B. Johnson Space
Center in Houston, Texas.

Approved for public release; distribution is unlimited.

This page intentionally left blank.

Precision Linear Shaped Charge Severance of Graphite-Epoxy Materials

INTRODUCTION

This paper presents Precision Linear Shaped Charge (PLSC) components designed to sever a variety of target materials. Recent data for the severance of graphite-epoxy panels or targets with PLSC are presented. A brief history of the requirement to originate the development of PLSC for weapon components at Sandia National Laboratories is presented.

The Department of Energy's (DOE) nuclear weapon systems have continually decreased in size. Today's relatively small weapons require the design of much more efficient, lighter, and smaller explosive components because fragments, air shocks, and pyro-shocks associated with the function of these components can damage electrical and other sensitive components located nearby. The DOE requirements for PLSC's are listed in Table 1. Therefore, linear shaped charge (LSC) components for weapon systems can no longer be empirically or experimentally designed for a given application. Many of today's designs require severing concentric cylinders, for example, where the LSC jet is designed to sever only one of the two cylinders as was the case for the B90/Nuclear Depth Strike Bomb. Therefore, code modeling and simulation technology must be utilized to obtain a better understanding of the LSC jet hydrodynamic penetration, fracture, shear and spall mechanisms associated with the severance of metallic as well as composite targets.

The design of a LSC involves the numerous variables^{1,2,3} shown and listed in Figure 1. Because LSC design methods and hardware fabrication methods from existing suppliers in the U.S. were not adequate for DOE weapon component requirements, Sandia has designed and developed the PLSC. Sandia's PLSC related capabilities are listed in Table 2. PLSC components^{4,5} have recently been designed and developed for the programs listed in Table 3. The PLSC explosive loading (GPF), target, and jet penetration are also listed in Table 3.

CONVENTIONAL LINEAR SHAPED CHARGES

LSC suppliers (Explosive Technology, Teledyne McCormich Self, Dupont, Jet Research, Ensign Bickford, etc.) in the U.S. all use the similar technology for the last 40 years of initially loading an explosive powder in a tube that is then swage-formed, drawn or shaped into the conventional chevron or wedge configuration as shown in Figure 2. This process does not

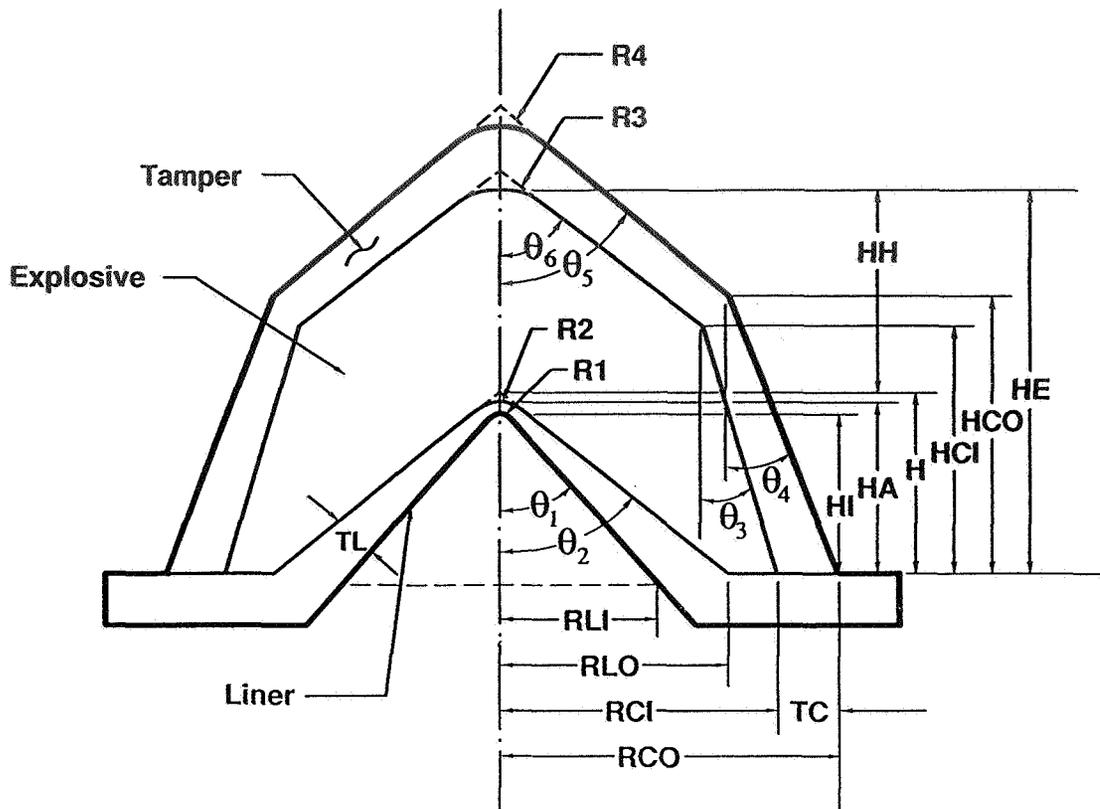
Approved for public release; distribution is unlimited.

TABLE 1.
WHY ARE PRECISION LINEAR CHARGES NEEDED?

IMPROVEMENTS IN DESIGN TECHNOLOGIES FOR WEAPON, MISSILE, AND OTHER SYSTEMS REQUIRING LINEAR SHAPED CHARGES HAS RESULTED IN THE CONTINUAL REDUCTION IN THE SIZE OF THESE SYSTEMS. THEREFORE, LINEAR SHAPED CHARGES WITH THE FOLLOWING CHARACTERISTICS ARE BEING REQUIRED:

1. LESS EXPLOSIVE REQUIRED TO SEVER A GIVEN TARGET
2. MORE REPRODUCIBLE TARGET SEVERANCE IN ORDER TO TAKE ADVANTAGE OF THE JET PENETRATION AS WELL AS THE ASSOCIATED FRACTURE
3. LESS TOTAL WEIGHT
 - A. EXPLOSIVE
 - B. LINER/WEDGE
 - C. TAMPER/CONFINEMENT
4. LESS TOTAL VOLUME
5. LESS COLLATERAL DAMAGE TO ADJACENT COMPONENTS
 - A. AIR SHOCK
 - B. PYRO-SHOCK THROUGH MATERIALS
 - C. MISSILE FRAGMENT DAMAGE
6. PRECISE CUTS OR SEVERANCE OF TARGET REQUIRED (EXAMPLES)
 - A. SEVER INTER CONCENTRIC CYLINDER WHILE NOT DAMAGING EXTERIOR CASING
 - B. SEVER PILOT EJECTION CONOPY WITH LESS RISK OF INJURING THE PILOT BEFORE OR AFTER EJECTION





- RLI = LINER INNER RADIUS
- RLO = LINER OUTER RADIUS
- RCI = CONFINEMENT/SHEATH INNER RADIUS
- RCO = CONFINEMENT/SHEATH OUTER RADIUS
- HI = LINER INNER HEIGHT
- HA = LINER ACTUAL HEIGHT
- H = LINER THEORETICAL APEX HEIGHT
- HCI = CONFINEMENT/SHEATH INNER HEIGHT
- HCO = CONFINEMENT/SHEATH OUTER HEIGHT
- HE = EXPLOSIVE HEIGHT
- HH = EXPLOSIVE HEIGHT ABOVE APEX
- TL = LINER THICKNESS
- TC = CONFINEMENT/SHEATH THICKNESS
- R1 = LINER INNER APEX RADIUS
- R2 = LINER OUTER APEX RADIUS
- R3 = CONFINEMENT/SHEATH INNER APEX RADIUS
- R4 = CONFINEMENT/SHEATH OUTER APEX RADIUS
- θ_1 = LINER INNER APEX HALF ANGLE
- θ_2 = LINER OUTER APEX HALF ANGLE
- θ_3 = CONFINEMENT/SHEATH INNER APEX HALF ANGLE
- θ_4 = CONFINEMENT/SHEATH OUTER APEX HALF ANGLE

FIGURE 1. POTENTIAL COMPONENT LSC CROSS-SECTION

TA0117.01.01

TABLE 2.
SANDIA'S PRECISION LINEAR SHAPED CHARGE CAPABILITIES

EXPERIENCED PROJECT PLANNING

CODE MODELLING/ANALYSIS/PREDICTION

- 1. LINEAR EXPLOSIVE SHAPED CHARGE ANALYSIS (LESCA) CODE
- 2. CODE DEVELOPED RECENTLY AT SANDIA

CONCEPTUAL AND PROTOTYPE DESIGN

- 1. DRAWINGS

HARDWARE FABRICATION

- 1. LOCAL
 - A. THOMPSON MACHINE SHOP
 - B. OSBORN MACHINE SHOP
 - C. ACCURATE SCREW MACHINE PRODUCTS, INC.
- 2. ENSIGN BICKFORD
- 3. PANTEX PLANT
- D. PICATINNY ARSENAL/BURLINGTON PLANT

TESTING

- 1. SANDIA EXPLOSIVE TEST FACILITIES
- 2. DIAGNOSTIC HARDWARE SELECTION
- 3. DATA ANALYSIS AND REDUCTION

DOCUMENTATION OF PLSC TASKS

- 1. PREVIOUS COMPONENT DESIGN TASKS HAVE BEEN PUBLISHED
- 2. TWO PATENTS PENDING ON PLSC COMPONENT DESIGNS



TABLE 3.

SANDIA NATIONAL LABORATORIES PLSC COMPONENTS

PROGRAM	PLSC (GPF)	TARGET	JET PENETRATION DEPTH * (INCHES)
1. TRIDENT II/D5	16	GRAPHITE-EPOXY	0.175
2. B90/NDSB	30	ALUMINUM	0.200
3. B90/NDSB	30	KEVLAR	0.106
4. O.D.E.S.	65	STEEL	0.180
5. SPECIAL FORCES	850	STEEL	1.000

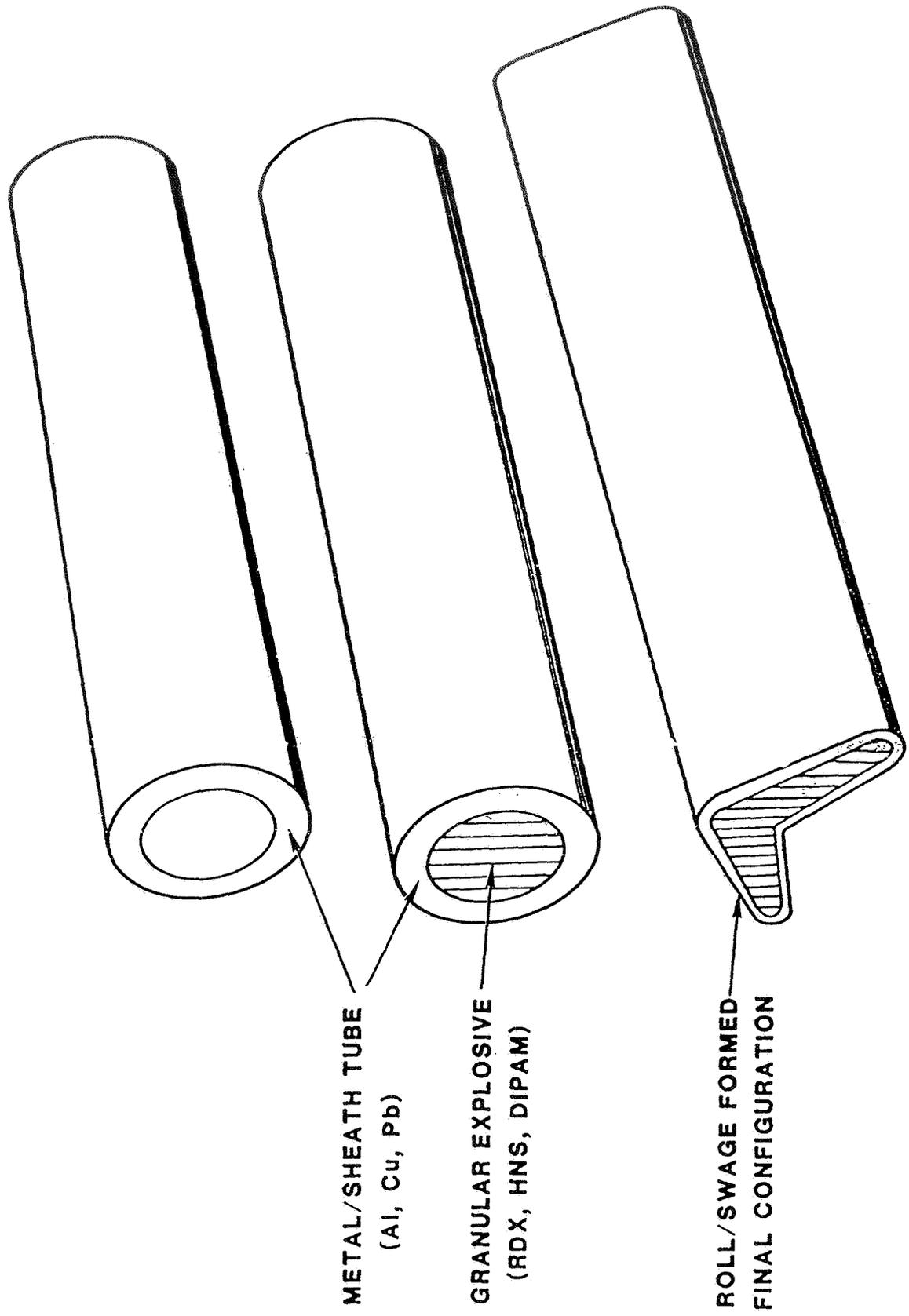
GPF - GRAIN/FOOT
 NDSB - NUCLEAR DEPTH STRIKE BOMB
 O.D.E.S. - OPERATIONAL DEPLOYMENT EXPERIMENT SIMULATOR
 * - METALLIC TARGET FRACTURE NOT INCLUDED



SANDIA NATIONAL LABORATORIES

FIGURE 2.

CONVENTIONAL LINEAR SHAPED CHARGE FABRICATION



permit precise, accurate, uniform or symmetric cross-sections to be fabricated as illustrated in Figures 3 and 4 for a 25 grain/foot, RDX explosive, and aluminum sheath LSC. Figure 4 shows jet penetration in aluminum versus standoff data for two different tests. The data from these two tests are not very reproducible and the optimum standoff is difficult to define. The density of the explosive at a given point (cross-section) and along the length is not uniform. The final density is relatively uncontrolled and has been shown to be near the theoretical maximum density for some components in recent years. This relatively high loading density can also make the initiation of the explosive more difficult. The end result of fabricating or producing a LSC by these conventional methods is a relatively inefficient and non-reproducible jet penetration in any target. This non-reproducibility of conventional LSC's does not allow the designer to take full advantage of the fracture or secondary severance mechanism associated with the jet penetration of metallic targets. For conventional LSC's, the explosive is first loaded into a tube which then becomes the material for the liner or wedge and tamper. Therefore, the disadvantages of conventional LSC's are listed in Table 4.

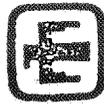
PRECISION LINEAR SHAPED CHARGES

The goal and optimum parameters desired for a PLSC design are listed in Table 5. With PLSC technology, the liner or wedge, tamper, and explosive are fabricated or produced separately or independantly. The liner and tamper materials can be different as indicated in Figures 5 and 6. Therefore, the most important part of the LSC, the liner, can be designed with precise, unique properties for the jet required to penetrate a given target. The liner material, geometry, and microstructure can be designed independant of the tamper material. The liner, tamper and explosive materials can be selected and fabricated to geometries that are optimized with the use of analytical codes. The tamper material, usually, but not always, is fabricated from high density material. The explosive can be machined, cast, buttered or extruded between the liner and tamper materials as indicated in Figure 7. PLSC explosive loading methods have been developed at Ensign Bickford and at the Pantex Plant. The explosive is added or assembled last rather than first as is done with conventional LSC's. With PLSC designs, the liner, explosive and tamper parts can be inspected prior to assembly. The independant fabrication of the PLSC parts is the major reason PLSC components are more efficient (less explosive weight, less total component weight and less volume for a given target) and much more reproducible for a given test and from test to test than conventional LSC's.

PLSC liners have been fabricated from copper, aluminum, nickel, tantalum, gold-plated aluminum, and gold-plated copper. PLSC components have been designed to sever aluminum, steel,

FIGURE 3.

REPRODUCIBILITY OF CONVENTIONAL LSC



LSC PEN. vs S.O. IN AI (6061-T6)

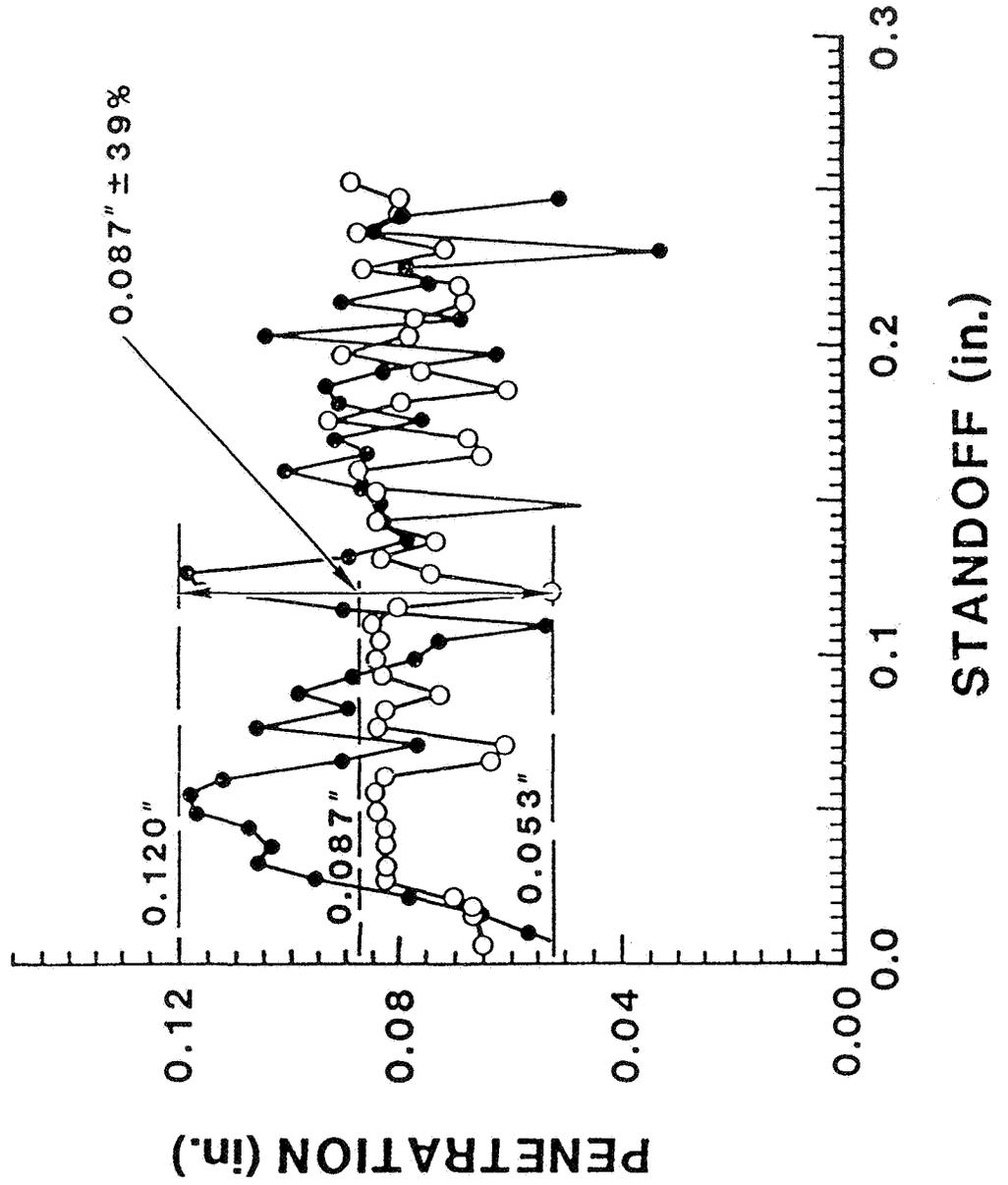


FIGURE 4.

CONVENTIONAL 25 gr/ft ALUMINUM SHEATH,
HNS EXPLOSIVE LSC CROSS-SECTIONS



MAGNIFICATION - 20X

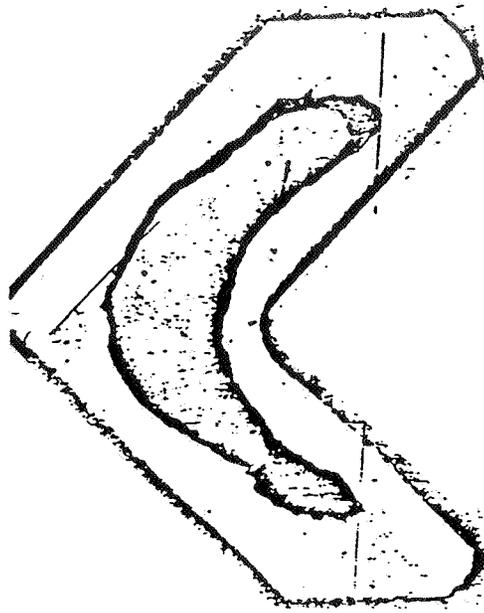
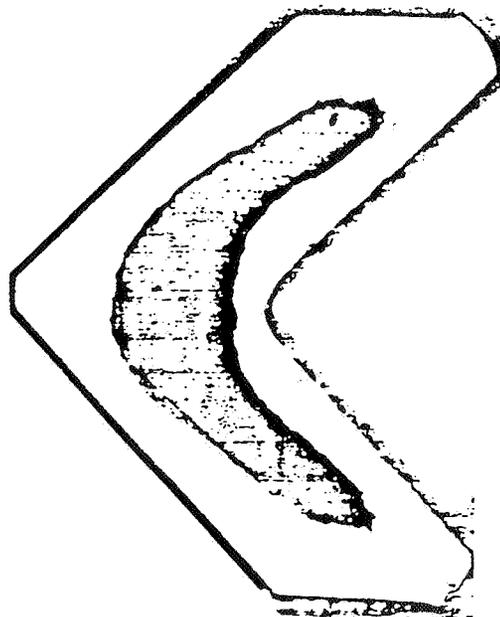


TABLE 4.

**CONVENTIONAL
LINEAR SHAPED CHARGE (LSC) DESIGNS**



I. DISADVANTAGES:

- A. NON-REPRODUCIBLE JET PENETRATION,
- B. NON-SYMMETRIC LSC CROSS-SECTIONS,
- C. NON-UNIFORM EXPLOSIVE DENSITY,
- D. NON-OPTIMIZED LSC CROSS-SECTION, AND
- E. HISTORICALLY, FOR NON-PRECISE JET CUTTING.
 - a. DEMOLITION WORK
 - b. SEPARATION STAGES IN OLDER - LARGER SYSTEMS

TABLE 5.

PRECISION

LINEAR SHAPED CHARGE (PLSC) DESIGN



I. GOAL:

A. DESIGN OPTIMUM PLSC

- 1. INCREASED JET PENETRATION
IN TARGET,**
- 2. IMPROVED JET REPRODUCIBILITY, AND**
- 3. MORE EFFICIENT - MINIMUM EXPLOSIVE.**

FIGURE 5.



