EXPLOSIVE SAFETY

EXECUTIVE LECTURE SERIES

GPO PRICE $ ____________

CFSTI PRICE(S) $ ____________

Hard copy (HC) ____________

Microfiche (MF) ____________

ff 653 July 65

N67-15981 (ACCESSION NUMBER) — N67-15991 (THRU)

152 (PAGES)

1 (CODE)

CR-81250 (NASA CR OR TMX OR AD NUMBER)

34 (CATEGORY)

FACILITY FORM 602

PRESENTED BY

FLORIDA OPERATIONS

7001 NORTH ATLANTIC AVE. CAPE CANAVERAL, FLORIDA

39565

FINAL REPORT

EXPLOSIVE SAFETY
EXECUTIVE
LECTURE SERIES (U)

Contract Number NAS 10-2189

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
John F. Kennedy Space Center
Cape Kennedy, Florida

June 1965

Approved: M. G. Wentzel

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TRW SPACE TECHNOLOGY LABORATORIES, TRW INC.
FLORIDA OPERATIONS • 7001 North Atlantic Avenue • Cape Canaveral, Florida

FOREWORD

The Explosive Safety Executive Lecture Series was designed to give top management a better understanding of their responsibilities for safety. Each lecture of the series covers a significant major problem area in explosive safety. The lecture content is intended to be of sufficient technical depth to be meaningful, while at the same time providing a broad coverage of the subject. The group of six lectures is designed to provide a general survey of explosive safety problems as related to launch area operations.

This report is a compilation of the course notes, lecture transcripts, and subjects discussed on the floor. The results are presented as a comprehensive reference to afford the manager a familiarity with space vehicle ordnance and explosive safety problems.

It is hoped that those in attendance at the Executive Lecture Series gained a greater appreciation for the KSC Safety Program - and their safety responsibilities as managers.

ACKNOWLEDGMENT

Safety problems are compounded in activities involving space vehicles because of the large amounts of hazardous materials present and because the complex systems and operations may expose these hazardous materials to dangerous interactions.

These hazards, although categorized as problems of safety, are the concern of management. The John F. Kennedy Space Center Safety Office is well aware of these hazards and, in sponsoring the Executive Lecture Series on Explosive Safety, has contributed greatly toward management development.

introducing the lecturers

DR. GEORGE J. BRYAN

Dr. Bryan has 20 years technical experience, including 17 years in the liquid & solid propellant propulsion field & the related field of ordnance & explosives. He is currently engaged in technical direction & systems engineering (including safety considerations) of Minuteman & its auxiliary rockets & ordnance. He has acted in a similar capacity on Thor, Thor-Able and related projects. While with the U.S. Naval Ordnance Laboratory, he served as a member on the Subroc propulsion, field testing & planning committees. He also acted in an advisory capacity on Polaris propulsion work, and directed research in the fields of propellant detonability & rocket ignition.
His safety responsibilities began as an undergraduate laboratory assistant & have extended throughout his career. He gained experience in industrial safety & handling of radioactive materials at Oak Ridge. At NOL, he served a term on the Explosive Safety Committee, was responsible for the safety of explosive research and advised on propellant & ordnance safety. He recently served on a committee which reviewed ETR, Delta, TAD & Asset operations & procedures from the standpoint of safety.
Dr. Bryan received his BS degree from the University of South Carolina, his PhD from the University of North Carolina & is a member of Sigma Xi.

LEONARD T. DOMBRAS

Mr. Dombras has 18 years technical experience, including 7 years of ballistic missile launch operations, 7 years as a research physicist on propulsion & propellants and 4 years in the chemical industry.
As Project Engineer, he is currently conducting a study of the KSC Safety Program. Since 1958, he has supervised the propulsion and ordnance checkout on Titan I, Titan II, Atlas-Centaur & Minuteman Programs. He has a comprehensive knowledge of solid and liquid rocket propulsion systems, ordnance devices, & propellant loading, handling, & disposal systems. He supervised the design and testing of the Titan I and Titan II propellant systems and was responsible for developing procedures and safety criteria for working with these propellants.
As a Research Physicist with Reaction Motors, Inc., he supervised the design and testing of experimental rocket systems used to evaluate exotic & high energy propellants including borane & fluorine compounds. His experience includes the design & testing of rocket ignition systems, gas generators, chemical jet reactors, shock tubes, liquid propellant guns & high pressure gas generators for launching carrier aircraft.
Mr. Dombras has a BS degree in Physics from Rutgers University and is a member of Sigma Xi.

FRANK FEDOWITZ, JR.

Mr. Fedowitz is currently engaged in the systems engineering and technical direction of the Minuteman ordnance systems development program including safety aspects and has participated in the Nuclear Weapon System Safety Group meetings on Minuteman. In addition, he is engaged in company sponsored ordnance projects for the various space programs. Prior to joining STL he was employed by Picatinny Arsenal, Dover, New Jersey, where he was responsible for various phases of the design and development of advanced artillery and rocket warheads; including fuzing, shaped charge design and warhead performance.

Mr. Fedowitz received his Bachelor of Mechanical Engineering degree from New York University.

JACK LARKS

Mr. Larks has 15 years of varied experience in structures research and analysis;physical testing and evaluation; product design engineering and analysis of production methods and processes for aircraft and missile components. For the last 9 years, he has been working in the aerospace industry.
He is presently Project Engineer responsible for analysis of facilities & mechanical systems on the ORL and LS study for NASA. Mr. Larks' experience includes responsibility for vibration testing of aircraft components, missile checkout and launch preparation (Thor); and during the past 5 years, supervision of construction, modification & refurbishment for Atlas, Titan I, Titan II, and Minuteman facilities. He has also performed research & evaluation of methods & materials applicable for missile operations such as exotic propellants, heat resistant materials, toxic propellant disposal & safety criteria for ordnance.
While associated with Thor, Thor-Able, Atlas, Titan & Minuteman, Mr.Larks worked with the following types of materials & devices: LOX-RP propellants; toxic,hypergolic and caustic propellants; Class 9 & 10 solid propellants;squibs, igniters, retrorockets & sofar bombs; storage, handling & transportation of propellants; decontamination and cleanliness of propellant systems.
Mr. Larks received his B.S. & M.S. degrees from Massachusetts Institute of Technology; is a registered Engineer in Florida & Oklahoma, & a member of Sigma Xi.

STANLEY H. RUSH

Mr. Rush has seventeen years technical experience, including fifteen years in the ordnance and propulsion field. He is currently engaged in the systems engineering and technical direction of the Minuteman ordnance system. He was responsible for ordnance system design criteria established for the Air Force Ballistic Missiles and was responsible for the destruct system design utilized on Minuteman. He has a comprehensive knowledge of ordnance systems, electro-explosive devices, design, loading, handling, and disposal of ordnance components.

Mr. Rush's ordnance and safety responsibilities began at Picatinny Arsenal in the design of fuzes, warheads and rocket motors. At Republic Aviation he was responsible for stores ejection systems, auxiliary power units, and armament installation. At TRW Space Technology Laboratories he has made major contributions to the ordnance system of Minuteman, Atlas, OGO and the Vela Satellite Program. Prior to his present assignment as Staff Engineer in the Weapons System Department, he was head of the TRW Space Technology Laboratories Ordnance Group.

Mr. Rush received his B.S. degree in Mechanical Engineering from New York University.

GEORGE N. WOODRUFF

Mr. Woodruff has 14 years of professional experience in liquid, gaseous and solid propellant rocket research, development and testing. For the past seven years, he has been involved with the flight test programs of the Titan I and Titan II missile systems. His responsibilities included propellant loading and handling systems, and the missile propulsion systems. In this work, he was concerned with all of the safety considerations involved in introducting the Titan II Toxic propellants onto the range. Mr. Woodruff was formerly a research physicist with Reaction Motors Inc., where he conducted a research program studying misfires of cartridge actuated devices (CAD). His experience also includes high - pressure combustion studies, rocket exhaust kinetics and impingement studies and work with solid propellant rocket sleds. Mr. Woodruff has a broad background in the handling of cryogenic and noncryogenic propellants, safety problems of high - pressure liquid and gas handling systems to 30,000 psi and small solid propellant devices.

Mr. Woodruff received his BS degree in Physics from Union College. He is an Associate Fellow of the American Institute of Aeronautics and Astronautics, a member of the AMA and RESA.

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Lecture Number One

"TOP MANAGEMENT RESPONSIBILITIES"

Part I

Dr. G. J. Bryan

1.0 INTRODUCTION

Historically, fatal accidents are relatively rare, but to witnesses their seriousness is vividly clear. Most near-misses are not documented.

The complexity of modern spaceships in launch configuration is far greater than that of early missiles. Ordnance and propellant subsystems and devices are present for propulsion, control, separation, destruct, and actuation purposes throughout these spaceships. The number of systems on Saturn approaches 100. High-energy RF fields, stray currents, electrostatic fields, and flammable vapors are often present.

The capability for destructive accidents is enormous. There is no excuse for not utilizing the safety knowledge we have gained. Much of this knowledge has been gleaned from the reports of accidents, some of which were fatal.

Is ordnance safety different from ordinary safety? Is it any more serious to kill a person by an ordnance accident than to have a truck driver employee be killed in a highway accident?

The answer to both of these questions is "YES." The immediate following question is "WHY?" There are three major differences involved:

- Employee's Dependence Upon Employer

  First, the truck driver has largely in his own brain, due to his past training and experience, the knowledge to avoid an accident. The individual working with ordnance is largely dependent on the procedures supplied to him, the safety of the equipment and facilities which he is using, and the training and indoctrination provided him. For this reason, the blame may well rest at some higher level in the organization.

- Public Attitude

  The second reason is that, due to the lack of a general understanding of ordnance safety problems, there is an immediate reaction to a death due to ordnance causes. This reaction is, "Was it just luck that kept this accident from killing many people rather than one?" In other words, past experience has shown that occasionally explosives and/or propellants have caused massive destruction of lives and property. The tendency is, therefore, to equate one death to the possible risk of many lives associated in the minds of the general public with any ordnance accident. (see Table 1, page 1-22)

- Unrecognized Factors

  The third reason that an ordnance accident is different is that experts in ordnance safety are continuously aware that there is danger due to unrecognized factors. Any ordnance accident requires detailed examination to determine the cause so that it can be added to the body of accumulated experience in preventing future accidents.

  There is often new information available, and we cannot afford to miss this information. The statement has been made that ordnance manuals have been written in blood. This statement is all too true.

  The reason that I have gone over differences between ordnance safety and ordinary safety is that it is unfair, and, in some cases, a serious shock for an individual at a middle to very high management position to suddenly realize that he is suspect for responsibility of an ordnance accident. It is even more of a shock if an inquiry shows that he is responsible. There have been cases of mental breakdown under such circumstances.

  An issue of the Armed Services Explosive Safety Board Publication related the case of a person who actually committed suicide when told of an accident. This man took his life because he thought he could have prevented the accident, had he been present.

2.0 BASIC RULES

There are two basic guidelines to a realistic ordnance safety program. First, no hazardous operations are to be performed. Second, any deviation from this rule must be approved by top management. Approval will normally not be given without overriding reasons, such as a national emergency or the fact that the risk taken in performing a dangerous operation is less than that involved by not performing the operation. Now with hazardous operations, I wish to mention here that I'm not including potentially hazardous operations. We have potentially hazardous operations at all times at KSC, but if we treat these operations correctly, they are not hazardous.

3.0 WHAT IS A HAZARDOUS OPERATION?

One question commonly asked is: "What is the dividing line between a hazardous and non-hazardous operation?" In other words, what constitutes a risk? This is clearly a gray area. As a rough guide, the following comments may be useful.

An ordnance operation should involve considerably less probability of injury than a normal job (such as machine shop work). Why is this? The reasons go back to some of the earlier comments. There are still unknown areas. One should assume that probabilities are somewhat worse than one calculates. Second, with ordnance, the hazard sometimes has a chain effect which can greatly enlarge the injury to people and the damage to property. The hazard involved in an ordnance operation should not even approach the hazard the individual takes in the use of local highways.

4.0 MANAGEMENT APPROACH

4.1 Determination of Responsibilities

The head of any organization will always have safety responsibilities. One of his first tasks is to have those responsibilities clearly defined, both as to extent and limitations. It is also important that his responsibilities be accompanied by authority. Where there is any doubt concerning this, it must also be clarified and correctly established.

4.2 Discharging of Responsibilities

Once the responsibilities and authority are established, the head of an organization must see that the responsibilities are discharged. This may be done by one or more of the following methods:

- He personally discharges them (normally possible only in small organizations).
- He delegates considerable responsibility to qualified subordinates.
- He contracts and provides for other organizations to assume these responsibilities.
- He gets written agreement with some Government organization to assume the responsibility.

In the latter two cases, residual monitoring responsibility must be performed to assure that the contracted or Government organization is dutifully and successfully performing its contract or agreement.

4.3 Organization

One of the functions of management is to establish an organization that can satisfactorily perform its safety responsibilities at all levels. A large organization's safety responsibilities will generally be shared between the line organization and a separate Safety Division. In a correctly oriented company, this parallel responsibility will create little friction because it arises from a need for efficiency and effectiveness.

There will generally be some people in the line or nonsafety staff organization who will have a significant portion of their time designated toward safety functions. This arises from two demands: the scarcity of highly qualified people in specialized fields of safety, and the need for some concentration of safety responsibility within line organizations. In a safety conscious organization the line organization will be asking for more help than the Safety Division can give, and the Safety Division will be eagerly requesting aid from specialists assigned to other divisions.

4.4 Leadership

The head of an organization must provide leadership in the field of safety. He must set an example for others to follow in attitude, action, and policy statements. This will directly affect his immediate subordinates and be reflected throughout the organization. He will set an example when he is present during an operation by following safety regulations and showing an active interest in safety aspects of the operation.

This same leadership function must be performed down the line through each supervisory level.

4.5 Monitoring and Probing

All levels of management have the responsibility of periodically probing and monitoring the safety requirements which they have placed on their subordinates. It is not enough to place the requirements and then say, "I have done my part." Any organization requires careful probing and testing to assure it is alive and healthy.

The head of an organization may make occasional inspections at the operating level. He will then look closely for any evidence of safety slackness. He will talk briefly with employees performing the work. He will find out if they know what their safety responsibilities are, if they understand the safety regulations which they are to follow, and if they show an interest in safety. Any weakness which he may find tells him that somewhere between top management and the working level of his organization, there is a safety weakness.

He will then take action to determine where that weakness is and to correct it. There are several approaches to this. Basically, they are standard management techniques which could apply to any problem so they will not be detailed here. Normally, training, indoctrination, or clarification of responsibilities will fix a weakness. Sometimes a transfer to a less critical position may be needed. Occasionally an employee may have to be fired.

5.0 PERFORMANCE OF DUTIES

A little thought will reveal the need for a safety organization with many safety responsibilities parallel to those of a line organization. This is due to a need for reducing the safety load on the line organization (which already has many varied responsibilities) without reducing the effectiveness of the safety condition of that organization. One of the critical functions of a separate Safety Division is to assure that a pipeline from the worker to the top management is ever present and functioning.

5.1 Training and Indoctrination

Training and indoctrination are important at all levels of an organization. Each superior must feel that it is up to him to insure that his subordinates are educated and supervised on safety.

In a certain sense, safety responsibility cannot be delegated. In a practical sense, there must be some delegation. In safety matters, as in other matters, it is important that one be careful in the choice of individuals to whom performance of safety responsibility is delegated. If a person is chosen who is not competent in the ordnance and propellant field, it must be clearly outlined to him that he must personally obtain the necessary training, or acquire (permanently or on loan) an individual who is competent to perform the necessary functions. If no one is present in an organization to do the required job, then an individual must be trained, hired, or brought in on a consultant basis.

All levels of an organization which are concerned with ordnance and propellant work must have some specialized training in ordnance and propellant safety. Supervisory personnel need such knowledge in order to select individuals to whom authority is to be delegated, to assess the magnitude of the safety problem in their area of operation, and to take adequate steps to maintain safety in their area of responsibility. Normally, there will be a basic safety course given to all employees. This will usually be arranged by the Safety Division in coordination with the Training Division and line organization. There will also normally be more specialized training courses given to those who directly handle ordnance or must work in close proximity to it. It is necessary to give occasional refresher courses as well as briefings on new changes of equipment or operations.

Indoctrination is always important at all levels. Of course, once the importance of safety is recognized, half the battle is won. An individual who is safety conscious will find out what his safety responsibilities are, he will request adequate training, he will look for problems, he will report problems, and he will solve problems. Indoctrination is important at each level from top management on down. Each supervisor must feel that it is up to him to insure that his men are educated and supervised in safety. He must simultaneously promote safety by persuasion and by force of authority.

5.2 Safety Planning

Safety planning involves a number of functions and is critical for efficient and effective operation. One of these is the early isolation of operations which require particular attention in order to be safe. Another of these is early recognition and determination of special facility and equipment requirements for safe operations. The advance recognition of a need for an increase in trained personnel, or of new procedures is important if schedules are to be safely met. A related, but somewhat different, problem is the participation in R and D phases so that safety is adequately considered in design of equipment, facilities and spaceships.

5.3 Procedures

The line organization will normally be responsible for preparation of overall procedures. As soon as they begin performing this function, they will immediately need Standard Operating Procedures for handling certain standardized safety situations. Ordinarily, they will eagerly accept those prepared by the Safety Division. Normally, the Safety Division will prepare an official handbook containing all Standard Operating Procedures and practices. This will be regularly updated.

The line organization is responsible to see that safety is adequately covered in all their procedures. Due to their many other responsibilities, the line organization personnel will inevitably lean heavily on the Safety Division (plus any specifically designated individuals in their operating section) to assure themselves that safety is adequately covered.

There are many dangers which may be visible to only a few specialists or a few individuals performing certain operations. In a "safety responsive" organization, such problems will be brought out into the open and discussed. This will normally result in the requirement that all procedures be reviewed by the Safety Division and by specifically designated specialists.

Good procedures are the cornerstone of safe operations with propellants and explosives. If well indoctrinated and trained employees are also equipped with high-quality procedures, the basic requirements for safe operations have been met. Safe equipment and facilities are also a requisite; however, good procedures can, in many cases, overcome recognized deficiencies in equipment and facilities. All operations must be performed by a procedure; all procedures must be reviewed by competent individuals; all changes to procedures must be reviewed by competent individuals. No exceptions to procedures should otherwise be permitted. This, of course, means procedures must be workable and they must be adequate.

The individual doing the work, in most cases, is not best qualified to write procedures for performing the operation. Neither is he the best for judging the safety of design. In most cases, a high-level supervisory or staff-level individual performs the final detailed review. Normally, this review will not be spread among many individuals, because very few people are competent to make such a review.

If no one is present to write the procedures, then an individual must be trained, hired, or brought in on a consultant basis. Unfortunately, there is no simple training course that will assure competence; however, the following general approach should give an individual the knowledge to draft procedures:

- Pertinent documents and manuals should be read.
- There should be a brief residence time at a facility which has similar safety problems.

- Specialists in related areas should be consulted.

With such preliminary training, an individual without previous specialized training, but with related knowledge, may be in a position to recognize many safety problems and to draw up rough procedures. When reviewing rough procedures, an individual recently trained in ordnance safety should ask the advice of experienced individuals working in related fields.

Once these procedures are developed, there is no substitute for the trained individual observing the procedure in detail during its first use, preferably on inert ordnance. Some revisions will normally result. This same walk-through is also a good time to have consultant assistance. Once safe ordnance procedures have been developed, it follows automatically that they should not be carelessly changed for format or similar purposes. In many cases, sequence is critical.

It is the responsibility of the supervisor in charge of an operation to check that procedures are being followed and that any unexpected problem is not treated with a makeshift procedure. If the individual performing the job deviates knowingly from a procedure, without permission of his supervisor, he will generally be considered personally responsible. This is so, provided he has been carefully indoctrinated in the importance of rigorously following procedures and provided the procedure was reasonable to follow.

If an accident results from a mistake in a procedure, those reviewing the procedure may bear responsibility. This will not be true if it is an unrecognized problem which an expert in the field would not have foreseen. Unfortunately, hindsight is often much clearer than foresight. This statement alone shows the importance of careful development and review of all ordnance procedures. If an individual writing the procedures is not qualified to do this job, his supervisor may be held responsible. This responsibility may reflect completely up the line unless each individual from the top to the bottom has been made clearly aware that no hazardous operations are to be performed. Only top management can make exceptions, and only qualified people will, therefore, review procedures. This might be considered, thus, as a third rule, although it is a result of application of the first two.

Accidents may result during an operation that is not recognized as an ordnance operation. It is thus clear that any operation performed around or near a motor, igniter, detonator, squib, or explosive charge or related device be examined for possible ordnance implications by a qualified individual or individuals. Procedures which are not at first thought hazardous may in actuality be quite dangerous. A thorough review may reveal that they have to be reclassified or changed to make them non-hazardous. This, of course, should occur before they are performed the first time, not in retrospect. The same sequence of responsibilities holds here as it does for a clearly definable ordnance operation.

5.4 Monitoring of Operations to Detect Safety Problems and to Determine that Safety Procedures are being Adequately Performed

There will always be a need for repeated surveillance of operations to detect unrecognized safety problems and to determine that safety portions of procedures are being adequately performed. This, again, is a joint responsibility between line and safety organizations. It is normally desirable to make dry runs of any new procedures. In these cases, safety monitoring is particularly important.

In certain operations, safety factors require a member of the Safety Division in constant attendance to ascertain that all safety precautions have been met.

5.5 Technical Liaison with Internal and External Organizations on Safety Matters

Close and early technical liaison on safety matters between all external and internal organizations involved is important. Geographic and distance barriers should not be allowed to stifle such interchange.

It is necessary that the line organization and Safety Division be in close communication. In large organizations this generally involves certain individuals in the Safety Division being constantly employed as mutual contacts. These individuals may sometimes be assigned to specific areas or buildings.

5.6 A Source of Assistance and a Depository of Information on Safety Matters

The Safety Division and certain specialists in the line department will normally perform this duty, which is self-explanatory in nature.

5.7 Facilities and Equipment

The design of new facilities, new equipment, and tools should receive the same careful safety review as do new operations. Designers should remove the human factor from hazards by making protection as permanent and as automatic as possible.

Adequate maintenance from a safety viewpoint is also a requisite. This is a joint Safety Division and a line organization responsibility.

5.8 Reporting Accidents

The facts associated with any accidental fire, deflagration, or explosion must be reported completely and accurately so that others doing similar work may be warned, and so that the best corrective action may be taken to prevent similar accidents.

Minor incidents, which in themselves do little or no harm, frequently give warnings of unsuspected hazards. These incidents should be widely reported and their significance given thorough consideration.

It is the duty of the line organization to see that all the facts are provided to the Safety Division. Normally, the Safety Division will also investigate as well as record such accidents and spread the results throughout the organization to other areas which may be affected. The Safety Division and line organization will normally share responsibility for developing preventive measures.

5.9 Individuals

Each employee must be indoctrinated to think of safety constantly, as this is the only way in which injury-free performance can be realized. It is impossible to bring about a fool-proof physical environment and set of rules; a setting in which no injury can happen. Personal safety depends on sincere safety-mindedness and good judgment on the part of each individual; not at occasional intervals, but continuously as an integral part of daily activity.

Safety-consciousness of most new technical employees needs to be developed. It is commonplace to find many shades of fatalism, exemplified in such pat expressions as "accidents are bound to happen." These are simply rationalizations for indifference or bravado. Most injuries are caused by specific carelessness or poor judgment on the part of someone. Each individual worker must be the major factor in his own safety and that of his neighbor. Every individual in the organization has safety responsibilities; these may vary greatly in magnitude. If every individual understands his responsibilities and discharges them in an effective and efficient manner, a safe organization will result.

