OAR 70-006

GUIDE TO PROBLEM ANALYSIS OF ADVANCED TECHNOLOGICAL OBJECTIVES

Methodology for Problem Research

Prepared by

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FOREWORD

In the Fall of 1967, an effort known as Technological Barriers Documentation Project was established in the Air Force Office of Aerospace Research (OAR). Its purpose was to augment the existing R&D communication practices with improved means of bringing problems of aerospace technology to the attention of Air Force scientists and engineers.

As the project progressed, it became apparent that only well-thought-out and challenging problems induce the responsive reaction of scientists. Thus attention had to be given to the methodologies of identifying, analysing, describing and documenting problems in a manner that would insure their validity and clarity.

The results are presented in this guide. They include the idea of team efforts to produce the required analyses, the Functional Flow Block Diagram (FFBD) to depict graphically the interdependence between the technological objectives and the specific problems, and the Problem Resume (PR) to describe the problem in sufficient detail and also inform the reader about the principal point of contact within the Air Force for subsequent technical communications.

The methodology used in the Air Force project is sufficiently general for adaptation to other military or government R&D management establishments. This guide is released for public dissemination with a hope that its use (and possible improvements) will contribute to the Nation's ability for better interaction with and use of its technological manpower.

ALEXANDER G. HOSHOVSKY
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GUIDE TO PROBLEM ANALYSIS OF ADVANCED TECHNOLOGICAL OBJECTIVES

This manual describes systematic means for deriving a structure of "bite-size" problems whose collective solution would make attainable the achievement of an advanced technological objective (ATO). These problems will document both the Technology Needs required for the ATO, and the Research Needs required to develop the needed technology. The process begins with the analysis of an objective, *infeasible of current attainment owing to a lack of supporting technology and basic knowledge*, and ends -- 10 to 25 years later -- with the accumulation of the base of knowledge and technology required to make the objective feasible.

The methodology outlined in this manual, hereafter termed "Problem Research," is designed to provide means to answer questions such as these:

o How does one pinpoint significant problems where research can make the greatest contribution?

o How can effective communication be established between scientists interested in phenomena -- how or why something happens -- and engineers and designers who are not so much interested in the how and why as in practical application?

o How does one demonstrate the relevance to Air Force needs of problems which are small enough -- discrete, specific delimited, "bite-size" -- to be attacked by work-unit level research?

While this manual focuses on the Problem Research process as if it were conducted as an independent activity, *Problem Research will normally be accomplished in conjunction with other studies already authorized and funded* -- feasibility, Concept Formulation, mission analysis, applications analysis, research opportunities, etc. Accomplishing Problem Research in this manner will add little to the manhour and dollar cost of the basic study and may even result in net savings.

OUTPUT OF PROBLEM RESEARCH

Although Problem Research produces paper products, abstracts of problems and a problem research report, its greatest dividend is the establishment of person-to-person relationships between those men with the expertise to produce and organize the new scientific knowledge required to make the objective feasible. At the same time, the process produces the tools which can be used to prove the relevance of fundamental research to Air Force needs.

Thus the process produces:

- o Definition of problem areas
- o Relationships between the people best equipped to find solutions
- o Proof of the validity of the research program to achieve the top-level objective.

Research Needs Defined

Through Problem Research, Research Needs are defined which are (1) specific -- discrete, small, "bite-sized" -- enough to be meaningful, and (2) relevant to *current* research. That is, they define needs for research results required to make possible weapons which can be built 20 or 25 years from now, only *if current research builds the necessary foundation* of new knowledge.

For one ATO, there may be ten problem areas, or a score, even a hundred, which, if solved would make the proposed objective feasible. Each Research Need is documented on a single-page Problem Resume (Figure 1). Problems documented on Problem Resumes should be so delimited and specific that the scientist who reads it quickly can tell whether the work he is doing is relevant to the problem stated. If it is, the scientists can be quickly in touch with the Problem Monitor whose name, address and telephone number are listed on the resume.

PROBLEM RESUME

UNCLASSIFIED
Security Classification

Problem Title

High Temperature Tolerance Electric Insulators

Abstract

Materials having dialectric breakdown strength of 60,000 to 90,000 volts per meter and resistant to oxidation and reduction at temperatures up to 3400 K are desired for insulation between electrodes of magnetohydrodynamic (MHD) electrical generators of advanced design for airborne or space applications.