NEW COMPONENT LINEAR SHAPED CHARGE FABRICATION

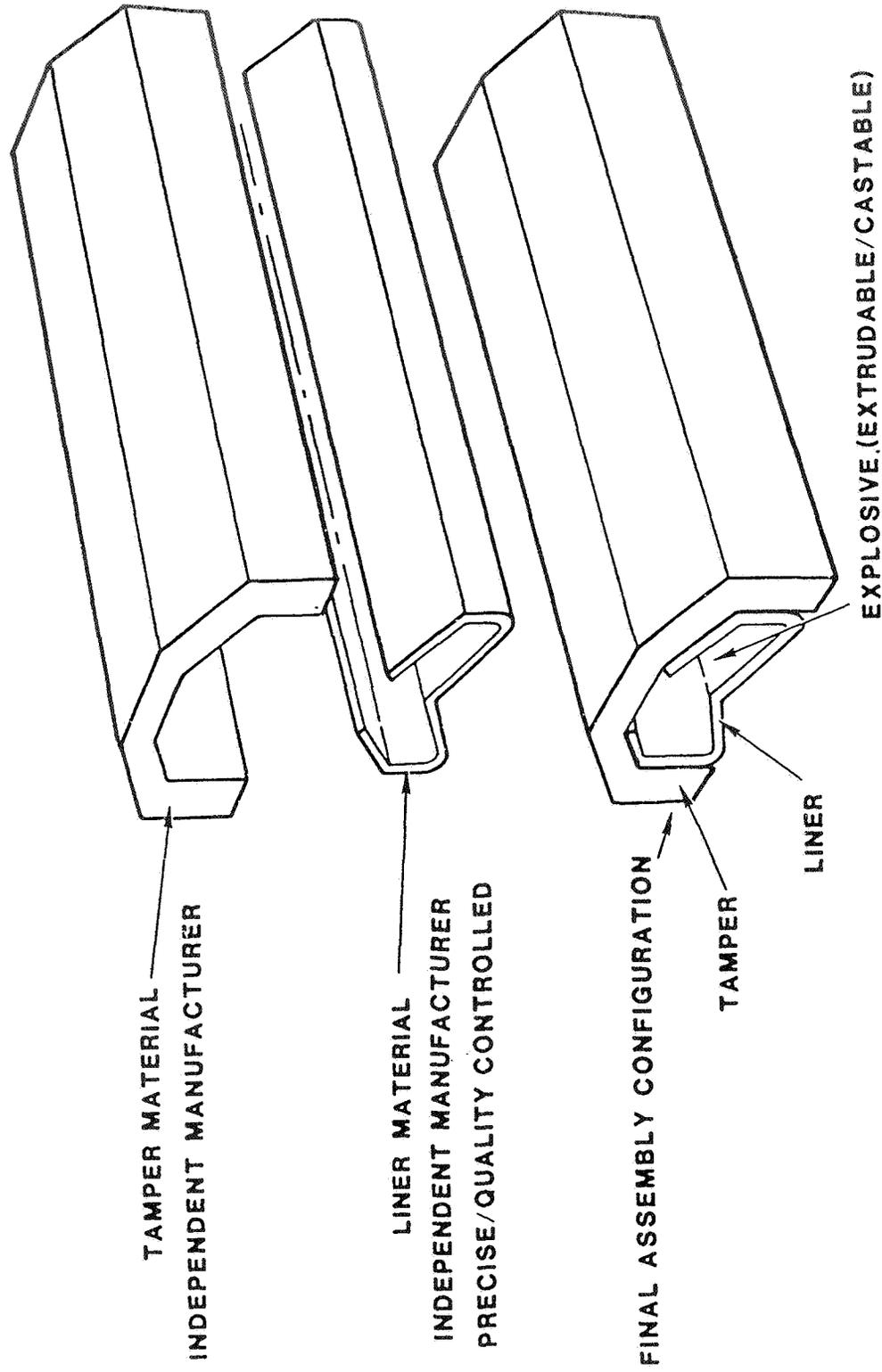
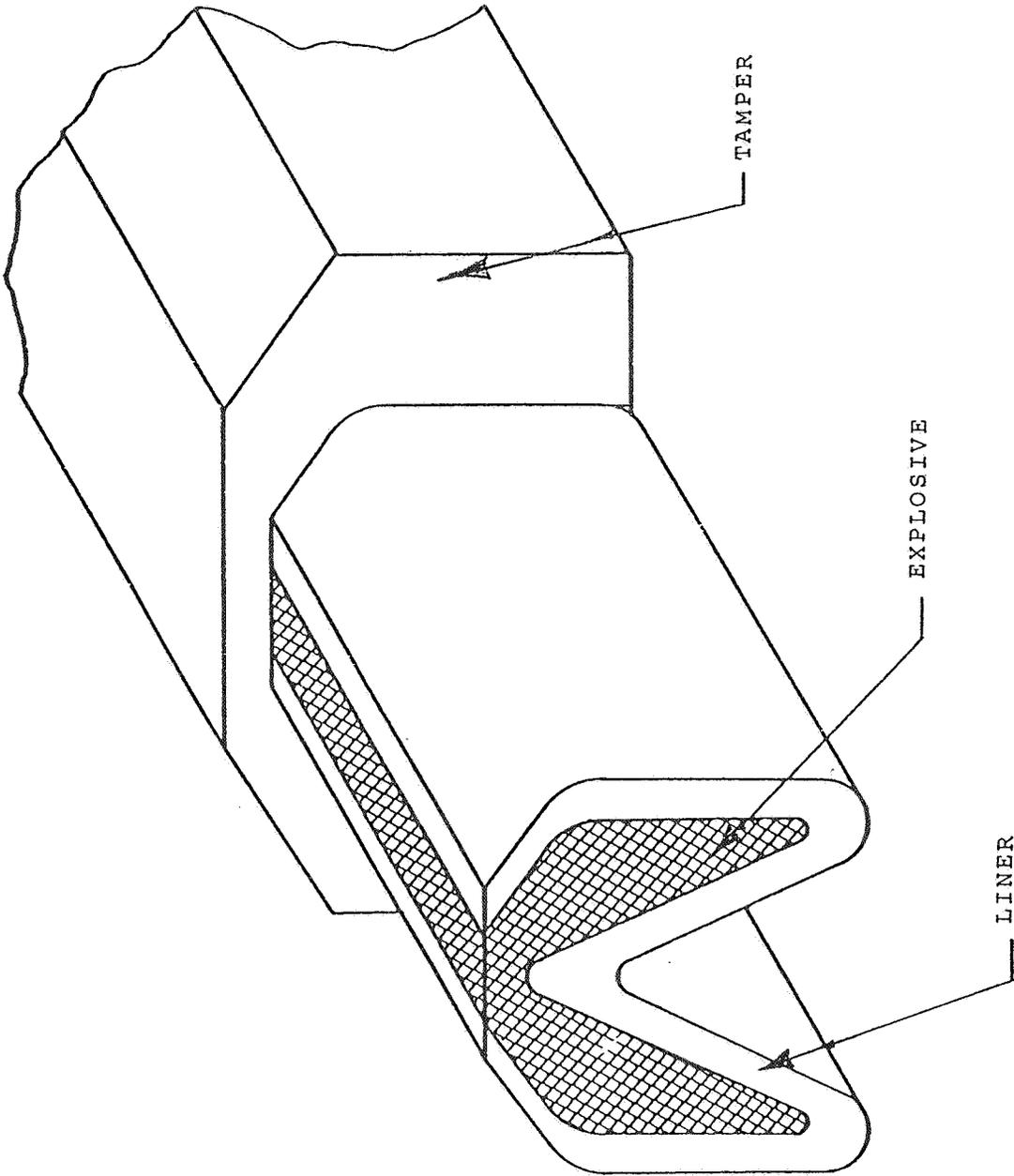




FIGURE 6.
COMPONENT LINEAR SHAPED CHARGE CONFIGURATION



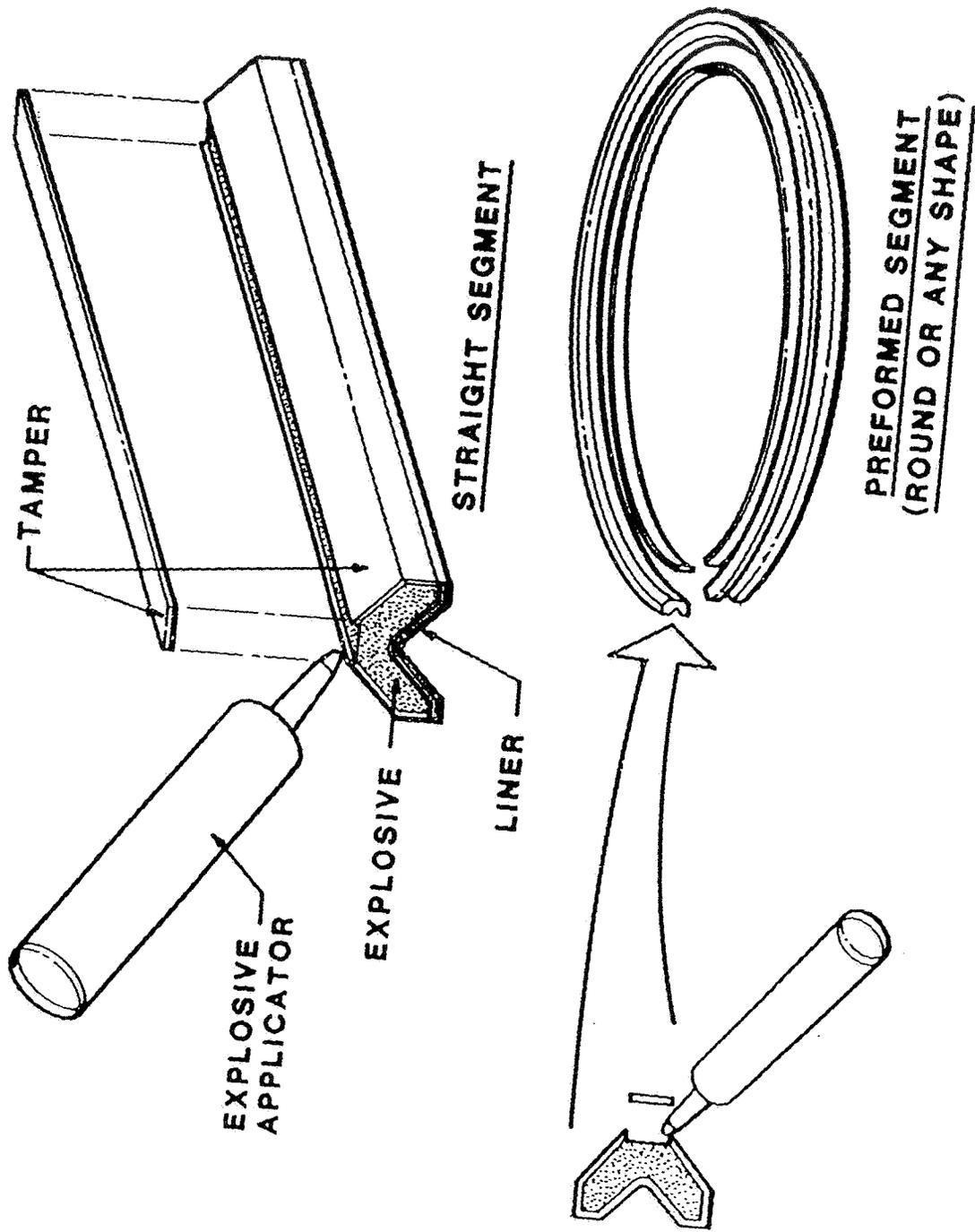


FIGURE 7. PLSC EXPLOSIVE LOADING

graphite-epoxy, Kevlar, and titanium materials. The reproducibility of the 30 grain/foot, LX-13 (XTX-8003 or PBXN-301) explosive, copper liner PLSC shown in Figure 8 is illustrated in Figure 9 for a variable standoff (PLSC in contact with the aluminum target at one end and at a 0.25 inch standoff at the other end of the 8 inch long target) and Figure 10 for a constant standoff (PLSC at a standoff of 0.100 inches over the 8 inch length of the target). The jet penetration versus standoff are compared for a PLSC (Figure 11) and conventional LSC in Figure 12. The 25 grain/foot explosive loading and aluminum liner were the same for both charges. The PLSC design was loaded with LX-13 explosive which is composed of 80% PETN and 20% inert Sylgard binder. Therefore, the actual explosive loading was only 16 grain/foot. The conventional LSC was loaded with HNS II explosive. The reproducibility of the jet penetration into an aluminum target for two different tests illustrated in Table 6. The maximum deviation for the two tests is within 4%. The PLSC advantages over conventional LSC's are listed in Table 7.

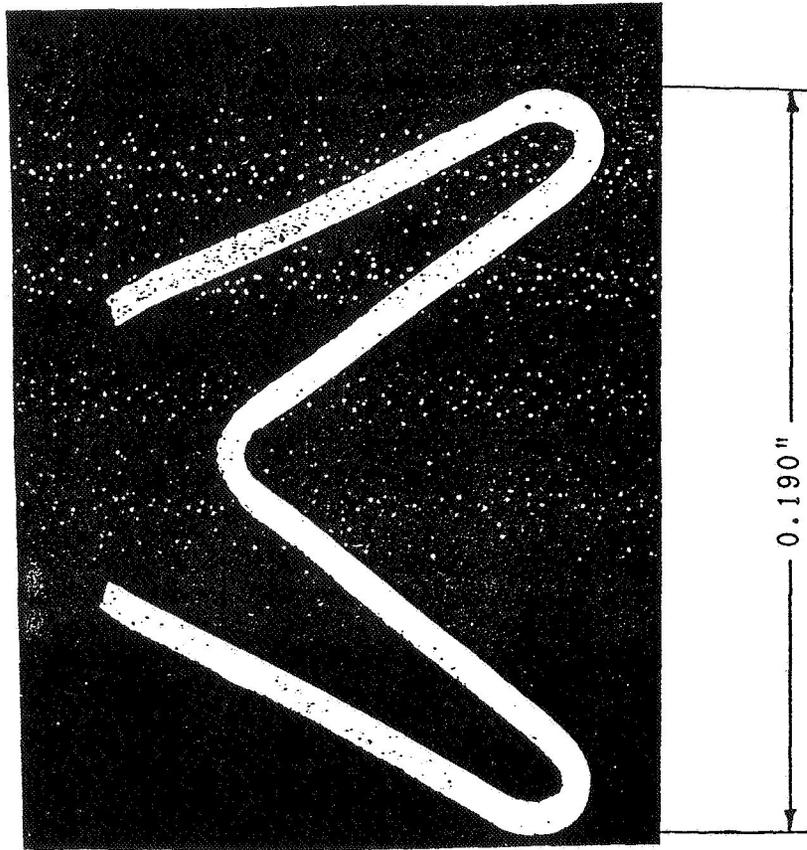
RECENT SANDIA PLSC COMPONENTS

PLSC's recently developed at Sandia National Laboratories have been designed to sever aluminum, steel, Kevlar, titanium and Graphite-Epoxy targets. Table 3 lists the programs for which PLSC components have been designed and developed. The PLSC explosive loading, target material, and severance thickness are listed in Table 3. The explosive used in most of these components was LX-13 or XTX-8003 which is 80% PETN explosive and 20% inert Sylgard binder. Therefore, for all LX-13 tests, the actual explosive (H.E.) grain per foot (GPF) loading is 80% of the PLSC loading.

The Trident II/D5 component was designed to sever the graphite-epoxy missile case (Stage separation component). One B90/Nuclear Depth Strike Bomb (NDSB) PLSC component was designed to sever an aluminum cylinder to release the parachute on target approach. The other B90/NDSB component was designed to sever 8 Kevlar parachute suspension lines to jettison the parachute after water impact. The Operational Deployment Experiment Simulator (O.D.E.S.) PLSC component was designed as a flight termination system and the annular PLSC cuts 4 inch diameter holes in each of two steel spheres containing the propulsion fuel for the third stage. The hypergolic fuel from the two spheres mixes and burns to terminate the flight.

The Special Forces PLSC was designed for Picatinny Arsenal. This PLSC was unique in that three short segments can sever a 1.0 inch thick "I" beam without subjecting friendly troops to

FIGURE 8.
PLSC6 COPPER LINER/ACTUAL CROSS-SECTION



SANDIA NATIONAL LABORATORIES

FIGURE 9.

PLSC6/LEXAN INSERT/STEEL CONFINEMENT



Sandia
National
Laboratories

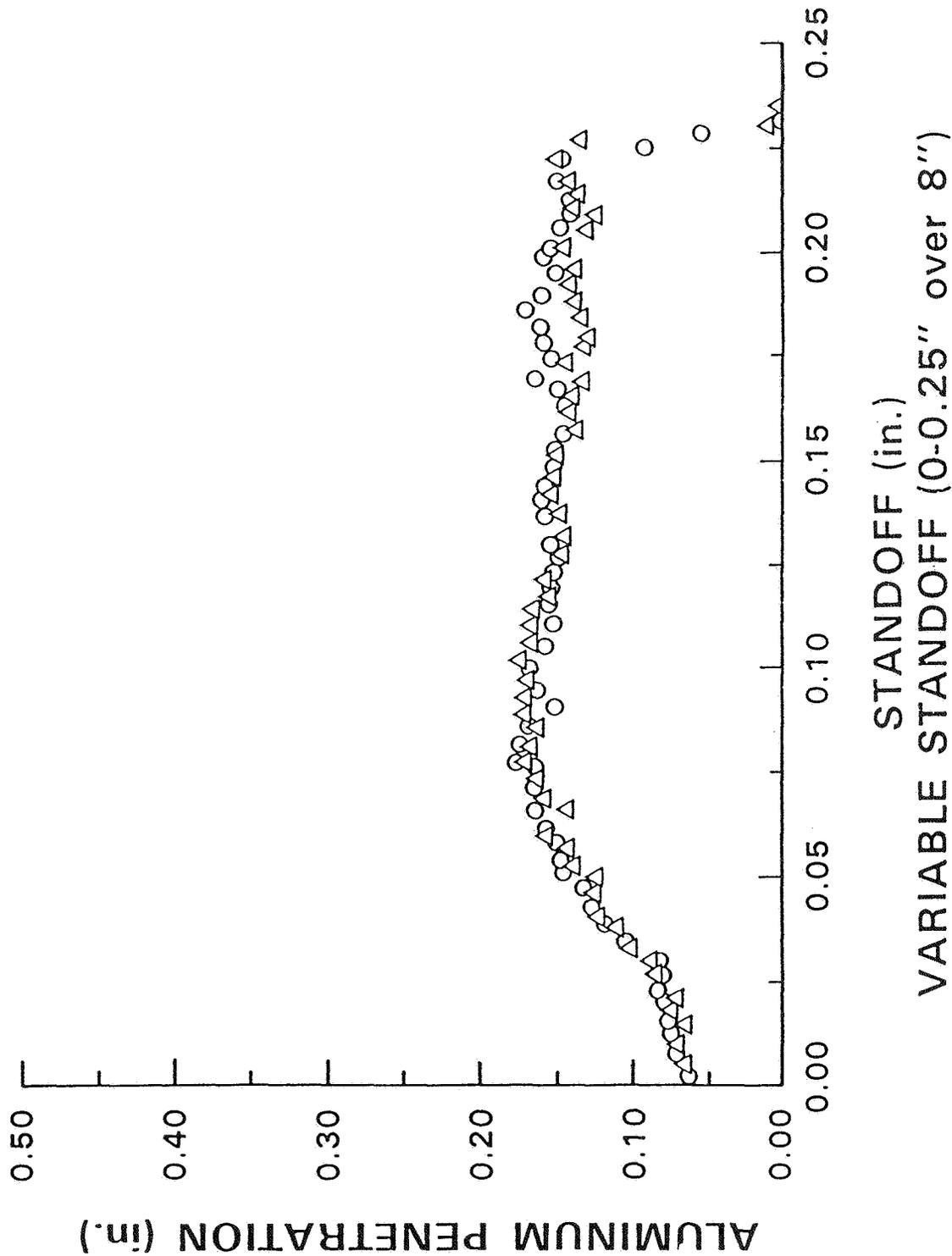
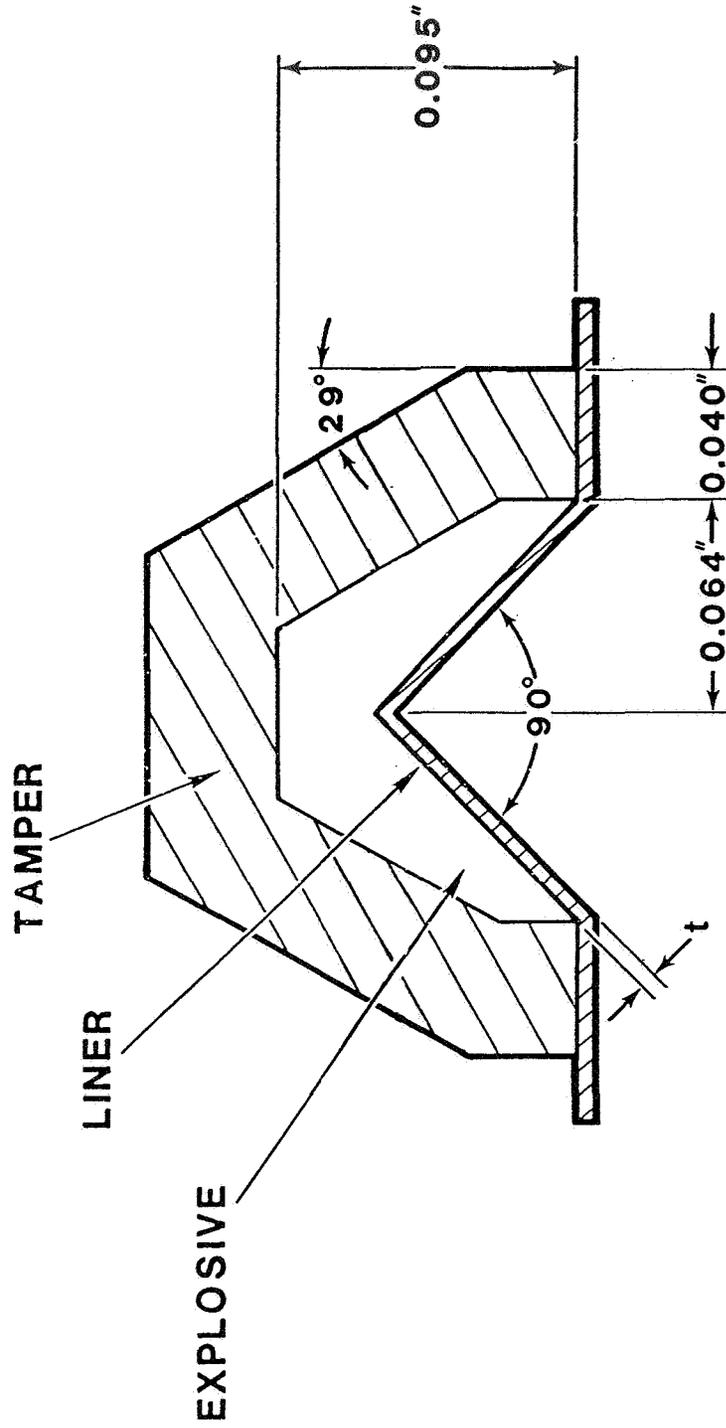


FIGURE 11.

PLSC 90° APEX ANGLE CROSS-SECTION



25 gr/ft, Al LINER, Al TAMPER



COMPONENT PLSC VS CONVENTIONAL LSC EXPERIMENTAL DATA



FIGURE 12.