6.0 ACCIDENT RESPONSIBILITY REACTION

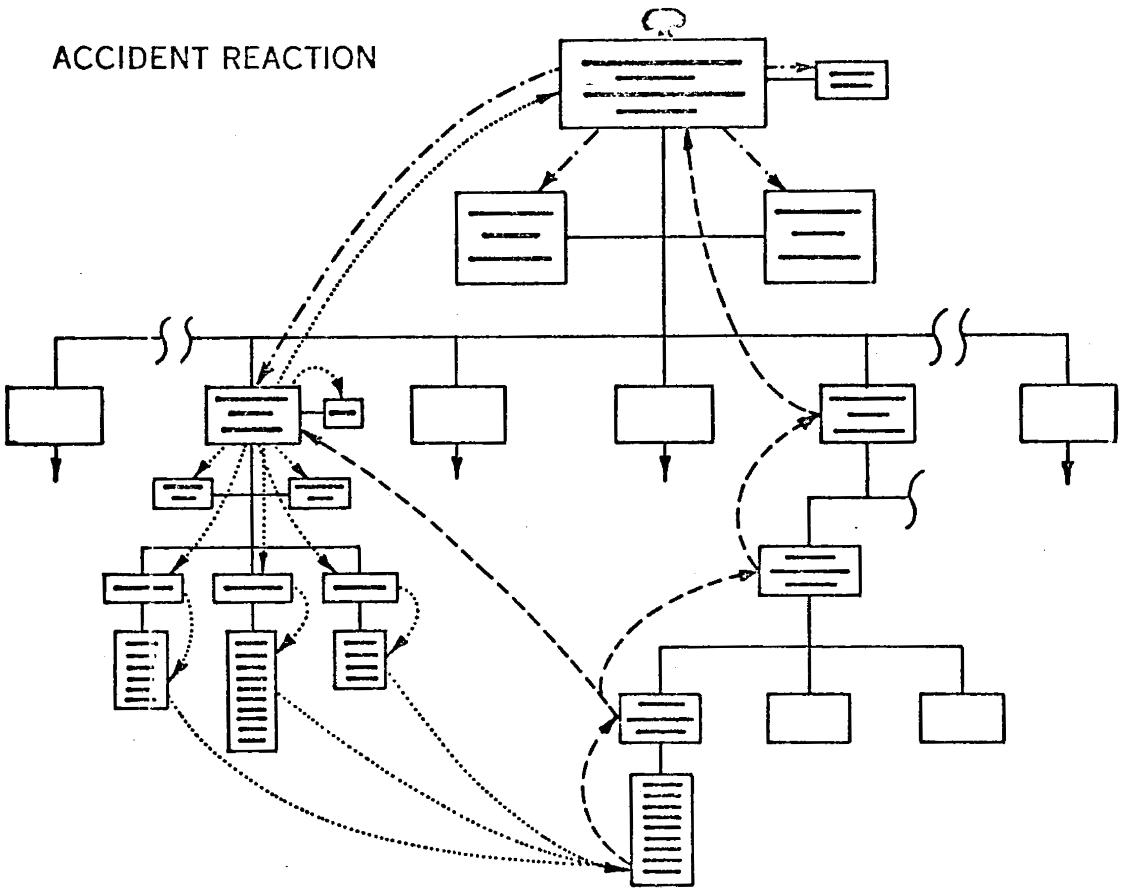


Figure 1-1

The above figure shows how an accident can reflect throughout an entire organization. You are not safe anywhere in the organization. There are many other responsibility connections besides those shown; anyone in an organization may become involved. For any who have not been in on the reporting and investigation of accidents, I can assure you that it is very serious, consumes a great amount of time, and there is an enormous amount of paper work involved.

7.0 CONCLUSION

Top management has heavy responsibilities in the field of Ordnance and Propellant Safety. These cannot be dodged. One cannot trust "luck." Their discharge is largely by the application of standard management techniques, but even management needs some specialized technical information. The remaining lectures are designed to give this technical information.

Inadequate safety can lead to horrible loss of life, enormous rebuilding costs and costs due to delay of programs, and even possible cancellation of projects. One accident can greatly exceed the cost of a good safety program.

Ordnance and Propellant Safety must be an integral part of engineering operations. Top management is responsible for seeing that everyone understands and discharges his responsibilities.

Lecture Number One

"TOP MANAGEMENT RESPONSIBILITIES"

Part II

Mr. L. T. Dombras

N67-15983

1.0 INTRODUCTION

KSC is one of the most publicized areas in the world, and one which probably will be involved with the greatest aggregate of potential hazards conceived by modern man. In considering the accident rate at KSC, it is a tribute to the KSC Accident Prevention Program to know that one is safer at work than at home.

Management must be concerned with safety. This concern is not based on self-survival or humane considerations alone. Rather, it is because management realizes that accidents interfere with program schedules and are extremely expensive in dollars, equipment, and in some cases, the loss of skilled personnel. This may seem to be a very cold and dispassionate viewpoint; however, it is a position which substantiates the funding for safety engineering.

2.0 MISSION 70

Recently the President of the United States appealed to Federal Agencies to reduce the carnage and disabilities which have cost our space program considerable time and expenditures. As a result, a program was initiated entitled "Mission 70". The purpose and the objective of "Mission 70" is to reduce the injury frequency rates of all Federal Agencies to at least 70% of the 1963 figures by 1970.

During 1963, the injury frequency rate for KSC was 2.78 disabling injuries for every million manhours worked. Your "Mission 70" target is to reduce this figure to 1.95 injuries per million manhours. This is quite a target for your organization because increasingly more hazardous operations will occur with the larger and more complicated space programs forecasted for KSC.

During President Johnson's speech concerning "Mission 70," the following statistics were presented:

OCCUPATIONAL ACCIDENT STATISTICS

	FEDERAL 1958-1964	NATIONAL ANNUAL RATE
DEATHS	1,200	13,800
DISABLING INJURIES	300,000	1,960,000
LOST MAN-DAYS	18,500,000	235,000,000+

Figure 1-2

3.0 INDUSTRIAL ACCIDENT PROGRAMS

In 1963, the cost to all Government Agencies as a result of injuries was 36.6 million dollars. From 1958 to date, the total cost of accidental injuries is estimated to be in excess of $1\frac{1}{4}$ billion dollars. Staggering as these statistics are, it is a fact, based upon the accomplishments in every major branch of industry, that practically every one of these accidents could have been prevented by dynamic safety organizations enjoying complete support and the backing of top management.

- Since 1926, National Safety Council data shows that occupational accidents in all industries were reduced to values approaching zero.

- The expenditures required to insure a good safety program are extremely small as compared with the cost of accidents. Imagine how much of the $1\frac{1}{4}$ billion dollars, mentioned above, could have been saved if safety offices were provided with more trained personnel and safety educational programs.

- Some degree of hazard is associated with every operation. A perfect safety program, that is one with no accidents, can only be achieved by giving meticulous attention to every form of activity that is carried on.

- Injury prevention does not require special theories or highly technical skill but depends to a great degree on "safety mindedness." This "safety mindedness" may be defined as a constant active attention to safety in every detail, every day, on the part of every individual involved in every manner.

- Any management, regardless of the size of the business or type of industry, can eliminate almost all injuries. Safety is your business, and it is one of your management responsibilities. Your obligation to your employees is that their safety should not be sacrificed or jeopardized in any way.

- Most injuries result from faulty equipment or hazardous operations. If you correct either of these causes, you may prevent injuries. Faulty behavior can be covered by training and creating the "safety mindedness" among your workers. However, minimum injury rates can only be achieved by reducing the physical hazards associated with your area of jurisdiction.

- Off-the-job accidents should be reduced. The gains scored by industry in this particular area have been significant. Promotional activities directed toward lessening off-the-job accidents have proven very worthwhile.

3.1 Industry and the KSC Safety Program

How does the KSC Safety Program compare with industry? KSC operations appear to combine the work conducted by practically all industries: chemical, manufacturing, electronic, aircraft, construction, and the toy industry. The spacecraft and booster programs involve many potentially hazardous operations interrelated into a very complex pattern. In industry, the guidelines and functions of the safety supervisors are generally clearly defined and the interfaces are capable of orderly analysis. KSC's operations with booster systems and space vehicles are continually changing from launch to launch and from program to program.

4.0 KSC SAFETY PROGRAM

KSC operations are complex and involve many operations which are potentially dangerous. The Safety Office is responsible to the Director (KSC) for control of the overall safety program performed by NASA or its contractor personnel. Specially trained representatives implement all safety aspects of operational and launch activities, industrial activities, explosives, accident prevention, traffic safety, etc.

The KSC Accident Prevention Program is basically executed by the Safety Office. Basic responsibilities and final authority on all matters of safety during operations performed by NASA and its contractors are assumed by the KSC Safety Office. The task assigned to your Safety Office is enormous -- the responsibilities are terrifying and the personal rewards are negligible. When things go right, the Safety Office is doing its job; but if accidents occur, the wrath of higher management descends upon the Safety Office. To a great degree, pure luck and chance play a big factor in the Accident Prevention Program.

4.1 KSC Safety Office

The function of a Safety Office is to develop safety standards, safety criteria for launch operations, and to provide engineering services in industrial explosives and operational safety. In addition, safety personnel conduct surveys and evaluate accidents and conduct safety training and promotional activities. The work assignments cover many many areas over a relatively large geographical area. In a recent study conducted by STL, we found that the Safety Office is not adequately staffed with a sufficient number of personnel to cover all areas of hazardous operations anticipated during 1965. Recent Government policies, resulting in a freeze on the number of personnel which KSC may acquire, may necessitate acquiring additional help through the contractors, and certainly the help of managers.

5.0 MANAGERS' RESPONSIBILITY

Top management's responsibility is to approve, sanction, and support the Safety Office. Without this support, the safety organization will disintegrate and become ineffective. Accident prevention is a good, sound business policy. As managers, you must also assist in safety promotion, educational activities, and training programs.

Every supervisor has personnel working directly for him who are involved in some form of physical activity. Since some degree of hazard is associated with every form of activity, the highest degree of injury prevention can only be achieved by insuring the safety of every operation in each assigned area of supervision. These areas may not appear hazardous, but remember, accidents do not require explosives, propellants or dangerous materials. And accidents don't just happen -- they are caused. How can management prevent accidents? Simply by creating a safety awareness among the entire work force. The large number of personnel working at Cape Kennedy cannot be monitored at all times by a small force of Safety Office personnel. All personnel must help to eliminate the causes of accidents.

As managers, you must back up your Safety Office in all operations and respect their responsibilities. Your efforts will be rewarded if you practice the following rules:

- Back up the Safety Office in all operations.
- Provide approval, sanction, and support.
- Aid in safety promotion.
- Create safety awareness.
- Assume safety responsibility as part of management.

6.0 NASA'S SAFETY RESPONSIBILITIES

The responsibilities of NASA Headquarters as outlined in the Management Manual, Chapters 2 and 23, are the overall direction of the NASA Safety Program. The NASA Safety Office at Headquarters is responsible for the overall direction of the NASA Safety Program. The instructions outlined in the Management Manual apply to NASA Headquarters and all its field installations. These instructions are relatively broad in treatment and general in nature, thereby allowing each field installation to develop its own safety program to meet the specific needs for problems which arise at each location.

In studying the NASA program, STL found that there is a very logical plan and Safety Accident Prevention Program. This plan is very adequately described by a story told by Dr. John Furbay, a noted lecturer. Dr. Furbay describes a bug which was born in the world's most expensive and beautiful persian rug.

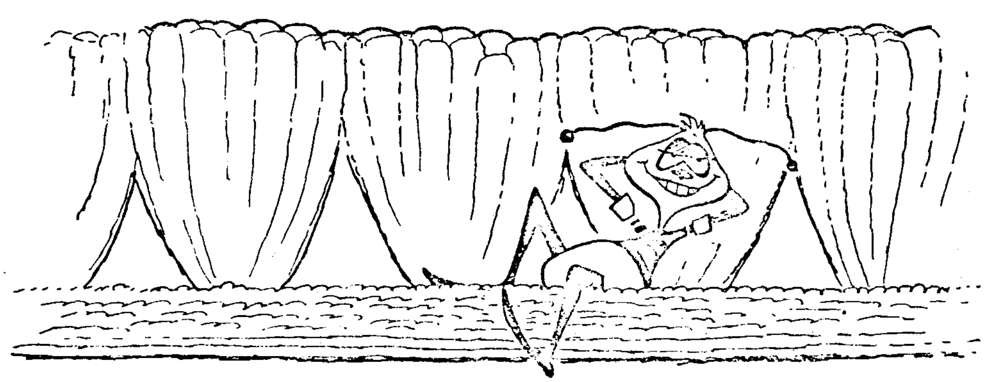


Figure 1-3. THE RUG BUG

This bug in the rug spent his entire life scampering around between the fibers eating crumbs and finally, after a very full life, it died. That bug lived in that rug all of its life, yet it died never realizing that it had lived in a pattern, a magnificent design. You cannot live like the bug in the rug. You must learn the pattern and your particular responsibilities in that pattern.

The overall design of the NASA Safety and Accident Prevention Program starts right at the top at NASA Headquarters in Washington. It is outlined in NASA Management Manual, Chapter 23, Instruction 23-1-1A.

The responsibilities of Headquarters are:

- Overall direction of NASA Safety Program.
- Development of basic policies and standards.
- Evaluation of program effectiveness.

7.0 POLICIES - NASA SAFETY ACCIDENT PREVENTION PROGRAM

The NASA Safety Office is responsible for the overall direction of the NASA Safety Program. Headquarters is responsible for the development of basic policies and standards with regard to the Safety Program at each field installation, and is also responsible for evaluating these programs with regard to effectiveness in order to reduce the number of accidents and injuries among Government Officers and employees. Final authority at the top management level is assigned to the Associate Deputy Administrator of Administration. Policies and the NASA Safety Accident Prevention Program are outlined in the NASA Management Manual. Instructions apply to all field installations including KSC. Instructions in the NASA Management Manual outline the following basic policies for the NASA Safety Accident Prevention Program:

- Ensure safety of NASA and contractor employees.
- Avoid delay of NASA programs due to accidents.
- Prevent damage to property and equipment.
- Assure proper protection of the public.
- Provide risk and loss factor data.

The preceding policies are to insure the safety of NASA and contractor employees during their work on NASA programs. In addition to these policies, NASA Headquarters also requires safety rules and guides for the prevention of injuries, accidents, and destruction to property. Uniform safety standards are broad in scope and place limits upon the following:

- Design and construction of equipment, facilities, and buildings.
- Procedures for the performance of hazardous operations.
- Standards for industrial hygiene.
- Standards for safety and related requirements in contractual clauses.
- Accident and injury investigation reporting.

8.0 KSC SAFETY RESPONSIBILITIES

The John F. Kennedy Space Center safety responsibilities are to develop a Safety Accident Prevention Program in accordance with NASA instructions. These responsibilities are:

- Develop a safety and accident prevention program.
- Provide leadership in accident prevention.
- Accident investigation and reporting.
- Ensure safety of all operations and facilities at KSC.

These instructions require that you provide continuous leadership in the prevention of injuries to personnel and damage to equipment and facilities. You must have the capability of reporting, investigating, and following-up action on accidents involving all persons on or near NASA installations, and you are to insure the safety of all operations and facilities used by NASA installations or its contractors working at these installations. When facilities at one installation are being utilized by one or more contractors or one or more NASA organizations, the resident director shall be responsible for the safety of all operations and facilities in such cases. These responsibilities and the guidelines by which they are carried out are being executed by the KSC Safety Office. They require your help if an accident-free program is to be achieved.

9.0 KSC SAFETY PROGRAM INTERFACES

The nature of the work at KSC requires numerous groups, agencies, and contractors working closely together under potentially hazardous conditions.

9.1 Contractor - KSC

Since KSC is responsible for the safety of all operations at the Space Center, the work performed by contractors must be monitored and the contractor's safety responsibility must be defined.

9.2 NASA Tenant Organizations

Practically every operation planned for KSC will involve several NASA organizations. Each one is responsible for specific portions of the launch program and each agency is responsible to its personnel for safety. However, KSC and the Director are responsible for the overall operations with regard to safety. It is important that tenant NASA organizations understand their responsibilities and that every effort be made to insure adequate coverage of all aspects of launch programs.

9.3 Internal KSC Groups

You, as managers, in dealing with the contractors, must interface with the KSC Safety Office and insure adequate protection of all NASA and contractor personnel working in your jurisdiction.

During some operations, several NASA organizations will be working concurrently on the space vehicle or booster system. In these instances the guidelines should be clear and well defined.

9.4 AFETR - KSC

Joint responsibilities exist between DOD - NASA; these interfaces are defined in the DOD/NASA (Webb-McNamara) Agreement, dated 17 January 1963, and subsequent jointly sponsored amendments.

SUPERVISORS' SAFETY CHECK LIST

Here are some items which you should consider during your normal work day and which should help reduce accidents to you and personnel working for you:

1. Accept safety as part of your job.
2. Recognize the relationship of good safety and good management.
3. Give good safety instructions to new employees.
4. Make known to all that you will deal harshly with chronic violators.
5. Provide safety equipment.
6. Form and assist safety meetings.
7. Investigate every accident and every incident.
8. Provide proper training.

TABLE 1

SOME DISASTERS INVOLVING PROPELLANTS AND/OR EXPLOSIVES
(EXCLUDING MINE EXPLOSIONS)

1917, December 6 - Halifax, Nova Scotia, Canada.
Explosion of war materials and fire; over 1,500 killed; 4,000 injured; 20,000 homeless; property loss $35,000,000.

1921, September 21 - Oppau, Germany.
Explosion of ammonium nitrate kills about 600 persons.

1937, March 18 - New London, Texas.
Natural gas explosion destroys schoolhouse; 413 children and 14 teachers killed.

1939, March 1 - Osaka, Japan.
Huge munitions dump explodes, wiping out village; 500 killed and injured: 300 houses destroyed: 8,313 homeless.

1939, July 10 - Penandara de Bracamonte, Spain.
Approximately 100 killed; 1500 injured; town demolished in explosion of munitions factory.

1941, June 8 - Smederevo, Yugoslavia.
Ammunition plant explodes; killing 1,000 and demolishing most of town.

1942, May 1 - Tessenderlo, Belgium.
Explosion in chemical works kills 250 workers, injures 1,000.

1944, April 14 - Bombay, India.
128 die in ship fire which causes explosion in ammunition dump; 1,000 injured.

1944, July 17 - Port Chicago, California.
Explosions at two ammunition dumps kill more than 300.

1947, April 16 - Texas City, Texas
Explosion of French vessel GRANDCHAMP destroys most of city; more than 500 dead or missing.

1947, August 20 - Cadiz, Spain.
Three hundred to 500 killed in explosion of shipyards.

1948, March 9 - Tsingtao, China.
Explosion of ammunition storehouse kills at least 200; several hundred injured.

TABLE 1 (cont'd)

1948, July 28 - Ludwigshafen, Germany.
Explosions and fire wreck chemical works of I. G. Farben Company; some 200 killed and several thousand injured; damage $15,000,000.

1948, September 22 - Hong Kong, China.
Fire and chemical explosion in warehouse; 135 killed, 57 injured.

1953, October 16 - Boston, Massachusetts.
Explosion and fire aboard U. S. aircraft carrier LEYTE kills 37, injures 40.

1956, August 7 - Cali, Columbia.
Seven trucks carrying dynamite explode; dead estimated at 1,100.

1958, June 23 - Santa Amaro, Brazil.
Fireworks explosion causes about 100 deaths.

1960, March 4 - Havana, Cuba.
French munition ship blows up, killing 75 - 100 and injuring 200.

Reference: Encyclopedia Americana

N67-15987

Lecture Number Two
"EXPLOSIVES AND PROPELLANTS IN ACTION"
Part I
Mr. J. Larks

1.0 THEORY OF DEFLAGRATION AND DETONATION

Before any discussion of explosives can be undertaken, the meanings of at least three words must be clearly understood: explosion, deflagration, and detonation.

1.1 Explosion

Explode - (ĕks·plōd′)

General: To cause to burst noisily.

Explicit: The sudden release of pressure in which a shock wave is created.

An explosion is a result, not a cause or a chemical reaction in itself. The pressure which causes an explosion may be built up gradually or rapidly. If the pressure is built up gradually, it must be in a confined volume to cause an explosion. The explosion of a steam boiler is a good example of pressure buildup in a confined volume; the explosion occurs when the container ruptures.

Many highly reactive chemicals can cause an explosion. The burning of powder in an artillery round is an example of rapid buildup of pressure in a confined volume. When the firing pin detonates the primer of a shell, the reactive material (powder) in the case liberates hot gases. As the gases expand, they force the projectile through the barrel of the gun. When the projectile leaves the barrel, the pressure is released suddenly and an explosion occurs. Note that the explosion is NOT the reaction, but the release of pressure.

Extremely reactive chemicals can cause an explosion in unconfined areas. In this case, the chemicals build up pressure faster than it can be dissipated to the surrounding atmosphere; the atmosphere, rather than a solid object or container, acts as the confining agent. Explosions, therefore, are dependent upon reaction rate and a size effect or scale.

1.2 Deflagration

Deflagrate - (dĕf′la·grāt)

General: To cause to burn away with sudden evolution of flame and rapid, sharp combustion.

Explicit: A chemical reaction producing vigorous evolution of heat and sparks or flame and moving through the material at a speed less than that of sound.

Deflagration is an exothermic reaction, that is, heat is liberated during the process. The exothermic reaction may be decomposition, oxidation, or combustion and the most familiar example of deflagration or flame is commonly termed burning. Deflagration can cause an explosion if the process is confined and causes a rapid pressure buildup. In the determination of deflagration, the important factor is the reaction rate. To visualize and define the mechanism of deflagration, the flame is defined as standing still with the fuel or unreacted material flowing into the flame and the products or reacted material flowing away from it. The rate at which the unreacted material or fuel flows into the flame is termed the burning velocity. Many mixtures and fuel materials have characteristic burning velocities which are dependent on temperature and pressure. Burning velocities of gases range from a few centimeters per second to about one meter per second.

When certain materials, termed explosives, are subjected to rapid increases in temperature, a temperature level is attained where volatilization from the surface, prior to the reaction of the material itself, creates heat resulting in a self-sustaining reaction. This temperature level is termed the "ignition temperature" of the material; it is at this point that deflagration begins. Deflagration can be termed a diffusion phenomenon, (similar to the spreading of an odor in still air).

Explosives may be divided into two classes; low explosives and high explosives. Pyrotechnic mixtures and loose black powder are termed low explosives and will undergo violent deflagration when sufficient heat is generated. Nitrocellulose materials ordinarily undergo rapid deflagration but, if confined, this can become detonation. Lead azide, termed a high explosive, will not deflagrate but will detonate even at one atmosphere pressure. TNT (trinitrotoluene) will deflagrate when loosely confined; however, if its confinement is such that high pressures are developed, this initial deflagration will be followed by detonation. Nitroglycerin, also termed a high explosive, will deflagrate at ordinary pressures in small quantities; however, the deflagration will produce a large amount of the heat and, detonation ensues if larger quantities are present. In large quantities, even ammonium nitrate (a very insensitive material) can be caused to detonate if confinement is such that high pressures can be developed during deflagration. An example of rapid deflagration is burning of a solid propellant retro rocket. The star-shaped core affords a large initial surface area which increases the mass burning rate ($\dot{m}$).

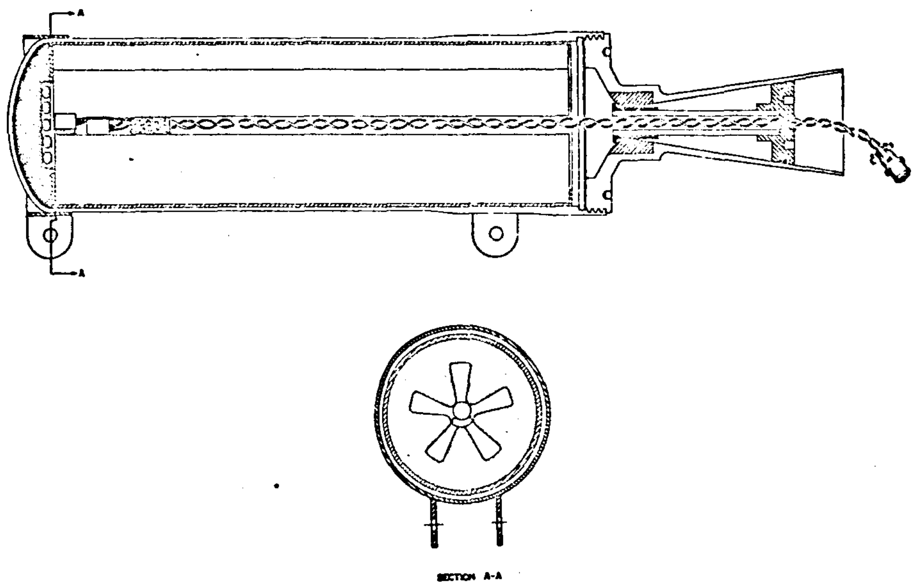


Figure 2-1. RETRO ROCKET

Thrust is kept approximately constant by maintaining an essentially constant surface area presented to the flame front from ignition through to depletion.

1.3 Detonation

Detonate - (dĕt′ŏ·nāt)

General: To producé a loud noise by the sudden liberation of gas in connection with chemical decomposition or combination; to explode with sudden loud report.

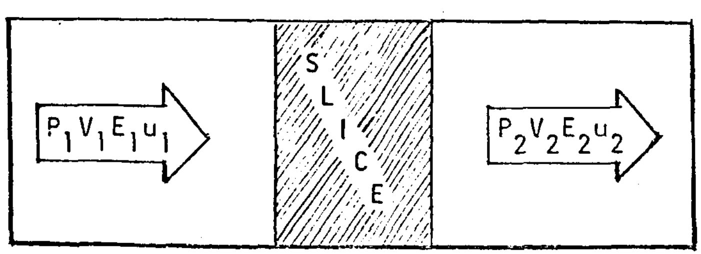
Explicit: A chemical reaction producing vigorous evolution of heat and sparks or flame and moving through the material detonated at a speed greater than that of sound.