Electrical conductivities at operating temperatures should not exceed 10^{-3} to 10^{-4} mho/cm. Ceramic materials should withstand thermal shock at operating temperature with high heating rates and temperature gradients, be resistant to corrosion by cesium or potassium carbonate vapors, and mechanical corrosion by flowing gases up to Mach 2 for 24 hours. Thermal expansion, material strength and geometry limitations will be accomodated by design flexibility.

The availability of suitable insulating material, when coupled with other advances, will permit design of MHD generators with much higher channel wall operating temperatures, thus contributing to increased generator efficiency and lower specific fuel consumption.

References

Kenneth R. Cramer and Robert J. Massey
Technological Barriers to the Development of a Competitive, Flight-Weight MHD Power Generator, OAR 69-0020, Office of Aerospace Research, August 1969
AD 859-947

5 Key words

High-temperature electrical insulators
MHD
Flight-weight MHD generators
Problem research
Technological problems

Problem Monitor - To provide (or obtain) information concerning this problem contact

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ATO #	7 Pb #	8 Function(s)	9 Date
1X	1X-10	2.2.1.1	8-18-69

The Problem Resume is designed not so much to *convey* the substance of a problem as to trigger the establishment of direct, person-to-person contact between scientist and technologist. This intention is based on the premise that person-to-person links constitute the primary channel through which the output of research flows to practical application. Conveying to the scientist the substance of a problem and to the technologist the alternatives available is normally accomplished through the give-and-take dialogue of technically qualified individuals.

Problems described on the Problem Resumes indicate hypothetical technological capabilities which, if actually achieved, would permit improved performance of a specified function. In effect the problem suggests an "If...then" statement: IF science and technology can provide the means to do what is asked for in the problem, THEN it would be possible to improve performance in the related function which would, in turn, contribute to attaining the ATO.

Relevance Proved or the "Audit Trail"

The Air Force relevance of problems documented on Problem Resumes is demonstrated through a documented means-ends chain extending from the "bite-size" problem documented on the resume to the ATO from which they were derived. This "audit trail" which confirms relevance is documented on an interrelated structure of functional flow block diagrams (FFBD's). Figure 2 illustrates the structure of FFBD's. (Normally, there is only one FFBD to a single 8 by 10 1/2-inch page.) The numbering shows the relationship of one FFBD to another. For example, 2.2.1 documents analysis of a subfunction of 2.2.

