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A REVIEW OF THE RESEARCH ORIGINS OF THE LANCE WEAPON SYSTEM–PROJECT HINDSIGHT–TASK 1 SUPPLEMENT

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Contract No. DA-01-021-AMC-14693(Z)
Battelle Memorial Institute
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January 1967

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ABSTRACT

This report includes a discussion of 57 research and exploratory development events that have been identified as contributing significantly to LANCE. Forty-six of these are research events. Eight of the research events deal with LANCE aerodynamics, four with propulsion, 24 with solid-state components used in the guidance and control system, and 10 with the research origins of the materials and manufacturing processes used in LANCE. In addition, 11 exploratory development events are identified. The principal concern of this study has been the identification of further research origins of LANCE and the 46 documented events are its major product. A further concern and obligation of this study has been to provide HINDSIGHT with some additional data on the research phenomenon including some further observations on the nature and route of research utilization.

FOREWORD

The purpose of this report is to present a survey of fundamental research contributing to the successful development of the LANCE weapon system. Included in this report are discussions of research inputs to a number of LANCE systems and technology areas. The circumstances of these research contributions to LANCE are discussed. The implications of these examples of research utilization are analyzed and some general observations and conclusions on the research payoff phenomena are given. This report was requested by the Army Missile Command as a supplemental contribution to Project HINDSIGHT.

CONTENTS

ILLUSTRATIONS

Section I. INTRODUCTION

Project HINDSIGHT is a broad-scoped Department of Defense (DOD) program aimed at identifying the technological contribution to modern military systems from research, from exploratory and advanced development, and from engineering activity. Phase I of the HINDSIGHT program started in 1963 and to date has accomplished the retrospective review of the research and developmental origins of 20 modern weapon systems. The principal products of these reviews are documented examples of research and exploratory development (RXD) events which have made significant contributions to the advancement of these systems over their predecessors or which have been responsible for the successful development and deployment of the systems. Important conclusions are being reached on the basis of careful interpretation and analysis of this large body of data on the utilization of technology and indeed on the consequences of the Research and Development Test and Evaluation function within DOD.

The LANCE weapon system, successor to the HONEST JOHN, was studied by an Army Missile Command (AMICOM) group at Redstone Arsenal, Alabama, in 1965. The final Task 1 report was published in December 1965. This study identified more than one hundred significant RXD events contributing to LANCE's development. These events all occurred within the last 20-year period, which is the time period of major interest to HINDSIGHT. The study was an exhaustive treatment of the developmental origins of LANCE. The number of the research events identified as contributing to LANCE was small, however.

This report is the result of a Battelle HINDSIGHT review study that was undertaken to identify further research events for LANCE. The Battelle study was conducted with some differences in scope and philosophy from the original AMICOM study on LANCE.

Some of the specific important differences in this regard were as follows:

1) The time frame of interest was expanded to include events which might have occurred before the 20-year limitation.
2) Less emphasis was placed on the importance of the research events having a strong program or administrative connection with LANCE.
3) Priority was given to identifying a broad-based contribution from fundamental research as opposed to highly defined research contributions uniquely applied in LANCE.

4) No restraint was imposed on the study as to the auspices under which candidate LANCE research events were accomplished.
5) The study included the identification of absolute research origins of LANCE as opposed to emphasizing the research events which contributed to the advancement of LANCE relative to HONEST JOHN.
6) The investigation was not intended to be exhaustive and no attempt was made to identify research contributions to all of the LANCE systems. The investigation was limited to a few subsystems or technologies in which the potential for identifying research events was expected to be high.

Further sections of this report elaborate on the background, scope, and procedure of this investigation. The substantive section of this report consists of narrative descriptions of research contributions to LANCE in aerodynamics, guidance and control (G & C), propulsion, and materials and processes. Research events are denoted in each of these areas.

Section II. DISCUSSION OF RESULTS

This report includes a discussion of 57 RXD events that have been identified as contributing significantly to LANCE. Forty-six of these are research events (according to the current DOD category of Research (6.1)). Eight of the research events deal with LANCE aerodynamics, four with propulsion, 24 with solid-state components used in the G & C system, and 10 with the research origins of the materials and manufacturing processes used in LANCE. In addition, 11 exploratory development events (DOD category of Exploratory Development (6.2)) are identified. The principal concern of this study has been the identification of further research origins of LANCE, and the 46 documented RXD events are its major product. It is known that a few of these events have also been documented in other HINDSIGHT studies as a result of their contribution to other systems. No particular attempt was made to avoid this additional reporting of events since the contributions to LANCE are also significant and unique and should be documented. A further concern and obligation of this study has been to provide HINDSIGHT with some additional data on the research phenomenon, including some further observations on the nature and route of research utilization.

Several conclusions and observations have been formed during the course of this study and on the basis of its results. These are given here, in summary, as the qualitative findings of this study:

1) The fundamental research payoff to modern military systems has been enormous and the specific contribution from "recent" science has been strong.
2) The science-technology interface is not characterized by a few rigorous factors but is strongly situation-dependent. It is not necessarily sequential with technology events following science events in a "logical" manner.
3) The payoff of directed research (in which the objective of the work is to produce an understanding of phenomena or specific knowledge which is needed for some particular application or class of applications) will occur with more guarantee, more quickly, and with greater focus on specific problems than undirected research (in which the objective of the work is the advancement of knowledge for its own sake, without regard for possible application).* There is, however, ample evidence

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*No attempt is made in these definitions nor within this report to separate the motivational nature of the scientist as a factor in classifying research as directed or undirected.

that a large and extremely significant return has accrued to modern military systems from the body of undirected research. In fact, some of the most profound contributions have come from activity of this type.

4) Fundamental research at the time of its performance appears relevant only to broadly stated technology problems. Specific relevance is fully definable only after the fact of application.

5) The general (body-of-knowledge) research contributions are usually found to be in a chain of RXD events that somewhere in time has uniquely branched toward a current system.

6) There appear to be no clearly definable criteria for insuring the relevance of undirected research to future needs. It is believed that the growing appreciation of needs analysis and the various forecast exercises do periodically point out those areas of fundamental research which deserve prime attention.

7) No generalizations regarding the value of a research event to a specific system can be made on the basis of the date of the event or the general extent of its application elsewhere.

8) There are extreme differences in the weights of the contribution of individual research events; hence, numbers of events, per se, are not a valid measurement of the contribution from fundamental research.

9) This particular sample of cases of research payoff to a modern military system or any other such sample, regardless of the number of events it includes, will be an incomplete portrayal of the contribution from research to that system.

10) The auspices under which research is done do not affect the quality of its production by virtue of administrative control of the work but rather by virtue of enhanced communications and working philosophy.

11) It is difficult to evaluate the return from research and hence to judge if the return on the research investment has been adequate. Certainly the "value" of the return cannot be measured in terms of monies nor directly compared to the investment. If a dollar value could be placed on the production of an R event, the implication would be that the equivalent contribution of the event could be "purchased" by other activity. It is believed that the contribution from research is unique and cannot be obtained through another type of activity.

1. Statement of Problem and Study Objectives

There is a trend within the DOD and industrial research community toward an attitude of introspection regarding the payoff of research endeavor. Efforts are being made to evaluate the extent of the return on basic and applied research. The mechanism and route of this return is being studied. The research/development climate which optimizes the potential for research utilization is being investigated. Criteria for planning the content of fundamental research programs for the strongest fertilization of DOD developmental programs are being sought.

There appear to be several reasons or motives for this analysis of the research phenomenon. The broad perspective of the motives shows them to be idealistic but not impractical. From this broad perspective the objective is to establish somehow a basis for research planning as a discipline. To be successful this will require that some invariants in the circumstances of high-payoff research programs be found and that the nature and dynamics of the interface between phenomena-oriented science and engineering be better understood. The narrow-scope view of the motives shows them to be aimed at a need to justify the effectiveness of past research efforts, to obtain better measures of the relevance of fundamental research to future needs, and to improve our ability to establish funding priorities.

At present, in either case, one of the basic needs is for data on research as a procedure in meeting defense needs. There is a strong call from DOD and the responsive industrial research community for data-generating studies, for diagnostic studies of research and its ramifications, and for workmanlike estimates of the worth of the research function and the extent to which it must be supported.

2. General Approach

The HINDSIGHT effort has as one of its major objectives to provide some of this needed understanding of research phenomena as well as to examine the exploratory development contributions to the 20 military systems which have been studied by HINDSIGHT to date.

Project HINDSIGHT consists of three separate tasks, as follows:

1) Task 1 is a series of studies of 20 weapon systems to define the contribution of RXD events to the engineering and operational development of the systems.
2) Task 2 is a look in depth at the management function in ten corporations and DOD laboratories that were shown in Task 1 to have been effective in using new technology for development of advanced weapon systems.

3) Task 3 is an attempt to relate research and development (R & D) payoff to investment through the use of analytical techniques.

The Project HINDSIGHT study was conducted for the LANCE missile system by an AMICOM working committee under the chairmanship of Mr. Lewis L. Gober. The results were published by AMICOM in December 1965 and revised in January 1966.[1] A short supplemental effort on LANCE HINDSIGHT was done by the U. S. Army Research Office, Durham (ARO-Durham), by directive from the Director of Army Research, Office of the Chief of Research and Development. ARO-Durham showed how six representative RXD events, listed in the AMICOM report as exploratory development, did in fact have their genesis in research.[2] The instructions to ARO-Durham had emphasized the need to identify further RXD events which were responsible for the major state-of-the-art advances in the current weapon system when compared with its predecessor.

On May 3 a similar directive was issued to instruct AMICOM to make an "additional effort to identify research events or a further input of research that might have advanced the state of the art in such a way as to make the LANCE System possible." Direct coordination with Colonel Isenson of the Office of the Director of Defense Research and Engineering was authorized. The detailed instructions given for the Materiel Command were cited as a guide to AMICOM.

Battelle accepted the assignment in June 1966 from AMICOM, through an existing Redstone Scientific Information Center contract to give additional Task 1 effort to identifying the contribution of research to LANCE. The objectives of the Battelle study were worked out between Battelle and Mr. Gober, AMICOM, according to his understanding of the directive to AMICOM. The proposed study was also discussed with Colonel Isenson. The study was conducted during the six-month period from June through December 1966. Briefings on the LANCE system and on the AMICOM Task 1 HINDSIGHT study were given to the Battelle working group early in August at Redstone. Contact with members of the original LANCE HINDSIGHT working committee at Redstone was maintained during the Battelle study. The details of the objectives of the Battelle study and ground rules agreed upon in discussion with Mr. Gober are described in the following paragraph.

3. Study Guidelines and Scope

The first objective of this study was to identify other research events contributing to LANCE. This objective was considered possible and compatible with the original HINDSIGHT study recommendation that other research events could be identified with additional effort. Further, the intent of looking for research origins which might predate the 20-year time restraint on the original study was considered likely to increase the probability of identifying future research events.

Departing from the results of the original LANCE study, several alternative approaches were possible. These were:

1) To trace already identified research events to additional research events probably further back in time.
2) To locate or identify independently additional research events either not recognized or perhaps not developed and documented in the original study.
3) To identify tentatively further exploratory development events or to start with documented exploratory development events and trace back to related research events.

A combination of the first two approaches was applied predominantly in the present study, although they are not considered to be definite methodologies. The third possibility, if generally workable, is at least considered to be less direct or productive. However, there are examples of this third method in this study. The details of the approaches used in searching out evidence of research contributions and of identifying research events will be described further in this report. It appears that there are actually no distinct methods of tracing the research events. An understanding of the implications of this fact constitutes an important part of the HINDSIGHT philosophy. One implication is that the science-technology interface is not characterized by a few rigorous factors but is strongly situation-dependent and is not necessarily sequential with technology events following science events in a "logical" manner.

A good understanding of what constitutes a research event is essential. First, those results accomplished with DOD research funds (6.1 funds) and potentially influencing the LANCE development should be legitimate research event candidates. There may be exceptions, however, since it is the nature of the work and the contribution and not the funding that counts. Things accomplished outside the framework just described must satisfy a sound definition of research. Barring some exceptions, this activity should be the kind of activity that is normally supported by 6.1 funding. Hence, in the LANCE HINDSIGHT report nomenclature we have the terminology and philosophy of an event's being "a 6.1 funding equivalent." A considerable amount of conceptual difficulty can be encountered in trying to arrive at a formal definition of research that is not subject to numerous exceptions. Ultimately in many cases, an appeal must be made to intuition in deciding what can be fairly classified as a research event. However, it is possible to be guided by the DOD HINDSIGHT definitions of an R (research or 6.1) event.[1] The definitions of XD (exploratory development or 6.2) activity are also given for clarification and distinction.[1]

- (6.1) Research
  Investigations in pure and applied mathematics and theoretical studies concerning natural phenomena.
- (6.1) Research
  Experimental validation of theory and accumulation of data concerning natural phenomena.
- (6.1) Research
  Combined theoretical and experimental studies of new or unexplored fields of natural phenomena.
- (6.2) Exploratory Development
  Conception and/or demonstration of the capability of performing a specific and elementary function, using new or untried concepts, principles, techniques, materials, etc.
- (6.2) Exploratory Development
  Theoretical analysis and/or experimental measurement of the characteristics of behavior of materials, equipment, etc., as required for design.
- (6.2) Exploratory Development
  Development of a new material necessary for the performance of a function.
- (6.2) Exploratory Development (Design)
  First demonstration of the capability of performing a specified and elementary function, using established concepts, principles, materials, etc.
- (6.2) Exploratory Development (Manufacturing)
  Development of a new manufacturing, fabrication, or materials-processing technique.

Research activity of this type is characterized by being largely phenomena-oriented, is motivated by an objective interest in those phenomena, and guarantees the satisfaction of no goals except a systematic attempt toward the acquisition of new knowledge or data. It must be emphasized that this type of research has guaranteed relevance only to broadly stated technology problems and cannot be effectively focused on specific problem solutions. The relevance or bearing that this activity has on existing or, yet undefined, future technology problems will be fully definable only after the fact. This after-the-fact demonstration of the relevance of the basic research function should be a major objective of a HINDSIGHT exercise.

The original LANCE HINDSIGHT investigation was restricted to events occurring during the last 20 years or essentially since World War II. Of course, the multiplication of DOD-sponsored research in that period has been so great that it is reasonable to expect the last 20-year period to embrace most of the highly pertinent research other than those contributions from the classical body of knowledge. There has been approximately a 15-percent growth in the federal support of basic research each year since 1940. An index of this growth is the funding for university research: $15 million in 1940 and $1.3 billion in 1966.[3,4] DOD was a heavy contributor in 1940 and still is, although NASA, NIH, and NSF fund more basic research than does DOD today.

In order to increase the probability of not overlooking important research origins of LANCE, the time period of interest was increased for the purposes of the Battelle study. The following periods of interest and concentration were suggested:

1) Since 1945—highest emphasis.
2) Twenty-five years prior to 1945—of interest.
3) Prior to World War I—lowest interest.

It is certain that there are differences in the weight of events, determined on the basis of the extent of the contribution made to LANCE. It is not a foregone conclusion that an old research event is less weighty than a recent event by the criterion of time of performance alone. Its eventual impact on LANCE must obviously enter the consideration. However, it is true that the older significant research results probably will have been so widely applied that their apparent uniqueness to any current system will have been lost. Such research events, however, may be found to be in a chain of events leading to a unique contribution to a current system (e.g., LANCE). Older research results of this type are therefore appropriate candidates for a HINDSIGHT event, providing that there are similarities in their support and the current support/funding practices. Certainly there are research events which pervade all modern technology that can no longer be considered appropriate HINDSIGHT events. The criteria by which these are exempted might be definable through a comparison of the differences in the format of modern national needs, investment, and research and the format of basic research in the classical period. In short, it is believed that the essential point is that when there is no investment in research, there is no question of payoff; hence, these classical research results are less appropriate to HINDSIGHT. Most of the classical research results are not the product of the same type of investment as is in practice today.

Another guideline required for this HINDSIGHT review was whether the search for events should be arbitrarily restricted to research performed by a particular type of agency or organization. Mr. Gober, AMICOM, instructed Battelle to consider events occurring on the part of the Army, Navy, Air Force, NASA, universities (U.S. or foreign), contractors, or individuals as being germane to this study and that they should be reported if application to LANCE could be shown.

This study attempted only to show further examples of research origins of LANCE rather than an exhaustive treatment of a few events. It appeared desirable to have examples that touched on several different technologies and that related to a few of the major missile subsystems. The working group was formed at Battelle with the intention that each member would restrict his individual investigations to potential research events within his technical specialty. The composition of this group was guided somewhat by suggestions from Colonel Isenson as to areas in which he believed additional or improved results could be obtained. The working group consisted of specialists in aerodynamics, guidance and control, propulsion, and materials and processes, and the study coordinator. Other members of the Battelle staff were consulted as needed during the study.

No attempt was made to identify or document additional exploratory development events affecting LANCE, although some were noted incidentally and recorded. It is believed possible to conduct a HINDSIGHT investigation along lines tailored to enhance the identification of pertinent research to the exclusion of other types of events. Specifically this requires that in the backtracing there is no effort to develop fully the evidence encountered of potential exploratory development events. This would not be a good study format for a more general HINDSIGHT investigation which would logically follow up all leads encountered, regardless of event type.

4. The Implication of a HINDSIGHT Review and Relevance to the Previous Task 1 Effort

The AMICOM LANCE HINDSIGHT study identified and documented a total of 111 R & D events. Five of these were identified as R events. The total number of events found in that study was entirely consistent with the general findings of HINDSIGHT that "A large number of significant science and technology events (50 to 100 or more) is readily identified as being utilized in the larger systems."[5] In this regard, the original study gave above-average demonstration of the RXD contribution. In fact, more RXD events were identified for LANCE than for any other military system for which a HINDSIGHT study was done. The five R events identified by AMICOM are also only slightly less than the general HINDSIGHT average, which shows that eight percent of the events identified for all studies are categorizable as science events (6.1 events or R events). However, these general statistics, when applied to a specific system such as LANCE, do not imply that an exhaustive treatment has already been done on the research origins of the system. It should be emphasized that additional research events are not "readily" found if the search is done within the same restraints as the original study. The AMICOM study was strictly controlled to the 20-year time restraint. The investigation worked very strongly from events within the formal LANCE program out to less direct events and required a high degree of documentation of the events. The study also apparently emphasized the search for events that "were considered to be the most outstanding (direct) contributors to LANCE." The AMICOM study was an excellent (and largely exhaustive) treatment within that framework. As previously discussed, several rationales have been advanced to account for the "paucity" of research events identified for LANCE. From the experience of conducting the present study, we cannot agree wholeheartedly with any of these rationales. Rather it appears that the AMICOM study emphasized the research inputs to LANCE of a specific character and occurring largely within the interim between HONEST JOHN and LANCE. Figure 1 demonstrates that the forte of the research contribution is not of that type. The figure oversimplifies the research contribution route but is believed to represent the major role of the R and XD functions.

From Figure 1 it is seen that, in order to detect the extensive research origins of LANCE (or any other modern military system), it is necessary to consider the broad-based or general contribution of research to the system. This is not seen to be just a bias but rather a justifiable emphasis which can lead to the recognition of significant research events. The point can be made best by the example of a quote from the AMICOM study:[1]

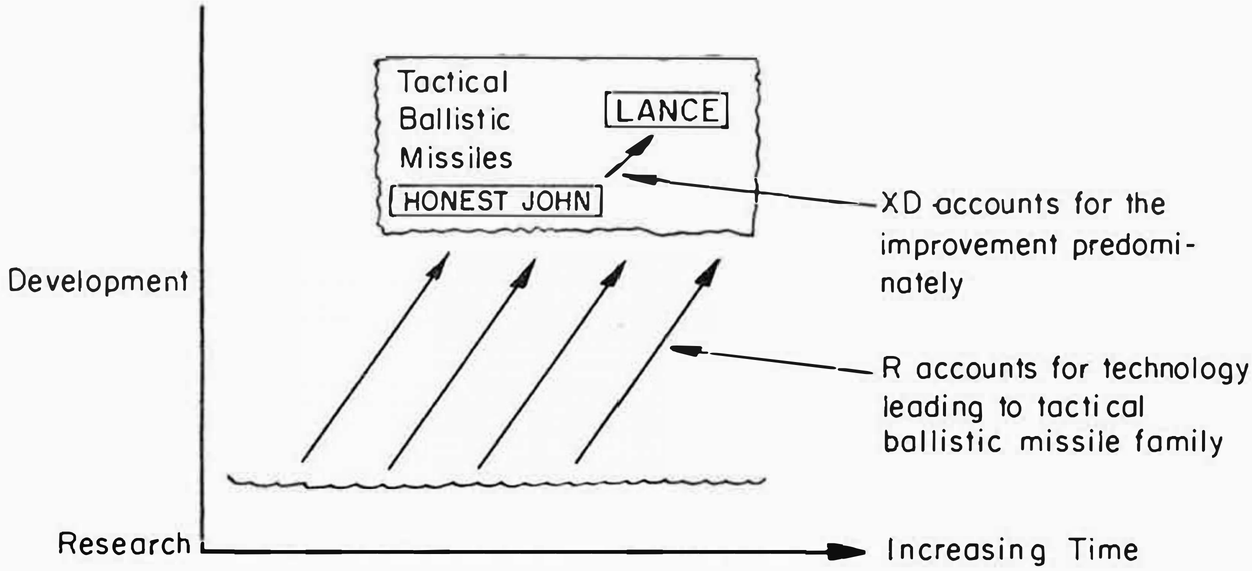

Figure 1. Schematic of the General Division in the Major Contribution from XD and from R Activities

"For some years, the general policy has been to avoid, whenever possible, the use of exotic materials and processes which might be difficult to procure or use in times of national emergency. This includes new materials which may not be available in quantity during a critical period or a process which is not already adapted to production. The LANCE system was proposed as an 'off-the-shelf' development program using state-of-the-art technology.

"In keeping with both the desire to use readily available materials and proven processes from the standpoint of being noncritical in times of emergency and meeting the 'off-the-shelf' requirement of the LANCE development program, few RXD events were expected in the areas of materials and processes."

This point of view is perhaps consistent with the ground rules of the AMICOM study which emphasized program events that made a unique contribution to LANCE, such as the molding of butyl seals and the adaption of electron-beam welding to LANCE fabrication. These are indeed significant events, critical to the final configuration of LANCE. Further, this type of event strictly satisfies the HINDSIGHT event requirements. This viewpoint does not, however, predispose the investigator to look for or emphasize more general (and often far more important) contributions to LANCE from the extensive body of materials-and-processes research occurring in the last 20 years and before. It is true that many of the benefits of this research are shared by LANCE with many other systems, but this in no way detracts from the validity of this research as an event candidate nor from the absolute value of its contribution to the LANCE system.

There are numerous materials and processes in LANCE which have research origins within the last 20-year period. All have some research basis. This report has treated some of these materials and processes by way of example. An enormous HINDSIGHT effort would be required to do justice to the research origins of the materials in LANCE. A study that is very strict in its event criteria will probably not give priority to those "general" research origins. In the particular case of the AMICOM study, priority was not given to this category of events, although the existence of some of these further research origins was recognized.

This example, concerning the materials in LANCE, has parallels in other areas affecting LANCE. The present study has taken the opportunity to show some of these research origins. It is believed that in many instances these general research events were more important to the eventual development of LANCE than some of the more documentable, direct, and seemingly critical events that have already been reported.

The failure to recognize the extent of the direct contribution to modern weapon systems (often by indirect paths) from fundamental research could lead to funding deemphasis requiring strict and somewhat arbitrary rulings on relevance. A recent article on HINDSIGHT states:[6] "There has been faith, though little systematic evidence, that basic research ultimately pays off in military value. Over the past few years, however, the large expenditures inspired by this faith have aroused a good deal of skepticism, and, as a consequence, there has been a growing interest in studies aimed at identifying the utilitarian consequences of nondevelopmental research." It is factual that some funded basic research programs have lacked real pertinence to the strongly mission-oriented DOD and thus partly justify the skeptical attitude. HINDSIGHT has not yet provided the weight of evidence that is needed to defend the basic research function against skepticism that the return is adequate. This report, of course, only adds a few favorable examples. It is believed that eventually a sufficient weight of evidence will be shown to deemphasize the current skepticism through the combined efforts of AFOSR,[7] ONR, HINDSIGHT, and through other diagnostic studies. It should be emphasized that HINDSIGHT has not, as some erroneously understand, categorically deemphasized the value of the research contribution to military systems. A general conclusion is being framed, however, on the basis of the total HINDSIGHT effort to date that recent science has made little contribution to advanced weaponry. One must be careful to understand this conclusion. Many implications, based on the working nomenclature of HINDSIGHT, are included in the word advanced. Strictly speaking, in HINDSIGHT nomenclature the word advanced refers to the difference between a current system and its predecessor. It is reasonably acceptable that basic research may not account for the major advances in a system when compared to its predecessor. It is another thing altogether to discount the absolute contribution of basic research to modern (advanced) weaponry.

