N93-20133

FIRST NASA AEROSPACE PYROTECHNIC SYSTEMS WORKSHOP

NASA PYROTECHNICALLY ACTUATED SYSTEMS PROGRAM

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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.

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

Pyrotechnic devices are usually considered by users, e.g., program managers, to be mmediately 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 "mature," no pyrotechnic research program exists. Further, no pyrotechnic technology developmental program exists.

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.

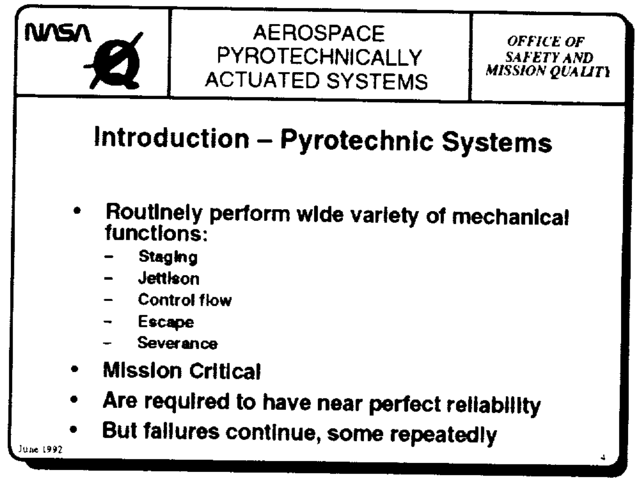

Fig. 1. Introduction to aerospace pyrotechnic systems applications.

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

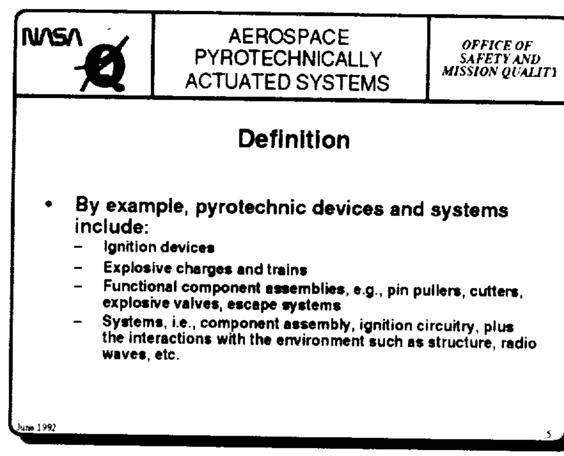

Fig. 2. Definition of pyrotechnics.

<u>Program need</u>. 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 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.

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).

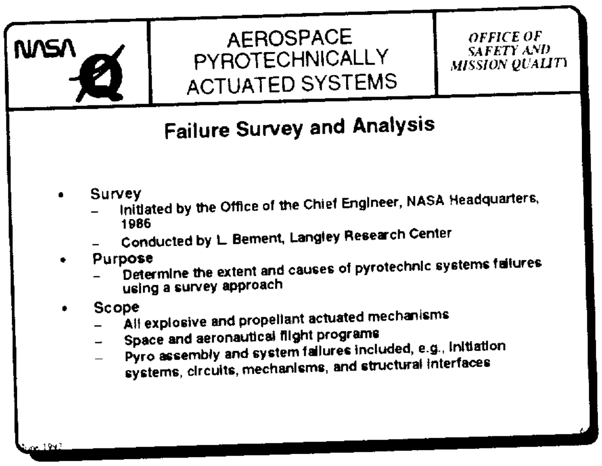

Fig. 3. NASA survey of pyrotechnic failures and analysis.

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 Committee[1] 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).

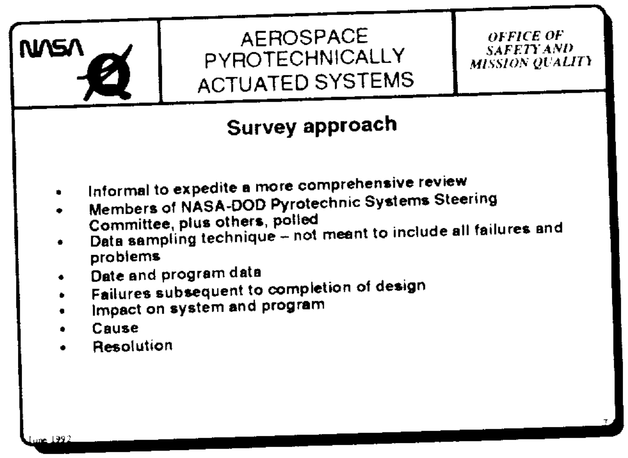

Fig. 4. Pyrotechnic survey approach.

<u>Problem survey</u>. 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).

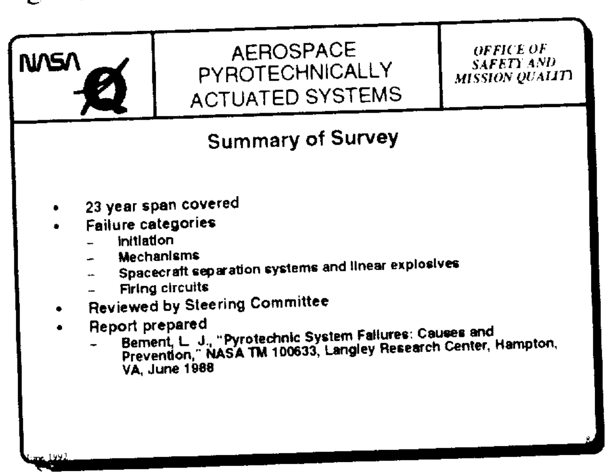

Fig. 5. Summary of survey.

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 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.

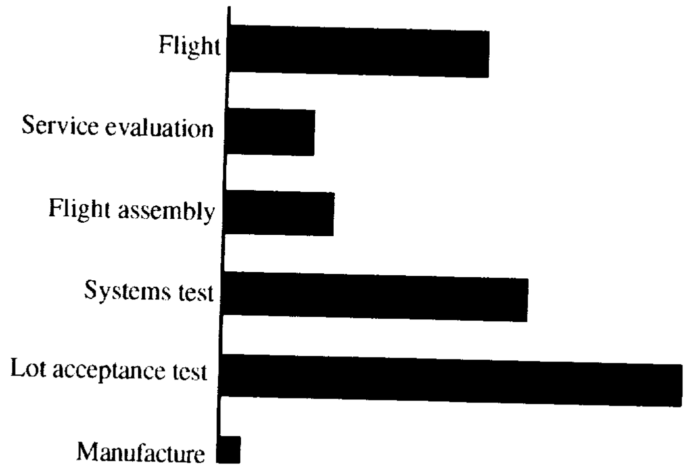

Fig. 6. Failures experienced during pyrotechnic life cycles.