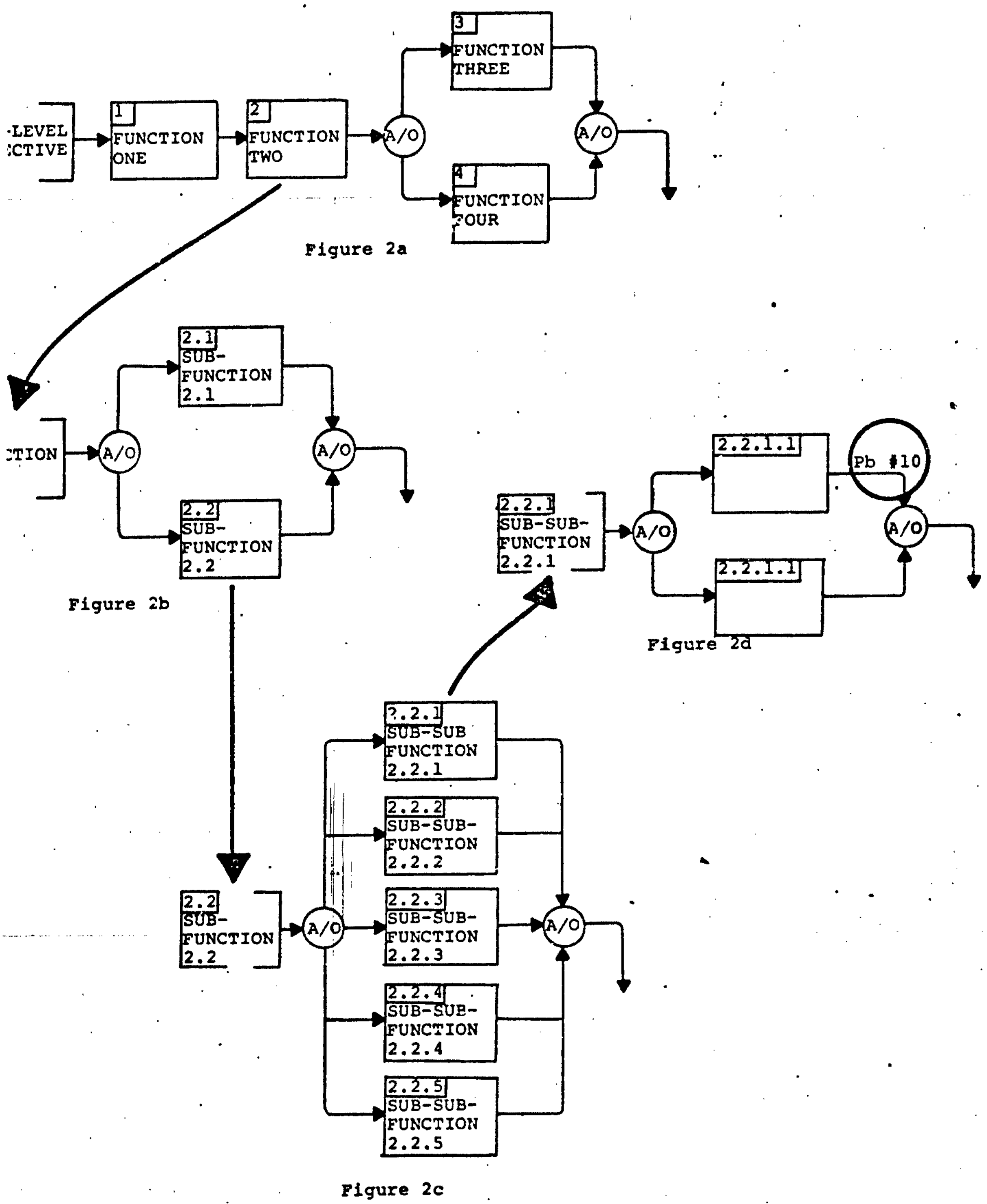

Figure 2 - FFBD's Document the "Audit Trail" for Problem Number 10

Consider the audit trail for the problem shown in Figure 1, "High Temperature Tolerance Electrical Insulators," which goes as follows:

- o Solution of the problem will contribute to the improvement of inter-electrode insulation, function 2.2.1.1, and thus
- o Make possible increasing the operating temperature of the MHD channel walls, function 2.2.1, which will, in turn
- o Permit increased generator efficiency, function 2.2, and thereby
- o Reduce specific fuel consumption, function 2, which will
- o Contribute to the ATO of providing the technology required to make possible development of a competitive, flight-weight MHD generator.

Communication Network

Use of the Problem Research process identifies the individual scientists and organizations whose work is particularly important to the attainment of the objective analyzed. The assignment of continuing responsibility to Monitors, establishes them as focal points for information related to their problem. This communication network is given visibility by publication of the names of Monitors on the Problem Resumes as well as by the listing of names and areas of cognizance on various registers. Through this responsive "information system," the Monitor for an ATO can become aware within days, even hours, of a breakthrough significant for the attainment of the objective.

"Intelligence" for Accomplishing the Objective

At the lowest cost in time and technical effort, the Problem Research process will produce information useful in achieving the objective capability.

This information includes:

o Current state of the art in each problem area. The current state of the art is an essential element in a complete definition of the problem since it defines one side of the gap which must be bridged to solve the problem.

o Organizations and individuals with the knowledge required to apply current knowledge and technology.

o Ongoing and planned research potentially useful for producing knowledge required to bridge the problem gap.

o Identity of scientists and organizations who are potential producers of the knowledge required to solve particular problems.

o Bibliographical data on the most significant reports or papers.

o A forecast on each problem showing the range of dates within which the consensus of inhouse experts indicates the problem will be solved *in the absence of any additional research effort*.

o An estimate of the extent to which solution of individual problems or achievement of the ATO can be accelerated through additional research effort, and the nature and cost of such effort.

<u>Beneficial By-Products</u>

In addition to the direct benefits associated with the identification of Research Needs, accomplishment of the processes outlined in this manual would produce other benefits:

o A rational and visible means for identifying pacing areas of Research and Exploratory Development.

o Cutting the time and dollar cost of Concept Formulation through prior assembly of the information required to demonstrate that "technology is sufficiently in hand."

o A framework for decentralizing the process of developing the knowledge base and technology base required to make selected ATO's feasible.

