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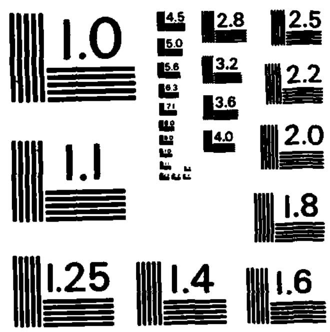
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FAILURE ANALYSIS SEMINAR: TECHNIQUES AND TEAMS

SEMINAR NOTES

VOLUME I

MARCH 1980

THE SYSTEMS EVALUATION OFFICE

US ARMY ARMAMENT
RESEARCH AND DEVELOPMENT COMMAND

DOVER, NEW JERSEY

VOLUME 1 CONTENTS

SUMMARY

The failure analysis strategy described in these notes is a diagnostic method for increasing the assurance that the root cause of a problem is identified, and an actual case study which illustrates the failure analysis concepts, is included.

The use of the special diagnostic methods described and teams structures are an effective way to analyze problems that are particularly difficult because they have some or all of the following characteristics:

- The technical problems involve several divisions or functions, often remotely located from each other.

- The problems are so technically complex that no one is completely sure of their cause.

- Major pieces of physical evidence were destroyed in test or are on inaccessible test ranges.

COURSE DESCRIPTION

Failure Analysis Seminar: Techniques and Teams (FASTT)

Description - the FAILURE ANALYSIS SEMINAR: TECHNIQUES AND TEAMS (FASTT) is a concentrated, high-intensity, three-day (24 hours) workshop/seminar designed for functional engineers and mid-level engineering management personnel. The sessions concentrate on identifying problem areas using an indepth, structured analysis of technical and operational problems. In a broader sense, FASTT is a diagnostic process and a "way of thinking" for engineering or technical personnel involved in the design and/or operation of complex systems. Logic diagrams and root cause analysis are two effective methods used in this course for confronting technical and managerial problems. These techniques are particularly productive when dealing with development failure and hardware malfunctions at any point in the life cycle of a product.

The course also focuses on the dynamics of team involvement - including differences in perceptions of problem areas, communication problems and individual differences. Special emphasis will be given to identifying interpersonal and organizational roadblocks which deter cooperative, innovative, and competent functioning in the small group environment.

COURSE OBJECTIVES:

... Techniques for a systematic, structured, analysis, and solution of a broad variety of technical and managerial problems by individuals and teams.

... Applying analytical techniques to "real world" problems.

... Awareness of group dynamics and what happens among and to team members.

MAJOR TOPICS:

- Logic diagrams
- Root cause analysis process
- Failure prevention aids
- Design reviews
- Idea generation techniques, i.e., brainstorming, morphology, etc.
- Coaching philosophy
- Management in the failure environment
- Leadership and communication skills
- Team dynamics and organization

FEATURES:

- Course notebook
- Case studies of real situations to help implement new skills
- Role playing and simulation to emphasize techniques
- Identification and improvement of your leadership styles

BIOGRAPHIC SKETCHES:

A.E. "Gus" Magistro - Systems Evaluation Office, ARRADCOM, Dover, N.J.

Magistro has been a leader in problem-solving team design and has trained over several thousand persons in problem-solving methods over the past ten years. His activities in missile system component design for the US Army.

In addition, his work in team problem-solving methods has been applied by major defense contractors to components, systems and processes. He has also consulted in the areas of problem-solving and creativity in the private sector.

Marie H. Panger - Project Director, Sterling Institute, Washington, D.C.

Panger is an experienced designer of management training programs. She serves as a consultant to business, industry, government and education in the areas of management development, organizational development, problem-solving and communications.

For the past several years she has worked with courses designed to particularly meet the needs of women in the areas of management. 1977 Bush Fellow; she also serves on the Board of Directors, Institute of Executive Women, University of Alabama.

PREFACE

The introduction of sophisticated and highly complex consumer products as well as state of the art weapons has resulted from (and in turn, demanded) extradorninary advances in the engineering state of the art. Unfortunately, great increases in technical sophistication have not been matched by significant advancement in the ability to deal with failures of this complex hardware.

Many diagnostic tools have evolved in peicemeal fashion to address the failure of specific components and built-in test equipment is included in many mature products and increasingly we find a trend to built-in test points and trouble shooting connectors. However, the design of methodologies which coordinate the flow of information concerning a failure are no more organized than the design of the test equipment. The conflicting information arising from the crash of a DC-10 at Chicago, IL, in 1979, is an example of the worst kind in failure analysis, and press release analysis. To offset the problems of the past and to provide a superior technical posture during failure situations, the diagnostic process described in the seminar evolved.

Each consumer product, weapon system or equipment produced and used goes through a life cycle, starting with concept development and concluding with the completion of operational life. During the time interval between these points in the life cycle there is much interfacing among project planners, developers, manufacturers, support personnel, test and evaluation and users, often worldwide. Indeed, the surfacing or problems and the reporting of failures throughout the product life cycle often requires a unique management system to plan, guide and execute the activities required to prevent failures or their recurrence.

In principle, many organizations have policies for the investigation of failures and many organizations have detailed record keeping functions for warranty purposes. However, relatively few organizations have a life cycle failure analysis and control function. Because of the disparity in failure emphasis, it is important that the participants be aware of the ned for a formal failure prevention and control systems. The tailoring of a failure control sytem to your organization's needs can be accomplished by using the seminar content as a baseline.

FAILURE ANALYSIS SEMINAR:

ORIENTATION

PURPOSE AND OBJECTIVES

- To acquaint participants with methods for gathering and organizing data related to failure situations by individuals and small teams.

- To identify the thrust of technical strategies aimed at preventing failure including design reviews, data base development, and periodic reporting.

- To demonstrate the effectiveness of team problem solving.

Key topics which support these objectives include Logic Diagrams, Root Cause Analysis, Generation of Failure Scenarios, Team Dynamics and Small Group Processes, and Failure Prevention Strategies. Workshops to illustrate these topics will encompass more than half the seminar schedule.

SEMINAR OUTLINE

The siminar outline indentifies discrete and significant items of information. These serve as baselines from which the instructor builds on the processes and content.

Within the allocated times, the instructor will exercise judgement in how detailed each topic will be. The course outline is intended to provide for presentation flexibility and each segment of the outline is an aid toward achieving the learning objectives.

REFERENCE MATERIAL

Reference material included or noted in the text complements the seminar outline by providing supporting materials and case studies. References included in the text represent key policy considered most pertinent to the seminar.

Failure analysis methods are dynamic and growing. Frequent improvements are expected as new methodologies for specific technologies are evolved. The loose-leaf format allows each participant to tailor the reference material to their specific discipline.

ORIENTATION

I. ADMINISTRATIVE MATTERS/OPENING AND REGISTRATION

A. Seminar Organization and Procedure

Learning Objectives

(1) To identify seminar purpose and objectives and to highlight elements of seminar content and presentation media.

(2) To identify and relate product availability, product assurance and design problems to seminar content.

(3) To introduce techniques for the definition, analysis, and solution of problems by individuals and teams.

(4) To develop competence in applying analytic techniques to "real world" problems.

(5) To create an awareness of group process - what happens between and to group members.

B. FASTT Seminar

Primary Purposes

(1) Provide an understanding of key problem-solving concepts and a policy for acquiring effective armament material, and illustrate a methodology for the analysis of problems.

(2) Reflect requirements for participants' application.

(3) Learner centered approach to training lecture supported material.

(a) Review seminar materials

(b) Learning reinforcement techniques

(c) Instructor and participants' roles

C. Topical Approach to Subject Matter

(1) Introduction and Orientation

(2) Team Operations Simulation

(3) General Concepts

(4) Logic Diagrams
- Workshop

(5) Root Cause Analysis
- Workshop

(6) Alternative Scenarios Evolution

(7) Case Study
- Workshop

(8) Coaching Philosophy
- Workshop

(9) Failure Prevention

(10) Recap and Close Out

D. Instructor and Participant Roles

(1) Instructor's Role

- Transmit Information
- Generate Discussion
- Debrief Activities

(2) Participant's Role

- Get Involved
- Use Time Effectively
- Feedback Problems and Progress
- Evaluate

FAILURE ANALYSIS STRATEGY[1]

Augustine E. Magistro

Introduction

A primary task of management and systems engineers is to establish the normal performance limits for an item, recognize abnormal performance or failure, determine the cause of failure, and derive effective solutions.

The determination of the cause of failure is often the most formidible task presented to engineers during the development of an item. In the early phases of a major tactical missile system, the Government agencies and contractors involved were very effective at quickly applying "fixes" to failures. In many cases, the apparent problem was treated, but often the same failure recurred. Significant costs in dollars, time and anxiety were suffered by several levels of management each time the corrective action was inadequate. Therefore, it became evident that a technique was required which assured that the root cause of a failure was detected and removed. In this atmosphere a series of innovations evolved which produced a failure analysis strategy which combined elements in a new way.

The failure analysis strategy assures that activities conducted to assess the basic or root cause of failures are adequate in scope, and are capable of identifying a'l the likely conditions which may have contributed to the problem. Data gaps and completeness of activities are a major focus.

[1]This article contains portions of material originally published as part of U. S. Army Missile Command Technical Report, Number RF-75-2 "Root Cause Analysis - A Diagnostic Failure Analysis Technique for Managers," 26 March, 1975, by Augustine Magistro, Picatinny Arsenal and Lawrence R. Seggel, U. S. Army Missile Command. The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

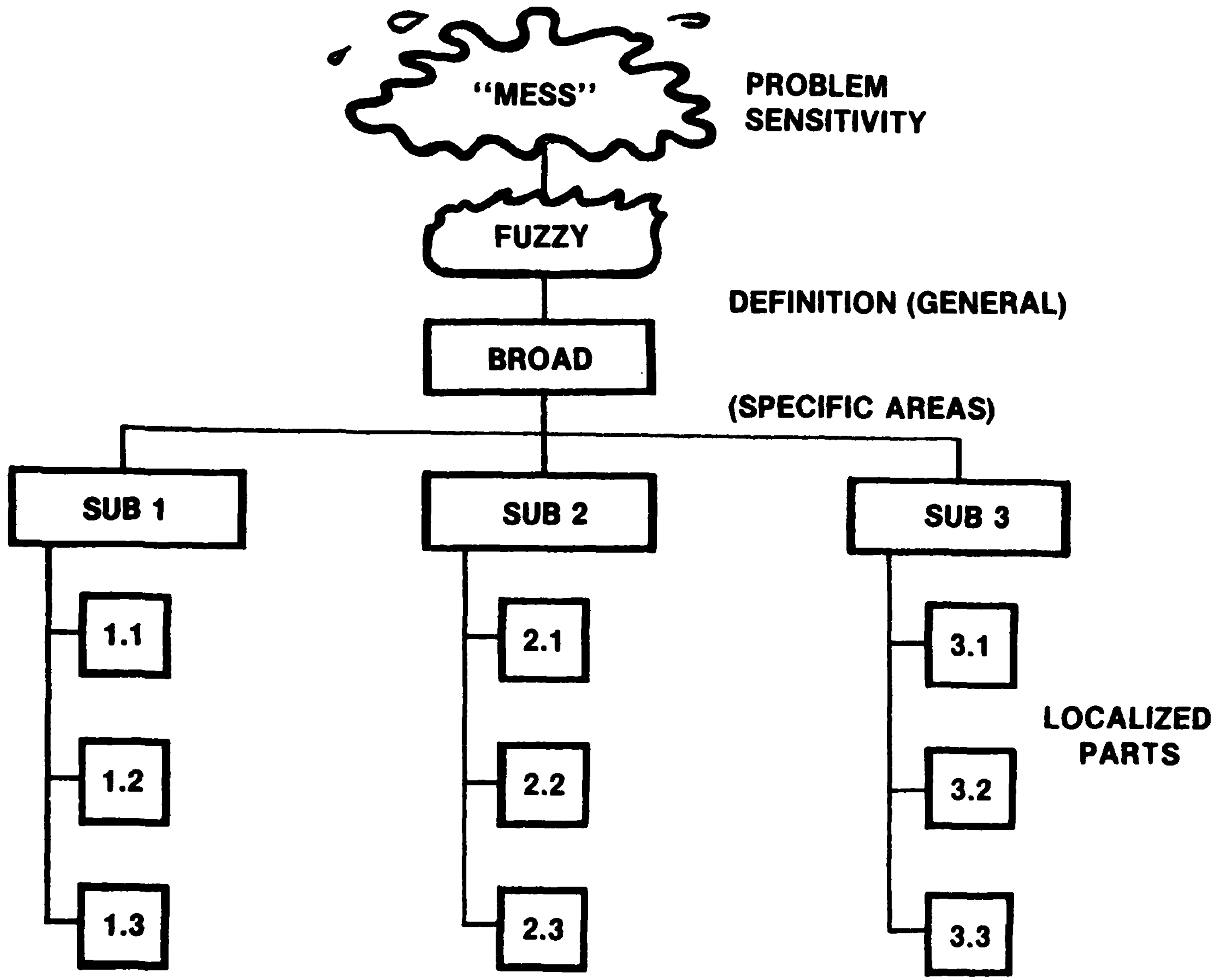
Failure Analysis Strategy

Generally most problems surface with the occurence of an apparent failure or deviation in performance and the first major activity in technical problem solving is to arrive at a statement of the problem which provides maximum visibility to the possible failure causes. An initial statment of the problem is evolved and the symptoms are described in terms of what happened and what were the events leading to the problem.

A typical problem statement is; "the car won't start. No sound heard when key is operated." In this case, the driver is the problem solver and must collect additional information in order to proceed. The driver is faced with a "mess" and since little information is available the driver must collect and organize new information about the problem. Figure 1 is a model of the process. First, the driver thinks about systems which could be involved and selects from among them the system which is likely to be involved. Next, the driver specified what subsystems could be involved and speculated that the battery, starter and solenoid were likely areas of investigation. The driver then considered components of the subsystems such as cables changes and mounting hardware for the starter. The hierarchy of the drivers analysis is depicted in figure 1 proceeds from general to specific areas, and when completed will display all the parts which may be involved in the problem. At the component level we have a "bite size" piece of the problem to investigate.

The driver would continue the analysis until a specific replaceable part was identified and replaced. The driver's problem solving would stop when the car was started, however, the auto designer is interested in isolating the causes of the problem. Thus the auto designer would continue the hierachial model evolution beyond the model of figure 1 to further isolate piece part failures. The auto designers objective is to establish the failure mode of the piece part and to prevent recurrence of component failure. Your role in the seminar is to act as the system designer.

PROBLEM SOLVING STRATEGY



Logic Diagram Background

Fault Tree Logic Analysis was initially developed in 1962 by Bell Telephone Laboratories in connection with the Air Force's Minuteman Missile System. Specifically, it was utilized to predict what combination of events and circumstances could cause an undesired event such as an unauthorized missile launch. Recently application of this technique was made to diagnostic failure analysis. This has been caused in part by the increased emphasis on new methods and techniques to improve the response time to the analysis system failures.

The logic diagram provides a convenient visual "roadmap" of the problem. It permits the problem solver to diverge and helps to eliminate tunnel vision.