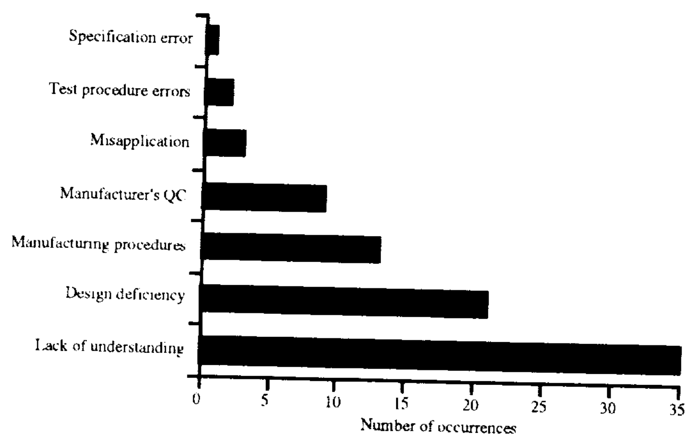

Fig. 7. Distribution of failures by cause.

Assessment of Survey Results

Deficient Areas	Recommended Tasks
• Design Approaches – generic specification – standard devices	• Design Approaches – prepare NASA specification handbook – select/verify existing hardware types
• Pyrotechnic Technology – research/development technology base – recognized engineering discipline – training/education – test methodology/capabilities – new standard hardware	• Pyrotechnic Technology – 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
• Communications – technology exchange – data bank & lessons learned – intercenter program support	• Communications – continue Steering Committee meetings – initiate symposia – establish pyro reporting requirements for NASA PRACA – perform as a Steering Committee function
• Resources – funds – research/development staff and facilities	• Resources – 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.

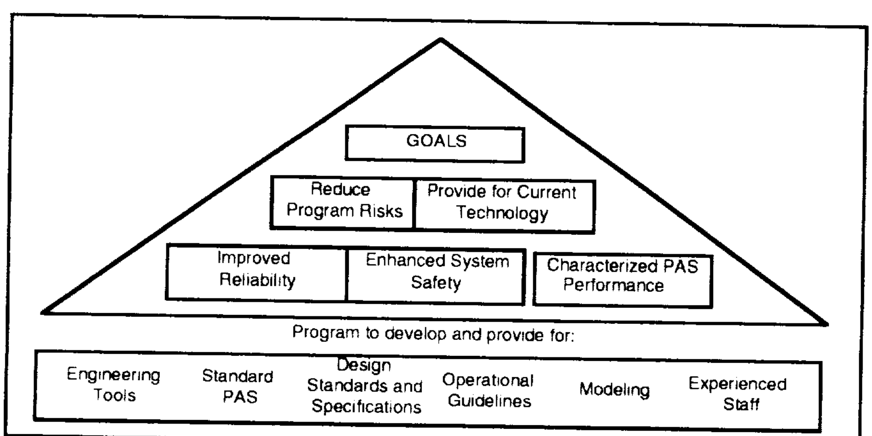

Fig. 9. Program goals and products.

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. Incorparate 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.

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

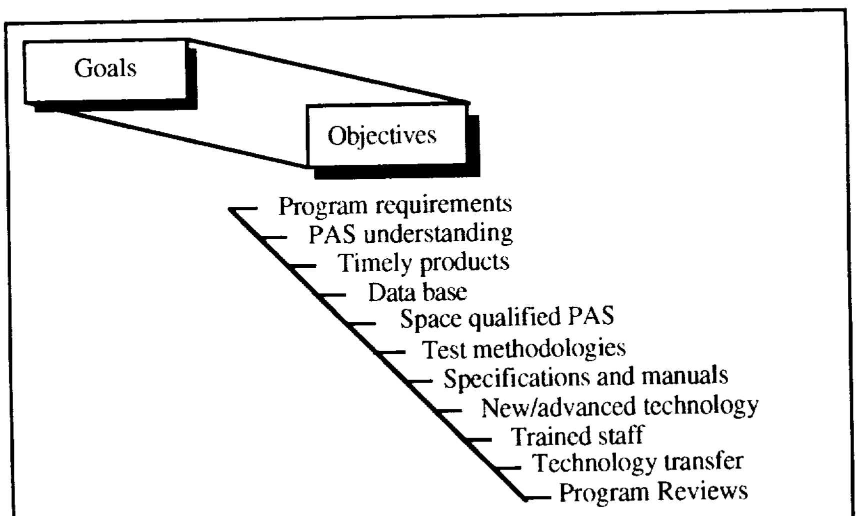

Fig. 10. PAS Program objectives.

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.

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.

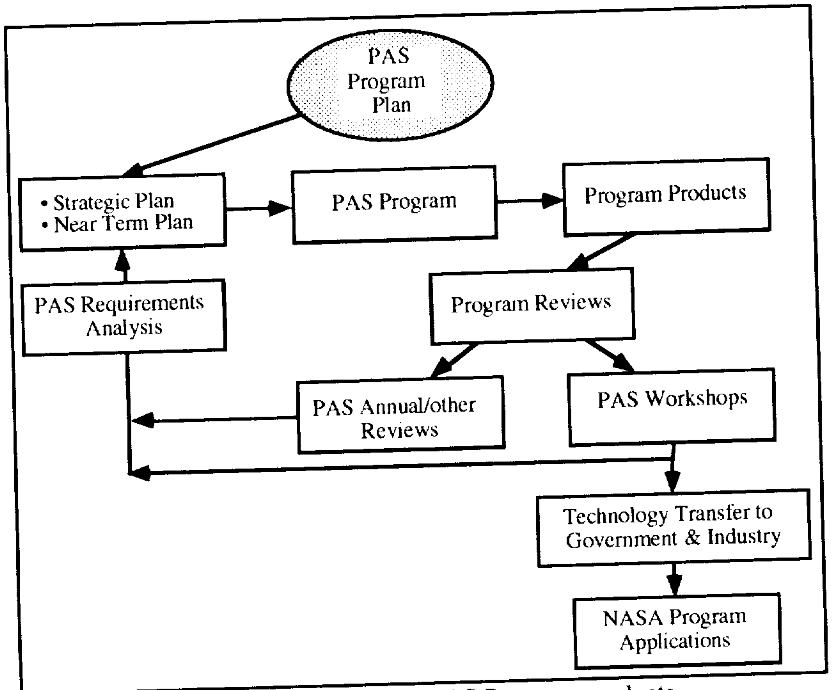

Fig. 11. Plan to assure use of PAS Program products.

