AD-A017 126

THE LASER-GUIDED BOMB: CASE HISTORY OF A DEVELOPMENT

Peter deLeon

RAND Corporation

Prepared for:

Deputy Chief of Staff, Research and Development
(Air Force)

June 1974

R-1312-1-PR
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A Report prepared for

UNITED STATES AIR FORCE PROJECT RAND

Rand
SANTA MONICA, CA 90406

The research described in this Report was sponsored by the United States Air Force under Contract No. F44620-73-C-0011 - Monitored by the Directorate of Operational Requirements and Development Plans, Deputy Chief of Staff, Research and Development, Hq USAF. Reports of The Rand Corporation do not necessarily reflect the opinions or policies of the sponsors of Rand research.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-1312-1-PR	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE LASER-GUIDED BOMB: CASE HISTORY OF A DEVELOPMENT		5. TYPE OF REPORT & PERIOD COVERED one in a series on Acquisition Studies 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Peter deLeon		8. CONTRACT OR GRANT NUMBER(s) F44620-73-C-0011
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Rand Corporation 1700 Main Street Santa Monica, California 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Directorate of Operational Requirements and Development Plans, Deputy Chief of Staff, Research and Development, Hq USAF		12. REPORT DATE June 1974 13. NUMBER OF PAGES 60
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Laser-guided bomb; acquisition and development; R&D management

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

see reverse side

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

This report is a case study of a successful R&D product--the laser guided bomb (LGB). The narrative begins with the work of the Army's Missile Command at the Redstone Arsenal (1962), continues with the initial LGB prototype competition between Texas Instruments (TI) and North American-Autonetics (1966), details the decisions within Hq USAF to continue the development through the engineering prototype contract with TI (1968), and ends with the award of the acquisition contract to TI (1969). Six facets of the LGB development are analyzed: competitive prototype development; early and repeated testing of system hardware; interaction of technology and requirements in design and performance specifications; incremental development; delegation of development decisions; and the availability of contingency development funds. These six features, working interactively, provided a flexibility in development that produced a low-cost, high-performance system within a relatively short time frame. (author)

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PREFACE

The research reported here is part of Rand's R&D and Acquisition Studies Program, supported by USAF Project RAND. Previous research done at Rand has dealt with studies of particular development programs,* institutional aspects of Air Force acquisition decisionmaking,† and improvements in system acquisition policy with respect to major weapon systems.‡

This case study of the development of one type of precision-guided munition examines the managerial and decisionmaking aspects of a specific development project, the interaction between advances in technology and user requirements, and the relationship between the government and private industry. It is the author's contention that these aspects are too often left unaddressed or, if considered, treated superficially (e.g., "a good project needs a good manager," or "cooperation is necessary"). More specific insights may be gained by a detailed case study.

This report uses only unclassified data, although in some cases the sources themselves are classified. This study should be useful to Air Force and other agencies engaged in R&D and acquisition decisions, particularly the offices of the DCS/Research and Development and DCS/Systems and Logistics in Hq USAF, the Air Force Systems Command, and the Director of Defense Research and Engineering.

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*For example, R. L. Perry, *System Development Strategies: A Comparative Study of Doctrine, Technology, and Organization in the USAF Ballistic and Cruise Missile Programs, 1950-1960*, RM-4853-PR, August 1966 (FOUO); and R. L. Perry, *A Prototype Strategy for Aircraft Development*, RM-5597-PR, July 1972.

†See, for example, B. H. Klein, W. H. Meckling, and E. G. Mesthene, *Military Research and Development Policies*, R-333, December 1958, and, more recently, see W. D. Putnam, *The Evolution of Air Force System Acquisition Management*, R-868-PR, August 1972.

‡See A. J. Harman and S. Henrichsen, *A Methodology for Cost Factor Comparison and Prediction*, RM-6269-ARPA, August 1970; and R. L. Perry, G. K. Smith, A. J. Harman, and S. Henrichsen, *System Acquisition Strategies*, R-733-PR/ARPA, June 1971.