Fault Tree Logic Diagrams

Fault logic is a pictorial representation of the various parallel and series combinations of subsystem and component failures which can result in a specified system failure (see Figure 2). The fault logic, when fully developed, may be mathematically evaluated to establish the probability of occurrence of the ultimate undesired event, as a function of the estimated probabilities of occurrence of identifiable contributory events. However, in many diagnostic studies quantification is not possible since failure rate data is not available. Only unquantified fault logic diagrams are described in this section. The logic diagram examples shown are simplified but serve to show the event relationship to the effects.

Fault Logic Construction

Development of a fault logic begins with the definition of the end system fault condition ("undesired event"). The system is then analyzed and all the logical combinations of function fault events which can cause the undesired event are postulated. Such an analysis is dependent upon a thorough knowledge of the system functions and equipment and an individual willing to explore many alternate failure scenarios. Each of the contributory fualt events is further analyzed to determine the logical interrelationships of system fault events which can cause them. Analysis if facilitated if the fault events are systematically classified according to failure cause. In this mannter a thee of logical relationships among fault events is developed. The development is continued until all relevant fault events on for the problem are defined in terms of basic, identifiable faults.

LOGIC BLOCK DIAGRAM

- THE LOGIC BLOCK DIAGRAM IS A SYSTEMATIC GRAPHICAL REPRESENTATION OF THE POSTULATED PROBLEM AREAS OF A DEVICE
- IT DEPICTS THE LOGICAL STEPS AND ALTERNATIVE PATHS OF POSSIBLE PROBLEM AREAS
- THE PURPOSE OF THE LOGIC BLOCK DIAGRAM IS TO PROVIDE AN OVERALL VIEW OF THESE POSSIBILITIES
- THIS IS A LIVING CHANGING DOCUMENT THROUGHOUT THE ANALYSIS UNTIL THE ROOT CAUSE IS IDENTIFIED

A summary of the steps for fault logic diagram construction follows:

1. Carefully analyze the system or component. Determine the sequence of events for normal operation, normal and abnormal operating environments and safety implications.

2. Specify the undesired event of the fault logic diagram. This may be failure of the total system, property damage, human injury, or any other event that might result in not satisfying requirements.

3. Initiate actual construction of the fault logic diagram. Determine, in a logical manner, the events that can cause the undesired effect.

4. Establish what major systems could be involved.

5. Determine what major components in the system could be involved.

6. Speculate how the component could fail.

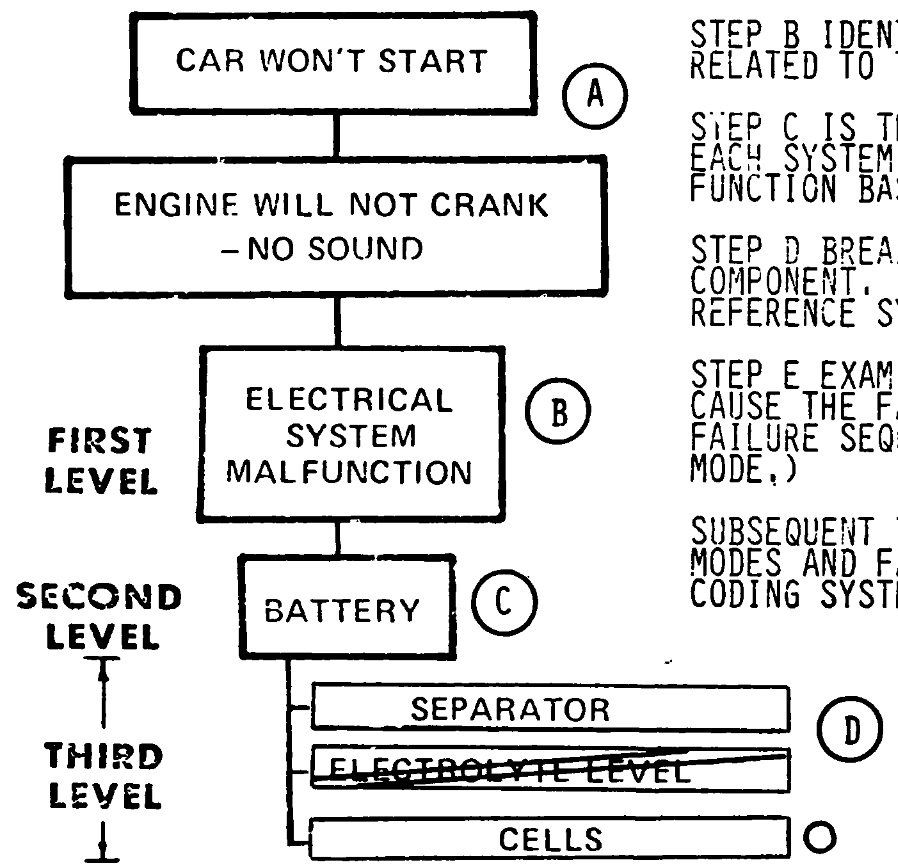
7. Determine which parts of the major components could cause the component of fail (Note: A functional construction related to components is perferred since it relates conveniently to part numbers).

8. Display this Process graphically.

9. All the logic events are given reference numbers in order to cross reference the basic fault event to other charts. Figures II through IV depict the construction order for an electrical system problem.

10. After the construction of the logic diagram is completed, each entry is evaluated. Diagonal lines are drawn thru events not considered likely to be involved and a circle is placed adjacent to likely causes. Most likely causes may also be designated by combinations of symbols. Figure 2 describes this process.

LOGIC DIAGRAM



LOGIC DIAGRAM CONSTRUCTION

STEP A IDENTIFIES MAJOR SYMPTOMS.

STEP B IDENTIFIES MAJOR SYSTEMS WHICH COULD BE RELATED TO THE SYMPTOMS.

STEP C IS THE LOCALIZATIONS OF COMPONENTS IN EACH SYSTEM WHICH COULD CAUSE THE SYSTEM TO MALFUNCTION BASED ON THE SYMPTOMS OBSERVED.

STEP D BREAKS OUT FAILURE MODES OF EACH COMPONENT. (A NUMBERING SYSTEM IS USED TO REFERENCE SYSTEMS, COMPONENTS AND FAILURE MODES.)

STEP E EXAMINES FAILURE SEQUENCES WHICH MAY CAUSE THE FAILURE MODE. (MANY DIFFERENT FAILURE SEQUENCES MAY PRODUCE THE SAME FAILURE MODE.)

SUBSEQUENT TO STEP E, THE MOST CREDIBLE FAILURE MODES AND FAILURE SEQUENCES ARE DESIGNATED BY A CODING SYSTEM SHOWN BELOW THE LOGIC DIAGRAM.

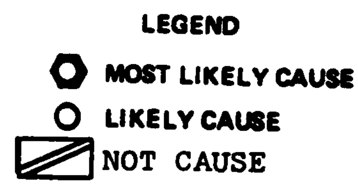


FIGURE 2 - LOGIC DIAGRAM CONSTRUCTION

Root Cause Anlaysis Format

Subsequent to the development of the logic diagrams, failure sequences are postulated and information which either refutes the sequence or supports it is assembled on standard columnar format, shown in Figure 3. It is a simple one, however, it must be conscientiously completed and updated to be effective. The presentation of information in the format of Figure 3 allows each failure sequence and its supporting rationale to be quickly reviewed.

The root cause analysis chart is executed as follows:

Failure Indication - A simplified statement of the observed failure and its symptoms are entered.

Cause Probability Estimate - The assignment of the failure mode cause probability estimate should be stated in terms of "not cause, probable contributor," "unlikely cause, likely cause" and "root cause." The probability estimate is useful in ranking failure modes.

Failure Mode - A potential failure mode from the logic diagram list is entered, one to a page. Pages are added as additional modes are evolved.

Failure Sequence - the failure mechanism of the postulated failure mode is briefly described, for each failure mode entered, and only one sequence is entered per page. Describe what is speculated to have happened. when it occured, who was involved, where on the part, how it is manifested, and why it failed.

Supporting Data - Actual test data, "facts" and substantiated analyses that are established from detailed investigation of the failure mode are listed. Facts that support the failure mode and failure sequence are briefly listed in just enough detail to be understood by the team.

Refuting data - All facts established during the detailed analysis of all data that refute the postulated failure mode and failure sequence are entered concisely.

Additional data and tests required - List required investigations together with their estimated completion date in this column. As the investigation proceeds it will become clear that there are gaps in the analysis or data available. This additional information would provide a basis determining whether the postulated failure mode is or is not the cause of the observed failure.

Corrective Action - Any corrective actions required should be indicated and the appropriate block checked. Interim actions or adaptive actions should also be entered in this area. Figure 4 thru 6 illustrate these steps.

The root cause analysis charts are "living" documents and when additional data are made available, prior entries are deleted and the results entered in either the supporting or refuting data columns.

[2]For description of Red Teams, see Volume 3.

Date Rev No.

ROOT CAUSE ANALYSIS CHART

Failure Indication: ENTER BRIEF STATEMENT OF FAILURE INDICATION

Cause Probability Estimate: USED DURING EARLY STAGES TO INDICATE CAUSE PROBABILITY WHEN LITTLE IS KNOWN ABOUT THE FAILURE

SPECULATION	EVALUATION		
	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Mode: LIST POSSIBLE MODES OF FAILURE. EXAMPLES: ITEM SHORT, ITEM OPEN, IMPEDANCE, FIN FAILURE. LIST ONLY ONE MODE PER PAGE. ENTER LOGIC DIAGRAM REFERENCE NUMBER. **Failure Sequence** CONCEIVABLE MECHANISMS WHICH COULD CAUSE THE FAILURE MODE TO OCCUR. THERE MAY BE SEVERAL MECHANISMS THAT COULD CAUSE A GIVEN FAILURE MODE TO OCCUR. DESCRIBE HOW, WHAT, WHERE, WHEN, WHY AND WHO WERE INVOLVED.)	ENTER DATA WHICH SUPPORT THE POSTULATED MODE AND SEQUENCES. EACH ENTRY SHOULD BE NUMBERED TO AGREE WITH THE FAILURE SEQUENCE ENTRY IT SUPPORTS.	ENTER . DATA WHICH REFUTE THE POSTULATED MODE AND SEQUENCES. EACH ENTRY SHOULD BE NUMBERED TO AGREE WITH THE FAILURE SEQUENCE ENTRY IT SUPPORTS (THERE MAY BE SUPPORTING AND REFUTING ENTRIES FOR EACH MODE AND SEQUENCE.)	AS A RESULT OF ENTRIES IN ANY OF THE COLUMNS ENTER SPECIFIC DESCRIPTION OF WHAT FACTS OR DATA MUST BE COLLECTED TO COMPLETE THE PROBLEM SOLVING PROCESS.

Corrective Action: NONE REQUIRED (Check One)

LIST THE STEPS OR MEASURES THAT CAN BE TAKEN TO PREVENT A FAILURE IN THIS MODE, e.g., DESIGN CHANGE, ADDITIONAL QUALITY CONTROL, TEST OPERATIONS, ETC.

Conclusion:

ENTER FINAL ESTIMATE OF THE CAUSE PROBABILITY AND SUMMARY STATEMENTS BASED ON THE CONTENT OF EACH MODE ANALYSIS

FIGURE 3 - ROOT CAUSE ANALYSIS CHART INSTRUCTION FORMAT

FIGURE 4 - SAMPLE ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: BECO AT ENGINE IGNITION

CAUSE PROBABILITY ESTIMATE: POSSIBLE

SPECULATION
FAILURE MODE
Instrumentation.
FAILURE SEQUENCE
Instru. short causes saturation on integ or V.A. or causes power battery drain.

EVALUATION		
SUPPORTING DATA	REFUTING DATA	ADD'L DATA TESTS REQ'D
None.	TM records all show normal functioning with no evidence of short; all TM monitoring points are current limited.	B H checkout at LTVAC-M.

FIGURE 5 - SAMPLE ROOT CAUSE ANALYSIS CHART

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: BECO AT ENGINE IGNITION

CAUSE PROBABILITY ESTIMATE: UNLIKELY

SPECULATION
FAILURE MODE
Shorted VCE power switch.
FAILURE SEQUENCE
Shorted transistor fires BTV at pulse battery activation.

EVALUATION		
SUPPORTING DATA	REFUTING DATA	ADD'L DATA TESTS REQ'D
None.	Functional checkout of power switch at LTVAC-M no evidence of pulse battery drain at activation on TM records.	None.

FIGURE 6 - SAMPLE ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: BECO AT ENGINE IGNITION

CAUSE PROBABILITY ESTIMATE: UNLIKELY

SPECULATION
FAILURE MODE
Failed VCE
FAILURE SEQUENCE
Positive saturation of V.A. or negative saturation of integ triggers BTV, giving BGG signal and driving the sustainer full-on.

EVALUATION		
SUPPORTING DATA	REFUTING DATA	ADD'L DATA TESTS REQ'D
None.	TM records show no saturation, no BGG, and a sustainer full-on signal; VCE checked OK on G&C SAIE and test console.	None.

The root cause analysis chart format fulfills several significant purposes:

- Provides a prompt overview of the status at any point during the failure analysis process. This is valuable to the team and to management.

- Describes and plans follow-on activity required to complete the analysis.

- Provides an auditable review record in the simplest terms which allows independent assessment by disinterested parties such as "red teams"[2] and "blue ribbon panels."

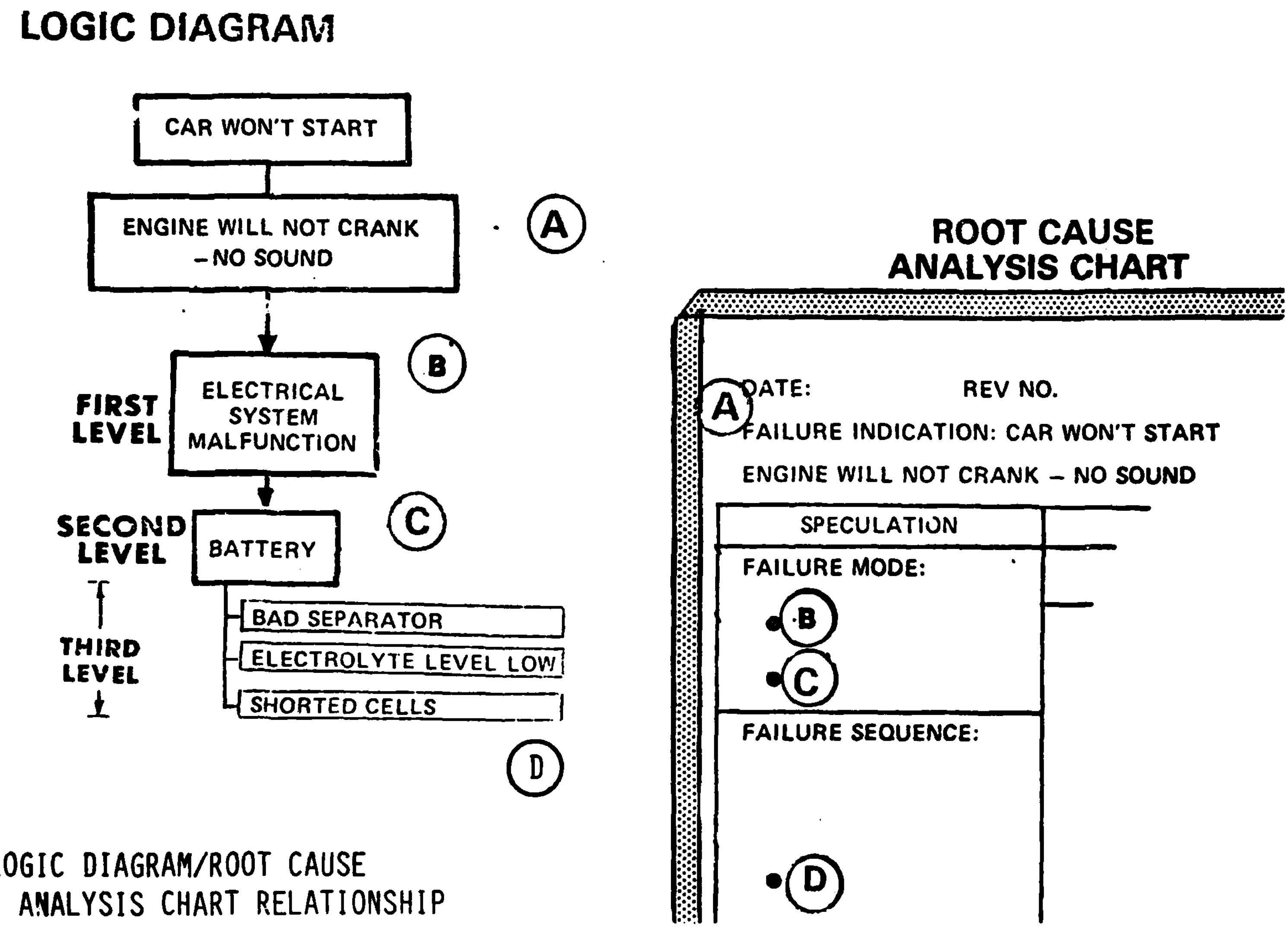
- Concisely presents the balance between confirming and refuting data upon which determinations are based.