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.

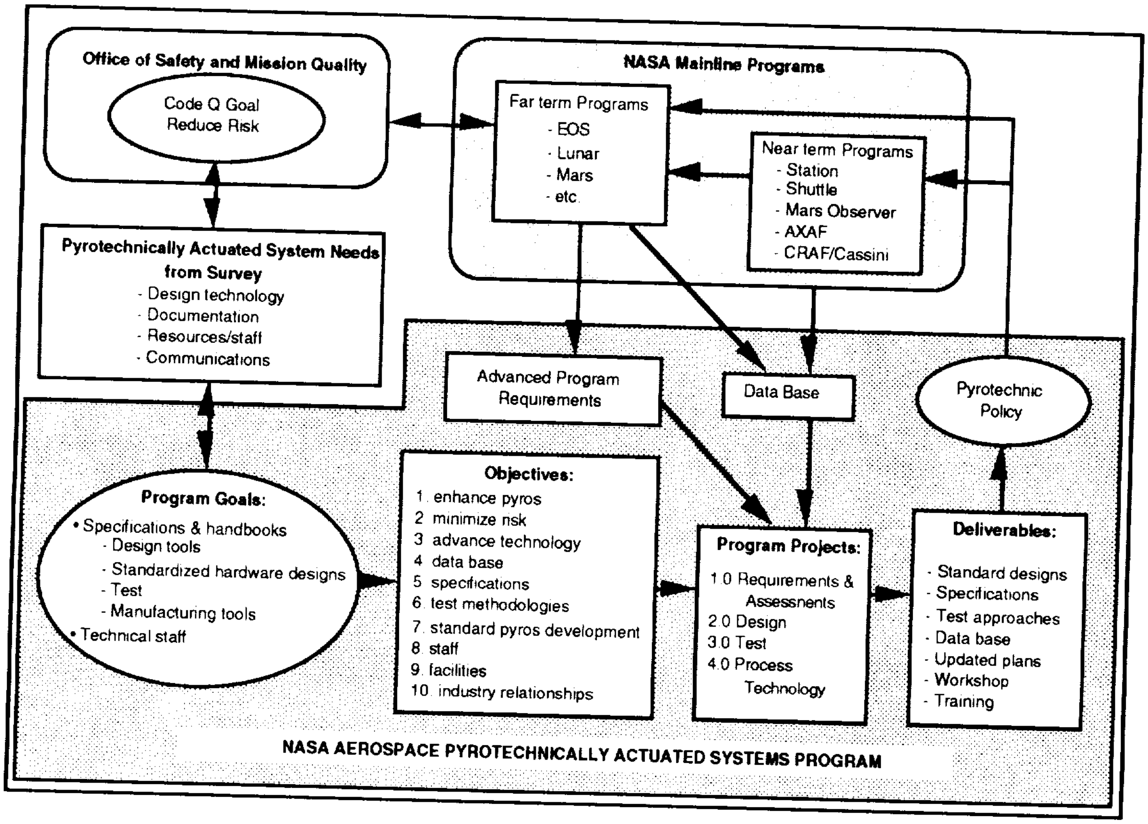

Fig. 12. Pyrotechnically Actuated Systems Program master flow chart.

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.

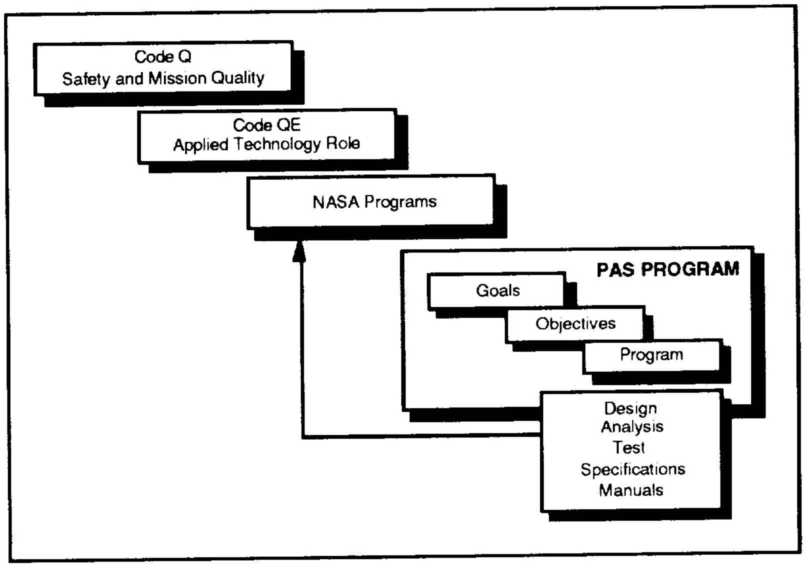

Fig. 14. Relationship of PAS Program to Code Q, QE, and NASA program roles.

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 andojects.

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 program element and the major products follows. The organization of the program is presented in Fig. 15.