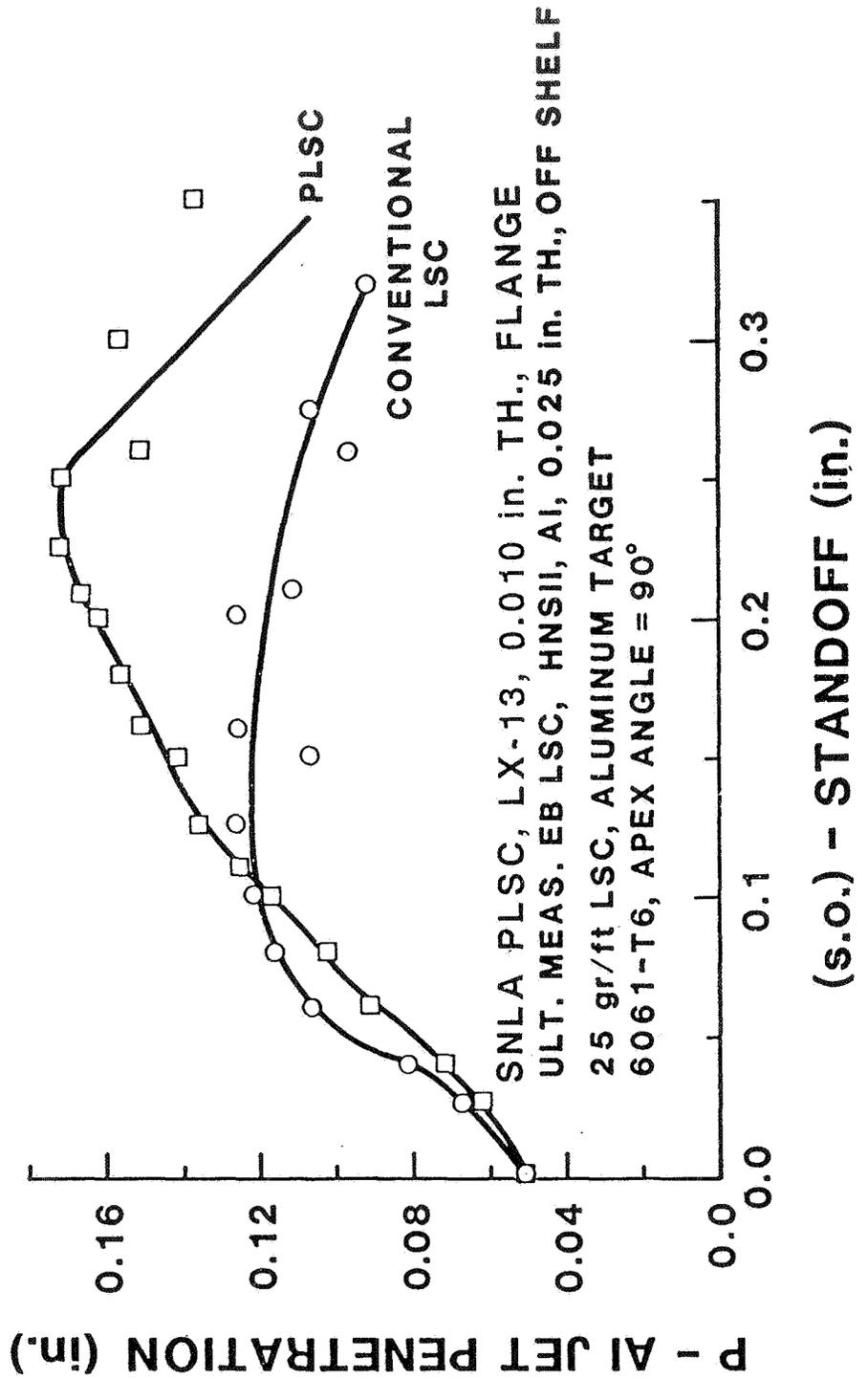




TABLE 6.
REPRODUCIBILITY OF 25 GR/FT, LX-13/AL COMPONENT LSC

Data near optimum standoff of about 0.235"
Liner thickness - 0.010"
Pantex tests/flange design

X (mm)	Penetration (in.)		Difference (in.)	Mean (in.)	% Deviation
	Test #10AL01	Test #10AL02			
150	.353	.350	.003	.352	0.8
160	.353	.347	.006	.350	0.9
170	.338	.344	.006	.341	0.9
180	.338	.344	.006	.341	0.9
190	.334	.353	.020	.344	2.6
200	.343	.366	.023	.355	3.1
210	.344	.372	.028	.358	3.9
220	.363	.368	.005	.366	0.5
230	.350	.363	.013	.357	1.7
240	.363	.366	.003	.365	0.3
250	.366	.366	.000	.366	0.0

TABLE 7.

PLSC ADVANTAGES OVER CONVENTIONAL LSC

- LESS EXPLOSIVE REQUIRED TO SEVER GIVEN TARGET
- LESS COLLATERAL DAMAGE
 - PYRO-SHOCK, BLAST AND FRAGMENTS
- LESS TOTAL WEIGHT (LINER, EXPLOSIVE & TAMPER)
- LESS TOTAL VOLUME
- MORE REPRODUCIBLE JET-TARGET PENETRATION DEPTH
 - FOR A GIVEN TEST
 - FROM TEST TO TEST
- ALLOWS DESIGNER TO TAKE ADVANTAGE OF FRACTURE
 - TARGET SEVERANCE DESIGN MARGIN



hazardous fragments. The tamping material used for this PLSC design was Plexiglas. The fragmentless, light total weight (easily portable on backpacks) and efficient design (850 grain/foot explosive loading to sever 1.0 inch thick steel beam) made this PLSC a very attractive design (Patent Pending). This PLSC design was less than half the weight of any conventional LSC available from suppliers in the U.S.

COMPUTER MODELING AND SIMULATION

Sandia has recently developed the Linear Explosive Shaped Charge Analysis (LESCA, old name was LSCAP) code⁶⁻⁹ for modeling and designing linear shaped charges. The code modeling features are listed in Table 8. The LSC cross-sections are assumed symmetrical and a typical modeling cross-section is shown in Figure 13. The graphical modeling capabilities are illustrated in Figures 14 - 16. The jet formation and explosive product gas expansion of the LSC sheath material is illustrated in Figures 14 and 15 for two different times. The code graphics for jet penetration, jet envelope angle (theta) and jet particle angle (alpha) are shown in Figure 16. The experimental and code predicted data are compared in this figure. The LESCA code predicted alpha and beta angles have compared favorably with experimental data as that shown in Figure 17. The LESCA code predicted jet penetration versus standoff are compared to experimental data in Figures 18 - 20 for the PLSC6, PLSC7 and PLSC8 designs, respectively.

SANDIA PLSC SEVERANCE OF GRAPHITE-EPOXY TARGETS

Sandia has recently conducted a study to extend the PLSC data for severing graphite-epoxy panels or targets. Data for PLSC severance of graphite-epoxy panels are listed in Table 9 for six tests. All tests were conducted using graphite-epoxy panels available from the Trident II/D5 program. The density of the graphite-epoxy was about 1.55 g/cc. Existing PLSC hardware with parameters as listed in Table 10 and from the previous programs listed in Table 3 were used in the tests listed in Table 9. The PLSC explosive plus inert binder (GPF), tamping (TAMP.) material, and standoff (S.O.) are listed in Table 9. The graphite-epoxy target number of panels, thickness, panels severed, and severed thickness are also listed in Table 9. All tests were conducted with the PLSC at a constant standoff (S.O.) from the graphite-epoxy panels as shown in Figure 21. An aluminum witness plate was located 0.060 inches from the back side of the graphite-epoxy panels to measure any residual jet penetration.

TABLE 8.

LINEAR SHAPED CHARGE ANALYSIS PROGRAM(LSCAP)
LINEAR EXPLOSIVE SHAPED CHARGE ANALYSIS(LESCA)/RENAMED

CODE RECENTLY DEVELOPED AT SANDIA

CODE MODELING FEATURES

1. SWEEPING/TANGENTIAL DETONATION
2. LSC - TARGET JET IMPACT ANGLE
3. LINER ACCELERATION AND VELOCITY
4. JET FORMATION PROCESS
5. JET PENETRATION PROCESS/MULT-LAYERED TARGETS
6. VARIABLE AND CONSTANT STANDOFFS

ANALYTICAL CODE

1. INEXPENSIVE
2. PARAMETRIC STUDIES
3. INTERACTIVE, EASY TO USE

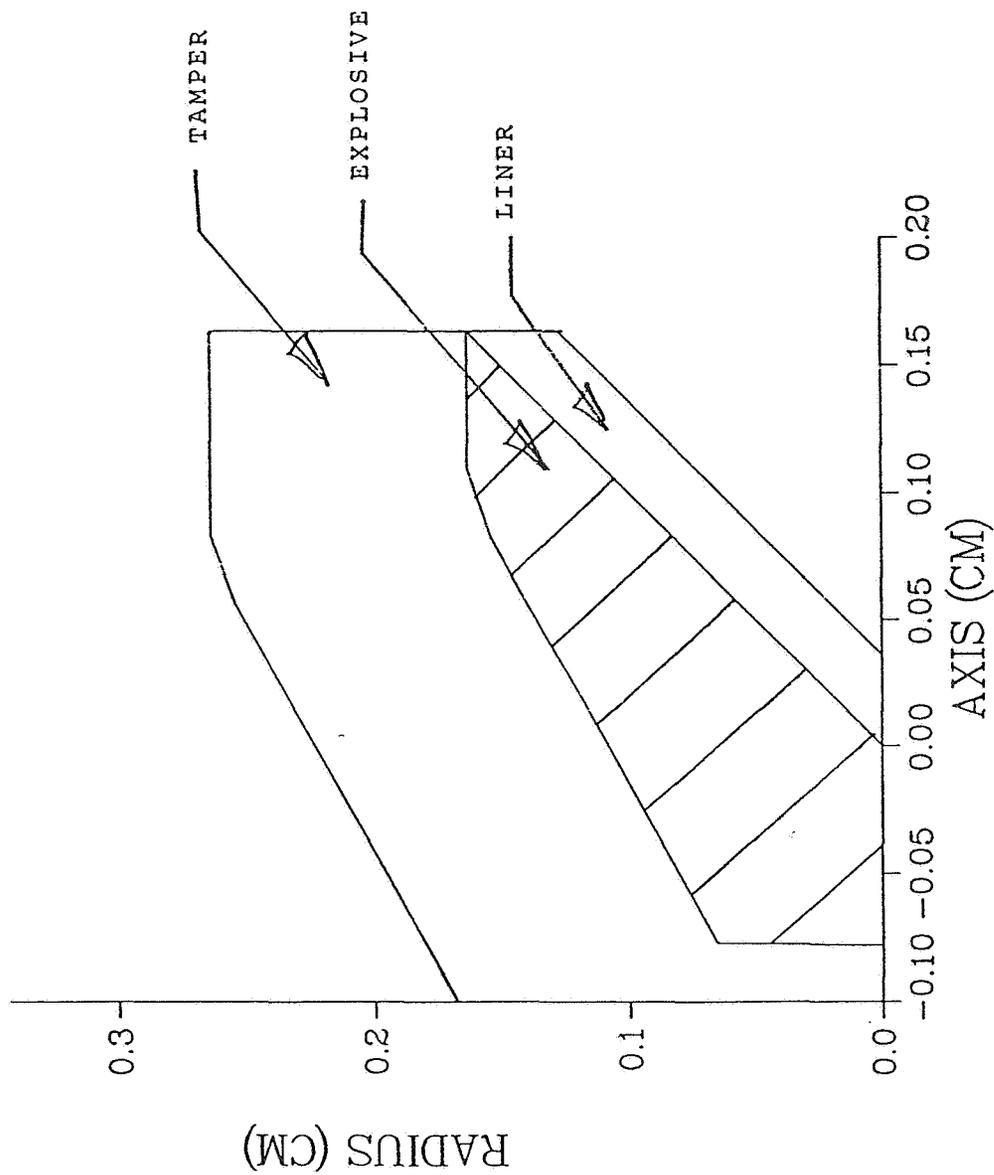


FIGURE 13.

LSCAP CODE MODEL CROSS-SECTION



25 gr/ft, LX-13 H.E., AL TAMPER, .010" THICK AL LINER



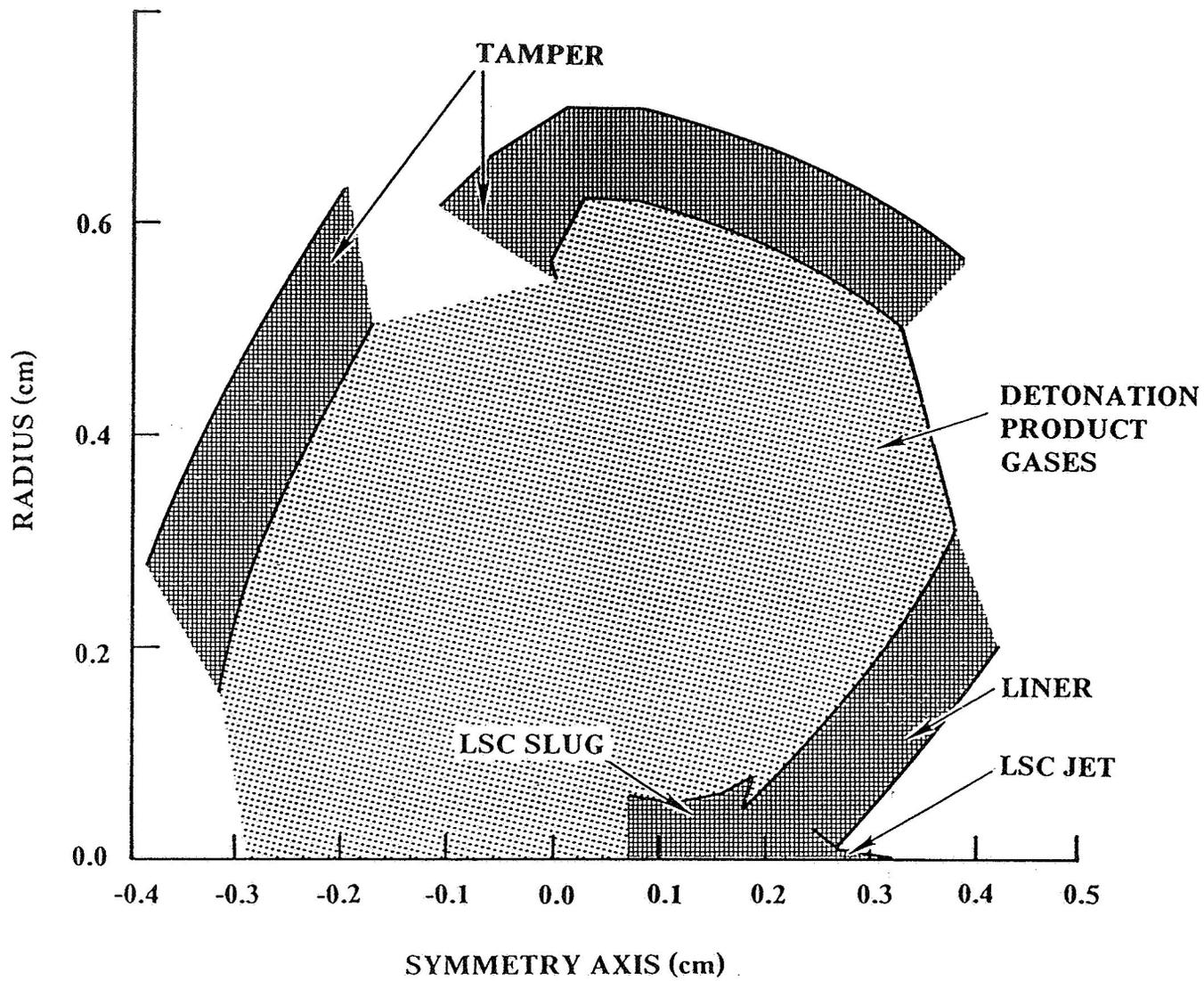


FIGURE 14. Graphical Representation of Half of the LSC Liner Collapse Process

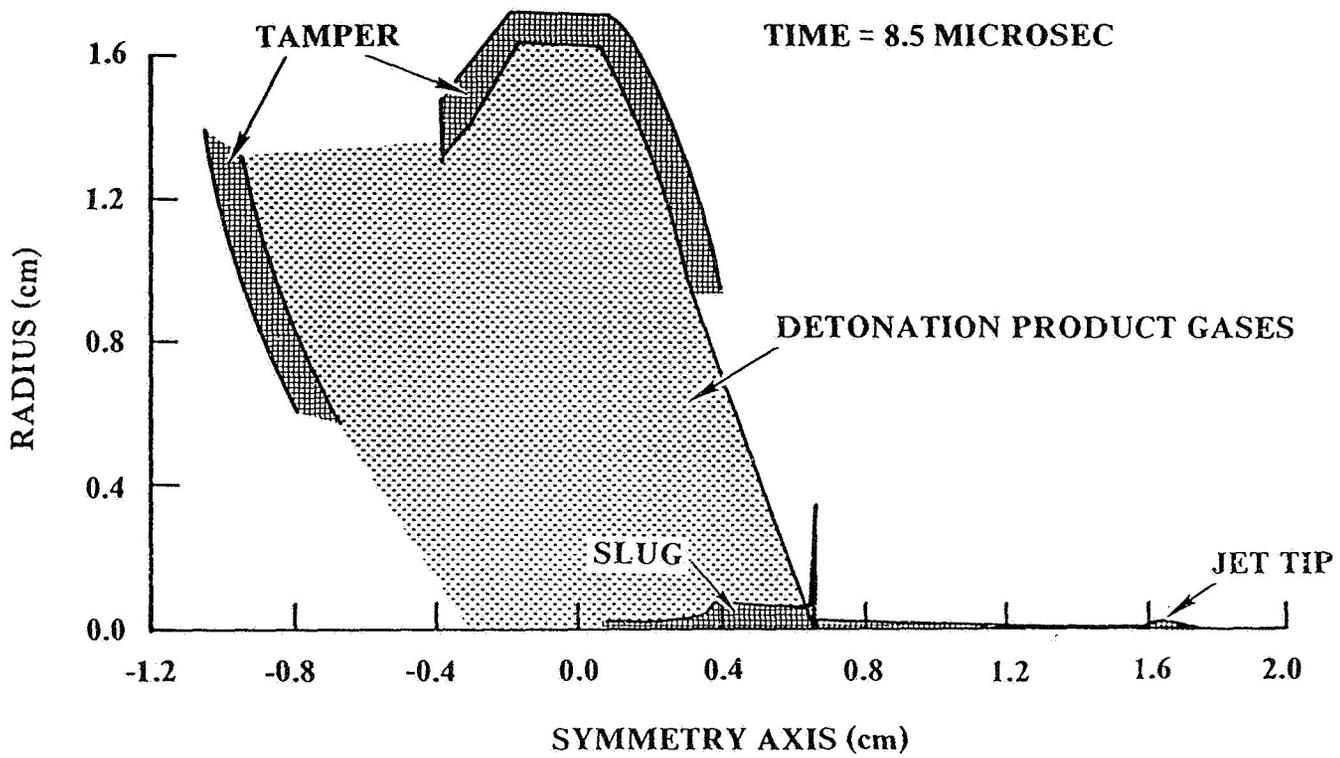


FIGURE 15. Graphical Representation of Half of the LSC Liner Collapse Process at 8.5 microseconds after Initiation of the Explosive

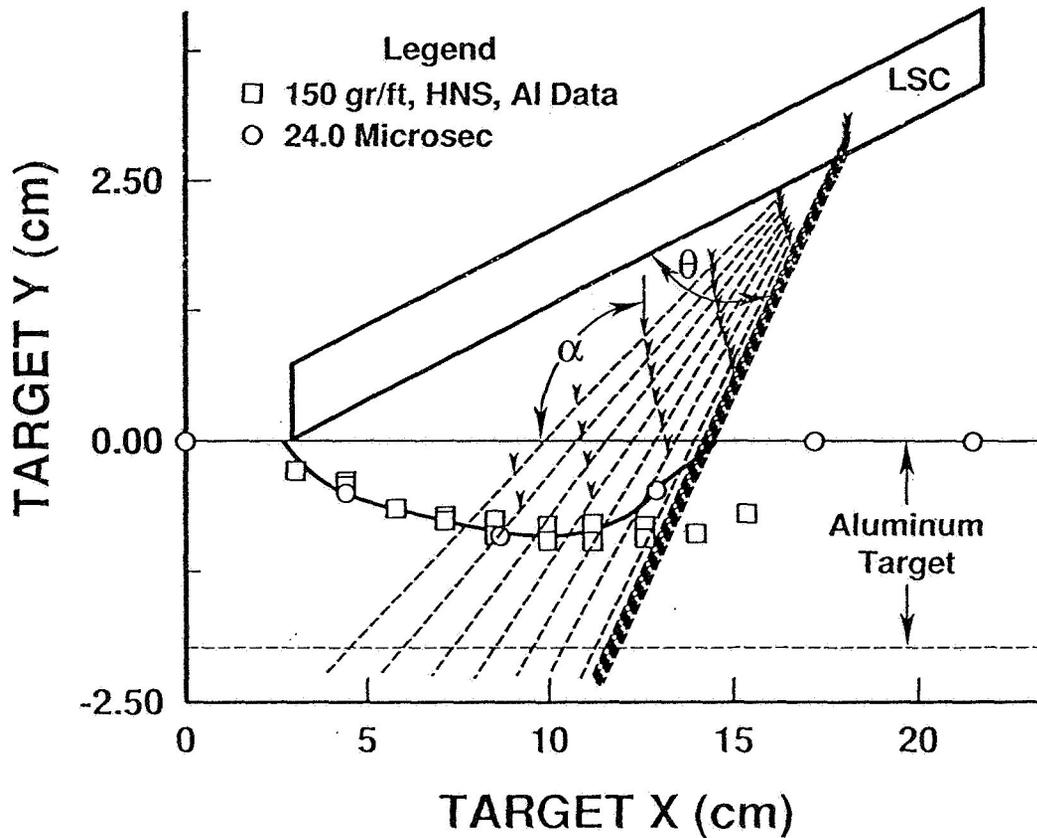
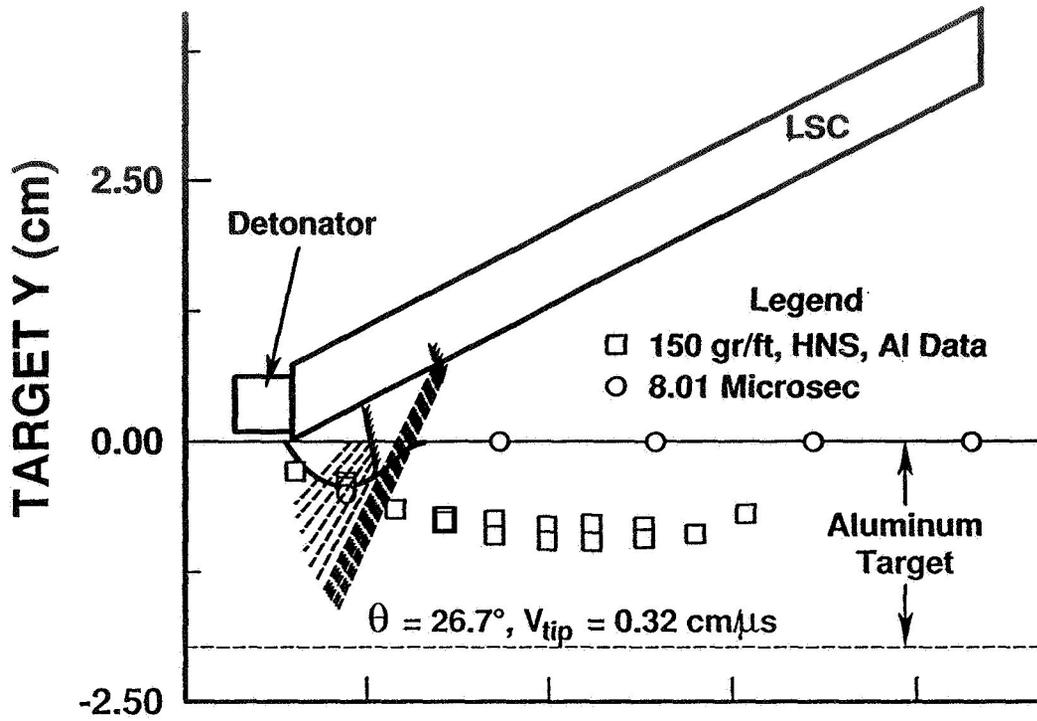
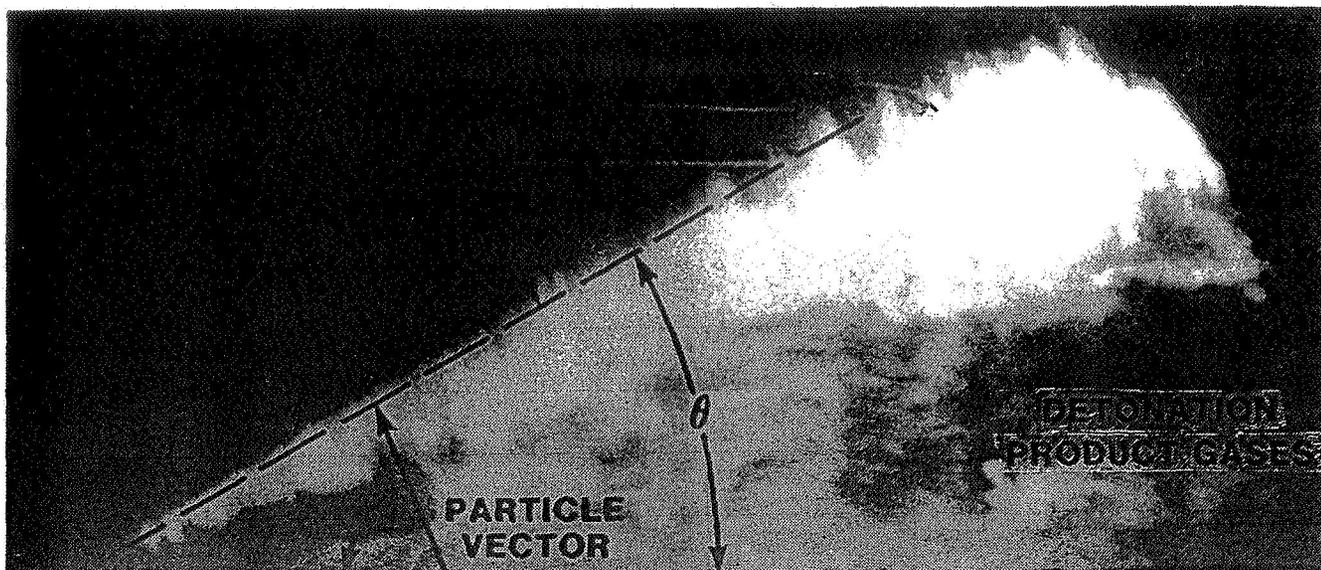
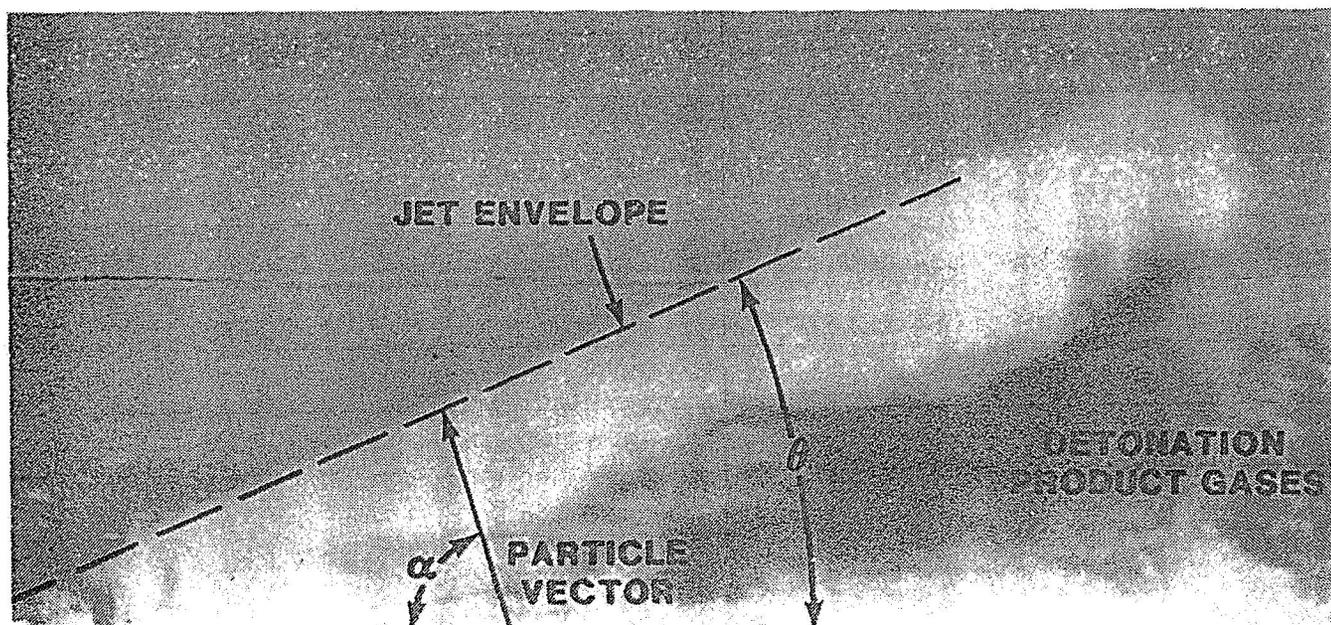