- When the root cause is identified, the information on the format explicitly describes the failure process and demonstrates that other causes are eliminated from contention.

This technique requires discipline to produce solutions. It takes patience and discipline at all levels of management to allow the analysis team to do the thorough diagnostic job that is required.

Logic Diagram and Root Cause Analysis Relationship

The logic diagrams and the root cause analysis columnar format supplement each other. The logic diagram provides a road map to guide the problem solver to each postulated cause of failure and the root cause analysis chart presents a scenario for each of the failures. All the data required to reach a conclusion concerning the likelihood of the scenario is presented in the format. Each event of the logic diagram is numbered and the event numbers are entered in the failure mode columns and thus the root cause analysis chart and logic diagram are cross referenced. Figures 7 and 8 illustrate this relationship.



LOGIC DIAGRAM/ROOT CAUSE
ANALYSIS CHART RELATIONSHIP

FIGURE 7

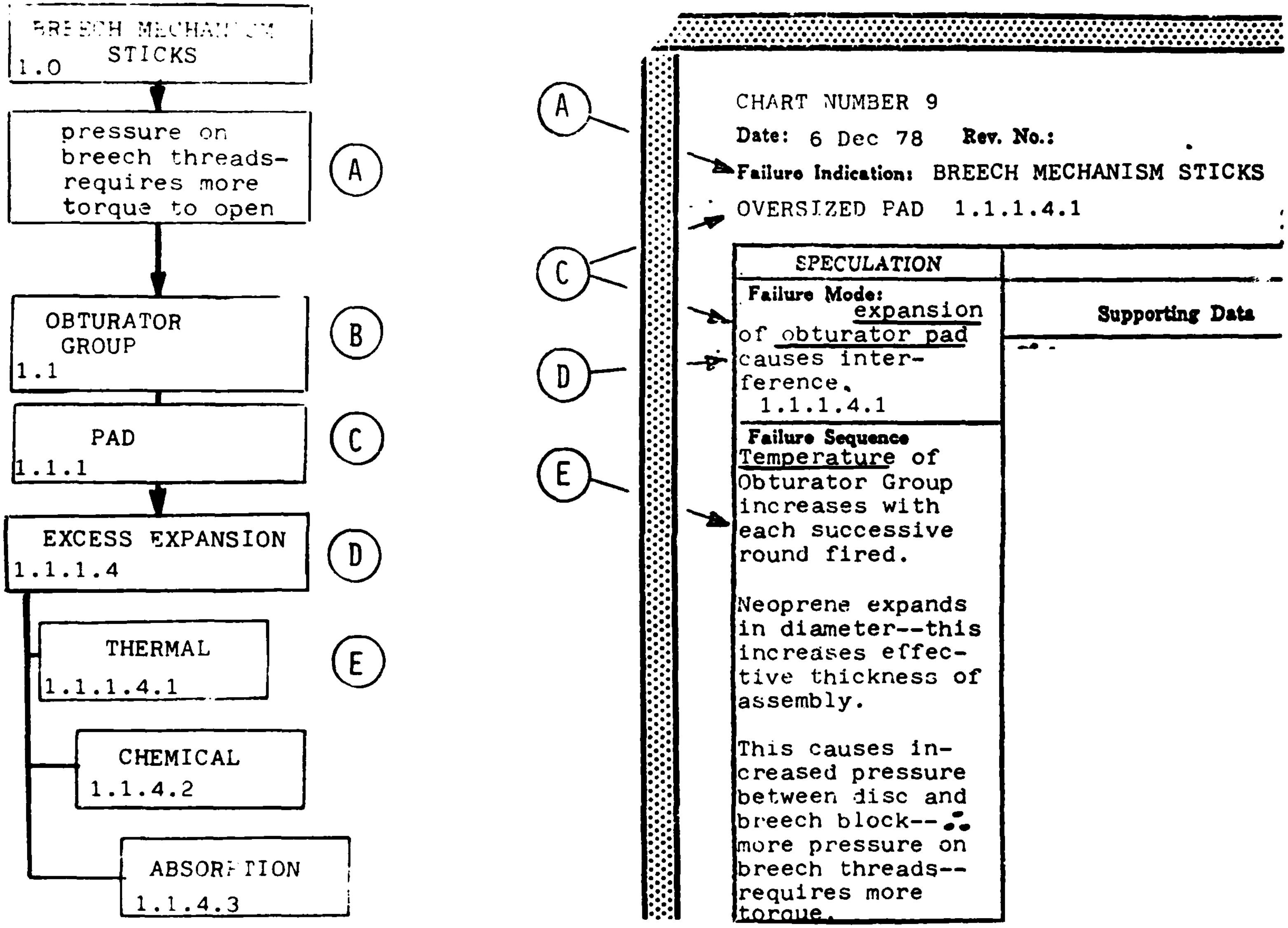


FIGURE 8 - BREECH LOGIC/ROOT CAUSE ANALYSIS CHART RELATIONSHIP

FIGURE 9

FAILURE ANALYSIS CHRONOLOGY

***PROBLEM SURFACES

***PROBLEM STATEMENT

***MANAGEMENT DECISION - "ROOT CAUSE" REQUIRED

***DIAGNOSTIC TEAM FORMALLY ESTABLISHED

***POSTULATE FAILURE MODES

***LOGIC TREE OF FAILURE MODES

***ALL CREDIBLE FAILURE MODES ESTABLISHED

***RANK ITEMS ON LOGIC DIAGRAM

***INITIATE FAILURE MODE AND SEQUENCE OF ROOT
CAUSE FORMAT - ONE PER SHEET

***SPECIFY ADDITIONAL DATA OR TESTS REQUIRED

***OBTAIN DATA CONFIRMING/REFUTING EACH MODE

***ANALYSIS OF DATA

***CATEGORIZE: MOST LIKELY/LIKELY/NOT LIKELY

***REDEFINE PROBLEM

***CONCENTRATE ON MOST CREDIBLE

***SPECIFY FAILURE MECHANISM OF MOST LIKELY CAUSE

***DUPLICATE FAILURE CAUSE

***"ROOT CAUSE" ESTABLISHED

***IMPLEMENT CORRECTIVE ACTION

***LESSONS LEARNED

***DEBRIEF/AUDIT

Importance of Verifying Facts

The first major activity in problem-solving is to arrive at a valid statement of the problem. All input data should be challenged; it is paramount for a manager or investigator to know the difference between the facts available and the assumptions.

It is essential that only established facts be entered in the supporting and refuting data columns. There is no allowance for supposition beyond the failure mode. The failure sequence column, together with the facts established and listed in the supporting and refuting data columns, will determine which failure modes are not the cause, which are potential contributors to the failure, and which one is the most probable root cause.

Some of the data will be available within moments of the failure, while other data may take weeks to assemble or develop. The data that are available within the first two to three days after the incident forms a basis upon which the root cause investigation is initiated. The remainder of the data become useful to refute or support particular failure modes. In some cases, new data might suggest previously unidentified failure modes. The following is a listing of some of the key sources of data:

- Test Data
- Telemetry Data
- Preliminary Test Reports
- Environmental Test Results
- Compatibility Tests
- Preflight Test Results
- Manufacturing Records
- Assembly Instructions
- Failure History Data Banks
- Inspection Data
- Quality Assurance Data
- Reject Reports
- Waivers and Deviations
- Critical Component Data
- Laboratory Simulations
- Previous Test Reports
- Historical Failure Summaries

Although the preceeding list is not all inclusive, it serves to show that there are many sources of applicable data that may provide insights and facts.

Use verified data from all available sources. Take steps to verify all data used as rapidly as possible. Be sure to identify assumptions and unverified data as such, so that they do not become confused with facts. Do not discard data as invalid without proving that the data are incorrect.

Root Cause Organization

Figure 9 presents a typical block diagram of an ad hoc root cause analysis organization. The ad hoc team approach is shown because it represents an organization appropriate for the investigation of the most difficult types of failures, (those where the data base is small, the known facts are few, the areas of possibility are many, and the time to reach a total understanding is expected to be more than several weeks). After the initial failure modes are listed on the root cause analysis chart and the initial failure data reviewed, it is generally apparent what type and magnitude of organization is necessary. Simplifications of this basic organization are obvious.

When a problem is of such magnitude as a required long-term involvement of personnel from several major organizations, it is beneficial to have an understanding at the highest levels of those organizations. This assures that the support required will be the type and quality needed and will be continuous. In the Government, separate commands and agencies as well as contractors and institutional consultants may be involved. Similar situations arise within industrial concerns. A charter delineating responsibilities of each individual on the team and especially the leader is a must; this charter must be agreed to by all organizations represented for an effective and efficient analysis.

- A brief statement of the problem.

- A statement of the significance of the problem.

- Designation of the root cause team leader.

- Designation of the site of the team's operations.

- Definition of the support required of each supporting organization; names of specific individuals, if practicable.

- Best estimate of the duration of the investigation.

The root cause team leader is the hub of the analysis. The team leader should possess the qualities of the top manager, i.e., an organized and disciplined individual. Technical skills are a secondary consideration.

The root cause team leader performs the following functions:

- Directs and controls the activities of the team.

- Prepares the ad hoc team charter if required.

- Arranges for he team staffing.

- Describes the root cause analysis technique.

- Establishes task teams.

- Distributes root cause analysis charts to task teams.

- Presents established facts describing the problem.

- Assists in listing "failure modes."

- Completes "failure sequence" on root cause analysis charts.

- Develops follow-on activities test and analysis requirements with due dates.

- Obtains support of technical specialists as necessary.

- Provides data outputs and findings to root cause team leader and other task teams.

- Iteratively update root cause analysis charts and assist in assigning cause probability estimates for each failure mode.

- Assures that assignment due dates are met.

- Prepared cost estimates and authorizations for management as required.

- Arranges for "red team" or "blue ribbon panel" reviews if the problem warrants that magnitude of independent review.

Each team should have an executive secretary who:

- Prepares listing of participants with addresses and phone numbers.

- Arranges meetings.

- Distributes minutes, reports, and data to the team members.

- Prepares and updates the root cause analysis chart.

- Maintains a chronological file of all material to serve as a reference information bank and allows the various task teams to acquire data without slowing up other teams. This can be very important because the regular cross feeding of information among the task teams speeds up the analysis process.

- Summarizes the findings of the various task teams and issues interim data to the teams.

- Prepares visual aids for briefings, conferences, etc.

- Directs the preparation of the final report of root cause.

The executive secretary may require secretarial support as a minimum and additional support will be dependent upon the magnitude of the problem under study and the size of the group. The organization and supporting staff should be kept to the minimum because larger groups are unwieldy and costly. There is no substitute for good judgement in this area.

The task teams consist of one to five individuals, with a given area of expertise. It is their function to evaluate the available data and develop supporting and refuting data for the root cause analysis chart on those failure modes that are within their area of expertise. The task teams will also determine what additional data are required to resolve each failure mode. They should write individual fact sheet reports on their findings. Dissemination of information findings among task teams and to the root cause team leader on a timely basis cannot be overemphasized. The crossfeeding of information allows for maximum progress and minimizes duplicative effort. Initial internal independent reviews can often be provided by other task teams and serve as an initial critique of the validity of the findings and conclusions drawn. In this way, perspective is gained.

The task teams may add to the failure modes list as the investigation provides new insights. Failure modes, once stated, cannot be arbitrarily deleted.

Technical specialist support of the activities may be necessary to perform specific analyses or tests. This is required to assure that the task team's time and talents are effectively used or to provide skills not present on the task team itself.

Root Cause Analysis Cycle

The root cause analysis process initially emphasizes problem analysis activities and does not consider corrective actions or "fixes" until at least a postulated cause has been identified. The process predicts failure scenarios and either eliminates them from contention or elevates them to the level of likely causes, via the assembly of relevant information. In general, the process does not consider solution until likely causes are explicitly identified and failure mechanism duplicated.

Alternative Evolution - The ability to structure the logic diagrams and the speculation section of the Root Cause Analysis Chart is enhanced by the generation of alternatives. The more alternatives considered the less chance of omitting a cause of a problem.

ALTERNATIVES

In all problem-solving situations there will be a number of alternatives that can be identified. Often we do not search for alternatives and so they are not as "apparent" as they could be if we would only look. To be creative problem-solvers, you will have to think of as many possible alternatives as you can for our objective to be accomplished. Do not at this point assess the value of any potential solution...just list it as a possibility. The deferring of the value of an idea is a key concept in evolving many ideas.

At this point, concentrate on making sure you are considering all possibilities. Only after you have all possible solutions listed should you begin to evaluate each of their potentials and feasibility.