A detonation can be differentiated from a deflagration by comparison of the manner in which the products flow and the rate, or speed, of the reaction. Detonation can be considered a wave phenomenon similar to the propagation of sound while deflagration is a diffusion phenomenon. In a detonation, the products or reactive materials flow toward the area of the reaction; in a deflagration this is opposite, that is, they flow away from the reaction. The speed of propagation of the reaction is faster in a detonation than the characteristic speed of sound in the material; the detonation being carried forward on the crest of the shock wave. A deflagration, with sufficient confinement and buildup, can become a detonation; however, the inverse cannot occur. Due to the formation of the shock wave and the sudden release of pressure, a detonation is always associated with an explosion; however, an explosion is not always due to a detonation.

To visualize the mechanism of detonation, the shock wave is frozen in time and considered to be standing still. A slice of the material containing the wave front of the shock wave is considered. Matter under exact conditions of pressure, specific volume, specific energy, and a particular velocity stream into this slice; however, the matter emerges from the slice under different conditions of pressure, velocity, specific volume and specific energy.

The hydrodynamic theory of detonation is the result of much research and its theoretical application. This theory is based on the known characteristics of shock waves and uses the chemical theory of absolute reaction rates.

The three laws of conservation of mass, energy, and momentum are used to establish three equations relating to the five variables; pressure, density, temperature, detonation rate, and transitional rate of the gaseous molecules of the reaction products.



EQUATIONS OF MOTION FOR A ONE DIMENSIONAL CASE

MOMENTUM $$\rho_o \frac{\partial u}{\partial t} = - \frac{\partial P}{\partial x}$$

ENERGY $$\frac{\partial E}{\partial t} - \frac{\partial Q}{\partial t} + \frac{\partial V}{\partial t} = 0$$

MASS $$\rho_o \frac{\partial V}{\partial t} = \frac{\partial u}{\partial x}$$

t = time

ρ_o = initial density

u = particle velocity

P = pressure

E = energy

Q = heat added per unit mass

V = specific volume

X = distance

x = LaGrange coordinate

$$\frac{\partial X(x,t)}{\partial x} = \rho_o V(x,t)$$

Figure 2-2

These laws express the following facts:

- Conservation of Mass

  The mass flow rates into and out of the slice are equal.

- Conservation of Energy

  The difference between the total energy, internal and kinetic, into and out of the slice, is equal to the net worth work performed by the gas.

- Conservation of Momentum

  The rate of momentum change in the slice is equal to the difference in pressure.

EQUATION OF STATE

$$pv = nRT + a(v)p$$

where:

p = pressure

v = volume

n = constant

R = gas constant

T = temperature

a(v) = average covolume

Figure 2-3

The equation of state is derived using the values shown in Figure 2-3 and a fifth equation is obtained by applying a physical principle. This principle states that a shock wave passes through a gas with a velocity equal to the sum of the translational velocity of the gas, plus the velocity of sound in the gas at its final temperature and density. By solution of the five simultaneous equations, the characteristics of a given explosion can be calculated.

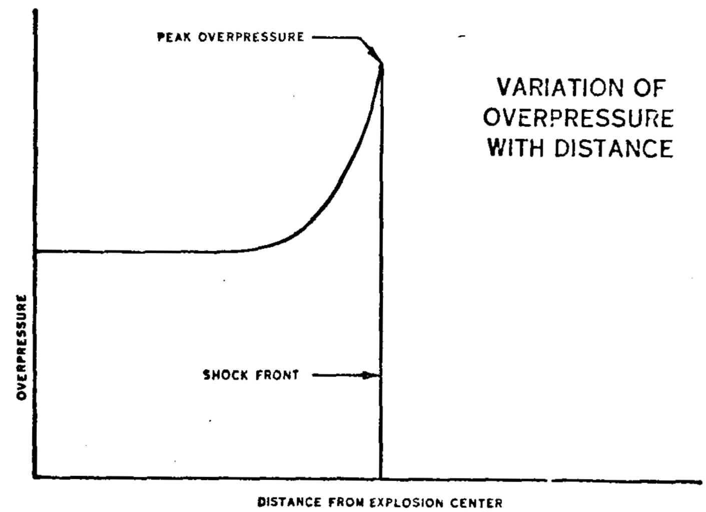


Figure 2-4

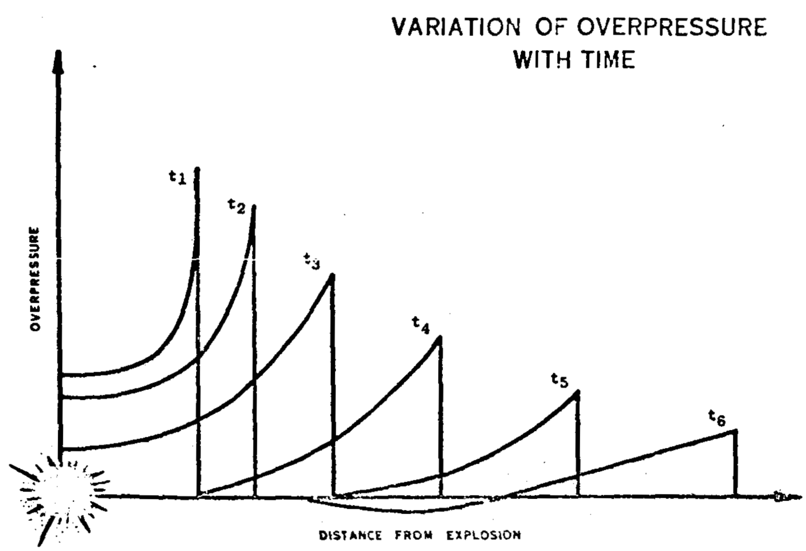


Figure 2-5

What are shock waves and how do they occur? Figure 2-4 depicts an idealized shock wave created by a sudden expansion and increase in pressure having taken place at the 0 point of the coordinate system. Time is not considered in looking at an isolated shock wave, but referring to Figure 2-5 it can be seen that with increasing time, as shown by numerically increasing subscripts on the t parameter, the shock wave essentially retains its basic shape as it moves out from the source center but steadily diminishes in peak overpressure values until, at some distance from the source--and together with some related time T, the wave will have been reduced to a negligible overpressure.

From the information obtained through the hydrodynamic theory, a mechanism of detonation can be visualized. After the detonator functions, a detonation zone, in which the chemical reaction is taking place, travels through the column of explosive.

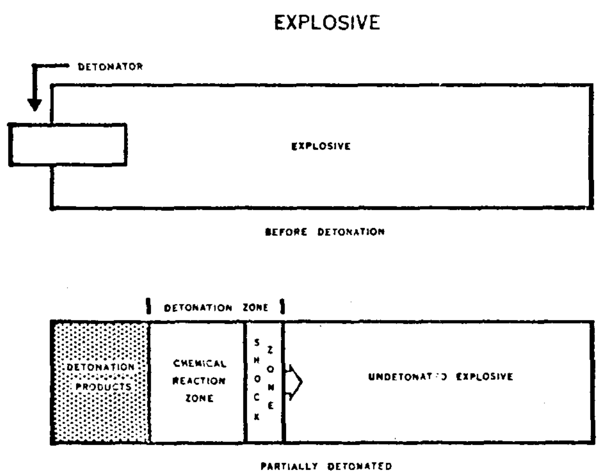


Figure 2-6

This detonation zone is generally considered to include a very narrow shock zone (10^{-5} cm) or shock wave. Little or no chemical reaction occurs in this shock zone, but the pressure reaches its peak. The detonation zone includes not only this shock zone, but also the chemical reaction zone (0.1-1.0 cm). Following this detonation zone are the detonation products. In front of the shock zone is the unreacted explosive in its original state of density, pressure, velocity, and temperature. At or near the beginning of the chemical reaction zone, the high temperature to which the material is raised by compression in the shock zone initiates chemical reaction. Maximum density and pressure occur at the beginning of the reaction zone, while the temperature and reaction rate reach their peaks at the completion of the chemical reaction. The detonation products flow with great velocity, but of lesser degree than the velocity of the detonation zone, toward the undetonated explosive. This is characteristic of detonation in contra-distinction to deflagration, in which case the reaction products flow away from the unreacted material. The velocity of advance of the detonation zone is termed the detonation rate.

As each individual molecule of explosive undergoes ordinary thermal reaction, starting with a low initial temperature, there is a lag effect or induction period that depends exponentially on the reciprocal of the initial absolute temperature. With an initial temperature of 725°C, the induction period is of the order of 10^{-5} second. With high initial temperatures, it appears that the last 75 percent of the reaction requires only about 10^{-11} second.

EXPLOSIVES

DETONATION CHARACTERISTICS

	Loading Density G/ML	Temperature °C.	Pressure 10 ATM	Detonation Rate M/Sec
Nitroglycerin	1.60	5,370	1.99	8,060
Tetryl	1.50	4,480	1.48	7,125
TNT	1.50	3,600	1.10	6,480
Ammonium Nitrate	1.00	1,350	0.25	3,420

Figure 2-7

N67-15985

Lecture Number Two

"EXPLOSIVES AND PROPELLANTS IN ACTION"

Part II

Dr. G. J. Bryan

1.0 INTRODUCTION

The behavior of propellants and explosives can be explained by a few basic ideas. Most of these are relatively simple, as so many important things are. In spite of their simplicity, only a few people fully use these basic ideas in their thinking and work.

2.0 DEFINITIONS

2.1 Webster's Definitions

- Burn

  To be on fire; to give forth light and heat - and eleven other meanings.

- Deflagrate

  To burn with sudden and sparkling combustion; to burn or vaporize suddenly.

- Explosion

  A violent bursting with noise, as in the case of explosives.

- Detonate

  To explode with sudden violence.

2.2 Scientific Definitions and Discussion

- Exothermic Reactions

  An exothermic reaction is one in which heat is released. In a fire, deflagration, or detonation, exothermic chemical reactions are always involved.

- Burning, Combustion, and Deflagration

  Burning and combustion are equivalent terms used to describe the process by which fires and deflagrations progress. These processes are generally limited to those in which heat is transferred from the hot zone to the reactants by convection, conduction, or radiation. There is no clear dividing line between a fire and a deflagration, since the difference is purely one of rapidity or violence.

- <u>Explosions</u>

An explosion is a sudden release of pressure. It is a result, not a cause in itself. A fire or deflagration may cause an explosion if sufficiently confined. A detonation is always an explosion, but not vice versa.

- <u>Detonations</u>

In a detonation, the reactants are heated by the adiabatic compression resulting from a shock wave. This heated zone then reacts rapidly enough to maintain the shock wave. Clearly, the reactants must be premixed. Strictly speaking, a detonation may be limited to those processes in which a shock wave of steady velocity is maintained. Some reactants may detonate at either of two different velocities. It is important to note that shock waves are rapidly attenuated in non-reactive media.

A shock wave is a strong pressure disturbance which is progressing through a material at a velocity greater than the velocity of sound in that material. The velocity of sound may be described as the velocity at which a weak pressure disturbance progresses in a material. This velocity is a constant at constant temperature of the material, but a shock wave may cover a wide range of higher velocities. The ratio of the shock-wave velocity to that of sound is called Mach number.

See Figure 2-7 below for a comparison between detonation and deflagration.

DEFLAGRATION		DETONATION
	HEAT TRANSFER	
CONDUCTION CONVECTION RADIATION		ADIABATIC COMPRESSION BY STRONG SHOCK
	SHOCK WAVE	
NO INTERNAL		ALWAYS INTERNAL
POSSIBLE EXTERNAL		ALWAYS EXTERNAL (except in vacuum)

Figure 2-8

- <u>Fuels and Oxidizers</u>

Combustion is often explained as being the chemical combination of a fuel (reducing agent) and an oxidizer.

An oxidizer may be loosely defined as a substance containing an excess of oxygen or halogen, with fluorine and chlorine being the most useful halogens.

Fuels may be loosely defined as substances containing carbon, hydrogen, and light metals. In many cases, this classification is unsatisfactory, particularly when both type radicals are contained within one molecule. Such borderline cases can generally be squeezed into a related classification of "oxidizer rich" or "oxidizer poor." An oxidizer-rich compound will decompose into compounds of which one or more will definitely be an oxidizer. An oxidizer-poor compound will decompose into compounds of which one or more will definitely be a fuel.

- Specific Impulse (I_{sp}) and Exhaust Velocity (c)

Specific impulse is a measure of propulsive effectiveness of a propellant. This is best expressed in units of lb_f - sec/lb_m, which has a direct physical interpretation. The effective exhaust velocity can be considered as the velocity of the exhaust products which have had an equivalent force applied to them per unit mass for one second, since one lb_f/lb_m will impart an acceleration of g ft/sec^2;

$$c = I_{sp}\, g \,, \quad \text{where c is in ft/sec.}$$

Note that this effective velocity has hidden within it corrections so that only the longitudinal component of the velocity vector of a nozzle with a given expansion angle is included, and also a correction for any differences in exit pressure and external ambient pressure is also included.

Using these cefinitions, the gain in a rocket's velocity for gravity and drag-free space becomes:

$$\Delta V = I_{sp}\, g \ln \left[\frac{\text{initial mass}}{\text{final mass}}\right]$$

(where the change in mass is due to propellant combustion). I_{sp} is often defined for convenience in computations as a constant, equal to the I_{sp} under vacuum conditions, plus a variable which is a function of the external ambient pressure.

3.0 DAMAGE ASSESSMENT

3.1 Total Mass

The mass of a propellant or explosive is a good measure of its maximum hazard potential under worst case analysis. This is generally reflected in the design of areas where they are handled. Of course, equal masses of explosives and propellants are not necessarily of equal maximum hazard potential. Solid propellant motors will generally bear a classification of either military Class 2 or Class 9 or the equivalent Classes B and A (Type 3) for ICC usage. The principal differences between these classes is in the ease of detonation; class 2 (or B) is not considered detonable in the form present whereas class 9 (or A (Type 3)) is detonable.

3.2 Mass Consumption Rate, Confinement, and Impact

In most cases, the rate at which a propellant or explosive releases energy is the most important factor in determining its damaging potentialities. See below.

$$\dot{m}$$

$\dot{m} = dm/dt$ where: m = mass and t = time

PROPELLANTS	EXPLOSIVES
S = surface area	ρ = density
ρ = density	U = shock velocity
r = linear burning rate	S = area of shock wave
$= bp^n$	
b = coefficient	
p = pressure	
n = exponent	
$\therefore\ \dot{m} = \rho Sr = \rho Sbp^n$	$\dot{m} = \rho SU$

Figure 2-9. MASS BURNING RATE

A piece of propellant burning in the open would simply be a fire hazard to nearby objects. It might, of course, set up a chain of disastrous events.

If the burning propellant were confined in a rocket, the duration of burning would be shorter, the rate of energy release would be higher, the effects would be more intense and directional, and the fire hazard would extend for a much greater distance in the direction the nozzle was pointing than it would on an unconfined burning. The hot exhaust products may exit at a velocity near 8000 ft/sec. Hot particles of aluminum oxide may be present to increase erosion and thermal transfer.

If the rocket were free to move or its force and/or jet could free it, then there would also be a projectile that could do damage to people, spaceship, equipment, and/or a facility. (The equation for ΔV can be used for calculating velocities of impact.) Since the intense jet would accompany it, damage and injury could easily be quite serious.

As soon as the rocket impacted any object, the possibility of destroying the rocket would be present. This would undoubtedly lead to a number of small, high-velocity fragments of case and burning propellant. This would greatly increase the probability of injury and damage over a wide surrounding area. Clearly, the damage caused by such a rocket would also be a function of its initial size.

Why is it that a rocket which explodes or is destroyed by impact is nearly always more dangerous than a similar mass of unconfined propellant? In the act of exploding, and even more so in the action of impact, there is usually considerable breakup and shattering of propellant. This may enormously increase the burning surface of propellant. By the burning rate law, $\dot{m}$ is proportional to surface area (other variables equal). This enormous increase in area may well be from 100 to 10,000 times the original area. Even with a shattered case, such an enormous area increase may actually release hot gases so rapidly that localized self-confinement is realized and $\dot{m}$ is even further increased by localized high pressure zones. Present evidence indicates that this self-confinement effect increases the violence of the explosion more rapidly than does increasing the mass of a rocket.

A detonating explosive releases its energy with extreme rapidity. Since a detonation shock front may propagate in excess of 8000 meters/sec (26,300 ft/sec), a sphere of 2.63 ft. in radius (equivalent to more than four tons of an explosive) could be consumed in 100 microseconds.

The pressure developed in a detonation may reach 1.5 million psi and the reflection of such a shock wave may exert pressures of 3.0 million psi. Such pressures are so terrific that an explosive resting on heavy steel plate may punch out its outline through the plate.

Velocities of particles from confining tubes or nearby objects will generally be less than half of the shock wave velocity. Even so, such fragment velocities may easily reach 7000 ft/sec. Drag will, of course, rapidly slow down such particles. Even so, lethal fragments will persist for quite large distances. Even very thin, light fragments can be penetrating at high velocities.

One distinguishing characteristic shown by detonating explosives is that even small quantities can closely approach the peak pressure developed by large masses. Fragments will thus be of similar velocities to those projected from large masses. A few grams of encased high explosives can easily kill or seriously injure a group of people.

Confinement of high explosives has three important results: initiation becomes easier, there may be a modest increase in detonation velocity, and the confining case acts as a source of high velocity fragments.

Detonation will fail to occur in an unconfined explosive if its dimensions are below specific (critical) lower limits. This is normally called a "critical diameter." This is of the order of a few centimeters or less for most explosives and for propellants which have been shown to be detonable. Some substances, ammonium nitrate being noteworthy, appear to require very large masses in order to propagate a detonation. Ordinarily, most encasing materials will have an effect similar to increasing the dimension of the charge - the higher the density and the greater the strength of this material, the greater the effect.

The sensitivity of a crushed or shattered material is nearly always much higher than that of the highly consolidated material. Propellants which cannot be detonated under violent initiation conditions may be expected to become comparable to ordinary explosives in sensitivity when in a finely divided form.

3.3 Blast Effects

When a rocket ignites, there is nearly always an ignition shock wave set-up. The surrounding air has not yet been set in motion. When a large burning rocket is shattered by impact, there is an enormous increase in the rate of product gas generation. A substantial shock wave may thus be set-up. There is always a shock wave during a detonation in air and a resulting air shock.

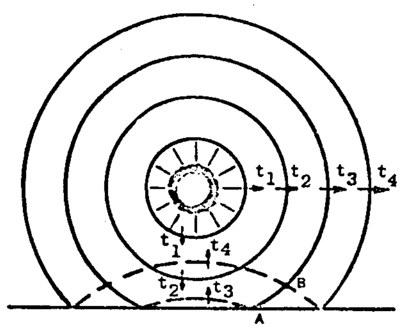
Even in a vacuum, the resulting products from a detonation will create an appreciable pressure on any intervening object. Calculations indicate that a one-pound charge of pentolite in a vacuum will produce a peak pressure of between 36 psi and 79 psi at a distance of 128 cm. Using cube root scaling laws, a 1000 pound charge in a vacuum would produce the same peak pressure at 1280 cm (42 ft). This value is roughly of comparable magnitude to the 60 psi to be expected in air for a representative explosive.

A description of some shock wave characteristics is illustrated in four figures; see Figures 2-4, 2-9, 2-10 and 2-11.

SHOCK FRONT VALUES

Peak Overpressure (psi)	Peak Dynamic Pressure (psi)	Maximum Wind Velocity (mph)
200	330	2,080
100	123	1,414
50	40	940
20	8	470
5	0.7	160

Figure 2-10



REFLECTED SHOCK WAVE

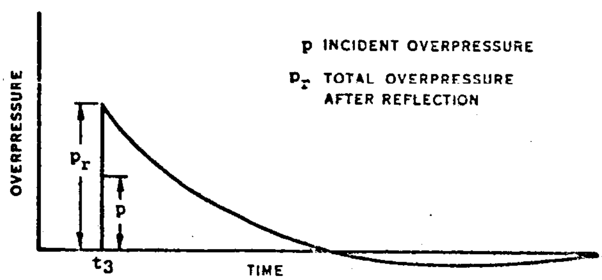


Figure 2-11

$$\frac{u}{U} = 1 - \frac{\rho_o}{\rho}$$

where: u = particle velocity

U = shock velocity

ρ_o = initial density

ρ = density in compressed zone

Figure 2-12. PARTICLE VELOCITY EQUATION

Damage is caused by the resultant effects of overpressure and dynamic pressure. The dynamic pressure increases more rapidly than the overpressure, so that there is a cross-over in relative magnitude. This dynamic pressure is the same dynamic pressure encountered in exterior ballistics. Calculations of the force exerted on an object also require a drag coefficient for computation (being one (1.0) for a head-on flat plate configuration).

The human body can sometimes take fairly heavy overpressures without fatality. Even in the case of initial survival, the impact of moving objects or the tossing of the body into an object may result in death.

A reflected shock wave also is shown in Figure 2-10 above.

4.0 PROPELLANTS

4.1 Liquid Propellants

- Liquid Monopropellants

  Practical liquid monopropellants are presently only a few in number. Hydrazine and hydrogen peroxide are representatives.

  Hydrazine is very insensitive; in fact, it has not been detonated by ordinary means. Heating a closed container or the presence of reactive contaminants can, of course, cause a pressure explosion. It is also poisonous.

  Note that hydrazine is a strong reducing agent. This is a characteristic property of a fuel. Hydrazine can indeed be used as a fuel in a bi-propellant system, although its derivatives have largely displaced it in such systems.

  Hydrogen peroxide is heat sensitive and in higher concentrations, detonable.

Many other monopropellants have been considered for use, and additional ones may be put to practical use in the future. In the past, monopropellants of I_{sp} greater than hydrazine have generally been too sensitive for use. Liquid monopropellants are particularly susceptible to the adiabatic compression of entrained bubbles causing ignition.

- Liquid Bi-propellants

Such systems are of many types. Liquid oxygen (LOX) with kerosene-type hydrocarbons, LOX with Hydrogen, LOX with Ethyl Alcohol, and Fluorine with Hydrogen are representative of clear-cut fuel-oxidizer systems. High energy fuels, such as hydrazine and unsymmetrical dimethylhydrazine (UDMH), may be used single or as a mixture with oxidizers such as LOX, Fluorine, N_2O_4, White Fuming Nitric Acid (WFNA), or Red Fuming Nitric Acid (RFNA).

Each ingredient of these must be considered singly for individual chemical reactivity and compatibility. With all of these, the greatest danger is present during loading and transfer operations and while the boosters are loaded. Spillage of any of these can easily cause fires and sometimes explosions. Some of them are quite poisonous, and some of them are extremely reactive with a wide range of materials. Simultaneously, spillage of fuel and oxidizer is the most serious type problem. Some of these are hypergolic so that there is an automatic fire; others form detonable mixtures.

4.2 Solid Propellants

Certain aspects of solid propellants will be described in other lectures.

- Double-Base Propellants

The principal constituents of double-base solid propellants are nitroglycerin and nitrocellulose. Modest quantities of a plasticizer, such as diethylphthalate, and smaller quantities of a stabilizer, such as diethylcentrallite, are also present. The stabilizer is slowly exhausted with age. If it becomes completely exhausted, particularly with large grains, self-heating and consequent explosion may result. The safe-life of any double-base propellant should always be ascertained. When there is any doubt, a manufacturer's representative should be contacted.

Extruded double-base grains may be used in small rockets. Cast double-base grains can normally, even in small rockets, permit more efficient rocket design. In modern rockets, the strictly double-base propellants are little used, but composite variations are used instead.

Double-base propellants are, in general, detonable, but do require strong initiation.

- Composite Propellants

Composite propellants may conveniently be divided into low energy binder systems (normally a type of synthetic rubber such as the older polysulfide or the newer polyurethane or polybutadiene-acrylic acid copolymer) and high energy binder systems, such as double-base propellant. These binders are heavily loaded with finely ground inorganic salts, such as ammonium perchlorate and finely divided metals such as aluminum.

In general, the high energy binder systems are detonable; whereas well-consolidated low energy binder systems are not. As previously mentioned, crushing, shattering, or shredding may be expected to make most of the low energy binder systems detonable.

- Pyrotechnic

Pyrotechnic is a term generally used in modern days to denote compositions which produce a high percentage of hot solid particles. In rockets, these are principally used in the ignition systems, either as the main igniter charge or as a booster charge between the squib and main charge. Boron-potassium nitrate is a typical pyrotechnic composit on. Rocket propellants are increasingly replacing these as the main charge, because of their greater reproducibility of action. The increasing use of metals in rocket propellants also makes them more suitable for ignition than older compositions.

It is dangerous to generalize on pyrotechnic compositions. Detailed study of the characteristics of individual systems is advised. Friction sensitivity, static sensitivity, compatibility, and surveillance require careful attention. When used as main charges for igniters, their irreproducibility can cause serious ignition peaks with consequent case rupture.

- Products of Combustion

After launch, problems occasionally arise, due to the products of propellant combustion mixing with air to form pockets of combustible or explosive gases. This is particularly true of metallized composite propellants, whose products usually contain large quantities of hydrogen and carbon monoxide. (Both are combustible and form detonable mixtures with air.)

The products of combustion may also be toxic: for instance, carbon monoxide, hydrochloric acid, and hydrofluoric acid.

5.0 EXPLOSIVES

5.1 Liquid Explosives

Liquid explosives have already been mentioned under the liquid propellant headings. Liquids are not intentionally used for explosive purposes in rockets at the present time.