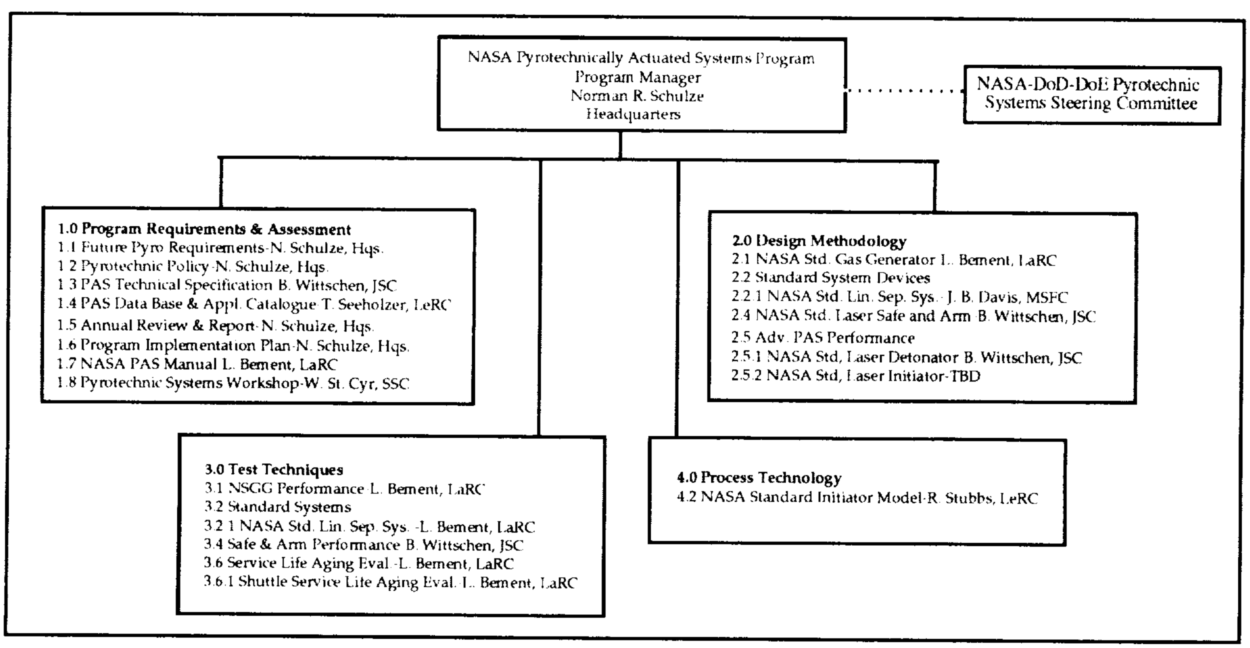

Fig. 15. PAS program organization.

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).

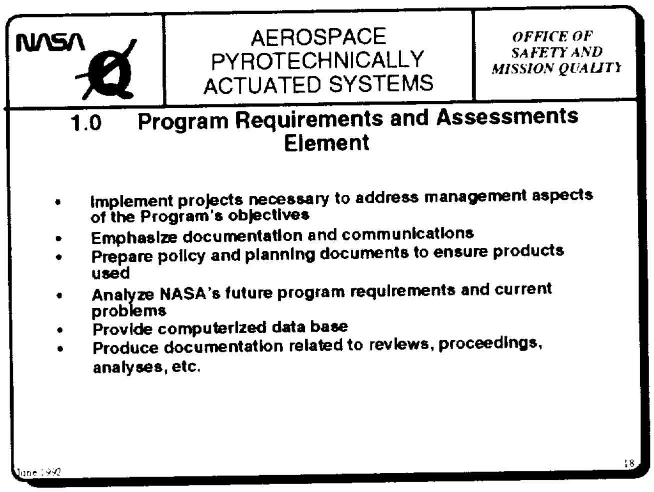

Fig. 16. Project 1.0, Program Requirements and Assessments Element.

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.

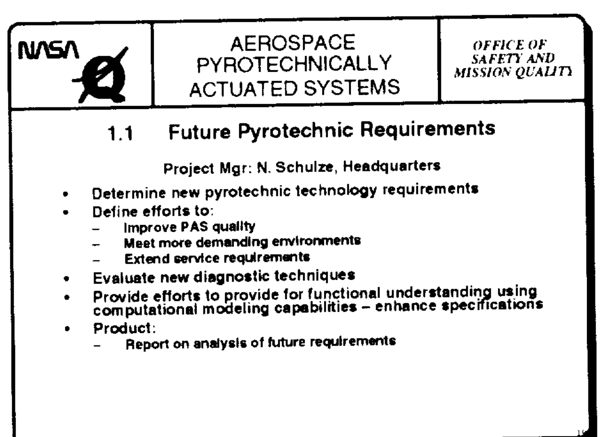

Fig. 17. Project 1.1, Future Pyrotechnic Requirements.

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).

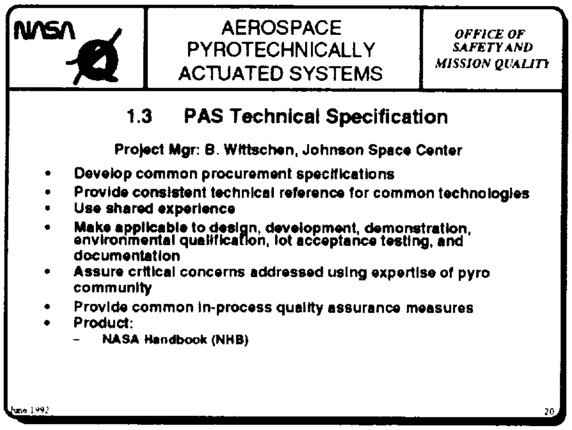

Fig. 18. PAS Technical Specification.

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).

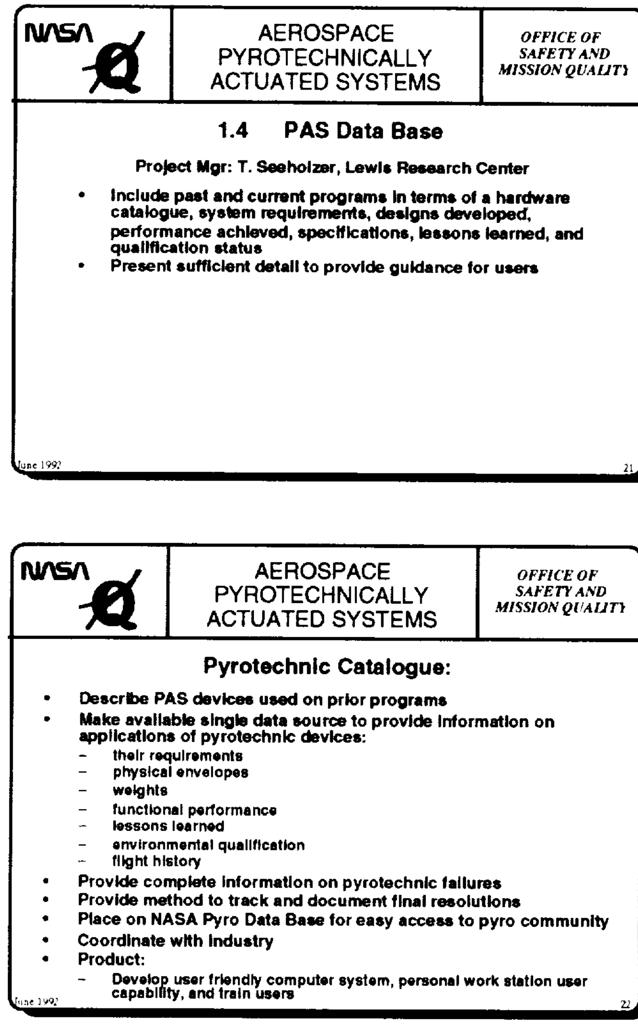

Fig. 19 a, b. Pyrotechnically Actuated Systems Data Base.