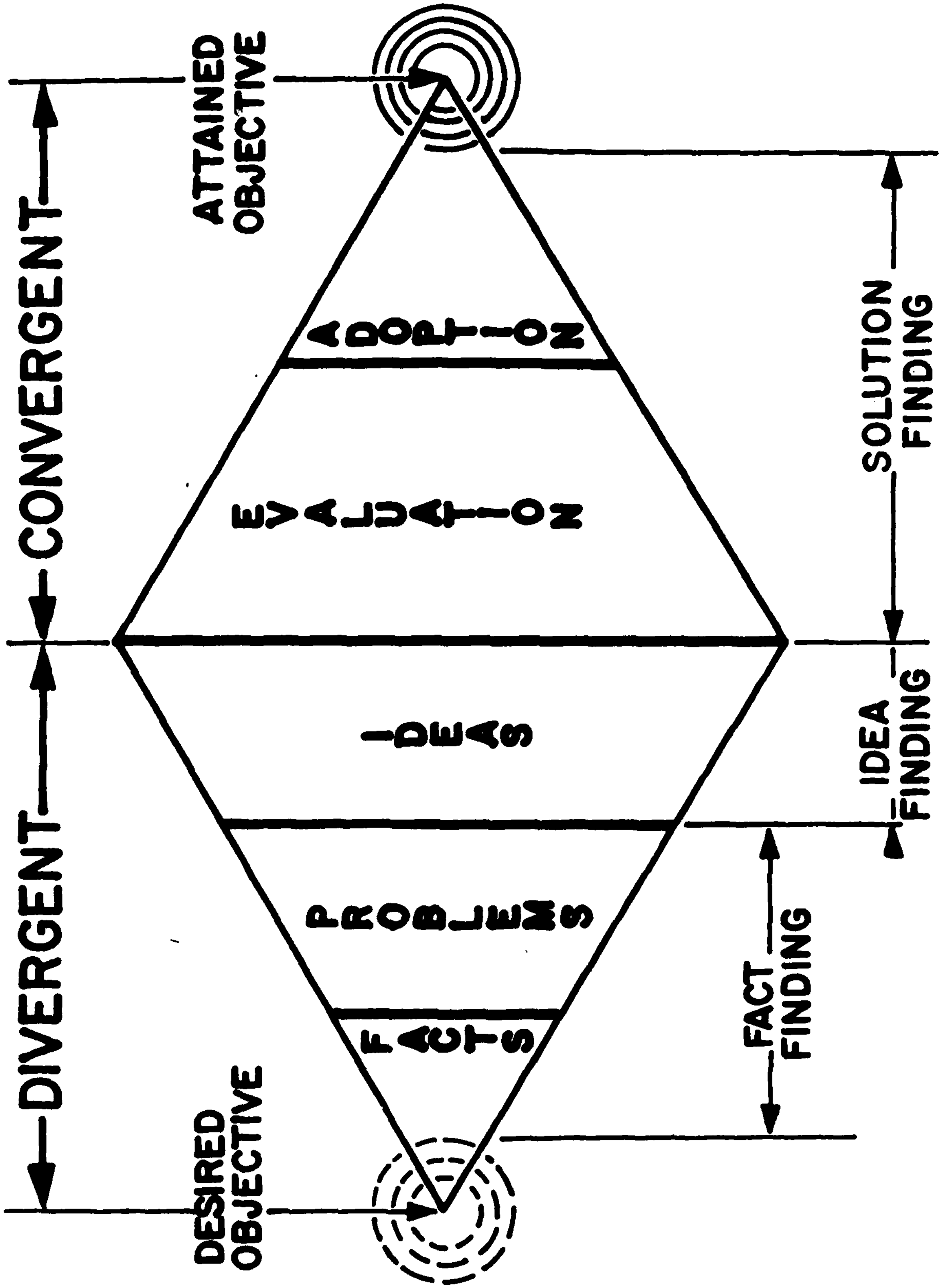
There are numerous techniques to increase your ideation potential -- brainstorming, morphology, metaphors, bionics, etc. Basic to all of these techniques is deferring judgement - not prejudging or inferring it "won't work." (See Osborn's "Rules of Brainstorming" and "Checklist.")

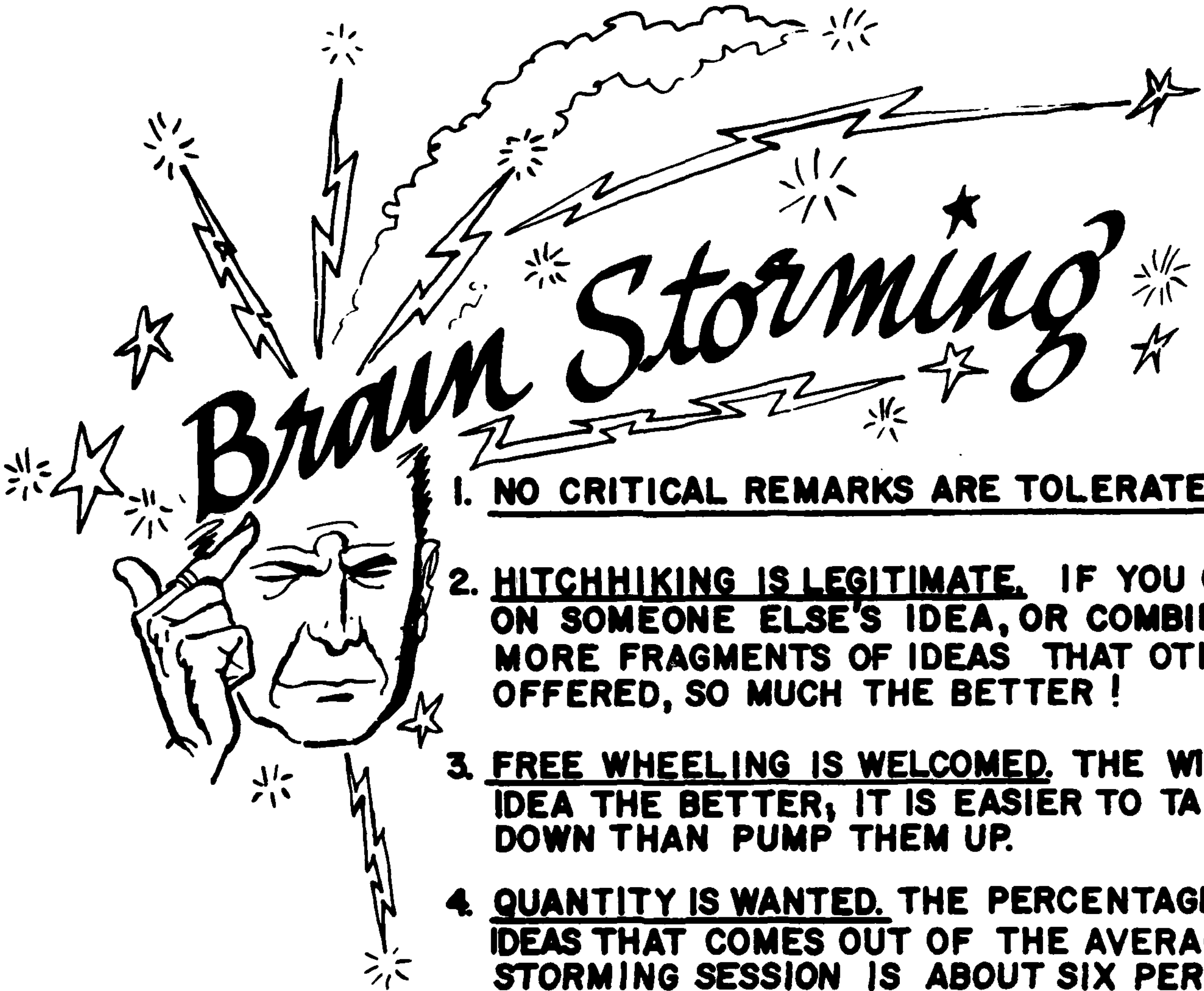
DEFERRED JUDGMENT

- IT HAS BEEN DEMONSTRATED THAT GENERATING A LONG LIST OF IDEAS WITHOUT JUDGING THE MERITS OF THE IDEAS ALLOWS THE PRODUCTION OF MANY MORE IDEAS
- THIS IS CALLED DEFERRED JUDGMENT
- DEFERRING JUDGMENT IS A PROCESS WHICH IS USED BY INDIVIDUALS OR GROUPS AND IS COMMON TO SEVERAL GROUP TECHNIQUES FOR THE PRODUCTION OF IDEAS

DEFERRED JUDGMENT (CONT'D)

- THE BEST KNOWN TECHNIQUE USING DEFERRED JUDGMENT IS BRAINSTORMING
- THE KEY TO THE PROCESS IS THE CREATION OF A CLIMATE WHICH ALLOWS CONTINUOUS DEVELOPMENT OF IDEAS IN THE ABSENCE OF ANY EVALUATION PROCESS
- THE LONGER THE LIST OF IDEAS, THE BETTER THE IDEA QUALITY


DIVERGENT
CONVERGENT
DESIRED OBJECTIVE
ATTAINED OBJECTIVE
FACTS
PROBLEMS
IDEAS
EVALUATION
ADOPTION
FACT FINDING
IDEA FINDING
SOLUTION FINDING



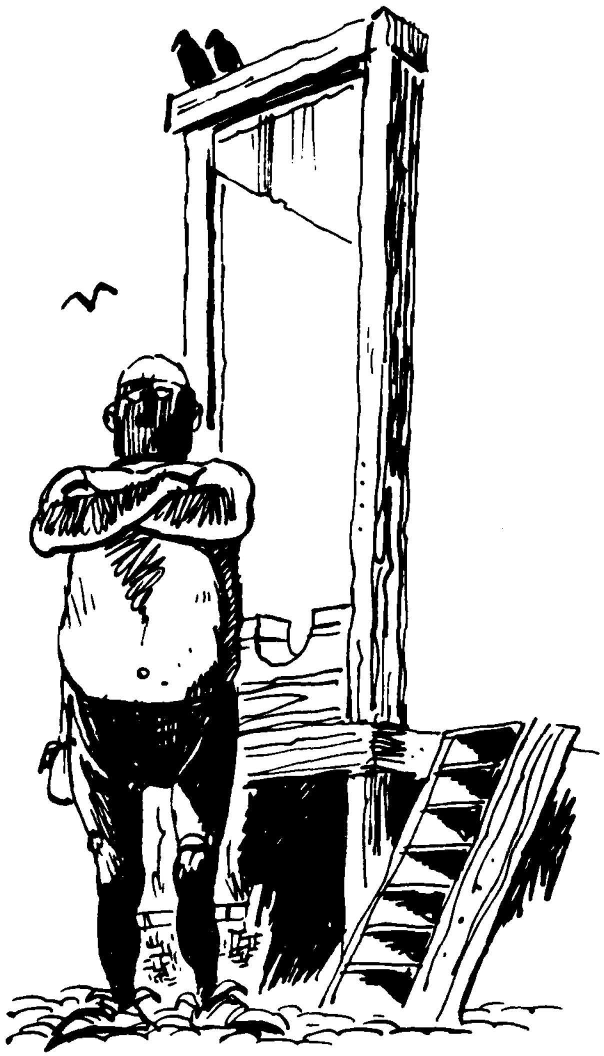
1. NO CRITICAL REMARKS ARE TOLERATED.

2. HITCHHIKING IS LEGITIMATE. IF YOU CAN IMPROVE ON SOMEONE ELSE'S IDEA, OR COMBINE TWO OR MORE FRAGMENTS OF IDEAS THAT OTHERS HAVE OFFERED, SO MUCH THE BETTER!

3. FREE WHEELING IS WELCOMED. THE WILDER THE IDEA THE BETTER; IT IS EASIER TO TAME THEM DOWN THAN PUMP THEM UP.

4. QUANTITY IS WANTED. THE PERCENTAGE OF USABLE IDEAS THAT COMES OUT OF THE AVERAGE BRAIN-STORMING SESSION IS ABOUT SIX PER CENT. OBVIOUSLY, THE MORE IDEAS, THE MORE WINNERS!

IDEA KILLING COMMENTS



A GOOD IDEA, BUT
AGAINST COMPANY POLICY
LET'S FORM A COMMITTEE
IT'S NOT PART OF YOUR JOB
IT HAS BEEN DONE BEFORE
WHO ELSE HAS TRIED IT?
IT'S TOO SOON
IT'S TOO LATE
LET'S MAKE A SURVEY FIRST
THE BOSS WON'T GO FOR IT
TOO HARD TO ADMINISTER
TOO HARD TO IMPLEMENT
TOO MANY PROJECTS NOW
TOO MUCH PAPERWORK
TOO OLD FASHIONED
YOU ARE OFF BASE

OSBORN'S RULES FOR BRAINSTORMING:

1. CRITICISM IS RULED OUT - Judgement is suspended until a later screeing or evaluation session. Allowing yourself to be critical at the same time you are being creative is like trying to get hot and cold water from one faucet at the same time. Results are lukewarm.

2. FREE-WHEELING IS WELCOME - The wilder the ideas, the better. Off-beat, inpractical suggestions may trigger in another participant ideas which might not have occured to them.

3. QUANTITY IS WANTED - The greater the number of ideas, the greater likelihood of "winners." It is easier to pare down a long list than to puff up a short list.

4. COMBINATION AND IMPROVEMENT ARE SOUGHT - In addition to contributing ideas of your own, members should try to combine and add to other ideas. HITCHHIKING is called for.

OSBORN's IDEA-SPURRING CHECKLIST:

PUT TO OTHER USES? In what other ways could this be used? What else could be made from this?

ADAPT? What is like this? What other ideas does this suggest? Is there something similar I could copy?

MODIFY? What change can we make? color, meaning, motion, sound, odor, taste, shape

MAGNIFY? What to add? Can it be stronger? Bigger? Longer? Multiply? Extra value?

MINIFY? What to subtract? What if it were smaller? How about dividing it? Slow it up? Make it lighter? Can I omit it?

SUBSTITUTE? What else instead? Who else instead? Could it be another place? Time?

REARRANGE? How else can this be arranged? Order changed? Another layout? Changing pace? Another sequence?

REVERSE? Transpose it? What are the opposites? What are the negatives? Another point of view?

COMBINE? How about an alloy? A blend? Combine units? Combine purposes? What about and ensemble? An assortment? Combine ideas? Other materials to combine?

QUESTIONS AS SPURS TO IDEATION:

HOW? WHY? WHERE? WHEN? WHAT? WHO? WHAT IF? WHY? WHY?
How to make it better? What parts need to be changed? Why is it necessary? Where should it be done? When should it be done? Who should do it? What if? Why is it a problem? What about?

NOMINAL GROUP BRAINSTORMING METHOD:

This method emphasizes private generation and ranking of solution. It enforces procedure for presentation of ideas and clarification. Debate and discussion are discouraged. Group can work productively with less confusion and less conforming.

The problem is presented to the entire group. Each person writes down his/her ideas, alternatives, solutions privately without discussing them. The ideas are recorded in a "round robin" fashion on a flipchart so everyone can see them. No evaluation is allowed at this time, only clarification of idea presented. Anyone in the group may ask another person for clarification. The entire list is reviewed and like ideas combined to avoid overlap. Each person ranks solutions privately. The results are tallied to determine relative support for each solution. The ranking is shared - again on a flipchart - and ranked again privately until a consensus is reached.

Implementation - Goal statement -

1. Who -

2. Will do what - other objectives

3. Under what conditions

4. To what degree of success (criteria). Checkpoints along the way.

This technique allows for task, social and emotional involvement in a group.