MANNING THE PROBLEM RESEARCH EFFORT

Participants in the Problem Research process include a Team Leader, Problem Analyst, Consultants in the technology of the objective, and Inhouse Scientists in disciplines relevant to various problems. After Research Needs have been fully defined (Phase I), Monitors are assigned to individual problems, the top-level objective and any major subobjectives. The duties of these participants are detailed in Figure 3, a fold-out chart bound as the last page of this report.

Of the many participants, only the Team Leader and the Problem Analyst devote a significant part of their time to the problem research effort. The ATO Consultants and Inhouse Scientists participate only to the extent needed to draw out their mind-stored knowledge and get it down on paper. Owing to the work of the Problem Analyst, the amount of time scientists and engineers devote to this "information retrieval" is kept to a minimum. They need not know anything about problem research before they start and documentation is not their responsibility. This responsibility belongs to the Problem Analyst who drafts documentation, develops its format, edits it properly and completes all the paper work. The knowledge of the experts is largely elicited through their marking up and criticizing the drafts the Problem Analyst provides.

The job of the Problem Analyst will normally be filled by a junior scientist or engineer who not only is a good writer but also works well with people.

THE PROCESS

The methodology in this manual is based on the assumption that most critical problems are already fairly well known to scientists and engineers working in various areas.[1] Problem

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[1]While known, these problems are seldom documented and so can be communicated only to immediate associates, only with great difficulty, and only at relatively high cost.

Research involves identifying the minds containing knowledge in depth of the problems related to a particular objective, *abstracting* the problems and *referencing* the individual in whose mind complete information of the problem is stored. Dissemination of Problem Resumes permits a wide group to become *aware* of both the problem and the individual to contact to acquire technical information in depth.

The Problem Research process is summarized in Figure 3, a fold-out chart bound as the last page of this manual.

As shown on Figure 3, there are two main phases in the Problem Research process: Phase I is devoted to defining the Technology Needs and Research Needs which must be met to achieve the ATO. Phase II, which extends from 10 to 25 years, is concerned with developing, collecting and organizing the knowledge required to make attainment of the objective feasible. Phase II ends at the time a development program designed to achieve the objective becomes a viable option.

Phase I is divided into two parts. Phase IA is a "quick and dirty," first-cut analysis to determine Technology Needs which must be met to attain the ATO. This analysis, accomplished at low cost, is primarily the work of the Team Leader and Problem Analyst in consultation with experts in the ATO technology. It is essential to determine Technology Needs first because from them are distilled Research Needs.

Technology Needs (Block 3) fall into three categories: those for which the technology is actually "on the shelf," those for which technology can probably be developed without additional fundamental understanding, and those for which development depends on knowledge to be obtained through research.

In Phase IB, the Technology Needs developed in Phase IA, are exposed to Inhouse Scientists within the Air Force research organization who will identify their scientific content. They will sort out those Technology Needs which will probably require additional fundamental knowledge for their solution, that is, determine Research Needs. At the same time, this process may also identify research-oriented sub-problems, the solution of which would help solve the technological problem documented in Phase IA resume. Appropriate Inhouse Scientists, in collaboration with the Problem Analyst, will then re-define problems with significant scientific content to tailor them as "want ads" for the required scientific knowledge (Block 9).

In the function covered by Block 7, a quasi-formal communication network is established for the development during Phase II of the base of knowledge and technology required for the attainment of the ATO. The assignment of Monitor responsibilities should not be interpreted as adding to the workload of the people assigned, since creative scientific and technical people all have an area in which they keep up and contribute to as a matter of professional competence.

The process depicted by the first five blocks of Figure 3 may be recycled several times during the course of analysis of a complex advanced technological objective (ATO). An initial team might break the ATO into a structure of sub-problems extending four or five levels. Later teams might then undertake the analysis of ATOs which are lower level problems of prior problem research efforts. For example, if Problem Research were applied to the national objective of cleaning up the environment, the process might be recycled a dozen times before it yielded the really critical Research Needs at a level of specificity that scientists could readily come to grips with these problems.

COST OF PROBLEM RESEARCH

The incremental cost of accomplishing Problem Research can be quite modest when accomplished in conjunction with related activities which are taking place. Such activities include various program studies (mission analysis, feasibility, mission analysis, technological barriers, etc.). By reaching the objectives of Problem Research in addition to the normal objectives of such activities, there may be some slight increase in cost, but it would contribute significantly to the usefulness of the results.