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).

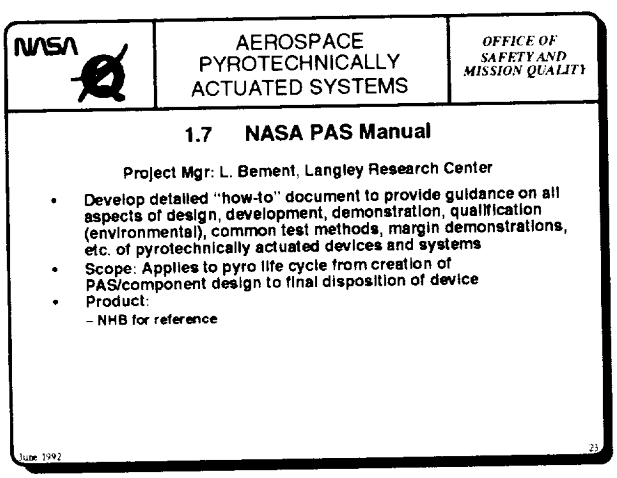

Fig. 20. NASA PAS Manual

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).

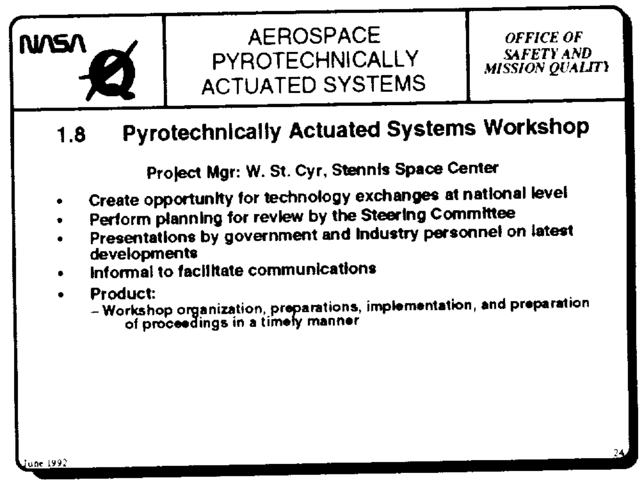

Fig. 21. NASA Pyrotechnically Actuated Systems Workshop.

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).

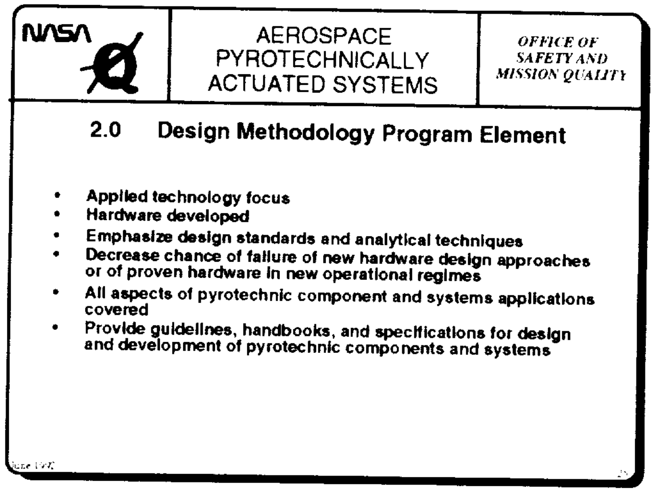

Fig. 22. Design Methodology Program Element.

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.

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

2.1 NASA Standard Gas Generator (NSGG)

Project Mgr: L. Bement, Langley Research Center

- Develop where the use of gas output is needed to perform a function rather than serving as ignitor:
  - Separation nuts, valves, cutters, switches, pin pullers, thrusters, mortars, bolts, etc.
- Common NASA GG
  - 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:
  - Qualified NSGG
  - Design specification (NHB)
  - Test reports

June 1992

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*

The development of a NASA Standard Linear Separation System (NSLSS) has been assigned a high system developmental 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 hardware which can be produced at a lower cost (Fig. 24).

NASA | AEROSPACE PYROTECHNICALLY ACTUATED SYSTEMS | OFFICE OF SAFETY AND MISSION QUALITY

2.2.1 NASA Standard Linear Separation System (NSLSS)

Project Mgr: Joe B. Davis. Marshall Space Flight Center

- Develop standard linear separation system
  - 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
  - Prepare NASA-wide technical specification

June 1992 27

Fig. 24. NASA Standard Linear Separation System.

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.

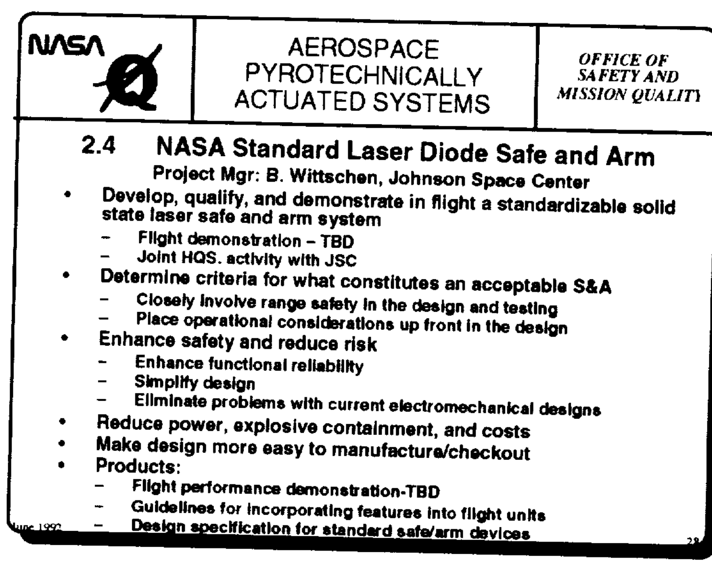

Fig. 25. NASA Standard Laser Diode Safe and Arm.

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).