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SUMMARY

The introduction of air-to-ground precision-guided munitions (PGM) into the USAF munitions inventory has already produced an extensive literature on the characteristics and potential of this new family of weapons. This report is a case study that examines the development and acquisition of an important example of this new weaponry--the laser-guided bomb (LGB), a first-generation PGM. The study begins with the initial Army research into laser guidance in 1962 and ends with the Operational Test and Evaluation of the Air Force LGB system in Southeast Asia in 1968. The report is primarily focused on the laser seeker unit itself; other components of the LGB system (such as the designator) and other PGMs (such as the electro-optical guided bomb) are discussed only as they relate to the LGB development. The main concern of the report is Air Force R&D management and strategies; this should not be interpreted as downgrading the roles and efforts of the various private firms that contributed to the development of the LGB.

Although the Air Force made limited use of radio-guided bombs during the Second World War and the Korean conflict (e.g., Azon, Razon, and Tarzon), the report begins with the laser work of the U.S. Army Missile Command (MiCom) at the Redstone Arsenal. Members of the MiCom research staff found that a target could be "designated" (that is, marked) by a pulsed laser beam and a guidance system could be designed to home in on the reflected laser light. By the early part of 1965, MiCom had developed the conceptual basis and contracted for a portion of the hardware of what was to become the laser guidance system. When the Army deemphasized the laser program, members of the MiCom staff shared their findings with the Air Force's Deputy for Limited War in the Aeronautical Systems Division (ASD). Personnel in the Limited War office at ASD then requested that MiCom hold a tri-service laser meeting in April at the Martin-Marietta facility in Orlando, Florida.

At approximately the same time (1964-1965), the Air Force R&D community was increasingly turning its attention to the short-term translation of technology into new or improved weapons systems. This emphasis

was manifested by the dedication of a contingency fund--Project 1559--for low-cost, short-time-horizon developments and by the formation of ASD's Detachment 5 at Eglin AFB; Detachment 5's charter specified that it was to provide "resident technical assistance and ... to improve the System Command's response to immediate tactical operational needs." Detachment 5 staff had already given some preliminary consideration to the possibility of laser guidance for free-fall munitions, and MiCom's tri-service Orlando briefing reinforced in their minds the possibility of such a system. Detachment 5 personnel indicated their interest in a laser-guided bomb prototype and received proposals from the Autonetics Division of North American Aviation (NA-A) and from Texas Instruments (TI). The bids were based on the companies' prior work with the Army; in May 1965, Detachment 5 forwarded both proposals to ASD for funding within Project 1559. That November, Autonetics signed a contract for $442,000 to deliver five guided test bombs; Texas Instruments contracted to build nine guided test bombs for $264,000. Both prototypes employed the M-117 (500-lb) bomb.

The primary difference between the two prototypes was their respective guidance mechanism: the Autonetics guidance kit featured a spring platform stabilized seeker head, proportional guidance, and canard control fins; the Texas Instruments version had an aerodynamically stabilized seeker head, "bang-bang" guidance, and tail control fins. The former was considered a logical extension of the extant technology; although the latter was a higher risk model, it was clearly lower cost. Rather than decide between the two on the basis of paper proposals, the Air Force chose to fund parallel developments, with a prototype competition between the two models. A series of feasibility tests of the two models was conducted between July 1967 and January 1968. Although both versions achieved significant CEP improvements over unguided bombs, test personnel recommended that the TI model should be put into production as soon as possible whereas the NA-A version required additional development.

Upon receiving notification of the test results, the Air Force reprogrammed $500,000 for a follow-on, engineering prototype contract with Texas Instruments in January 1967. However, it soon became apparent that a half million dollars was not enough money to purchase the desired number of kits. In March a Southeast Asia Operational Requirement arrived at Hq USAF requesting an LGB system for deployment in the SEA theater. Prompted by this request, in May 1968 the Air Force signed a contract with TI for 50 seeker kits at a cost of $1.35 million; the additional $850,000 was also reprogrammed. At the Air Staff's request, some of the kits were to be tested on the MK-84 (2000-lb) munition.

On 20 July 1967, the laser-guided bomb project was designated Project Paveway and a project office was set up within the Aeronautical Systems Division. On 21 September, a Requirements Action Directive for the LGB was issued that listed the desired characteristics: CEP no greater than 25 ft; guidance reliability at least 80 percent; delivery from either a dive mode or a level run; and operational deployment no later than June 1968. On 15 January 1968, the Air Force issued Development Directive 69 approving a production program of $4.7 million for 293 LGB seeker kits in FY 1968.