These studies routinely identify problems which are discussed in reports. The utility of this problem information is degraded, however, because the information is buried in the report and can neither be retrieved nor selectively disseminated at reasonable costs. Even if the entire report gets into the hands of a potential producer of knowledge required to solve one of these problems, he probably would not wade throught the report to find and assimilate the problem. If, on the other hand, the potential producer receives only a one-page problem resume with a title indicating it is in his area of interest, he is much more likely to read it. Then noting in the sources listed on the resume certain research reports, he might then discover their value. Selective dissemination of resumes therefore has another benefit: increasing the use of original reports.

The absolute cost of carrying through the process depicted in Figure 3 is surprisingly low. An experimental Problem Research analysis of problems in developing a competitive, flight-weight MHD generator (OAR 69-0020, AD 859-947) was carried through Phase IA for a total cost of $6,195. This figure included <u>all</u> costs, even allowing for overhead (at 90%) on the salary of inhouse participants. Since this was an experimental effort, there is good reason to believe that the cost could be brought down considerably with experience and the availability of qualified junior officers and civil service personnel as problem analysts.

The most significant cost reduction possibilities do not lie directly in the problem research process, but rather in the elimination of work which otherwise would have been undertaken. While not called, Problem Research, the equivalent is now going on, even though full benefits are not being realized. Major contractors conduct studies and analyses in an attempt to predict the areas of technology vital for future defense business. Since the results of these efforts are closely held, the same basic analysis may be duplicated by several different contractors.

Systematic and comprehensive problem research by the Air Force, based on a set of truly advanced technological objectives for capabilities of extraordinary significance, would eliminate the need for much of the redundant study effort which is now going on. While the costs of the current analytical effort is not visible, it is paid for by the Government as overhead. Probably more significant than dollar savings from reducing these redundant activities is freeing of scientific and technical brainhours for more productive use.

THE ROLE OF PROBLEM RESEARCH IN MAKING ATTAINABLE AN ADVANCED TECHNOLOGICAL OBJECTIVE

(NOTE: Originally this figure was a long fold-out chart. For the ease of reading overlap and tape the pages together.)

PARTICIPANTS IN THE PROBLEM RESEARCH PROCESS

THE TEAM LEADER acts as "Project Manager" for the problem research effort. Later, he normally continues as the ATO Monitor during the process of building the base of knowledge and technology required to make attainment of the advanced technological objective (ATO) feasible. The Team Leader should be an inhouse staff member knowledgeable in the ATO area.

THE PROBLEM ANALYST serves as consultant to the Team on problem research methodology and is the writer/editor for all documentation, thus relieving the experts of this burden. The Problem Analyst prepares documentation in collaboration with the substantive experts by preparing multiple drafts for mark-up and criticism by the senior author. Junior inhouse staff members will normally serve as Problem Analyst.

ATO CONSULTANTS are experts in the field of the advanced technological objective. Either inhouse or contract experts may serve in this role.

INHOUSE SCIENTISTS are those scientific and technical staff members most highly qualified in the area of particular problems. They provide information and technical judgments related to particular problems through oral dialogue with the Team Leader.

MONITORS (for individual problems, the ATO, and major sub-objectives) are inhouse staff members who are assigned responsibilities related to developing the base of knowledge required for solution of individual problems or the attainment of the ATO or major sub-objectives. Monitors serve as focal points for all types of information relative to solution of the problem or attainment of the objective. The name, address and telephone number of the assigned Problem Monitor appears on the Problem Resume.

DELIVERABLE PRODUCTS OF THE PROBLEM RESEARCH PROCESS

PRODUCT #1 - Definition of the objective. This product consists of (1) a schematic diagram (if the objective involves a device), (2) a set of functional flow block diagrams (FFBD's) covering essential functions in the device's operation, and (3) target performance specifications.

PRODUCT #2 - A set of FFBD's documenting the structure of functions and subfunctions where improved performance promises to contribute most effectively to attainment of target performance objectives.

PRODUCT #3 - Problem Resumes documenting technological problems (Technology Needs) whose solution collectively provide the technology required for attainment of performance called for in Product #1.

PRODUCT #4 - Problem Resumes documenting Research Needs, i. e., problems whose solution would provide the basis for solution of the technological problems in Product #3.

PRODUCT #5 - An analytical report which predicts the time frame in which the knowledge and technology necessary for attainment of the ATO will probably be available. This report also outlines a program of support for pacing areas of research designed to reduce the time required to make the ATO attainable.