BLOCKS OR HOLDING PATTERNS TO IDEA GENERATION:

PERCEPTUAL BLOCKS (occur especially when problem is first perceived)

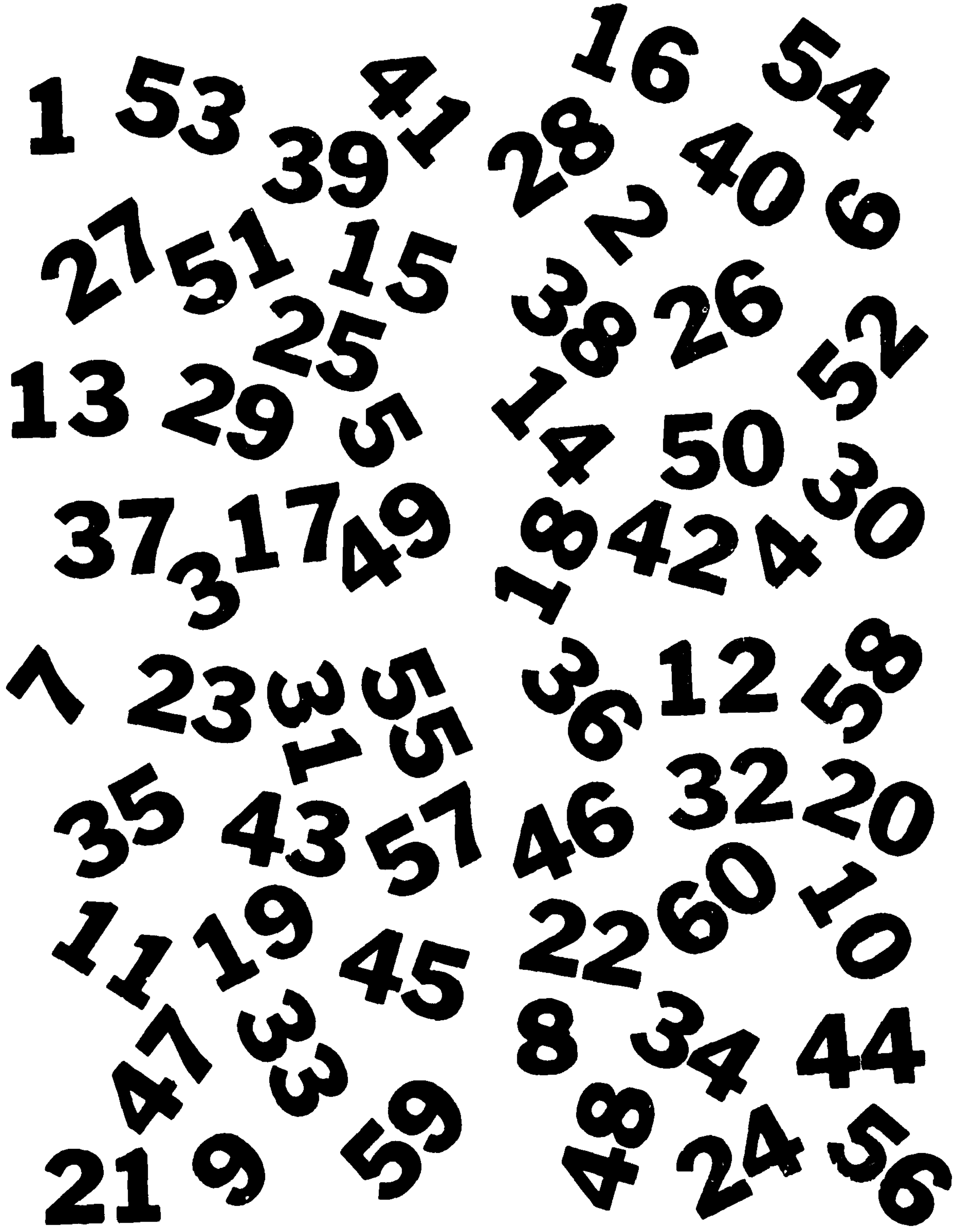
- Difficulty in isoloating the problem (can't separate object from field)
- Difficulty in narrowing the problem to much (paying little attention to the environment)
- Inability to define terms or isolate attributes
- Failure to use all of the senses in observing
- Difficulty in seeing remote relationships
- Difficulty in not investigating the "obvious"
- Difficulty arising from not recording "trivia"
- Failure to distinguish between cause and effect
- Inability to view problems from various viewpoints
- Seeing what you expect to see
- Stereotyped views
- Premature labelling

CULTURAL BLOCKS (acquired by exposure to a given set of cultural patterns)

- Desire to conform to an accepted pattern
- Must be practical and economical above all things so that judgment comes into play to early
- Not polite to be too inquisitive and not wise to doubt
- Overemphasis on competition or on cooperation
- Too much faith in statistics
- Too much faith in reason and logic
- Tradition is preferable to change
- Any problem can be solved by scientific thinking and lots of money
- Taboos

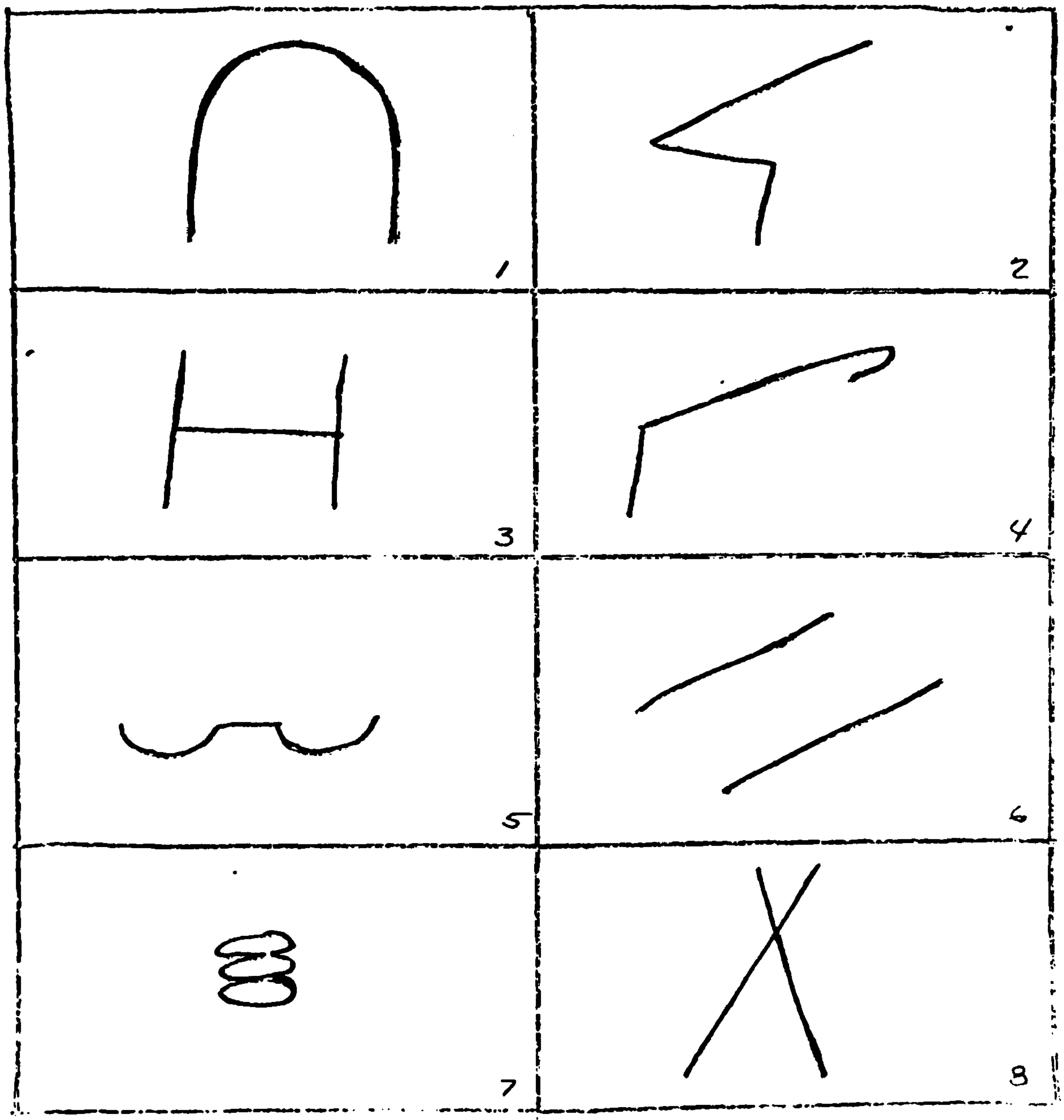
EMOTIONAL BLOCKS (color and limit how we see and how we think about a problem)

- Lack of challenge - problem failure to engage our interest
- Excessive zeal - over motivation to succeed quickly, can only see one direction
- Fear to make a mistake, to fail, to risk
- Prefer to judge ideas, rather than to generate them
- Cannot relax, incubate, "sleep on it"
- Difficulty in rejecting a workable solution and searching for a better one
- Fear of supervisors and distrust of subordinates/colleagues
- Refusal to take detour in reaching a goal
- Diffuculty in changing set (no flexibility)
- Lack of dirve in carrying problem through to completion, testing it out



1 53 39 41 16 28 54 40 6
27 51 15 2 38 26 52
25 13 29 5 14 50 30
37 17 3 49 18 42 4
7 23 31 55 36 12 58
35 43 57 46 32 20 60 10
11 19 45 22 8 34 44
47 33 59 48 24 56
21 9

FIGURE COMPLETION



TEAM BUILDING - GROUP DYNAMICS

Sometimes it seems the only thing we do is attend meetings. Seldom is any task or project solely an individual one. Meetings, committees task force efforts, team efforst all require a high order of skills to ensure that such group expenditure of time is productive and worthwhile. Coordinating efforts, clarifying responsiblities, assigning tasks, making progress reports, combining needed expertise, presenting a team's completed work for approval and implementation are several of the more important group tasks we are constantly involved in.

In a team setting all of the different understandings and perceptions of each individual present add a futher diliemma. The leader, as well as each participant, needs to be aware of the impact of individual differences to help cope with one's own and others' likely "hidden agendas." Each person on a team has a responsibility to help facilitate the team's effort; this requires awareness and attention to group proces as well as to the content of topics discussed.

Reaching clarity of understanding and consensus in a group requires a set of particular skills - not always easily understood:

- Establishing a climate of free expression
- Acceptance and encouragement of differences to facilitate exploration
- Means to handle conflict and lower anxiety
- Expressing consensus and gaining agreement
- Moving forward to further concerns

These skills can be improved by recognizing and acting upon the fact that every group has two functions: 1) TASK FUNCTIONS and 2) SOCIAL FUNCTIONS. The purpose of the TASK FUNCTIONS is to keep the group working on the task at hand - getting the work done. The purpose of the SOCIAL FUNCTIONS is to maintain constructive group relations among the members and to keep diverse individuals working together as a team. This means dealing with individual and group feelings and attitudes which may prevent the progress of the group towards its goal. There are certain TASK FUNCTIONS and SOCIAL FUNCTIONS in every group - these are explained below:

TASK FUNCTIONS:

- INITIATING: Proposing tasks or goals, defining the team problem, suggesting a procedure for solving the problem

- INFORMATION SEEKING: Requesting facts, seeking relevant information about team concern, asking for ideas or suggestions

- CLARIFYING: Elaborating, interpreting, or reflecting ideas and suggestions; clearing up confusions; indicating alternatives and issues before the team

- SUMMARIZING: pulling together related ideas, restating suggestions after the team has discussed them, offering a conclusion for the team to accept or reject.

SOCIAL FUNCTIONS:

- ENCOURAGING: Being friendly and responsive to others; accepting other and their contributions

- EXPRESSING GROUP FEELINGS: Sensing the feelings, moods, and relationships within the team; sharing one's own feelings with others

- HARMONIZING: Attempting to reconcile disagreements, reducing tension, getting people to explore their differences

- MODIFYING: When one's own idea or status is involved in a conflict, offering to modify one's own position; admitting error; facilitating the participation of others, suggesting procedures for sharing opportunity to discuss team's problems

- EVALUATING: Evaluating team functioning and production; expressing standards for team to achieve. measuring results and evaluating degree of team commitment.

COHESIVENESS - THE KEY TO SUCCESSFUL TEAM WORK

Cohesiveness refers to the ability of the team to stick together. Cohesiveness encourages productivity, morale, and communication. Teams with high team loyalty have greater productivity, higher morale, and better communication than teams with little cohesiveness.

- PRODUCTIVITY: Cohesive productive teams do more work because members take the initiative and help one another. They distribute the work load - take up the slack in times of stress.

- MORALE: Morale of the team members is closely tied to cohesiveness. If the team is important to them, people pay attention to its problems - will spend time an effort in behalf of the team, and "glory" in its successes.

- COMMUNICATION: Cohesiveness encourages disagreements and questioning - both are necessary to communication. Members of a highly cohesive team disagree among themselves. Cannot stand by and watch others do a shoddy job - their team is at stake.

The symptoms of low cohesiveness - teams have meetings which are quiet, polite, boring and apathetic. People seldom disagree; there is little give and take discussion. Important decisions are handled quickly, with little comment.

The symptoms of high cohesiveness - team meeting tend to be noisy, full of humor, disagreement, personal byplay and some argument. Few important questions are raised without a thorough airing. Discussion may well continue after the meeting is over.

INFORMATION ON TEAMS

A task oriented small team is composed of three or more people working together to do a clearly specified job. Research in small group work indicates that five is an excellent number for a team working on problems. Sever or nine are workable. Teams composed of an even number of people are not as efficient as groups totaling an odd number. In groups of five or less, all participants speak to one another, even those who speak very little. In groups of seven or more, the quiet members cease to talk to one another and talk only to the top leaders. As groups get even larger, talk centralizes around only a few people. Group interaction falls off. As the group gets larger, we tend to form small teams (cliques) within the larger team.

One of the first questions most people in the new work group ask is: How do I relate to these people? A member's role is worked out jointly by the person and the team. One of the most important features of group dynamics is the power of nonverbal and verbal communication to get people to act as others in the group do. Every new team must go through a "tension" period during which roles are tested - where am I on this team?

LEADERSHIP

In his role behavior a leader uses three different skills - TECHNICAL, HUMAN and CONCEPTUAL. Though they interrelated in practice, they can be considered separately.

- TECHNICAL skill refers to a person's knowledge of, an proficiency in, any type of process or technique. I.E., skills learned by engineers, accountants, etc, in the practice of their specialties. This skill is the distinguishing feature of job performance at the operating level; but as employees are promoted to leadership responsibilities, their technical skills become proportionately less important. They increasingly depend on the technical skills of their subordinates.

- HUMAN skill is the ability to interact effectively with people and to build teamwork. No leader at any organizational level escapes the requirement for effective human skill. It is a major part of his role behavior.

- CONCEPTUAL skill becomes increasingly important in higher managerial/leadership roles, because these leaders are dealing more with long range plans, broad relationships, and other abstractions. Conceptual skills deal with ideas, while human skill concerns people, and technical skill is with things. Conceptual skill enables a manager to deal successfully with abstractions, to set up models and to devise plans. It helps him to see relationships between groups, both within and without his organization.

Different types of functions and different levels of leadership require different mixes of skills. A further breakdown in leadership skills:

- Ability to state issues in such a way that group does not become defensive
- Ability to supply essential facts
- Ability to draw people out so that members will participate
- Ability to restate accurately ideas and feelings expressed
- Ability to wait out pauses
- Ability to ask questions - stimulate problem solving behavior
- Ability to summarize - more it along
- Ability to follow through on commitments, responsibilites etc.

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3. Source Book in Failure Analysis, American Society for Metals, 1974.

4. Prevention of the Failure of Metals Under Repeated Stress by Batelle Memorial Institute, John Wiley & Sons, Inc., 1949.

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10. C. Lipson, "Why Machine Parts Fail," Machine Design, May-December, 1950.