HINDSIGHT readily acknowledges the general or "body-of-knowledge" contribution to modern systems from basic research. It also emphasizes the apparent increased payoff and the time acceleration of the payoff which comes from a format of "directed research" and deemphasizes the contribution from recent undirected science.

This report falls short of providing authoritative answers to the outstanding questions about the research payoff phenomena. The report has attempted to provide HINDSIGHT with some additional philosophical data on the research phenomena, some systematic evidence of the basic research payoff from both recent and classical science, and some further understanding of the nature and route of this payoff (science-technology interface).

Section III. EXAMPLES OF RESEARCH EVENTS CONTRIBUTING TO THE SUCCESSFUL DEVELOPMENT OF LANCE

This section includes discussions of research contributions to LANCE in the following areas:

1) Aerodynamics.
2) Guidance and Control.
3) Propulsion.
4) Materials and Processes.

Summaries of RXD events identified in these discussions are given in the appendices of this report. For convenience, events in each paragraph are numbered beginning with the number one. References to original LANCE HINDSIGHT events which may bear the same number as the Battelle events are always distinguished.

1. Aerodynamics

a. LANCE Aerodynamic Research Origins

All the aerodynamic events considered in the original AMICOM HINDSIGHT study were concerned with base drag phenomena, particularly under conditions of sustainer operation. In all, six aerodynamic events were identified, one of which was categorized as an R event. The original study, following its rather strict event criteria, considered the base drag work to be the only unique aerodynamic contribution required for LANCE. In the base drag area the original study observed that "the lack of thorough research programs in this area (prior to LANCE development) prior to 1962 forced empirically based choices to be made in the LANCE (base) configuration selection." A further observation of the AMICOM study was that potential events existed in the areas of stability, damping, drag (except base), and so forth; but these occurred prior to 1950 and were omitted on that basis. The rationale for this particular time cutoff was not explained, although it is expected that there was not sufficient time to investigate these events.

The objective of the present study was to show research inputs in aerodynamic areas other than base drag. These research origins were not expected to be a part of the LANCE developmental program. The formal program efforts concerning aerodynamics are characterized by extensive experimentation based on prior theoretical and experimental basic research results. This prior body of basic research has had applications in systems other than LANCE. In other words, these are general research events that nevertheless have had a significant influence on LANCE. Basically, the influence on LANCE came through the use of this research as guidelines for experimentation. The dependence of the LANCE program experimental efforts on this body of research has been discussed with Ling-Temco-Vought (LTV) personnel during this study.

The effort to backtrace the research events pertinent to LANCE aerodynamics originated with discussion with personnel at Redstone who performed the original aerodynamic studies for LANCE HINDSIGHT. These discussions assisted in identifying LANCE/LTV reports on the experimental aerodynamics analysis in the area where we believed additional research bases could be shown. It was apparent that the experimental efforts depended on research efforts in the past 15 to 25 years that were referenced in the reports on the experimental work. Later conversations with LTV personnel (Mr. R. G. Anderson and Mr. R. J. Keatley) confirmed the influence and use of these prior research results. From this point, an extensive literature search and collection was made and analysis was undertaken to trace the nature and growth of this research base. A chain of research results was identified, several of which are considered significant HINDSIGHT events.

Most of this prior research work was done under the auspices of the National Advisory Committee for Aeronautics (NACA) and is characteristic of the early supersonic emphasis in this country. It was not possible to document these events extensively with respect to the scope of effort and funding. Rather, an emphasis was placed on attempting to show the interdependence of this work and the route by which LANCE was eventually influenced. The work performed in this time period (early and middle 1940's) was a direct outgrowth of the problem which was realized to be in the future in supersonic flight. Therefore, in a strict sense this work was directed but to a broad and basic class of problems. Specific applications were lacking and the work had the characteristics of basic research, being largely phenomena-oriented.

On the basis of a limited review of the aerodynamic development of the LANCE missile, it appears that the aerodynamic studies can be grouped into three major categories, as follows:

1) Basic component analysis.
2) Interference effects.
3) Drag estimates.

A great deal of the aerodynamic characteristics were obtained by empirical methods from wind tunnel tests. The experimental guidelines and pretest estimates were based on prior theoretical and experimental basic research results. These results were also used to extend and supplement the data obtained from wind tunnel tests. The following is a discussion of the research efforts that contributed to the aerodynamic development of LANCE in each of the three categories mentioned above.

b. Basic Components Analysis

The LANCE missile derives its sustained rolling motion for stability purposes from the canted, swept fins. The aerodynamic moment produced by the fins can be derived from results based on swept wing theories. This would be considered a first approximation independent of interference effects. Three basic research studies[8,9,10] have been identified as directly contributing to the fin component analysis.

These studies were (1) Eugene Love's work[8] on triangular wings at supersonic speeds, (2) Margery Hannah's analysis[9] of span-loading for various body motions, and (3) John DeYoung's work[10] on wing loading at subsonic speeds. These three studies were basic research studies of a general nature in that they were not performed for application to a specific system. A short description of the studies is given below.

(1) Eugene Love. This study was performed in 1949 at the Langley Aeronautical Laboratory, Langley Field, Virginia. The study was an experimental investigation of 22 triangular wings at supersonic speeds. Two airfoil sections were used with 11 different apex angles. The tests were made to determine the effects of giving a generous curvature to the leading edge of a series of triangular wings with the object of realizing a greater proportion of theoretical leading-edge suction and thereby increasing the wing efficiency. These tests were also performed to extend the data for wings with higher thickness ratios.

(2) Margery Hannah. This study was performed in 1952 and published as a NACA Technical Note. On the basis of linearized supersonic flow theory, the theoretical spanwise load distribution resulting from constant vertical acceleration was calculated for a series of thin, sweptback, tapered wings with streamwise tips. The results of the analysis are given in the form of equations for the spanwise load distribution. A series of design charts permitting rapid estimation of spanwise loading for a wing with given aspect ratio, taper ratio, leading edge sweepback, and Mach number were prepared.

(3) John DeYoung. This study was published as a NACA report in 1947. The result of the study was a method of predicting symmetric span loading for a certain class of wings. The geometry of these wings is limited in that they must have symmetry about the root chord, must have a straight quarter-chord line over the semispan and must have no discontinuities in twist. A procedure was derived for finding the lift-curve slope, pitching moment, center of lift, and induced drag from the span load distribution. A method of accounting for the effects of Mach number and for changes in section lift-curve slope was developed.

Curves were prepared which reduce the problem of finding the symmetric loading on all wings falling within the prescribed limits to the solution of not more than four simultaneous equations.

From the three studies mentioned above, it was possible to trace back to other research efforts which influenced these three studies. The dependence of a particular study on prior work is not always clear For example, a theoretical model is not necessarily dependent upon data which substantiate the model. However, derived results using a given theoretical model are dependent upon that model. It was usually possible to define those studies which influenced or contributed to the subject matter of the study.

Two reports[11,12] by R. T. Jones were obtained from the references given in Love's report. These two reports were basic research studies on the characteristics of swept wings at supersonic speeds. These reports were published as NACA reports in 1945 and 1947.

In the first of these two reports,[11] Jones points out that in the case of an airfoil of infinite aspect ratio moving at an angle of sideslip, the pressure distribution is determined solely by the component of motion in a direction normal to the leading edge. The analysis indicates that for aerodynamic efficiency, wings designed for flight at supersonic speeds should be swept back at an angle greater than the Mach angle and the angle of sweepback should be such that the component of velocity normal to the leading edge is less than the critical speed of the airfoil section. This principle may also be applied to wings designed for subsonic speeds near the speed of sound, for which the induced velocities resulting from the thickness might otherwise be sufficiently great to cause shock waves.

Various developments in aerodynamic theory made it possible for Jones to estimate the lift-to-drag ratio obtainable for practical configurations other than the two-dimensional model assumed in his report.[11]

In the second of his reports,[12] he applies these new theoretical results (based on the theory of small disturbances) to obtain estimates of the lift-to-drag ratios that may be achieved with an efficient aircraft at supersonic speeds. The analysis indicates the effects of aspect ratio on wing efficiencies.

In the process of backtracing, studies[13,14,15] were made in which further research efforts were identified that made a contribution to the study of Hannah. John Martin and Isabella Jeffreys made a study[13] on span load distributions resulting from angle of attack, rolling, and pitching for tapered sweptback wings with streamwise tips, and the general techniques outlined in this study were used by Hannah.[9] The results of the analysis of the study by Martin and Jeffreys[13] are presented as a series of design charts. Some illustrative variations of the spanwise distribution of circulation with the various design parameters are presented. This report was published in 1951. Studies by Frank Malvestuto and Dorothy Hoover[14,15] were published in 1950. The subject of these two reports was the characteristics of thin sweptback tapered wings with streamwise tips and subsonic leading edges at supersonic speeds. From these reports,[14,15] Hannah used the approximate expressions for the pressure coefficient and the velocity disturbance potential for the various wing motions studied.

DeYoung's study[10] was performed using a method developed by J. Weissinger.[16] Weissinger's work was published in Germany in 1942. He derived two relatively simple methods for determining the lift distribution on sweptback wings at subsonic speeds. His methods give a better representation of the distribution of circulation over the wing area compared with the Prandtl lifting-line theory. One method is based on the assumption of a lifting surface and the other is based on a slightly modified model of previous lifting-line theory.

Other studies[17,18,19] used by DeYoung are partly from his own previous work. Studies[17,18] performed by DeYoung and associates contributed to the study by DeYoung and Harper.[10] One of these studies[17] compared three theoretical methods of calculating span load distribution, those developed by V. M. Falkner, William Mutterperl, and J. Weissinger. The methods were applied to five swept wings. These methods were examined to establish their relative accuracy and ease of application. Experimentally determined loadings were used as a basis for judging accuracy.

From the analysis it was found that the Weissinger method would be best suited to an overall study of the effects of planform on the span loading and associated characteristics of wings. The method gave good, but not best, accuracy but involved by far the least computing effort. The Falkner method gave the best accuracy but at a considerable expense in computing effort and hence appeared to be most useful for a detailed study of a specific wing. The Mutterperl method offered no advantages in accuracy or facility over either of the other methods.

In DeYoung's work,[18] the Weissinger method was applied to a series of wings encompassing probable ranges of sweep, aspect ratio, and taper ratio to determine the wing characteristics associated with additional-type loading. The results (including span load distribution, spanwise center of pressure, lift-curve slope, and aerodynamic center) were reduced to graphical form as a function of wing plan form.

The computation technique used by DeYoung[10] was previously developed by Stevens.[19] In Stevens' work[19] a computation procedure based on the Weissinger method was devised so that the basic span loading and associated aerodynamic characteristics could be rapidly predicted for wings having arbitrary values of sweep, aspect ratio, taper ratio, and twist.

This report by Stevens,[19] together with that by DeYoung,[18] allows a simple and rapid prediction of both the basic and additional loading characteristics for wings of arbitrary planform.

Figure 2 is a "flow" diagram of the work previously discussed. The diagram shows the interplay and routes of influence between this research work and the LANCE developmental effort. The groupings of this work which constitute separate events are indicated. In all, at least four R events were identified in this investigation as contributing significantly to LANCE in the area of aerodynamic components analysis. This is a conservative grouping since most of the studies discussed are sufficiently significant and unique as to be events independently.

A brief description of the four events and the discrete state-of-the-art advancement which they represent is included in Appendix A of this report. These events are identified as events A-1 through A-4.

c. Interference Effects

The problem referred to in this subparagraph is the variation in the aerodynamic characteristics of missile components when they are coupled together to obtain a system. The deviation in component aerodynamic characteristics will affect the overall characteristics of the missile. The coupling effects are referred to as interference effects. For example, consider a wing-body system and the lift

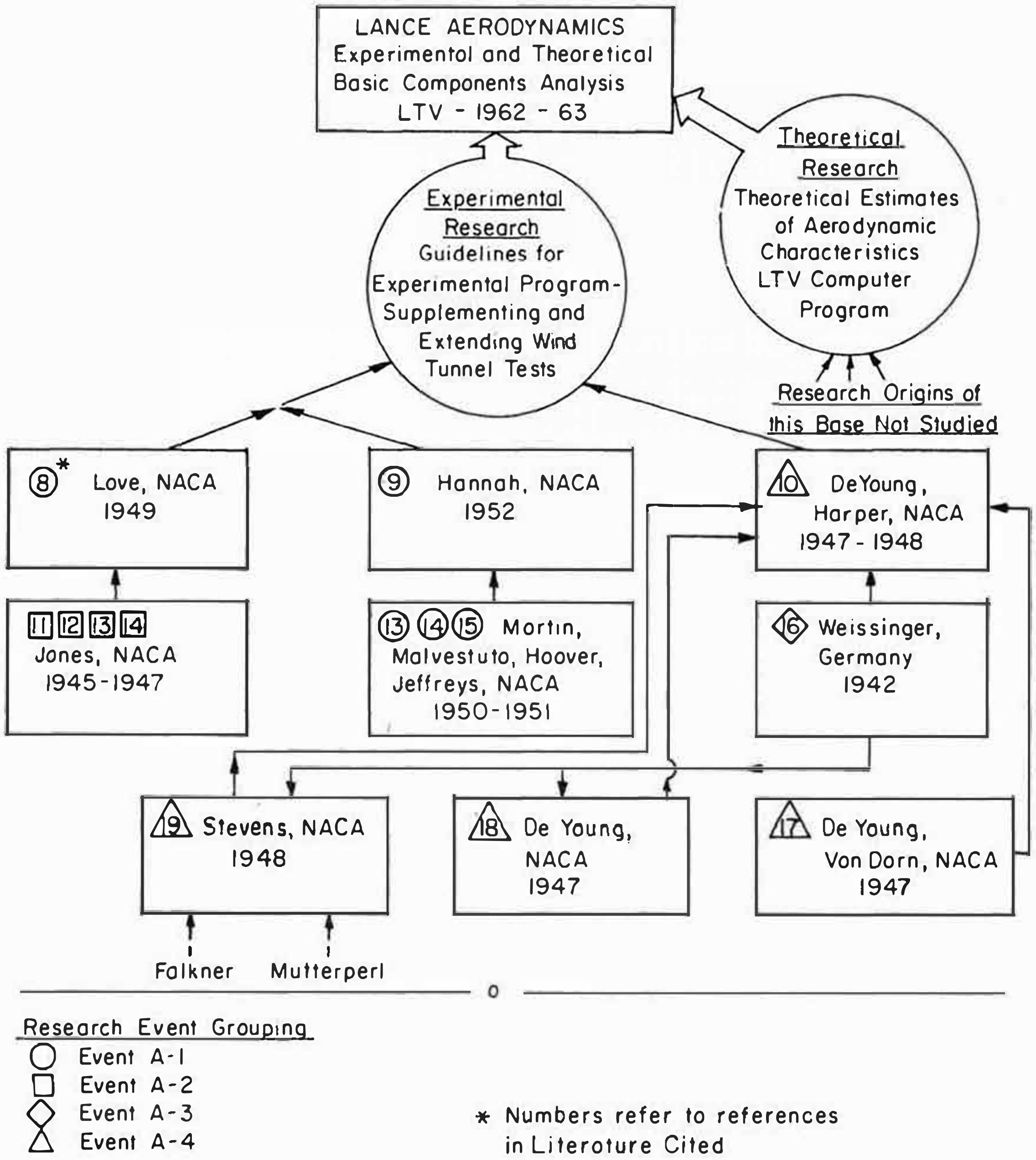

Figure 2. Research Origins of Experimental Research Base for LANCE Aerodynamic Components Analysis

produced by this system. It is well known that the lift produced by the system will not equal the lift produced by the individual components taken independently.

LTV aerodynamicists used the results of a study[20] by Pitts, Nielsen, and Kaattari to estimate the interference effects between the fins and a body of revolution. The work performed by Pitts, Nielsen, and Kaattari was a basic research study on interference effect at subsonic, transonic, and supersonic speeds for various wing-body-tail combinations. The report of this study was published in 1953.

Nielsen and associates published results of an earlier study[21,22] which contributed to the study by Pitts, Nielsen, and Kaattari.[20] This earlier work was published in 1950 and 1952. Both of these studies are of a basic research nature.

Nielsen and Pitts[20] use some work done by R. T. Jones on the aerodynamics of airfoils at supersonic speeds.[23,24] These studies were published in 1945 and 1946 and are included in event A-2 discussed in the subparagraph on components analysis. The results of these studies are used to define the basic wing loading characteristics of wings without interference effects. A study by P. A. Lagerstrom[25] published in 1950 was also used by Nielsen to define the basic aerodynamic loading on conical wings. Lagerstrom used linearized supersonic theory in his investigation of the aerodynamics of conical wings. Spreiter's analysis[26] of the trailing vortex sheet and its effect on the downwash behind wings influenced the development of wing-body-tail interference problems discussed by Pitts, Nielsen, and Kaattari.[20]

Two other research efforts,[27,28] independently done by Carlo Ferrari and Harvard Lomax, influenced the study by Nielsen.[20] These two reports were written in 1948 and 1951 on the subject of interference effects between wing-tail-body combinations and did not make a direct contribution to Nielsen.

The studies by Ferrari and Lomax taken together are a fairly general contribution in the area of wing-tail-body interference effects in transonic and supersonic flow. These studies could have made a direct contribution to LANCE, but this was not so by choice. Nielsen's work was more complete in that it included interference effects in subsonic, supersonic, and transonic flow. The studies by Ferrari and Lomax[27,28] can therefore be considered as a semiparallel event with Nielsen's work.

In all, only one event is defined in this subparagraph on interference effects. This event was primarily due to Nielsen and associates. Figure 3 is a diagram showing the collections of studies and contributions

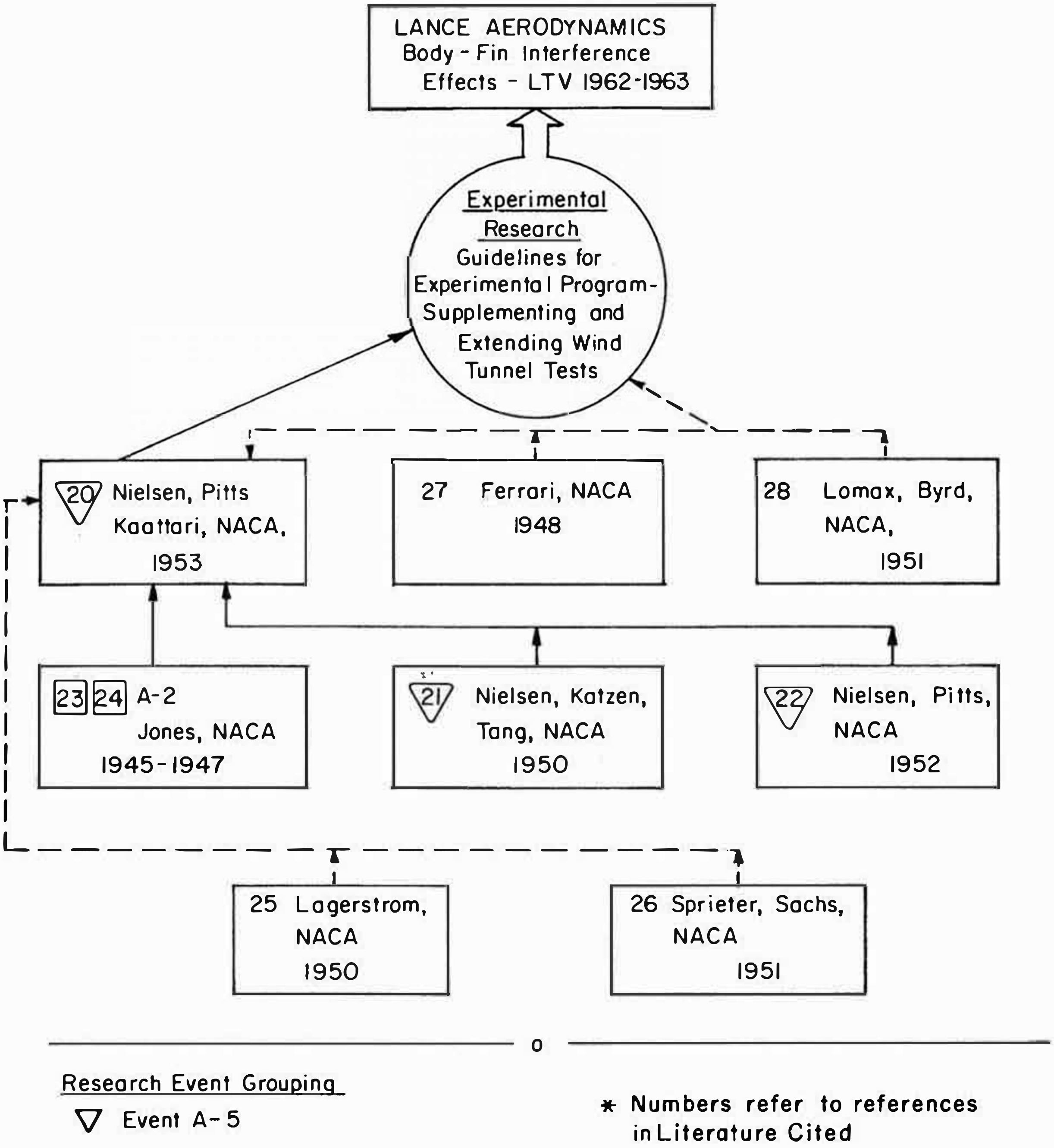

Figure 3. Research Origins for LANCE Interference Effects Analysis

which define this event. This event, A-5, is also influenced by event A-2 through the work of R. T. Jones[23,24] (Figure 2). In Figure 3, dotted lines indicate routes of influence rather than direct contribution. Event A-5 is documented in Appendix A.

d. Drag Estimates

It is required that some knowledge of the skin friction drag be known as an input to the total drag estimate of the LANCE missile. The degree of accuracy required in estimating the total drag for this missile is important because of the propulsion system requirements which maintain a vacuum trajectory. Estimates of the skin friction drag were made using the results of a study[29] by Sommer and Short. This study gives results for skin friction from free-flight tests under conditions of turbulent boundary layers and with severe aerodynamic heating. The experimental data were used to arrive at a theoretical model for turbulent boundary layers based on a modified Rubesin-Johnson T' method. The Rubesin-Johnson method[30] was developed for laminar boundary layers with zero heat transfer.

The results of the study by Sommer and Short were published in 1954 as a NACA report. The data were collected for Mach numbers from 2.8 to 7.0 at conditions of high rates of heat transfer. It was also shown that the theoretical model devised by Sommer and Short agreed well with the experimental values over a wide range of Mach number and heat-transfer conditions. This study was a basic research effort which made a significant contribution to LANCE.

The analysis performed by Rubesin and Johnson leading to the Rubesin-Johnson T' method[30] was also a basic research effort published in 1949. They point out that frictional dissipation in the boundary layers of bodies in high-speed fluid streams produce such large temperature ranges that the effect of the variation of fluid properties must be considered in the analysis of skin drag and heat transfer. When this report was written, existing experimental data on the characteristics of the laminar and turbulent boundary layers were of insufficient scope for a general understanding of these phenomena. Only the study of the laminar boundary layer had been approached analytically, to varying degrees of approximation, by authors in the past. A review of the state-of-the-art in laminar boundary layer theory constitutes a major portion of the Rubesin-Johnson study. The emphasis of the study was directed to the development of the Rubesin-Johnson T' method.

Other studies that influenced the analysis performed by Sommer and Short are a report by E. R. Van Driest, published in 1951, entitled

"Turbulent Boundary Layer in Compressible Fluids"[31] and a study by Chapman and Kesler.[32]

Van Driest's study[31] is concerned with two major problems encountered in high-speed flight: the determination of skin friction and skin temperature. Since the friction drag is a considerable portion of the total drag of a guided missile, it follows that miscalculation of the friction drag can result in considerable error in missile range. Furthermore, skin temperature is an important factor in the structural design of a high-speed missile. These two problems are a result of the presence of the fluid boundary layer. This study analyzed the turbulent boundary layer case. The purpose of the study was to derive a general formula for skin friction including heat transfer to a flat plate in compressible fluids. This study by Van Driest was preceded by other works,[33,34] all on turbulent boundary layer theory. Together, Van Driest's works constitute an event.

The study by Chapman and Kesler[32] is similar in experimental nature to the one by Sommer and Short, except that the test Mach numbers were lower than those in the test performed by Sommer and Short. This study was an analysis to determine average skin-friction coefficients, in the absence of heat transfer, for completely turbulent flows along the cylindrical portion of cone-cylinder bodies of revolution having overall fineness ratios of 10, 15, and 25. The friction data were obtained by directly measuring forces. Mach numbers ranging from 0.5 to 3.6 Reynolds numbers between 4 million and 32 million were investigated. At a Mach number of 2.0, data were obtained for different pressure distributions by distorting the flexible-plate walls of the wind tunnel. This study was published in 1953 as a NACA Technical Note. In all, three events are identified in connection with drag analysis by LTV on the LANCE.

Figure 4 shows the routes of influence and contribution to LANCE from these events. The three events (A-6 through A-8) are documented in Appendix A.