PHAS

DECISION IS MADE TO PERFORM PROBLEM RESEARCH ANALYSIS OF A LONG-RANGE, ADVANCED TECHNOLOGICAL OBJECTIVE (ATO)

Attainment of the ATO is presumed to be (1) of exceptional value to the Air Force and (2) impossible at the present time owing to lack of supporting technology. Problem Research will be used to (1) identify supporting technology which, if available, would make the ATO attainable and (2) determine if such technology is currently "on the shelf." If it is not on the shelf, then the process must be continued to (3) determine if it can be produced on the basis of available knowledge, and, if this is not possible, (4) define the scientific content of the problems which must be solved to provide the sought-for technology.

1 TEAM LEADER AND PROBLEM ANALYST DEFINE OBJECTIVE

They describe, and express quantitatively where possible, capabilities which would constitute attainment of the objective.

PRODUCT #1

2 TEAM LEADER, ATO CONSULTANTS, AND PROBLEM ANALYST, IDENTIFY FUNCTIONS WITH THE MOST LEVERAGE

They define and document structure of functions and sub-functions where performance improvement will contribute most effectively to attainment of the ATO.

PRODUCT #2

TEAM LEADER, ... TANTS, AND ... DOCUMENT TECH...

Technology Need... specific advanc... logy which wou... ment of the ... possible. The... Needs are docum... Problem Resurc... the Team Leade... Problem Monit...

PRODU...

CONT'D →

CONT'D →

PHASE IA - THREE MONTHS

PHASE I - ANALYZE OBJECTIVE -- DETERMINE TECHNOLOGY NEEDS -- DETERMINE F:

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PROBLEM ANALYST,
UNCTIONS WITH
EVERAGE

e and document
of functions and
ons where per-
mprovement will
most effectively
ent of the ATO.

ODUCT #2

4 CIRCULATE TECHNOLOGICAL
PROBLEMS TO APPROPRIATE
INHOUSE SCIENTISTS

Resumes of technological
problems are circulated to
inhouse scientists most
knowledgeable in relevant
disciplines.

NOT REPRODUCIBLE

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TEAM LEADER, ATO CONSUL-
TANTS, AND PROBLEM ANALYST
DOCUMENT TECHNOLOGY NEEDS

Technology Needs indicate
specific advances in techno-
logy which would make attain-
ment of the objective
possible. These Technology
Needs are documented on
Problem Resume forms with
the Team Leader listed as
"Problem Monitor."