5.2 Solid Explosives

- Initiating and Priming Explosives

Initiating and priming compounds are explosives which are easily detonated. In rockets, initiating and priming explosives are usually initiated electrically; they are also carefully protected from other methods of initiation. Lead azide and lead styphnate are representative initiating explosives.

Where detonation is not desired, but rather ignition (priming), initiating explosives may be used in conjunction with, or replaced by, pyrotechnic compositions (such as a mixture of potassium chlorate and lead thiocyanate).

Whenever possible, such initiating or priming devices should be protected by effective safing and arming devices (S&A). The S&A device provides physical and electrical isolation until late in launch countdown. This is probably the most important point in rocket safety. Unfortunately, small rockets and other small systems are often not so protected and special work-around procedures, such as late installation, must be used.

- Boosting Explosives

  Explosives of intermediate sensitivity (such as tetryl) which can be initiated by an initiating explosive, often are placed between the initiator and the main charge. This insures detonation of the main charge. There is an increasing trend toward replacing such booster charges with a low density pressed charge of materials such as RDX. This greatly increases the impact sensitivity of the RDX, but retains the other superior qualities, such as high temperature stability.

- Bursting or Working Charge

  RDX compositions, TNT, PETN, Tetryl and other materials are used for this purpose. Some of these materials also may be used as boosting compositions, or even as additives in initiating and priming trains. Due to its high thermal stability and high brisance, RDX is increasingly being used in rocket and launch vehicle operations.

6.0 CONCLUSION

Propellants and explosives can cover the full range of uncontrollable fires, deflagrations, and detonations when accidentally ignited. When we study them in detail, it is amazing that our record of success is as high as it is. Clearly, painstaking thoroughness in planning and action is necessary to prevent accidental ignition. We must design our facilities, equipment, and operations so that injury and destruction are minimized in case of accidents.

N67-15986

Lecture Number Three

"Electrical Detonators and Squibs & Their Associated Initiation & Ignition Trains"

Mr. S. H. Rush

1.0 INTRODUCTION

Ordnance system safety engineering has changed drastically over the last five years. Engineering advances are easily recognized when comparison is made between the ordnance systems of early missiles and one of the current space vehicles. As ordnance systems have become more sophisticated and additional safety hazards have been identified, the methods required to provide ordnance safety have become increasingly complicated.

Throughout this discussion the terms electro-explosive device and initiator will be used interchangeably to represent either a squib or a detonator. Strictly speaking, the following definitions apply:

- Initiator - a general term that is used to describe any electro-explosive device (EED).
- Squib - A pyrotechnic device. It is a deflagration device which produces a burning phenomenon. A squib is used to ignite propellants which produce high temperature gases to perform work.
- Detonator - Initiates a high explosive. It is, in itself, a high explosive device and produces a detonation which may initiate other high explosives.

2.0 SAFING DEVICES

A primary safing device is required on all ordnance systems. The primary safing device is a unit which has, as a minimum requirement, the capability of breaking the electrical circuit (firing circuit) to the initiator. Two types of safety devices are the arm-disarm switch and the safe and arm device.

ARM-DISARM SWITCH SAFE POSITION
STAGE SEPARATION AND THRUST TERMINATION

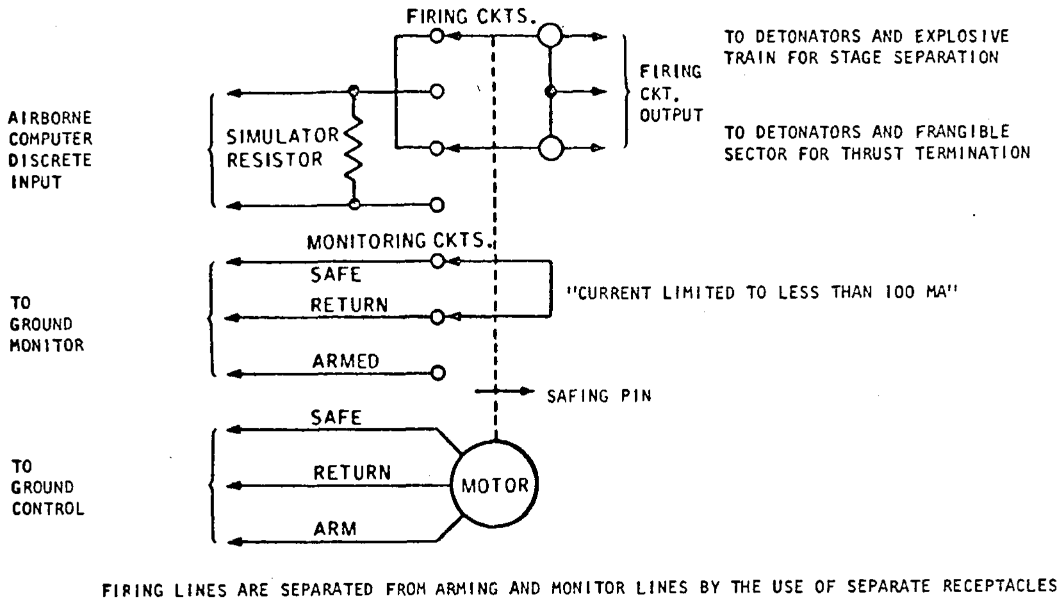


Figure 3-1

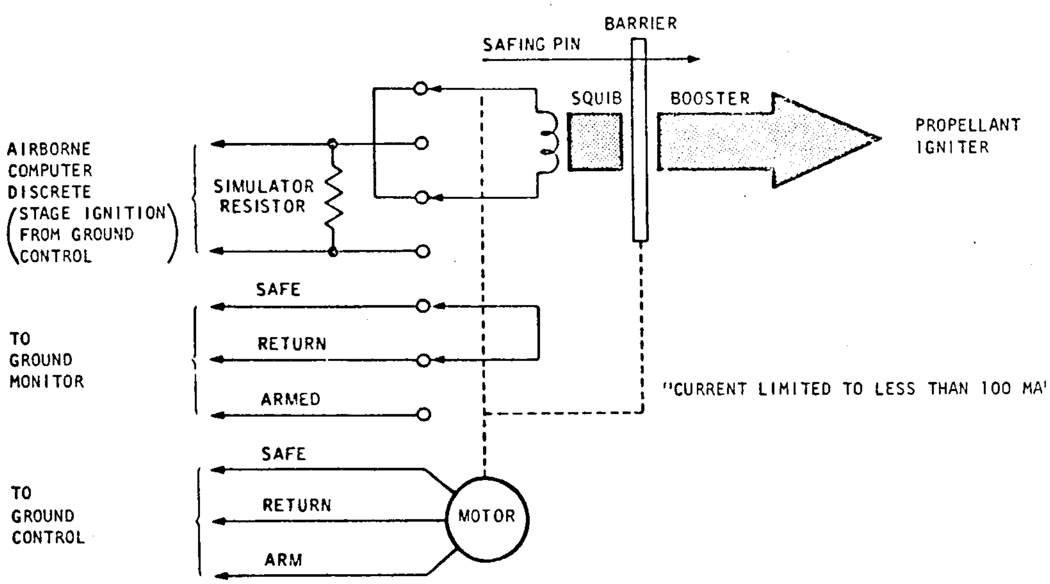
2.1 The Arm-Disarm Device

An arm-disarm device makes and breaks the electrical circuit to the electrical initiators. Figure 3-1 is a general electrical schematic of an arm-disarm switch. This device meets minimum requirements as it is capable of breaking the firing circuit. The arm-disarm device can be powered by a motor-operated switch, a solenoid-operated switch, a relay, or by any of several other methods.

2.2 The Safe and Arm Device (S&A)

An S&A device must be detonator safe; that is, if the sensitive elements are initiated in the "safe" position, the subsequent explosive or pyrotechnic train will not be initiated. To do this, a barrier must be placed between the EED and the remainder of the explosive or pyrotechnic train. This is done with sliders or with rotors which, when the system is armed, turn the rotor or move the slider into line with the rest of the explosive train. To conduct the detonator safety test, the EED is initiated in various positions from the full-safe to the full-arm position and the point at which the explosive or pyrotechnic train will be set-off is determined. The probability of initiation and the detonator safety of the system can be determined from the results of this test.

SAFE & ARM DEVICE - SAFE POSITION
(ENGINE IGNITION SYSTEMS)



FIRING LINES ARE SEPARATED FROM ARMING AND MONITOR LINES BY THE USE OF SEPARATE RECEPTACLES

Figure 3-2

Shown above is a general schematic of an S&A device in the "safe" position. This is a redundant device as two initiators are utilized; however, this schematic shows only one side of the system. One of the important features is the safing pin arrangement. The safing pin holds both the barrier and the switches in the "safe" position until it is removed and an arming command is received. The barrier of this S&A device is between the initiator and booster. Resistors are provided as an integral part of the primary safety device so that complete checks of the electrical system can be conducted from the power supply up to the electrical initiator. The resistors are designed into the devices so that electrical circuit checks can be made without utilizing a simulator. Using a simulator requires that the electrical connectors must be made and broken several times resulting in a reduction in reliability and safety.

2.3 Uses of Safety Devices

It is preferable to standardize the devices in any vehicle where many primary safety devices are used since a greater degree of reliability and safety can be assured. Many more tests may be made on one type of device than could be made on several types; thus, a high reliability factor can be maintained.

S&A devices are used in all explosive systems where inadvertent initiation would result in an accident of catastrophic proportions; e.g., inadvertent engine ignition or inadvertent initiation of the destruct system. An S&A is utilized where both electrical and explosive (or pyrotechnic) safety is required.

An arm-disarm device is usually used for stage separation. If the staging joint is a compressive type joint, inadvertent initiation of the stage separation system would not result in collapse of the missile. If the missile does not incorporate a compressive type joint, and if inadvertent initiation tends to result in a missile collapse, then an S&A device should be used.

The thrust termination system could use an arm-disarm device since inadvertent initiation would not result in a catastrophic accident. There are no standardized methods of determining whether an S&A device should be used or an arm-disarm device; the entire system must be studied. The type of damage that would occur if the initiator inadvertently went off must be determined; e.g., would the complete missile be destroyed? would personnel be injured? would there be damage to property? The final decision must be made on the basis of the degree of safety required and the possible results of an inadvertent initiation.

3.0 SAFETY CRITERIA FOR ORDNANCE COMPONENTS

There are many safety criteria for ordnance components. All of the following apply to S&A devices and all but the first criterion apply to arm-disarm switches.

- Detonator Safe

  There is one requirement of an S&A mechanism that is not required of an arm-disarm device; it must be "detonator safe." Detonator safe means that if the sensitive elements are initiated in the safe position, the subsequent explosive or pyrotechnic train will not be initiated. A mechanical barrier between the sensitive material and the charge accomplishes this interruption.

- Safety Pin

A safety pin must be utilized for the transportation, handling, or assembly of the primary safety device. This safing pin has a special purpose; if arming power is on the system, the pin cannot be removed. The pin, of course, is removed prior to launch. If a technician attempts to remove the safing pin from the safety device and finds that he cannot, it is an indication that something is wrong with the system and that corrective action must be taken.

- Not Manually Armed

Primary safety devices should be designed so that they cannot be manually armed but they may be manually disarmed. This important safety requirement is to prevent inadvertent manual arming of the system. If an abort or system failure occurs prior to launch and the systems have been armed (electrically), it may be necessary to manually disarm the safety device. This can be done by reinserting the safing pins which automatically move the safety device back to the "safe" position.

- Remotely Armed or Disarmed

It is mandatory that the safety devices can be armed or disarmed remotely. There should also be a remote monitor circuit in series with each of the safety devices so that any movement of the devices toward the "arm" position will cause an alarm or a power shutdown.

- Visual Indication of Status

A visual indication at the mechanism of the "arm" or "safe" status of the unit is required. This is a redundant (but necessary) feature. When a technician is required to remove or insert the safing pins, he must be able to determine visually the "arm" or "safe" status of the primary safety device.

- Electrically Disconnected in "Safe" Position

Squibs and detonators should be shorted-out in the "safe" position; i.e., they are electrically disconnected. This is a guard against spurious currents, as well as accidental closing of the circuit, and subsequent firing of the EED.

- Isolation

Physical and electrical isolation of the firing circuits is required. That is, the actuation and monitoring circuitry and the firing circuitry should be physically separated. The circuits should be in different electrical connectors to guard against mismating or bending of connector pins which could bypass the safety device. This would cause a hazardous condition. Therefore, it is best to have the monitoring and activation circuits physically separated from the firing circuits (not only in the connector itself but also in the internal wiring of the primary safety device).

- One Amp No-Fire Characteristic

  The EED should not fire if subjected to the electrical power of 1 watt, 1 amp for a limited time. Range Safety requires that the EED be subjected to 1 watt, 1 amp for 5 minutes without firing for acceptance.

- High Reliability

  The final requirement is that the safety characteristics be demonstrated to a reliability of 99.5% at a 95% confidence level. This value is with relationship to the 1 watt, 1 amp no-fire characteristic of the detonator safety criterion.

4.0 MISSILE ORDNANCE WIRING

In ordnance work, people have always been most concerned with the initiator rather than the complete ordnance system; however, ordnance goes much further than this. All components which make up the ordnance system (power supply, cabling, primary safety device, etc.) must be studied. You cannot look at the initiator alone and say, "This is it, if this is safe, everything else is safe." It may not be true!

There are requirements placed on the wiring circuits for additional safety:

- Selected Routing or Isolation

  Isolation requires the electrical and physical isolation of the firing circuits and other power control and electronic circuitry. The selected routing of missile ordnance wiring through airborne cables and conductors is required. The monitor and actuation lines or wires should not be next to, or intertwined with, the firing circuits.

- Twisted and Shielded Wires

  Twisting and shielding of firing circuits must be provided to shield them from all internal and external (audio and RF) electromagnetic fields.

- Thermally Insulated Wires

  Thermally insulated wire should be used to preclude short-circuiting the critical ordnance circuits.

- Grounded Wires

  Static grounding and RF bonding must be provided in accordance with MIL-B-5087. The grounding points must be selectively established to reduce inductive stray electrical energy coupling paths and to reduce the maximum effective antenna aperture formed by the firing leads. Range Safety requires that twisted, shielded wires have the shielding grounded. The object is to eliminate ground loops in the system. If the shield is isolated, there may be differences in the static potential which cause current surges in the field itself. Grounding the shield can eliminate these loops in the wiring, with the shield acting as the conductor. All various lead wires must be grounded to a common ground in the missile.

5.0 DESTRUCT SYSTEMS

There are two types of destruct systems that must be on each missile. The first provides a capability to command destruct the vehicle. The second serves a premature stage separation destruct function. If there is a mishap in an upper stage (such as inadvertent separation or ignition, or a physical breakup), the stages below the mishap must be destroyed and the stages above must be capable of being command destructed.

The tendency on multi-stage vehicles has been to have the propulsion contractor for each stage also furnish the destruct system for that stage. Because of the different types of destruct systems which result from this kind of action, the integration of the overall vehicle destruct system becomes very difficult and results in a degradation of both safety and reliability. In order to overcome this, some missiles use an integrated system which provides an identical destruct charge on each of the stages with a single command destruct S&A and identical premature stage separation S&A mechanisms on each stage. Because of the commonalty of the destruct system, the components can be tested to demonstrate high reliabilities (a minimum of 99.5% at a confidence level of 95%).

A typical integrated destruct system features a single command destruct S&A with interconnecting primacord and linear shaped charges. Each system is identical on each stage. Premature stage separation (PSS) S&As are provided on all except the upper stage. The PSS S&A is lanyard-operated with the lanyard bridging the interstages. In the event of a premature initiation of the rocket motor or physical breakup across the interstage, the lanyard is pulled and rotates the sensitive explosive component into line. Simultaneously the laynard closes a series of switches between the battery and the PSS S&A thereby permitting current to flow to the detonator thus initiating the destruct system on the stage and the stages below. The upper stage or stages can be destroyed by initiating the destruct S&A. The system is completely redundant so that a high reliability is achieved.

6.0 HAZARDS TO ELECTRO-EXPLOSIVE DEVICES

Electro-explosive devices (EEDs) require protection from the following sources: test equipment, electrostatic discharge, electromagnetic fields, and induced voltages.

6.1 Test Equipment

The electrically initiated explosive components should have a minimum of one ampere no-fire and 3.5 ampere all-fire characteristics. The 1 amp no-fire requirement means that the initiator can be subjected to 1 ampere current for some period of time and it will not fire. The 3.5 ampere all-fire means that the initiator should fire 100% of the time when subjected to 3.5 amperes. The first is a safety requirement; the other is a reliability requirement. The requirements as delineated by Range Safety would be 1 watt, 1 ampere no-fire for 5 minutes to demonstrate the no-fire level. If possible, all initiators should be subjected to 1 watt, 1 ampere for 5 minutes in order to cull out the units which are marginal. It is necessary, however, to test the initiator to determine whether repeated applications of 1 watt, 1 amp no-fire for 5 minutes would degrade the system.

6.2 Electrostatic Discharge

Presently EEDs are designed such that they will not be initiated by a capacitor charged to about 3 kilovolts. The possibility of having this large a charge build up accidentally is rather remote. At the present state-of-the-art, the possibilities of going to higher initiation voltages are impractical. With very high voltage discharges (20 or 25 KV) the dielectric in the initiator would break down and the system would be overdesigned.

There has been quite a bit of literature which shows that the human body can actually store up to 600,000 ergs; however, there isn't 100% efficiency in transfer. There is a loss when an EED is initiated under electrostatic discharge. It is presently possible to prevent static accumulations of a few kilovolts, so there is no need to go to higher discharge voltages.

6.3 Electromagnetic Fields

Air Force Document 80-2 defines the electromagnetic environment as 2 watts per square meter up to 50 megacycles (mc) and 100 watts per square meter from 50 mc on up to 40,000 mc. The ordnance system must be designed to survive in these electromagnetic environments; i.e., exposure to these specified environments must not result in any safety problems in handling, transportation, installation or operation.

Further exposure to the specified RF environment should not result in degradation to performance and should not reduce the reliability of the device to perform its intended function.

The field that the initiator actually receives depends on the shielding of the system itself. It depends on the attenuation in the cabling and the attenuation due to the physical location of the unit in the vehicle itself. It is possible to have a field intensity of 100 watts per square meter and, due to attenuation, have a value much less than that at the unit itself. For this reason, the tests should be done on a complete system. Individual components may not be able to meet requirements when sitting on a table and being subjected to 100 watts per square meter; however, when they are actually mounted in the way in which they are to be used on the vehicle, they may be so shielded that they can withstand the field intensity requirement of 100 watts per square meter.

7.0 POSSIBLE SOLUTIONS TO ELECTROMAGNETIC HAZARDS

There have been three possible solutions to electromagnetic hazards. One is the exploding bridgewire system (EBW) which is a high voltage and high energy system. The second is a low voltage - medium energy system; a hot wire system known as the 1 ampere no-fire and 1 watt no-fire for 5 minutes. The third one is a low voltage - high current with RF suppression.

There is not much difference in the energy requirements between the low voltage-medium energy systems and low voltage - high current systems. The current requirements are within the realm of a missile power supply; there is only a slight difference in the amount of current required. The differences, for instance, would be about 3-1/2 amps all-fire for a conventional hot wire versus about 12 amps on high energy or medium energy initiators.

7.1 The Exploding Bridge Wire (EBW) Approach

One attempt to meet the RF requirements resulted in EBW systems being utilized in missile and space vehicle ordnance systems. EBW systems were initially developed for nuclear weapons because of the fast firing time (less than 5 microseconds) which could be realized. The EBW initiator can meet the RF requirements and uses only secondary explosives or pyrotechnics. The problem, of course, is that the initiator may not be sensitive but the firing unit is sensitive to RF radiation. The firing unit can be triggered by RF while the initiator itself is relatively safe. Much effort has been expended in shielding the firing unit against electromagnetic radiation.

An EBW consists of an RF filter, a transistor inverter, a high voltage transformer, a rectifier, a capacitor, a trigger gap switch, and the EBW initiator. The RF filter eliminates stray RF signals. The transistor inverter forms an apparent AC signal from the DC power and the high voltage transformer steps the voltage up to a few kilovolts. The rectifier increases the current in the high voltage and also converts the AC back to DC. The capacitor stores the energy which, when the proper signal is received, sparks across the trigger gap switch and ignites the EBW initiator.

In addition, a monitor circuit is provided for monitoring the capacitor and for bleed-off of the system. The bleed-off circuit is required in the event of an abort after the capacitor has been charged; if this happened, it would be necessary to bleed-off the charged capacitor. One of the drawbacks in the system is the time required to bleed the charge off the capacitor. This time for bleed-off (approximately 30 seconds) is a safety hazard. With other systems (Safe and Arm Devices) the system can be safed in milliseconds.

The firing pulse goes through a trigger discrimination circuit into a pulse forming network. These are coded signals which are required for initiation of the trigger switch. The pulses have a certain shape and amplitude and the trigger switch will react only to this type of signal; this eliminates initiation by spurious signals. The trigger gap switch, however, is susceptible to radiation and, therefore, shielding of the EBW firing unit is required. The number of electronic components in series, however, tends to degrade the reliability of the overall system.

7.2 The Low Voltage - Medium Energy Approach

The one-watt system is basically a one-ohm bridge wire with a desensitized bridge wire head or a heat sink around the bridge wire to conduct the heat away from the sensitive explosive elements. However, the one-watt requirement has no physical meaning when compared with a full intensity requirement of 100 watts per square meter which is the human tolerance level. There has been some disillusionment with one-watt no-fire systems even though much time and money has been spent in their development.

The Range requirements are that the EED shall withstand a field intensity of 100 watts per square meter over a frequency range or meet the Range requirements. It is the belief of most people that the environmental requirement of 100 watts per square meter is more realistic than the one-watt no-fire requirement.

There are four main advantages to using the low voltage - medium energy EED system::

- It meets ETR requirements.
- It can be used in combination with an arm-disarm switch.
- On-board power can be used (28 volt power supply and conventional cabling). The high voltage transmission lines that are required in the EBW system are not necessary for this type of system.
- It is a lighter weight than the EBW type.

There are also, however, disadvantages to using the low voltage - medium energy EED system:

- The system requires the development of a new initiator.
- Even though the EED meets the one-watt requirement, it may not meet the actual field intensity requirements of 100 watts per square meter.

7.3 Low Voltage Approach

The low voltage - high current, with RF suppression is another attempt to overcome the electromagnetic hazards problems. The attempted solution here has been in the introduction of attenuators in the initiator plug or in close proximity to the initiator. This work has been carried on by the Navy and the

Army using enclosure and suppression techniques. The major problems have been in incorporating a suppression technique of reasonable size.

The low voltage system affords the maximum prelaunch confidence checks as compared with an EBW system. The firing discrete signals can be checked through a simulator resistor in the primary safety device without checking through the initiator itself. This permits a system self-check while the safe and arm mechanism or arm-disarm mechanism is in the "safe" position. The safe and arm status of the system can be commanded remotely. The system can be immediately safed if a launch abort occurs. Most of the safe and arm mechanisms and arm-disarm switches can be safed in 40 to 100 milliseconds, compared to the 20 to 30 seconds required to bleed-off the EBW systems. The arming and safing capability may be checked prior to launch during systems checkout tests. An EBW system cannot be armed without charging the capacitors.

The low voltage - high current system with RF protection has many advantages:

- It meets both the Eastern Test Range and Western Test Range requirements.
- It can be used with an arm-disarm switch and safe and arm device because it uses missile on-board power.
- Existing initiators can be used.
- The RF protection attenuators can be mounted in or around the existing initiators.

As is the case with all systems, however, this device also has its disadvantages:

- The RF suppression system must be integrated with the initiator.
- It is necessary to certify the initiators over the frequency range of 10,000 to 40,000 mc. This is extremely difficult to do because there is no test equipment available for direct test at these frequencies.

8.0 CONCLUSIONS

The design of the ordnance system is not the design of the initiator alone; the overall system must be studied. It is necessary that the ground equipment which provides the signal must be studied. The cabling, power supplies, cable routing, shielding requirements, and grounding requirements must all be included.

As systems become more and more complex and more and more ordnance items are used on missiles and space vehicles, the hazards compound because of the additional units that must be incorporated into the system. In order to assure safety and reliability - which go hand in hand - it is necessary to look at the total system and not individual components. Testing and analysis must be done on a total system basis.

N67-15987

Lecture Number Four

"SENSITIVITY OF EXPLOSIVES AND PROPELLANTS TO IMPACT AND FRICTION"

Mr. Frank Fedowitz, Jr.

1.0 INTRODUCTION

Most readers who have worked at Cape Kennedy for a period of time are well-aware of the developments that have taken place in recent years in the field of bigger and better boosters. These larger boosters have required developments of higher and higher energy propellants. In the past, there was a great difference between propellants and explosives; but, as a result of the development of newer propellants, the line of demarcation, or difference, between propellants and explosives is not as great as it was before. Primarily, this is because they either contain fair percentages of explosives, or behave in a similar manner to explosives, especially inadvertently.