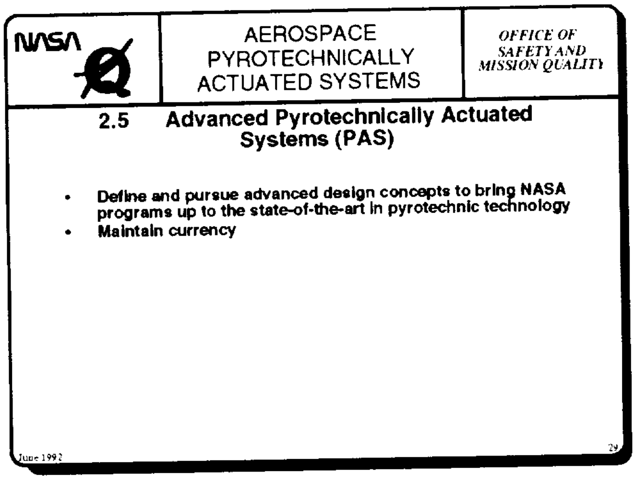

Fig. 26. Advanced Pyrotechnically Actuated Systems.

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,

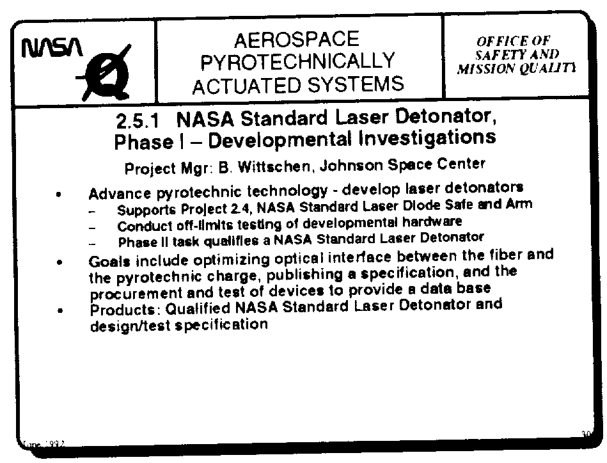

Fig. 27. NASA Standard Laser Initiator (NSLI).

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)

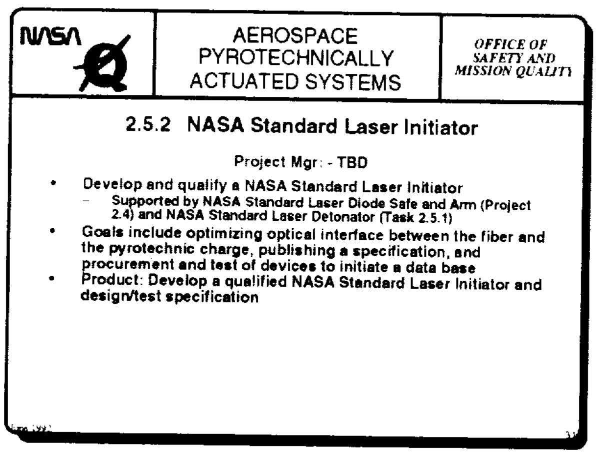

Fig. 28. NASA Standard Laser Initiator.

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).

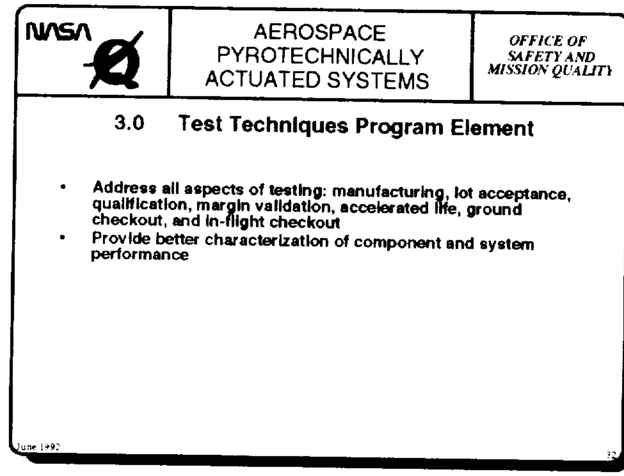

Fig. 29. Test Techniques Program Element.

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).

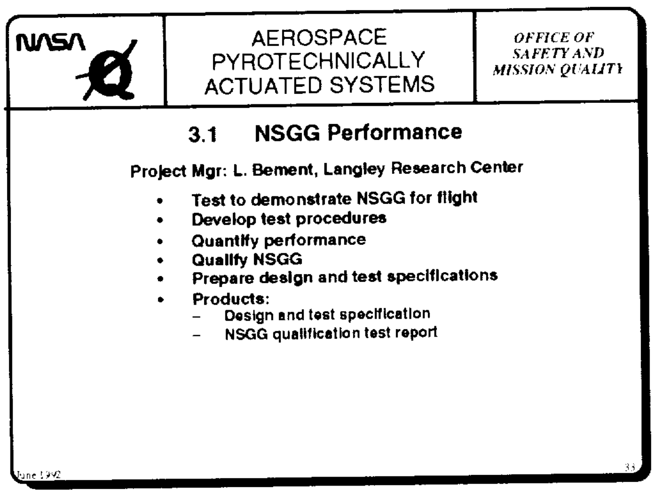

Fig. 30. NSGG Performance.

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).

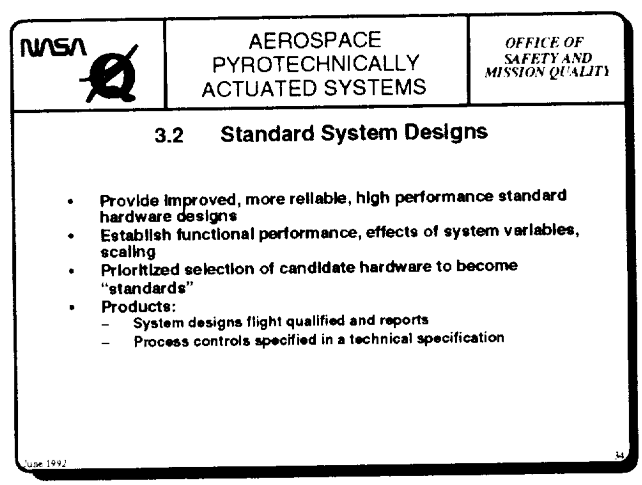

Fig. 31. Project 3.2, Standard Systems Designs.