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Source:
University of Michigan, Engineering Summer Conference, Professor Charles Lipson

APPENDIX A

BLANK ROOT CAUSE ANALYSIS CHARTS

Date: Rev. No.:

ROOT CAUSE ANALYSIS CHART

Failure Indication:

Cause Probability Estimate:

WHAT

WHERE

WHEN

WHY

HOW

WHO

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

Corrective Action: ____ NONE ____ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date:

Rev. No.:

Failure Indication:

Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	**Additional Data Tests Required**
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

Date: Rev. No.:

ROOT CAUSE ANALYSIS CHART

Failure Indication:

Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date:

Rev. No.:

Failure Indication:

Cause Probability Estimate:

WHAT

WHERE

WHEN

WHY

HOW

WHO

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: Rev. No.:

Failure Indication: Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

Date: Rev. No.:

ROOT CAUSE ANALYSIS CHART

Failure Indication:

Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: Rev. No.:

Failure Indication: Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date.　　　　Rev. No.:

Failure Indication:　　　　Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)　　　　Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: Rev. No.:

Failure Indication: Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: Rev. No.:

Failure Indication: Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: **Rev. No.:**

Failure Indication: **Cause Probability Estimate:**

	SPECULATION	EVALUATION		
	Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
WHAT WHERE WHEN WHY HOW WHO	**Failure Sequence**			

Corrective Action: ___ NONE ___ REQUIRED (Check One) **Conclusion:**

ROOT CAUSE ANALYSIS CHART

Date: **Rev. No.:**

Failure Indication: **Cause Probability Estimate:**

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: Rev. No.:

Failure Indication: Cause Probability Estimate:

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

WHAT

WHERE

WHEN

WHY

HOW

WHO

Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

ROOT CAUSE ANALYSIS CHART

Date: Rev. No.:

Failure Indication:

Cause Probability Estimate:

WHAT

WHERE

WHEN

WHY

HOW

WHO

SPECULATION	EVALUATION		
Failure Mode:	Supporting Data	Refuting Data	Additional Data Tests Required
Failure Sequence			

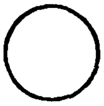
Corrective Action: ___ NONE ___ REQUIRED (Check One)

Conclusion:

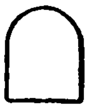
APPENDIX B

LOGIC DIAGRAMS

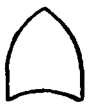
A FAULT OR EVENT CAUSED BY A COMBINATION OF CONTRIBUTING EVENTS.



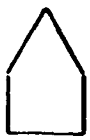
A FAULT OR EVENT CAUSED BY A COMPONENT OR SUB-ASSEMBLY FOR WHICH A PROBABILITY CAN BE ASSIGNED. ELIPSES ARE FREQUENTLY USED AS AN ALTERNATE TO CIRCLES FOR EASIER TYPING.



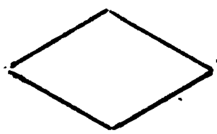
AND GATE, THE OUTPUT EXISTS ONLY IF ALL THE INPUTS ARE PRESENT SIMULTANEOUSLY.



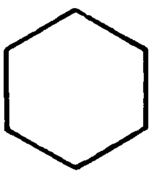
OR GATE, THE OUTPUT EXISTS IF ANY (OR ANY COMBINATION) OF THE INPUTS ARE PRESENT.



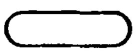
AN EVENT WHICH IS CONSIDERED TO BE A NORMAL EVENT.



A FAULT THAT IS NOT DEVELOPED FURTHER DUE TO LACK OF INFORMATION OR IMPORTANCE.



INHIBIT GATE, ALLOWS APPLICATION OF A RESTRICTION OR CONDITIONAL EVENT.

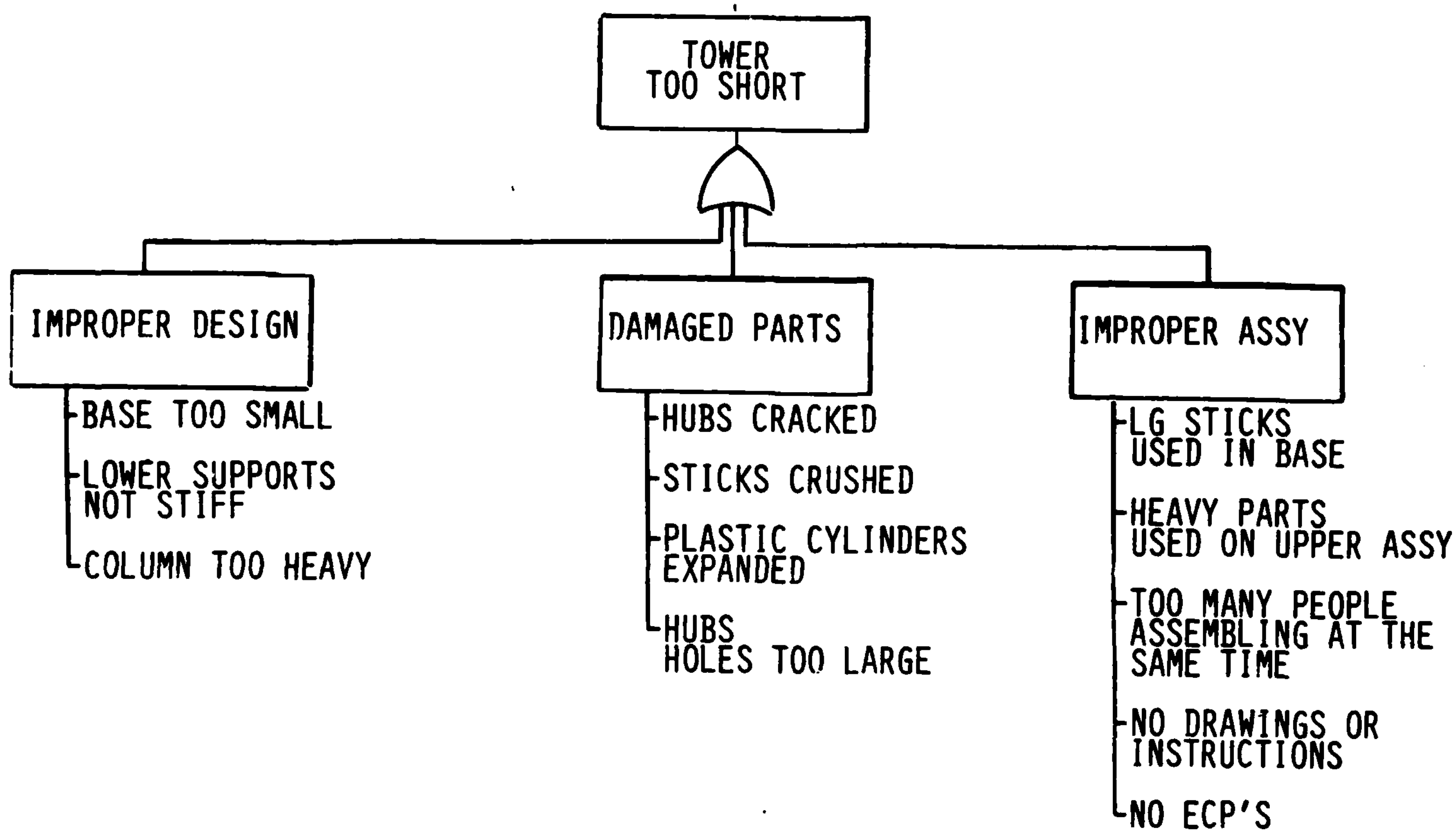


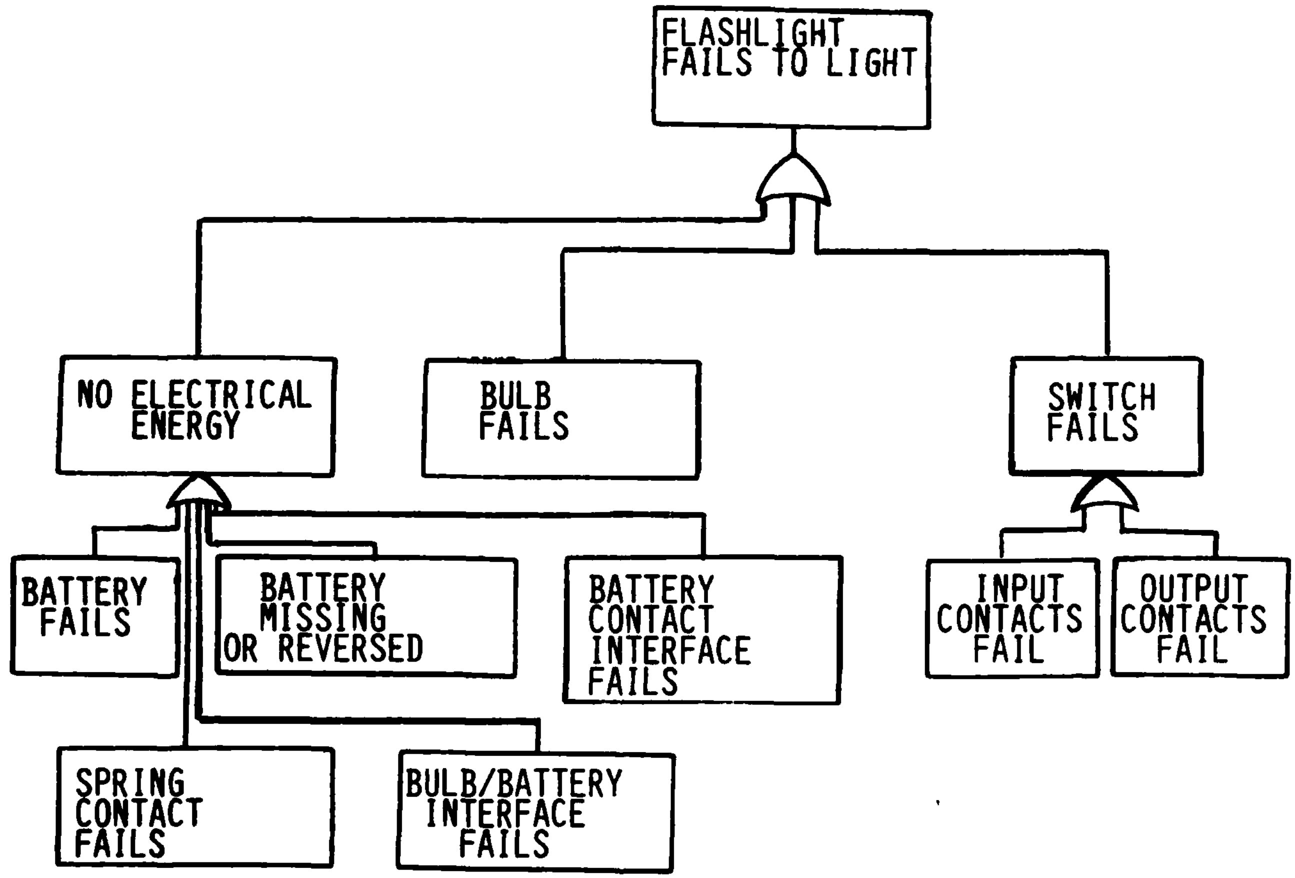
INDICATES RESTRICTIONS OR CONDITIONS.

USED AS A CONNECTING SYMBOL FOR A SIMILAR CONDITION AT ANOTHER PART OF THE TREE.