PRODUCT #3

5 TEAM LEADER RECEIVES
FEEDBACK FROM INHOUSE
SCIENTISTS

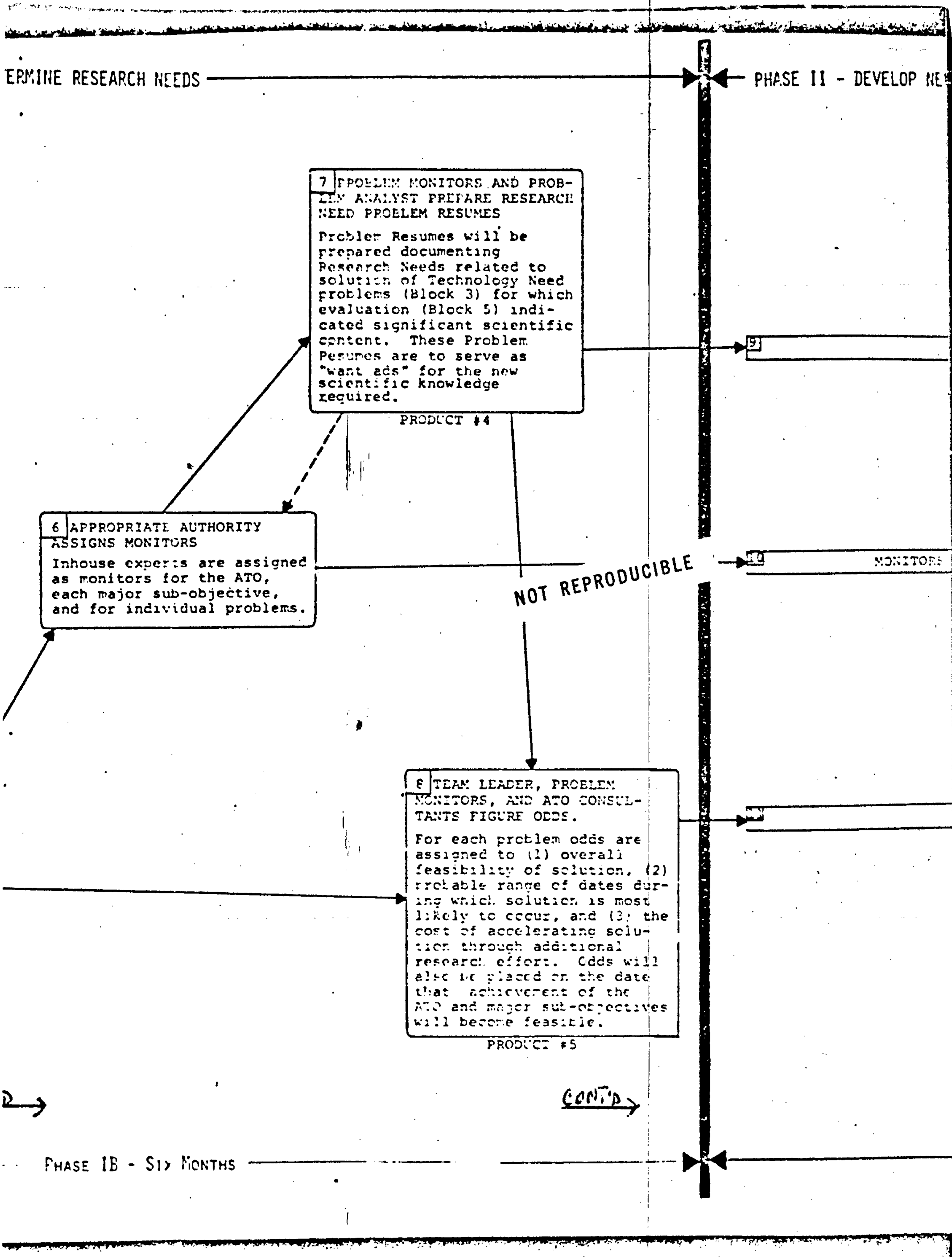
Team Leader talks over
each Technology Need with
Inhouse Scientists to (1)
learn current state of the
art, (2) identify leaders
in relevant research, (3)
identify problems with
significant scientific
content, and (4) obtain
judgments for use in
Block 8 function.

CONT'D

CONT'D

- THREE MONTHS

PHASE


ERMINE RESEARCH NEEDS
PHASE II - DEVELOP NE
7 PROBLEM MONITORS AND PROBLEM ANALYST PREPARE RESEARCH NEED PROBLEM RESUMES
Problem Resumes will be prepared documenting Research Needs related to solution of Technology Need problems (Block 3) for which evaluation (Block 5) indicated significant scientific content. These Problem Resumes are to serve as "want ads" for the new scientific knowledge required.
PRODUCT #4
9
6 APPROPRIATE AUTHORITY ASSIGNS MONITORS
Inhouse experts are assigned as monitors for the ATO, each major sub-objective, and for individual problems.
NOT REPRODUCIBLE
10
MONITORS
8 TEAM LEADER, PROBLEM MONITORS, AND ATO CONSULTANTS FIGURE ODDS.
For each problem odds are assigned to (1) overall feasibility of solution, (2) probable range of dates during which solution is most likely to occur, and (3) the cost of accelerating solution through additional research effort. Odds will also be placed on the date that achievement of the ATO and major sub-objectives will become feasible.
PRODUCT #5
CONT'D
PHASE IB - SIX MONTHS

IASE II - DEVELOP NEW KNOWLEDGE AND TECHNOLOGY REQUIRED TO MAKE ATTAINMENT OF THE OBJECTIVE FEASIBL

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TO
OF
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NOT REPRODUCIBLE