FIGURE 16. LESCA JET PENETRATION GRAPHICS



PHOTOGRAPH OF 150 gr/ft, RDX, Al SHEATH, LSC JET

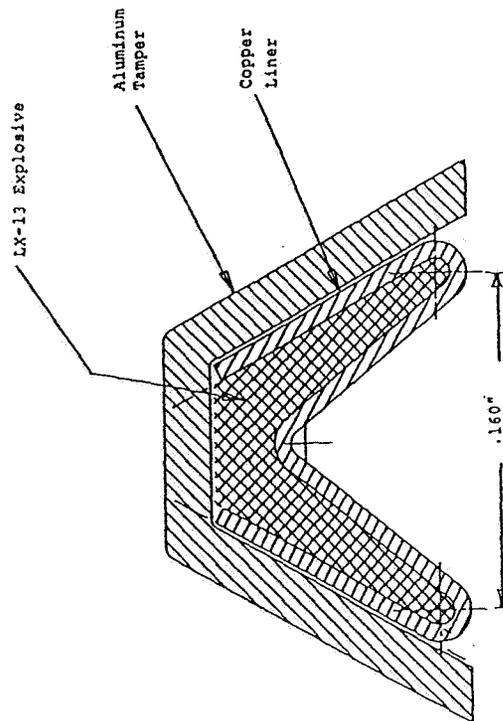
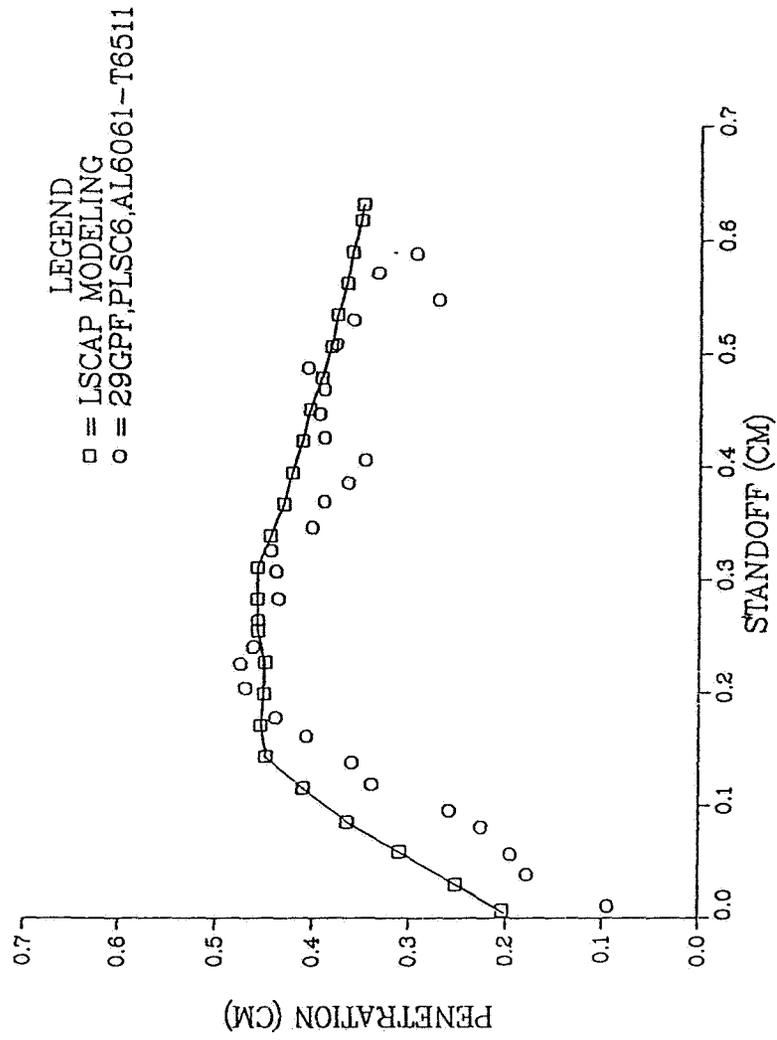


PHOTOGRAPH OF 220 gr/ft, RDX, Al SHEATH, LSC JET

FIGURE 17. LSC JET EXPERIMENTAL DATA

PLSC6 CROSS-SECTION/PENETRATION VERSUS STANDOFF

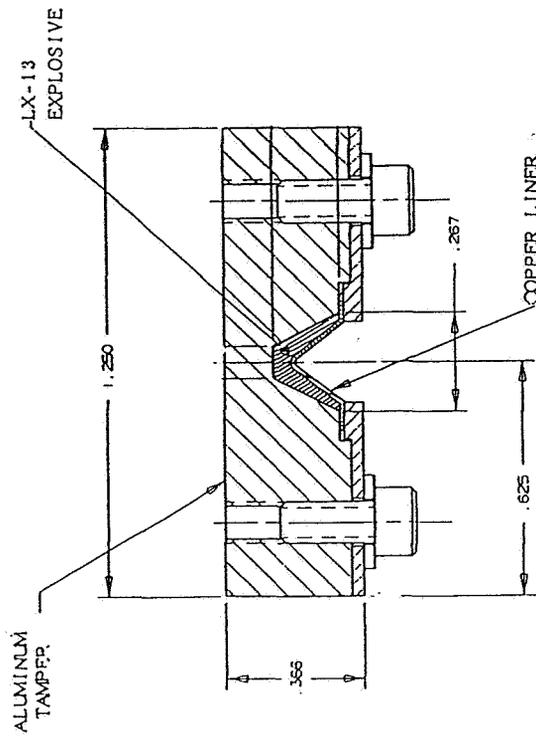
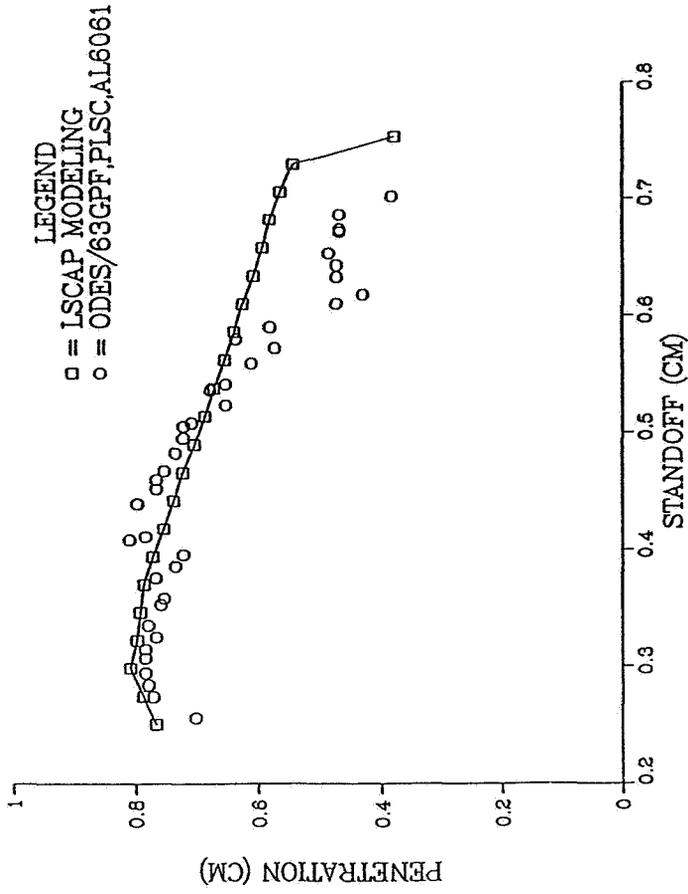
FIGURE 18.



SANDIA NATIONAL LABORATORIES

FIGURE 19.

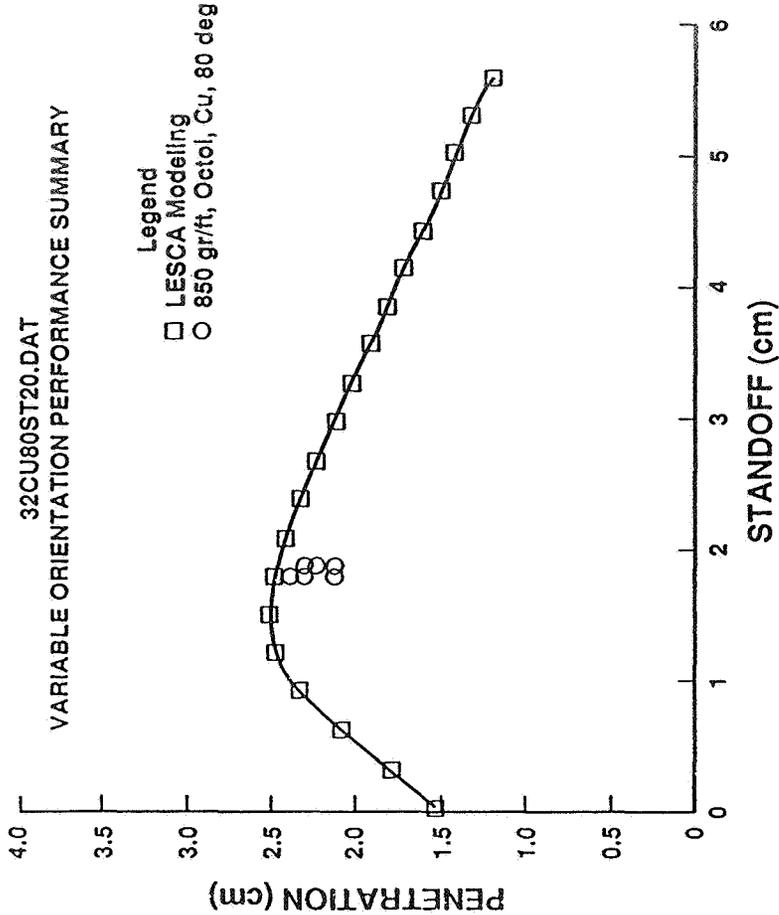
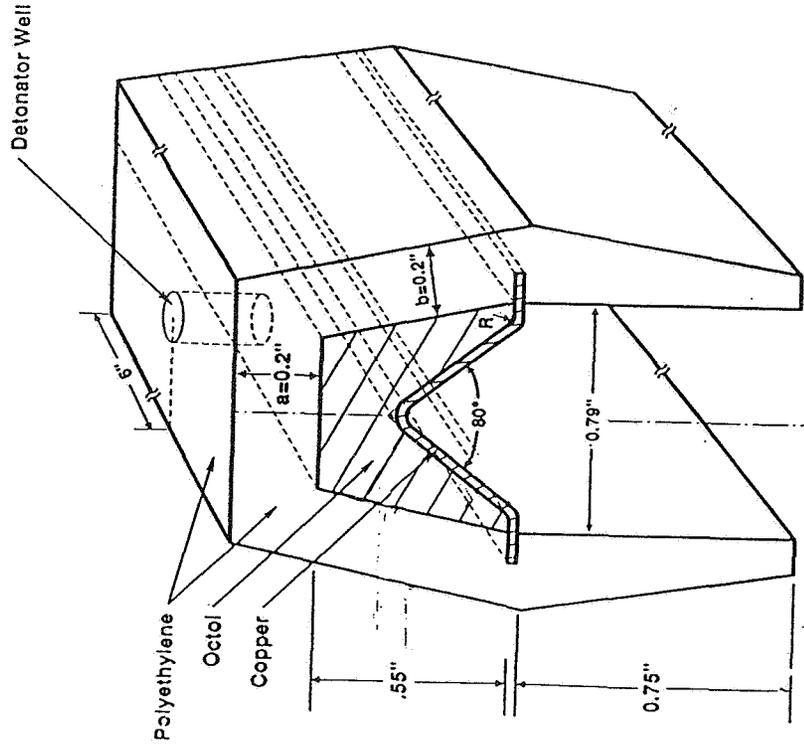
PLSC7 CROSS-SECTION/PENETRATION VERSUS STANDOFF



SANDIA NATIONAL LABORATORIES

PLSC8 CROSS-SECTION/PENETRATION VERSUS STANDOFF

FIGURE 20.



SANDIA NATIONAL LABORATORIES

TABLE 9.
 PLSC SEVERANCE OF GRAPHITE-EPOXY PANEL DATA

TEST NO.	PLSC (GPF)	TAMPER	S.O. (IN)	NUMBER PANELS	THICK (IN)	PANELS SEVERED	SEVERED THICKNESS
1	16	AL	.080	1	.175	1	.175
2	16	AL	.080	1	.175	1	.175
3	30	STEEL	.100	2	.350	2	.350
4	30	STEEL	.100	3	.525	2	.350
5	73	AL	.137	2	.350	2	.350 *
6	68	AL	.137	3	.525	3	.525

GPF - GRAIN/FOOT

NDSB - NUCLEAR DEPTH STRIKE BOMB

O.D.E.S. - OPERATIONAL DEPLOYMENT EXPERIMENT SIMULATOR

* - 0.025 INCH RESIDUAL JET PENETRATION(AL WITNESS)



SANDIA NATIONAL LABORATORIES

TABLE 10.

PLSC SEVERANCE OF GRAPHITE-EPOXY MATERIAL

. PLSC

. EXPLOSIVE: LX-13/XTX-8003
. LINER: COPPER
. TAMPER: ALUMINUM OR LEXAN

. PLSC4: 16 GRAIN/FOOT
. PLSC6: 30 GRAIN/FOOT
. PLSC7: 66 GRAIN/FOOT

. GRAPHITE-EPOXY MATERIAL

. SOURCE: TRIDENT II/D5 PANELS
. 0.175 INCH THICKNESS PER PANEL
. DENSITY: 1.45 G/CC



SANDIA NATIONAL LABORATORIES

PLSC7/TRIDENT II (DS) GRAPHITE EPOXY
 PANEL TEST CONFIGURATION

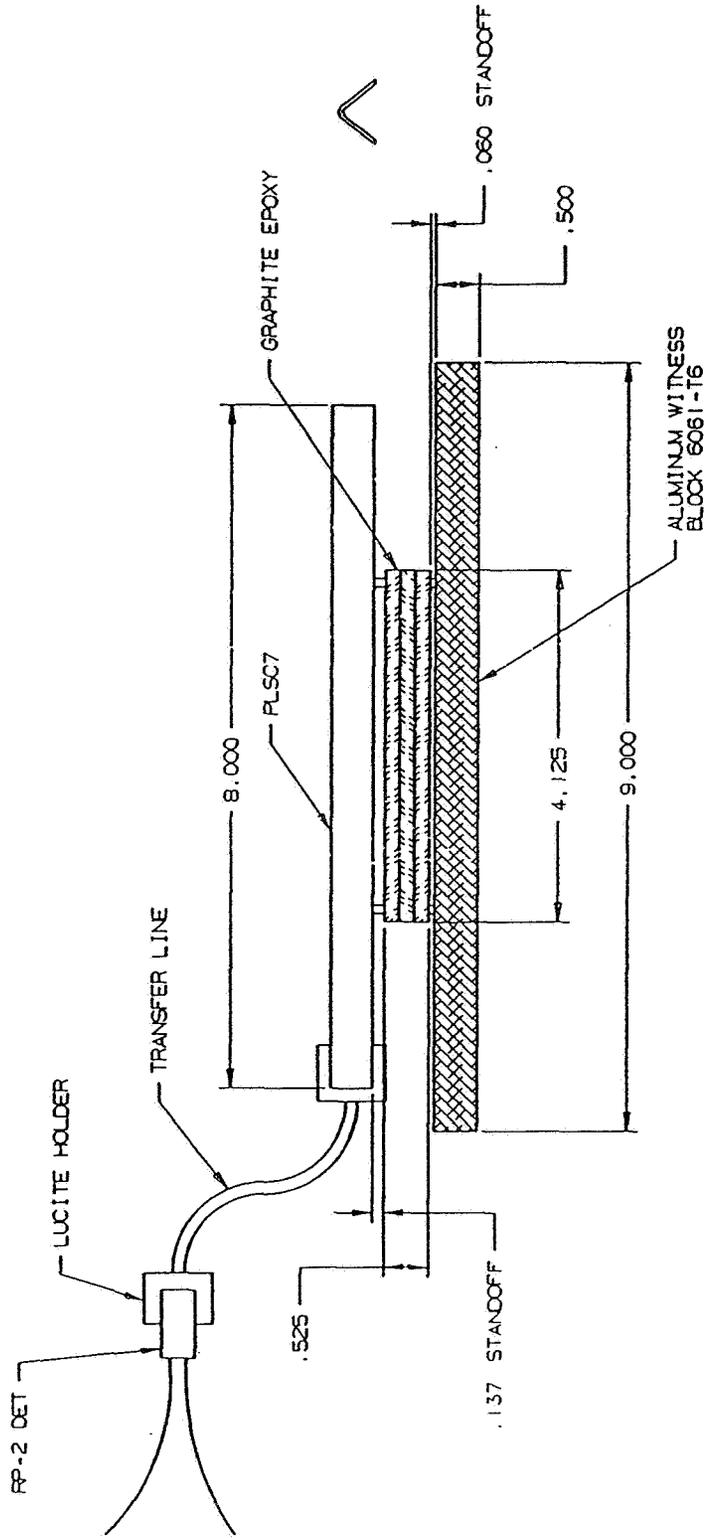


FIGURE 21. TEST NUMBER 6 CONFIGURATION/TABLE II

Figure 21 shows a typical test configuration for Tests Number 1 - 6 (Table 9). Actual side and top view photographs of test 6 are shown in Figures 22 and 23, respectively. The post-test results including the severed graphite-epoxy panels (3 each), PLSC7 aluminum housing (top and bottom pieces, and other hardware are shown in Figure 24. The PLSC7 actual cross-sections (cut and polished) are shown in Figure 25. The PLSC7 liner is shown on the right in this figure (magnified 16 times). PLSC jet severance versus PLSC explosive loading data are summarized in Figure 26. PLSC jet severance data for graphite-epoxy and aluminum targets are compared in Figure 27. The aluminum data includes only jet penetration and no fracture since the target was very thick. Typically for these PLSC designs, the fracture can result in doubling the total severance thickness (jet penetration plus fracture). Therefore, if fracture were included in the data of Figure 27, the aluminum and graphite-epoxy data would be very similar. However, since the aluminum density of 2.77 g/cc is about twice the graphite-epoxy density of 1.55 g/cc, the graphite-epoxy material is clearly the more jet resistant material.

DISCUSSION AND SUMMARY

The data listed in Table 9 shows the PLSC4 (16 grain/foot) will sever one graphite-epoxy panel 0.175 inches thick with no residual jet penetration (Tests Number 1 and 2). The PLSC6 (30 grain/foot) will sever two panels 0.350 inches total thickness with no residual jet penetration (Tests Number 3 and 4). The PLSC7 (68 grain/foot) will sever three panels 0.525 inches total thickness with no residual jet penetration (Test Number 6). The PLSC7 will sever two panels 0.350 inches total thickness with a 0.025 inch residual jet penetration in the aluminum witness plate.