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

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)

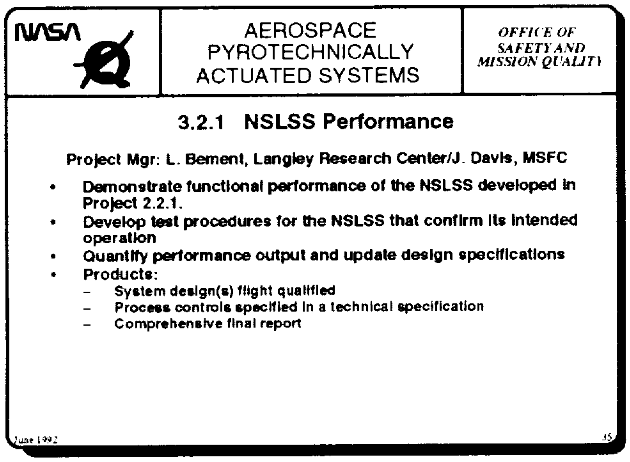

Fig. 32. Project 3.2.1, NSLSS Performance.

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

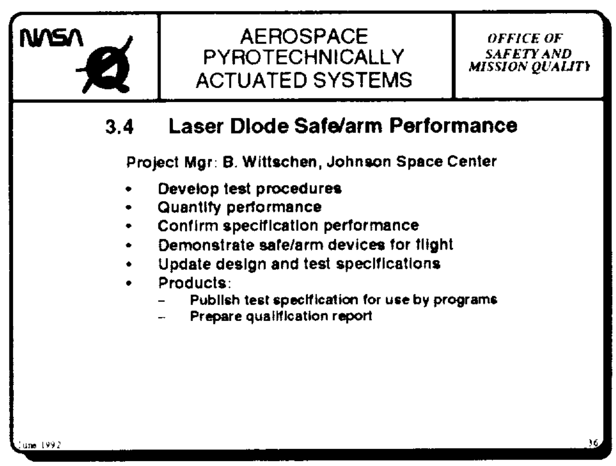

Fig. 33. Laser Diode Safe and Arm Performance.

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).

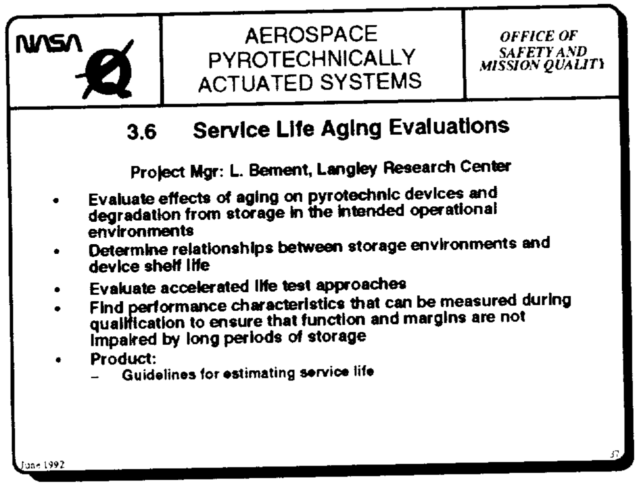

Fig. 34. Service life aging evaluations.

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)

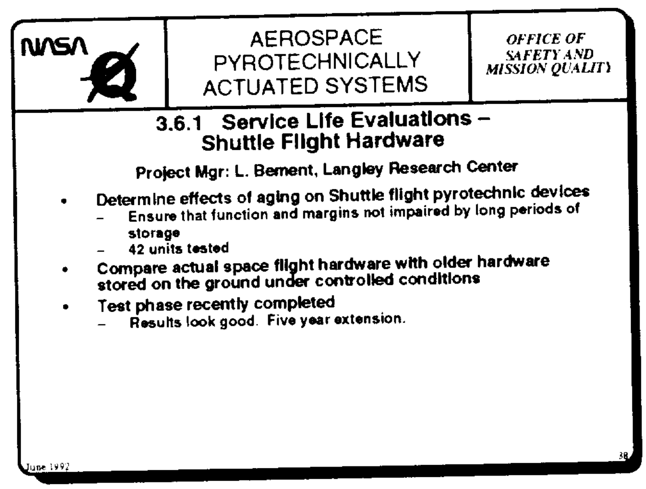

Fig. 35. Service Life Evaluation of Shuttle hardware.

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 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 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:

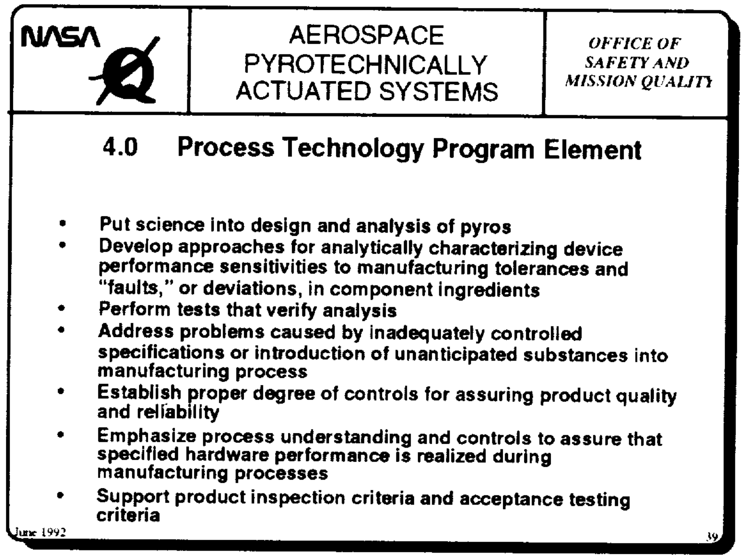

Fig. 36. Modeling - Process Technology Program Element.

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.