2.0 INITIATION OF EXPLOSIVES AND PROPELLANTS

Safety is of paramount importance in the manufacture, the test, and the use of propellants and explosives. One index of the safety, of these materials or components containing them, is sensitivity. In order to understand the importance of sensitivity and the variations in sensitivity, one must have some background of the process, from the point of initiation of explosives and propellants to either deflagration (burning) or detonation.

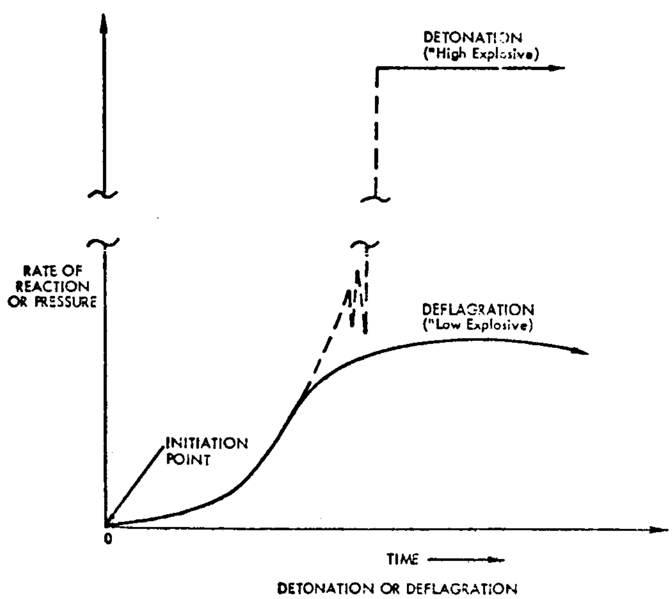


Figure 4-1

Figure 4-1 is a graphical representation of what occurs from the time a propellant or explosive item is initiated, to the time it is progressing at a steady state. The process starts at the initiation point (at time zero), through action of a squib, a detonator, or an inadvertent initiation. As time progresses, the reaction accelerates. In the case of a deflagration or a burning process, (for propellants), this reaction proceeds at a rate of a few inches per second and at a pressure of perhaps 1,000 psi. In the case of an explosive, or a propellant which is misbehaving, a sudden change in reaction rate occurs which leads to a detonation. The reaction rate in a detonation process is very rapid, in the order of 600 to 2,400 feet per second. The pressures associated with this rate are in the neighborhood of one hundred thousand atmospheres. Obviously, there is a great difference between deflagration and detonation. A knowledge of the conditions of initiation is very important; primarily, in the case of whether one does or doesn't want it to occur. There have been numerous initiation studies of propellants and explosives; and of course, everyone who has studied the phenomenon, has proposed some sort of test to determine the sensitivity characteristics of the material. There are as many tests as there are studies of initiation. One of the primary factors to understand, is that initiation requires a given input of energy into the system, usually a rapid input of energy, and not necessarily heat energy. The energy input can be through impact, frictional forces, a number of miscellaneous forms, and of course, heat.

2.1 Impact Energy

Heat is produced if an explosive or propellant is impacted. This may be caused by the flow of the materials due to the impact, a compression of gas or vapor bubbles in the material, or shearing of different portions of the propellant or explosive; all of which tend to form "hot spots." "Hot spot," a term used in explosive work, is considered to be a small area in the propellant or explosive where the input energy is concentrated. The "hot spot" theory is the presently accepted theory of initiation for propellants and explosives.

2.2 Friction Energy

Frictional initiation is another means of initiation and is actually similar to impact. It is attributed to the formation of hot spots, similar to those formed by impact, except for the rates of formation and method of energy supply.

2.3 Thermal Initiation

Thermal initiation is caused by heating the propellant or explosive to the point where it decomposes and/or ignites.

2.4 Miscellaneous Causes for Initiation

Initiation may also be brought about by electrostatic discharge, gamma radiation, ultraviolet radiation, or visible radiation. Radiation is considered to decompose the material into more sensitive compounds, which then are more sensitive to previously mentioned types of input energy.

3.0 SENSITIZERS AND DESENSITIZERS

The sensitivity of a material can be affected in a number of ways, some of which are discussed in the following sections.

3.1 Mechanical Sensitizers

Perhaps the most common sensitizing effect is a mechanical effect. A hot spot could be formed around a particle of grit, a piece of sand, or other material mixed in with the propellant or explosive. The properties of the grit are very important; hardness, shape, size, and most important, its thermal characteristics. The melting point of the grit particle is important. When an impact, or a frictional force is applied, a hot spot starts forming at the site of the grit particle. If the melting point of the grit particle is low, before the hot spot can build up to a high enough temperature to initiate the propellant or explosive, the particle may either decompose, or melt, and eliminate the source of the hot spot. If, on the other hand, the melting point of the grit particle is higher than the melting point of the explosive or propellant, the temperature of the hot spot will increase to a point where the propellant or explosive will be initiated. Another type of mechanical source of initiation which has to be considered, especially during assembly-type operations, is the screw thread. A bit of propellant or explosive in a thread can be subjected to a localized high energy input, and can easily be a source of initiation as the mating part is assembled to it.

3.2 Chemical Sensitizers

A second method of sensitization is achieved by means of chemicals. Chemical sensitizers tend to lower the decomposition energy of a material. For example, consider copper and ammonium perchlorate combinations. When copper is in contact with ammonium perchlorate, it lowers the decomposition temperature of the ammonium perchlorate. As another example, copper in contact with ammonium nitrate directly increases its sensitivity. Therefore, in any design work or fabrication of these assemblies, copper is kept from contact with either ammonium nitrate or ammonium perchlorate. In order to check the compatibility of different materials with explosives and propellants, a type of compatibility test is run between the propellant or explosive and any material that may come in contact with them. The test is usually conducted at an elevated temperature in which a test tube size sample, or larger, is subjected to elevated temperature, and decomposition products are measured after a period of time. Double base propellants, nitroglycerin or nitrocellulose containing propellants, have their own problems also. They tend to decompose slowly, producing an acid product which tends to increase the sensitivity. However, stabilizers are incorporated in these propellants which selectively react with the decomposition product, and remove them from the system, so they do not have an adverse effect.

3.3 Physical Sensitizers

A third method of sensitization or desensitization is a physical method. Temperature changes, either high temperatures or low, can cause changes in the crystal size of an explosive or propellant, thereby either sensitizing them if they are sensitive to their crystal size or desensitizing them. Of course, as temperature increases, reaction rate increases, so the temperature has a direct sensitizing effect.

4.0 MEASUREMENT OF SENSITIVITY

One might think that there should be a correlation between the input energy required to initiate a material and its output energy. Figure 4-2 illustrates

Figure 4-2. SENSITIVITY VS. BRISANCE (OUTPUT)

Decreasing Impact Sensitivity	Decreasing Brisance
Lead Azide	RDX
PETN	PETN
RDX	TETRYL
TETRYL	TNT
TNT	Lead Azide

(Other test methods will produce some rearrangement.)

the input/output relationships for a few of the normal military explosives. Lead Azide, for example, shows a relationship of a high impact sensitivity for a low Brisance or output. Brisance, by the way, is a term for shattering power of the explosive. There may be some inverse relationship for Lead Azide, but for the other explosives the relationship does not exist. It becomes apparent from Figure 4-2, that there is really no correlation that can be made between input and output power. How then does one measure sensitivity? A number of effects regarding sensitizers and desensitizers have been mentioned and the many ways in which the sensitivity of propellants or explosives may vary has been explained. One may be led to believe that it might be a bit difficult to measure the sensitivity of a material accurately. This is definitely true. Most testing, thus far developed, has been developed toward the aim of trying to resemble field conditions and actual operational type conditions.

4.1 Types of Tests

Figure 4-3 is a partial list of tests. Of the twelve tests listed, the twelfth

Figure 4-3. SENSITIVITY TESTS

1. Impact Test (falling weight)
2. Friction Test (sliding weight)
3. Card Gap Test
4. Bullet Impact Test
5. 40 foot Drop Test
6. Minimum Detonating Charge
7. Critical Diameter
8. Electrostatic Discharge
9. Auto Ignition Temperature
10. Vacuum Stability Tests
11. Differential Thermal Analysis
12. Et Cetera

one is the most complicated; it consists of twenty or thirty more tests that have been used throughout the industry. Everyone has some sort of test, that they think is the best test, for measuring a particular type of sensitivity.

Three of these tests use heat input as a means of initiation; Numbers 9, 10, and 11. Four use impact of one sort or another; Numbers 1, 2, 4, and 5. Three use detonability of the propellant or explosive as an indication of its sensitivity; Numbers 3, 6, and 7. Number 8 is a measure of the electrostatic sensitivity.

- Thermal Testing

  In thermal sensitivity testing, temperature is usually the parameter that is being looked for; i.e., temperature at which a reaction occurs, or the time at which reactions occur at certain temperatures. The auto-ignition test, for example, is a test in which one looks for flame, or detonation or initiation of some sort, to occur at a particular temperature. The differential thermal analysis test is similar to the auto-ignition test, in that its criteria involves heat generation; but in addition to flame, other heat generation. Thermogravimetric analysis is one of the et ceteras in Figure 4-3, and looks for a weight change as the sample is heated. There are many sources of variability in these types of tests. One can imagine that the heating rate, the sample size, compaction of the sample, and the material from which the container is made, all affect the result. These variations require that anyone, who is going to make a comparison between tests, must be careful, and be sure they have all the data and know all the differences between the different tests before a valid comparison between tests can be made.

- Impact Testing

  The next type of tests is the impact tests and, as in the case of the thermal tests, comparison here again is very difficult. Results are sometimes ambiguous and there are many variations in the testing. The "hot spot" theory states that one has to produce localized heat at a fairly high rate in order to initiate a compound. Therefore, the method of energy application is important, and the mechanics of the apparatus itself enter into the variations in the results that one obtains. For example, the hardness of the material, the finish, the thermal characteristics are again important. In addition, there are problems with the decision standards that are used in these tests. Many people use the "Three S system," (Sight, Sound, and Smell), to determine whether a reaction has taken place or not. Some others may be a bit more sophisticated and use measuring devices - but these also have variations.

4.2 Impact Sensitivity and Tests

In impact testing, before the "hot spot" theory was developed, people thought that impact either produced a direct excitation of the explosive or propellant molecules or a rupture of the molecules themselves. The "hot spot" theory, however, states that rapid, localized heating of the material is required to effect initiation. Figure 4-4 is an example of one of the pieces of test apparatus that is used for determining the impact sensitivity of a material. This is the Picatinny Arsenal standard apparatus. It is not an extremely complicated piece of equipment, nothing more than a weight that is suspended on a calibrated stand and then dropped onto an assembly, containing the material under test which is supported on an anvil. Figure 4-5 is another example of an impact

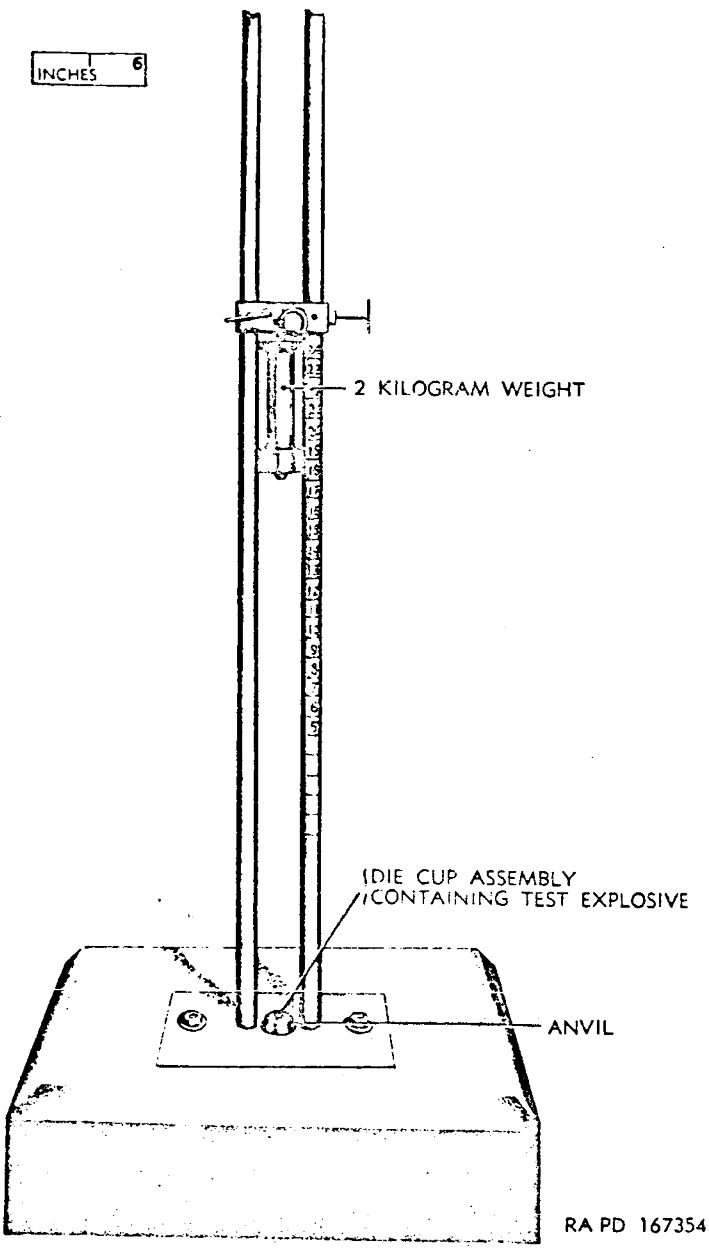


Figure 4-4. PICATINNY APPARATUS

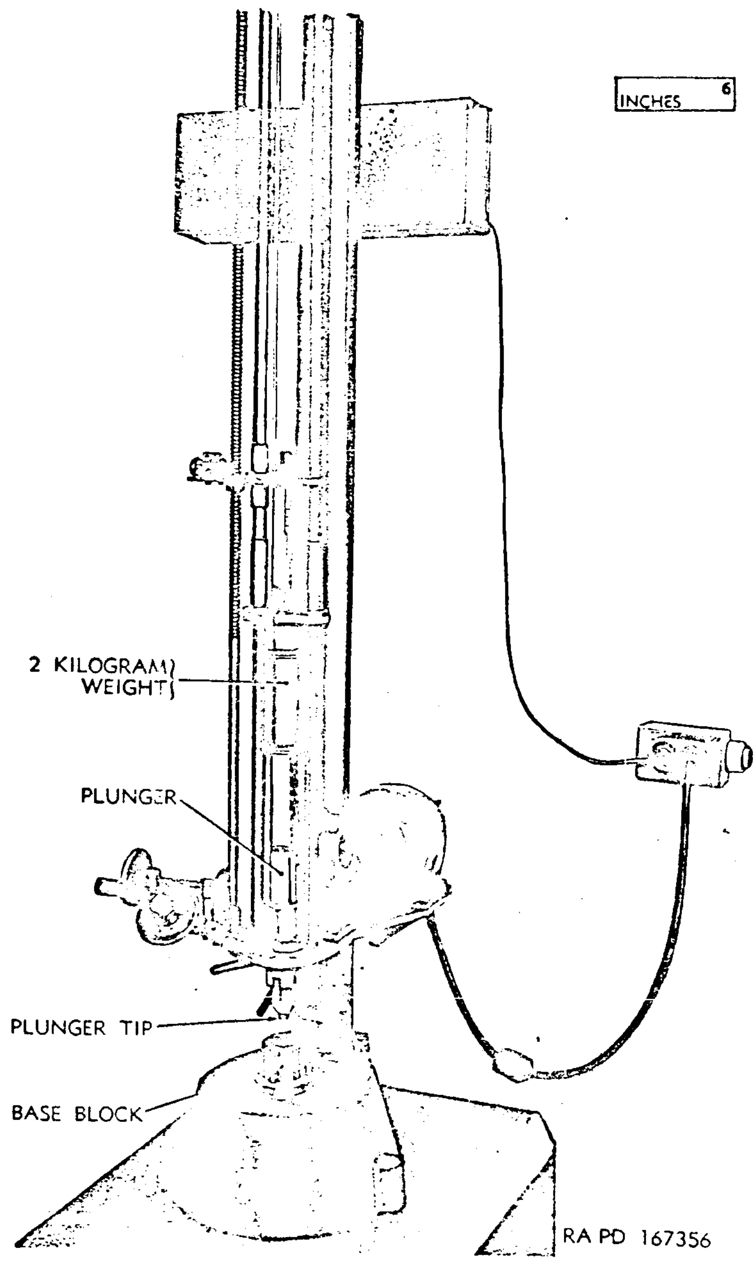


Figure 4-5. BUREAU OF MINES APPARATUS

apparatus; it is the Bureau of Mines impact apparatus. It looks somewhat more sophisticated than the Picatinny Apparatus, but is actually no better. In a few instances, it does not produce quite as good results. There are many variations in impact sensitivity which can occur. One of these variations is due to temperature and is shown in Figure 4-6. When the impact test is performed at varying temperatures, the impact height, the height to which the

Figure 4-6. EFFECT OF TEMPERATURE ON IMPACT SENSITIVITY

TEMPERATURE, °C	PICATINNY ARSENAL IMPACT TESTER HEIGHT IN INCHES		
	RDX	TNT	AMMONIUM NITRATE
25	8	14	31
75			28
80		7	
90	8	3*	
100			27
105	5	2*	
150			27
175			12*

*Molten State

weight has to be raised in order to set off the explosive or propellant under test, varies very widely with respect to temperature. The tests were performed on some of the standard military propellants and ammonium nitrate. The asterisked numbers indicate those tests in which the material was in the molten state. One can see that the molten material is extremely sensitive. Within the general using range of the explosives or propellants their sensitivity is relatively constant; i.e., up to 170°F. A number of variables have been mentioned, because the measurement of sensitivity is fraught with variables. For example, with an impact apparatus, if one has nicely polished steel surfaces and tests a primary explosive like mercury fulminate (a primary explosive being one which is very easily set off by heat or impact and is used in initiators), it usually explodes at a height of about two centimeters, on the Picatinny apparatus. PETN initiates at a height of approximately 15 centimeters and RDX at a height of 25 centimeters or so. TNT generally does not initiate on the Picatinny apparatus when using polished steel surfaces. All one has to do, is to add a thin layer of tin foil over the TNT and it becomes almost as sensitive as RDX, so the tin foil, just in intimate contact, tends to act as a physical sensitizer. Wax is another compound which may sensitize or desensitize a material. If wax is put on the surface of the sample being tested, it may lower the impact height (increase the sensitivity). But if wax is mixed intimately into the material it acts as a desensitizer, a very good desensitizer, and is in standard use in military explosives such as RDX and Composition B. Most foreign materials, when added to explosives or propellants, tend to desensitize, only if they have low melting points and they are not gritty substances, as was mentioned before. With all these variations in testing, when one tries to analyze the results in order to gain either a no-go point or an all-go point (all-fire point) the results usually fall in a normal distribution or S-shaped curve. See Figure 4-7.

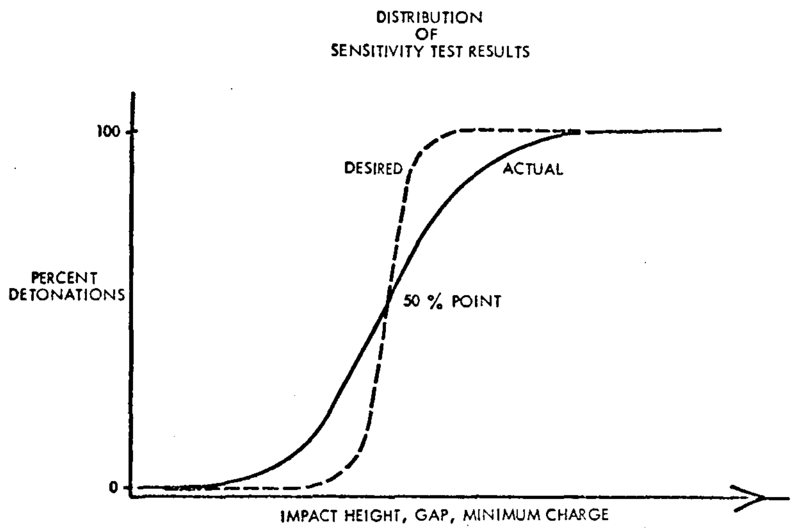


Figure 4-7

For example, assume that the impact apparatus is being used. The normal propellant no-fire point will be at one extreme, and as the impact height is increased, one starts getting more initiations. An S-shaped curve will slowly form, until the 100% point is reached, at which time the curve levels off. It is a fairly flat curve, or a gradual sloping curve, in most actual circumstances. What is really desired, is a fairly steep curve; wherein the no-go point is fairly close to the all-fire point. This may be approached by cleaning up the test methods and trying to standardize methods thereby minimizing variations. The designer, or user, of a system containing detonators or squibs, wants to know the no-fire or all-fire characteristics extreme detail; with a high reliability at a high confidence level. If it is a 1 amp no-fire squib or detonator, one wants to be sure it does not go off at 1 amp. One method, other than running thousands of tests in order to arrive at a high reliability, i.e., thousands of tests subjecting each squib to 1 amp, is to use what is called the Bruceton analysis. The Bruceton or staircase analysis method is shown below.

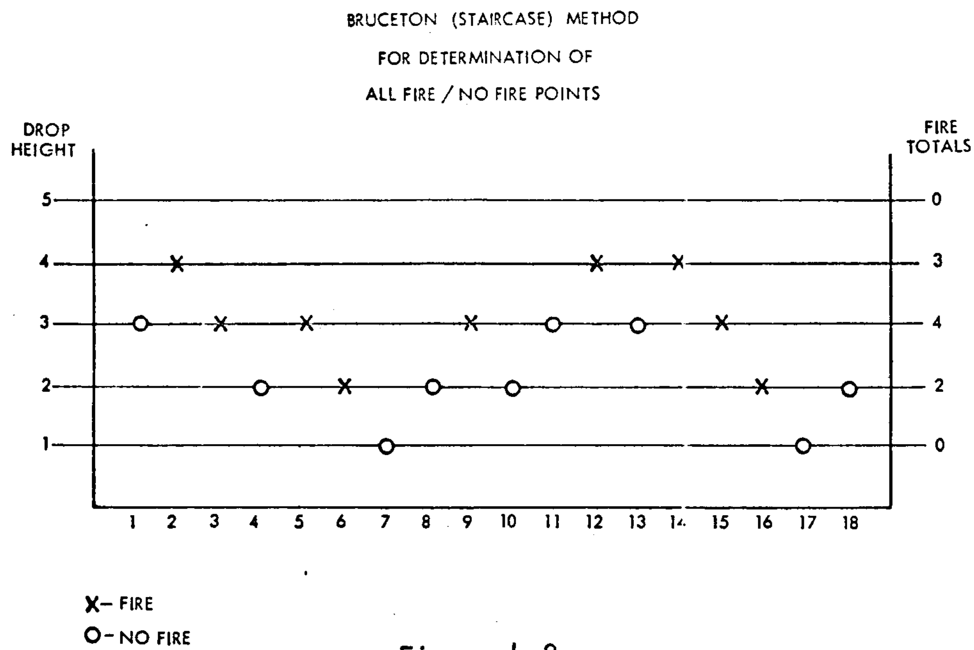


Figure 4-8

In this method, one chooses a variable; such as the drop height, in the drop test machine, or a current varying around the 50% fire current of a squib. A series of tests is run, in which each time one gets a no-fire, he will either increase the current, or increase the drop height. Each time one gets a fire, he will decrease the current, or decrease the drop height. A Bruceton analysis is run, usually with many more than the 18 tests shown in the figure. From this series, as can be seen on the right side, a distribution of results is obtained from which a determination can be made as to where the mean value lies and the variability around the mean. Once the mean value is obtained, using statistical processes, one can derive, with a high reliability, results which show that no detonation or no firing will occur at a certain point. For example, in this instance, one may get an answer that, with a 99/ reliability at 90/ confidence level, no samples will fire when the weight is dropped from 1 centimeter. The main advantage of the Bruceton analysis, is to reduce the number of test items required for a given reliability. One can imagine, that if the items cost $1,000 apiece, it would be senseless to shoot up a thousand items; especially if he can get the same or equivalent result with 50 items. Determining no-fire characteristics and all-fire characteristics is a very important analysis with regard to safety.

4.3 Frictional Sensitivity and Tests

Friction sensitivity, as was mentioned earlier, is similar to impact, in the sense that it is explained by localized hot spots being produced. Figure 4-9

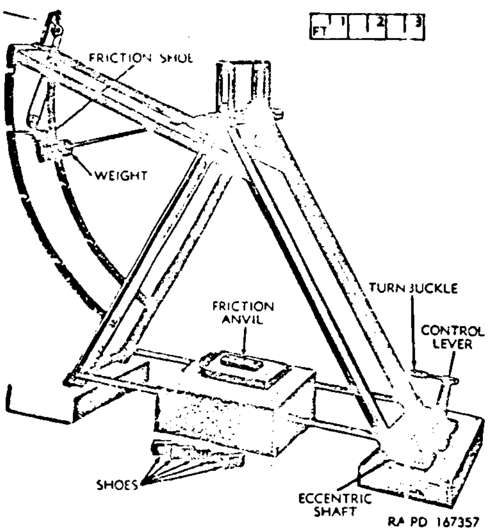


Figure 4-9. PENDULUM FRICTION TEST APPARATUS

illustrates one piece of apparatus that is used in determining friction sensitivity of a material. It consists of a pendulum with a weight, attached to the end is a friction shoe, (either a fiber shoe or a steel shoe), and the friction anvil, which is a serrated or grooved anvil, on which some explosive is placed. The test is performed by releasing the pendulum and allowing it to brush across the anvil; determining through use of the Three S system, how many initiations, snaps, crackles or pops occur. Usually, one tests about 10 samples and the results are turned out as the number of initiations per the ten samples, or percentage of initiations. There is not much of a correlation between the results one obtains from the impact test or the friction test. The only thing that can be said about it is that the friction test appears to use at least as much kinetic energy as the impact test.