Sandia has expertise in the design of explosive shaped charges, in-house developed analytical (SCAP, LESCA, etc.) and two and three-dimensional hydrocodes (CSQ, CTH, etc.), test facilities including state-of-the-art diagnostics, and local hardware fabrication sources for PLSC components. Smaller DOE weapon systems have dictated or required the design and development of more efficient and more reproducible linear shaped charge components. The same PLSC technology developed for the weapon programs can be applied to stage separation, flight termination systems, disablement devices, canopy release pilot ejection systems, conventional weapons, etc. required by commercial, DOD, and NASA programs

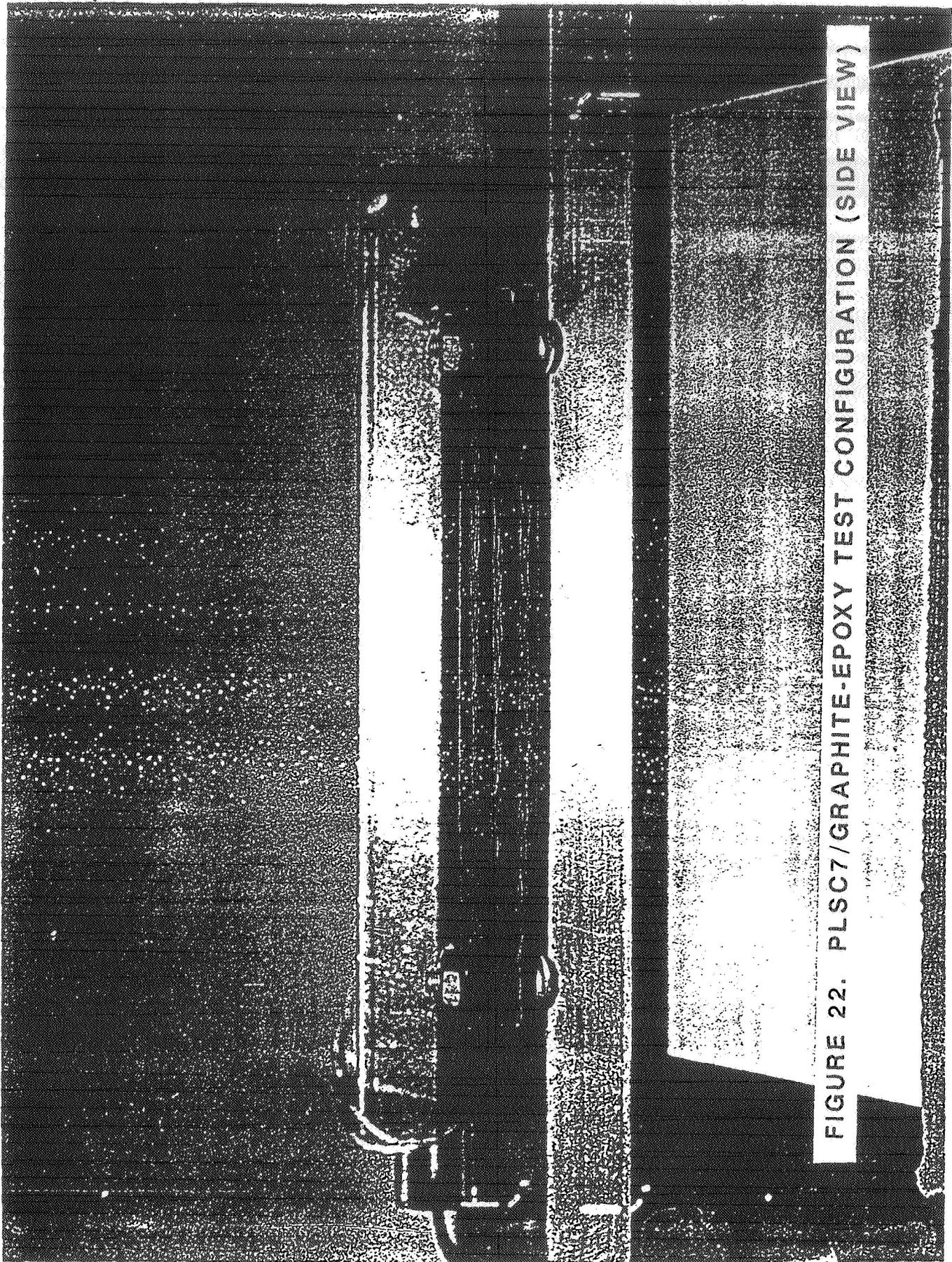
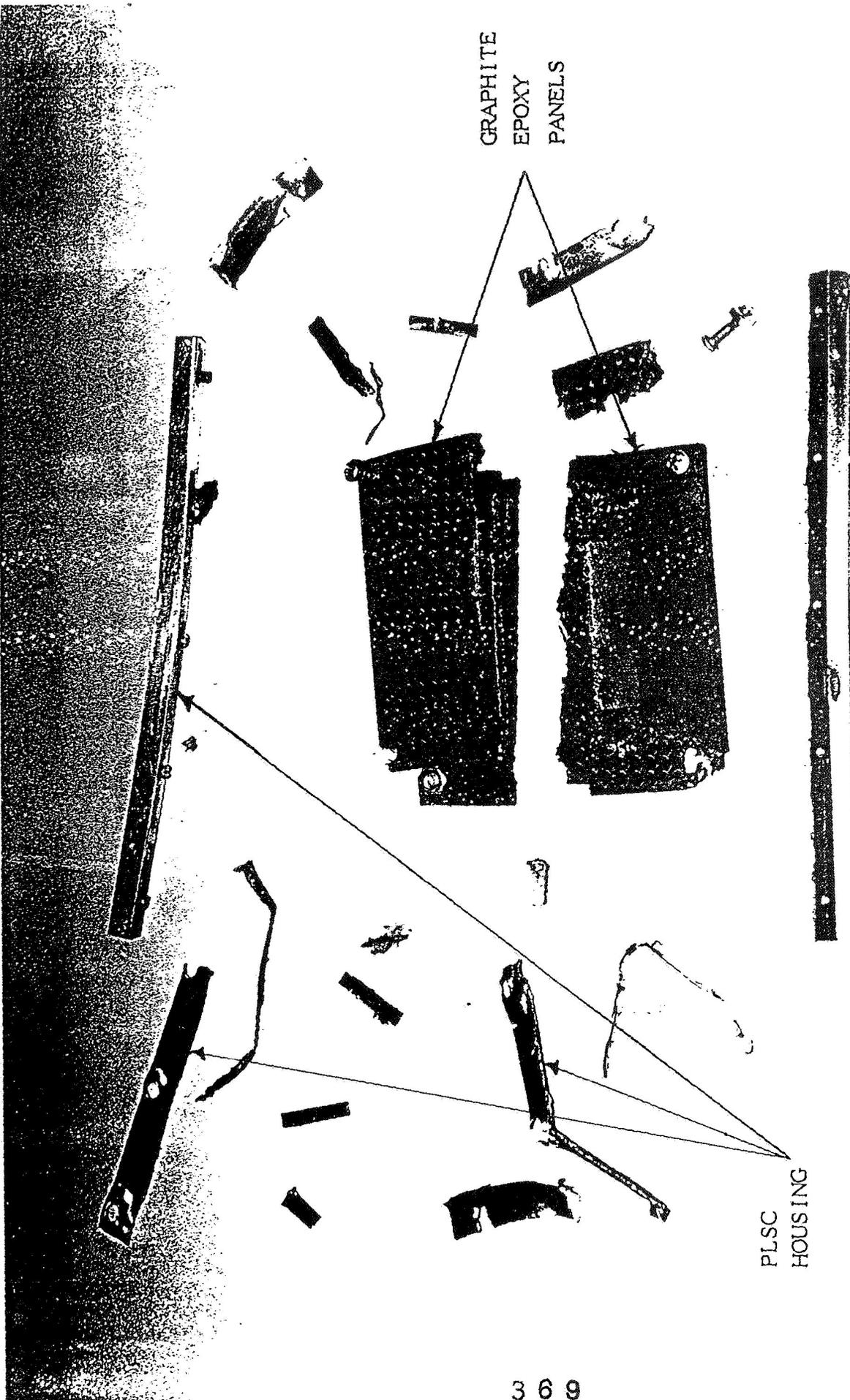


FIGURE 22. PLSC7/GRAPHITE-EPOXY TEST CONFIGURATION (SIDE VIEW)



FIGURE 23. PLSC7/GRAPHITE-EPOXY TEST CONFIGURATION (TOP VIEW)



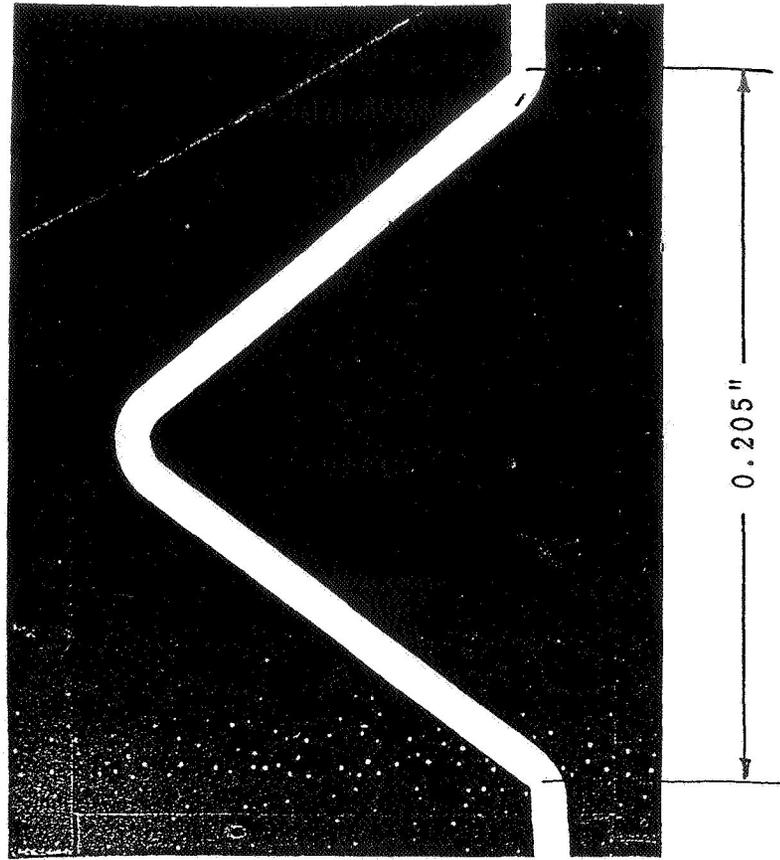
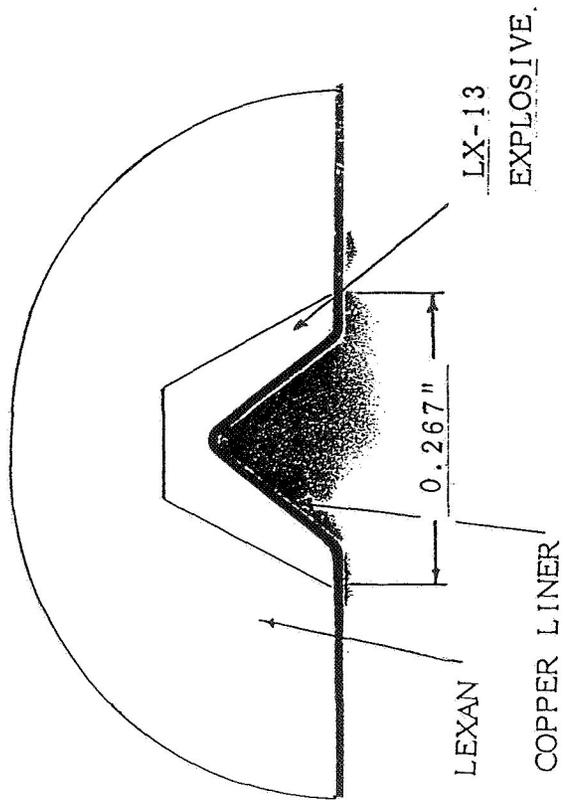
GRAPHITE
EPOXY
PANELS

PLSC
HOUSING

PLSC 7: 68 GPF/LX.13 EXPLOSIVE/CU LINER/ST TAMPER
TARGET: TRIDENT II/D5 GRAPHITE -EPOXY/3 PANELS/0.525" TH.
TEST NO. 6

FIGURE 24. POST-TEST/SEVERED GRAPHITE EPOXY PANELS

FIGURE 25.
PLSC7 (63 GRAIN/FOOT) ACTUAL CROSS-SECTION



MAGNIFIED: 16 TIMES

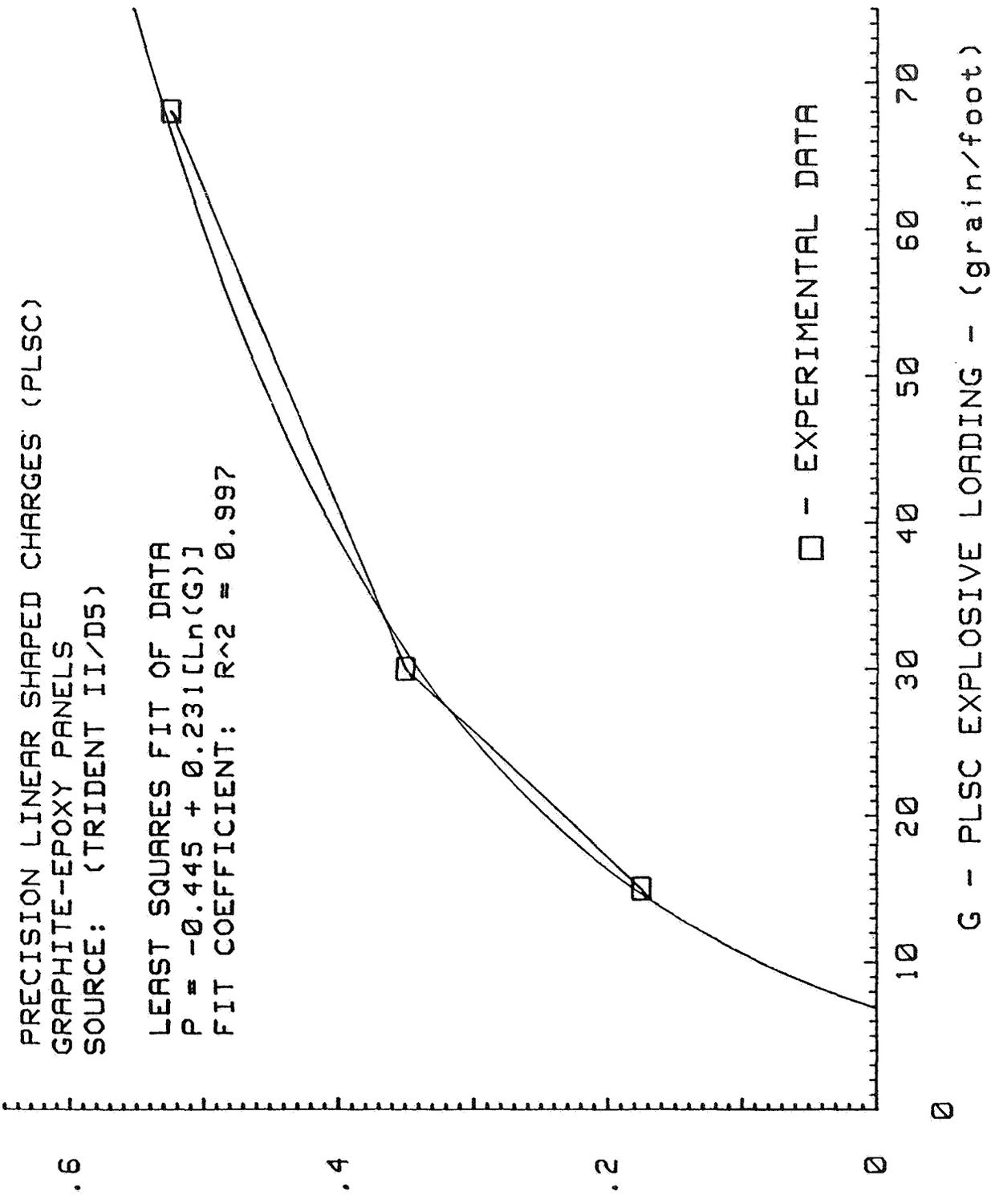


SANDIA NATIONAL LABORATORIES

P-PLSC JET SEVERANCE THICKNESS-(inches)

PRECISION LINEAR SHAPED CHARGES (PLSC)
GRAPHITE-EPOXY PANELS
SOURCE: (TRIDENT II/D5)

LEAST SQUARES FIT OF DATA
 $P = -0.445 + 0.231[\ln(G)]$
FIT COEFFICIENT: $R^2 = 0.997$



□ - EXPERIMENTAL DATA

G - PLSC EXPLOSIVE LOADING - (grain/foot)

FIGURE 26. PLSC JET SEVERANCE THICKNESS (P) VERSUS
PLSC EXPLOSIVE LOADING (G)/GRAPHITE-EPOXY TARGETS

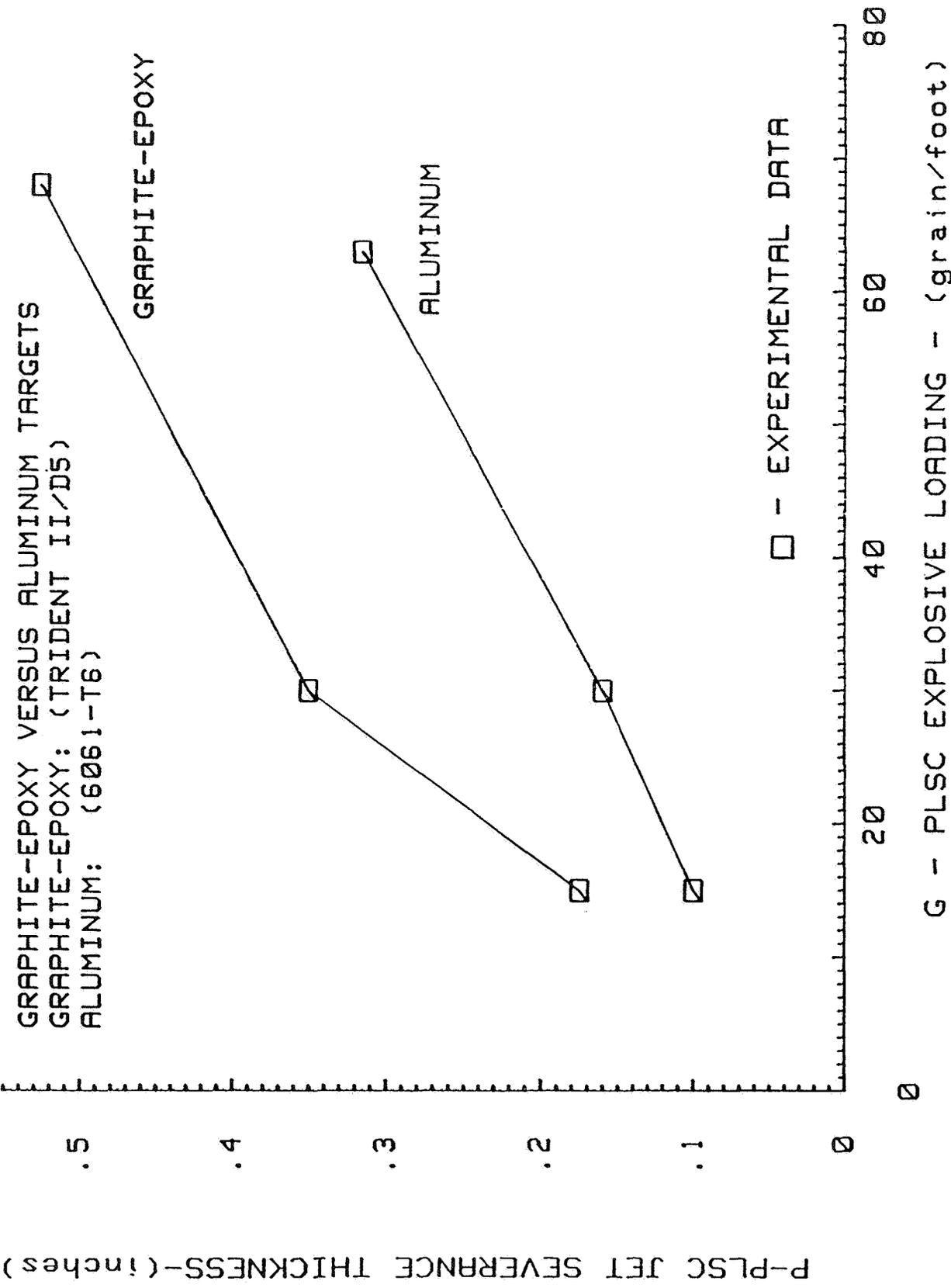


FIGURE 27. PLSC JET SEVERANCE THICKNESS (P) VERSUS PLSC EXPLOSIVE LOADING (G)

Sandia is prepared to transfer this technology to NASA, DOD, private industry, etc. and would like to be a partner in the design, development and production of PLSC components. Our customer, DOE, has required that we supply PLSC components with all the requirements listed in Table 1. Sandia has produced PLSC components to meet these requirements. NASA, DOD and the missile contractors have yet to require LSC's with the attributes of a PLSC and therefore private industry is allowed to supply components based on 40 year old fabrication technology by oversizing or over-killing the design.

References

1. Vigil, Manuel G., Harlan, Jere G., "Optimal Design and Fabrication of Reproducible Linear Shaped Charges", Sandia National Laboratories, SAND86-0982, 1986.
2. Vigil, M.G., "Design and Development of Precision Linear Shaped Charges", SAND89-0196C, Proceedings of the 9th International Symposium on Detonation, Portland, Oregon, August 28 - Sept. 1, 1989.
3. Vigil, M.G., "Design of Linear Shaped Charges Using the LESCA Code", Sandia National Laboratories, SAND90-0243, March 1991.
4. Vigil, M.G., Marchi, D.L., "MC3938 Flight Termination System for the Sea Lance/NDB Program", Sandia National Laboratories, Sand87-1528, September 1987.
5. Vigil, M.G., Marchi, D.L., "MC3991 Parachute Cutter Development for the Sea Lance/NDB Program", Sandia National Laboratories, SAND87-0876, May 1987.
6. Robinson, Allen C., Vigil, Manuel G., "An Analytical-Experimental Comparison of 150 and 220 Grain Per Foot Linear Shaped Charge Performance", Tenth International Symposium on Ballistics, San Diego, CA, Oct. 27-29, 1987.
7. Robinson, A.C., "SCAP-A Shaped Charge Analysis Program - User's Manual for SCAP 1.0", Sandia National Laboratories, SAND85-0709, April 1985.
8. Robinson, A.C., "Asymptotic Formulas for the Motion of Shaped Charge Liners", Sandia National Laboratories, SAND84-1712, Sept. 1984.
9. Robinson, A.C., "Multilayered Liners for Shaped Charge Jets", Sandia National Laboratories, SAND85-2300, Dec. 1985.

22P

1993010963

493077

N93-20152

SAND92-0324C

**EXPLOSIVE COMPONENT ACCEPTANCE TESTER
USING LASER INTERFEROMETER TECHNOLOGY**

Richard D. Wickstrom
William W. Tarbell

Division 2514
Explosive Projects and Diagnostics
Sandia National Laboratory

Presented At

NASA Aerospace Pyrotechnic Systems Workshop
June 9-10, 1992
Lyndon B. Johnson Space Center
Houston, TX

Abstract

Acceptance testing of explosive components requires a reliable and simple to use testing method that can discern less than optimal performance. For hot-wire detonators, traditional techniques use dent blocks or photographic diagnostic methods. More complicated approaches are avoided because of their inherent problems with setup and maintenance. A recently developed tester is based on using a laser interferometer to measure the velocity of flying plates accelerated by explosively actuated detonators. Unlike ordinary interferometers that monitor displacement of the test article, this device measures velocity directly and is commonly used with non-spectral surfaces.

Most often referred to as the VISAR technique (Velocity Interferometer System for Any Reflecting Surface), it has become the most widely-accepted choice for accurate measurement of velocity in the range greater than 1 mm/ μ s. Traditional VISAR devices require extensive setup and adjustment and therefore are unacceptable in a production-testing environment. This paper describes a new VISAR approach which requires virtually no adjustments, yet provides data with accuracy comparable to the more complicated systems. The device, termed the Fixed-Cavity VISAR, is currently being developed to serve as a product verification tool for hot-wire detonators and slappers. An extensive data acquisition and analysis computer code has also been created to automate the manipulation of raw data into final results.

This paper describes the unique aspects of the hardware and the requirements for installation at the production facility. The algorithms for the data analysis are presented to show how the raw data are converted into flyer velocity as a function of time. Representative results from hot-wire detonators are described.