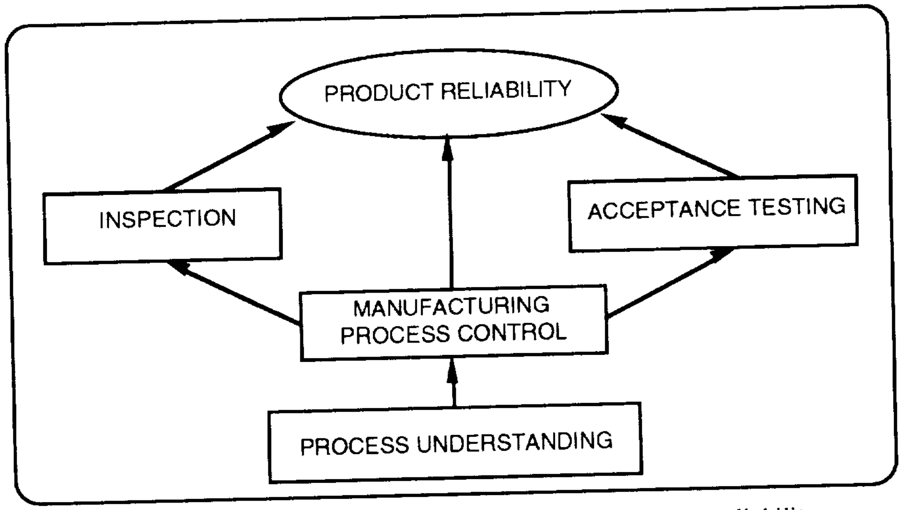

Fig. 37. Interrelationships between PAS Program and product reliability.

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.

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.

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.

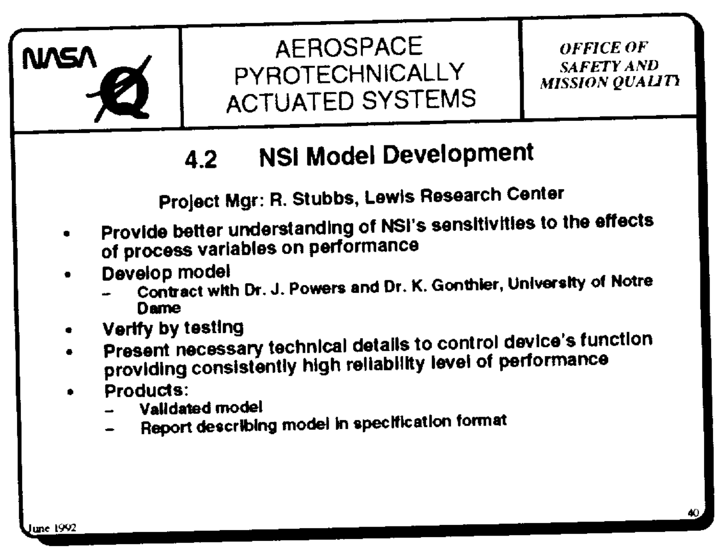

Fig. 38. Project 4.2, NSI Model Development.

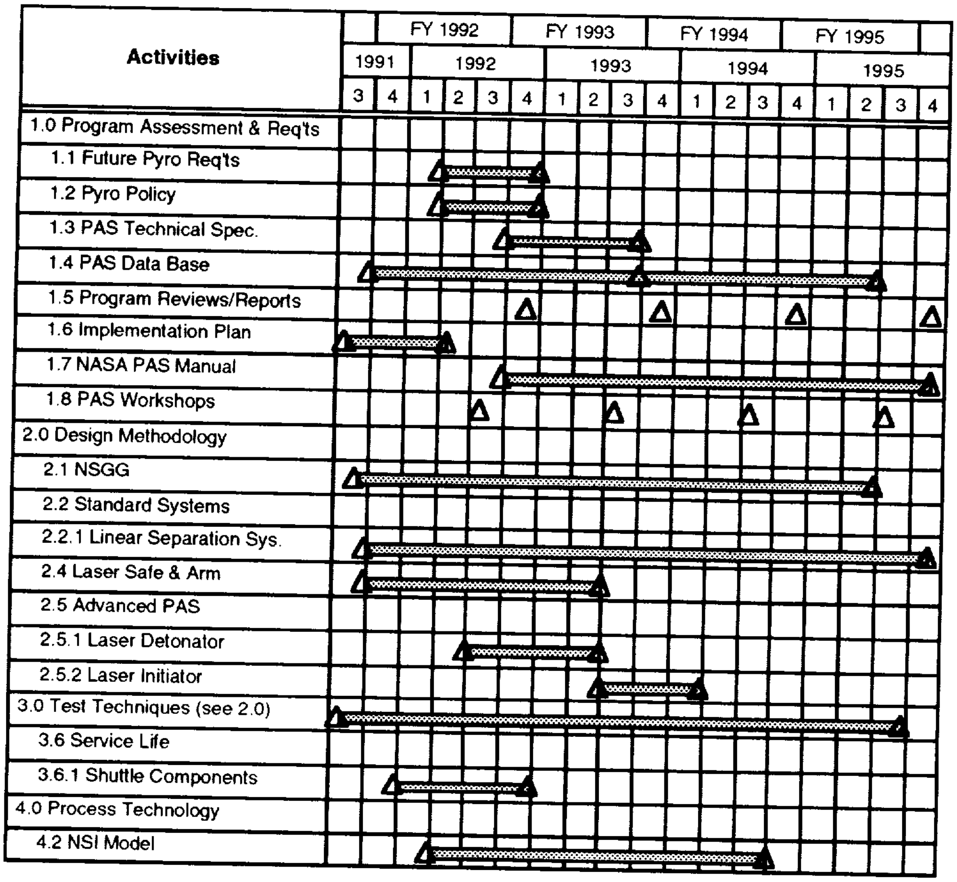

Fig. 39. PAS Program schedule.

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).

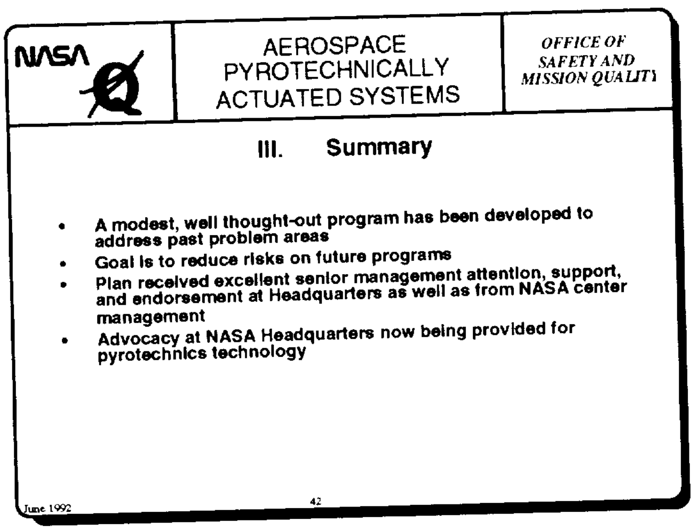

Fig. 40. PAS Program Summary.

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.

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

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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.

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