2. Guidance and Control

The LANCE missile is guided by the mechanization of an ingenious concept known as DC-Automet. This concept employs a two-degree-of-freedom gyroscope, an accelerometer and integrator, and a simple axial and attitude control system. Details are not given here because of doubt concerning classified material involved; however, DC-Automet permitted the G & C problems of the LANCE to be solved

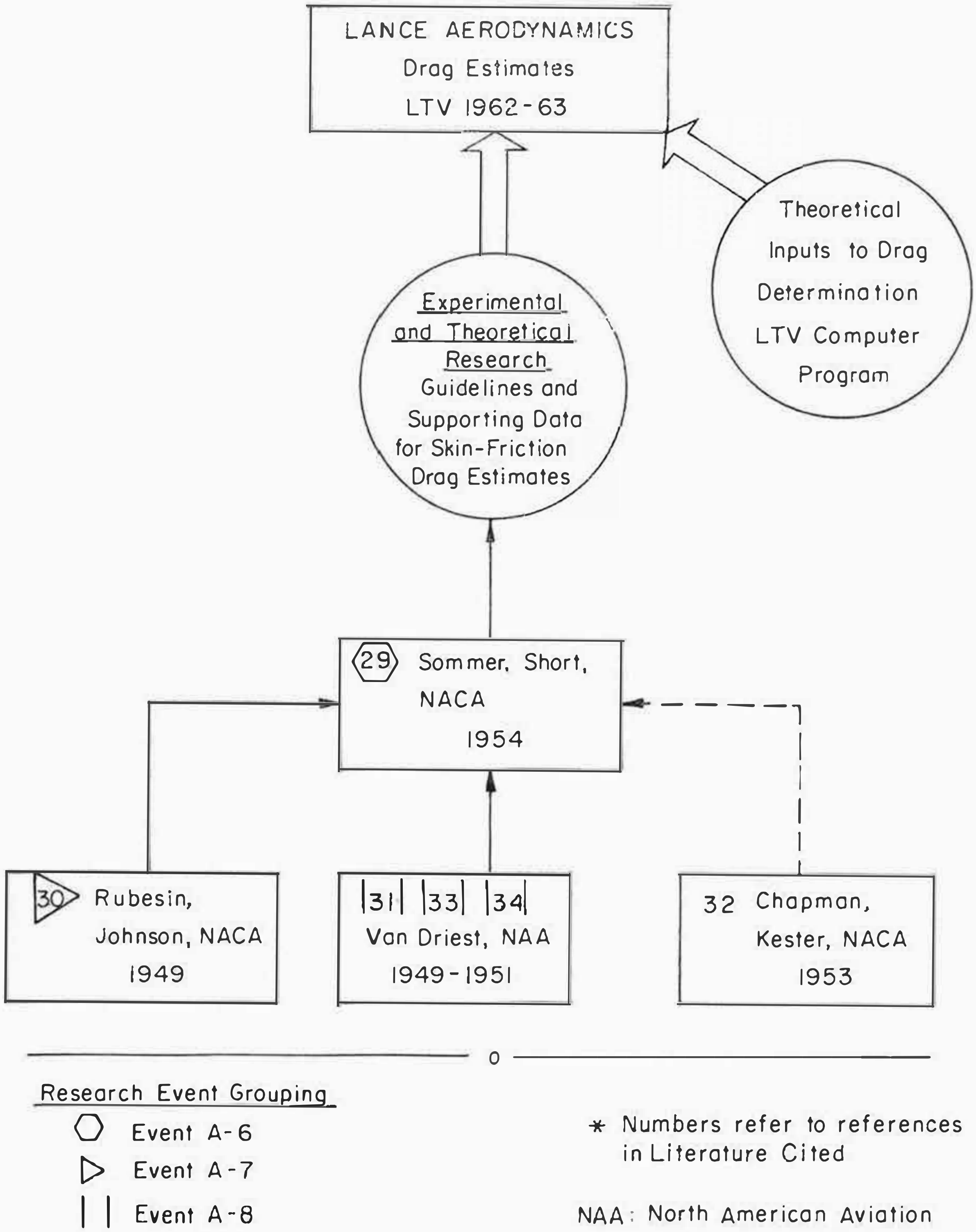

Figure 4. Research Origins of LANCE Skin Friction Analysis

in a far less complex and costly manner than could have been done with other then-available technology.

The original LANCE HINDSIGHT report presented the major RXD events associated with G & C of the LANCE missile and the major components (gyroscope and accelerometer) associated with the G & C system. One area not thoroughly covered was that of the electronic devices used in the velocity computer, control logic, and accelerometer electronics. This paragraph, then, deals with RXD events which made possible the use of various semiconductor devices used in the LANCE G & C electronics. It is believed that the use of semiconductor devices in the LANCE G & C system was assumed at the start of the LANCE program in 1963 because of their lower power and space requirements and high reliability. Three types of semiconductor devices used in LANCE G & C electronics are the diffused, mesa, silicon, n-p-n transistor; the planar, epitaxial, silicon, n-p-n transistor; and the silicon, field-effect transistor. It is believed that these devices were all used in more or less standard circuit configurations for the application involved and that there were no unusual circuit techniques or device applications involved.

The remainder of this paragraph is divided into four subparagraphs. The first gives an outline of the developments in theoretical physics which led up to formulation of modern theories of semiconductors and of rectification. The second subparagraph deals with the development of semiconductor device theory and invention of various semiconductor devices. The next discusses advances made in the fields of materials and processes which permitted development of modern semiconductor technology. The last subparagraph discusses the interrelationships between the various areas of research involved in the first three subparagraphs.

a. Physical Theory

In 1900, Max Planck started a revolution in physics by postulating the quantum theory to account for the observed frequency spectrum of radiation from a blackbody; this observed spectrum was greatly at variance from that predicted by classic physical theory.[35] Planck's theory stated that energy could only be radiated in parcels which he called quanta and that quanta of a higher frequency f_2 contain more energy than quanta of a lower frequency f_1. In 1905, Einstein theoretically extended this concept to account for photoelectric emission.[36] Eleven years later, Millikan experimentally verified Einstein's photoelectric equation.[37]

Similar advances were being made in other branches of physics. In 1911, Rutherford[38] postulated a nuclear theory of the atom in which the positive charge of the atom is concentrated in a very small nucleus rather than being distributed throughout the atom, as previously hypothesized by Thomson. Geiger and Marsden[38] in 1913 experimentally verified Rutherford's model by α-scattering experiments. Also in 1913, Bohr[38] attempted to develop a quantum model of the atom, combining elements of Planck's theory and Rutherford's model. For a long time, Bohr's model could not be successfully extended to a two-electron atom, however. Other theoretical developments were needed before this could be done.

In 1924, de Broglie[38] suggested that matter particles might also possess some characteristics of waves. In 1927, Davisson and Germer[39] in experiments on electron diffraction were able to verify that electrons possess wave characteristics. Other developments followed rapidly. In 1925, the Schrodinger[40] wave equation was formulated. This equation described satisfactorily the laws of motion of an electron and introduced the wave function ψ. Also in 1925, Pauli[40] postulated that no two electrons could be in the same quantum state (i. e., possess the same four quantum numbers). This statement has become known as Pauli's Exclusion Principle and is basic to an understanding of semiconductor behavior. In 1926, Fermi and Dirac[36] independently proposed a form of statistics which took cognizance of the Exclusion Principle. It has been found that the Fermi-Dirac statistics give a realistic description of the manner in which electrons are distributed in metals. This burst of theoretical activity in the mid-1920's resulted in the discipline of quantum mechanics.

Theoreticians were not slow to apply the new tools which were available. In 1928, Summerfeld[41] and Bloch[42] published theories of metallic conduction based on Fermi-Dirac statistics and quantum mechanics. Each of these theories resolved some of the problems of the classical Drude and Lorentz[42] theories but left other questions unresolved. Some problems remaining were those of explaining the nonconduction of insulators and the temperature dependence of semiconductor resistivity. Then in 1931, A. H. Wilson[43] published a classic paper which is recognized as being the genesis of the modern theory of semiconductors. By considering free electrons moving in a field which is periodic in three dimensions and by postulating bands of allowed and disallowed energies, Wilson was able to arrive at a model that was valid for both metals and semiconductors.

In 1939, Mott,[44] Schottky,[45] and Davydov[46] independently proposed relatively correct models for rectification occurring at the junction between a metal and a semiconductor. Prior attempts had resulted in models which predicted rectification in the wrong direction. About this time, the pressures of World War II began to be felt, and both theory and practice were to be given the stimulus of fulfilling urgent need.

b. Device Theory and Device Development

During the 1930's, the emerging technology of uhf communications demanded detectors different from those used for detecting r-f signals. R. S. Ohl[47] of Bell Telephone Laboratories (BTL) from 1934 to 1940 investigated methods for using silicon, point-contact diodes as microwave detectors. Also during this period, Scaff and Theurer[46] of BTL studied a number of aspects of metallurgical problems of silicon. The outset of World War II provided a tremendous impetus to crystal diode research and development since improved detectors were essential for properly functioning radar. Groups were established at the Massachusetts Institute of Technology (MIT), BTL, General Electric (GE), Sperry, the University of Pennsylvania, and Purdue University to engage in crash programs in semiconductor device development. Although the war work was device-oriented, much basic work was done in support of development. In particular, BTL extensively investigated properties of silicon and Purdue investigated properties of germanium. Although silicon had better application characteristics, the groups at Sperry and Purdue concentrated on germanium because it was easier to process to the required purity.

After the war, some of these laboratories continued their work; however, in many cases the work tended to be phenomenon-oriented to a greater extent than before. In particular, at BTL, W. Shockley directed a group in a basic research program to gain a better understanding of the manner in which semiconductor rectifiers work. This program led J. Bardeen[48] in 1947 to postulate the existence of a space charge layer at the semiconductor surface. This theory was validated in 1948 by experiments carried out by Brattain and Shockley[49,50] of BTL. Bardeen and Brattain[51] performed further experiments to attempt to bias the surface layer; this work led to invention of the point-contact transistor, which was announced in 1948. The theory of the point-contact transistor was presented by Bardeen and Brattain[52] in 1949.

New results in both theory and devices came fairly rapidly after the original work. In 1949, Shockley[53] presented the theory of the p-n junction; junction transistors were demonstrated by Shockley, Sparks, and Teal[54] in 1951. In 1948, Pearson[55] of BTL experimentally produced the so-called "field effect" in the laboratory. In 1952, Shockley[56] presented a theory showing that this effect could be used in a transistor.

In 1953, Dacey and Ross[57] of BTL reported on experiments which yielded a field-effect transistor which performed substantially in agreement with the results predicted by Shockley's theory. In 1956, Lee,[58] Tanenbaum,[59] and Thomas[59] of BTL announced the high-frequency, mesa transistor. This development was made possible by the diffusion process discussed under subparagraph c. below.

c. Materials and Processes

As mentioned in the previous subparagraph, Ohl of BTL did significant work during the 1930's on silicon, point-contact rectifiers for use as detectors in uhf and microwave communications. The work supported by the National Defense Research Committee (NDRC) during the war in this area is reported in the book by Torrey and Whitmer.[60] The basic work on germanium (done at Purdue under the direction of Lark-Horovitz) is covered extensively in an article by Lark-Horovitz.[61] This work was funded by NDRC during the war and later by the Atomic Energy Commission and U.S. Army Signal Corps. The work done by the Purdue group included determining conductivity, Hall coefficients, thermoelectric power, and optical properties of germanium at various levels and types and impurities and for different temperature ranges. Similar work on the properties of silicon was carried out at MIT, BTL, and the University of Pennsylvania.

The materials research during the war and up to 1948 made it clear that type and amount of impurities contained in a semiconductor had profound effects on its behavior. This, in turn, led to attempts to obtain ultrapure germanium and silicon to which exact amounts of given impurities could be added. From 1948 to 1950, Teal and Little of BTL experimented with "pulling" a large single crystal of pure germanium by starting with a "seed" and a molten bath of germanium. This method produced germanium with great perfection of crystal structure.[62] By 1952, this method was extended by Teal and Buehler[63] to silicon. During the same period, Teal and Sparks were able to modify the crystal-pulling apparatus so that single crystals of germanium containing p-n and n-p-n junctions could be grown. Also, concurrently, the alloying technique was developed by Hall and Dunlap.[64]

About 1952, Pfann[65] of BTL originated the technique of zone refining to produce germanium of extreme purity. In this technique, r-f heating is used to melt a transverse section of an ingot. As the ingot moves with respect to the coils, the molten zone moves from one end of the ingot to the other. Since impurities in germanium and silicon tend to congregate in the molten section, this moving section tends to sweep impurities to one end of the ingot. By repeating the process, germanium (and, eventually, silicon) could be obtained with only 1 part in 10^{10} being impure. This compares with the 98 percent pure silicon which was available 15 years previously at the start of World War II.[65] The zone-refining technique yielded very pure germanium and silicon which could be used in the pulling or alloying process to form junctions and transistors. Neither of these techniques was capable of producing transistors which could operate in the megacycle regime, however, due to inability to fabricate very thin base regions.

Research on the diffusion process by Dunlap of GE and Fuller of BTL[65] led to fabrication of both germanium and silicon transistors at BTL in 1955.[58,59] By means of this technique, base regions only a fraction of a micron thick may be formed, permitting operation up into the hundreds of megacycles. The diffusion process led directly to development of the mesa transistor which could be fabricated by the hundreds on a single slice of collector material.

The late 1950's produced the currently important "planar" process, developed by Fairchild Transistor Corporation.[66] In this process, an oxide is thermally grown on the silicon slice prior to diffusion of the base and emitter regions. An additional technique of great importance is epitaxial growth of the collector region. This was announced by BTL in 1960, but Christensen and Teal[65] had done research on the technique in the early 1950's. Using the epitaxial technique, it is possible to grow from the gas phase a thin, high-resistivity collector region of given impurity level on a low-resistivity substrate. One advantage of this technique is that it produces a mesa transistor with lower series collector resistance than the earlier techniques allowed. Epitaxial process techniques have been successfully applied to both mesa and planar transistors.

Modern transistors, such as those used in the LANCE missile, are fabricated by use of various combinations of the diffusion, epitaxial, and oxide-deposition techniques.

d. Discussion

The LANCE missile uses a large number of semiconductor devices of certain types in its G & C electronics. The three preceding subparagraphs have attempted to show that a number of RXD events contributed to the existence of these devices at that point in time when they were needed by LANCE. It is perhaps fanciful to trace the origin of modern semiconductor techniques back to Planck's conception of the quantum theory. In fact, however, the initial discovery of a semiconductor phenomenon was observed by Faraday in 1833 when he observed (and, eventually, silicon) could be obtained with only 1 part in 10^{10} being impure. This compares with the 98 percent pure silicon which was available 15 years previously at the start of World War II.[65] The zone-refining technique yielded very pure germanium and silicon which could be used in the pulling or alloying process to form junctions and transistors. Neither of these techniques was capable of producing transistors which could operate in the megacycle regime, however, due to inability to fabricate very thin base regions.

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It may be profitable to look at the manner in which the RXD events considered were distributed in time; this is shown in Figure 5. The events have been grouped into five major categories:

1) Physical Theory - those events which helped explain certain physical occurrences.
2) Theory of Metals and Semiconductors - those events which utilized events in 1) above to further man's understanding of the behavior of metals and semiconductors.
3) Device Theory - those events which used theoretical advances to explain observed device phenomena and to predict the possibility of constructing new devices.
4) Device Invention and Development - those events which culminated in the invention of a totally new device or in development of a device with greatly improved characteristics.
5) Materials and Process Exploration - those events which added to man's knowledge of the basic properties of materials and those events which permitted the manufacture of certain devices or the practical use of certain materials.

Certain observations can be made from Figure 5. From initial conception of the quantum theory in 1900 to development of quantum mechanics in a reasonably useful form took 27 years. Only four additional years transpired before Wilson formulated a fairly complete theory of semiconductors. An additional 17 years passed before invention of the point-contact transistor. All other major types of transistors followed within five years. A point to make here is that fruits of research activities may be difficult to predict and may be a generation or more in the future, but significant research always has payoff many times in excess of the effort which went into it.

It is interesting to note the influence areas. BTL literally dominated the field between 1948 and 1956 insofar as RXD events are concerned. Various reasons could be given to account for this dominance: superior personnel, a head start due to government support during the war, an atmosphere dedicated to RXD-type thinking and activities. All of these factors were, no doubt, of importance; however, the most important aspect was probably having all necessary personnel, techniques, and facilities in-house (and not only in-house, but in an environment which encouraged interchange of ideas and coordination of effort).

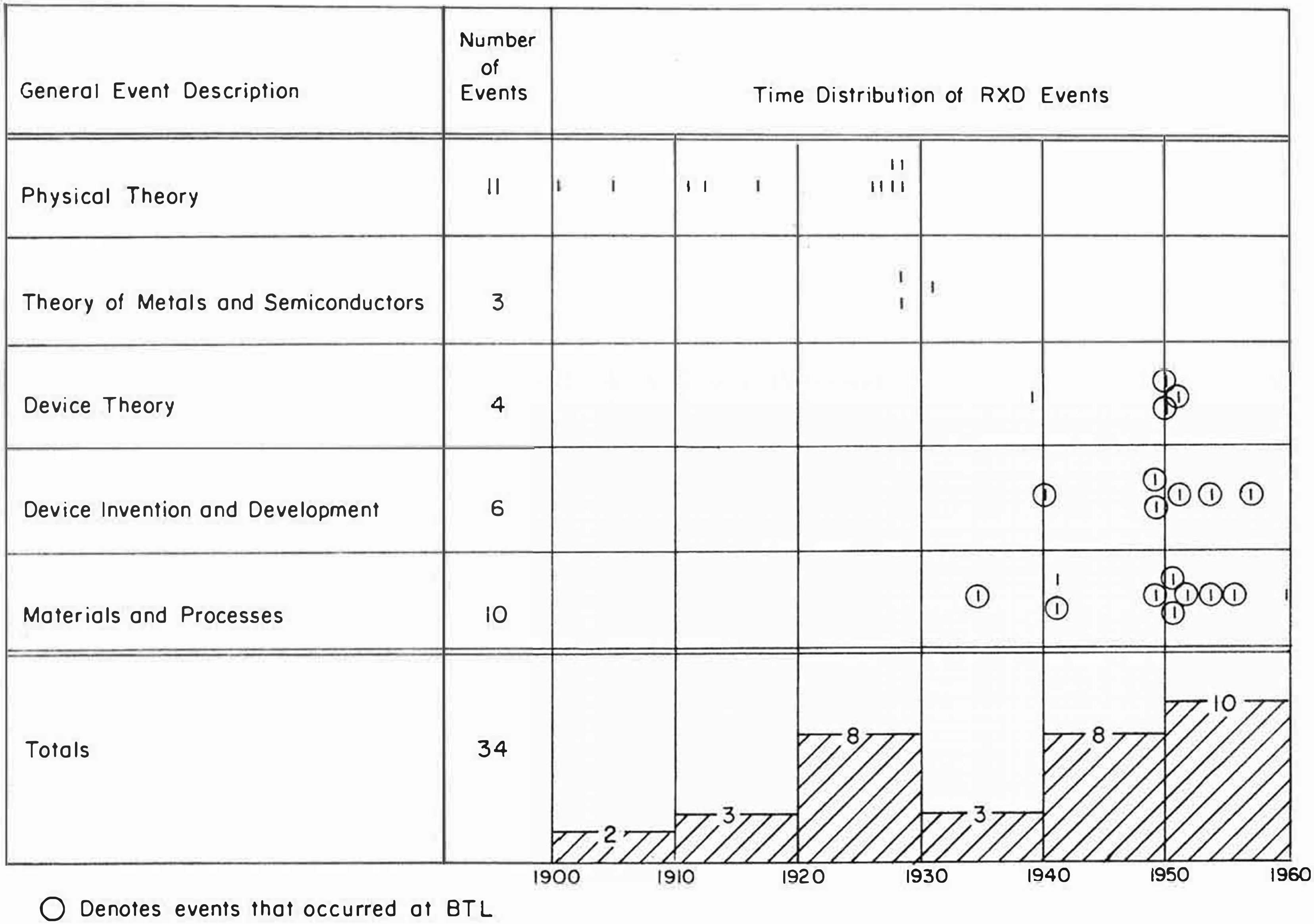

Figure 5. Time Distribution of LANCE G & C Electronics RXD Events

If an experimenter needed silicon with a specified impurity level, he could request it directly of a metallurgist and receive it quickly. If he wanted clarification of a theoretical point in order to decide which way his experiment should be directed, he could seek it from the man who had propounded the theory. When this type of environment exists, progress in RXD events is bound to be more rapid than if a large amount of outside assistance is needed or if an experimenter must become his own metallurgist and theoretician.

Figure 6 groups the 34 RXD events into 11 categories in order to trace the research origins of transistor devices used in LANCE and to show the interrelationships involved. From Figure 6, it is quite easy to trace back to the quantum theory as one research origin for transistors. Some might argue that quantum theory, quantum mechanics, and the nuclear theory of the atom are all part of the general body of scientific knowledge and thus should not be considered as research background for specific scientific developments. These people would say that the origin of transistors should be traced back only to Wilson's paper[43] in 1931. In actuality, this is an indefensible position. Only seven years earlier, none of the apparatus of the wave mechanics was available, and Wilson's theory could not have been formulated without it. The path then leads quite naturally back to Planck's discovery of the quantum theory in 1900. This is one of those events which was dependent on the genius of one man and on his willingness to break away from long-held "truths" in order to follow his genius to its obvious conclusions. One cannot say how long it would have been before someone else discovered the quantum theory, had it not been for Planck.

As shown in Figures 5 and 6, 34 separate events have been identified. There has been insufficient time to develop or document these events more fully. The intention of this investigation was rather to present a macroscopic and integrated view of the enormous research origin of the solid-state components in LANCE. Fairly, by their nature, not all of these events are classifiable as 6. 1-R events. Some of the work, more experimental and applied or device-oriented, corresponds to the format of 6.2 work. A resume of all the events, calling out the work that is considered to constitute an event and the classification of the event, is given in Appendix B. Twenty-four of the events have been classified as R events and 10 as XD events.

3. Propulsion

This investigation of the possible research origins of the LANCE propulsion system used the approach of attempting to "trace

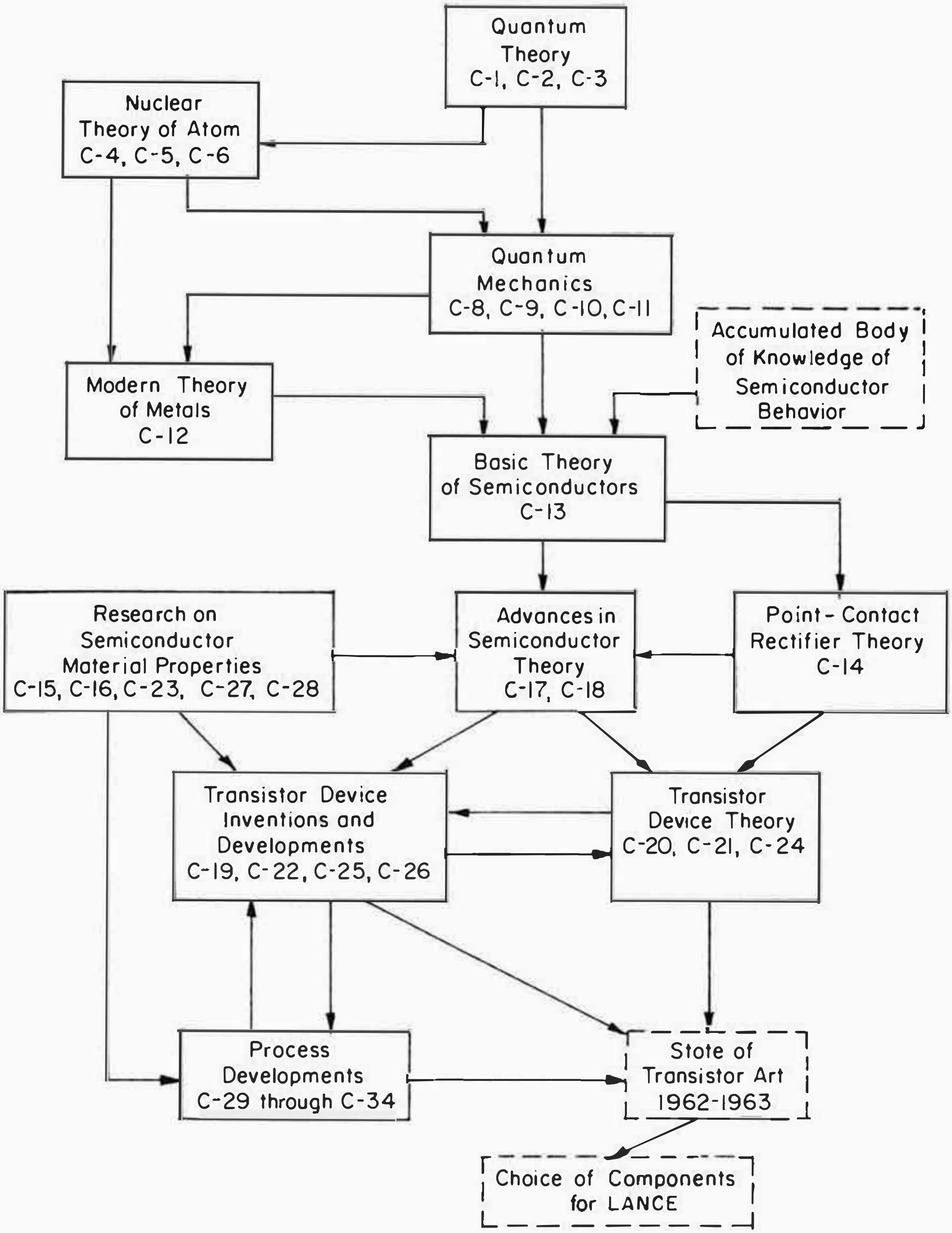

Figure 6. Research Origins of Transistors Used in LANCE G & C

back" from specific exploratory development propulsion events documented in the AMICOM LANCE HINDSIGHT report. Mr. J. Connaughton, AMICOM member of the LANCE HINDSIGHT working committee, cooperated with the Battelle investigator and provided some leads for potential events antecedent to those that he had documented in the original study. The specific results of this investigation have been limited, partly due to time limitations and also due to the fact that some of the event areas appear to be terminal or branch off to other event areas which are already exhaustively documented in HINDSIGHT. In all, it was concluded that the AMICOM report exhausted most of the events that can be identified within the scope and level of effort of the present study.