VISAR Operating Principles

Laser velocity interferometry is based on the Doppler principle that light reflected from a moving object has a shift in frequency related to the velocity of that surface. This shift in frequency is superimposed on the original frequency of the light. The shift is detected by dividing the light returned from the target into two or more paths that appear equal (the optical length), but in fact have appreciably different delay times (transit time). The delay is accomplished by placing one or more etalons into one path. The apparent position of the mirror in the delay leg is closer to the beamsplitter by the amount:

$$x = h(1-1/n) \quad (1)$$

where h is the length of the etalon and n is the index of refraction of the material. The corresponding delay time is given by:

$$\tau = (2x/c) \quad (2)$$

where c is the velocity of light in free space. The factor of two in the equation is caused by the fact that the light passes through the etalon a total of two times, once before and then after reflection from the mirror.

In a single-leg VISAR, the incident light returned from the target is split by a beam splitter (BS) into two paths, each terminated by a mirror. A quarter wave plate in the delay path causes the P portion of the light to be retarded by a phase angle of 90° with respect to the S component. The light passes through the etalon once before reflection from the mirror and then a second time before returning to the BS. The light in the reference path travels a shorter distance because the etalon is not in position. The components are aligned so that the two returned beams are recombined on a different portion of the BS than where the initial separation took place. The BS splits the recombined light into two separate beams that are 180° out of phase. Either or both of the recombined beams can be used to detect the interference caused by the phase shift in the incident beam.

Passing one beam through a polarizing BS allows the P component to pass while reflecting the S component at 90° from the original direction. The electrical signals from the photomultiplier (PM) tubes are termed Data-1 and Data-2, for the S and P components, respectively. In a push-pull VISAR arrangement, the second recombined beam from the BS is transmitted to a different polarizing BS and to an additional set of PM tubes. The signals from these detectors are designated as Data-1' (S) and Data-2' (P). The signals contain the same interference information as the first path, but opposite in phase. The signal from each of the PM tubes in one leg is inverted electronically and added to the corresponding signal from the other leg. Thus, Data-1 is added to the inverse of Data-1' and Data-2 is combined with the inverse of Data-2'. This eliminates spurious common mode signals such as self-light, which are equally added components in both PM tube signals. The signal amplitude of the combined output is twice that of a single PM tube.

A PZAT (piezoelectric angular translator) is used in Path 1 to mount the mirror, allowing minute changes in the path length to be induced by applying a corresponding electrical signal. This feature allows target motion to be simulated during setup to check the output of the detecting devices. A second purpose is that the light level at the start of the experiment can be set to cause the output of the S-component detector to be at the full-dark (minimum output) level. This simplifies the trigger level setting on the digitizers used to record the output of the PM tubes. Thirdly, minor adjustment to the parallelism of the mirrors can be done by applying a different voltage to each of the three segments of the PZAT.

The recorded output from the combined signals is used to determine the target velocity in accordance with the following equation:

$$u = \frac{\lambda \phi(t)}{2r (1 + \Delta\nu/\nu)} \frac{1}{1 + \delta} \quad (3)$$

where λ is the wavelength of the laser, $\phi(t)$ is the instantaneous phase angle between Data-1 and Data-2, $\Delta\nu/\nu$ is a correction for shock-induced changes in the index of refraction of a window, and δ is the correction for the etalon index of refraction dependence with the doppler-shifted wavelength. The correction factor δ is 0.0339 for the fused silica typically employed as etalon material. The correction factor $\Delta\nu/\nu$ is zero unless a clear "window" is placed against the rear surface of the target. From the definition of the velocity-per-fringe (VPF) constant, equation 3 can be rearranged to yield:

$$u = \frac{\lambda \phi(t)}{2.0678 r} = \text{VPF } \phi(t) \quad (4)$$

A "circle plot" is obtained by combining the Data-1 and Data-2 records, with Data-1 on the abscissa and Data-2 on the ordinate and time as a parameter. Because the two records are in quadrature, a perfect result would be a circle centered about zero. Loss of signal level causes the amplitude of the two records to decrease resulting in a shorter length instantaneous vector. The phase change is determined from the circle plot using the following:

$$\phi(t) = \arctan \left[\frac{\text{Data-2}(t)}{\text{Data-1}(t)} \right] - \phi(0) \quad (5)$$

where $\phi(0)$ is the initial phase angle at time 0. Various factors can contribute to imbalance of the two signals with resulting distortion or displacement of the circle plot. Variations in amplitude or vertical shift of the raw data cause relatively small uncertainties in the final result, but specification of the center of the plot is important because it serves as the reference point for the phase angle determinations using equation 5.

In some instances, the acceleration of the target is so great that the fringe frequency (number of fringes produced per unit time interval) exceeds the capability of the electronics. In this instance, it is said that fringe information is "lost" and the standard data reduction will result in an abnormally low velocity. (The same principle applies for rapid decelerations except that the resulting velocity will be higher than the actual value.) Simply stated, the phase angle calculated from the data points before and after the loss region represents only the fractional part of the lost information, but not the integer number of fringes. Thus, the data analysis technique for these situations requires specification of the time when the loss occurred and the integer number of missing fringes. This process results in ambiguity because the number of fringes specified directly affects the value of all subsequent velocity values. Resolution of this issue is provided by the use of a dual-delay-leg VISAR as described in a later paragraph.

Dual-Delay-Leg VISAR

The ambiguity caused by rapid target acceleration is resolved by means of a dual-delay-leg VISAR. This system consists of two separate VISAR units monitoring the same target motion. The key

element is that each system has a different VPF constant created by means of different length etalons. The technique uses an equal BS in the path of the light returned from the target to spilt the light into two portions. Each of the two beams is then directed to a separate, but nearly identical VISAR.

During the data reduction process following the event, the records from each system are analyzed separately and then compared. When fringes are added to the data of the one system, the resultant velocity must agree with the value obtained by a similar process for the other system. Because the VPF's are significantly dissimilar (typically at least 20% different), the fringe addition process will result in only a few combinations that provide agreement between the results from the two different systems. For example, assume system 1 has a VPF of 0.7, while system 2 is 1.0. Adding three fringes to the former results in a velocity change of 2.1 mm/ μ s. The obvious operation is then to add two fringes to system 2 to give an additional 2.0 mm/ μ s. Exact agreement between the two multiples is not required at this point because the final result is dependent on the fraction-of-a-fringe portion that is also available from the actual records. The accuracy of the fringe addition process is determined visually by comparing the resulting velocity profiles to judge the correspondence in the results.

Note that the ambiguity in the above example is not completely resolved because equivalent agreement could be attained by a simple multiple of the fringe addition. In other words, the fringe addition could as well have been six and four for system 1 and system 2, respectively. The determination would then have to be if these operations result in clearly unrealistic velocity values. For typical explosive components such as detonators or slappers that have terminal velocities on the order of 2.5 to 4.5 mm/ μ s, selecting VPF constants similar to those in the example will yield only one realistic set of velocity records through fringe addition operations.

Fixed-Cavity VISAR Component Acceptance Tester

The fixed-cavity VISAR (FCV) was developed with the objective of simplifying the operation of the more traditional table-type system. To this end, the goal was to replace most of the optical components with a system that does not require operator adjustment for proper operation. In the systems mentioned above, most of the components are mounted in laboratory fixtures that permit virtually endless adjustment. This capability is not desirable in a production-testing environment because of the high level of expertise required and the potential for compromising the results. After several years of development, the FCV has now been implemented into a production tester.

The cavity portion of the FCV consists of an aluminum tube nominally 42 mm in diameter and 100 mm long, which holds the optical components in precise alignment. The delay bar acts as an etalon placed directly in contact with the main BS. The light from the target is directed onto the rear surface of the delay bar, where it passes through the length of the bar before reaching the main BS at the front surface. The portion of light transmitted is reflected from a small front-surface mirror mounted on a PZAT. The fraction of the light reflected from the BS passes back through the delay bar to an 1/8-wave plate. The plate is mirrored on the rear surface to cause the light to pass back through to create a total delay of 1/4-wave (90°). The two beams are recombined at the delay bar/BS interface, with one portion passing out the front of the delay bar where it is reflected from a small mirror adjacent to the PZAT. The second portion of the recombined beam travels through the delay bar and out the rear surface.

The FCV module contains PM tubes and the VISAR cavity. Each of the PM tube fixtures has two tubes and a BS to split the light into S and P components. The PM tubes each have a high voltage input and a coaxial cable output. Light is transmitted from the target by a fiber optic cable, where it is expanded and collimated by a lens assembly on the FCV module. Adjustments are only required during the initial assembly for the position of the PM tube fixtures and the alignment of the collimating lens assembly. The entire module is placed in a closed box to prevent damage to the components.

A second module is used to direct the laser beam into the target chamber and collect the light returned from the target's surface (Module D). The open light beam from the laser source to the target is contained within a light-tight enclosure to prevent accidental exposure. The beam is reflected by two small mirrors so as to pass through a hole in the large collection mirror. The beam is focused onto the target placed in an explosive chamber by a lens (225 to 325 mm focal length). The target is placed on a fixture that allows three directions of motion through servo motor drives. The diffuse light returned from the target is collimated by the focusing lens and collected by the large mirror arrangement. Because the beam is expanded at this point, most of the light is reflected from the large collection mirror. A dichroic mirror deflects approximately 90% of the laser light into the telescope and fiber coupler where it is transmitted to Module A. The remaining 10% of the laser light and all of the broadband light is viewed by a standard TV camera that allows active viewing of the beam to target alignment. Only a minor portion of the return beam is lost by passing through the small drilled hole in the large collection mirror. The small turning mirrors are positioned so that this portion of the returned light does not enter into the laser cavity.

All of the electrical devices and the laser are controlled by the PC located in the tester rack outside the test area. The software has been designed to perform a series of checks on the system prior to the actual firing of the component. For example, a ramp wave signal generator causes the PZAT to change the length of the reference beam path in the cavity. This results in an apparent constant change in velocity that produces a number of "fringes" from the combined PM tube outputs. The tester verifies that the fringe patterns are of the correct frequency and phase relationship. It also calculates the positive and negative amplitudes to insure that the PM tubes are "balanced". Any signal loss or degradation in any of the light paths will cause the program to halt processing and warn the operator.

During a normal shot sequence, the operator is instructed to perform certain actions, such as supply the component serial number, verify bridgewire resistance, and actuate the firing button. Data reduction is fully automated to produce plots of the firing pulse current and voltage waveforms, shot statistics (i.e. function time, flyer velocity, standoff distance, etc.), and a determination of whether the unit passed or failed (based on preset specifications supplied by the component engineer). The program accumulates the test data and performs calculations to determine lot reliability and uncertainty parameters that are required by the Department of Energy. It then stores all of the information onto a removable hard disk cartridge for permanent retention.

Listing of Figures Used in Presentation

<u>Figure</u>	<u>Contents</u>
1	Title
2	Background
3	System Design Considerations
4	Approach
5	VISAR Test Bay at UPHX
6	Surface Characterization System
7	Fixed-Cavity Interferometer
8	Detonator Fixture
9	Results
10	Fringe Data
11	Velocity and Displacement Plots
12	Table - Test Results
13	Conclusions

**EXPLOSIVE COMPONENT ACCEPTANCE TESTER
USING LASER INTERFEROMETER TECHNOLOGY**

**RICHARD D. WICKSTROM
WILLIAM W. TARBELL**

**DIVISION 2514
EXPLOSIVE PROJECTS AND DIAGNOSTICS
SANDIA NATIONAL LABORATORY**

PRESENTED AT

**NASA AEROSPACE PYROTECHNIC SYSTEMS WORKSHOP
JUNE 9-10, 1992
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TX**



SANDIA NATIONAL LABORATORIES

BACKGROUND

HISTORY:

- TRADITIONAL TABLE-BASED VISAR'S REQUIRE CONTINUOUS ADJUSTMENT BY A SKILLED OPERATOR.
- PRODUCTION TESTER DESIGN PHILOSOPHY DICTATES THAT A SYSTEM BE AUTOMATED AND THAT THE TESTER RESULTS BE UNAFFECTED BY HUMAN SUBJECTIVITY.
- THE FIXED-CAVITY VISAR IS VIRTUALLY FREE OF ADJUSTMENTS AND THEREFORE LENDS ITSELF WELL TO IMPLEMENTATION INTO A PRODUCTION TESTER.

PROJECT OBJECTIVE:

- BUILD FULLY AUTOMATED TESTER BASED ON VISAR TECHNOLOGY THAT CAN BE USED TO MEASURE THE VELOCITY OF EXPLOSIVELY DRIVEN FLYING PLATES.



SANDIA NATIONAL LABORATORIES

SYSTEM DESIGN CONSIDERATIONS

- EXISTING PT3506 SIP GAGE TESTER CHOSEN TO PROVIDE FIRESET STIMULUS, COMPUTER I/O, AND INTERLOCK CONTROL.
- VISAR MODULES AND EQUIPMENT ARE PLACED IN SEPARATE RACK.
 - FIBER OPTIC CABLE TO LASER AND COMPONENT
 - HPIB INTERFACE TO PT3506
- NO ABSOLUTE CALIBRATION STANDARD BY WHICH THE SYSTEM CAN BE CHECKED.
 - BEFORE EACH SHOT, USE COMPUTER CONTROL TO VERIFY ALL SYSTEM PARAMETERS THAT COULD AFFECT TEST RESULTS
 - PROVIDE COMPONENT FIXTURE WITH KNOWN STANDOFF TO COMPARE TO DISPLACEMENT RECORD
- UNIT SURFACE PREPARATION:
 - SURFACE OF COMPONENT PREPARED BY MICRO-SAND BLAST
 - SURFACE DIFFUSENESS MEASURED BY SCATTEROMETER



APPROACH

- MINIMAL NUMBER OF OPERATOR ADJUSTMENTS OR INPUTS
 - FIXED-CAVITY TECHNOLOGY
 - TESTER CONTROLS OPERATION
 - AUTOMATED DATA REDUCTION TO VELOCITY AND DISPLACEMENT PLOTS

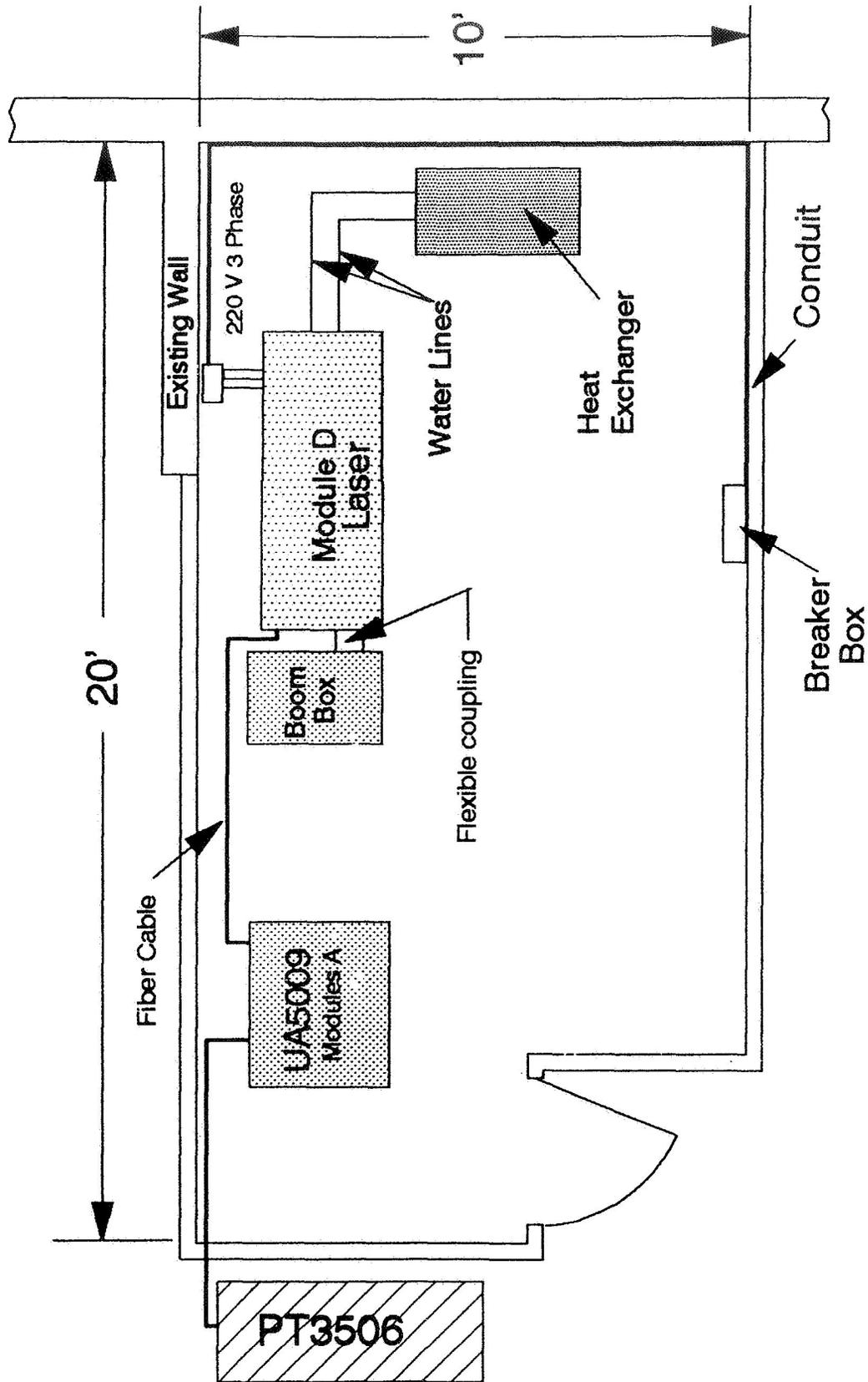
- BUILD TWO IDENTICAL SYSTEMS
 - UNIT 1 AT UNIDYNAMICS-PHOENIX
 - UNIT 2 AT EG&G-MOUND