FAULT TREE SYMBOLS

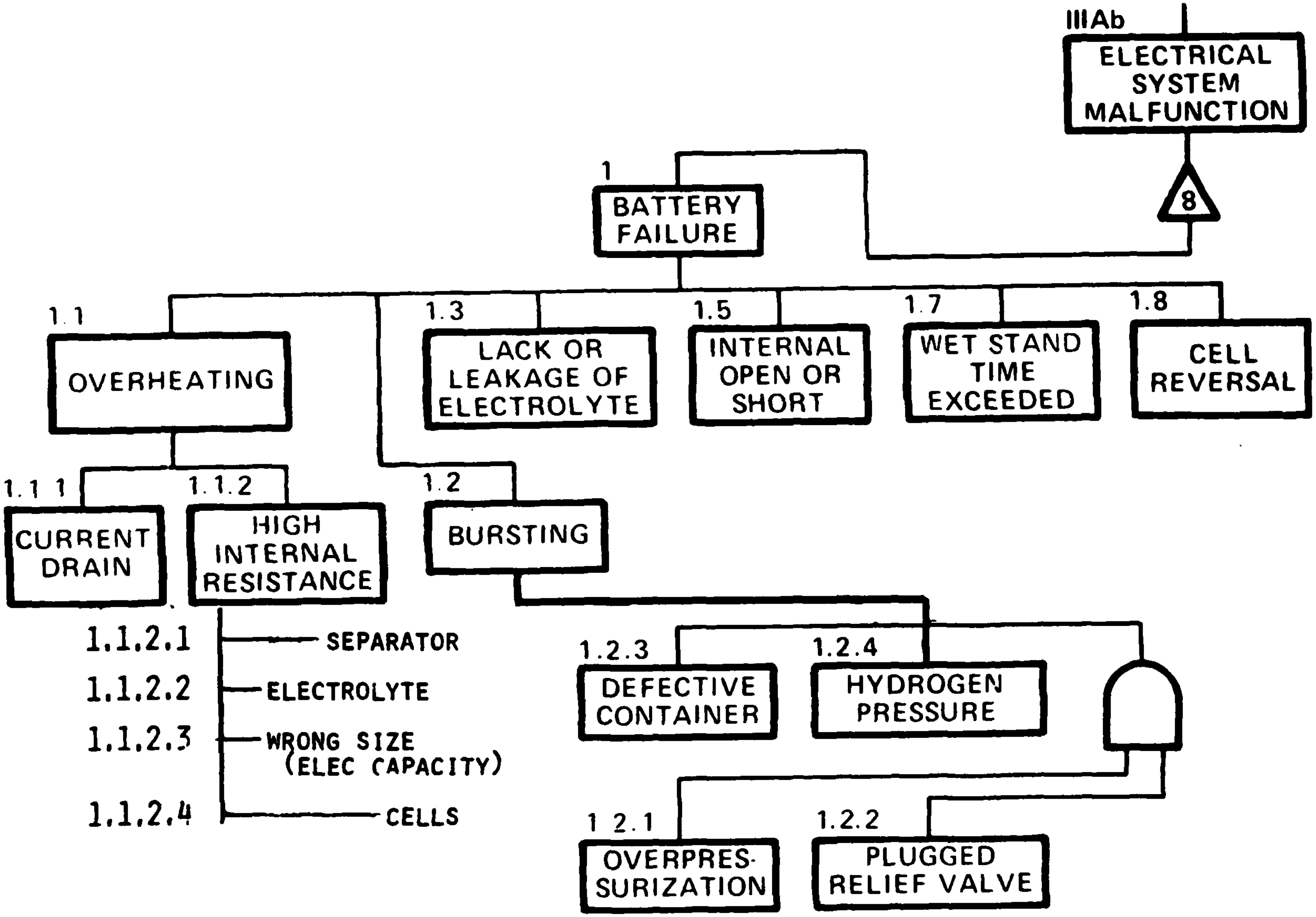
SAMPLE - TINKER TOY LOGIC

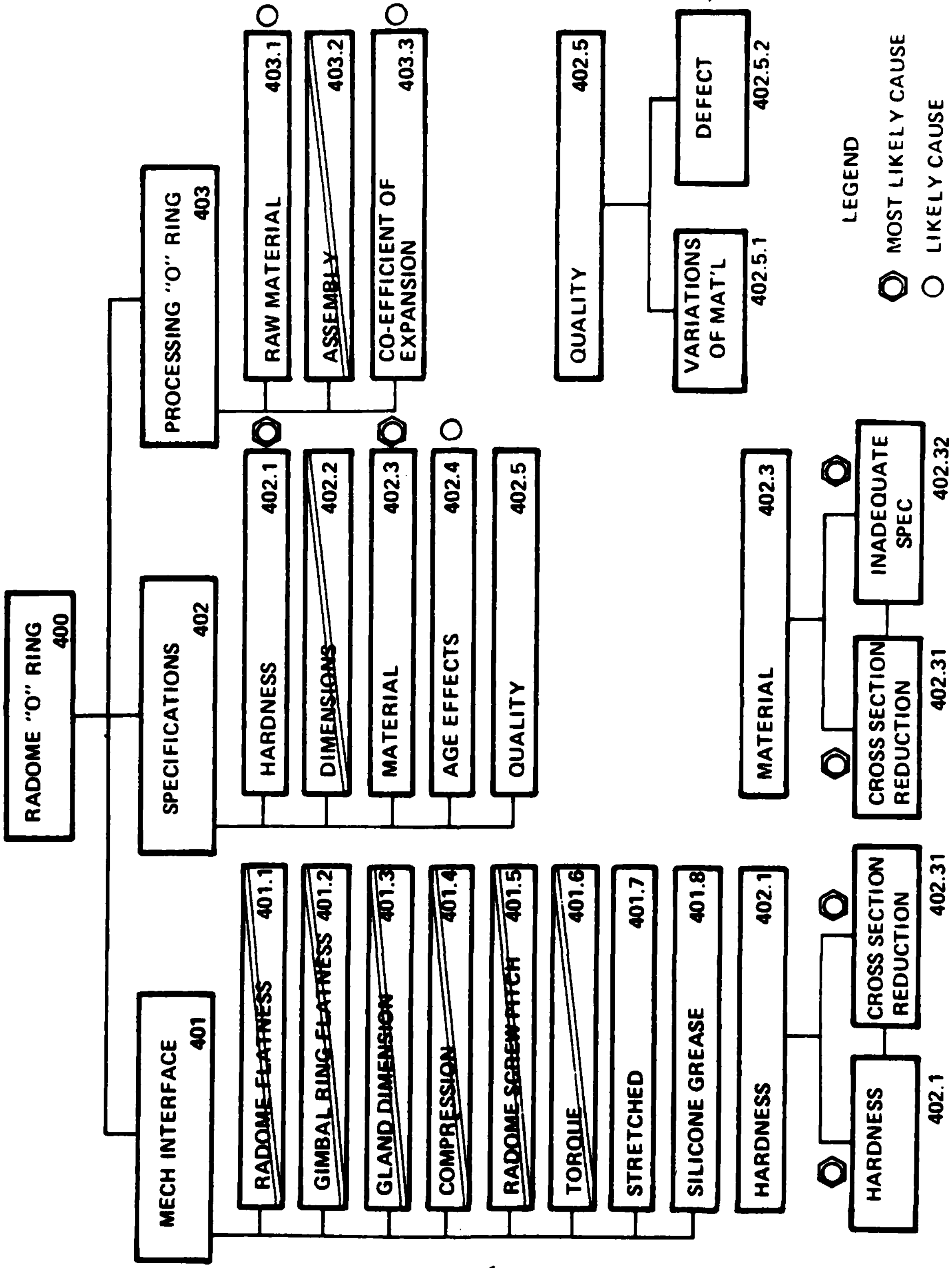




FLASHLIGHT LOGIC DIAGRAM

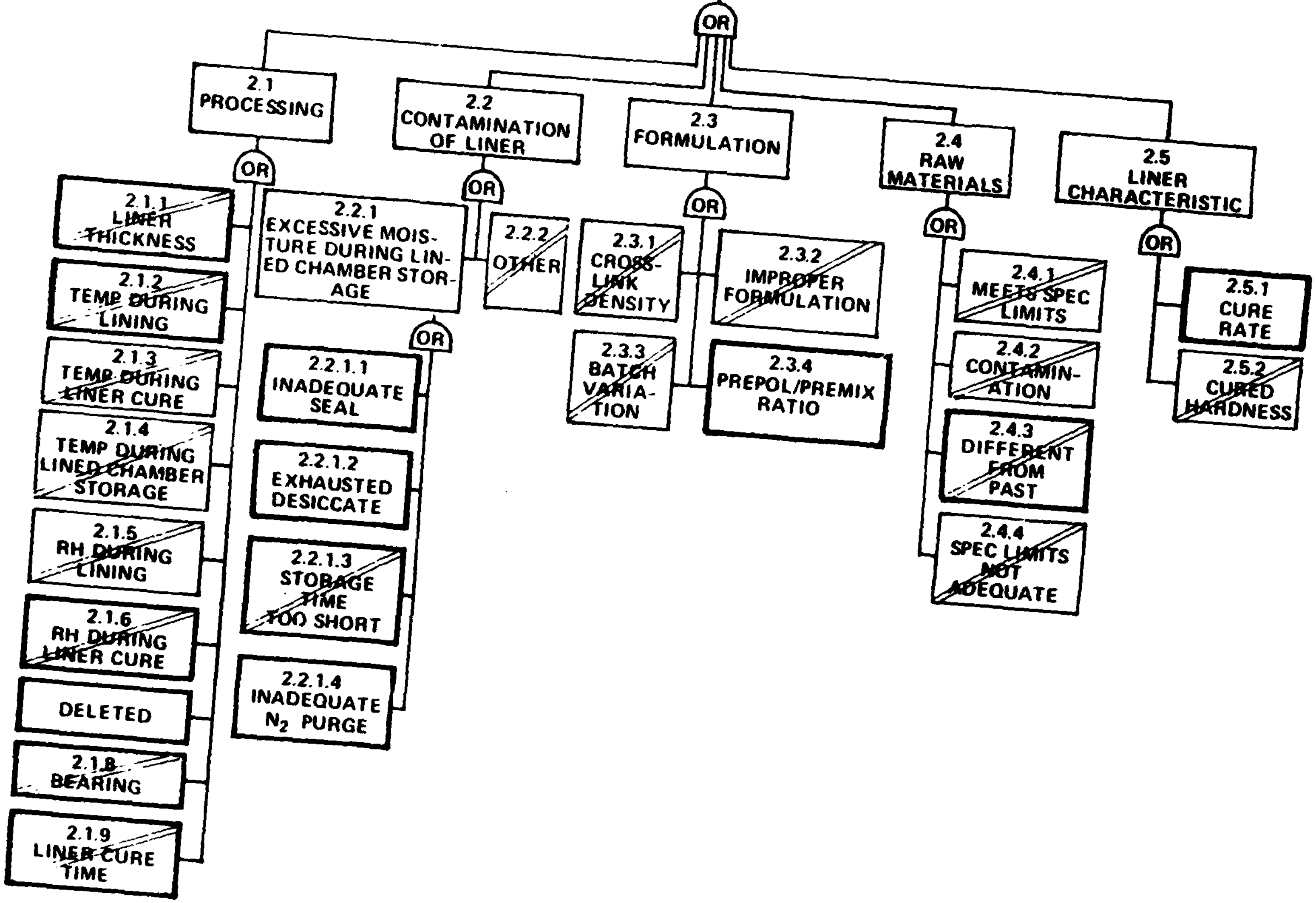
LOGIC TREE INDICATING CAUSES OF BATTERY FAILURE

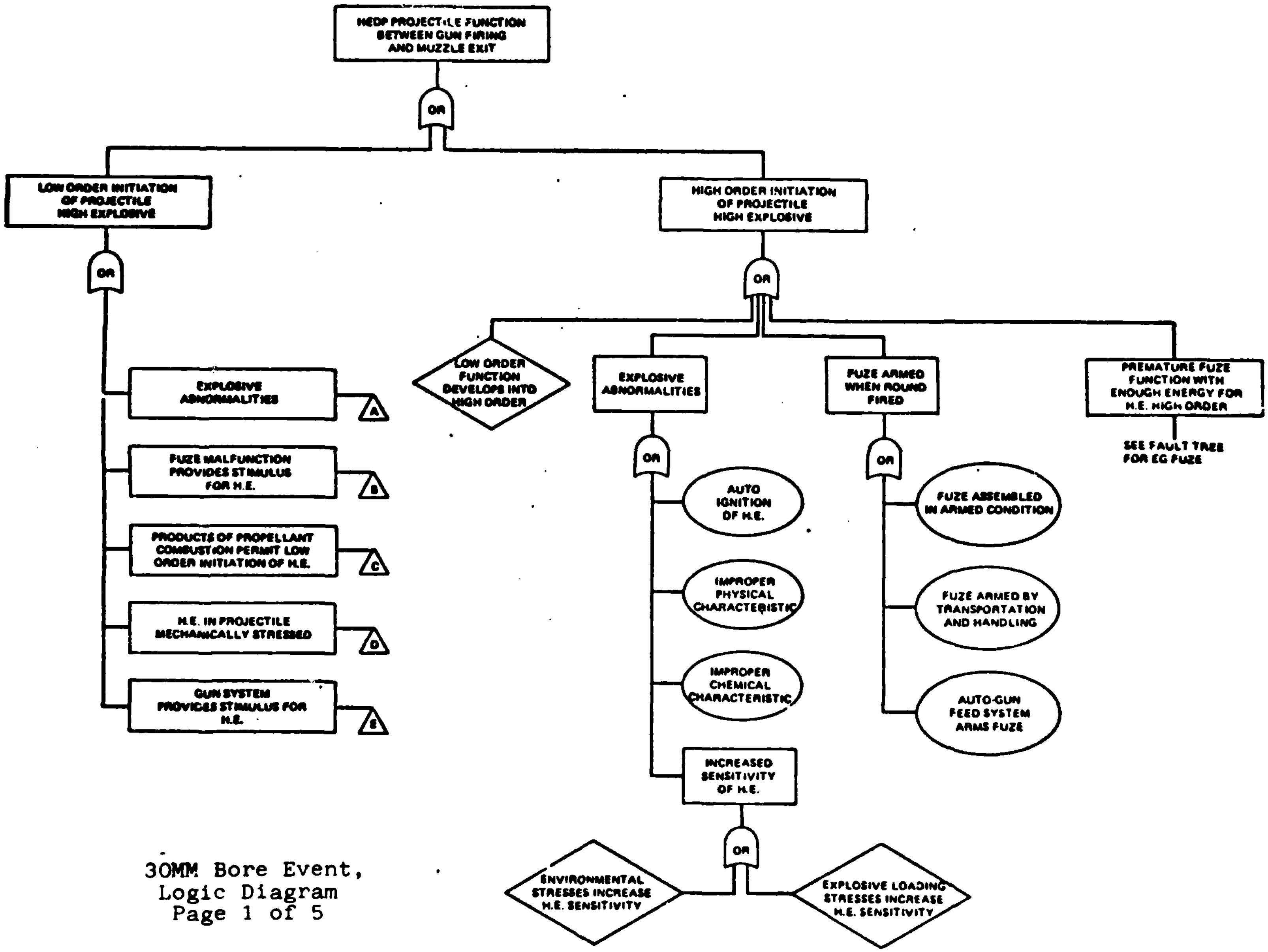




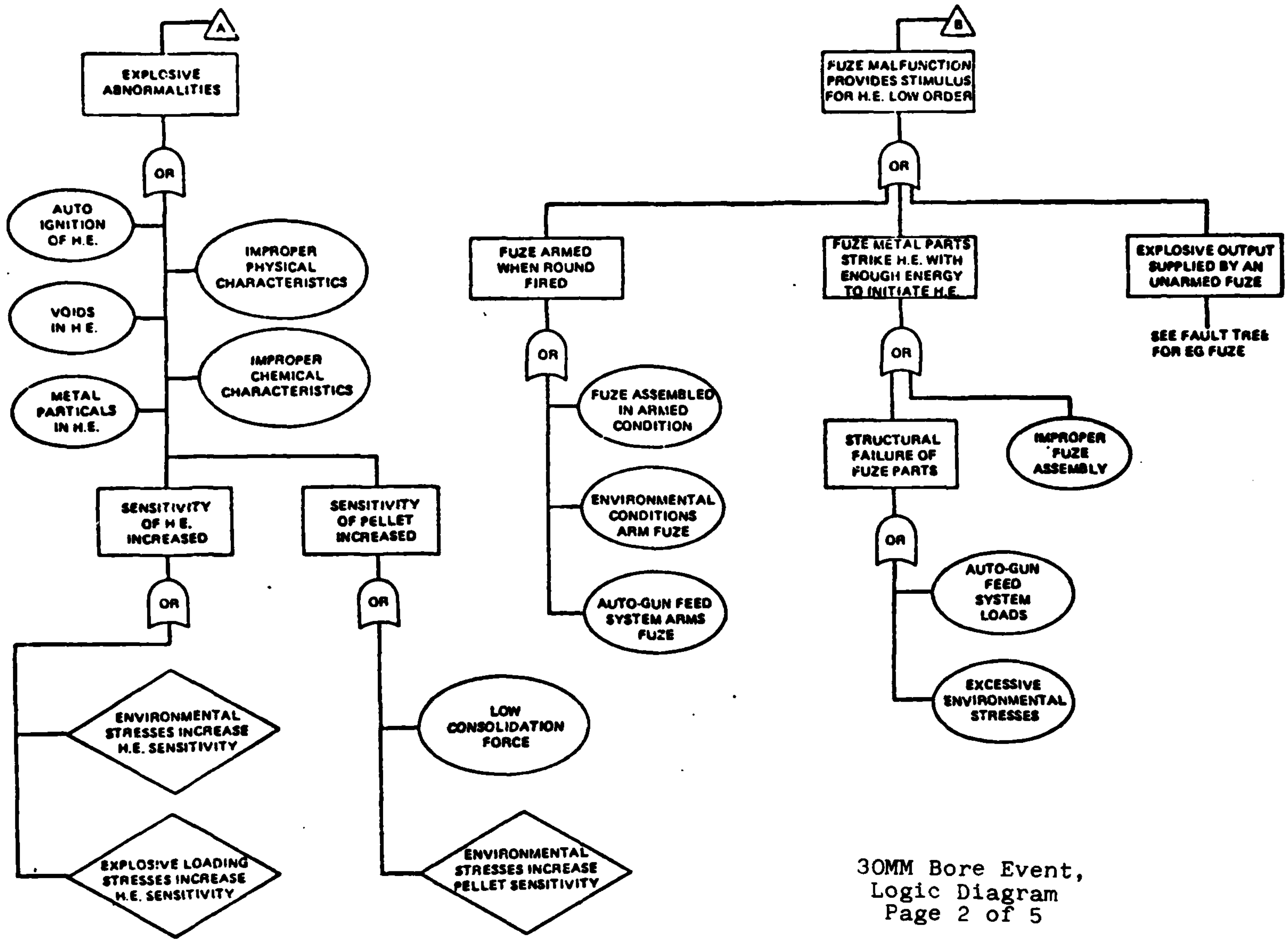
RADOME "O" RING 400
MECH INTERFACE 401
SPECIFICATIONS 402
PROCESSING "O" RING 403
RADOME FLATNESS 401.1
GIMBAL RING FLATNESS 401.2
GLAND DIMENSION 401.3
COMPRESSION 401.4
RADOME SCREW PITCH 401.5
TORQUE 401.6
STRETCHED 401.7
SILICONE GREASE 401.8
HARDNESS 402.1
HARDNESS 402.1
CROSS SECTION REDUCTION 402.31
HARDNESS 402.1
DIMENSIONS 402.2
MATERIAL 402.3
AGE EFFECTS 402.4
QUALITY 402.5
MATERIAL 402.3
CROSS SECTION REDUCTION 402.31
INADEQUATE SPEC 402.32
RAW MATERIAL 403.1
ASSEMBLY 403.2
CO-EFFICIENT OF EXPANSION 403.3
QUALITY 402.5
VARIATIONS OF MAT'L 402.5.1
DEFECT 402.5.2
LEGEND
MOST LIKELY CAUSE
LIKELY CAUSE