4.4 Bullet Impact Test

The Bullet Impact Test is a combination of friction and impact. It utilizes a

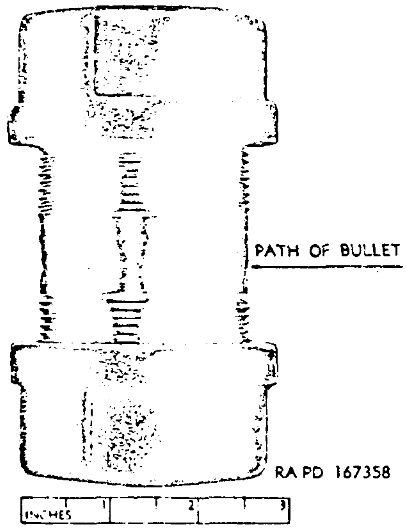


Figure 4-10. BULLET IMPACT TEST BOMB

very complicated piece of equipment; a piece of pipe with two end caps screwed onto it. This type of test may seem to have more of a military value. But it does produce results, which do tend to fall into the same category as friction and impact sensitivity tests. This test is performed with a piece of explosive loaded pipe and, at a range of 30 yards, a .30 caliber bullet is fired into it; determination is made whether the explosive initiated, burned, or what did happen. Obviously, a test like this supplies much more energy, to the material being tested, than the friction test or the impact test. The sensitivity of a material undergoing this test, depends very much on the strength of the container and some of the physical properties of the material itself. For example, if one takes pure, loosely packed, powdered RDX or Composition B, these will usually be initiated by bullet impact, even if they are simply contained in a paper container. Only the very insensitive materials fail to initiate in this test, unless heavily encased; for example, TNT. In general, regarding sensitivity, a low density powder tends to be more sensitive than a cast material; which in turn, is somewhat more sensitive than a very highly pressed material.

Under some relatively standard conditions for the bullet impact test, the normal ratings of the common explosives (from lower sensitivity to increasing sensitivity) are: TNT at the least sensitive end; Composition B, Tetryl, RDX and PETN at the more highly sensitive end. This is approximately the same order that results with the impact and friction type machines; primarily the impact machines. A side effect, however, comes into being with the bullet impact test - size. TNT didn't show reproducibly in a small bullet impact test; however, a large bomb filled with TNT will almost always go off with at least a low order detonation. Aluminum is a sensitizer when it comes to the bullet impact test, especially in large charges. This can be explained due to the aluminum particles causing numerous hot spots in the material.

4.5 Heat Sensitivity and Tests

Heat, as was said earlier, tends to cause the decomposition of a material and increases the rate of reaction as the temperature increases. Most propellants and explosives exhibit a critical high temperature, below which the material is very stable and above which it becomes less stable. Nitroglycerin, for example, has a temperature in the area of about 125°F. Above 125°F, it starts undergoing some adverse changes after a period of time; whereas below 125°F, there are no effects due to aging. TNT and Tetryl, and a number of the other highly used military explosives, have critical temperatures up in the hundreds of degrees.

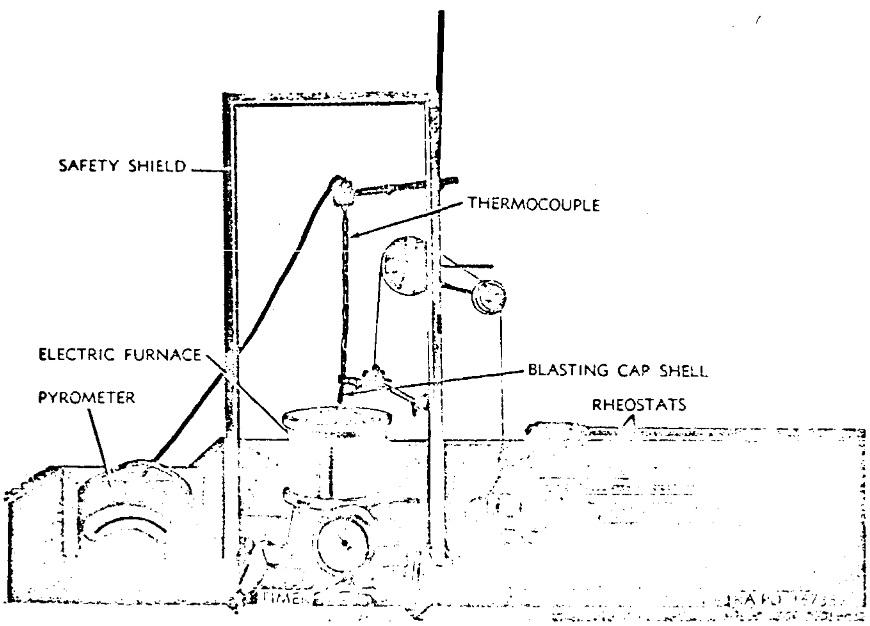


Figure 4-11. EXPLOSION TEMPERATURE TEST APPARATUS

Figure 4-11 illustrates one of the pieces of equipment used for determining explosion temperature. It is a relatively simple arrangement, primarily an electric furnace, in which is put some Wood's metal, (a low melting point metal that is used in sprinkler systems for fires), and an empty blasting cap shell. The explosive, or propellant, is loaded in the shell and is lowered into the molten Wood's metal. The object is to try to obtain the temperature at which flashes, detonations, or reactions occur. The test is run over a small range of temperatures, then it is determined at what temperature the test sample exploded in a five-second period. The five-second temperature is one of the standard ways of recording this sensitivity. Another similar method, uses molten Wood's metal on which particles of the material are dropped, and, using the Three S system, it is determined whether or not it reacted.

4.6 Spark Sensitivity

Another type of sensitivity test is electrostatic sensitivity testing. We are all familiar with the fact that electroexplosive devices tend to be sensitive devices, when it comes to electrostatic discharges. One, therefore, protects against electrostatic or arc discharges across electroexplosive devices. As far as explosives and propellants are concerned, there is no standardized type of test. The results of some tests are shown in Figure 4-12.

SENSITIVITY OF EXPLOSIVES
TO
ELECTRIC SPARKS

HAZARDOUS	NOT HAZARDOUS
Black Powder	PETN
Lead Azide	RDX
Mercury Fulminate	TNT
Tetryl	

Figure 4-12

PETN, RDX, and TNT are relatively nonhazardous, when it comes to electrostatic type discharges. A look at the hazardous side of Figure 4-12 shows, however, that most of the primary explosives are sensitive to electrostatic discharge. Tetryl, though not a primary explosive, is somewhat sensitive to discharges. Black powder heads the list--it is extremely hazardous when it comes to electrostatic discharge. There is another type of sparking action which may cause an initiation of a material. This is the nonelectric-type spark, i.e., those produced in grinding operations, or hammering on another metal. Most explosives and propellants are hazardous with respect to this type of hot spark. This is one of the prime reasons that nonsparking tools are used in all assembly operations having explosive devices. Black powder, again, tends to lead the list as far as being the most hazardous item.

4.7 Solid Propellant Sensitivity

The tests that have been discussed usually give very good correlation with respect to explosives handling experience obtained over a number of years. If an explosive shows up as a very low impact sensitive item, it usually has not experienced too many inadvertent initiations due to impact, and the opposite holds true for a highly sensitive impact item. But, when it comes to using some of these tests for screening solid propellants, the results do not appear to correlate too well with actual experience. Many times, a propellant which has been in standard use for a number of years looks hazardous by virtue of the results of an impact or friction testing machine. A number of tests indicate these propellants to be just as sensitive as some of the high explosives.

- Card Gap Test

  Figure 4-13 illustrates a test which seems to give reasonable correlation with the actual handling experience of propellants. The sensitivity of the sample is determined by attempting to detonate it with a Tetryl booster which is separated from the sample by a varying thickness of inert material (.010 inch thick cellulose acetate cards). The greater the number of cards through which the shock wave from the donor detonates the sample, the greater is the sensitivity of the sample. This test is performed by varying the number of cards (slowly increasing) until no detonations of the propellant are obtained. Points are then determined for 0, 50 and 100%. This, again, is suited very well to a Bruceton analysis, in order to arrive at highly reliable results with a minimum number of samples. The criteria for detonation of a propellant or a nondetonation are its effect

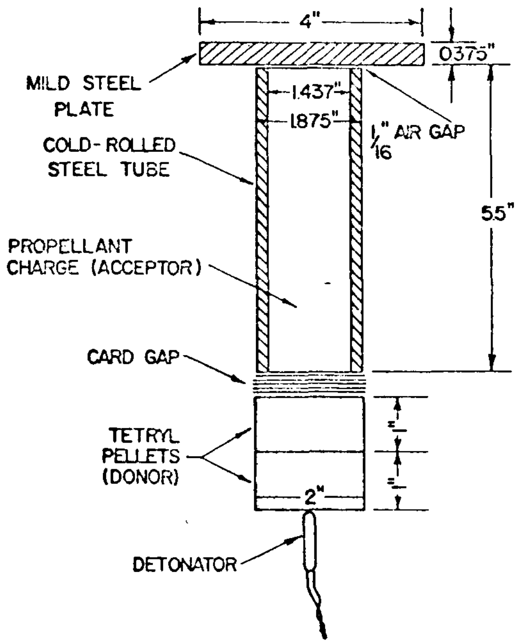


Figure 4-13. SHOCK SENSITIVITY TEST APPARATUS

on the witness plate. A detonation punches a clean hole through the witness plate, whereas a nondetonation, or a burning action, will either do no damage or slightly bow or dent it. Looking at the results of some of the double base and composite propellants, most of the composite propellants, most of the composite propellants, polyurethene, polyvinylchloride types, do not detonate in the diameter tested. "In the diameter tested" is mentioned because there is a variability, which will be covered later, called the "critical diameter" of the material. The double base propellants, on the other hand, do sometimes detonate. This is especially true, if they have an explosive binder included within them. Then, they do detonate and act like explosives.

- Defective Propellant Grains

There is another area of concern in solid propellant sensitivity, and this is defective grains. Solid propellants are sometimes notorious for exploding, either during or after ignition. Some investigations performed by Dr. Bryan and his associates were concerned with the sensitizing effect of voids in solid propellants, (holes, cracks, or bubbles). Figure 4-14 illustrates some of the results obtained. The vertical axis shows card gap test results; i.e., the higher the number of cards through which a detonation occurs, the more sensitive the sample is. The horizontal axis shows card gap test variations with temperature. A solid propellant with no defects looks fairly insensitive. As the number of voids start increasing, the sensitivity appears to increase. Note that there are two types of voids shown: continuous voids, which could be cracks that run through the material; and noncontinuous voids, small bubbles throughout the material. There is not much variation in sensitivity, with respect to temperature, with the continuous voids. However, when one looks at the results for the

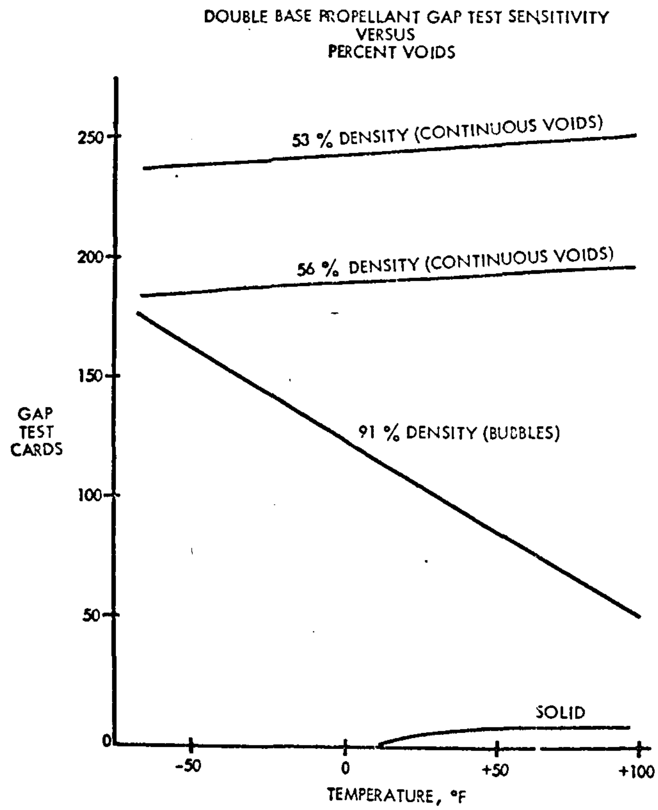


Figure 4-14

noncontinuous voids, (or bubbles), it was initially a bit shocking to see how sensitive the samples became at lower temperatures. This was subsequently explained along the lines that: although there may be discontinuous bubbles throughout the material, at the lower temperatures these materials are more brittle, and as the material is hit with a shock or an ignition shock, it is simultaneously heating and starting to burn, thus cracking the propellant. A number of small cracks running through the propellant, connecting the different bubbles and increasing the surface area, results in an essentially continuous void in the propellant. It is obvious then, that there is a tremendous difference in sensitivity of solid propellants, with respect to the number of voids or defects that are present in a grain.

5.0 CROSSOVER PROBLEMS

One of the problems encountered in all tests performed is called "crossover." Crossover is a term which explains that results obtained from one test may not necessarily be in the same sequence as other tests. Different type tests show different sensitivity relationships. The solid propellant card gap test shows one sensitivity and the friction or impact test is another sensitivity. (See Figure 4-15.)

RELATIVE SENSITIVITIES OF CERTAIN PROPELLANTS AND EXPLOSIVES BY SEVERAL TEST METHODS

IMPACT I	IMPACT II	GAP TEST	AUTO-IGNITION TEMPERATURE	ELECTROSTATIC	CRITICAL RADIUS FOR AUTO-IGNITION
TNT	TNT	Double Base	TNT	Double Base	RDX
RDX	RDX Tetryl	TNT	Lead Azide	TNT Tetryl	TNT
Tetryl PETN	Double Base	Tetryl	RDX	PETN	Composite
Lead Azide	Lead Azide		Tetryl	Lead Azide	Double Base
	PETN		PETN		

Figure 4-15

There is a crossover between the first two impact tests, shown on the left portion, between the lead azide and PETN. Normally, lead azide is an extremely sensitive material and PETN is somewhat less sensitive. But in the second impact test, the lead azide showed up as less sensitive than PETN. By the way, increase in sensitivity is downward on this chart. Looking at lead azide in the remainder of the tests, if one were to judge the sensitivity of lead azide only on temperature results, one might think it was a fairly safe nonsensitive explosive, almost as good as TNT. But one has to look at all the characteristics. Lead azide auto-ignition temperature is the only type of sensitivity that is low. Looking at the double base propellants shown in the figure, the shock test shows different results than the impact test. There is, again, a crossover between the double base and the TNT, or the others. The last test on the right, is an analytical evaluation of the explosives and propellants similar to the radioactive material critical mass. It is assumed here that a larger and larger diameter sphere of the explosive or propellant is constructed, and finally a point is reached where internal decomposition products, and the temperatures produced, cause initiation of the material itself. Luckily though, the diameters arrived at in this analysis are much larger than diameters being used in any missile or space system, now or in the future. However, this is another method of evaluating a possible mode of sensitivity.

6.0 SCALE-UP PROBLEMS

Another factor in evaluating the results of tests is the scale-up factor. It is the comparison of test results between small scale (few milligram samples up to a few pounds) to the amount actually used in full scale rocket motors. As was stated earlier, and as can be seen in the next figure, there is a parameter called the critical diameter of an explosive or a propellant. The critical diameter is the diameter of a material, below which the material will not sustain a detonation and above which, it will sustain a detonation if it is initiated. RDX and PETN, on the left side of the figure, have relatively small critical diameters, in the area of less than a half centimeter or so, depending on the confinement. TNT has a somewhat greater critical diameter. Propellants (ammonium nitrate for example) have a much larger critical diameter than normal military explosives. Some propellants don't have an apparent critical diameter; i.e., they never detonate. Critical diameter is an important fact in evaluating the results of sensitivity tests. Although a sample may show up as a nondetonable in a small diameter, it may show up as detonable in the full scale application. There are a number of full scale tests that are important and must be performed in evaluating sensitivity of missile systems, as shown in Figure 4-17. These tests were for a particular missile system which was developed. The smaller upper stage in the left portion is known to be a

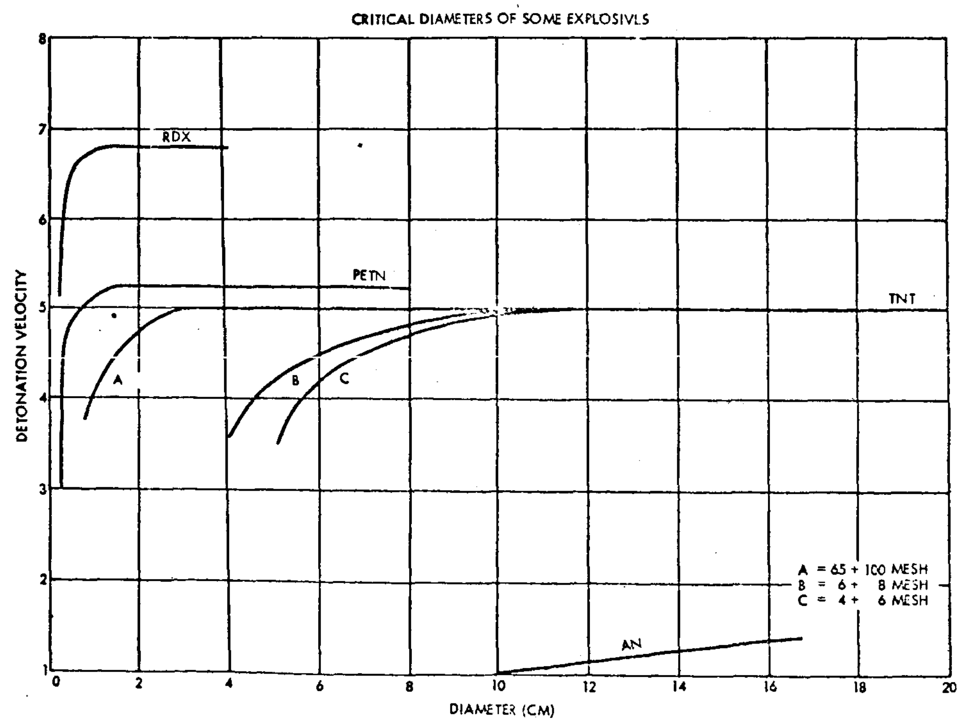


Figure 4-16

Figure 4-17. FULL SCALE TEST

detonable propellant. The larger stage on the right was not known to be detonable at the time. What was done then, in a sense, was to booster it, similarly to a card gap test in effect, with the upper stage as the donor. It was desired to find out whether the lower stage would detonate. The method used was to initiate the upper stage to see if it would, in turn, initiate the lower stage.

These full scale tests are very important when it comes to the ICC and military hazard classification of the item for transportation and storage. This type of testing is important in determining the ICC and military hazard classification for storage and shipment. Class A, detonable-type propellant, according to the ICC standards has to be handled a lot more carefully than a Class B or burning type propellant.

7.0 CONCLUSIONS

In general, in handling any of these materials, there are a few general rules, shown in Figure 4-18, which should be lived by when handling any propellants or explosive items. These rules happen to be taken directly from the explosive industry, but are applicable to anyone handling these materials. The prescribed safety regulations are usually based on as much data as possible, from all tests, and are usually very conservative. Assembling an item, or disassembling an item, should not be done near other propellants or explosives, or in an area where

GENERAL RULES FOR HANDLING EXPLOSIVES

1. Consult the prescribed safety regulations.
2. Conduct all work in the prescribed space, never near storage spaces of bulk explosives or propellants.
3. Keep all work areas free from contaminants.
4. Avoid accumulation of charges of static electricity.
5. Avoid flame and spark-producing equipment.
6. Keep to a minimum the number of personnel at work in the same area, but one man should never work alone.
7. Be sure that the chambers for "loading" and "exploding" are well shielded.

Figure 4-18

there might be extraneous people. Reasons for keeping an area free of contaminants is obvious. One doesn't want to have something sensitized by having sand or grit get into it.

Nonsparking type shoes and grounding straps are extremely important when it comes to electroexplosive devices. Care must be taken not to use the handy screwdriver you happen to have in your back pocket. Never use a steel screwdriver when working on explosive items. Keep the number of personnel down in an area where work is going on. That is important. Loading and unloading in the proper areas reduces the danger to other people.

Modern high-energy propellants either contain explosives, in varying degrees, or behave in a similar fashion to explosives, with respect to input energy and output energy. Propellants and explosives can be handled with safety, as has been demonstrated in the many years of their use. However, with the number of new compositions being developed and the variability of sensitivity test results, one must use care in evaluating the characteristics of an item with respect to its safety.

Lecture Number Five

"SPECIAL PROBLEMS OF LIQUID PROPELLANTS"

Part I

Mr. L. T. Dombras

1.0 INTRODUCTION

Since liquid propellants are used to produce large volumes of gases at extremely high temperatures, they are inherently dangerous. In some cases, the reaction products are also hazardous. Therefore, to prevent accidents, all personnel involved in operations using these propellants should be trained to handle them properly.

Numerous liquid propellants have been successfully used and many more exotic propellants are contemplated in future rocket and control systems. A perfect propellant combination, that is, one having no undesirable qualities, has yet to be discovered. As a matter of fact, some liquid propellant chemists appear to follow the theory that if a substance is discovered which has an evil smell, is highly toxic, corrosive, explosive, and generally dangerous it very probably would make a good propellant.

Oxidizers are notorious for being particularly corrosive and hazardous. Most oxidizers react readily with hydrocarbons such as paint, oils, and many other substances normally found around launch areas. Fuels, on the other hand, in the presence of air or an oxidizer, are dangerous from the fire hazard standpoint.

2.0 PRINCIPLES OF LIQUID PROPELLANT MOTORS

The same basic principles and calculations used in evaluating solid propellant motors apply to the liquid propellants. In both cases, the source of energy for propelling a rocket is contained as latent chemical energy. This energy is released during the chemical reaction. The heat from the chemical reaction is imparted to the gaseous products which escape through the throat area of the rocket motor. The nozzle provides the means for efficiently expanding the gases so that the heat energy is converted into kinetic energy which propels the vehicle.

In most cases, the high combustion temperatures of liquid propellants require cooling of the thrust chamber and portions of the nozzle assembly. This cooling is accomplished by transferring the heat to one of the propellants prior to its injection.

Liquid propellant systems are generally more complicated than solid motors. At this time, liquid propellant motors have many advantages over the solids; specifically, the capability of being throttled to various thrust levels and, of course, they can be turned on and off during flight. This is a definite advantage if in-flight trajectory correction is required. Solid rockets soon will be capable of reliable restarts; however, more research is needed in this particular area.

The figure of merit used to evaluate liquid propellants is called the specific impulse (I_{sp}). Specific impulse is defined as the amount of thrust in pounds of force delivered for each pound of mass of propellant flowing in one second. From a chemical standpoint, it may also be defined as being proportional to the square root of the heat of reaction and inversely proportional to the square root of the average molecular weight of the exhaust products.

$$I_{sp} = \frac{F}{\dot{w}} = \left(\frac{K\Delta H}{\overline{M}}\right)^{\frac{1}{2}}$$

where: F = thrust in pounds - force

$\dot{w}$ = flow rate in pounds per second

K = mechanical-heat conversion factor

ΔH = heat of reaction

$\overline{M}$ = average molecular weight of exhaust

The above equation shows that in order to achieve high specific impulse, the chemical reaction should produce a large amount of heat per unit mass and the exhaust products should have as low a molecular weight as possible. This is why a combination of diborane (B_2H_6) and oxygen difluoride (OF_2) produces such a high specific impulse. These propellants produce high combustion temperatures and reaction products with a very low molecular weight.

The oxidizer-to-fuel mixture ratio must be controlled to provide the maximum possible specific impulse. In some cases, a trade-off is necessary between the combustion temperature and the molecular weight of the exhaust products. Most propellant combinations produce the highest combustion temperature at the stoichiometric (theoretical chemical mixture) ratio. With some propellant combinations, a higher specific impulse can be achieved by operating slightly on the fuel-rich side. This results in a slightly lower combustion temperature but has the advantage of a lower average molecular weight of the exhaust products, since they contain more hydrogen. This trade-off is called the "optimum mixture ratio."