- ABLE TO MEASURE HOT-WIRE AND EBW DETONATORS
 - CAN BE USED FOR SLAPPERS

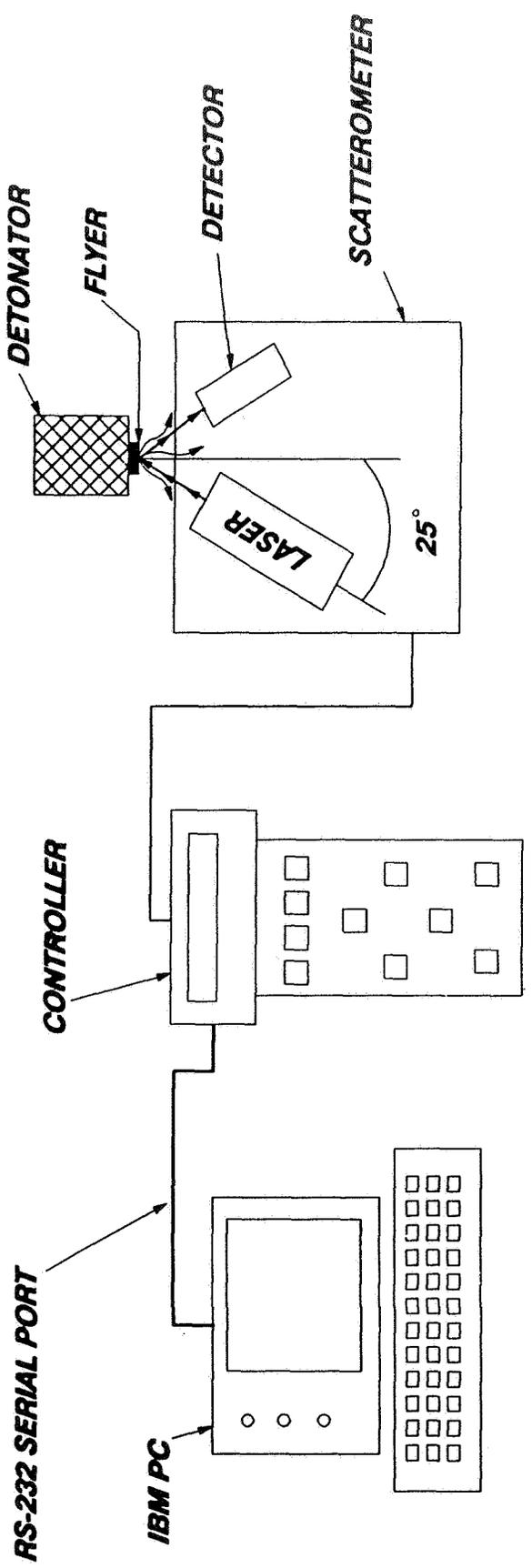


SANDIA NATIONAL LABORATORIES

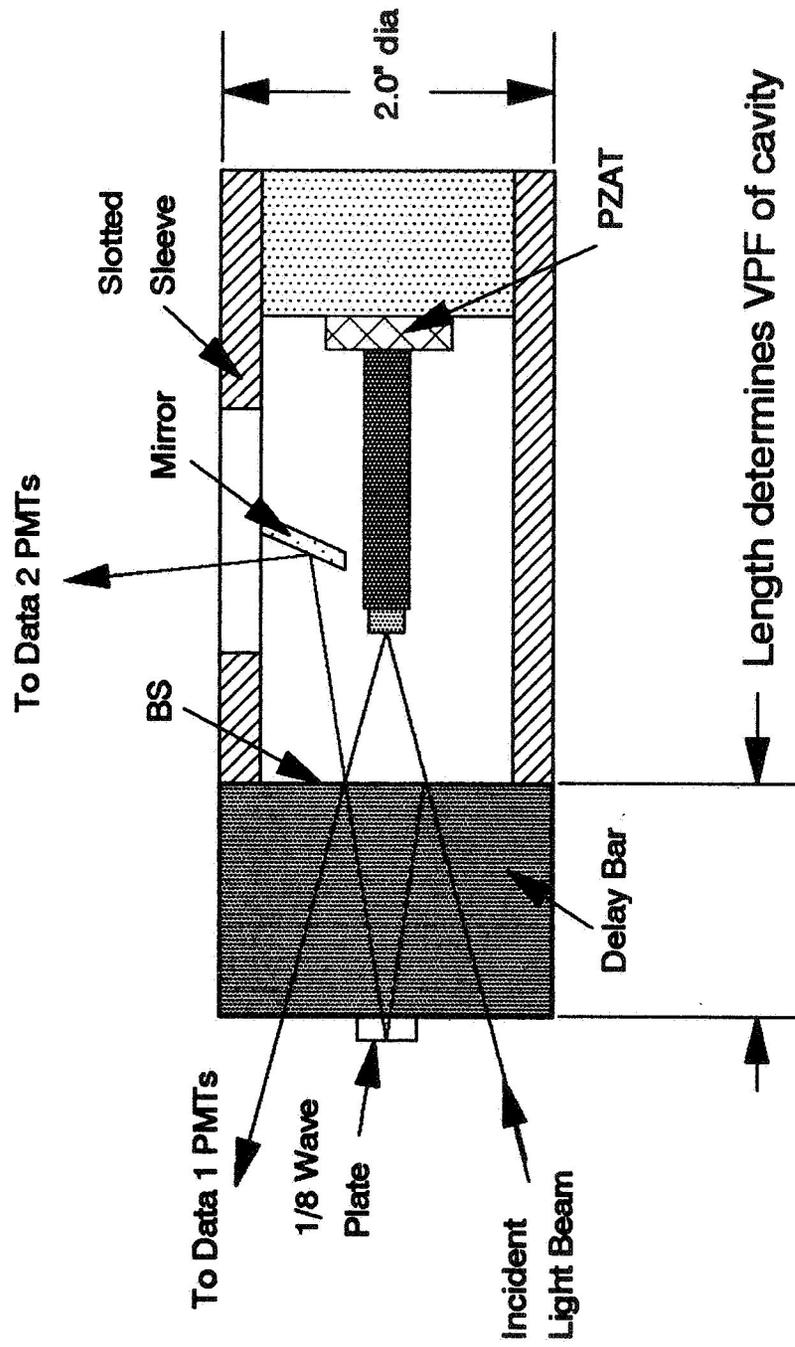
VISAR TEST BAY AT UPHX



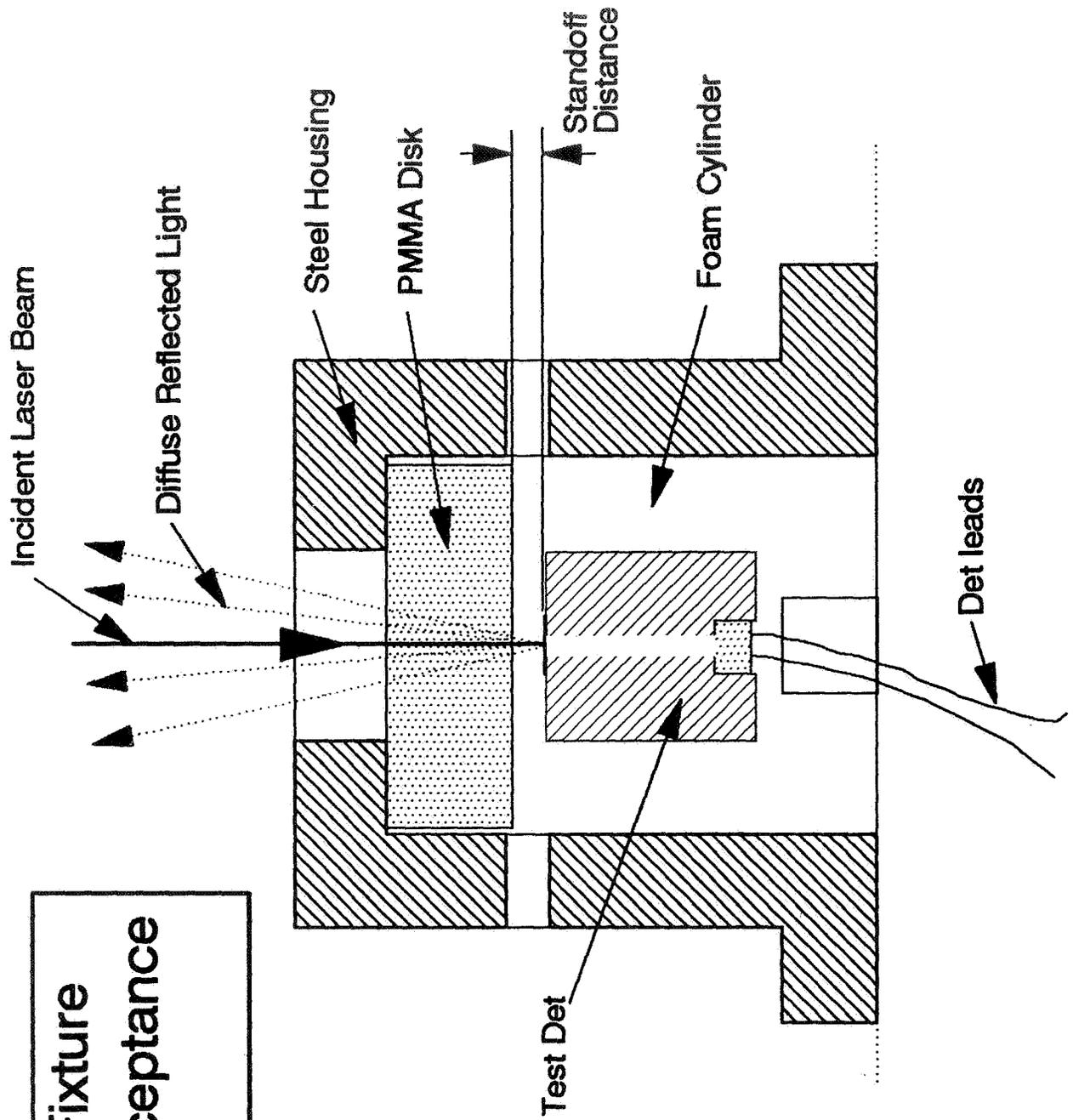
OPTICAL SYSTEM FOR SURFACE CHARACTERIZATION OF VISAR TARGETS



Fixed-Cavity Interferometer



**Detonator Fixture
for FCV Acceptance
Tester**



RESULTS/TYPICAL DATA

- **RAW DATA:**
 - FOUR CHANNELS OF INTERFERENCE DATA FOR EACH MODULE
 - COMBINATION OF INTERFERENCE WAVEFORMS GIVES "FRINGE" RECORDS (DATA 1 AND DATA 2)
 - CIRCLE PLOT CREATED BY PLOTTING DATA 1 AGAINST DATA 2
 - VELOCITY INCREMENT IS PROPORTIONAL TO PHASE ANGLE BETWEEN TWO CONSECUTIVE POINTS (ONE TIME INTERVAL)

- **VELOCITY DATA:**
 - VELOCITY HISTORIES FROM THE TWO LEGS SHOULD AGREE WITHIN EXPERIMENTAL UNCERTAINTY
 - ABRUPT INFLECTION POINT SHOULD APPEAR ON BOTH RECORDS WHERE THE FLYER CONTACTS THE STOPPER PLATE

- **DISPLACEMENT DATA:**
 - OBTAINED FROM TIME INTEGRATION OF THE VELOCITY HISTORIES
 - INFLECTION POINT COMPARED TO KNOWN STANDOFF DISTANCE

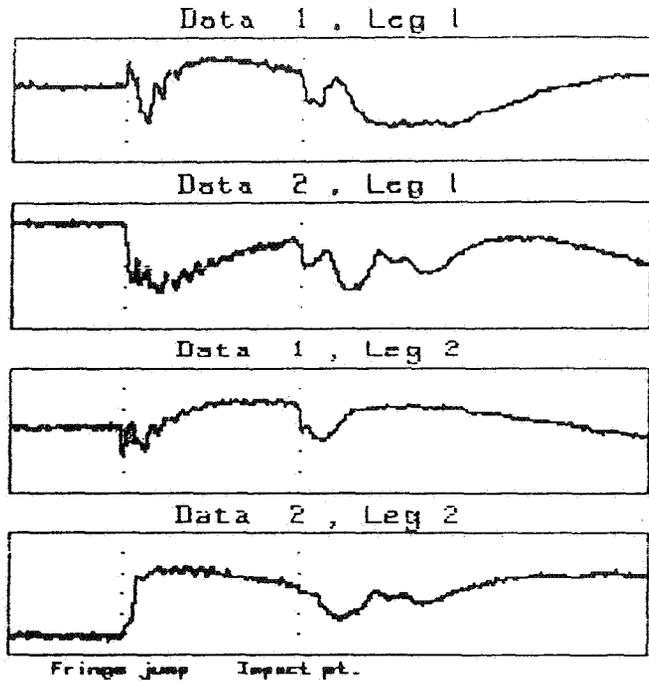


SANDIA NATIONAL LABORATORIES

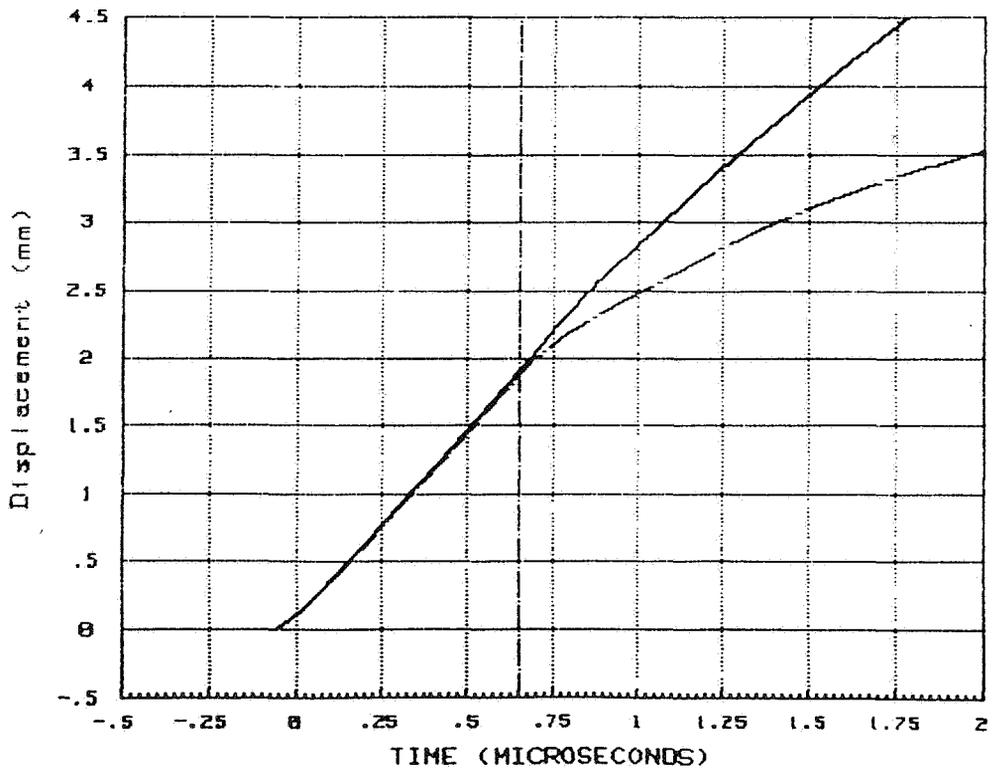
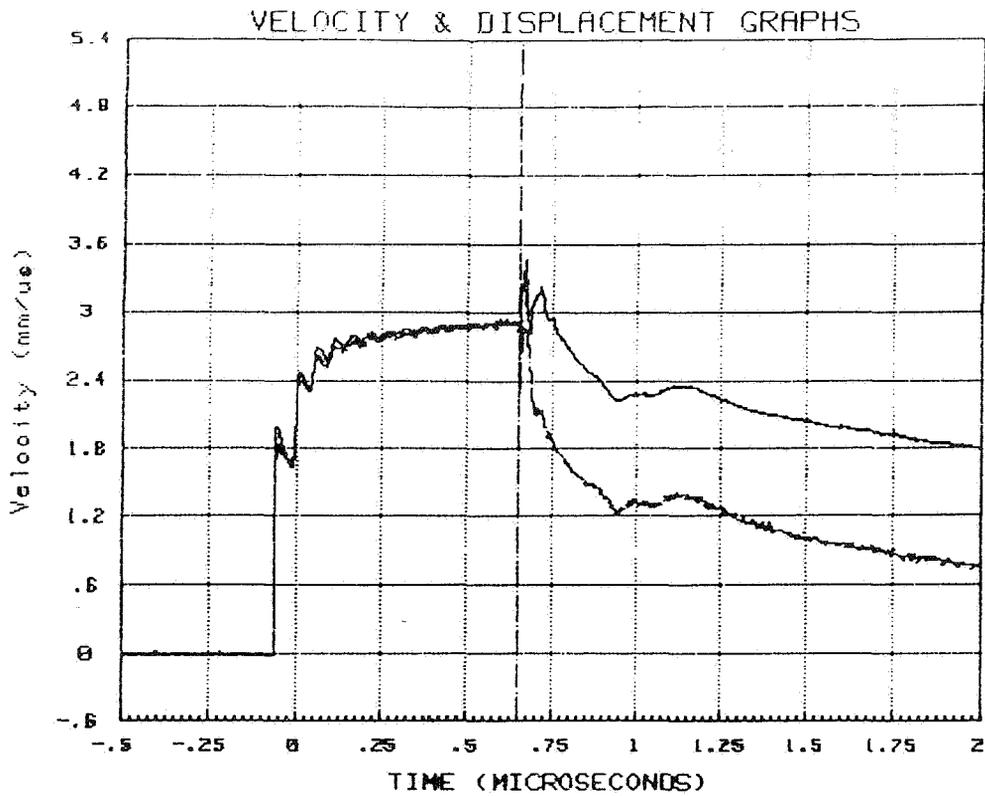
DETONATOR
 AMBIENT ROOM FIRING
 TESTER: Test-O-matic S/N 001
 SERIAL NUMBER 000018

REDUCTION STATISTICS

Start reduce time: -5.E-7
 Stop reduce time: 2.E-6
 Maximum dv/dt (L1): 7.2427E+7
 Pt 1st motion (L1): 1996
 Maximum dv/dt (L2): 6.2643E+7
 Pt 1st motion (L2): 1971
 Add fringes L1: 2
 Add fringes L2: 1
 Maximum dv/dt (L1): 2.131E+8
 Impact pt (L1): 2327
 Maximum dv/dt (L2): 2.7235E+8
 Impact pt (L2): 2324
 Impact distance L1: 1.9896
 Impact distance L2: 1.881



DETONATOR
AMBIENT ROOM FIRING
TESTER: Test-O-matic S/N 001
SERIAL NUMBER 000018



CHECKOUT TEST RESULTS

SHOT NO.	DET NO.	VELOCITY (MM/US)	DISPLACEMENT (MM) MEAS	DISPLACEMENT (MM) PRETEST
1	01	2.88	2.78	2.03
2	34	2.87	2.00	2.03
3	16	2.93	2.04	1.91
4	18	2.90	1.91	1.91
5	86	2.89	1.91	1.91
6	40	2.90	1.71	1.79

UNIT 1 MEAN VELOCITY - 2.88 0.02 MM/US (6 TESTS)

SNL AREA II VISAR - 2.833 0.036 MM/US (30 TESTS)



SANDIA NATIONAL LABORATORIES

CONCLUSIONS

- **SUCCESSFUL RESULTS WERE OBTAINED FOR EACH OF THE TEST DETONATORS FIRED TO DATE.**
- **VELOCITY RESULTS AGREE WITH PREVIOUS FULL TABLE DATA.**
- **STOPPER PLATE PROVIDES ACCURATE FIDUCIAL FOR CALIBRATION OF DISPLACEMENT RESULTS.**
- **SYSTEM DIAGNOSTICS ARE RESPONSIVE TO CHANGES IN HARDWARE OR COMPONENTS.**
- **SURFACE PREPARATION AND MEASUREMENT PROVIDES ACCURATE INDICATOR PRIOR TO PLACEMENT INTO FIXTURE.**
- **SYSTEM CAN EASILY BE EXTENDED TO MEASURE EBW AND SLAPPER DETONATORS.**



SANDIA NATIONAL LABORATORIES

This page intentionally left blank.

for the NSI and Pin Puller

Joseph M. Powers¹ and Keith A. Gonthier²

Department of Aerospace and Mechanical Engineering

University of Notre Dame

Notre Dame, Indiana 46556-5637

presented at the

NASA Aerospace Pyrotechnic Systems Workshop

June 9-10, 1992

Lyndon B. Johnson Space Center

Houston, Texas 77058

¹Assistant Professor, 219-239-5978, powers@neumann.ame.nd.edu

²Graduate Assistant

Approved for public release; distribution is unlimited.

3 9 7

Acknowledgements

Support

NASA-Lewis Research Center

NAG-1335

Dr. Robert M. Stubbs, Monitor

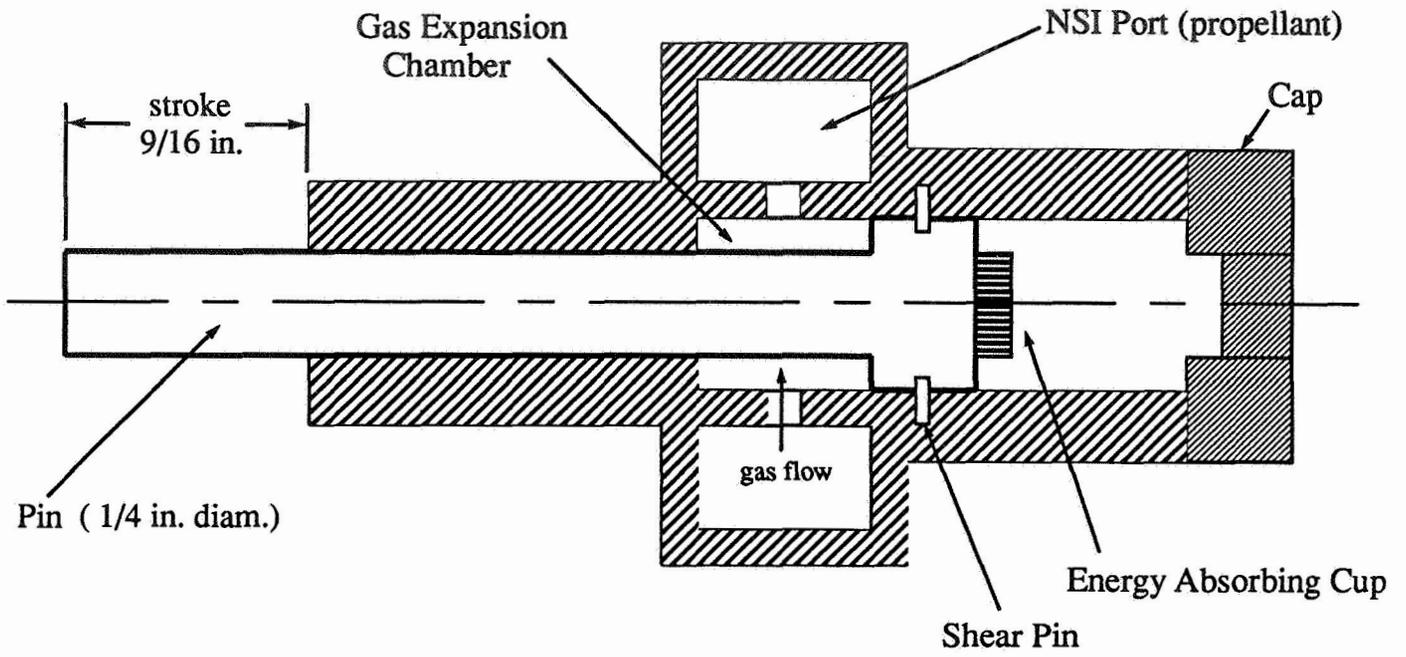
Discussions

Prof. P. Barry Butler

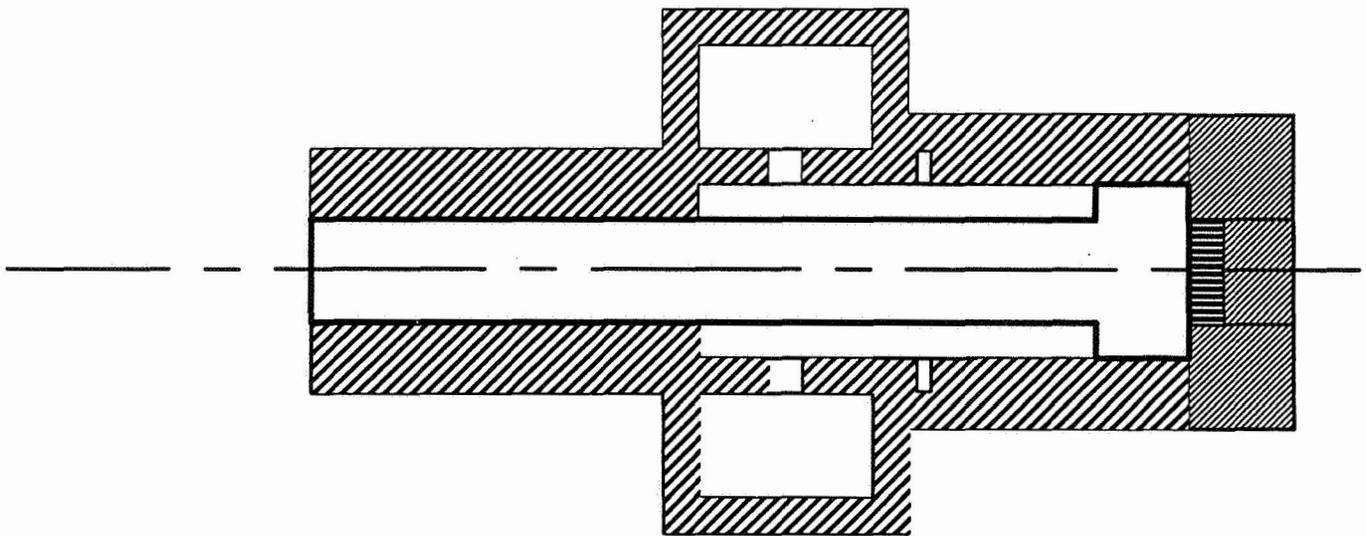
University of Iowa

NSI Driven Pin Puller

(unretracted pin)



(retracted pin)



Review

Sources for guidance in model development:

- Pin-puller tests: Bement, Schimmel, et al.
- Pyrotechnics chemistry: McLain, Conklin
- NSI ignition study: Varghese
- Multiphase combustion: Baer, Nunziato, Krier, Powers, etc.
- Automobile airbags: Butler
- Solid propellants: Williams, Kuo, Strehlow, etc.
- Solid state combustion synthesis: Varma

Engineering Problems

- occurrence of operational failures
- qualification only after many tests
- difficult to predict behavior of new formulations
- difficult to quantify effects of modifications
 - diffusive heat transfer
 - molecular heat transfer
 - pin puller geometry
 - friction
 - apparantly random sample behavior

Modeling Approaches

- Full Scale Models
 - time-dependent
 - three-dimensional spatial gradients
 - multiple species, multiple reactions
 - fully resolved chemical kinetics
 - compressibility
 - turbulence
 - real gas effects
 - boundary layers
 - *essentially no detailed kinetic data available*
 - *more complex than justified by data*

- Empirical Models
 - experimentally-based correlations
 - reliable in limited ranges
 - somewhat inflexible
- Simple Models-*present approach*
 - analytically tractable
 - judgment required
 - simplicity at expense of loss of rigor
 - introduction of ad hoc assumptions
- Stochastic Models
 - estimates for uncertainty required
 - could be coupled with simple model

Assumptions for Simple Model

- no spatial variation

$$- t_{acoustic} \sim \frac{L}{c} \sim \frac{0.01m}{1000m/s} = 1 \times 10^{-5}s$$

- constant density solid pyrotechnic
- constant surface area of pyrotechnic
- linear pyrotechnic burn rate known
- constant temperature wall
- simple convective heat transfer

$$- t_{conv} \ll t_{cond} \sim \frac{L^2}{\alpha} \sim \frac{(0.01m)^2}{0.001m^2/s} = 0.1s$$

- simple radiative heat transfer

$$- t_{rad} \sim \frac{\rho_g c_{vg} L}{\sigma T^3} \sim \frac{1kg/m^3 1000J/(kgK) 0.01m}{1 \times 10^{-7} J/(sm^2 K^4) (1000K)^3} = 0.1s$$

- negligible heat transfer from gas to solid
- negligible wall friction and shear pin resistance
- non-negligible pin inertia
- multicomponent ideal gas behavior
- temperature dependent specific heat
- Gibbs free energy minimization
 - determines heat of reaction
 - determines mass fractions of gas products

Conservation Principles

for background see

Powers, Stewart, and Krier, "Theory of Two-Phase

Detonation—Part I: Modeling, Part II: Structure,"

Combustion and Flame, V. 80, 1990.

$$\begin{aligned}\frac{d}{dt} [\rho_g V_g] &= \rho_s A r \\ \frac{d}{dt} [\rho_s V_s] &= -\rho_s A r \\ \frac{d}{dt} [\rho_g V_g e_g] &= \rho_s A r e_s + h A (T_w - T_g) \\ &\quad + \sigma A (\alpha T_w^4 - \epsilon T_g^4) - P_g \frac{dV}{dt} \\ \frac{d}{dt} [\rho_s V_s e_s] &= -\rho_s A r e_s \\ m_p \frac{d^2}{dt^2} \left[\frac{V}{A} \right] &= P_g A\end{aligned}$$

Constitutive Relations

$$r = a + bP_g^n$$

$$P_g = \rho_g R T_g \sum_{i=1}^{N_g} \frac{Y_i}{M_i}$$

$$e_g = \sum_{i=1}^{N_g} Y_i \left(h_{fi}^o + \int_{T^o}^{T_g} c_{pi}(\hat{T}_g) d\hat{T}_g \right) - R T_g \sum_{i=1}^{N_g} \frac{Y_i}{M_i}$$

$$e_s = \sum_{i=1}^{N_s} Y_i \left(h_{fi}^o + \int_{T^o}^{T_s} c_{pi}(\hat{T}_s) d\hat{T}_s \right)$$

$$V = V_g + V_s$$

Y_i estimated from minimization of Gibbs free energy

Variables

$$e_g, V_g, T_g, P_g, \rho_g,$$

$$e_s, V_s, T_s,$$

$$V, Y_i, r$$

Constants

$$\rho_s, A, h, T_w, \sigma, \alpha, \epsilon, m_p, a, b, n, R, M_i$$

Piston Energy calculation

Knowledge of $P_g(t)$ and $V(t)$ allows calculation of work done by pyrotechnic material:

$$W(t) = \int_0^t P_g(\hat{t}) \frac{dV(\hat{t})}{d\hat{t}} d\hat{t}$$

Current Solution Approach

- use NASA Lewis CEC code to estimate equilibrium products via minimization of Gibbs free energy
- solve coupled ODE–algebraic system
 - numerical integration of ODE
 - SLNL-CHEMKIN package to determine gas energy
- calculate work done by gas
- compare peak pressure and work with observations