The development of the LANCE propulsion system falls naturally into three divisions, namely, the thrust vector control system development, the nozzle development, and the propellant development. Some amplification has been possible as regards research related to the thrust vector control system and the propellant development, but efforts to amplify on the research inputs to the nozzle development have been largely unsatisfactory. It was found that the development is apparently documented through the Rocketdyne classified literature, to which access was not obtained before this writing.

a. Thrust Vector Control

Since thrust vector control is a very important aspect of any rocket powered vehicle, it caused considerable concern during the LANCE development. In the LANCE, thrust vector control is achieved by secondary injection into the exhaust cone of the nozzle. The Project HINDSIGHT - Task 1 report devotes three events to this subject.

The most pertinent of these events is concerned with the United Aircraft work by Hausmann[67] during which an oblique shock was created in a primary air stream, in supersonic flow, by the secondary injection of an airjet. The concept of creating the oblique shock in the nozzle had occurred at United Aircraft and had been patented. The work reported in the Task 1 report demonstrated feasibility of this concept.

An earlier event[68] at United Aircraft seems directly related to this patented work and, in fact, of a much more fundamental nature. This work was performed by Hausmann in association with Kuhrt. This investigation was conducted to determine the applicability of shock interference to the control of supersonic vehicles. This type of control is based on the aerodynamic interference of induced shock wave pressure fields with a lifting surface.

As a generality, the tests used several wing shapes in conjunction with a series of two-dimensional wedges to demonstrate that shock wave pressure fields could be used to affect materially the aerodynamic properties of a lifting surface. On the basis of encouraging results obtained from the initial two-dimensional exploratory tests of shock control, a test program was established to supplement the original data and to investigate the problems associated with a three-dimensional configuration and also to investigate the potentialities of shock control by the use of airjets exhausting from the missile body adjacent to the wing surface. The effect of shock interference produced by the various airjet configurations was expressed as a wing lift coefficient. The test data obtained showed that a lift equivalent to that obtained with the wing at an angle of incidence of three degrees was obtained by the use of jet shock interference. This statement is interpreted to mean that the shock-induced thrust was significant. Since thrust vector control operates as a consequence of this sidethrust, these experiments anticipated the subsequent United Aircraft work and, thus, the LANCE engine thrust vector control system development.

In an elementary and perhaps oversimplified manner, it may be stated that shock-induced pressure fields can be created by deviating the flow direction of a supersonic stream. In the United Aircraft work, the wedge on the wing "bent" the originally horizontal stream upward, creating a shock wave, centered at the structural discontinuity and tilted downstream. The region behind this shock wave was at a higher static pressure than the initial undisturbed flow. When the deviated stream passes the end of the wedge, it expands around the "corner" created by the wedge, and this expansion of the stream gives rise to a system of expansion waves and a region of reduced pressure. The net side thrust depends upon the relative magnitudes of the positive and negative pressure fields and the areal extent covered by them. Again as a generality, these shock and expansion waves are all examples of Prandtl-Meyer flow.

Prandtl-Meyer flow has been studied extensively. The original paper[69] was authored, of course, by Prandtl. This paper appeared in Physikalische Zeitschrift in 1907 and was entitled "Neue Untersuchungen über die strömende Bewegung der Gase und Dämpfe." Certainly, this work represents a fundamental research event and although rather far removed timewise, it is nonetheless directly applicable to the LANCE development.

b. Oxidizer Development

The development of nitric acid into the IRFNA form for use as an oxidizer in rocketry is well documented through HINDSIGHT event P-202.* This event carries activities back to Zborowski and pre-Peenemünde days. These activities were, of course, all strongly directed to rocketry and necessarily were of a stepwise exploratory development fashion. There is one prior event, which was very briefly reported, that deserves consideration, for it possesses the true spark of originality. In 1930, Sander[70] in Germany actually demonstrated the use of nitric acid in a liquid fuel motor. Although documentation for this event is very scant, to all appearances it was one of the early keys to liquid propellant rocketry and as such deserves classification as a research event.

c. Engine Hardware

The engine development for LANCE was largely a design problem and most of the events associated with it have been classified as exploratory development within the HINDSIGHT - Task 1 report. One significant aspect of the engine development was the need for a control of the sustain-phase thrust, and to fulfill this need a variable orifice-area injector was developed. Within this effort was the development and subsequent patenting of a fluid metering device, and this development has the nature of a hybrid event. Admittedly, it is strongly biased toward an approach designated as exploratory development. At the same time, the metering is achieved by variable but controlled passageways, and a detailed study of the fluid mechanics in such channels necessarily possesses originality and has the essence of research activity. Accordingly, the activities of North American[71] which led to the issuance of the patent are defined as a research event.

The four research events identified in this paragraph are documented on fact-data forms in Appendix C.

4. Materials and Processes

In the development of a new system, such as the LANCE weapon system, there is little or no time for material-and-process research. The selection of materials and manufacturing processes must be fixed early in the design stage so that the detailed design can be completed. It is obvious, then, that the basic research which

*See LANCE event P-24, AMICOM Task 1 report.

resulted in the development of the materials subsequently selected must have been conducted prior to the selection-of-materials event in the LANCE development. It is important, therefore, that materials with certain properties and reliability were available for use in the LANCE system at the appropriate time.

The materials-selection events, then, are important events in the LANCE system development. Although they cannot be categorized as RXD events, the RXD events which preceded the material selection are significant events which permitted the development of the LANCE system as finally designed.

The materials selected for a given system must meet certain criteria. They must have the requisite properties to meet the performance requirements, they must be capable of being fabricated to the required shape and size, and they must have proven reliability. No new untried material will meet these requirements. Thus, the materials selected for any system may have been the result of research conducted a few years or many years prior to the material-selection event. It also should be recognized that the development of a material is a continuing process where each incremental improvement may be a basic research event or a natural developmental evolution. For example, the LANCE developmental activity related to the molding of the butyl rubber seal for the expulsion piston certainly involved learning which will be retained, is reproducible, and is a general contribution to butyl rubber technology.

The previous LANCE study identified a few materials events that had been responsible for significant and unique LANCE developments. It should be possible to trace almost every material used in the system or its components back to the original research which developed that material.

The faith of the materials researcher in this premise cannot be emphasized too strongly. In recent years, materials (and processes) have posed a higher frequency of state-of-the-art limitation than perhaps in any other technology or disciplinary area. To deny or deemphasize the role of research in overcoming these problems shows considerable naiveté about the nature of the attack that has successfully advanced the state of the art beyond many of these limitations. As a general rule, the materials that have met the radical and stringent new requirements for strength, thermal resistance, and chemical compatibility have been "new" developments of fairly recent research origin. They are, further, generally acknowledged to be the products of materials research motivated to varying degrees by the recognition of needs or potential application.

Discussions were held with AMICOM materials people, knowledgeable regarding LANCE, to identify what materials and processes were used in the development of LANCE. This was not a casual process. Materials lists were not found to be readily available and if this is a general situation, it is conceivable that the use of uncommon materials and their research implications could be overlooked in a HINDSIGHT effort. Some of the important materials identified during this investigation are listed below:

1)	Missile case:	2014T6 aluminum.
2)	Motor housing:	Tens 50 aluminum casting.
3)	Nozzle (outer):	Refrasil ablative material on maraging steel.
4)	Nozzle (inner):	Refrasil (ablative) on both sides of a 300 series stainless.
5)	Inner nozzle insert:	High density SiC.
6)	"O"-ring seals:	Silicone rubber and Teflon.

Some of the processes which were used to fabricate parts for the LANCE system were identified as follows:

1) Electron-beam welding of motor cases.
2) Shear forming of motor cases.
3) Numerical control machining.
4) Molding of butyl seals.

Of the above list, electron-beam welding and molding of butyl seals were listed as XD events in the original LANCE report. In a separate report from ARO-Durham, the development of butyl was traced back to its original announced development in 1940. With a broader treatment of rubber technology, basic research was traced back to the 19th century. A similar treatment was given to aluminum alloys by ARO where they pointed out that the discovery of age-hardening mechanisms occurred in the early 1900's.

It is the opinion of the authors that similar treatments could be used for almost all the materials used in the LANCE system. Process developments could be treated similarly. Thus, the selection of materials and processes to be events will have to be made arbitrarily. It must be emphasized that this present discussion is not considered to be an exhaustive treatment of the materials and processes on which LANCE is dependent.

A few of the materials and processes have been selected to demonstrate how basic research was involved in the materials development which ultimately benefited the LANCE system.

a. The Aluminum Alloy 2014T6

In the LANCE system, the fuel tank and the oxidizer tank are manufactured from the aluminum alloy 2014 containing 4.4 Cu, 0.8 Si, 0.8 Mn, and 0.8 Mg heat treated to the T6 condition (solution treated, quenched, and aged condition). This alloy has been in common usage for well over 20 years and its development could hardly be called a research event pertinent to the LANCE development. However, it can be used to illustrate the importance of basic research to materials development over a long time period.

The aluminum industry and consequently aluminum alloy usage can be traced back to the discovery by Hall in the United States and Heroult in France (both in 1886) that aluminum could be recovered by electrolysis of alumina dissolved in cryolite. This process, with the natural improvements that evolved over the years, is still the basic process used to produce the aluminum used in today's aluminum alloys.

The early usage of aluminum was restricted by its low strength and high ductility and considerable research went into alloy development. Age hardening, as we know it today, was unknown at that time. Thus, the discovery of age hardening by Alfred Wilm in 1906, while working in Berlin for the Prussian Military Authority, is a significant basic research event. Wilm discovered that certain aluminum alloys were very soft when quenched but would harden spontaneously with time at room temperature. Following Wilm's discovery came the development of the Duralumin alloy (4 Cu, 0.5 Mg, 0.5 Mn, 0.5 Si). The 2014 alloy is obviously a modification of the Duralumin alloy developed as a result of Wilm's discovery.

Much basic research has been conducted on the age-hardening mechanism since Wilm's discovery, which has led to a better understanding of the hardening reaction and the application of age-hardening principles to other alloy systems.

The selection of 2014T6 for the LANCE system meets the requirements set forth earlier: the selection of a material which has the requisite properties and proven reliability for the application. It represents the application of a material which has a long history of reliable performance. However, it remained to establish that this alloy would perform reliably in the specific environment of this application. The XD event, M-5,* provided a "Device for Determining the Occurrence

*LANCE Project HINDSIGHT Report - Task 1, December 1965.

of Stress Corrosion for Materials in Long Term Storage" and was an important event in the LANCE program.

It should also be recognized that the research on the phenomena and mechanism of stress corrosion, extending over a period of several decades, was responsible for the awareness of its possible effects in LANCE and thus indirectly for the process event, event M-5, documented in the LANCE HINDSIGHT study by AMICOM. Stress corrosion is a very complex failure mechanism and what is understood about it today is still very much empirical. It is interesting that some large research programs are currently being funded by ARPA and by the Air Force to study stress corrosion cracking. There are many aspects to this problem and legitimately several classes of phenomena. It would be possible to show many notable research events associated with stress corrosion, liquid metal embrittlement, hydrogen embrittlement, and so forth, all bearing on the understanding behind event M-5. However, this was not undertaken in this study.

No additional research origins of the aluminum alloy 2014T6 have been discussed here than were pointed out in the ARO discussion. At least two events mentioned here and by ARO should be specifically denoted as LANCE research events.

The first is the classical event by Hall and Heroult (working independently) which is the basis of the aluminum industry (M-1, 1886). The second is the discovery of age hardening by Wilm (M-2, 1906), from which the development of the Duralumin alloy stems.

b. 18-7-5 Maraging Steel

The material required for the thrust chamber sustainer shell must have a combination of very high strength and good toughness. This requirement led to the selection of 18-7-5 maraging steel. Unlike the 2014 aluminum alloy development, the maraging steel development is relatively recent, the first publication being in March 1962.[72] The important basic discovery that led to the maraging steel development was the application of age-hardening principles to a martensitic steel. Decker and co-workers of the International Nickel Company Research Laboratory were responsible for the basic research and subsequent development which resulted not only in a new alloy concept but in the proven producibility of the 18-7-5 maraging steel (18% Ni-7% Co-5% Mo). Thus, a new material with attractive properties was ready when the LANCE system was being designed.

The work of Decker et al on the application of age-hardening principles to a martensitic steel is considered a significant research event pertinent to LANCE and is denoted here for the first time as a LANCE R event (M-3, 1962).

c. Silicon Carbide Nozzle Insert

A high-density silicon carbide (SiC) refractory is employed as an insert in the throat section of the sustainer motor of the LANCE propulsion system. The insert material is a product of the Carborundum Company and is designated as KT Silicon Carbide. [73]

The development of KT Silicon Carbide occurred in the 1950's and is a patented material. [74] Its uniqueness is that it is a self-bonded refractory material (at least 96.5% SiC) having greater density, strength, and resistance to abrasion and oxidation than other commercially available silicon carbide refractories. The latter are characterized as composite materials bonded by a silicate, carbon, or silicon nitride. Also, KT can be fabricated into complex shapes to precise tolerances. [75]

Since 1946, various commercial and experimental silicon carbide materials have been subjected to extensive evaluation for rocket nozzle application in both simulated and actual rocket motor firing tests under government contracts. Also, the development of silicon carbide materials was a concurrent R & D effort of both industry and government.

The selection of KT Silicon Carbide for the nozzle insert of the LANCE sustainer motor was based on proven reliability of this material in other similar applications. Optimization of the configuration of the insert to achieve the performance requirements of the sustainer motor should be considered an exploratory development event in the LANCE program through the cooperative efforts of the propulsion system contractor (Rocketdyne) and the Carborundum Company. [73] The development of the cold molded Dense Silicon Carbide by Taylor of the Carborundum Company is a significant LANCE R event (M-4, 1962). The optimization of the insert configuration is further considered to be a notable XD event in the LANCE program (M-5, 1962-1964).

d. Refrasil-Phenolic Ablative Materials for LANCE Weapon System

Protection of underlying components and structures and preservation of shape in critical areas exposed to extremes of temperature are necessary in rocket propulsion systems. Protection could be attained through regeneration, insulators, heat sinks, or ablative materials. In general, temperatures and gas velocities are too high for the use of purely insulating materials. Likewise, heat sinks within practical weight limits cannot absorb the very high heat flux. Refrasil ablative materials were chosen in LANCE to provide the protection needed.

Ablators are sacrificial protection structures which function by a combination of decomposition and insulating properties. Heat is absorbed by decomposition of the resin binder to give low molecular weight gaseous products. This is not only an endothermic reaction, but the gasses formed furnish some shielding from radiation. As the resin decomposes, a porous char is formed which further assists in protection by its insulating qualities. Resins receiving the most attention include phenolics, epoxies, silicones, and combinations of these. Thermoplastic materials are generally unsuitable because of their melting characteristics. It is apparent that resins must be chosen with both the decomposition products and the char properties in mind.

Because the ablators are exposed to high stresses from the very high gas velocities, it is usually necessary to reinforce the ablator with fibrous materials. Fibers so far studied have included organics, such as nylon, asbestos, glass, silica, and ceramic. Choice of fiber depends upon its heat stability and maintenance of strength at the elevated temperatures within the char. In the case of organic fibers, actual decomposition of the fiber may add to the heat-absorbing qualities of the ablator. Orientation of the fibers is important because of the high gas velocity. Laminate structure with the plies parallel to the gas stream would be expected to be peeled off in successive layers. An attempt is therefore made to have as high a proportion as possible of the fibers oriented at an angle to the gas stream. Preferred orientation cannot be established in the case of an irregular shape such as a rocket nozzle.

Ablative materials are evaluated under simulated use conditions by exposure to heat sources such as oxygen-hydrogen torches, plasma jets, and some rocket engines. None of these simulated tests are completely adequate and use conditions are the final criteria. Choice among different ablative materials will depend upon factors such as weight, strength, ease of fabrication to the desired shape, and expected environment (oxidative, reducing, neutral).

The need for high-temperature-resistant fibers led to the study of Refrasil as a reinforcing fiber for ablative materials. This fiber was first used as insulating batts for early jet engines. As prepared by the

H. I. Thompson Fiberglass Company, glass fiber is leached with acids to a residue which is 96 to 99 percent silica. After washing and drying, the leached fiber is heated to eliminate the porosity resulting from the leaching. Refrasil, with its high silica content, has a melting point of 3000°F. The earliest application of Refrasil in ablative materials[76] was done by the Missile and Space Vehicle Department of GE in 1958. A further account of this early work appeared in 1959.[77]

There are undoubtedly a number of significant research events associated with the development of Refrasil ablatives. As far as can be determined, the parent event relevant to LANCE is the work done by GE in about 1958. This event is of significance to LANCE and is denoted as an R event (M-6, 1958).

e. Teflon and Related Polymers

Teflon (polytetrafluoroethylene), Kel-F (polychlorotrifluoroethylene), and other fluoroplastics had their origin in the basic chemistry conducted in the 1930's. This work was done in large part by Du Pont in connection with refrigerants development that culminated with the commercial introduction of "Freon" refrigerants in 1931.

This development reflected probing in depth the chemistry of organic fluorine and chlorine compounds. Additional work with the same class of chemical compounds led to the discovery of Teflon (at Du Pont) in 1938. Semiplant production was started in 1941 and commercial production in 1950. Continuing research has improved the polymer varieties and properties available. High-temperature resistance, outstanding electrical properties, and chemical resistance make this class of polymers extremely useful in military applications.

Although the impetus for the work that led to this class of polymers was commercial, much of the early and continuing research is basic. It is directed only toward examining the molecular structure of the polymers as a means of better understanding their physical and chemical properties. Much of the research of highly crystalline polymers of this type resembles that conducted in connection with the basic studies of metals.

In numerous instances, various military services have underwritten R & D, sometimes basic and at other times applied, in efforts to apply these polymers to very specific environmental applications.

At the small components level, the applications of Teflon in LANCE are numerous. The criticality of this material in some of these applications also should not be underrated. The research event leading to the discovery of Teflon in 1938 is an extremely signigicant event to LANCE and the whole of modern technology. This event is denoted as R event M-7.

Further investigation of the research origin of Teflon would reveal a chain of significant research events leading to the variety of commercial products and components such as are used in LANCE. Also, as implied in the previous discussion, a backtracing investigation from the 1938 event would show a variety of related supporting research.

f. Silicone Rubber

Silicone polymers (rubbers, varnishes, plastics, and lubricating fluids), as widely used in present weapons systems, all had their origin in basic chemical research conducted prior to 1944. The outstanding contributions of pure chemistry to these materials developments were made by Professor F. S. Kipping of the University of Nottingham in England. Between 1899 and 1944 he contributed 54 papers on silicon chemistry.

Kipping's interest in organo-silicon chemistry was strictly academic. He searched for a better understanding of silicon chemistry. He apparently wished to demonstrate a separate chemistry of silicon similar to that of carbon. He wanted to understand the effect of substitution of silicon for carbon in a compound with respect to that compound's reactivity.

In 1937, Kipping was presenting a lecture reviewing his work and reported gloomily, "as . . . the few [organo-silicon compounds] which are known are very limited in their reactions, the prospects of any immediate and useful advance in this section of organic chemistry does not seem to be very hopeful."[78]

Kipping was wrong with his prediction. In 1944, silicones were introduced commercially. In 1943, the Dow Corning Corporation was formed by Dow Chemical Company and Corning Glass. The new company supplied organo-silicon products demanded by the military in World War II. An example is the water-repellant treatments given glass fiber stuffing for life jackets so that they would float. The Japanese had shut off our supply of Kapok.

The earliest issued patents were assigned, however, to GE in 1941,[79] and this company also was an early supplier of this new type of polymer. These patents covered various silicone products and processes for making them. The chemistry involved drew heavily on the early fundamental work on the chemistry of silicon-organic materials by Kipping and others.

The end of the war marked the beginning of a whole range of products with most unusual properties. Silicone rubber was introduced at this time. No other rubber offers the low sensitivity of this rubber to temperature. It is flexible from as low as -130°F and as high as 550°F. This is achieved because of the chemical structure of the polymer, involving a silicon-oxygen backbone with pendant methyl groups on the silicon atoms.

Methods of production of silicone rubber and other silicone products have been constantly improved by industry (Dow Corning, GE, and others). The varieties of polymers, design of seals, and improvement of compounds for specific applications have continued under industrial and military support. Along with this applied R & D work have come incremental investigations into the more fundamental behavior of this unique class of polymers.

It is believed that without Kipping's basic research work we simply would not have silicone rubber products today. It is apparent from the past discussion that many research events could be documented from the history of silicone rubber. For the purpose of this review, we will consider the individual advancement of silicon chemistry by F. S. Kipping in England as the principle research event extending almost continuously over half a century (M-8, 1899-1944).

g. Numerical Control Machining

Experience of the past several years indicates that numerically controlled machining has contributed significantly to the attainment of acceptable levels of manufacturing capability related to advanced military and aerospace requirements. Current and potential benefits of numerically controlled machining include savings in lead time, increased reproducibility, reduced tooling, less floor-to-floor machining time, improved inspection, reduced rejections, simpler setups, elimination of templates, and increased flexibility and versatility.[80]

The LANCE missile system is an excellent example of military hardware which has benefited from numerically controlled machining. In the very early stages of the missile development, numerically controlled machining was introduced to insure accurate part reproduction with a minimum of expensive tooling. For example, each missile, less the warhead, contains six bulkheads and thirteen other parts or assemblies which receive some machining under numerical control. In addition, the launcher and loader-transporter also contain numerous parts and subassemblies which employ this advanced process of machine tool control.

The history of numerical machining goes back almost 20 years. In 1947, J. C. Parsons coupled a jig borer with automatic processing equipment to become the first man to control a metal cutting process directly with preprogrammed coded numerical data.[81] On the strength of this development, Parsons won a study contract with the U. S. Air Materiel Command. Parsons turned to MIT for help, where the idea was ultimately proved feasible. MIT was then awarded a direct contract for developing an experimental milling machine under digital control.[81,82]

The MIT/Air Force numerical control study was conducted in three phases. Phase I was essentially a basic research study of numerical control principles. Phase II involved the construction of the experimental milling machine. Phase III, conducted by the Air Force, analyzed the machine operations and evaluated the economics of numerical control.[83]

The next, crucial step in the application of numerical controls to machining resulted from purchase requests, by the U. S. Air Force, for machine tools which required their development. Except for the controls, those early tools were improved versions of conventional machines. The demonstration of improvements in efficiency and versatility resulting from the novel control systems stimulated later developments and culminated in new types of machine tools.