3.0 GENERAL PROPELLANT REQUIREMENTS

In choosing a propellant combination for a specific mission or project, four major factors must be considered: economics, physical properties of the propellants, chemical properties, and the operational requirements.

3.1 Economic Factors in Selecting Liquid Propellants

One of the primary economic factors considered in selecting a liquid propellant combination is cost. A large percentage of propellant research money is allocated to evaluating the hazards of the propellant system. Additionally, the relative cost on a pound basis and the size of the mission involved determine which propellant combination will be used. A large booster of the Saturn V category will require a large quantity of propellant. Approximately 5 to 7 years are required in developing a missile or large booster system. The large number of tests and static firings required during this period can become extremely expensive.

Another factor which must be considered is the availability of raw materials required to manufacture the propellant. Although some exotic propellants produce very high specific impulses, they cannot yet be manufactured in the quantities necessary for engine development and qualification. Facilities and equipment necessary for the production of rocket propellants should be available to eliminate unnecessary delays during the engine research phase.

3.2 Physical Properties Desired in Liquid Propellants

- High density is desirable in a propellant since a greater mass can be carried in a relatively small airframe. Large tanks mean more weight and are more vulnerable to meteriod impact and the effects of solar radiation in outer space.

- Low vapor pressure is a desirable quality. Propellants having relatively high vapor pressures can overpressurize the missile tankage if the temperature becomes too high. A low vapor pressure is also important because it reduces the possibility of pump cavitation which results when gas bubbles are formed at the inlet of a high speed pump.

- A low freezing poing is required if launches are anticipated during cold periods. Even more important is the extremely low temperature encountered in space. The propellant must not freeze or slush or it will block small openings and valves.

- Low viscosity propellants simplify pumping problems. It allows better injection and mixing of the propellants and provides better combustion and, therefore, better specific impulse. Low viscosity propellants also simplify pump, thrust chamber and injector designs.

3.3 Chemical Properties Desired in Liquid Propellants

There are many chemical properties desirable in liquid propellants. A discussion of these properties follows.

- High Heat of Combustion - Highly reactive propellant combinations which produce a high heat of combustion are desirable since these combinations generally provide high specific impulse. Many highly reactive propellants have been synthesized; however, because of cost and availability, they are not ready for use in large booster systems.

- Low Molecular Weight of Exhaust Products - High specific impulses are achieved with propellants having very low molecular weight exhaust products. This is the reason LH_2 is used in interplanetary spacecraft; it provides the high impulse required of the upper stage motors.

- Chemical Stability - Chemical stability is desirable if propellants are to be transported over long distances, stored for long periods at the launch area, or used in very long space flights which require restarts.

- Low Ignition Delay - In very large, high thrust rocket systems, propellant flow rates may be of the order of thousands of pounds per second. Ignition delays of any significant magnitude, during engine start and during the inject on process, can result in instability and destruction of the engine. The ignition delay time, therefore, must be minimized. In some cases this can be done by slightly preheating the propellants or by using chemical sensitizing agents.

- Non-Corrosiveness - Propellants should be compatible with the materials in the airframe tankage and motor. With the exception of liquid oxygen, most oxidizers in current use have corrosive qualities. This problem is circumvented by choosing compatible materials or by special treatment of surfaces which will be exposed to corrosion.

3.4 Operational Requirements of Liquid Propellants

In some cases the choice of a liquid propellant is affected by the operational requirements imposed by launch facilities or program objectives. These operational requirements apply more to military ballistic missiles than space booster systems. Some factors which must be considered are:

- Stability - Propellants should be stable over long storage periods.
- Sensitivity - Propellants should be insensitive to mechanical shock.
- Toxicity - Toxicity should be minimized if boosters containing large amounts of propellants are launched near inhabited areas.
- Reactivity - Propellants should not react with materials used in storage tanks, missile tanks, or motor components.

Some military missions require that the reaction products be difficult to detect visually and that they have a minimum attenuation of RF signals.

4.0 LIQUID PROPELLANT SYSTEMS

Various propellant systems have evolved and have been developed for different applications. A brief discussion of these systems follows:

4.1 Monopropellants

A monopropellant is normally a stable liquid under ambient pressures and temperatures. When suitably initiated, it decomposes to produce hot gases without the addition of either a fuel or oxidizer. Some examples are hydrogen peroxide, ethylene oxide, hydrazine, and nitromethane.

These propellants can be decomposed by several techniques. Most monopropellants will react simply by elevating their temperature to the decomposition point or by introducing catalysts. Hydrogen peroxide, for example, reacts vigorously when in contact with silver or potassium permanganate. The V-2 and Redstone turbo-pumps were driven by hot gases produced by passing hydrogen peroxide through a catalyst bed of potassium permanganate.

The specific impulse of monopropellants is relatively low when compared with other liquid propellant systems. They are used primarily in gas generators, vector control devices, and retro systems. Their prime attribute is simplicity.

4.2 Bipropellants

Bipropellants are the most common systems used in present day rockets. They consist of a liquid oxidizer and a liquid fuel which are injected independently into the combustion chamber. These systems are relatively complex since they require two different propellant tanks, turbo-pumps, and pressurization systems. However, they do produce the highest specific impulses obtainable with conventional propellant systems.

In the future, it is highly probable that liquid hydrogen and liquid fluorine will be used. This combination offers the highest performance potential of presently known chemical propellants. The handling and materials problems for great quantities of these propellants must be overcome before they can be used for space operations.

4.3 Hybrid Propellant Combinations

Hybrid propellant combinations consist of one solid and one liquid propellant. The general configuration of a hybrid propellant rocket consists of a solid grain having an internal passage through which liquid propellant is injected. The liquid reacts with the solid on contact and creates the high pressure and high temperature gases required for propulsion. Considerable research is presently in progress to develop hybrid systems because they are simple, require pumping only one liquid, and can be repetitively turned on and off. The problem which must be overcome is inadvertent breakup of a solid propellant causing it to be expelled from the nozzle, thereby lowering the total impulse of the system. Another obstacle which must be overcome is the development of a proper injection and mixing system which will maintain a relatively constant chamber pressure and oxidizer to fuel burning ratio.

4.4 Thixotropic Propellants

It has been recognized for some time that marked increases in impulse can be achieved by adding finely ground metals or hydrides to liquid propellants. The major problem encountered has been in keeping these fine metallic particles suspended so that the mixture is homogenous. Recently, methods have been devised for suspending solids in liquids by making them gelatinous - very much like "Jello". These mixtures, when in a gel form, are called thixotropic. Under ordinary conditions the finely ground metals are added to the fuel, the fuel is mixed thoroughly and, when agitation has ceased, the propellant turns into a gel which can be stored for considerable time. When the gel is submitted to a shear force it immediately becomes a liquid. Large boosters of the future may very well utilize thixotropic propellants containing fine suspensions of aluminum, beryllium, lithium, or their hydrides.

engine start, the pyrophoric is injected into the thrust chamber with the fuel, and on contact with the oxygen, it ignites. Ignition by this technique is generally smooth. Pyrophoric compounds must be handled carefully since a leak or spill will produce a fire if air or any oxidizer is present.

5.3 Pyrotechnic Devices

These igniters consist of a small solid propellant charge which produces a high temperature flame. A small squib is usually initiated by an electrical bridgewire which in turn ignites a larger solid initiator. Various designs are used in current rocket systems; for example, the Titan I incorporated a series of initiators arranged in a Christmas tree configuration. This arrangement increased the ignition reliability and assured a large amount of flame during the start phase.

Another pyrotechnic device, used mostly in large solid motors, is the "pyrogen" igniter. This device is similar to a small solid propellant rocket. Holes in its case direct jets of flame into the rocket's main motor chamber. This intense flame quickly ignites all exposed uninhibited surface of the propellant grain. Pyrogen igniters are reliable, provide reproducible starts and are easily installed or replaced.

5.4 Ignition by Electrical Energy

Electrical energy may be used to ignite small motors directly or larger motors indirectly.

Small rocket motors can be successfully ignited by electrical energy using glow plugs, hot wires, arcs and exploding bridgewires.

Large rocket motors require a tremendous amount of energy to provide reliable ignition; therefore, electrical devices are used to initiate small squibs which in turn ignite larger initiators.

5.5 Hypergolic Ignition

Hypergolic propellants ignite spontaneously when mixed together at ambient pressure and temperature. Some well known rockets using hypergolic propellants are Vanguard (Stage II), Titan II, and Agena. This type of ignition is desirable as it eliminates the need for igniters and electrical devices (other than valve solenoids). Hypergolic propellants provide a reliable means for repeated starts in space and lunar return missions.

6.0 HAZARDS ASSOCIATED WITH LIQUID PROPELLANTS

There are many and varied hazards associated with liquid propellants. Some of these are discussed below.

6.1 Cryogenic Hazards

- Cryogens, being extremely cold, can damage skin tissue and result in serious permanent injury.
- Very large spills have been known to weaken the structural materials normally found on launch complexes.
- Cryogens must not be trapped in closed systems which do not contain a suitable venting capability. The gases formed can generate sufficient pressure to produce an explosion. A relief valve or burst disc (or both) is mandatory to prevent overpressures.
- Another hazard which may be encountered with cryogens, such as liquid helium and hydrogen, is that air will condense and freeze in these liquids if allowed in the system, thereby becoming enriched with oxygen. If the containers are not free of hydrocarbons, a serious fire hazard and possible explosion can occur.
- Rapid pumping of cryogens into warm storage or missile tanks can result in sudden flash-off and the evolution of tremendous quantities of gas which could result in rupture of the system.

6.2 Contamination Hazards

Numerous fires and small explosions have been reported which were the result of unclean liquid oxygen systems. Oil films left in the system as a result of improper degreasing techniques or from fingerprints can react with liquid oxygen under proper conditions. Adequate quality control and frequent system sampling will help eliminate this problem.

In some instances, nitrogen tetroxide systems may require detanking and neutralization of residual propellants. Recent investigations indicate that some of the cleaning solutions used in these tanks reacted with residual nitrogen tetroxide and formed explosive products. By following recommended procedures and by using authorized neutralizing agents, accidents of this nature can be eliminated.

Hydrogen peroxide, although a monopropellant, can be handled safely if proper precautions are taken. Since hydrogen peroxide reacts readily in the presence of catalytic agents, it must be stored in containers which have been passivated. This passivation process involves treating the surface of containers or piping, either with chemicals or by exposing them to reduced concentrations of hydrogen peroxide. Unless this is done, concentrated hydrogen peroxide will react slowly, bubbles of gas and heat will be evolved, thereby causing a buildup in pressure and an increase in the reaction rate. If the reaction becomes too rapid, a violent explosion may result.

6.3 Static Electricity Problems

Static electricity has been the cause of numerous fires and explosions. Fluids, either conductive or non-conductive, will build up a static potential if sprayed or allowed to drop through air or vapors. If the pumping systems are not thoroughly bonded to a common ground, a spark can occur. Several cases have been reported where gasoline and similar substances were ignited by static discharge during a pumping process. It is recommended that, if possible, liquids be pumped into the bottom of a tank or, if this is not possible, from the top through a long stand pipe with an opening which is below liquid level. The wide flammability range and low ignition energy recuired to initiate combustion of hydrogen requires extra precautions.

6.4 Spills

Several accidents have been reported which are believed to have been caused by spilling liquid oxygen on the ground. One of these accidents occurred during a liquid oxygen transfer from a truck to a storage tank. A steady leak of liquid oxygen apparently penetrated the surface of a macadam road. Subsequently, a technician dropped a wrench on the spill area and an explosion occurred resulting in serious injury and extensive property damage.

In working with hypergolic propellants, care must be exercised to prevent leaks. Fires have been reported which resulted from spillage of UDMH which penetrated the surface of the paint of an engine test facility. Although the area of spillage was cleaned, a later spill of a small amount of oxidizer caused a fire. Many booster engine systems contain a large number of transducers and propellant lines which are wrapped with reflective foil to protect them from radiation temperatures. The accumulation of propellants under these wrappings must be avoided.

Hypergolic propellants present serious fire hazards if spills are not neutralized. Wherever possible, the fuel and oxidizer systems must be separated and care must be exercised to eliminate the possibility of using a fuel system component in an oxidizer system. This is best achieved by using different fittings or line sizes to differentiate between oxidizer and fuel system component.

6.5 Adiabatic Compression and Ignition

Ignition of propellants has occurred as a result of adiabatic compression of gaseous bubbles in a liquid system. An adiabatic process is defined as one in which no heat enters or leaves a system. If a gas bubble is compressed very rapidly, very high temperatures can be attained in the compressed gas. The theoretical temperature which may be attained by adiabatic compression is shown below.

THEORETICAL TEMPERATURE ATTAINED

BY ADIABATIC COMPRESSION

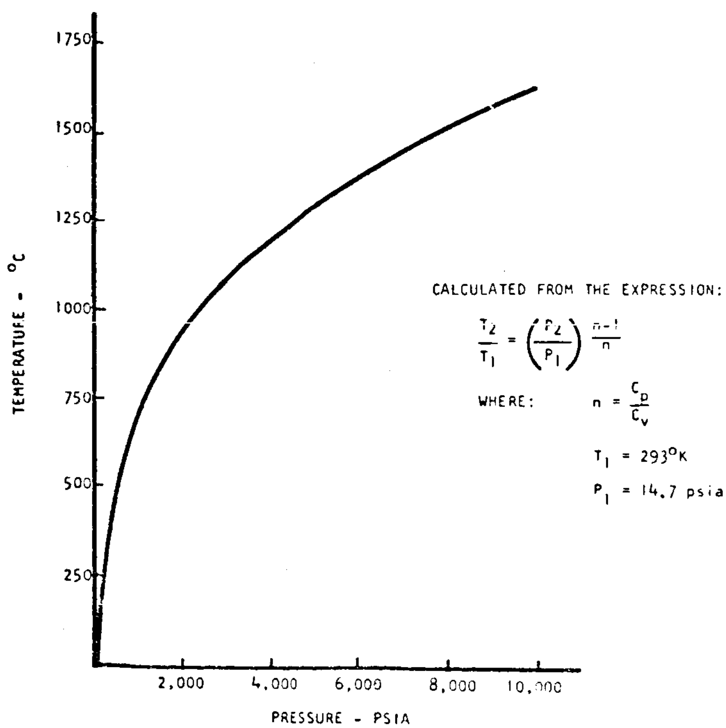


Figure 5-1

If a bubble is instantaneously compressed to about 2000 psia (which is possible in high velocity pumping systems), a temperature of almost 900°C. (1650°F.) can be attained. If a contaminant is present or if the liquid is a monopropellant, a small reaction is possible which can trigger a more serious monopropellant explosion. Adiabatic compression problems can be avoided by incorporating pressure accumulators, or by closing system valves slowly to prevent "water-hammer" effects.

7.0 CONCLUSIONS

In conclusion, the most serious safety hazard involved in dealing with liquid propellants is not the propellants themselves but the personnel handling them. Personnel working with liquid propellants, in many cases, become disdainful of the inherent hazards. Initial training must be followed by a continuous training program which incorporates demonstrations, qualification tests, lectures, and pertinent up-to-date information on accident prevention techniques.

A follow-up training program of this type will serve two purposes:

1. It will prevent the occurrence of accidents which normally result from boredom.
2. It will bring personnel up-to-date on accidents which have occurred, will increase their knowledge of propellant hazards and will train them in the hazards anticipated with future propellants.

N67-15989

Lecture Number Five

"SPECIAL PROBLEMS OF LIQUID PROPELLANTS"

Part II

Mr. G. N. Woodruff

1.0 TOXIC PROPELLANTS

Toxicity is one of the major problems associated with certain liquid propellants. Typical of toxic propellants are nitrogen tetroxide (N_2O_4), Unsymmetrical dimethylhydrazine (UDMH), fluorine, hydrazine, monomethylhydrazine (MMH), and chlorine trifluoride (CTF).

2.0 DEFINING TOXIC HAZARD LIMITS

"Toxic" means that inhalation of enough of the vapor, or skin contact with the liquid, will be injurious to health in some manner. The word "toxic" implies to the layman rapid injury or death, however, this is not the same meaning that industrial hygienists apply to the word. "Toxic" does not define a hazard since a great many things with which we come in daily contact are toxic to some degree. To define the toxic hazard associated with a propellant, or for that matter, any material, some numerical value is required. There are several numerical values which apply to work in the missile launching and space fields; the most important of these are the Maximum Allowable Concentration and the Emergency Tolerance Limit.

2.1 The Maximum Allowable Concentration (MAC)

The limits of toxicity which have been accurately established are the lower limits; that is, the concentrations which present no danger to humans. The working lower limit is called the Maximum Allowable Concentration (MAC). The MAC represents a figure for vapor or dust concentrations to which a human can be exposed for 8 hours a day, 5 days a week, for all of his working life without injury to his health. It is important to note that this is a weighted average concentration; that is, that exposures to slightly larger concentrations, followed by periods of no exposure or lesser exposures will presumably do no harm.

Figure 5-2. MAXIMUM ALLOWABLE CONCENTRATION (MAC)

	ppm	mg/m^3
Nitrogen Tetroxide		
as N_2O_4	2.5	.
as NO_2	5.0	9.0
UDMH	0.5	1.0
Hydrazine	1.0	1.3
MMH	0.2	
Iodine	0.1	1.0
DDT		1.0
Pyrethrum		2.0
Lindane		0.5

The MAC did not grow out of the rocket industry and the handling of liquid propellants. It is a figure which originated in the chemical process industries, where workers are exposed to chemical fumes and vapor on a daily basis. MAC's are commonly expressed in terms of parts per million of vapor in air (ppm), or as milligrams of material per cubic meter of air (mg/m^3). Figure 5-2 shows some of the MAC values for propellants which may be used on the Apollo program.

To get some idea as to the relative toxicity of these propellants, one can compare their MAC values with a number of insecticides commonly used around the home; e.g., pyrethrum, lindane and DDT have MAC limits equivalent to those of the propellants. Even moth crystals are toxic and have an MAC of about 400 ppm. Just as in the home, where insecticides are not used all day every day, people engaged in launch operations are not usually exposed to vapor concentrations on a daily basis. A launch vehicle arrives, is checked out, and finally propellants are loaded on board. The actual time that personnel, other than those in the propellant storage areas, may be exposed to toxic vapors is only a few days per month. However, a launch operation presents the risk of releasing a large quantity of propellant at one time, and creates a situation where personnel may be exposed to high concentrations for very short periods of time.

2.2 Emergency Tolerance Limit (ETL)

Hygienists have established some numbers which are guidelines for once-in-a-while exposure and are to be used only in the case of an emergency. These values, the Emergency Tolerance Limits, are emergency tolerances and are not recommended by anyone as planned working limits. The Emergency Tolerance Limit is a time-weighted number which establishes exposure limits for varying concentrations of vapor, based on the time of exposure to the vapor. Figure 5-3 shows the ETL's established for selected missile propellants.

Figure 5-3. EMERGENCY TOLERANCE LIMITS

Time in Minutes	5	15	30	60	
NO_2 *	35	25	20	10 *	parts per million
MMH **	600	200	100	50	
UDMH *	50	35	20	10	

*American Council of Government Industrial Hygienists
**American Industrial Hygiene Association

Some discussion of other parameters which might be used to define toxicity may be in order. The MAC and ETL figures are those which the body can withstand without injury, either temporary or permanent. It is very difficult to obtain much data on exactly what the body can tolerate and, of course, impossible to obtain lethal limits, except by extrapolating data from laboratory tests on animals. Extrapolated lethal figures are available, but have no application to daily operation.

3.0 HAZARD SOURCES

A toxic problem is caused by vapor (or fume, etc) or liquid coming into contact with a human. In theory, toxic propellants are handled in closed systems and no such contact is possible; however, experience belies that theory.

When using liquid propellants there are three sources of toxic hazards possible in the launch environment: the leak, the spill, and the disaster.

- The leak is the smallest of these and also the most prevalent. A study of history of the Titan II and other missiles using storable propellants, shows that leaks occur in unattended systems. Leaks primarily originate at gaskets and seals, or in castings which may have porous imperfections. Generally, leaks present no major toxic hazard; the quantities involved are comparatively small.

- The spill represents the most serious source of a toxic hazard. Spills, in general, do not occur unless people are around. Disconnects, fittings, and propellant loading operations are sources of spills which may involve quantities of propellants, from one gallon up to several hundred gallons. Spills may present a major toxic hazard or a major thermal hazard, or both. Spills are the problems to be considered most seriously.

- A disaster may cause a major toxic hazard. Launch vehicles have been known to explode or impact on the Cape. In the past these were LOX-RPI fueled vehicles which presented only fire and explosion hazards. Currently the Titan II and Apollo systems carry storables and, in addition to the fire hazard, a toxic hazard is present. The exact location of the hazard is impossible to predict since the problem can occur either on the launch stand or in the early portions of flight.

4.0 MINIMIZATION AND CONTROL OF TOXIC HAZARDS

4.1 Minimization of Toxic Hazards

Once the sources of the hazards are known, methods for minimizing the hazards may be established. There are four effective methods employed to minimize toxic hazards: design, procedures, education, and protection.

- The design of the system is the first step; it should be designed as failsafe as possible. Wherever feasible, components should be used that have been proven in service. Fittings, seals, and joints should be kept to a minimum in all space vehicle systems.

- Procedures and education are the two most important factors in controlling toxic hazards. These two methods will be considered simultaneously because of their interdependency. The following incident is related as an example of what can happen when procedures are not followed and personnel are not properly educated. A procedure was not followed and two valves were not closed. As a result, several hundred gallons of nitrogen tetroxide backed into a vent system. A safety procedure was not available to handle this problem. In an attempt to cope with the situation, water was dumped on the spill. (Water and nitrogen tetroxide mix to form nitric acid, but in the mixing, nitrogen tetroxide vapors are evolved.) Eventually there were two problems: a dense cloud of nitrogen tetroxide vapor and a pool of nitric acid.

Following procedures would have prevented this spill and proper education would have minimized the hazard. Procedures and education offer the most promising methods for eliminating and for reducing toxic hazards.

- Protection is the fourth method of combating a toxic hazard. Protection is provided for anyone working on potentially hazardous systems and for those in the immediate area. Protection is actually a combination of minimizing and controlling; once a hazard is present, protection can only minimize the personal danger to the people working in the area. Procedures and education will indicate the requirement for protection which is effective only in the event of an immediate danger.

4.2 Control

If a hazard occurs it may be suppressed and/or neutralized. Suppression is a quick step which does not eliminate the hazard, but reduces it to the point where people can come into the area and make necessary corrections. As an example, nitrogen tetroxide vapors from spills may be suppressed with a fine spray of water (NOT A DELUGE). However, the net result will be nitric acid which must be neutralized.

- There are three effective methods for the suppression of toxic propellant spills: a) A fine water spray will minimize the rate of vaporization and removes previously vaporized propellant from the atmosphere. b) Freezing will solidify the propellant and prevent any further vaporization. c) Foams may be applied and will prevent further vaporization while simultaneously diluting the propellant as the foam deteriorates.

- There is only one method of neutralization: a chemical reaction. The specific chemical neutralization is different for each propellant. In general, propellants must be diluted before they can be neutralized so that suppression must precede neutralization.

N67-15990

Lecture Number Six

"PROCEDURES - THE CORNERSTONE OF SAFETY"

Part I

Mr. J. Larks

(Written by G. J. Bryan and J. Larks)

1.0 INTRODUCTION

Good procedures are the cornerstone of any effective safety program. They are essentially the tactics and strategy of the battleline. They are vital for safe operations as well as for meeting engineering requirements. If a program is being performed with good procedures, this is good evidence that it is under control and vice versa. Control of procedures is a vital element in the control of a program.

What is a procedure? It is a written step-by-step set of clear directions which incorporates safety aspects and effectively performs an operation. In addition, it is designed for quality control buy-off and as a permanent record.

Only reasonable intelligence should be assumed for the individual performing the job. Substitution of highly educated engineers for technicians is no excuse for poor or missing procedures. Good indoctrination and training are required. These are a complement to good procedures - not a substitute. In theory, a good procedure could probably be performed without special training. (This would, of course, not be allowed.)

Why are we putting so much emphasis on procedures? There are four major reasons:

1. Good procedures are vitally important with regard to safety as well as engineering requirements.

2. Experience has shown that the development and use of good procedures requires heavy emphasis at all levels of management and operation.

3. Experience also indicates that few individuals fully appreciate the systematic approach and thoroughness of detail required to prepare and use procedures.

4. Items 2 and 3 are partially due to widespread psychological antagonism to the regimentation and tedium involved in the thorough preparation and use of procedures.

In many respects, procedures should be considered as a piece of equipment which must be designed, prepared, delivered on date, and used for its intended purpose. And a procedure, like a piece of equipment, must be modified (revised) when necessary to do its job.

2.0 PREPARATION, REVIEW, AND APPROVAL OF PROCEDURES

2.1 Identification and Naming

The first step in preparing a procedure is to determine the units of operation which require coverage. This selection of unit operations should have been made during early R & D phases for the more significant procedures. Otherwise, how are the right test equipment, the right facilities, and correctly trained men to be available on schedule? These are all-important from the safety viewpoint, as well as the engineering viewpoint. In many cases, it will be found that there are many procedures which have not been given early recognition, because they are not closely tied to long lead times. The responsibility and authority, to identify and assemble the names of all unit operations needed, must be delegated early in the definition phase.