Future

- wall friction
- shear pin effects
- spatial resolution
- grain size effects
- burn rate experiments
- detailed chemistry
- stochastic effects

Conclusions

- literature search shows little published articles on modeling of pyrotechnically driven actuators
- insufficient constitutive data for full-scale model
- simple deterministic model appears useful to better guide design
- assumptions of simple model preclude capturing of many observed phenomena
- results from simple model should be first evaluated then decisions made regarding where to make improvements

APPENDIX A - List of Participants

Aerojet - ASRM Division
Chris J. Zimmerman
Bldg. 1960, Department 7210
P.O. Box 1270
Orangeville, CA 95662-1270
(916) 355-2907 (FAX) 355-6048

Aerojet - ASRM Division
Leigh W. McDaniel
Bldg. 1960, Department 7210
P.O. Box 1270
Orangeville, CA 95662-1270
(916) 355-4849 (FAX) 355-6048

Aerojet Propulsion Division
Gerald E. Litzinger
Dept. 5236 - Building 2019A
P.O. Box 13222
Sacramento, CA 95813-6000
(916) 355-4794 (FAX) 355-6543

The Aerospace Corporation
James Gageby
MS M4/907
2350 E. El Segundo Blvd.
El Segundo, CA 90245
(310) 336-7227 (FAX) 336-1474

The Aerospace Corporation
Selma Goldstein
MS M4-907
P.O. Box 92957
Los Angeles, CA 90009-2957
(310) 336-5969 (FAX) 336-1474

Allied Signal Aerospace Co.
James L. Hendrix
Dept. 343-3 MS FK41
P.O. Box 419159
Kansas City, MO 64141-6159
(816) 997-3483 (FAX) 997-4113

Allied Signal Aerospace Co.
Allan G. Bennett
Dept. 343 MS MY40
P.O. Box 419159
Kansas City, MO 64141-6159
(816) 997-3615 (FAX) 997-5649

Allied Signal Aerospace Co.
Larry Sheets
K.C. Division, D/855, FN40
P.O. Box 419159
Kansas City, MO 64141-6159
(816) 997-4892 (FAX) 997-2411

Analex Corporation
Floyd Smith
3001 Aerospace Parkway
Brookpark, OH 44142-1003
(216) 977-0201 (FAX) 977-0200

Analex Corporation
Paul Steffes
3001 Aerospace Parkway
Brookpark, OH 44142-1003
(216) 977-0123 (FAX) 977-0200

Analex Corporation
Dan Trowbridge
3001 Aerospace Parkway
Brookpark, OH 44142-1003
(216) 977-0204 (FAX) 977-0200

Boeing Aerospace & Electronics
Jim Fitzpatrick
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9050 (FAX) 483-3096

Boeing Defense & Space Group - Space Systems
Mark K. Kosai
M/S 8C-09
P.O. Box 3999
Seattle, WA 98124
(206) 773-2048 (FAX) 773-8197

EG&G Mound Applied Technologies
Thomas M. Beckman
P.O. Box 3000
Miamisburg, OH 45343-0987
(513) 865-4551 (FAX) 865-3491

EG&G Mound Applied Technologies
Alan C. Munger
P.O. Box 3000
Miamisburg, OH 45343-0987
(513) 865-3544 (FAX) 865-3491

EG&G Mound Applied Technologies
Daniel Kramer (COS-3)
P.O. Box 3000
Miamisburg, OH 45343-0987
(513) 865-3558 (FAX) 865-3680

EG&G Mound Applied Technologies
Ed Spangler
P.O. Box 3000
Miamisburg, OH 45343-3000
(513) 865-3528 (FAX) 865-3491

Energetic Materials Technology
Peter Ostrowski
P.O. Box 6931
Alexandria, VA 22306-0931
(703) 780-5854 (FAX) 780-4955

Ensign Bickford Aerospace Co.
Arthur D. Rhea
640 Hopmeadow St.
P.O. Box 427
Simsbury, CT 06070
(203) 843-2360 (FAX) 843-2621

Ensign Bickford Aerospace Co.
David W. Ewick
P.O. Box 427
Simsbury, CT 06070
(203) 843-2425 (FAX) 843-2621

Ensign Bickford Aerospace Co.
Stephen R. McComb
640 Hopmeadow St.
P.O. Box 427
Simsbury, CT 06070
(203) 843-2873 (FAX) 843-2621

General Dynamics Space System Division
Reuben Gilmore
Mail Zone 21-8550
P.O. Box 85990
San Diego, CA 92186-5990
(619) 547-7067 (FAX) 974-4000

Hercules Aerospace
David A. Cole, P.E.
P.O. Box 210
Rocket Center, WV 26726
(304) 726-5489 (FAX) 726-4730

Hercules Inc.
Pat McAllister
M/S N1EA1
P.O. Box 98
Magna, UT 84044
(801) 251-6192 (FAX) 251-6676

Hi-Shear Technology Corp.
Harold Karp
24225 Garnier Street
Torrance, CA 90509-5323
(310) 784-7853 (FAX) 325-5354

Hi-Shear Technology Corp.
Gregory G. Krisilas
24225 Garnier Street
Torrance, CA 90509-5323
(310) 784-7828 (FAX) 325-5354

Hi-Shear Technology Corp.
Jerry D. Callaghan
24225 Garnier Street
Torrance, CA 90509-5323
(310) 784-2100 (FAX) 325-5354

Hi-Shear Technology Corp.
Scott Tindol
24225 Garnier Street
Torrance, CA 90509-5323
(310) 784-7842 (FAX) 325-5354

Hughes Aircraft Company
Space & Communications Group
Jack Heifferon
Building S64 - MS B403
P.O. Box 92919
Los Angeles, CA 90009
(310) 364-7513 (FAX) 322-9164

Hughes Aircraft Company
EDSG - Initiation Lasers
M. J. (Mike) Weiner
Bldg. E-1, M/S B118
P.O. Box 902
El Segundo, CA 90245-0902
(310) 616-3985 (FAX) 616-4468

Jet Propulsion Laboratory
Anthony Agajanian
MS 158-224
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-9339 (FAX) 393-4860

Laser Diode Inc.
Gerard Henein
1130 Somerset St.
New Brunswick, NJ 08901
(908) 249-7000 ext 210 (FAX) 249-9165

Laser Diode Inc.
Steve Klunk
1130 Somerset St.
New Brunswick, NJ 08901
(908) 249-7000 ext 218 (FAX) 249-9165

Laser Diode Inc.
Jim Pooladdej
1130 Somerset St.
New Brunswick, NJ 08901
(908) 249-7000 ext 219 (FAX) 249-0027

Lockheed Corporation
Les J. Wynn
Mail Code C50
2400 NASA Road One
Houston, TX 77058-3799
(713) 333-7795 (FAX) 333-7541

Lockheed Engineering & Sciences Co.
James L. Shaffner
Mail Code C50
2400 NASA Road 1
Houston, TX 77058-3799
(713) 333-7013 (FAX) 333-7541

Lockheed Engineering & Sciences Co.
R. E. Gibson
Mail Code C50
2400 NASA Road 1
Houston, TX 77058-3799
(713) 333-6041 (FAX) 333-7541

Lockheed Missiles & Space Co.
Richard G. Hallmark
Org. 8P-01, Bldg. 154
1111 Lockheed Way
Sunnyvale, CA 94089-3504
(408) 742-0428 (FAX) 756-3746

Los Alamos National Laboratory
James E. Kennedy
MS - P950
Los Alamos, NM 87545
(505) 667-1468 (FAX) 667-6301

McDonnell Douglas Electronic Systems Co.
Edward M. Tribula
MS 111-1182
P.O. Box 516
St. Louis, MO 63166-0516
(314) 232-1266 (FAX) 777-6408

McDonnell Douglas Electronic Systems Co.
William L. Floyd
M.S. 21-2D
5301 Bolsa Ave.
Huntington Beach, CA 92647
(714) 896-1454 (FAX) 896-6959

McDonnell Douglas Electronic Systems Co. - L&ES
Dale F. Waldo
Dept. 44A0 MS 111-1182
P O Box 516
St. Louis, MO 63166
(314) 233-1515 (FAX) 777-6408

McDonnell Douglas Electronic Systems Co. - L&ES
Barb A. Soltz
M/S 111-1182
P O Box 516
St. Louis, MO 63166-0516
(314) 232-1515 (FAX) 777-6408

McDonnell Douglas Missile Systems Co.
David R. Sumpter
Mail Code 3065660
P O Box 516
St. Louis, MO 63166-0516
(314) 234-3900 (FAX) 777-2639

McDonnell Douglas Space Systems Co.
Ian Whalley
Mail Code A3-P550/11-1
5301 Bolsa Ave.
Huntington Beach, CA 92647
(714) 896-6491 (FAX) 896-1106

National Aeronautics and Space Administration
Daniel R. Mulville
Director, Technical Standards Division
Code QE
Washington, DC 20546
(202) 453-8742 (FAX) 755-0901

National Aeronautics and Space Administration
Norman R. Schulze
Code QE
Washington, DC 20546
(202) 358-0537 (FAX) 358-2777

NASA Johnson Space Center
Barry C. Wittschen
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9042 (FAX) 244-5585

NASA Johnson Space Center
Henry O. Pohl
Director of Engineering
Code EA
2201 NASA Road One
Houston, TX 77058
(713) 483-93971

NASA Johnson Space Center
Scott Hacker
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9042 (FAX) 483-3096

NASA Johnson Space Center
Maureen L. Bibeault
Code EP63
2201 NASA Road One
Houston, TX 77058
(713) 483-8799 (FAX) 483-1340

NASA Johnson Space Center
James Johnson
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9042 (FAX) 483-3096

NASA Johnson Space Center
Carl W. Hohmann
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-4533 (FAX) 483-3096

NASA Johnson Space Center
Christopher Brown
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9049 (FAX) 483-3096

NASA Johnson Space Center
William Hoffman
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9056 (FAX) 483-3096

NASA Johnson Space Center
George W. Bulcken
SRM&QA/Loral
P.O. Box 58128
Houston, TX 77525-8128
(713) 355-2469 (FAX) 335-2348

NASA Johnson Space Center
Kenneth I. Poast
Code EP6
2101 NASA Road One
Houston, TX 77058
(713) 483-4514 (FAX) 483-1340

NASA Johnson Space Center
Keith E. Van Tassel
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9053 (FAX) 483-3096

NASA Johnson Space Center
Darin N. McKinnis
Code EP5
2201 NASA Road One
Houston, TX 77058
(713) 483-9052 (FAX) 483-3096

NASA Johnson Space Center
Jay Wright
Code ND25
2201 NASA Road One
Houston, TX 77058
(713) 483-2949 (FAX) 483-2675

NASA Johnson Space Center
Ray Shearer
SRM&QA/Loral
P.O. Box 58128
Houston, TX 77525-8128
(713) 355-2499 (FAX) 335-2361

NASA Kennedy Space Center
Al Parrish
Code TV
MS D-23
Kennedy Space Center, FL 32899
(407) 861-3653 (FAX) 867-2167
NASA Langley Research Center
Larry Bement
Code 433
Hampton, VA 23665-5225
(804) 864-7084 (FAX) 864-7009

NASA Marshall Space Flight Center
Joe B. Davis
Code ED53
Marshall Space Flight Center, AL 35812
(205) 544-7019 (FAX) 544-8110

NASA Stennis Space Center
Wendy Holladay
Building 1100
Code FA10
Stennis Space Center, MS 39529-6000
(601) 688-1927 (FAX) 688-1485

NASA Stennis Space Center
William W. St. Cyr
Code HA20
Building 1100
Stennis Space Center, MS 39529-6000
(601) 688-1134 (FAX) 688-1925

NASA Wallops Flight Facility
John Hickman
Building N-159
Wallops Flight Facility
Wallops Island, VA 23337
(804) 824-2374 (FAX) 824-1518

Naval Air Warfare Center
Henry J. John, Jr.
Weapons Division (Code 3213)
China Lake, CA 93555-6001
(619) 939-7528 (FAX) 939-7226

Naval Air Warfare Center
Imelda Nee
Code 3293
China Lake, CA 93555-6001
(619) 939-7766 (FAX) 939-7562

Naval Air Warfare Center
Homer O. Valle
Weapons Division (Code 3030)
Range Safety (P4008)
Pt. Mugu, CA 93042
(805) 989-7142/7607 (FAX) 989-7743

Naval Research Laboratory
Charles Morgan
4555 Overlook Ave. S.W.
Washington, DC 20375-5000
(202) 767-6530 (FAX) 767-4633

Naval Research Laboratory
Mark Fratta
MS 8112
4555 Overlook Ave. S.W.
Washington, DC 20375-5000
(202) 594-7330 (FAX) 767-4633

Naval Surface Warfare Center
Gerald Laib
Code R12 Building 30-118
10901 New Hampshire Blvd.
Silver Springs, MD 20903-5000
(301) 394-2324 (FAX) 394-4826

Naval Surface Warfare Center
Indian Head Division - Code 5220
Jose M. Gutierrez
101 Strauss Ave.
Indian Head, MD 20640-5035
(301) 743-4447 (FAX) 743-4881

Naval Surface Warfare Center
Indian Head Division - Code 5310
Craig A. Pfleeger
101 Strauss Ave.
Indian Head, MD 20640-5035
(301) 743-4217 (FAX) 743-4881

Naval Surface Warfare Center
Indian Head Division - Code 5240E
Tom Blachowski
101 Strauss Ave.
Indian Head, MD 20640-5035
(301) 743-4243 (FAX) 743-4881

Naval Surface Warfare Center
Indian Head Division - Code 5220C
Philip A. Renn
101 Strauss Ave.
Indian Head, MD 20640-5035
(301) 743-4946 (FAX) 743-4881

Northrop Corp.
Ed Drumheller
E110/89
One Northrop Ave.
Hawthorne, CA 90260
(310) 332-0886 (FAX) 332-3066

Pacific Scientific Corp.
Energy Systems Division
Bob LaFrance
7073 West Willis Road, Box 5002
Chandler, AZ 85226-5111
(602) 796-1100 (FAX) 796-0754

Pacific Scientific Corp.
Energy Systems Division
Donald J. Behrens
7073 West Willis Road
Box 5002
Chandler, AZ 85226-5111
(602) 796-1100 (FAX) 796-0754

Quantic Industries, Inc.
Kenneth E. Willis
900 Commercial Street
San Carlos, CA 94070-4084
(415) 637-3074 (FAX) 592-4669

Sandia National Laboratories
Steven M. Harris
Organization 2513
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-0949 (FAX) 844-5924

Sandia National Laboratories
William Kass
Division 2234
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-6844 (FAX) 844-8168

Sandia National Laboratories
Jere G. Harlan
Organization 2512
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-4401 (FAX) 844-4709

Sandia National Laboratories
Richard D. Wickstrom
Dept 2514
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-8019 (FAX) 844-5924

Sandia National Laboratories
John A. Merson
Division 2512
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-2756 (FAX) 844-4709

Sandia National Laboratories
Weng Chow
Division 2235
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-9088 (FAX) 844-8168

Sandia National Laboratories
William W. Tarbell
Organization 2514
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-7690 (FAX) 844-0820

Sandia National Laboratories
Ron L. Hospelhorn
Department 2346
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9113 (FAX) 844-1214

Sandia National Laboratories
Robert E. Setchell
Department 5166
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-3847 (FAX) 844-7431

Sandia National Laboratories
Robert W. Bickes Jr.
Organization 2513
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-0423 (FAX) 844-5924

Sandia National Laboratories
Paul V. Dressendorfer
Dept. 2235
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-5373 (FAX) 844-8168

Sandia National Laboratories
Dennis E. Mitchell
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-8294 (FAX) 844-5924

Sandia National Laboratories
Kent Meeks
Department 5166
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-1040 (FAX) 844-7431

Sandia National Laboratories
Manny Vigil
Dept. 2513
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-4660 (FAX) 844-4709

Sandia National Laboratories
Kevin J. Fleming
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-8510 (FAX) 844-0820

Sandia National Laboratories
John D. Matthews
Organization 2514
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-8763 (FAX) 844-5924

Sandia National Laboratories
J. F. Jones
Department 2574
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-8656 (FAX) 844-1214

Sandia National Laboratories
F. Jim Salas
Organization 2512
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-3265 (FAX) 844-4709

Santa Barbara Research Center
Hughes Aircraft Company
Jim Aloise
75 Coromar Drive B30/12
Goleta, CA 93117
(805) 562-4910 (FAX) 562-4024

Santa Barbara Research Center
Hughes Aircraft Company
Larry Snarr
75 Coromar Drive B30/12
Goleta, CA 93117
(805) 562-4002 (FAX) 562-4024

Santa Barbara Research Center
Hughes Aircraft Company
Roman Gonzales
75 Coromar Drive B30/12
Goleta, CA 93117
(805) 562-7705 (FAX) 562-7882

Schimmel Company
Morry L. Schimmel
8127 Amherst Avenue
St. Louis, MO 63130
(314) 863-7725 (FAX) 727-8107

Scot Inc.
Jed Potter
25341 Via Oriol
Valencia, CA 91355
(805) 259-4426 (FAX) 259-4426

Scot Inc.
John Cobbett
2525 Curtiss St.
Downers Grove, IL 60515
(708) 969-0620 (FAX) 969-4719

Special Devices, Inc.
Robert Ritchie
16830 W. Placerita Canyon Rd.
Newhall, CA 91321
(805) 259-0753 (FAX) 254-4721

Special Devices, Inc.
William J. Sipes
16830 W. Placerita Canyon Rd.
Newhall, CA 91321
(805) 259-0753 (FAX) 254-4721

Spectra Diode Laboratories
Richard Craig
80 Rose Orchard Way
San Jose, CA 95134
(408) 943-9411 (FAX) 943-1070

Teledyne McCormick Selph
Robert W. Ingnam
3601 Union Road
P.O. Box 6
Hollister, CA 95024-0006
(408) 637-3731 ext 225 (FAX) 637-5494

TRW Ballistic Missile Division
Lien C. Yang
M/S SB2/1021
P.O. Box 1310
San Bernardino, CA 92402-1310
(714) 384-7309 (FAX) 384-7273

Unidynamics
Paul Redd
102 S. Litchfield Road
Goodyear, AZ 85338
(602) 932-8574 (FAX) 932-8949
United Technologies/USBI
C. F. Webster
Building 188
P.O. Box 1900
Huntsville, AL 35807
(205) 721-2342 (FAX) 721-2263

Universal Propulsion Co., Inc. (UPCO)
Tom Wergen
25401 North Central Ave.
Phoenix, AZ 85027-7837
(602) 869-8067 (FAX) 869-8176

University of Notre Dame
Joseph M. Powers
Aerospace & Mechanical Engineering
365 Fitzpatrick Hall
Notre Dame, IN 46556-5637
(219) 239-5978 (FAX) 239-8341

University of Notre Dame
Keith A. Gonthier
Aerospace & Mechanical Engineering
365 Fitzpatrick Hall
Notre Dame, IN 46556-5637
(219) 239-5978 (FAX) 239-8341

U. S. Air Force
Aeronautical Systems Division
Lawrence Rogers
ASD/ENECC Building 126, Bay 222
Wright Patterson AFB, OH 45433-6503
(513) 255-6920 (FAX) 476-7572

U. S. Air Force
Stephan Tipton
OC-ALC/LSES
Tinker AFB, OK 73145
(405) 736-7444 (FAX) 736-3714

U. S. Air Force/30th Space Wing
Mark Gotfraind
30 SPW/SESX
Vandenberg AFB, CA 93437-6021
(805) 734-8232 ext
(FAX) 734-8232 ext

U. S. Air Force/30th Space Wing
Abe M. Takasugi
30 SPW/SESX
Vandenberg AFB, CA 93437-6021
(805) 734-8232 ext 69751
(FAX) 734-8232 ext 58030

Commander, U.S. Army
White Sands Missile Range
STEW-S-NR-CE (A. Lechuga)
White Sands Missile Range, NM 88002-5137
(505) 678-4126 (FAX) 678-3795

UTC/Chemical Systems Division
K. S. Lai
P.O. Box 49028
San Jose, CA 95161-9028
(408) 776-4327 (FAX) 776-4444

Vitro Corporation
William C. Wells
Suite 300W
600 Maryland Ave., S.W.
Washington, DC 20024

Whittaker Ordnance
Michael C. Todd
2751 San Juan Road
Hollister, CA 95023

APPENDIX B - Written Questions and Answers

Question:

Response:

Dr. Lien C. Yang (TRW)

Absorptive particulated doped HMX and PETN can be initiated by laser. But the threshold may degrade post environmental test, especially temperature cycling. Are there plans to perform any test?

Dr. J. A. Merson (Sandia Nat. Labs)

Yes. Powder separation may be a problem. It is no different than bridgewire decoupling and therefore there are engineering solutions.

Dr. Richard Craig (Spectra Diode Labs)

As you develop a standard laser diode safe and arm:

- 1) How do you get input from system and component manufacturers?
- 2) How will you distribute your concepts to the community?

Mr. Barry Wittschen (NASA/JSC)

1) The word "standard", as applied to a laser safe and arm may be a misnomer. What we are going to attempt to do is identify major criteria for system configuration, methods for implementing inhibits, methods for qualifying the S&A and acceptance test requirements.

2) The most critical application for the S&A is in flight termination systems (FTS). FTS requirements are established by the range safety organizations. The primary input will therefore develop through dialogue with the ranges and then be distributed by the ranges in the form of revisions to their own safety requirements. Additional distribution will be through future NASA and AIAA conferences.

Dr. Lien C. Yang (TRW)

Is it possible to re-adopt ASI (Apollo Standard Initiator) output charge design using $\text{TiH}_2/\text{KeLO}_4$ composition for increasing the gaseous output? ASI was extensively tested in 1960's. Large performance data base exists.

Mr. Larry Bement (NASA/LaRC)

No possibility exists to change the output charge in the NSI, as it is now qualified. The $\text{TiH}_2/\text{KeLO}_4$ may be some benefit for the NASA Standard Gas Generator, but the ignition and primary charge must remain Zr/KeLO_4 .

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE January 1993	3. REPORT TYPE AND DATES COVERED Conference Publication July 9-10, 1992		
4. TITLE AND SUBTITLE First NASA Aerospace Pyrotechnic Systems Workshop			5. FUNDING NUMBERS	
6. AUTHOR(S) William W. St. Cyr, Compiler				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John C. Stennis Space Center Code HA20 - Building 1100 Stennis Space Center, MS 39529-6000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Code QE Washington, DC 20546			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CP-3169	
11. SUPPLEMENTARY NOTES Hosted by the Johnson Space Center, Houston, TX				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This NASA Conference Publication contains the proceedings of the first NASA Aerospace Pyrotechnic Systems Workshop held at the Johnson Space Center, Houston, Texas, June 9-10, 1992. The papers are grouped by sessions: Session 1 - Pyrotechnically Actuated Systems; Session 2 - Laser Initiation; Session 3 - Modeling and Analysis. A fourth session, a panel discussion and open forum, concluded the workshop.				
14. SUBJECT TERMS Pyrotechnics			15. NUMBER OF PAGES 436	
			16. PRICE CODE A18	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

NASA-Langley, 1993

PRECEDING PAGE BLANK NOT FILMED

National Aeronautics and
Space Administration
Code JTT
Washington, D.C.
20546-0001
Official Business
Penalty for Private Use, \$300

SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
NASA
PERMIT No. G27



POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Return