Commercial numerical control machines were soon placed on the market, including a numerical control profile skin miller, a numerical control turret drilling machine, and a numerical control design embodying the mill-drill-bore-tap concept.[81] During 1961, U. S. industry offered 156 different numerical control machine tools and 48 control systems, and by 31 December 1963, 3583 machines had been shipped to users at a cost of $217 million.[81]

In view of its revolutionary concept, the growth of numerical control machining has been phenomenal. In its simplest concept, a numerical control machine is a complex system of electronic equipment and mechanical motions which need to be properly programmed, manually or by computer, in order to accomplish its mission.[81]

At present, control systems for machining tools operate from fixed programs. That is, the programmer specifies the path that the center of the cutter should follow, as well as the speeds, feeds, and cut depths. To avoid trouble, some programmers are conservative in choosing metal removal rates. This is especially true for new materials and those known to be difficult to cut. Such conservatism results in higher processing costs because expensive equipment is operated at slower than optimum machining rates. Furthermore, higher-than-expected temperatures, tool forces, tool wear, and vibration cause poorer finish and dimensional inaccuracies.[80] By the proper selection of all machining factors, however, the programmer can optimize production rate while minimizing tool breakage. Consequently, suitable background data relating tool life and surface quality to speed, feed, depth of cut, and to the machining behavior of the workpiece material must be available to the part programmer.[84]

Machining data based on tool life curves for titanium, high-strength steels, superalloys, and refractory metals are available to the programmer as a result of concentrated research efforts sponsored principally by the U.S. Air Force.[85] The Machining Data Handbook prepared for the Rock Island Arsenal, Ordnance Corps, U.S. Army, incorporates these data with input from industry.[84]

The U.S. Air Force also has sponsored basic research into new tool materials in an effort to reduce tool wear and thus increase machining accuracy.[86] Areas of investigation included the carburized high-speed steels, cast-to-shape tool alloys, atomized and consolidated tool alloys, and carbides with high-melting matrix phases.[86] The Carborundum Company has undertaken the development of ceramic material systems for use on refractory metal and superalloy parts.[87] The Denver Research Institute, University of Denver, investigated new cemented-carbide systems.[88]

A better understanding of "machining effects" on metals has been obtained from a research study done on "surface integrity" at Metcut Research Associates. Surface integrity includes factors such as metallurgical transformations, hot and cold plastic deformation, residual stress, and micro- and macrocracks.[89]

An Air Force project at the Cincinnati Milling Machine Company determined the dynamic stability of machine tool/metal cutting systems at the "drawing stage" of the machine tool development. This basic research study should provide machine tool manufacturers with the analytical techniques needed to determine the conditions required for chatter-free performances of machine tools before they are manufactured.[90]

Current R & D effort on numerically controlled machining is about $3,300,000 annually in the United States, with greatest emphasis on "programming" to help educate designers and production people use the available equipment more efficiently. The U.S. Air Force is directly supporting only about 10 percent of the total R & D effort with the greatest effort being made by the Aerospace Industries Association. Some activity is going on in the area of automated design and an ever-increasing effort is being expended on adaptive controls. The areas of inspection, setup, and tooling are modestly active.[80]

This discussion gives an idea of the scope of research associated with numerical control machining either directly on methods and theory or indirectly on machinability, tool life, effectiveness, and so forth. Not all of this work can be fairly denoted as events affecting or contributing to LANCE, although the payoff of this research to military systems in general has been great. For the purpose of this HINDSIGHT review, the principal R event is considered to be the combined efforts by Parsons as the conceptual innovator in 1947 with MIT extending and supporting the concept through research. This event has affected LANCE. The absence of numerical control machining may not have prohibited the successful development of any system but program effectiveness would have been different. This R event is denoted as M-9, 1947.

h. Shear Forming

Shear forming is a process used for shaping seamless, hollow metal parts such as the LANCE motor case by the combined forces of rotation and pressure.[91] Shear forming has a number of names that have been used since its development. Some nonproprietary names include roll forming, shear spinning, and flow turning.[91] The term shear forming, however, will be used herein to cover all of these processes.

Spinning, the forerunner of shear forming, is believed to have been developed in China during the 10th century and introduced in Europe during the 14th century. It has been used ever since, particularly when forming items not readily made in one piece by pressing.[91]

An increased interest in spinning occurred during World War II and the Korean War. The process appeared to be ideally suited for making cylindrically shaped aircraft parts in relatively small quantities because tool costs and setup times were far below those required for deep-drawing operations. Since highly skilled metal spinners were not available at the time and no time existed to train personnel, the process was mechanized. This permitted higher tool forces and the forming of thicker parts for high-strength materials. Thus, the process of shear forming was born. [73]

The success of shear forming relies a good deal on accommodating a complicated forming process to the mechanical properties of the material being formed. Avitzur and Yang[84] investigated the forming process of a cone and postulated that a shear-type deformation occurred as the shear forming rollers progressed through the part. In their research, they were able to calculate the displacement velocity, strain rate, and stress fields for a so-called "Von Mises" material.* The power consumed was computed from the strain rate and stress fields involved. [92]

Kobayashi, Hall, and Thomsen[93] also studied the theoretical mechanism of shear forming cones. They found that the predicted tangential (or power spinning) forces for aluminum and lead, for several spinning conditions, agreed with their experimental results. In addition, the normal force and axial force components were also evaluated with fair agreement between theory and experiment. [93]

Kalpakcioglu, [94] using an idealized model of the shear-forming process, defined and formulated some of the basic quantities in the shearing mechanism (shear strain, shear strain rate, specific energy, and tangential force). Kalpakcioglu[95] also investigated the shear spinnability of metals. He predicted the maximum permissible thickness reduction without fracture during forming in terms of stress systems occurring in an idealized deformation zone, using a two-dimensional process. Mechanical properties versus spinnability test results were then evaluated for cast iron, aluminum alloys, stainless steels, and copper. [95]

Kalpakcioglu and Kegg[96] collaborated in another research study on the shear formability of metals. They found that the shear formability of a metal can be indicated most consistently by percent reduction-in-area data.

During shear forming of tubing, the amount of reduction that can be taken in one pass is limited by the mechanical properties of the material.

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*A Von Mises material is assumed to be homogeneous, isotropic, and nonstrain hardenable. Further, the metal would undergo no elastic deformation and consequently no volume change.

The forces required for shear forming tubes, either forward or backward, have not been clearly defined. Kobayashi and Thomsen[97] analyzed the spin forming process for tubing and presented approximate solutions.

Kalpakcioglu[98] found that the maximum permissible reduction for ductile materials depends on the state of stress in the deforming area and on the material properties. Again the maximum reduction can be predicted from tensile reduction-in-area data for both cone and tube spinning.[98]

The United States Air Force has sponsored a number of programs in order to investigate the various facets of shear forming and how this process could be used in the manufacture of missile cases.

The Curtiss-Wright Corporation[99] undertook a program to establish the fundamental aspects of shear forming. The first phase established the effect of shear-forming process variables on dimensions. The second phase explained the effect of process variables in terms of the nature of metal flow under the shear-forming rollers. The third phase used the previous information to help manufacture complex shapes and to solve manufacturing problems. The alloys used included 6061 Al, 17-22A steel, 321 stainless steel, N155 and Inconel X750 superalloys, and Ti-6Al-4V.

The Marquardt Corporation[100] determined the shear-forming characteristics of various materials, including N155; 19-9Dl; 19-9DX; Inconel; 2024Al; HK31A Mg, Ti-5Al-2.5Sn, and CP titanium. They concluded that all materials investigated could be successfully shear spun from a metallurgical viewpoint. Generally speaking, severe cold work was imparted to the as-spun part, and accordingly some metals increased their tensile strengths as much as 100 percent, while elongation and bend ductility values decreased.

The Aerojet-General Corporation[101] investigated the effect of shear forming on properties of steel. They determined the effect of shear forming on the uniaxial mechanical and metallurgical properties of 4335V low-alloy steel in the as-spun, spun and stress-relieved, and hardened and tempered conditions. They also determined the effect of shear forming on the biaxial strength when the steel was at the 200,000 psi uniaxial yield strength level. Finally, they investigated the effect of shear-forming tool marks and/or the direction of spinning on the properties parallel with and transverse to the spinning-tool marks.[101]

Temco Electronics and Missiles Company[102] was awarded a contract to determine and evaluate mechanical property data for 32 alloys that had been fabricated by shear forming using various amounts of reductions. The materials included four types of stainless steel, superalloys, titanium alloys, alloy steels, and aluminum alloys. The results of this research included information and data on mechanical properties, degrees of cold work imparted, surface finish, and types of defects occurring.[102]

The AVCO Corporation[103] undertook a program to select a material and to develop a shear-forming process for fabricating a rocket motor case. This program also evaluated the deformation of materials which in the metastable austenitic condition would develop biaxial strength values in excess of 300,000 psi. The conclusions indicated that 18NiCoMo maraging steel offered the greatest potential of attaining these strengths while exhibiting good spinnability[103] (see also event M-3).

GE[104] applied shear-forming techniques for manufacturing a lightweight rocket case from a single forging of high-strength steel.

The manufacture of seamless cylinders from high-strength alloys for solid-fuel rocket cases requires reliable data on material properties and shear-forming techniques. Successful shear-forming techniques existing today took years to perfect and were initially based on the efforts of many individual investigators. Recognizing the possible widespread need for general data covering shear-forming techniques, the U.S. Army, Navy, and Air Force initiated a variety of R & D projects. Shear forming, up to that time, was not considered to be an economical proposition; however, with the high cost of modern materials, the process is now recognized as having distinct advantages over some of the more conventional fabricating methods. These include savings in material costs and a stronger component resulting from the improved grain flow produced by cold working.

It is seen that shear forming is an evolutionary outgrowth of spinning and is not marked by a distinct recognition or innovative event. The important research origins in this area are those research events which have resulted in shear forming's becoming a practical process. A major part of this work did not occur until the early 1960's. We consider the combined efforts of Yang, Kobayashi, Kalpakcioglu et al to develop a theoretical model of the shear-forming process an important research event. This event is denoted as R event M-10, 1960-1961. There are other research efforts and exploratory development events in this picture of the evolution of shear forming but these will not be called out specifically as RXD events. As far as HINDSIGHT is concerned, the major event is the body of research defined by M-10 which has provided a base for the development of shear forming as a practical manufacturing process.

i. Electron-Beam Welding

Electron-beam welding was selected as the method for fabricating tactical prototype LANCE missile propellant tanks to minimize the reduction in strength in heat-affected zones when tungsten-inert gas was used. In the LANCE development this event was more than a selection-of-process event because the application of electron-beam welding to large systems had not been demonstrated previously. The development of the electron-beam welding technique for use in the LANCE system has already been classified as an exploratory development event (see event M-1, Project HINDSIGHT Report - Task 1, "Research and Exploratory Development Origins of the LANCE Weapon System"). However, prior to that development, significant basic research had been conducted on electron-beam technology and electron-beam welding.

Although electron-beam technology can be traced back to vacuum technology and the science of electron emission, the significant developments occurred in the mid-1950's.[105] J. A. Stohr of the French Atomic Energy Commission and W. L. Wyman of the Hanford Atomic Products Operation independently investigated the use of focused electron beams as heat sources for welding reactive metals used in nuclear applications. Following these announcements, considerable research and development went into the electron-beam welding process with the result that by the early 1960's electron-beam welding was a recognized joining method and its limitations and usefulness became better understood. Therefore, it remained for exploratory development, such as that done in the LANCE program, to apply the process to hardware fabrication. The research event of Stohr and Wyman on the use of focused electron beams as welding heat sources is the parent event in the area of electron-beam welding. This R event is denoted as event M-11.

Ten R events and one XD event have been identified in this discussion. These events are documented specifically in Appendix D.

Section IV. OBSERVATIONS AND CONCLUSIONS

In the previous discussions, a total of 57 RXD events have been identified. Of these events, 46 have been classified as R events and the remaining 11 as XD events. As stated previously, the principal concern of this study has been to identify further research contributions to the LANCE missile. Therefore, the principal product of this investigation is considered to be the 46 R events. The 11 XD events are considered to be significant contributions to LANCE which were noted incidentally during this investigation but which were not classifiable as R events due to the character of the work involved. We are confident that still further research origins or events could be identified even within the subject scope of this particular investigation. The particular sample of events or any other such sample, regardless of the number of events it includes, will be an incomplete and thus an arbitrary portrayal of the contribution from research to that system. A HINDSIGHT investigation will always miss the less isolatable and more subtle contributions from research that are not amenable to event-type documentation.

Since this particular sample of research events is not considered to be a general cross section of the research contribution to LANCE, it would be misleading to reach general statistical conclusions on the basis of the event data. Research payoff has a variety of characteristics, stemming from the fact that R events themselves are all of an individual and distinct nature and that the route of the payoff is also individualistic and situation-oriented. General statistical conclusions regarding research payoff phenomena may be misleading regardless of sample size. However, this particular sample size is considered to be large enough for some reliability to be placed in the implications of the time distribution of the events. Figure 7 shows a summary of the event types identified in this report and their time distribution. Considerable caution should be exercised in interpreting this plot relative to LANCE and general conclusions should probably be avoided. The plot is interesting in that it vividly shows the significant contribution from "recent" research. It should also be noted that the distribution has not been overweighted in the recent period by the G & C events, although the total distribution may be unduly biased by the large number of G & C events. The five R events of the AMICOM report are clearly seen from Figure 7 to be less than a representative sample of the research contribution. This claim cannot be made absolutely but is strongly implied by the lack of parallel with the larger sample.

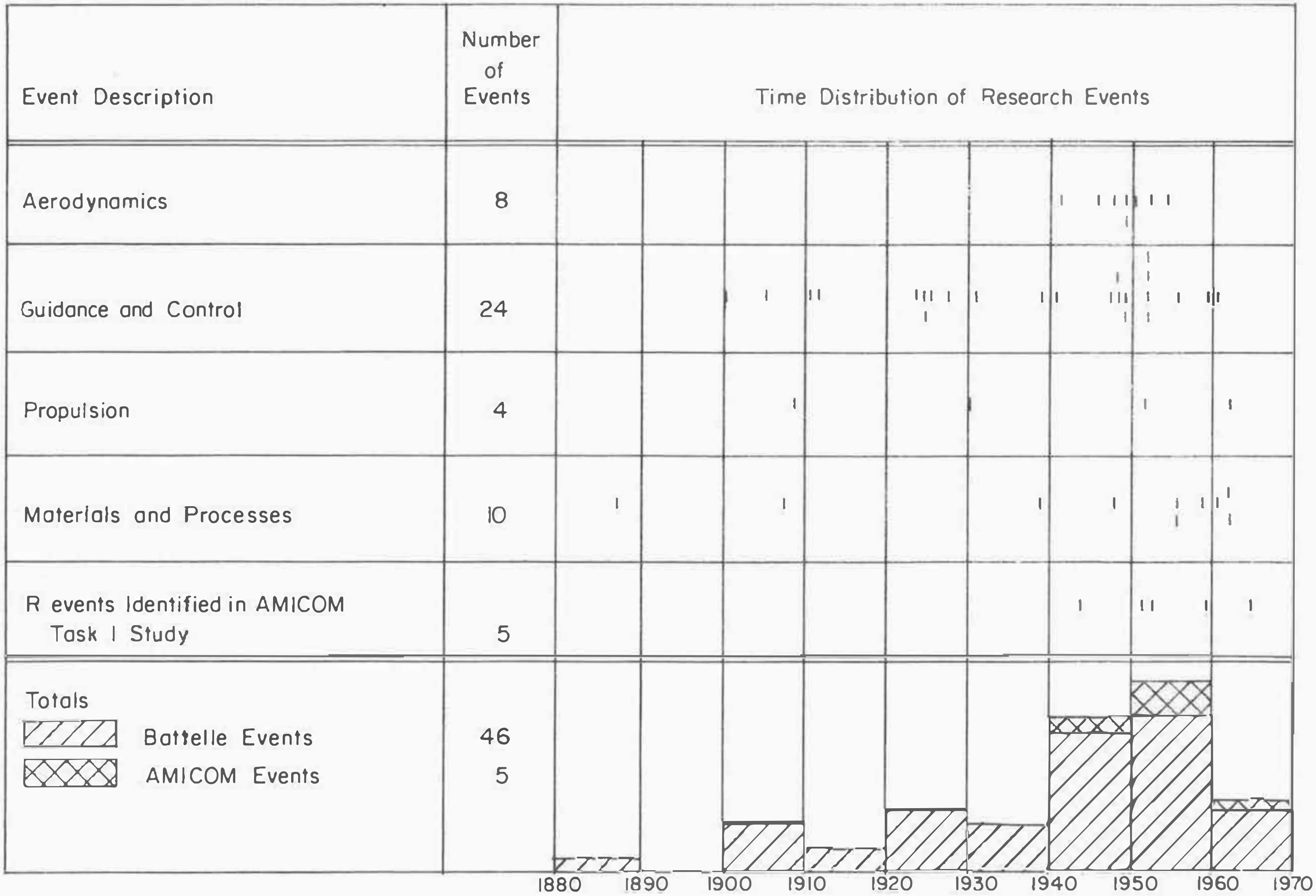

Figure 7. Time Distribution of LANCE R Events

Some qualitative conclusions and observations regarding the contribution from basic research to modern weapon systems are of interest. These conclusions are based on the results of this study and also draw from other research experiences of the investigators who have conducted this study. First there may be some meaning in the attitude of the typical researcher to the HINDSIGHT philosophy. His attitude reveals some resentment at attempting to give a specific account of the return from basic research. It has been our experience that this attitude is rather general. The good faith of the researcher in this attitude should be taken for granted since he is seldom found to be doubtful of the fact of a significant return from basic research. To the contrary, he usually expects that the body of fundamental research effort has paid off in such diverse ways and so widely that the contribution is self-evident. This attitude is not totally justifiable since basic research is an investment and it is reasonable to examine the nature and extent of the return. It is, however, essential to understand that the return from basic research can never be conclusively tabulated nor can it be strictly shown to have a specific value proportional in some way to the investment.

A commonly suggested model of the basic research function puts most of the emphasis and value on the body-of-knowledge type contribution of basic research. This model emphasizes the role of basic research in increasing the data base or the state-of-the-art level or in translating science into shelf-technology, and so forth. This general contribution is a major part of the basic research contribution but it is often an unnecessarily vague way to "show" the credit. More specific research contributions are demonstrated by the specific examples of a direct payoff in the R events identified in this and other HINDSIGHT studies. To fail to recognize the existence of both the general and the specific contribution, or to give one or the other undue emphasis to the detriment of the other, is unfair to the basic research function. To oversimplify, one attitude is based on faith and broad general evidence that the basic research function has paid off and, in a sense, fear that the best argument for this will not be made by specific examples taken individually. The opposite attitude accepts that credit should be granted to the body-of-knowledge contribution but emphasizes the importance of the specific payoff. This latter attitude, in the extreme, is skeptical of the practical importance of the payoff of research if it cannot be specifically shown.

Of course, all such questions regarding the proof of a significant contribution from basic research are subordinate to the best aims of HINDSIGHT, which are to provide data and insight which will ultimately aid in improving the contribution of funded research. HINDSIGHT accepts the absolute fact of a payoff; there is no question on this point. Rather the interest is in whether funded research is having a continuous and sufficient payoff to weapon systems and which facets of this research have paid off most rapidly and to the best effectiveness overall.

A major observation of this particular study is that the basic research payoff to modern military systems has been enormous and that the specific contribution from "recent" science has been strong. It is the opinion of this study group, based on the experience of conducting this study as well as experience drawn from similar state-of-the-art studies, that all modern weapon systems have generally benefited from basic research in many fundamental areas, such as materials, processes, design theory, electronics, energy conversion and storage, combustion, sturctural mechanics, management science, and so forth. There is evidence of both a specific and a general body-of-knowledge type of research payoff in the LANCE system. The claim of an enormous research payoff applies to the general research contribution that has been necessary to make a modern system possible from its technological beginning. No basis was found in this study from which to disagree strongly with the general conclusion of HINDSIGHT that the contribution from recent research to advancing a given system over its predecessor has been less significant than that from exploratory development and engineering.

However, we still consider the contribution from recent science to LANCE to be strong. Of course, the observation on the part of HINDSIGHT that the contribution from recent scient to "advanced" systems has been small is a conclusion general to all the systems studied and is less significant to LANCE than to some others. LANCE is actually weakly linked (i. e., by technology) to its predecessor, HONEST JOHN.

There is considerable interest in the DOD and research community, from the point of view of research planning and management, in finding effective criteria for determining the relevance of basic research to long-term future needs. This question of relevance is seen to be closely allied to the question of the value of directed research as opposed to undirected research. One of the major conclusions sighted in the first interim report on Project HINDSIGHT[5] was that "in the systems studied, the contributions from recent research and science were greatest when the effort was oriented (directed)." It should be noted that usage of the term oriented or directed was meant to describe the motivation of the research scientist rather than the nature of the work in which he was engaged. The term directed necessarily has implication as well as to the degree to which the work itself is directed or undirected to a specific problem area. The following observation is suggested concerning the distinction in payoff from research when it is directed and when it is undirected. It appears obvious that the payoff of directed research will occur with more guarantee, more quickly, and with greater focus on a specific problem area. On the other hand, there is ample evidence that a large and extremely significant return has accrued to modern military systems from the body of undirected research which during its conduct was wholly phenomena-oriented and not focused in any specific way on existing or envisioned technology problems. Further, in this work it appears that the investigators had no motivation by which it could be stated that their work was directed in any degree. Even in LANCE it is evident that in the long run some of the more significant and weighty research contributions have come from activity of this type.

It is certain that directed research has a distinct character. It is believed that this research is not only more strongly focused on specific state-of-the-art problems but that this focusing also has a somewhat restrictive effect. It is not intended to imply that this type of restriction or focus is detrimental to the quality of the work. It is agreed that it can bring about rapid return on the work. On the other hand, if this were the total format of the research investment, then it would necessarily limit investigation in areas not deemed immediately important but for which there is no guarantee of an unforeseen future need or importance. That is, a format exclusively devoted to directed research would have the danger and indeed a strong possibility of causing future dislocations in the form of technological deficiency. A mix of research effort is required. The DOD must, for example, support a basic program of research related to physical sensors. At the same time and in some reasonable proportion it will have needs for sensor research directed toward meeting certain specifications stemming from existing or foreseeable problems and application needs. Of course, practical funding and effort limitations obviously force a decision on priorities, and current needs or problems are strong contenders. Hopefully, priority can be effectively assigned to basic research endeavor of high relevance to future needs. There is considerable evidence that relevance cannot be guaranteed in every case and there would be considerable danger in attempting to control this factor dogmatically. On the other hand, it is clear that the DOD cannot afford to support a basic research, carte blanche.

We believe that needs analysis and forecast exercises can periodically point out, with sufficient clarity, those areas of basic research that deserve prime attention from period to period. In other words, the question of relevance may not be quite the quandary that is often made of it if a reasonable level of risk can be tolerated.

Dr. McKenzie of Ford Motor Company Research recently stated that For had found that involvement in fundamental research in those areas generally pertinent to the organization, with extreme freedom to the individual researcher (within that framework), has payoff directly in financial benefits, prestige, competitiveness, and so forth.[3] This appears to be a realistic format for the larger segment of the research industry. It is of course true that not all of the basic research being funded today is defensible. There are examples of unproductive effort as well as of work that is not relevant to long-term needs and that can be identified as such with little risk.

Some observations are also in order concerning the effects on the research payoff resulting from the auspices under which the work was done. One of the conclusions of HINDSIGHT thus far has been that "the relative efficiency of production of science and technology events which have been utilized in defense is substantially higher when funded and managed by the Defense Department or defense industry than it is when funded and managed by the nondefense sector of government or industry."[5] It is believed that by its nature the science activity (6. 1 or fundamental research effort) is not strictly amenable to direction in the administrative sense. That is, the production of this effort cannot be administratively controlled or programmed. Therefore, we believe that any distinctions in the productivity of this effort related to auspices are not connected to the fact, per se, that the work is funded and managed by DOD but rather to some incidental and beneficial environmental situation that may result from the fact that it is funded and managed by DOD. Such a benign environment could be found, and often is found, in the nondefense sector of government or industry, however. Most of the work which is funded and managed by DOD, or the in-house work, is done in some manner of collective environment in which communication is optimized. This is believed to be the key to the efficiency of production.

A similar situation is described in Section IV, Paragraph 2. b of this report, in which the investigators at BTL had a broad-based effort involving optimum communications between those individuals who had advanced the theories of solid-state devices and those who were working on materials and processes leading to the development of actual device hardware. Likewise, the work contributing to the aerodynamics of LANCE was done almost exclusively under the auspices of NACA and here again communications were good. One should not discount, however, the unique benefit to undirected research effort that can result from the work's being DOD-funded and managed. Considerable incentive can be given to the fundamental research investigator when he is aware of both application potential and broad problem areas. In summary, the point is that the auspices under which the work is done do not affect the quality of production by virtue of administrative control of the work but rather by virtue of enhanced communications and working philosophy.

These are the general observations that have been made on the basis of this study. Other conclusions and observations are included in the substantive paragraphs of this report and are more specifically related to the event areas and subject matter involved. We have specifically refrained from any statistical reduction of the event data other than the indication from Figure 7 of the peak period of the research contribution. Any inferences based on the ratio of government laboratory events to university events and the like have been avoided.

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Appendix A

AERODYNAMICS

RXD Event Description

1. Title: (A-1) Theoretical and Experimental Contribution to Aerodynamics of Swept Wings at Supersonic Speeds

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Aerodynamic Fins

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event advanced the knowledge of the aerodynamics of swept wings at supersonic speeds.
   b. Relationship to Contemporary Science and Technology: At the time of this event a better understanding of the aerodynamics associated with swept surfaces was needed because of their suitability in supersonic flight.
   c. Relationship to Succeeding Development or to System Performance: This event contributed to the experimental test program to study the aerodynamic characteristics of LANCE.

6. Type of RXD Event: Research

7. Key Technical Personnel: E. S. Love; M. E. Hannah; K. Margolis; J. C. Martin; I. Jeffreys; F. S. Malvestuto; D. M. Hoover

8. Date of Event:

   a. Termination: 1952
   b. Initiation: 1949

9. Duration: 3 years

10. Organization: NACA

11. Organization Type: Government Laboratory

12. Financial Support: Extent of Funding Unknown

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: The results of this event were used by LTV aerodynamicists to supplement and extend the wind tunnel data generated during the development of LANCE.
    b. Previous Activity: Previous work in Germany during the early 1940's and the work by R. T. Jones of NACA established a basis for this event.