LOGIC DIAGRAMS- SUSTAINER/LINER UNBOND

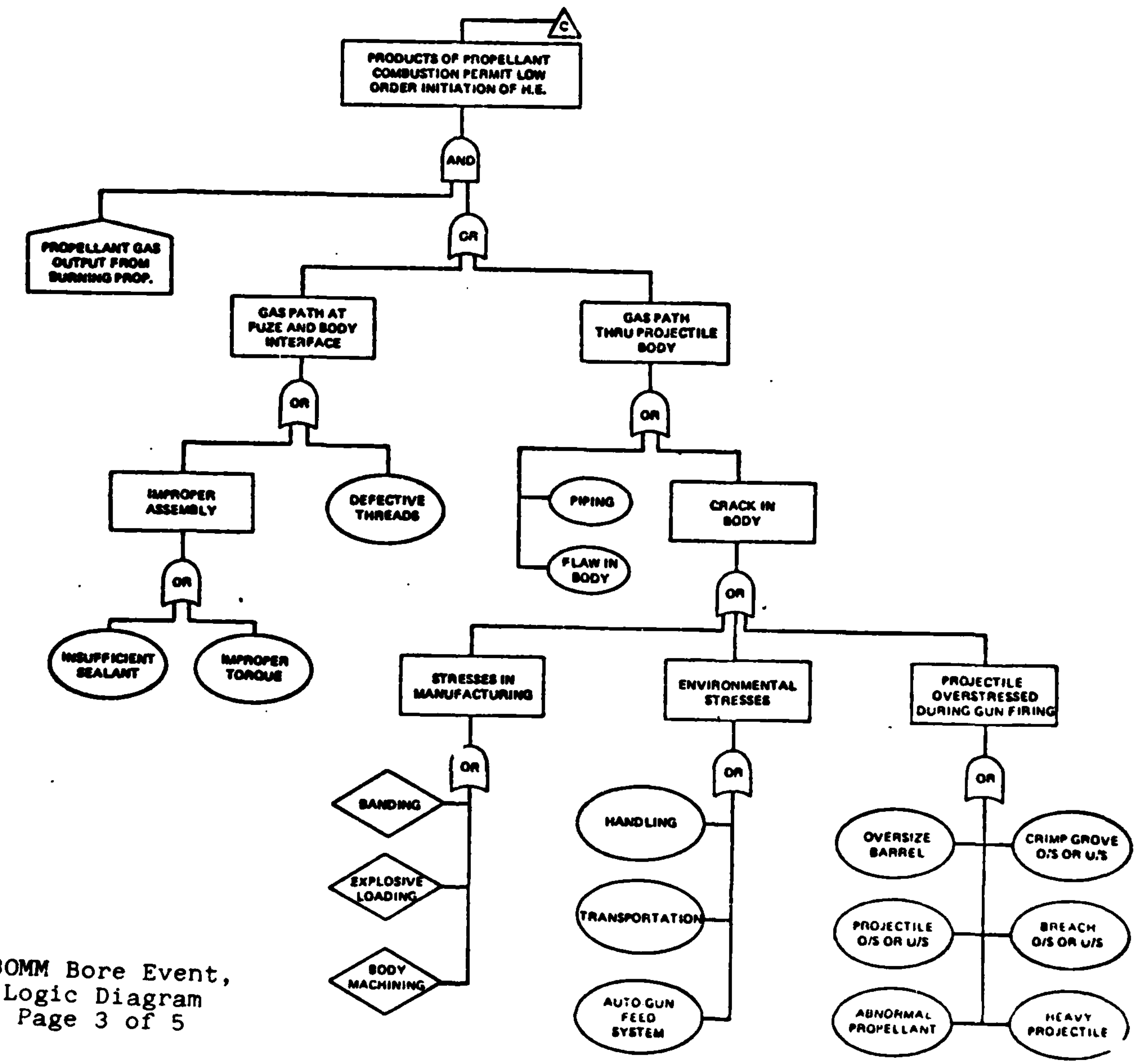




30MM Bore Event,
Logic Diagram
Page 1 of 5



30MM Bore Event,
Logic Diagram
Page 2 of 5



30MM Bore Event,
Logic Diagram
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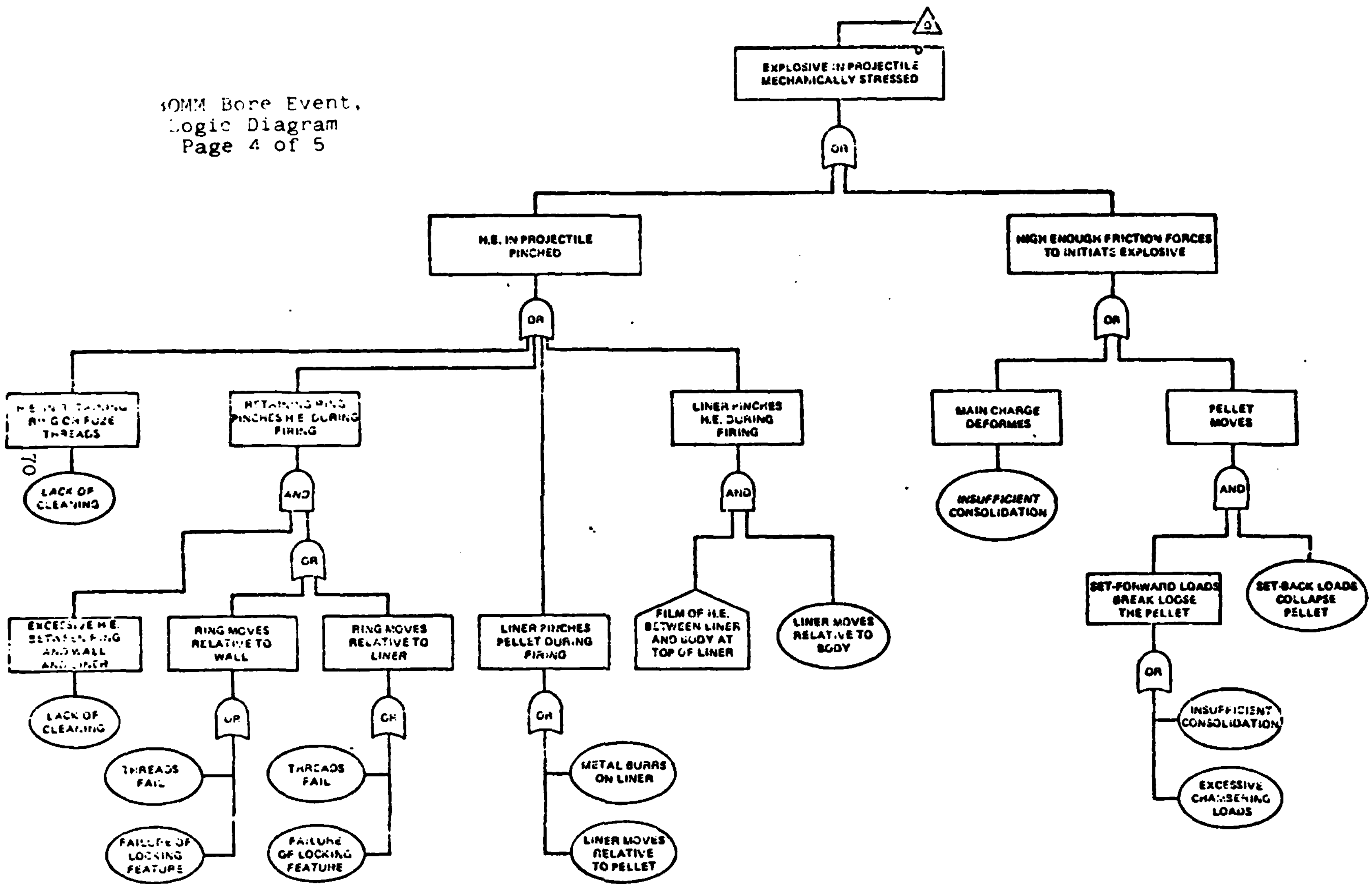
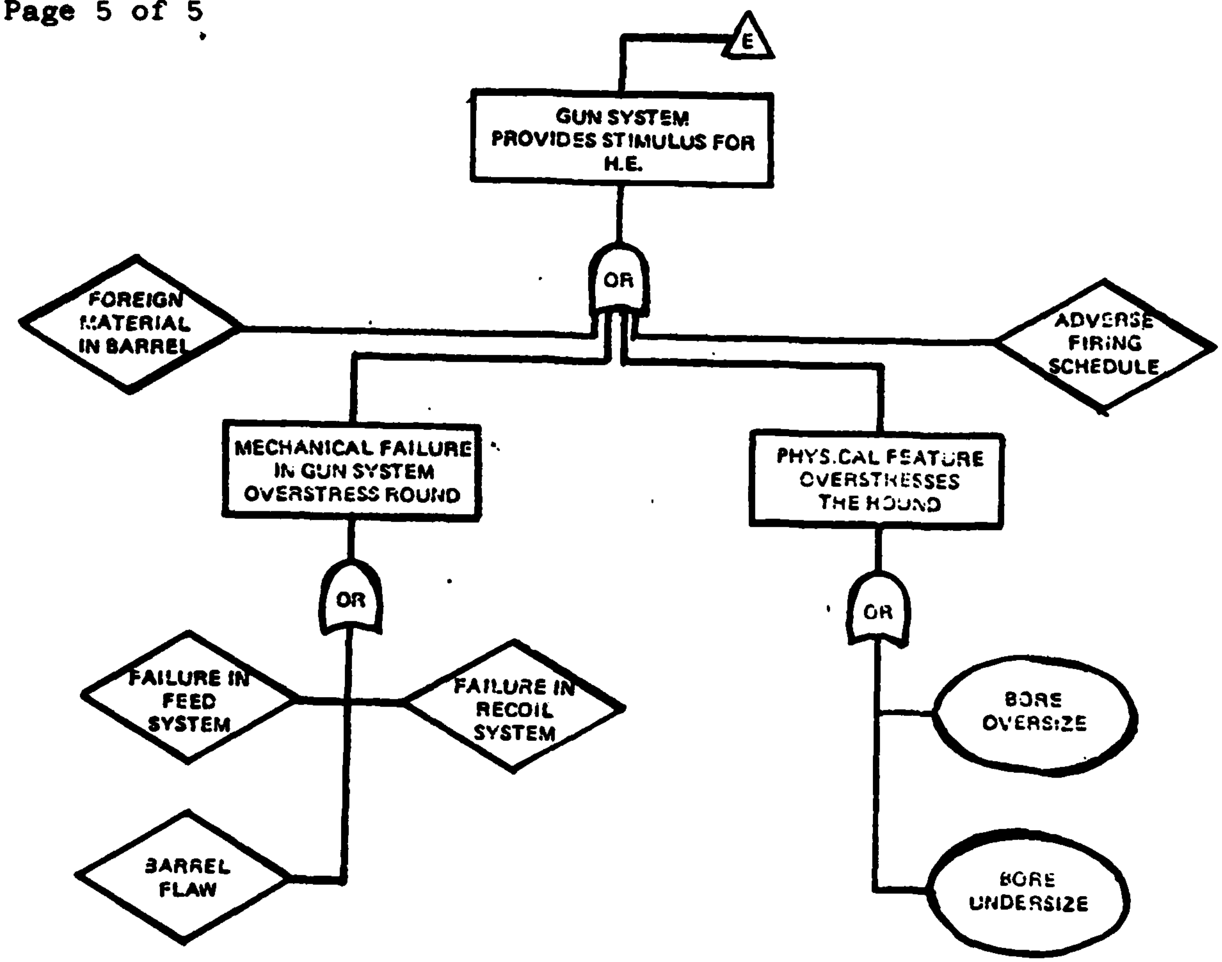
60MM Bore Event,
Logic Diagram
Page 4 of 5

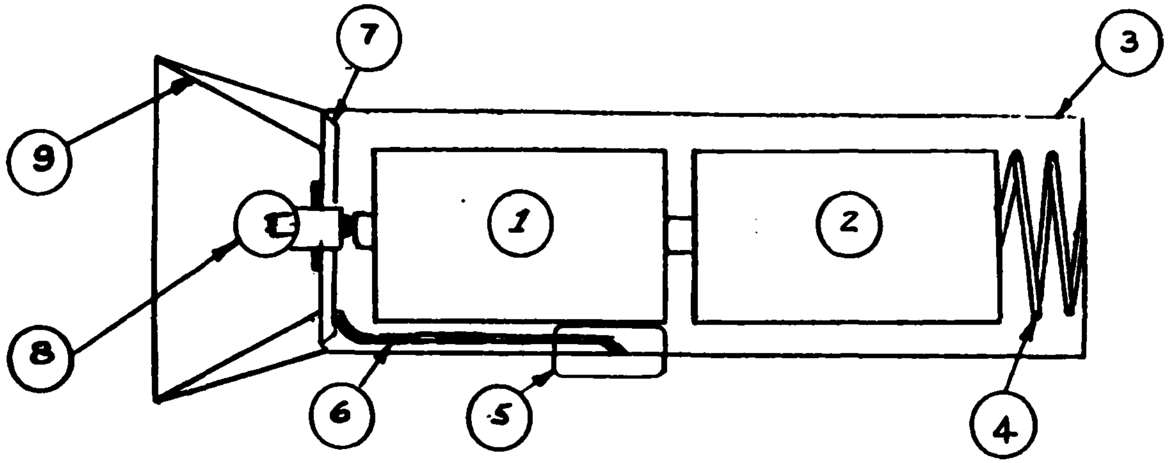


30MM Bore Event,
Logic Diagram
Page 5 of 5



CASE STUDY #1

FLASHLIGHT WON'T LIGHT



LEGEND

1	BATTERY	4	SPRING	7	OUTER BULB CONTACT
2	BATTERY	5	SWITCH SLIDE	8	BULB
3	CASE	6	SLIDE CONTACT	9	REFLECTOR

CASE STUDY #2

CAR STARTING PROBLEM -

1973 Chevrolet - 80,000 miles - side mount battery terminal

Visual evidence present -

- Car driven predominantly in city, short trips
- Hole in top surface of battery case adjacent to positive terminal
- Clear liquid oozing out of hole in battery

- Intermittent starting 1-3 tries
- Once started, car runs normal
- Car jump-started 3 times in a 24-hr. period, continues to run until ignition is turned off
- Battery label sticker on top of battery charred entire length
- Car started each time jumped - $6.00, average time - 1 hour
- Battery replaced one year ago

- Generator discharge light does not light up
- Flashers work; radio, air conditioning works
- Two days prior--overheating problem - temp light lighted when car idled in traffic
- Never replaced alternator

CASE NOTES

- General condition of engine compartment dirty, greasy -- indicates need for maintenance
- Key difficult to insert into ignition
- Ignition lock has excessive play
- Excessive rust in areas of battery/clamps
- Electrical system is negative ground

TEAM ASSIGNMENT

To prepare a logic diagram of all possible systems, sub-stems and/or components which could be root cause of this problem.

Facts which are described in the case study should be considered as minimum information. Use your past experience, knowledge of auto operation to include as many relevant areas as possible.

Assume you can consult with driver by phone to collect additional information - what questions would you ask?