2.2 Assignment of Responsibility

Once an operation has been isolated, it must be assigned by management to someone for development of a procedure. Due dates for completed (reviewed and revised) procedures must also be assigned. These dates must be maintained in much the same manner that hardware arrival dates are maintained.

Individual procedures will normally be prepared to cover a logical unit of work. These unit procedures must then be tied together in a logical and safe sequence. This compilation needs the same thorough approach required for preparing, reviewing, approving, using, and changing of unit procedures. Logical groups of procedures must be designated, and the responsibility for unifying them must also be assigned.

The initial preparation of a procedure will generally be assigned to an individual who will directly supervise an operation.

2.3 Preparation

A procedure is a working document. Its language should be concise, clear, simple, direct, and unambiguous. Illustrations should be liberally used. Clear-cut criteria of acceptance and rejection should be included. In preparing a procedure we need to examine it to ascertain that it contains:

1. A statement of the purpose of the operation.
2. A correct list of all equipment, tools, and drawings needed.
3. Initial status of item on which work is to be performed.
4. Detailed steps to be performed.
5. Provision for recording data.
6. Provision for recording that steps have been correctly performed.
7. Provision for recording problems uncovered and bringing such problems to the attention of the correct people to resolve them. (This may be in the form of reference to an SOP.)
8. Final status and disposition of items on which work has been performed.
9. Detailed safety comments and procedural steps in the introductory portion and in the body of the procedure. These must be in the most effective location and sequence.

The person writing a procedure must be thoroughly familiar with all of the equipment that is to be used, both test and flight equipment. He should also be familiar with the environment in which the operation is to be performed, the building and area, along with special features and other nearby operations (active or inactive).

The procedure writer should, of course, be familiar with earlier procedures. Many elementary procedures must be worked out early in R & D in order to develop, procure, or locate adequate and available test equipment, special tests and cables, facilities, and flight equipment. These procedures are never satisfactory as actual procedures. Many procedures are often not worked out at all in early R & D; for instance, visual receiving and inspection, and maintenance and checkout procedures for test equipment. In many cases, fairly detailed procedures are developed at home plants during checkout for static firing or other tests. These are usually very helpful, but generally require significant changes before being used at Cape Kennedy.

Safety publications covering SOP's and general safety information should be available to the procedure writer. Some of these, such as standard building or area precautions, may be incorporated with little change. Others, such as grounding, shielding, no voltage checks, etc., will require thoughtful attention to see that they are appropriately incorporated along with other engineering step-wise detail.

The writer should have a safety checklist available, preferably as part of a safety publication. A few simple questions will often show weak points: Is special clothing, special building design, or other special safety equipment needed? Have all grounding details, clothing details, equipment details, weather restrictions, necessary sequences, etc., been carefully and clearly stated? Is there some special hazard present? What can be done to reduce that hazard? Should tight restrictions be maintained on personnel access? Is remote operation necessary?

To uncover all ordnance or propellant problems, it is desirable to list all ordnance or propellant items present or nearby. Each item should then be examined versus the planned operation to see whether there is a safety problem. This process will often uncover unsuspected problems from operations not originally considered to have ordnance or propellant safety implications.

A walk-through visualization should be made after the first rough draft. This means that the operation would not actually be performed, but the writer would examine equipment, switches, safety equipment, facilities, etc., as they were called for in his procedure. In many cases, when inert equipment is involved, he may then informally have the procedure performed by a technician. This should only be done with the approval of his supervisor and the reviewer(s) for his procedure.

2.4 Fog Index

To evaluate the clarity and brevity of written procedures, we can make use of a yardstick known as the "Fog Index." This is a tool to gauge the readability of material. The Fog Index corresponds roughly with the number of years of schooling a person would require to read a passage with ease and understanding. The steps for the calculation are:

FOG INDEX

$$(W_{avg} + W_{3\ syl}) \times 0.4 = FI$$

Where:

W_{avg} = average number of words per sentence

$W_{3\ syl}$ = percentage of three or more syllable words

	FI
Bible	7
Atlantic	12
Scientific American	13

Figure 6-1

- Find the average number of words per sentence using a sample of at least 100 words (W_{avg}).
- Count the number of words of three syllables or more per 100 words ($W_{3\ syl}\%$).
- Add the two factors together and multiply by 0.4.
- Do not count words which become polysyllables (3 or more) by the addition of "ed" or "es", such as created (ed) and trespasses (es), or are a combination of simple words, such as bookkeeper.

A Fog Index for a procedure should not exceed twelve and should generally be in the 8 to 10 bracket.

FOG INDEX EXAMPLE

Safety Notice

At a recent meeting of the Safety Committee, it was reported that in some locations water is left running, equipment is operating, and other conditions exist where no special instructions have been left for Watchmen.

Will you please warn the members of your staff to post a sign on any equipment that is to be kept operating during the night, or if water is to keep flowing, etc. In the absence of such instructions, it will be the duty of the Watchmen to disconnect electrical equipment, turn off any water they find running, or turn off any kind of running machinery. When it is necessary to have items operating during the night, in addition to the note stating "Do Not Turn Off", the name and telephone number of the person responsible should be noted in order that the Watchman may contact that person in the event something seems to go wrong during the night, such as overheating, etc. Your cooperation will be greatly appreciated.

FOG INDEX - 17 plus

Total Words - 164
Total Polysyllables - 20
W_{avg}-35-33-33-57-6: 33
$W_{3\ syl}$- 12%

Safety Notice

Neglect of night instructions for watchmen was reported at a recent Safety Committee meeting.

Will you please warn your staff again to post a sign on equipment that is to run at night or have water flowing. When such signs are lacking watchmen are instructed to turn off water or running machinery. When apparatus must operate at night be sure to mark with a "Do Not Turn Off" sign and add name and phone number of person in charge. The watchman will call that person if something seems to go wrong during the night. Thank you for your help.

FOG INDEX - 8

Total Words - 99
Total Polysyllables - 4
W_{avg}-14-23-15-27-15-5: 16
$W_{3\ syl}$- 4%

Figure 6-2

2.5 Review and Approval

After the initial output is ready, the originator needs access to a reviewing authority or authorities who can cover all technical reports of the procedure (including safety).

The initial contact with the reviewing authority or authorities will often result in considerable dismay to the procedure writer, particularly during initial phases of a new program when the experience factor is low. When this occurs, the reviewer must often perform a training role. Since the reviewer will usually be a busy man with many other duties, he cannot afford to succumb to the temptation to do the job himself. This training will later result in his review requiring no more than a reasonable amount of time.

In larger organizations, it is advantageous to have a procedure handbook and a short procedure writing course available. Often "tech writer" assistance is available. Where such assistance is available, the reviewer has the right to expect that the procedure writer make use of it. Unfortunately, even in a large organization, the initial product the reviewer receives may be in "sad shape." Sometimes earnest conversations, with the procedure training head or his superior, will be more fruitful than the training of individuals.

The reviewer must always keep in mind that most people respond better to tact than they do to temper, but firmness is nearly always a requisite. After all, the reviewer has his reputation at stake for the technical soundness of a procedure which he approves. The high level of experience and competence needed, for final review of ordnance and propulsion procedures, was in the first lecture.

The reviewer will normally require his own presence during the first formal run. This should be done with inert ordnance and propulsion systems at the beginning of a program. Often this is also desirable later in a program. His attendance will normally be required during the first live run.

Review and approval may sometimes be combined in one person. There should be a method of sign-off, so that review and acceptance of all necessary parties must be signified in writing, prior to use of a procedure.

3.0 REVISION OF PROCEDURES

The most important requirement for revisions is that they be as carefully prepared and reviewed as the original procedure. Paperwork should normally be designed, so that page revision is possible without the necessity of rewriting an entire procedure. Changes in procedures should be highlighted in some manner, so that the reviewer has to review only the changes, and not the entire procedure, or even the entire page. High-level review requires care not to overuse the reviewer's time.

Good procedures should require few changes, but a definite and essential route for effective revision must be established. Format and literary matters should be incorporated in the original; later changes for such reasons should be discouraged. It must be realized that a change of format requires detailed word-by-word study of the writer and of the reviewer. Seemingly slight changes in wording, or in sequence, can have serious safety and/or other engineering consequences.

There must be a definite method established, whereby the appropriately revised procedure is the procedure used, not a superseded one, and not one designed for new equipment which is not yet being utilized.

<u>REVISION OF PROCEDURES</u>

- Careful preparation and review
- Pagewise revision
- Highlight the changes
- Definite and effective approval route
- Insure correct procedure usage

Figure 6-3

4.0 ENFORCEMENT OF PROCEDURES

Rigid enforcement of working exactly by procedures and doing all work by procedures, is critical for safe operations as well as for engineering reasons. This requires that procedures must be proper and workable. If they are not, they should be revised, not ignored. If time is of the essence, then qualified people can be brought to the operation to make, review, and approve revisions on the spot.

Intense indoctrination and rigid enforcement is normally needed to have complete compliance with procedures. Such compliance is critical and must be obtained. Active management backing is necessary at all levels.

A few questions are of particular importance for ordnance and propellant operations. Have all personnel performing these procedures been properly trained, indoctrinated, and certified? Do technicians and their supervisors know who must approve changes in procedures? Have personnel, working in the vicinity of ordnance devices and propellants, been trained and indoctrinated, so that they will not blunder into an ordnance problem?

5.0 CONCLUSIONS

If all operations are performed according to well prepared and adequate procedures, safe and effective operations will result. Although basically simple to do, this occurs only if management insists on their organization preparing and using good procedures early in a program; and continuously monitors that this situation is maintained throughout the program. Procedures are indeed the cornerstone of any safe, effective test program.

N67-15991

Lecture Number Six

"STATIC ELECTRICITY AND LIGHTNING HAZARDS"

Part II

Dr. G. J. Bryan

1.0 SQUIB AND DETONATOR SENSITIVITY

The voltages required to cause detonators and squibs to fire are very small. Most of those used at Cape Kennedy meet the "1 amp no-fire" specification and their resistances range from 0.04 to 1.0 ohm. This means that 1 ampere is exceeded when 0.04 to 1.0 volts are applied to these respective resistors.

SQUIB

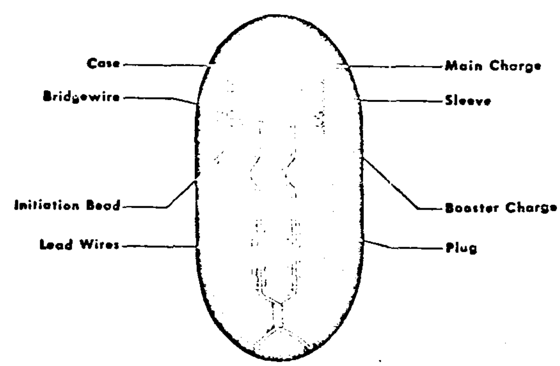


Figure 6-4

The amount of energy required to initiate either a squib or a detonator is very small when it is applied as a sharp spike. Exaggerated energy levels of 400,000 ergs magnitude are sometimes quoted, when this figure may actually be referring to a type of static electricity test in which a 5000 ohm resistor is in series. In this case nearly all of the energy goes into the series resistor. Values of 200 to 20,000 ergs are in the correct range, with the lower figure being more typical of detonators and the higher more typical of squibs. Unless reliable data is available proving higher values, 200 ergs should be used. Such values can be obtained, using square wave generators combined with a carefully set-up high speed oscilloscopic recording. Many initiators also exhibit greater sensitivity is being measured, rather than the sensitivity due to bridge wire heating.

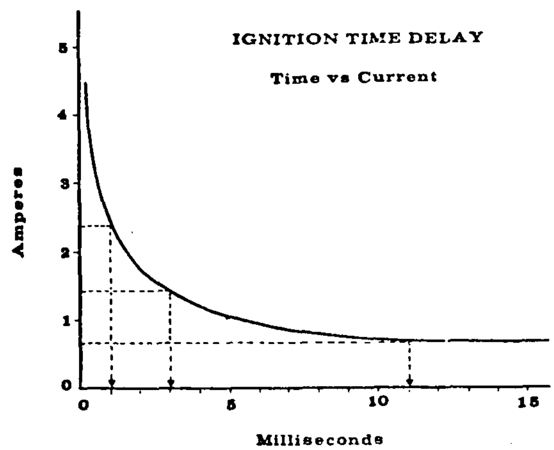


Figure 6-5

Do not make the mistake of figuring minimum initiating energies from minimum firing currents! The exact opposite condition is more nearly applicable. Minimum energy is required when very little of the energy is conducted from the wire and thus most of it is effective in heating the wire. This only occurs under very high rates of energy application in which initiation occurs in less than one millisecond.

For static electricity and lightning, the minimum initiating energy is generally the principle sensitivity yardstick. This may also be a good index for RF sensitivity, particularly for pulsed RF. The minimum voltage required for initiation is often the controlling sensitivity index for stray currents and sometimes for RF.

2.0 STATIC ELECTRICITY

Accidental initiation of squibs and detonators and of vapors and dusts by static electricity is considerably more frequent than is generally recognized. Fatal accidents are generally well publicized. Where injury is slight or nonexistent, very little publicity results.

The most positive protection of ordnance against static electricity is to have the detonator in a safe-and-arm device. This should not only protect the sensitive element, but also prevent propagation of ignition or detonation and be self-contained in case the squib or detonator alone is somehow set off. This is definitely the preferred method of protection.

When squibs or detonators are not protected with safe-and-arm devices, they should at least be electrically shielded and the firing leads should be connected to that shield through a resistor of the order of a few hundred thousand ohms resistance. These should be present when shipped. This will give considerable protection. Any operations involving these devices should be done in a thoroughly grounded environment, including nearby personnel. Details of such grounding will normally be covered in SOP's. This grounding is somewhat more complex than might be immediately apparent, though it is simple in principle. Late-in-countdown installation of such unprotected devices is often requisite. Weight penalties from this can often counterbalance any savings in weight obtained by not using safe-and-arm device protection.

Insofar as possible, static accumulating materials should be kept away from unprotected squibs and detonators. Nonconductors are in general suspect, particularly many of the common packaging plastics. There are conducting plastics available to cover many applications. Any static accumulators used around unprotected squibs, detonators, explosive vapors or dusts are difficult to justify and should be specifically provided for if unavoidably present.

There are various survey meters which can detect the accumulation of static electricity. Their use, along with several "wiping cloths" for generating charges, can be quite helpful in assessing the static electricity hazards of an area. Nonconductors do vary greatly in their ability to act as static accumulators.

In considering static electricity, the following three functions require attention:

- Generation - Some type of friction or flow is generally involved. This may be a person's clothing or shoes brushing against an object, the flowing of a liquid, the flow of particles, the flow of suspended particles (dust, mists, rain), the action of machinery, the mixing or agitation of solvents, or other type motion process. Motion is a part of life and work, but careful grounding and selection of contacting material (cotton is better than most synthetic clothing) can help reduce generation.

- Accumulation - The positive or negative charges generated must be accumulated if a voltage is to be built up. Thorough grounding prevents this. Nonconductors are hard to ground, but may be discharged by wiping with a grounded conductor.

- Discharge - To cause a problem an accumulated charge must discharge. If sensitive elements such as squibs, detonators, vapors, or dusts are protected so that they are not part of the discharge path, then no problem will result. If intentional discharge is provided for, then a problem can be prevented.

3.0 LIGHTNING

More deaths are caused by lightning in the United States during an average year than by tornadoes or hurricanes. According to the National Bureau of Vital Statistics, an average of 230 persons a year were killed by lightning from 1946 to 1955. In Florida, 8.8 deaths per year occur (based on 1955 through 1964, inclusive). The figure has been lower in more recent years (possibly due to the increasing urbanization). On the basis of population, it appears that a person in the United States currently has about a one-in-a-million yearly chance of being struck by lightning. This does not give a true picture of the odds because rural areas have more fatal strikes and fewer people than urban areas. It has been estimated that 90 percent of the cases in which persons were fatally struck by lightning occurred in rural areas. That's not the whole story either. According to the Lightning Protection Institute, lightning kills more than 600 persons annually if persons who die in fires caused by lightning are included. An additional 1,500 more are injured and property damage amounting to $120 million is done. Where you are and what you do, during a lightning storm, can make your chances uncomfortably good for being in or near a lightning strike.

<u>LIGHTNING SAFETY</u>

<u>Safe Locations</u>

- Within building with lightning protection
- Inside steel-topped automobile

<u>Unsafe Locations</u>

- Under tall tree
- Water shore
- Walking highway
- Atop building
- Open field
- Open water
- Mountain top

Figure 6-6

There is much misunderstanding and lack of knowledge about how lightning occurs and what a person should do during a storm. Standing under a tree, particularly if it is isolated and tall, is one of the best ways to be killed by lightning (whether you are touching the tree or not). Standing in the water is inviting trouble in two ways: by direct stroke because you are the highest point on a flat surface, or through the water from a nearby strike.

Actually, a steel-topped car is one of the safest places during a lightning storm. No instance of a fatality in a car from a strike has even been recorded.

One of the worst problems about lightning is that people underestimate it. How many times a year would you figure that lightning strikes the land area of the United States? If you guessed 29.5 million times you're right (8 strikes per square mile). Each day, throughout the world, an average of 44,000 thunderstorms produce about 100 lightning strokes per second. According to Peter E. Viemeister, in his excellent work on this subject, The Lightning Book, an average 30,000-ampere stroke under 125 million volts may develop 3,750 million kilowatts. This is more than the total capacity of all the power plants in the United States. But because the duration is short, only about 250 kilowatt-hours are used, worth about $7.50.

The U. S. Weather Bureau has compiled an isokeraunic map of the United States, by which it is possible to estimate the average number of thunderstorm days per year for any area. Central Florida is tops for the United States with up to 100 days each year. By contrast, the West Coast has fewer than five days per year. (The number of storms per year is 140/5 for Central Florida/West Coast.)

Some spots receive far more than their fair share of lightning strikes. High points, reaching up from the ground above other nearby objects on the earth's surface, take the brunt of lightning attacks. Tall trees, mountaintops, flagpoles, church spires, barns, and tall buildings are among the leaders.

The Empire State Building took sixty-eight strokes in three years. This dispels the idea that lightning never strikes twice in the same place. The fact is--and it is worth remembering--that lightning more than likely will strike the same place twice if it doesn't destroy the thing it hit the first time. It's true there are many random strikes that are never repeated, but choice spots, whether because they are tall or located in areas with a good conductive ground, are hit repeatedly. This explains why rural areas have most lightning fatalities. Tall buildings in cities take the strikes at their tops and conduct the electricity safely into the ground.

One curiosity of lightning fatalities is that five times as many men are killed as women. This undoubtedly reflects the fact that more men than women are outdoors at any given time, and thus have more exposure, but it also mirrors a difference in attitude about lightning. Men tend to ignore lightning and go right on doing whatever they are at; women, on the other hand, take no shame in being afraid of it, and head for the best protection they can find.

It is possible to be just plain unlucky, as the tragic case of an Illinois farmer illustrates. The Weather Bureau reports that the man's barn was set afire by lightning and the conflagration killed all his livestock except two horses. A week later lightning struck again, destroying his metal hay shed; then a few days later it flicked along a fence and knocked the farmer unconscious. A month after that he was standing in a neighbor's barn when lightning struck him in the chest and killed him but damaged nothing else.

Lightning may be separated into four broad classes:

- Cloud-to-Ground and Ground-to-Cloud - Generally jumps from cloud to ground with return stroke from ground to cloud. When building heights exceed 200 feet, there is a significant probability of earth to cloud strokes. For the Empire State Building (1250 feet height) eighty percent are of the latter type.
- Cloud - includes intracloud, intercloud, and cloud to air.
- Tornado type - interior of tornado is typically an area of continuous and high intensity electrical discharge.
- Ball or Bead.

Only the first and third types will be discussed, but cloud types may sometimes cause trouble due to induced ground voltages. Cloud-to-ground lightning is essentially a transient DC discharge. It is characterized by a rise time of the order of a few microseconds and a general irregular decay over a period of perhaps 0.25 seconds. Test records have indicated that:

- Seventy percent of the strokes have a peak potential of over 2,000,000 volts.
- The maximum peak potential sometimes exceeds 20,000,000 volts.
- Peak currents of 50 percent of the strokes will exceed 13,000 amperes.
- Peak currents of 10 percent of the stroke will exceed 32,000 amperes and maximum currents may exceed 160,000 amperes.
- Most lightning initiates as a shift of electrons from a cloud to earth.

Direct impact of a lightning strike on a solid propellant rocket or explosive device would have an excellent probability of starting a serious fire at the impact point. Except for the impact point, heating by conduction through a metal case would often not cause a problem, but should be studied on an individual case basis. The possibility of inducing dangerous voltages into a squib or detonator is significantly high when the squib or detonator is not in a safe-and-arm device. Great care must be taken to protect such squibs and detonators, particularly when they are installed in motors or firing trains. Buildings containing such devices might well be equipped with a separate elevated "cone of protection" type of lightning protection, as well as being proviced with good building structural grounding.

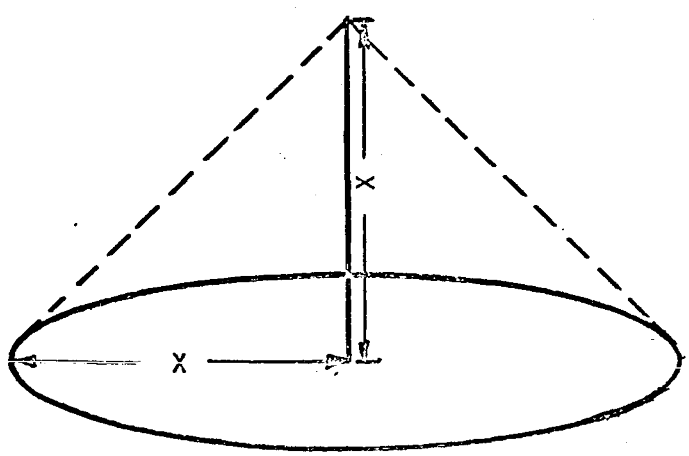


Figure 6-7. CONE OF PROTECTION

Lightning protection can be most simply considered from the zone of protection approach. A well grounded, pointed, upright conductor will protect the zone included by a cone terminating at its point and with a base equal in radius to

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Where tall steel towers and steel-framed buildings exist at Cape Kennedy, they give excellent protection from direct lightning strikes, provided they are well grounded. They will also probably be struck fairly frequently. There must thus be careful attention given to the protection of ordnance devices which might create a hazard, should they be initiated by induced currents or by currents resulting from arc-over.

Careful studies of tornadoes have shown that they are very intense electrical storms as well as windstorms. This electrical activity appears to be of a continuous type (more like a massive corona discharge). Since tornadoes are frequent in this area, this electrical characteristic should be kept in mind when assessing their possible damage to a rocket or ordnance facility.

The onset of lightning at a particular place can be predicted with considerable success while storms are still some distance away. These devices generally use field strength measurements plus counting and measuring of the electromagnetic fields resulting from lightning discharges. They can be of considerable assistance in planning operations on an hourly basis.

4.0 CONCLUSIONS

Static electricity and lightning have a significant probability of initiating squibs or detonators and damaging electronic equipment unless they are protected by safe-and-arm devices or by careful grounding plus other protective techniques. These are also quite dangerous with respect to initiating fires or explosions in the vapors and dusts which occur during many operations, such as handling liquid propellants and solvents.

(This lecture was accompanied by a film which is highly recommended to the reader; "Static Electricity", obtainable from the American Gas Association, Inc., New York, New York.)

its height. A number of points which are vertically connected to the ground, and also horizontally connected near their points, will give a tent-like zone of protection.

A steel frame building will give excellent protection, provided it is well grounded and has lightning rods installed.

The above types of protection do not give complete protection from induced voltages and secondary arcs. The very high peak currents mentioned above are accompanied by intense electromagnetic fields which can induce significant voltages in nearby lines. In addition, a few ohms resistance to ground will, (by direct IR drop), permit large voltages to build up with possible arc-over to nearby conductors.

When the need for secondary protection exists, double-layer protection can be of great help. A well-grounded, steel-frame building may be one layer. A separate lightning-rod system of aerial protection may be used for the other layer. Particularly sensitive devices might be screened by copper screening if very high protection from the electromagnetic field is desired.

Pointed lightning rods do serve to reduce the electrical potential by early discharge, as well as act as a preferred path.

Ungrounded objects such as tall trees are poor conductors and are thus not protectors, although they are sufficiently preferred paths to act as a focus for lightning discharge. When lightning strikes trees it may jump to a nearby object. It also tends to spread out about the base of the tree. If the ground is dry, a person or animal may be connected through his feet. Five hundred and three sheep were killed in this manner by a single lightning stroke. In some cases it would seem worthwhile to run a well grounded lightning rod up a tree, thus changing a hazard into a protective shelter.

Much of this discussion has been about people. Wherever there is a hazard to people, there is a hazard to unprotected ordnance devices and electronic equipment. In fact, particularly with respect to induced voltages, the ordnance devices and electronic equipment may be considerably more sensitive than a person.