14. RXD Event Circumstances: Fundamental aerodynamics research in support of increasing emphasis in flight in supersonic regime. Well-defined advancement based on work by Love and supported by results of several NACA investigators.

15. Sources:

National Advisory Committee for Aeronautics, INVESTIGATIONS AT SUPERSONIC SPEEDS OF 22 TRIANGULAR WINGS REPRESENTING TWO AIRFOIL SECTIONS FOR EACH OF 11 APEX ANGLES by Eugene S. Love, 1949, NACA Report No. 1238.

National Advisory Committee for Aeronautics, SPAN LOAD DISTRIBUTIONS RESULTING FROM CONSTANT ANGLE OF ATTACK, STEADY ROLLING VELOCITY, STEADY PITCHING VELOCITY, AND CONSTANT VERTICAL ACCELERATION FOR TAPERED SWEPT-BACK WINGS WITH STREAMWISE TIPS: SUBSONIC LEADING EDGES AND SUPERSONIC TRAILING EDGES by Márgery E. Hannah and Kenneth Margolis, 1952, NACA TN No. 2831.

National Advisory Committee for Aeronautics, SPAN LOAD DISTRIBUTIONS RESULTING FROM ANGLE OF ATTACK, ROLLING, AND PITCHING FOR TAPERED SWEPTBACK WINGS WITH STREAMWISE TIPS: SUPERSONIC LEADING AND TRAILING EDGES by John C. Martin and Isabella Jeffreys, 1951, NACA TN No. 2643.

National Advisory Committee for Aeronautics, LIFT AND PITCHING DERIVATIVES OF THIN SWEPTBACK TAPERED WINGS WITH STREAMWISE TIPS AND SUBSONIC LEADING EDGES AT SUPERSONIC SPEEDS by Frank S. Malvestuto, Jr., and Dorothy M. Hoover, 1950, NACA TN No. 2294.

National Advisory Committee for Aeronautics, SUPERSONIC LIFT AND PITCHING MOMENT OF THIN SWEPTBACK TAPERED WINGS PRODUCED BY CONSTANT VERTICAL ACCELERATION: SUBSONIC LEADING EDGES AND SUPERSONIC TRAILING EDGES by Frank S. Malvestuto and Dorothy M. Hoover, 1950, NACA TN No. 2315.

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Prepared By: Ross G. Luce
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (A-2) Determination of a Theoretical Model for Swept Wings in Supersonic Flow

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Aerodynamic Fins

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event established a theoretical model for swept wings in supersonic flow.
   b. Relationship to Contemporary Science and Technology: At the time of this event a general theoretical model was required for the aerodynamic analysis of swept wings.
   c. Relationship to Succeeding Development or to System Performance: This event provided an understanding of swept wing flow phenomena which influences the work performed in event A-1.

6. Type of RXD Event: Research

7. Key Technical Personnel: R. T. Jones

8. Date of Event:

   a. Termination: 1947
   b. Initiation: 1945

9. Duration: 2 years

10. Organization: NACA

11. Organization Type: Government Laboratory

12. Financial Support: Unknown

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: The results of this event were used by aerodynamicists in event A-1 to predict theoretically the characteristics of swept wings in supersonic flow.

b. Previous Activity: Previous analysis and theories used by Jones are thin airfoil theory, Ackert's theory, and Bollay's work in the area of swept surfaces.

14. RXD Event Circumstances: Basic research prior to LANCE affecting LANCE through its contribution to the aerodynamic development of fins.

15. Sources:

National Advisory Committee for Aeronautics, WING PLANFORMS FOR HIGH-SPEED FLIGHT by Robert T. Jones, 1945, NACA Report No. 863.

National Advisory Committee for Aeronautics, ESTIMATED LIFT-DRAG RATIOS AT SUPERSONIC SPEED by Robert T. Jones, July 1947, NACA TN No. 1350.

National Advisory Committee for Aeronautics, PROPERTIES OF LOW-ASPECT-RATIO POINTED WINGS AT SPEEDS BELOW AND ABOVE THE SPEED OF SOUND by Robert T. Jones, 1945, NACA TN No. 835.

National Advisory Committee for Aeronautics, THIN OBLIQUE AIRFOILS AT SUPERSONIC SPEED by Robert T. Jones, 1946, NACA TN No. 851.

Prepared by: Ross G. Luce
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (A-3) Theoretical Model for Lift Distribution on Swept-back Wings in Subsonic Flow

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Aerodynamic Fins

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: This event established a theoretical model for predicting the aerodynamics of swept wings in subsonic flow.
    b. Relationship to Contemporary Science and Technology: At the time of this event, a more detailed theoretical model was required of the lift distribution which includes the effects of the geometry of the wing.
    c. Relationship to Succeeding Development or to System Performance: This event provided an understanding of swept wing flow phenomenon and influenced future theoretical developments in subsonic analysis.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. Weissinger

8. Date of Event:

    a. Termination: 1942
    b. Initiation: Unknown

9. Duration: Probably the culmination of work covering 3 to 4 years of activity.

10. Organization: ZWB Germany

11. Organization Type: Foreign/ government Laboratory

12. Financial Support: Unknown

13. System Interface Activity:

a. Contemporary and Succeeding Activity: The results of this event were used in event A-4 to predict theoretically the aerodynamics of swept wings in subsonic flow.
b. Previous Activity: -

14. RXD Event Circumstances: This event was motivated by the need for an improved theoretical model of the lift distribution compared to the Prandtl lifting-line theory accepted at the time.

15. Sources:

National Advisory Committee for Aeronautics, THE LIFT DISTRIBUTION OF SWEPTBACK WINGS by J. Weissinger, 1942, NACA TN No. 1120.

Prepared by: Ross G. Luce
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (A-4) Theoretical Determination of Aerodynamic Characteristics of Swept Wings with Arbitrary Planform in Subsonic Flow

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Aerodynamic Fins

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event is a general theoretical analysis to determine the aerodynamic characteristics of swept wing with arbitrary planforms in subsonic flow.
   b. Relationship to Contemporary Science and Technology: When this event occurred there was a general need for aerodynamic data for swept wings with arbitrary planforms. The motivation of this work was the accumulation of data for improving the theoretical understanding of swept wings.
   c. Relationship to Succeeding Development or to System Performance: The results of this event were used by LTV aerodynamicists to predict the aerodynamics of the fins on the LANCE missile.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. DeYoung; C. W. Harper; N. H. Van Dorn; V. I. Stevens

8. Date of Event:

   a. Termination: 1948
   b. Initiation: 1946

9. Duration: 2-3 years

10. Organization: NACA

11. Organization Type: Government Laboratory

12. Financial Support: Unknown

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: This event aided in the experimental test program performed by LTV to determine the aerodynamics of LANCE.
    b. Previous Activity: The work performed in Germany by J. Weissinger (A-3) was used in this event.

14. RXD Event Circumstances: Circumstances unknown. The motivation was probably the recognition of data gaps.

15. Sources:

National Advisory Committee for Aeronautics, THEORETICAL SYMMETRIC SPAN LOADING AT SUBSONIC SPEEDS FOR WINGS HAVING ARBITRARY PLANFORM by John DeYoung and Charles Harper, 1947-1948, NACA Report No. 921.

National Advisory Committee for Aeronautics, A COMPARISON OF THREE THEORETICAL METHODS OF CALCULATING SPAN LOAD DISTRIBUTION ON SWEPT WINGS by Nicholas H. Van Dorn and John DeYoung, 1947, NACA TN No. 1476.

National Advisory Committee for Aeronautics, THEORETICAL ADDITIONAL SPAN LOADING CHARACTERISTICS OF WINGS WITH ARBITRARY SWEEP, ASPECT RATIO, AND TAPER RATIO by John DeYoung, 1947, NACA TN No. 1491.

National Advisory Committee for Aeronautics, THEORETICAL BASIC SPAN LOADING CHARACTERISTICS OF WINGS WITH ARBITRARY SWEEP, ASPECT RATIO, AND TAPER RATIO by Victor I. Stevens, 1948, NACA TN No. 1772.

Prepared by: Ross G. Luce
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (A-5) Theoretical Determination of Wing-Body-Tail Interference Effects at Subsonic, Transonic, and Supersonic Speeds

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Fin-Body Interference

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event is a general theoretical analysis of wing-body-tail interference effects at subsonic, transonic, and supersonic speed.
   b. Relationship to Contemporary Science and Technology: This event advanced the state of the art of interference effects on aerodynamic bodies.
   c. Relationship to Succeeding Development or to System Performance: The results of this event were used by LTV aerodynamicists to predict interference effects between the basic body of revolution and the fins.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. N. Nielsen, W. C. Pitts; G. E. Kaattari, E. D. Katzen; K. K. Tang

8. Date of Event:

   a. Termination: 1953
   b. Initiation: 1950

9. Duration: 3 years

10. Organization: NACA

11. Organization Type: Government Laboratory

12. Financial Support: Unknown

13. System Interface Activity:

   a. Contemporary and Succeeding Activity: This event has made a contribution that continues to be applicable to modern aerodynamic systems, such as LANCE.
   b. Previous Activity: Work done at NACA in the late forties and early fifties in such areas as lift distribution and interference effects provided a contribution to this event.

14. RXD Event Circumstances: Unknown

15. Sources:

National Advisory Committee for Aeronautics, LIFT AND CENTER OF PRESSURE OF WING-BODY-TAIL COMBINATIONS AT SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS by William C. Pitts, Jack N. Nielsen, and George E. Kaattari, 1953, NACA TN No. 1307.

National Advisory Committee for Aeronautics, LIFT AND PITCHING-MOMENT INTERFERENCE BETWEEN A POINTED CYLINDRICAL BODY AND TRIANGULAR WINGS OF VARIOUS ASPECT RATIOS AT MACH NUMBER OF 1.50 AND 2.02 by Jack N. Nielsen, Elliott D. Katzen, and Kenneth K. Tang, 1950, NACA TN No. 3795.

National Advisory Committee for Aeronautics, WING-BODY INTERFERENCE AT SUPERSONIC SPEEDS WITH AN APPLICATION TO COMBINATIONS WITH RECTANGULAR WINGS by Jack N. Nielsen and William C. Pitts, 1952, NACA TN No. 2677.

Prepared by: Ross G. Luce
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (A-6) Free-Flight Determination of Skin-Friction in the Presence of Severe Aerodynamic Heating Associated with Turbulent Boundary Layer

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Body Drag Estimates/Configuration

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event is a study of the skin-friction associated with severe aerodynamic heating. A theoretical model is developed based on experimental data.
   b. Relationship to Contemporary Science and Technology: At the time of this event a better understanding of skin-friction associated with high heating rates was required.
   c. Relationship to Succeeding Development or to System Performance: The results of this event were used in the development of LANCE in estimating total drag.

6. Type of RXD Event: Research

7. Key Technical Personnel: S. C. Sommer; B. J. Short

8. Date of Event:

   a. Termination: 1954
   b. Initiation: Unknown

9. Duration: Probably one-year program

10. Organization: NACA

11. Organization Type: Government Laboratory

12. Financial Support: Unknown

13. System Interface Activity:

a. Contemporary and Succeeding Activity: This event still provides valid data usable in the analysis of current systems.

b. Previous Activity: Studies performed by Rubesin and Van Driest, included as events A-7 and A-8, were used in this event to obtain a theoretical understanding of the problem.

14. RXD Event Circumstances: Fundamental research prior to LANCE motivated by data needs.

15. Sources:

National Advisory Committee for Aeronautics, FREE-FLIGHT MEASUREMENTS OF TURBULENT-BOUNDARY-LAYER SKIN FRICTION IN THE PRESENCE OF SEVERE AERODYNAMIC HEATING AT MACH NUMBERS FROM 2.8 TO 7.0 by Simon C. Sommer and Barbara J. Short, 1954, NACA TN No. 3391.

Prepared by: Ross G. Luce Date: 9 January 1967
Battelle Memorial Institute

RXD Event Description

1. Title: (A-7) Development of a Theoretical Model to Predict Laminar Boundary Layer Skin Friction With Heat Transfer and Zero Pressure Gradient

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Body Drag Prediction

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event was a theoretical study to develop a model to predict laminar boundary layer skin friction with heat transfer and zero pressure gradient.
   b. Relationship to Contemporary Science and Technology: When this event occurred, there was a general need for the basic understanding of boundary layer phenomenon and the associated skin friction.
   c. Relationship to Succeeding Development or to System Performance: The results of this event were used in event A-6 for a theoretical definition of the problem.

6. Type of RXD Event: Research

7. Key Technical Personnel: M. W. Rubesin, H. A. Johnson

8. Date of Event:

   a. Termination: 1949
   b. Initiation: -

9. Duration: Unknown

10. Organization: NACA

11. Organization Type: Government Laboratory
    University

12. Financial Support: Unknown

13. System Interface Activity:

   a. Contemporary and Succeeding Activity: This event has been used in succeeding studies as a thoeretical model for determining skin friction associated with laminar boundary layers.
   b. Previous Activity: Unknown

14. RXD Event Circumstances: Fundamental research prior to LANCE

15. Sources:

M. W. Rubesin and H. A. Johnson, A CRITICAL REVIEW OF SKIN-FRICTION AND HEAT-TRANSFER SOLUTIONS OF THE LAMINAR BOUNDARY LAYER OF A FLAT PLATE, Transactions of the ASME, 1949.

Prepared by: Ross G. Luce
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (A-8) Development of Theoretical Methods to Determine Characteristics of Turbulent Boundary Layers

2. Weapon System: LANCE

3. Subsystem: Aerodynamic Configuration

4. Element: Body Drag Estimates/Configuration

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event is a general study of methods to determine the characteristics of turbulent boundary layers.
   b. Relationship to Contemporary Science and Technology: At the time of this event, more information regarding the theoretical modeling of turbulent boundary layers was needed.
   c. Relationship to Succeeding Development or to System Performance: The results of this event were used by Sommer and Short in event A-6 for the development of a theoretical model. Event A-6 made a more direct contribution to LANCE studies.

6. Type of RXD Event: Research

7. Key Technical Personnel: E. R. Van Driest

8. Date of Event:

   a. Termination: 1951
   b. Initiation: 1949

9. Duration: 2 years

10. Organization: North American Aviation, Aerophysics Laboratory

11. Organization Type: Industrial (Profit)

12. Financial Support: Unknown

13. System Interface Activity:

a. Contemporary and Succeeding Activity: These methods are still a valid basis for boundary layer analysis.
b. Previous Activity: Unknown

14. RXD Event Circumstances: Fundamental research prior to LANCE

15. Sources:

E. R. Van Driest, TURBULENT BOUNDARY LAYER IN COMPRESSIBLE FLUIDS, Journal of the Aeronautical Sciences, March 1951.

North American Aviation, Aerophysics Laboratory, THE TURBULENT BOUNDARY LAYER FOR COMPRESSIBLE FLUIDS ON AN INSULATED FLAT PLATE by E. R. Van Driest, 15 September 1949, AL-958.

North American Aviation, Aerophysics Laboratory, THE TURBULENT BOUNDARY LAYER FOR COMPRESSIBLE FLUIDS ON A FLAT PLATE WITH HEAT TRANSFER by E. R. Van Driest, 27 January 1950, AL-997.

Prepared by: Ross G. Luce
Battelle Memorial Institute
Date: 9 January 1967

Appendix B

GUIDANCE AND CONTROL

RXD Event Description

1. Title: (C-1) Formulation of Quantum Theory

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various solid-state devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of the conception and formulation of the quantum theory.
   b. Relationship to Contemporary Science and Technology: The quantum theory made it possible to explain thermal radiation from a blackbody and other phenomena which could not be handled by classical physics at that time.
   c. Relationship to Succeeding Development or to System Performance: Concepts embodied in the quantum theory were fundamental to development of semiconductor devices used in LANCE. It was central to a good theory of semiconduction.

6. Type of RXD Event: Research

7. Key Technical Personnel: Max Planck (German)

8. Date of Event:

   a. Termination: 1900
   b. Initiation: Unknown

9. Duration: Unknown

10. Organization: University of Berlin

11. Organization Type: University

RXD Event Description

1. Title: (C-2) Formulation of Theory of Photoelectric Effect

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various solid-state devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of using quantum theoretical principles to explain the photoelectric effect.
   b. Relationship to Contemporary Science and Technology: This theory was completely at odds with contemporary science in that it attributed corpuscular properties to light, which was considered purely a wave phenomenon.
   c. Relationship to Succeeding Development or to System Performance: This event was required for a complete theory of semiconductors, since photoelectric effect is a basic property of semiconductors.

6. Type of RXD Event: Research

7. Key Technical Personnel: Albert Einstein

8. Date of Event: 1905

   a. Termination: 1905
   b. Initiation: 1904 or 1905

9. Duration: Unknown

10. Organization: Individual (at this time, Einstein was working as an examiner in the Swiss Patent Office in Zurich.)

11. Organization Type: Individual

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

Max Born, ATOMIC PHYSICS, Fifth Edition, New York, Hafner Publishing Company, circa 1952.

Prepared by: R. J. Conlon
Battelle Memorial Institute Date: 19 December 1966

RXD Event Description

1. Title: (C-3) Experimental Verification of Einstein's Photoelectric Equation

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various solid-state devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: By means of precise experiments, this event validated Einstein's photoelectric equation.
   b. Relationship to Contemporary Science and Technology: Since Einstein's explanation of photoelectric effect was purely theoretical, and existing experimental data were not at all precise, this event established the correctness of a revolutionary concept.
   c. Relationship to Succeeding Development or to System Performance: This event enabled theoretical physicists to use the Einstein relationship with confidence and contributed to understanding of semiconductor phenomena.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: Robert Millikan

8. Date of Event:

   a. Termination: 1916
   b. Initiation:

9. Duration: Unknown

10. Organization: University of Chicago

11. Organization Type: University Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Unknown
Exploratory development prior to LANCE

15. Sources:

R. A. Millikan, A DIRECT PHOTOELECTRIC DETERMINATION OF A PLANCK'S "h", *Physical Review*, Vol. 7, No. 10, 1916, pp. 355-388.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 20 December 1966

RXD Event Description

1. Title: (C-4) Discovery of Nuclear Theory of the Atom

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various solid-state devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of formulation of an atomic theory which stated that the positive charge of the atom is concentrated in a nucleus of very small diameter with respect to overall atomic dimensions.
   b. Relationship to Contemporary Science and Technology: This event was in conflict with more widely held views that the positive charge was distributed.
   c. Relationship to Succeeding Development or to System Performance: A correct concept of a nuclear atom was required before semiconductor behavior could be understood and explained.

6. Type of RXD Event: Research

7. Key Technical Personnel: E. Rutherford (English)

8. Date of Event:

   a. Termination: 1911
   b. Initiation:

9. Duration: Unknown

10. Organization: Manchester University

11. Organization Type: University Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

F. K. Richtmyer and E. H. Kennard, INTRODUCTION TO MODERN PHYSICS, Fourth Edition, New York, McGraw-Hill Book Company, Inc., 1947.

Prepared by: R. J. Conlon
Battelle Memorial Institute Date: 20 December 1966

RXD Event Description

1. Title: (C-5) Verification of Nuclear Atomic Model by α - scattering Experiments

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: By passing stream of α - particles through gold and silver foil of various thicknesses and observing the number of scintillations caused on a ZnS screen at various angles, Rutherford's atomic model was verified.

   b. Relationship to Contemporary Science and Technology: Early (1909, 1910) experiments suggested Rutherford's model; later ones confirmed it.

   c. Relationship to Succeeding Development or to System Performance: This event verified the nuclear theory of the atom. This was critical for later theoretical developments.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: H. Geiger (English)
   E. Marsden (English)

8. Date of Event:

   a. Termination: 1913
   b. Initiation: 1909

9. Duration: About four years

10. Organization: Manchester University

11. Organization Type: University Laboratory

12. Financial Support: Maybe about four man-years

13. System Interface Activity: None (See Item 9)

a. Contemporary and Succeeding Activity:

b. Previous Activity:

14. RXD Event Circumstances: Unknown. Exploratory development prior to LANCE

15. Sources:

F. K. Richtmyer and E. H. Kennard, INTRODUCTION TO MODERN PHYSICS, Fourth Edition, New York, McGraw-Hill Book Company, Inc., 1947.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 20 December 1966

RXD Event Description

1. Title: (C-6) Formulation of Model of Hydrogen Atom Based on Quantum Principles

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event applied quantum principles to atomic theory by assuming quantum states for electron orbits of the hydrogen atom.
   b. Relationship to Contemporary Science and Technology: Classical physics could not deal with Rutherford's nuclear model of the atom since it could not prove both mechanical and electromagnetic stability simultaneously.
   c. Relationship to Succeeding Development or to System Performance: This event was instrumental in explaining atomic structure and behavior and was a prelude to later concepts developed in quantum mechanics.

6. Type of RXD Event: Research

7. Key Technical Personnel: Niels Bohr (Danish). Bohr worked under Rutherford in 1912 before returning to Denmark.

8. Date of Event:

   a. Termination: 1913
   b. Initiation: -

9. Duration: Unknown

10. Organization: University of Copenhagen

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

F. K. Richtmyer and E. H Kennard, INTRODUCTION TO MODERN PHYSICS, Fourth Edition, New York, McGraw-Hill Book Company, Inc., 1947.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 20 December 1966

RXD Event Description

1. Title: (C-7) Postulation That Matter Particles Should Possess Wave Properties

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the suggestion of Prince Louis de Broglie that natural symmetry demands that particles should possess wave properties since radiant energy had been shown to have corpuscular properties.
   b. Relationship to Succeeding Development or to System Performance: This event led to the formulation of quantum mechanics, which is needed for understanding the behavior of semiconductor materials and devices.

6. Type of RXD Event: Research

7. Key Technical Personnel: Louis de Broglie (French)

8. Date of Event:

   a. Termination: 1924
   b. Initiation: -

9. Duration: Unknown

10. Organization: Unknown. Work done in France.

11. Organization Type: Unknown

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

   a. Contemporary and Succeeding Activity:
   b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE.

15. Sources:

F. K. Richtmyer and E. H. Kennard, INTRODUCTION TO MODERN PHYSICS, Fourth Edition, New York, McGraw-Hill Book Company, Inc., 1947.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 20 December 1966

RXD Event Description

1. Title: (C-8) Experimental Verification of Wave Properties of Electrons by Means of Electron Diffraction Experiments

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of illuminating a single crystal of nickel with a stream of low-voltage electrons: diffraction curves plotted from the data of these experiments yielded results predicted by de Broglie.
   b. Relationship to Contemporary Science and Technology: This event verified de Broglie's hypothesis that matter particles have wave properties.
   c. Relationship to Succeeding Development or to System Performance: This event permitted physicists to have confidence in existence of wave properties of electrons.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: C. Davisson and L H. Germer

8. Date of Event:

   a. Termination: 1927
   b. Initiation:

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

a. Contemporary and Succeeding Activity
b. Previous Activity:

14. RXD Event Circumstances: Unknown. Exploratory development prior to LANCE

15. Sources:

C. Davisson and L. H. Germer, DIFFRACTION OF ELECTRONS BY A CRYSTAL OF NICKEL, Physical Review, Vol. 30, No. 6, 1927, pp. 705-740.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 20 December 1966

RXD Event Description

1. Title: (C-9) Discovery of Fundamental Equation of Quantum Mechanics

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of the discovery of the wave equation which mathematically expresses Bohr's quantum state model of the atom as modified by de Broglie's hypothesis.
   b. Relationship to Contemporary Science and Technology: This event tied together several topics in a mathematically significant way and introduced probability concepts to determination of particle position and momentum.
   c. Relationship to Succeeding Development or to System Performance: This event was necessary for the orderly development of theories of metals and semiconductors.

6. Type of RXD Event: Research

7. Key Technical Personnel: E. Schrödinger (Austrian)

8. Date of Event:

   a. Termination: 1925
   b. Initiation: -

9. Duration: Unknown

10. Organization: University of Zurich

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

William Wilson, A HUNDRED YEARS OF PHYSICS, London, Gerald Duckworth and Company, Limited, 1950.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 21 December 1966

RXD Event Description

1. Title: (C-10) Discovery of the Exclusion Principle

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of the postulation that no two electrons in an atom can be in an identical quantum state.
   b. Relationship to Contemporary Science and Technology:
   c. Relationship to Succeeding Development or to System Performance: This event permitted development of an approximate theory of many-electron atoms.

6. Type of RXD Event: Research

7. Key Technical Personnel: W. Pauli (Austrian)

8. Date of Event:

   a. Termination: 1925
   b. Initiation: -

9. Duration: Unknown

10. Organization: University of Hamburg

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. <u>Sources:</u>

William Wilson, A HUNDRED YEARS OF PHYSICS, London, Gerald Duckworth and Company, Limited, 1950.