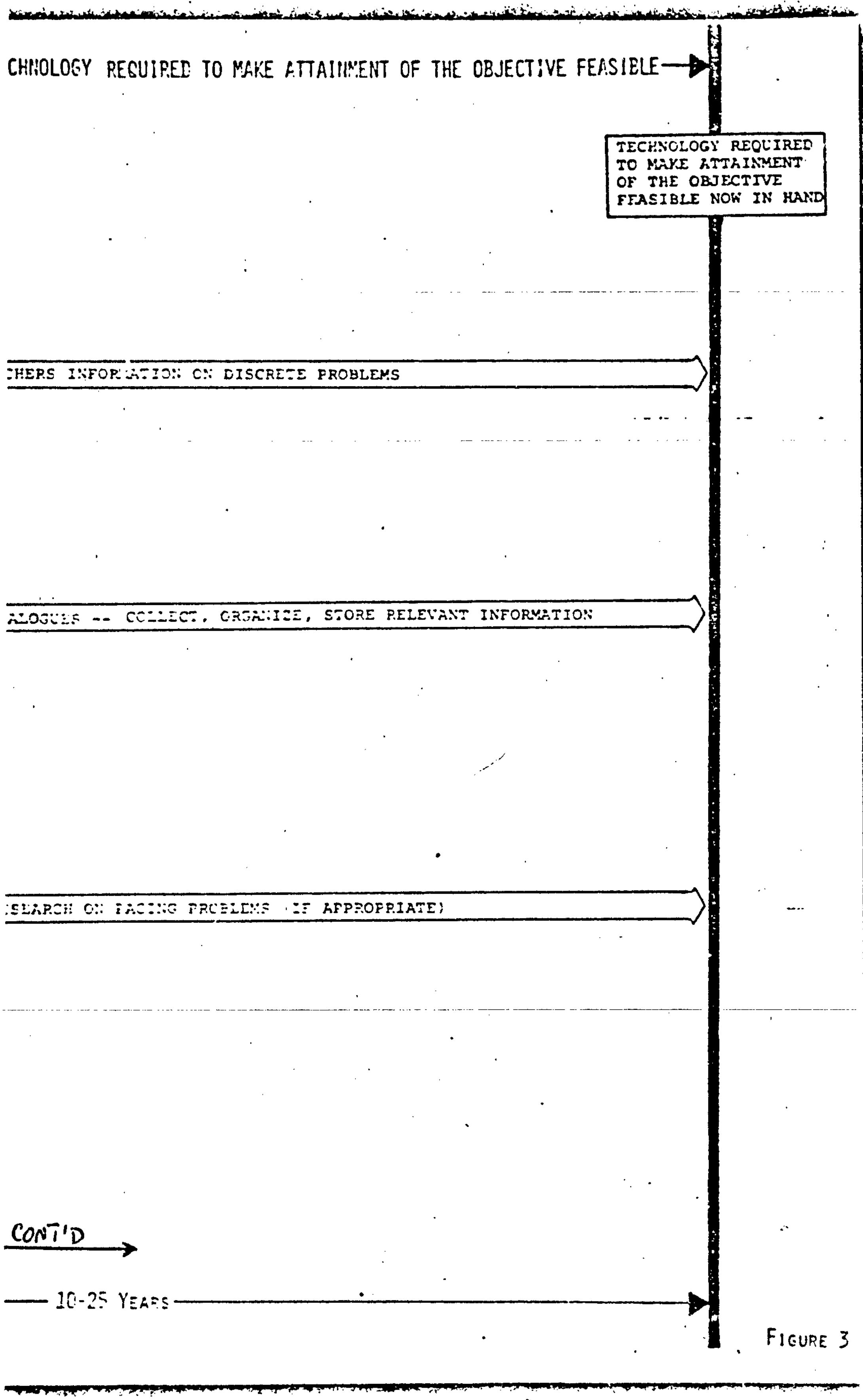
PROVIDE RESEARCHERS INFORMATION ON DISCRETE PROBLEMS

MONITORS PARTICIPATE IN DIALOGUES -- COLLECT, ORGANIZE, STORE RELEVANT INFORMATION

"FORCE FEED" RESEARCH ON FACING PROBLEMS (IF APPROPRIATE)

CONT'D →

10-25 YEARS



CHNOLOGY REQUIRED TO MAKE ATTAINMENT OF THE OBJECTIVE FEASIBLE
TECHNOLOGY REQUIRED TO MAKE ATTAINMENT OF THE OBJECTIVE FEASIBLE NOW IN HAND
CHERS INFORMATION ON DISCRETE PROBLEMS
ALOGUES -- COLLECT, ORGANIZE, STORE RELEVANT INFORMATION
SEARCH ON FACING PROBLEMS (IF APPROPRIATE)
CONT'D
10-25 YEARS

FIGURE 3

unclassified

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ABSTRACT

The guide provides description of procedures used in an experimental project of the Air Force to identify, describe and document the problems of technological nature encountered or expected in the development of advanced systems or components. The objective of the project was to develop tools and procedures for improved R&D communications between R&D managers, technology users and the scientists and engineers.

FORM 1473