<u>Prepared by:</u> R. J. Conlon
Battelle Memorial Institute

<u>Date:</u> 21 December 1966

RXD Event Description

1. Title: (C-11) Formulation of Statistics Valid for Particles Obeying Pauli's Exclusion Principle

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Orgin, Technical Activity, and Outcome: This event resulted in formulation of a type of statistics, different from Maxwellian and Bose-Einstein statistics, which took into account the Pauli exclusion principle.
   b. Relationship to Contemporary Science and Technology: Contemporary statistics were incapable of describing the behavior of particles subject to the Pauli exclusion principle.
   c. Relationship to Succeeding Development or to System Performance: This event made possible an analytical treatment of the manner in which electrons move in metals and semiconductors. Thus, it was necessary before a valid theory of semiconductors could be formulated.

6. Type of RXD Event: Research

7. Key Technical Personnel: P. A. M. Dirac (England)
   E. Fermi (Italy)

8. Date of Event:

   a. Termination: 1926
   b. Initiation: -

9. Duration: Unknown

10. Organization: Cambridge University
    University of Florence

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

Max Born, ATOMIC PHYSICS, Fifth Edition, New York, Hafner Publishing Company, circa 1952.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 21 December 1966

RXD Event Description

1. Title: (C-12) Conception of Theory of Metals Using Concepts of Quantum Mechanics

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event was the first successful application of quantum mechanics to a theory of electrons in metals using the Pauli exclusion principle and Fermi-Dirac statistics.
   b. Relationship to Contemporary Science and Technology: Prior to this event, contemporary theories of metals could not explain some experimentally observed properties of metals such as specific heat.
   c. Relationship to Succeeding Development or to System Performance: This event was one of the starting points used by Wilson (see event C-13) in formulating his successful theory of semiconductors.

6. Type of RXD Event: Research

7. Key Technical Personnel: A. Sommerfeld (German)

8. Date of Event:

   a. Termination: 1928
   b. Initiation: -

9. Duration: Unknown

10. Organization: University of Munich

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

Stanley Raines, THE WAVE MECHANICS OF ELECTRONS IN METALS, New York, Interscience Publishers, Inc., 1961.

Frederick Seitz, THE MODERN THEORY OF SOLIDS, New York, McGraw-Hill Book Company, Inc., 1940.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 21 December 1966

RXD Event Description

1. Title: (C -13) Modern Theory of Semiconductors

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: This event consists of formulation of a theory of semiconductors which was sufficient to explain all observed phenomena.
    b. Relationship to Contemporary Science and Technology: Sommerfeld (event C-12) and Bloch had forwarded theories of metallic conduction which could not be applied to semiconductors because of their inability to cope with temperature coefficient of resistance.
    c. Relationship to Succeeding Development or to System Performance: Much succeeding work in the development of semiconductor theory, materials, and devices was based on this event and refinement of Wilson's theory.

6. Type of RXD Event: Research

7. Key Technical Personnel: A. H. Wilson (English)

8. Date of Event:

    a. Termination: 1931
    b. Initiation: -

9. Duration: Unknown

10. Organization: Cambridge University

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

A. H. Wilson, THE THEORY OF CRYSTAL RECTIFIERS, Proceedings of the Royal Society of London, Vol. 171, 1939, pp. 27-38.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 22 December 1966

RXD Event Description

1. Title: (C-14) Theories of Rectification at a Metal-Semiconductor Junction

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the concurrent publication of three theories of recitification at metal-semiconductor junctions.
   b. Relationship to Contemporary Science and Technology: Contemporary theories of rectification explained the phenomenon by the "tunnel" effect; this resulted in prediction of current flow in the wrong direction.
   c. Relationship to Succeeding Development or to System Performance: This event was important to a correct theoretical understanding of this type of junction.

6. Type of RXD Event: Research

7. Key Technical Personnel: N. F. Mott (English)
   W. Schottky (German)
   B. Davydov (Russian)

8. Date of Event:

   a. Termination: 1939
   b. Initiation: -

9. Duration: Unknown

10. Organization: Bristol University (Mott)
    Other affiliations unknown

11. Organization Type: University

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

N. F. Mott, THE THEORY OF CRYSTAL RECTIFIERS, Proceedings of the Royal Society of London, Vol. 171, 1939, pp. 27-38.

J. Joffe, SCHOTTKY'S THEORIES OF DRY SOLID RECTIFIERS, Electrical Communication, Vol. 22, No. 3, 1945, pp. 217-225.

G. L. Pearson and W. H. Brattain, HISTORY OF SEMICONDUCTOR RESEARCH, Proceedings of the IRE, Vol. 43, No. 12, 1955, pp. 1794-1806.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 22 December 1966

RXD Event Description

1. Title: (C-15) Investigation of Point-Contact Silicon Diodes as Detectors of Microwave Energy

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: This event consists of development of silicon detectors for microwave energy.
    b. Relationship to Contemporary Science and Technology: Vacuum tube detectors were not adequate as higher frequencies were being experimented with.
    c. Relationship to Succeeding Development or to System Performance: This event proved the praticality of silicon rectifiers for use as detectors at radar frequencies.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: R. S. Ohl

8. Date of Event:

    a. Termination: 1940
    b. Initiation: 1934

9. Duration: About 6 years

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown (See Item 5)

13. System Interface Activity: None

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Exploratory development on solid-state devices prior to LANCE

15. Sources:

J. H. Scaff and R. S. Ohl, DEVELOPMENT OF SILICON CRYSTAL RECTIFIERS FOR MICROWAVE RADAR RECEIVERS, Bell System Technical Journal, Vol. 26, No. 1, 1947, pp. 1-30.

Prepared by: R. J. Conlon
Battelle Memorial Institute Date: 23 December 1966

RXD Event Description

1. Title: (C-16) Investigation of Metallurgy of Silicon

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consisted of research into purifying silicon and producing silicon with controlled amounts of impurities. One result of this work was generation of a p-n junction.
   b. Relationship to Contemporary Science and Technology: Because of large amounts of impurities in commercially available silicon, many of its semiconducting properties were obscured and not understood.
   c. Relationship to Succeeding Development or to System Performance: This event provided background for later preparation of ultrapure semiconductor materials.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. H. Scaff
   H. C. Theurer

8. Date of Event:

   a. Termination: 1941
   b. Initiation: 1934

9. Duration: About 7 years

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

a. Contemporary and Succeeding Activity:

b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

G. L. Pearson and W. H. Brattain, HISTORY OF SEMICONDUCTOR RESEARCH, Proceedings of the IRE, Vol. 43, No. 12, 1955, pp. 1794-1806.

Prepared by: R. J. Conlon
Battelle Memorial Institute Date: 23 December 1966

RXD Event Description

1. Title: (C-17) Theory of Space-Charge Layer at Semiconductor Surface

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the postulation of special surface energy states at the surface of a semiconductor to explain the space-charge layer at the surface.
   b. Relationship to Contemporary Science and Technology: Contemporary theory could not adequately explain all aspects of metal-semiconductor junction rectification.
   c. Relationship to Succeeding Development or to System Performance: The understanding born of this event led the way to invention of the transistor and of the semiconductor devices used in LANCE.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. Bardeen

8. Date of Event:

   a. Termination: 1947
   b. Initiation: 1947

9. Duration: N/A - Innovative period

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

   a. Contemporary and Succeeding Activity:
   b. Previous Activity:

14. RXD Event Circumstances: Unknown. Innovation or postulation of theory.

15. Sources:

J. Bardeen, SURFACE STATES AND RECTIFICATION AT A METAL TO SEMICONDUCTOR CONTACT, Physical Review, Vol. 72, 1947, pp. 717-727.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 23 December 1966

RXD Event Description

1. Title: (C-18) Experimental Proof of Existence of a Space-Charge Layer at Semiconductor Surface

2. Weapon System: LANCE

3. Subsystem: Guidance & Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of an experiment, successfully performed, to validate the theory of event C-17.
   b. Relationship to Contemporary Science and Technology: The theory had been advanced; this event proved it to be valid.
   c. Relationship to Succeeding Development or to System Performance: Validation of event C-17 helped lead the way to invention of the transistor.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: W. H. Brattain
   W. Shockley

8. Date of Event:

   a. Termination: 1948
   b. Initiation: 1948

9. Duration: Probably about a month

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. Underlined: RXD Event Circumstances: Unknown. Exploratory development prior to LANCE

15. Sources:

W. H. Brattain and W. Shockley, DENSITY OF SURFACE STATES DEDUCED FROM CONTACT POTENTIAL MEASUREMENTS, Physical Review, Vol. 72, 1947, p. 345.

W. H. Brattain, EVIDENCE FOR SURFACE STATES FROM CHANGE IN CONTACT POTENTIAL ON ILLUMINATION, Physical Review, Vol. 72, 1947, p. 345.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 23 December 1966

RXD Event Description

1. Title: (C-19) Invention of the Point-Contact Transistor

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the invention of the point-contact transistor.
   b. Relationship to Contemporary Science and Technology: This event was the natural outgrowth of contemporary science and technology at BTL.
   c. Relationship to Succeeding Development or to System Performance: This event made possible the semi-conductor devices used in LANCE.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. Bardeen, W. H. Brattain

8. Date of Event:

   a. Termination: 1948
   b. Initiation: 1948

9. Duration: N/A

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Research innovation prior to LANCE

15. Sources:

J. Bardeen and W. H. Brattain, THE TRANSISTOR, A SEMI-CONDUCTOR TRIODE, Physical Review, Vol. 74, 1948, pp. 230-231.

Prepared by: R. J. Conlon
Battelle Memorial In.titute

Date: 23 December 1966

RXD Event Description

1. Title: (C-20) Formulation of Theory of the Point-Contact Transistor

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in LANCE G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of generation of a theory to explain operation of the point-contact transistor.
   b. Relationship to Contemporary Science and Technology: This event was a result of the close contact between theoretical and practical branches of the field at this particular time.
   c. Relationship to Succeeding Development or to System Performance: This event contributed to understanding of the transistor action and was of value in later work.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. Bardeen, W. H. Brattain

8. Date of Event:

   a. Termination: 1949
   b. Initiation: 1948

9. Duration: One year

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None

    a. Contemporary and Succeeding Activity
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE. Formulative period of new theory.

15. Sources:

J. Bardeen and W. H. Brattain, PHYSICAL PRINCIPLES INVOLVED IN TRANSISTOR ACTION, *Physical Review*, Vol. 75, pp. 1208-1225.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 23 December 1966

RXD Event Description

1. Title: (C-21) Formulation of Theory of p-n Junction and p-n Junction Transistors

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of discovery and formulation of a theory explaining phenomena occurring at a p-n junction including transistor operation of such a junction.
   b. Relationship to Contemporary Science and Technology: This event was a logical result of the contemporary effort at BTL.
   c. Relationship to Succeeding Development or to System Performance: Discovery of this theory led to construction of n-p-n and p-n-p junction transistors.

6. Type of RXD Event: Research

7. Key Technical Personnel: W. Shockley

8. Date of Event:

   a. Termination: 1949
   b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown.

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

W. Shockley, THE THEORY OF p-n JUNCTIONS IN SEMICONDUCTORS AND p-n JUNCTION TRANSISTORS, Bell System Technical Journal, Vol. 28, 1949, pp. 435-489.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 27 December 1966

RXD Event Description

1. Title: (C-22) Invention of Junction Transistor

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of invention of the junction transistor.
   b. Relationship to Contemporary Science and Technology: This event was in the main stream of contemporary activity at BTL.
   c. Relationship to Succeeding Development or to System Performance: This event was a necessary occurrence for junction transistors to be available for LANCE.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: W. Shockley, M. Sparks, G. K. Teal

8. Date of Event:

   a. Termination: 1951
   b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Exploratory development prior to LANCE

15. Sources:

W. Shockley, M. Sparks, and G. K. Teal, p-n JUNCTION TRANSISTORS, Physical Review, Vol. 83, 1951, pp. 151-162.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 27 December 1966

RXD Event Description

1. Title: (C-23) Laboratory Demonstration of Field Effect

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Field-effect transistors used in LANCE

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the laboratory demonstration of modulating the conductivity of a thin semiconductor sample which was thin enough that the space-charge layer was a significant portion of the thickness.
   b. Relationship to Contemporary Science and Technology: This experiment was done in an attempt to gain further understanding of semiconductor surface properties before the occurrence of event C-18.
   c. Relationship to Succeeding Development or to System Performance: This event led to a theory of a field-effect transistor.

6. Type of RXD Event: Research

7. Key Technical Personnel: G. L. Pearson

8. Date of Event:

   a. Termination: 1948
   b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory (Profit)

12. Financial Support: Unknown

13. System Interface Activity: None. (See Item 5)

   a. Contemporary and Succeeding Activity:
   b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

W. Shockley and G. L. Pearson, MODULATION OF CONDUCTANCE OF THIN FILMS OF SEMICONDUCTORS BY SURFACE CHANGES, Physical Review, Vol. 74, 1948, pp. 232-233.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 27 December 1966

RXD Event Description

1. Title: (C-24) Theory of Field-Effect Transistor

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Field-effect transistors used in LANCE

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of development of a theory utilizing the field effect in a manner to produce transistor action.
   b. Relationship to Contemporary Science and Technology: This event resulted from interest in using the field effect in state-of-the-art applications.
   c. Relationship to Succeeding Development or to System Performance: This event let to invention of the field-effect transistor and its subsequent use in LANCE in state-of-the-art applications.

6. Type of RXD Event: Research

7. Key Technical Personnel: W. Shockley

8. Date of Event:

   a. Termination: 1952
   b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

W. Shockley, A UNIPOLAR "FIELD EFFECT" TRANSISTOR, Proceedings of the IRE, Vol. 40, 1952, pp. 1365-1376.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 27 December 1966

RXD Event Description

1. Title: (C-25) Invention of Field-Effect Transistor

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Field-Effect transistors used in LANCE

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of invention and fabrication of a field-effect transistor with high input impedance and current gain.
   b. Relationship to Contemporary Science and Technology: This event had been predicted by Shockley (event C-24).
   c. Relationship to Succeeding Development or to System Performance: This event demonstrated operation of the field-effect transistor (FET) and led to development of those FET's and uses considered to be state of the art by the start of the LANCE program.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: G. C. Dacey and I. M. Ross

8. Date of Event:

   a. Termination: 1953
   b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

   a. Contemporary and Succeeding Activity:
   b. Previous Activity:

14. RXD Event Circumstances: Unknown. Exploratory development of devices used in LANCE, prior to LANCE program.

15. Sources:

G. C. Dacey and I. M. Ross, UNIPOLAR "FIELD EFFÊCT" TRANSISTOR, *Proceedings of the IRE,* Vol. 41, 1953, pp. 970-979.

Prepared by: R. J. Conlon
Battelle Memorial Institute Date: 28 December 1966

RXD Event Description

1. Title: (C-26) Invention of Mesa Transistor

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Those mesa transistors used in the LANCE system

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: This event consists of the mesa transistor, which had the capability of functioning at higher frequencies than other transistors at the time.
    b. Relationship to Contemporary Science and Technology: Contemporary transistors were limited by cutoff frequencies of about 100 Mc. This event resulted in devices with cutoff frequencies above 100 Mc and promised up to 1000 Mc.
    c. Relationship to Succeeding Development or to System Performance: This event led to development of devices and techniques that could be used in LANCE as state of the art.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: M. Tanenbaum, D. E. Thomas, C. A. Lee

8. Date of Event:

    a. Termination: 1956
    b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

   a. Contemporary and Succeeding Activity:
   b. Previous Activity:

14. RXD Event Circumstances: Unknown. Exploratory development of devices used in LANCE prior to LANCE program.

15. Sources:

Charles A. Lee, A HIGH-FREQUENCY DIFFUSED BASE GERMANIUM TRANSISTOR, Bell System Technical Journal, Vol. 35, 1956, pp. 1-22.

M. Tanenbaum and D. E. Thomas, DIFFUSED EMITTER AND BASE SILICON TRANSISTORS, Bell System Technical Journal, Vol. 35, 1956, pp. 1-22.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 28 December 1966

RXD Event Description

1. Title: (C-27) Research in Materials and Devices for Radar Detection

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of R & D work sponsored during World War II by NDRC at various industrial and university laboratories.
   b. Relationship to Contemporary Science and Technology: At the start of World War II, silicon had proven to be an acceptable detector of microwave frequencies. NDRC set up a massive program to investigate properties of Si and Ge and to develop new and better devices.
   c. Relationship to Succeeding Development or to System Performance: Without the impetus which this event provided in funding, training of personnel, expansion of laboratory facilities, etc., it is doubtful that normal research into semiconductor devices would have yielded results in a timely enough fashion to benefit LANCE.

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: F. Seitz; K. Lark-Horovitz; V. Johnson; H. Torrey; C. Whitmer; R. Ohl

8. Date of Event:

   a. Termination: 1945
   b. Initiation: 1941

9. Duration: About 4 years

10. Organization: University of Pennsylvania; BTL; Purdue University; MIT; Sperry Gyroscope Company; GE

11. <u>Organization Type:</u> University Laboratories
Industrial Laboratories

12. <u>Financial Support:</u> Many millions of dollars

13. <u>System Interface Activity:</u> None (See Item 5)

    a. Contemporary and Succeeding Activity
    b. Previous Activity:

14. <u>RXD Event Circumstances:</u> Unknown. Broad-based work on solid-state materials used in LANCE

15. <u>Sources:</u>

Henry Torrey and Charles A. Whitmer, CRYSTAL RECTIFIERS, New York, McGraw-Hill Book Company, Inc., 1948.

<u>Prepared by:</u> R. J. Conlon
Battelle Memorial Institute

<u>Date:</u> 28 December 1966

RXD Event Description

1. Title: (C-28) Investigation of Various Properties of Germanium

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: This event consists of research into determining basic properties and behavior of germanium.
    b. Relationship to Contemporary Science and Technology: This effort was started in World War II and continued when it looked probable that semiconductors would assume an increasingly important role in the future.
    c. Relationship to Succeeding Development or to System Performance: Much basic information which was relied upon by the theoreticians and inventors at BTL was generated during the course of this effort.

6. Type of RXD Event: Research

7. Key Technical Personnel: K. Lark-Horovitz; V. A. Johnson; H. M. James; H. Y. Fan; S. Benzer

8. Date of Event:

    a. Termination: 1952
    b. Initiation: 1941

9. Duration: 11 years

10. Organization: Purdue University

11. Organization Type: University Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown

15. Sources:

THE NEW ELECTRONICS by Karl Lark-Horovitz, The Present State of Physics, Arranged by Frederick S. Brackett, American Association for the Advancement of Science, Washington, D.C., 1954, pp. 57-127.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 29 December 1966

RXD Event Description

1. Title: (C-29) Experimental Growing of Large Crystals by the "Pulling" Technique

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the experimental growth of large single crystals of germanium and silicon by means of the pulling technique.
   b. Relationship to Contemporary Science and Technology: This technique enabled crystals of low impurity content to be grown. In addition, these crystals had near-perfect lattice structure.
   c. Relationship to Succeeding Development or to System Performance: This technique led to growth of p-n junctions by pulling; this type of junction was used in the first junction transistors.

6. Type of RXD Event: Research

7. Key Technical Personnel: G. K. Teal; J. B. Little; E. Buehler

8. Date of Event:

   a. Termination: 1952
   b. Initiation: 1948

9. Duration: 4-year emphasis period

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None

a. Contemporary and Succeeding Activity:

b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

G. K. Teal and J. B. Little, GROWTH OF GERMANIUM SINGLE CRYSTALS, Physical Review, Vol. 78, 1950, p. 647.

G. K. Teal and E. Buehler, GROWTH OF SILICON SINGLE CRYSTALS AND OF SINGLE CRYSTAL SILICON p-n JUNCTIONS, Physical Review, Vol. 87, 1952, p. 190.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 28 December 1966

RXD Event Description

1. Title: (C-30) Development of Alloy Technique for Growing p-n Junctions

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the invention of the alloy technique for growing semiconductor junctions for rectifiers and transistors.
   b. Relationship to Contemporary Science and Technology: The pulling technique resulted in fairly linear distribution of impurities; the alloy technique permitted nonlinear placement of impurities and different device geometries and characteristics.
   c. Relationship to Succeeding Development or to System Performance: This event presaged later development of the diffusion technique (event C-32).

6. Type of RXD Event: Research

7. Key Technical Personnel: W. C. Dunlap; R. N. Hall; J. S. Saby

8. Date of Event:

   a. Termination: 1950
   b. Initiation: -

9. Duration: Unknown

10. Organization: GE

11. Organization Type: Industrial

12. Financial Support: Unknown

13. System Interface Activity: None

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

R. N. Hall and W. C. Dunlap, p-n JUNCTIONS PREPARED BY IMPURITY DIFFUSION, Physical Review, Vol. 80, 1950, pp. 467-468.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 28 December 1966

RXD Event Description

1. Title: (C-31) Invention of Zone-Refining Techniq...

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the invention of the zone-refining technique for producing semiconductor material of extremely low impurity, about 1 part in 10^9.
   b. Relationship to Contemporary Science and Technology: Other contemporary techniques could not produce semiconductor materials with this low an impurity level. As a result, new techniques became possible.
   c. Relationship to Succeeding Development or to System Performance: This event made possible standard transistor manufacturing techniques which were in use at the start of the LANCE program.

6. Type of RXD Event: Research

7. Key Technical Personnel: W. G. Pfann

8. Date of Event:

   a. Termination: 1952
   b. Initiation: -

9. Duration: Unknown

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

Richard L. Petritz, CONTRIBUTIONS OF MATERIALS TECHNOLOGY TO SEMICONDUCTOR DEVICES, Proceedings of the IRE, Vol. 50, 1962, pp. 1025-1038.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 28 December 1966

RXD Event Description

1. Title: (C-32) Research on Diffusion Processes for Semiconductor Materials

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of basic research conducted on diffusion processes.
   b. Relationship to Contemporary Science and Technology: Neither grown-junction nor alloyed transistors could be fabricated with narrow enough base regions or small enough junctions to permit practical transistor performance at very high frequencies.
   c. Relationship to Succeeding Development or to System Performance: This event led to the ability to form base regions only a fraction of a micron thick. In addition, the process is more adaptable to mass production manufacturing and led to the mesa transistors which were state of the art at the start of the LANCE program.

6. Type of RXD Event: Research

7. Key Technical Personnel: W. C. Dunlap (GE)
   C. S. Fuller (BTL)

8. Date of Event:

   a. Termination: 1956
   b. Initiation: 1950

9. Duration: 6-year emphasis period

10. Organization: GE
    BTL

11. Organization Type: Industrial Laboratories

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Sources:

Richard L. Petritz, CONTRIBUTIONS OF MATERIALS TECHNOLOGY TO SEMICONDUCTOR DEVICES, Proceedings of the IRE, Vol. 50, 1962, pp. 1025-1038.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 29 December 1966

RXD Event Description

1. Title: (C-33) Invention of Planar Manufacturing Process

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of the planar process for fabricating transistors with stable surface characteristics.

   b. Relationship to Contemporary Science and Technology: This event produced a superior method for fabrication of transistors with extremely low leakage currents and good current gain at low values of current.

   c. Relationship to Succeeding Development or to System Performance: Most of the transistors used in LANCE were manufactured by the planar process. Good reliability and stable operation are characteristics of silicon planar transistors.

6. Type of RXD Event: Research

7. Key Technical Personnel: J. Hoerni

8. Date of Event:

   a. Termination: 1959

   b. Initiation: -

9. Duration: Unknown

10. Organization: Fairchild Transistor Corporation

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

   a. Contemporary and Succeeding Activity:

   b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE program.

15. Sources:

Richard L. Petritz, CONTRIBUTIONS OF MATERIALS TECHNOLOGY TO SEMICONDUCTOR DEVICES, Proceedings of the IRE, Vol. 50, 1962, pp. 1025-1038.

J. A. Hoerni, SEMICONDUCTOR DEVICE, U.S. Patent 3,064,167, 13 November 1962.

Prepared by: R. J. Conlon
Battelle Memorial Institute

Date: 29 December 1966

RXD Event Description

1. Title: (C-34) Research on Epitaxial Growth of Crystals

2. Weapon System: LANCE

3. Subsystem: Guidance and Control

4. Element: Various semiconductor devices used in G & C electronics

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: This event consists of research into epitaxial growth of crystals from the gas phase with controlled, final impurity levels.
   b. Relationship to Contemporary Science and Technology: This event permitted fabrication of mesa transistors with low collector series resistance. This was not possible with other, standard techniques.
   c. Relationship to Succeeding Development or to System Performance: This event permitted development of planar epitaxial transistors in time to be included in LANCE.

6. Type of RXD Event: Research

7. Key Technical Personnel: H. Christenson; G. K. Teal; H. H. Loar

8. Date of Event:

   a. Termination: 1960
   b. Initiation: 1954

9. Duration: 6-year emphasis period

10. Organization: BTL

11. Organization Type: Industrial Laboratory

12. Financial Support: Unknown

13. System Interface Activity: None (See Item 5)

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Unknown. Fundamental research prior to LANCE

15. Richard L. Petritz, CONTRIBUTIONS OF MATERIALS TECHNOLOGY TO SEMICONDUCTOR DEVICES, Proceedings of the IRE, Vol. 50, 1962, pp. 1025-1038.

Prepared by: R. J. Conlon
Battelle Memorial Institute
Date: 29 December 1966

Appendix C

PROPULSION

RXD Event Description

1. Title: (P-1) Work of Hausman and Kuhrt on Prandtl-Meyer Waves at United Aircraft, 1950

2. Weapon System: LANCE

3. Subsystem: Propulsion

4. Element: Thrust Vector Control

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: Work originated from need for sophisticated aerodynamic controls. After a vigorous test program it was successfully demonstrated that control based on the aerodynamic interference of induced shock wave pressure fields with a lifting surface was feasible.
    b. Relationship to Contemporary Science and Technology: Opened another avenue of aerodynamic control.
    c. Relationship to Succeeding Development or to System Performance: Shock wave control within the exhaust nozzle is commonplace in rocketry.

6. Type of RXD Event: Research

7. Key Technical Personnel: G. F. Hausmann, W. A. Kuhrt

8. Date of Event:

    a. Termination: September 1950
    b. Initiation: Uncertain

9. Duration: Unknown, estimated as one year

10. Organization: Supersonic Aerodynamic Group
    Research Department
    United Aircraft Corporation

11. Organization Type: Private Industry, Aircraft Manufacturer

12. Financial Support: U. S. Navy Bureau of Ordnance Contract

13. System Interface Activity:

a. Contemporary and Succeeding Activity: Led to the development of thrust vector control.
b. Previous Activity: Extensive activity in supersonic aerodynamics.

14. RXD Event Circumstances: An imaginative approach was taken to study a persistent problem.

15. Sources:

Meteor Report, UAC-48 AERODYNAMIC CONTROL OF SUPERSONIC VEHICLES BY THE USE OF SHOCK-INDUCED PRESSURE FIELDS.

Prepared by: Raymond E. Hess
Battelle Memorial Institute

Date: 10 January 1967

RXD Event Description

1. Title: (P-2) Fundamental Studies in Gas and Vapor Flow Work of Prandtl, 1907

2. Weapon System: LANCE

3. Subsystem: Propulsion

4. Element: Thrust Vector Control

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Work began through the imaginative initiative of an outstanding fluid dynamic scientist.
   b. Relationship to Contemporary Science and Technology: Strongly advanced study of supersonic flow.
   c. Relationship to Succeeding Development or to System Performance: Strong contribution to development of supersonic flight.

6. Type of RXD Event: Fundamental Research

7. Key Technical Personnel: Ludwig Prandtl

8. Date of Event: Work was reported in 1907. Fluid dynamic research was a lifelong endeavor of Prandtl; thus, initiation and termination dates are uncertain.

   a. Termination: -
   b. Initiation: -

9. Duration: See Item No. 8

10. Organization: University of Göttingen

11. Organization Type: Educational

12. Financial Support: Unknown - presumably university funds

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: Stimulated fluid dynamic research.

b. Previous Activity: Extensive investigation into fluid dynamics.

14. RXD Event Circumstances: Part of an active and imaginative research program.

15. Sources:

L. Prandtl, NEUE UNTERSUCHUNGEN ÜBER DIE STRÖMENDE BEWEGUNG DER GASE AND DÄMPFE, Physikalische Zeitschrift, 1907.

Prepared by: Raymond E. Hess Battelle Memorial Institute   Date: 10 January 1967

RXD Event Description

1. Title: (P-3) Study and Implementation of the Use of Nitric Acid as a Liquid Rocket Fuel

2. Weapon System: LANCE

3. Subsystem: Propulsion

4. Element: Propellants

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: This event had its genesis in the use of oxidative combustion as an energy source for propulsion. This event successfully demonstrated the potential of nitric acid as an oxidizer in rocketry.
    b. Relationship to Contemporary Science and Technology: Encouraged further work.
    c. Relationship to Succeeding Development or to System Performance: Led to full-scale development of oxidative combustion rockets.

6. Type of RXD Event: Research

7. Key Technical Personnel: Fredrich Wilhelm Sander

8. Date of Event: 1930

    a. Termination: Unknown
    b. Initiation: Unknown

9. Duration: Unknown

10. Organization: Unknown, work performed in Germany.

11. Organization Type: Unknown

12. Financial Support: Unknown

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: Encouraged studies in use of nitric acid as a rocket propellant.

b. Previous Activity: Unknown

14. RXD Event Circumstances: Unknown

15. Sources:

Personal Communication, Dated 15 October 1965, to Mr. J. Connaughton, Army Missile Command, Redstone Arsenal, Alabama, from Mr. R. F. Muraca, Director, Analyses and Instrumentation, Stanford Research Institute, Menlo Park, California.

Prepared by: Raymond E. Hess
Battelle Memorial Institute

Date: 10 January 1967

RXD Event Description

1. Title: (P-4) Fluid Dynamics of Liquids When Confined to Unusual Passages

2. Weapon System: LANCE

3. Subsystem: Propulsion

4. Element: Injector

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Interest arose from need for variable thrust system and resulted in a patentable variable area injector.
   b. Relationship to Contemporary Science and Technology: Represented an advance in thrust control.
   c. Relationship to Succeeding Development or to System Performance: Added sophistication to LANCE system.

6. Type of RXD Event: Research

7. Key Technical Personnel: Dennis J. Dermody, Camille Spiesman, Dmitri P. Buergin

8. Date of Event: January 1962 (Date of Patent)

   a. Termination: Unknown
   b. Initiation: Unknown

9. Duration: Unknown, estimated as one year

10. Organization: North American Aviation

11. Organization Type: Private Industry, Aircraft Manufacturer

12. Financial Support: Presumably Company Funds

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: Encouraged more sophisticated thrust control design.
    b. Previous Activity: Considerable

14. RXD Event Circumstances: The need for an injector suited to a variable thrust engine stimulated this work.

15. Sources:

U. S. Patent No. 3,234,731, VARIABLE THRUST DEVICE AND INJECTOR, Dennis J. Dermody, Canoga Park, Camille Speisman, Tarzana, and Dimitri P. Buergin, Woodland Hills, California, Assignors to North American Aviation, Inc., Filed 10 January 1962, Serial No. 166, 452, 14 Claims (Cl. 60-35.6).

Prepared by: Raymond E. Hess
Battelle Memorial Institute

Date: 10 January 1967

Appendix D

MATERIALS AND PROCESSES

RXD Event Description

1. Title: (M-1) The Electrolytic Winning of Aluminum From Alumina Dissolved in Cryolite

2. Weapon System: LANCE

3. Subsystem: Fuel and Oxidizer Tanks

4. Element: Aluminum Alloy 2014T6

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Discovery of the electrolytic process for alumina reduction to aluminum in 1886 (the Hall Process).
   b. Relationship to Contemporary Science and Technology: At time of this event, aluminum had been neglected as an engineering material due to the large amount of energy required to separate the metal from the oxide.
   c. Relationship to Succeeding Development or to System Performance: This discovery of an economical process for winning aluminum from its ore provided the world with a light-weight metallic element which became the base for a broad and growing family of alloys, including those used in LANCE.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: Charles Martin Hall, inventor of the Hall Process of aluminum production

8. Date of Event:

   a. Termination: Research and development of aluminum base alloys will continue for many years.
   b. Initiation: 1886

9. Duration: The actual period of the Hall process was approximately two years from inception to commercial application.

10. Organization: The Pittsburgh Reduction Company - Private activities of Hall. Later (1907), company name was changed to Aluminum Company of America.

11. Organization Type: Industrial Profit or Private Enterprise

12. Financial Support: Unknown

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: Aluminum Alloy 2014T6 was selected for tankage based upon its proven capability and adaptability.
    b. Previous Activity: Aluminum alloy 2014T6 was developed over 20 years ago as an outgrowth of the original discovery by Hall.

14. RXD Event Circumstances: None required for LANCE since the aluminum alloy 2014T6 had a known capability. Event by selection.

15. Sources:

    Author of Historical Background
    H. Russell Ogden, Battelle Memorial Institute

Prepared by: John R. Van Orsdel
Battelle Memorial Institute

Date: 6 January 1967

RXD Event Description

1. Title: (M-2) Discovery of Age Hardening

2. Weapon System: LANCE

3. Subsystem: Fuel and Oxidizer Tanks

4. Element: Aluminum Alloy 2014T6

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Early usage of aluminum was restricted by its low strength and high ductility. Therefore, considerable research went into alloy development. In 1906, the phenomenon of age hardening was discovered by Alfred Wilm.

   b. Relationship to Contemporary Science and Technology: Discovery of the age hardenability of certain alloys, including 2014T6, provided light-weight aluminum with sufficient strength to become an important structural metal.

   c. Relationship to Succeeding Development or to System Performance: Aluminum alloy 2014T6 is over 20 years old and had a proven capability and adaptability for the LANCE tankage.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: Alfred Wilm

8. Date of Event:

   a. Termination: Although a thorough understanding of age hardening was not achieved until 1935, the original phenomenological discovery was made by Wilm in 1906.

   b. Initiation: Unknown since age hardening was an accidental discovery of Wilm's during his work on aluminum alloy development, which he began in 1902.

9. Duration: Unknown period

10. Organization: Prussian Military Authority

11. Organization Type: Military

12. Financial Support: Unknown

13. System Interface Activity: Event affects LANCE by virtue of the selection of 2014T6 alloy for LANCE. Interface of event not clearly definable according to a. and b. below.

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Basic research prior to LANCE

15. Sources:

    Historical Background by H. Russell Ogden

Prepared by: John R. Van Orsdel
Battelle Memorial Institute

Date: 6 January 1967

RXD Event Description

1. Title: (M-3) Age Hardening of Martensitic Steels

2. Weapon System: LANCE

3. Subsystem: Thrust Chamber

4. Element: Sustainer Shell

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: The maraging steels are the products of research to adapt the age-hardening principles to martensitic steels.
   b. Relationship to Contemporary Science and Technology: At the time of this event, the application of age hardening to martensitic steels was not recognized.
   c. Relationship to Succeeding Development or to System Performance: The material required for the thrust chamber sustainer shell must have a combination of very high strength and good toughness. The prior research leading to the development of 18-7-5 maraging steel had provided a ready-made alloy for this difficult application.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: R. F. Decker, J. T. Eash, and A. J. Goldman, International Nickel Company Research Laboratory

8. Date of Event:

   a. Termination: Maraging steel 18-7-5 was developed in 1962; other alloys are currently under development which will make use of the maraging principle.
   b. Initiation: 1962

9. Duration: Undetermined

10. Organization: International Nickel Company

11. Organization Type: Profit Laboratory

12. Financial Support: Unknown

13. System Interface Activity:

a. Contemporary and Succeeding Activity: The result of this successful research has been the development of a new series of high-strength structural steel alloys including the maraging steel selected for use in LANCE.
b. Previous Activity: Previous application of age hardening to aluminum provided an indirect contribution to this event.

14. RXD Event Circumstances: Basic Research Prior to LANCE

15. Sources: Historical Background

1. H. Russell Ogden, Battelle Memorial Institute
2. R. F. Decker, J. T. Eash, and A. J. Goldman, 18% NICKEL MARAGING STEEL, Trans. ASM, Vol. 55, 1962, pp. 58-76.

Prepared by: John R. Van Orsdel
Battelle Memorial Institute Date: 6 January 1967

RXD Event Description

1. Title: (M-4) Development of Cold Molded Dense Silicon Carbide (Known Commercially as KT Silicon Carbide)

2. Weapon System: LANCE

3. Subsystem: Sustainer Motor Nozzle

4. Element: Throat Insert

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: The development of dense silicon carbide occurred in the 1950's and was patented in 1962. It was sought as an improvement over previously used mixtures containing degradable binders.
   b. Relationship to Contemporary Science and Technology: The research leading to the development of KT Silicon Carbide was prompted by the need for improved rocket nozzle materials.
   c. Relationship to Succeeding Development or to System Performance: KT Silicon Carbide was selected for LANCE based upon proven reliability in similar applications.

6. Type of RXD Event: Research

7. Key Technical Personnel: Kenneth M. Taylor, Carborundum Company

8. Date of Event:

   a. Termination: 1962 with filing for patent
   b. Initiation: In 1950's, exact date not determined

9. Duration: Estimated 5 years

10. Organization: Carborundum Company, Niagara Falls, New York

11. Organization Type: Profit Laboratory, Industrial

12. Financial Support: Estimated $150, 000 by Both Industry and Government

13. System Interface Activity: Event affects LANCE by virtue of materials selection. No strict interface activity.

   a. Contemporary and Succeeding Activity:
   b. Previous Activity:

14. RXD Event Circumstances: LANCE profited by previous research on rocket nozzle materials.

15. Sources:

James F. Lynch, Battelle Memorial Institute
Mr. A. Pisano, Carborundum Company
Kenneth M. Taylor, Inventor, Carborundum Company
Carborundum Company Literature

Prepared by: John R. Van Orsdel — Battelle Memorial Institute — Date: 6 January 1967

RXD Event Description

1. Title: (M-5) Optimization of SiC Nozzle Insert Configuration

2. Weapon System: LANCE

3. Subsystem: Sustainer Motor Nozzle

4. Element: Throat Insert

5. Technical Significance: XD event not fully investigated. Technical significance not evaluated in this study.

   a. Origin, Technical Activity, and Outcome:
   b. Relationship to Contemporary Science and Technology:
   c. Relationship to Succeeding Development or to System Performance:

6. Type of RXD Event: Exploratory Development

7. Key Technical Personnel: Cooperative efforts of Rocketdyne and Carborundum Company engineers.

8. Date of Event:

   a. Termination: Configuration of the nozzle insert was optimized for LANCE-1964
   b. Initiation: 1962

9. Duration: 2 years

10. Organization: Rocketdyne and Carborundum Company

11. Organization Type: Profit Laboratories, Industrial

12. Financial Support: Unknown

13. System Interface Activity: Unknown

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Optimization of nozzle configuration as a part of nozzle (materials) development.

15. Sources:

James F. Lynch, Battelle Memorial Institute
Mr. A. Pisano, Carborundum Company

Prepared by: John R. Van Orsdel, Battelle Memorial Institute — Date: 6 January 1967

RXD Event Description

1. Title: (M-6) Incorporation of Refrasil in Ablative Material

2. Weapon System: LANCE

3. Subsystem: Booster and Sustainer Motors

4. Element: Structural Thermal Protection

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Refrasil is a product of the H. I. Thompson Fiberglass Company and was first used as insulating batts in jet engines. The earlier use in ablative materials was done by the Missiles and Space Vehicle Department of GE in 1958.

   b. Relationship to Contemporary Science and Technology: The need for high temperature and erosion resistant materials which was magnified by the advent of rocket engines and reentry vehicles was the driving force behind the development of these materials.

   c. Relationship to Succeeding Development or to System Performance: Refrasil ablative was available as a result of previous diligent research when the development of the LANCE system was initiated.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: Work reported by I. J. Gruntfest, L. H. Slinker, and V. N. Saffire, "The Behavior of Reinforced Plastics at Very High Temperatures", The Society of the Plastics Industry, Inc., 250 Park Avenue, New York, New York, 1959.

8. Date of Event:

   a. Termination: 1959

   b. Initiation: 1958 or possibly a few years before

9. Duration: 2 to 5 years estimated

10. Organization: H. I. Thompson Fiberglass Company
    Missiles and Space Vehicle Department, GE

11. Organization Type: Profit Laboratories, Industrial

12. Financial Support: Unknown

13. System Interface Activity: No interface activity pertinent to LANCE

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: The demanding characteristics of high performance rocket motor and reentry nose cones necêssitated development of improved heat and erosion resistant materials prior to the LANCE development and serve the developers well.

15. Sources:

Historical Background by Dr. R. I. Leininger
Battelle Memorial Institute

Prepared by: John R. Van Orsdel
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (M-7) Discovery of Teflon

2. Weapon System: LANCE

3. Subsystem: Numerous Small Components

4. Element: "O"-Rings

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Teflon had its origin in the basic chemistry conducted by Du Pont in the early 1930's in connection with refrigerants development which culminated with the commercial introduction of "Freon" in 1931.
   b. Relationship to Contemporary Science and Technology: This development reflected probing in depth the chemistry of organic fluorine and chlorine compounds. Additional work in this class of chemicals led to the discovery of Teflon at Du Pont in 1938.
   c. Relationship to Succeeding Development or to System Performance: The high temperature stability and chemical resistance of Teflon make it extremely useful as "O"- ring seals in military applications.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: Laboratory Personnel at Du Pont

8. Date of Event:

   a. Termination: 1950, at which time commercial production began.
   b. Initiation: 1938, at the time of Teflon's discovery as a result of earlier work in the chemistry of fluorine and chlorine compounds.

9. Duration: Approximately 20 years

10. Organization: E. I. du Pont

11. Organization Type: Profit Laboratory, Industrial

12. Financial Support: Unknown

13. System Interface Activity: Interface activity not definable

    a. Contemporary and Succeeding Activity:
    b. Previous Activity:

14. RXD Event Circumstances: Teflon was a commercial product at the time of the LANCE development. However, many years of basic research were expended in Teflon development.

15. Sources:

    Historical Background by Bailey Bennett
    Battelle Memorial Institute

Prepared by: John R. Van Orsdel, Battelle Memorial Institute   Date: 9 January 1967

RXD Event Description

1. Title: (M-8) Advances in Silicon Chemistry

2. Weapon System: LANCE

3. Subsystem: Numerous Small Components

4. Element: "O"-Rings

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Silicone polymers had their origin in basic chemical research prior to 1944. The pure academic interest of Professor F. S. Kipping of the University of Nottingham, England, resulted in his contributing 54 papers on silicon chemistry. However, the earliest patents on silicone products were assigned to GE in 1941. Silicone rubber was introduced at the end of World War II.
   b. Relationship to Contemporary Science and Technology: Silicone rubber was the product of basic research to find an elastic material capable of meeting modern demands for heat and chemical resistance.
   c. Relationship to Succeeding Development or to System Performance: Silicone rubber is a high quality rubber which has much greater capability than natural rubber and which finds broad application in military equipment.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: Professor F. S. Kipping of the University of Nottingham and many research scientists of GE and Dow Corning Corporation.

8. Date of Event:

   a. Termination: Silicone rubber was introduced at the end of World War II (approximately 1946).
   b. Initiation: 1899

9. Duration: 45 years

10. Organization: 1. Nottingham University
2. GE
3. Dow Corning

11. Organization Type: 1. University, Academic
2. Profit Laboratory, Industrial
3. Profit Laboratory, Industrial

12. Financial Support: Unknown

13. System Interface Activity: No interface activity of this type. Advances in silicon chemistry are an event to LANCE by virtue of the selection of silicone rubber components. Details of this selection are unknown.

a. Contemporary and Succeeding Activity:
b. Previous Activity:

14. RXD Event Circumstances: Silicone rubber is a product of organo-chemical research initiated by Professor Kipping, who believed that a separate chemistry of silicon, similar to that of carbon, could be a reality.

15. Sources:

Historical Background by Bailey Bennett
Battelle Memorial Institute

Prepared by: John R. Van Orsdel, Battelle Memorial Institute — Date: 9 January 1967

RXD Event Description

1. Title: (M-9) Theoretical Development of Numerical Control Machining

2. Weapon System: LANCE

3. Subsystem: Airframe

4. Element: Bulkheads and Other Parts

5. Technical Significance:

    a. Origin, Technical Activity, and Outcome: The conceptual innovation of numerical control machining is accredited to J. C. Parsons in 1947 with MIT extending and supporting the concept through research.
    b. Relationship to Contemporary Science and Technology: Except for the innovation in controls, the early tools were improved versions of conventional machines.
    c. Relationship to Succeeding Development or to System Performance: Once the advantages of numerical control were realized in terms of savings in lead time, increased reproducibility, reduced tooling, elimination of templates, etc., government and industry contributed broadly to its greater use and LANCE was a significant user.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: J. C. Parsons

8. Date of Event:

    a. Termination: 1947
    b. Initiation: Unknown

9. Duration: Estimated 5 to 10 years

10. Organization: Individual, followed with help from MIT

11. Organization Type: 1. Individual
    2. University Research

12. <u>Financial Support:</u> U. S. Government and Industry
Currently amounting to about $3.3 million annually.

13. <u>System Interface Activity:</u>

a. Contemporary and Succeeding Activity: Numerical control machining is being rapidly integrated into large machining operations throughout the industry at this time.
b. Previous Activity: No specifically applicable previous activity other than machine tool technology. Event has the characteristics of innovation.

14. <u>RXD Event Circumstances:</u> Probably none directly associated with LANCE. Event by virtue of process selection.

15. <u>Sources:</u>

Historical Background by Carl T. Olofson
Battelle Memorial Institute

<u>Prepared by:</u> John R. Van Orsdel
Battelle Memorial Institute
<u>Date:</u> 9 January 1967

RXD Event Description

1. Title: (M-10) Research in the Development of Shear Forming as a Practical Manufacturing Process

2. Weapon System: LANCE

3. Subsystem: Airframe

4. Element: Motor Case

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Although primitive forms of shear forming can be seen in the earliest time of man's working with metals, the drive for sophistication did not occur until about 1960.
   b. Relationship to Contemporary Science and Technology: At the time of this event there was an increased interest in spinning. The need to produce thicker parts by a similar process led to shear forming.
   c. Relationship to Succeeding Development or to System Performance: Exact relationship to succeeding development is unknown. Shear forming was selected as the motor case fabrication process. A numer of companies had done application work with the process providing a basis for this selection.

6. Type of RXD Event: Basic Research

7. Key Technical Personnel: B. Avitzur and C. T. Yang
   S. Kobayashi, I. K. Hall, and
   E. G. Thomsen
   S. Kalpakcioglu

8. Date of Event:

   a. Termination: 1961
   b. Initiation: 1960

9. Duration: 1 year minimum

10. Organization: Curtiss-Wright Corporation
Marquardt Corporation
Aerojet-General Corporation
Temco Electronics and Missiles Company
AVCO Corporation
GE

11. Organization Type: Profit Laboratories, Industrial

12. Financial Support: Much corporate and government money supported the research; total amount unknown.

13. System Interface Activity:

a. Contemporary and succeeding activity: The process is broadly used today in making large circular or cylindrical objects of seamless, high-strength quality.
b. Previous Activity: The organizations listed in 10 above had all conducted applications programs in shear forming. This activity had advanced the process to a readily usable status.

14. RXD Event Circumstances: Research accomplished prior to LANCE needs.

15. Sources:

Historical Background by Carl T. Olofson
Battelle Memorial Institute

Prepared by: John R. Van Orsdel
Battelle Memorial Institute

Date: 9 January 1967

RXD Event Description

1. Title: (M-11) Conceptual Innovation and Application of Electron Beam to Welding

2. Weapon System: LANCE

3. Subsystem: Propellant Tanks

4. Element: Closure Welds

5. Technical Significance:

   a. Origin, Technical Activity, and Outcome: Significant developments occurred in the mid-1950's when focused electron beams were used as heat sources for welding reactive metals used in nuclear applications.
   b. Relationship to Contemporary Science and Technology: Research leading to this application was motivated as a logical consequence of emphasis on electron-beam physics.
   c. Relationship to Succeeding Development or to System Performance: By the early 1960's, sufficient research had been done to reveal the usefulness and limitations of electron-beam welding so that the technique could be adapted to fabrication with some exploratory development.

6. Type of RXD Event: Research
   Initial discovery of usefulness of a focused electron beam was definitely basic research.

7. Key Technical Personnel: J. A. Stohr, French Atomic Energy Commission
   W. L. Wyman, Hanford Atomic Products Operation

8. Date of Event:

   a. Termination: Approximately 1962
   b. Initiation: Approximately 1954

9. Duration: 8 years

10. Organization: Hanford Atomic Products Operation, U. S. Government

11. Organization Type: Not for Profit

12. Financial Support: Unknown

13. System Interface Activity:

    a. Contemporary and Succeeding Activity: Electron-beam technology and its use as a welding tool has grown rapidly since the mid-1950's, making it an adaptable process for LANCE fabrication.
    b. Previous Activity: This event was preceded by steady growth in the physics and technology of electron emission, beam generation, and focusing, vacuum technology and related fields which provided a basis for this innovation.

14. RXD Event Circumstances: Basic research accomplished prior to LANCE.

15. Sources:

Historical Background by H. Russell Ogden
Battelle Memorial Institute

Prepared by: John R. Van Orsdel
Battelle Memorial Institute

Date: 9 January 1967

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13. ABSTRACT

This report includes a discussion of 57 research and exploratory development events that have been identified as contributing significantly to LANCE. Forty-six of these are research events. Eight of the research events deal with LANCE aerodynamics, four with propulsion, 24 with solid-state components used in the guidance and control system, and 10 with the research origins of the materials and manufacturing processes used in LANCE. In addition, 11 exploratory development events are identified. The principal concern of this study has been the identification of further research origins of LANCE and the 46 documented events are its major product. A further concern and obligation of this study has been to provide HINDSIGHT with some additional data on the research phenomenon including some further observations on the nature and route of research utilization.

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