The testing of the engineering prototype begun in November 1967 at Eglin AFB was transferred to Southeast Asia in May 1968 for theater evaluation. Replacement of the tail guidance fins with front canard control fins was a major design change in the TI model during these tests. Also, the MK-84 was first tested during this series. The result of the evaluation of the system was so positive that the Air Force ordered an additional 1000 seeker kits. Used initially for suppression of antiaircraft activity and interdiction, the LGB (and later, the electro-optical guided bomb) came to the public's attention when President Nixon authorized resumption of the bombing of North Vietnam in 1972. Labelled "smart bombs," they provided the Air Force with much more accurate bombing capabilities combined with a less vulnerable attack profile.

This study chronicles the development of a single munition. One should not generalize from such a small sample. It is possible, however, to highlight the main factors that made the LGB a successful development and, in conjunction with other R&D case studies, use this empirical evidence to provide a better understanding of the general R&D processes. In addition, the procedures used in the LGB development might prove to be directly applicable to the development of future generations of PGMs.

The research suggests that there were at least six features of the development that contributed to its success:

- Competitive prototype development
- Early and repeated testing of system hardware
- Technology/requirements interaction
- Incremental development
- Delegation of development decisions
- Availability of contingency development funds.

It should be emphasized that these features are highly interrelated and mutually reinforcing; with the partial exception of the last item, they can be viewed as a development policy package.

Competitive Prototype Development allowed the Air Force to compare the prototype performance of two relatively different systems and to judge if the general concept were viable and, if so, which prototype performed better. More specifically, it compared the high-cost/medium-risk NA-A design with the low-cost/high-risk TI design, thus providing a hedge against the uncertainty that usually characterizes the development process. *Early and Repeated Testing of the System Hardware* not only provided data for a relatively rapid, iterative design process (i.e., design modifications based upon test results), but also provided reliable evidence upon which decisionmakers could base subsequent requirements and production decisions. The *Technology/Requirements Interaction* refers to delaying rigid design and operational specifications until tests have provided data on which specifications can be realistically based. Under such a procedure, the technology is allowed to define the performance parameters, thus assuring the convergence of the extant technology and desired operational requirements at an acceptable cost.

In *Incremental Development* there are a number of discrete development phases, such as advanced and engineering development, which are linked by decision nodes. The LGB development had at least three such choice nodes: the original decision to fund the feasibility prototypes; the decision to continue the development with the engineering prototype;

and the actual production decision. A second feature of incremental development is the importance of demonstrating a system's feasibility before addressing the reliability and maintainability features of the system. In this case, the Air Force did not complete worldwide qualification tests on the LGB system until after the system was deployed in SEA. *Delegation of Development Decisions* during the LGB development was particularly noticeable; significant program decisions were made by the people, relatively low in the R&D chain of command, who possessed the pertinent information. This was partially due to working with a contract that lacked detailed specifications during the early stages of the development. Finally, the availability of *Contingency Development Funds* provided money to begin the project within a reasonably short period of time; had the feasibility prototypes contracts gone through the normal budgetary channels, additional time would have been required.

If one were to characterize the development of the LGB in a single word, that word would be "flexibility." The six features of the development identified above served interactively to present multiple design and managerial alternatives to the various decisionmakers. The availability of two competing prototype models, the lack of strict design specifications or operational requirements until testing had determined what specifications and performance parameters were feasible, the ability of the project managers to make significant design alternatives without contract modification, and the incremental manner in which the development progressed all contributed to this flexibility.

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ACKNOWLEDGMENTS

Due to the relatively recent development and public disclosure of laser-guided bombs, there is a paucity of R&D literature on the subject. Therefore, much of this research is based upon interviews with people who participated, either directly or indirectly, in the development. These include personnel at: Hq USAF, Washington, D.C.; Hq Air Force Systems Command, Andrews AFB, Maryland; Hq Tactical Air Command, Langley AFB, Virginia; Aeronautical Systems Division, Wright-Patterson AFB, Ohio; the Armament Development and Test Center, Eglin AFB, Florida; the Naval Weapons Center, China Lake, California; Texas Instruments, Missiles and Ordnance Division, Dallas, Texas; and Rockwell International (formerly North American), Columbus, Ohio, and Anaheim, California. In addition, I have talked or corresponded with a number of people who were associated with one or more of these organizations at one time and who have since moved to other positions.

Confidentiality precludes specific attribution of my sources.* I am, nonetheless, indebted to all of those who offered me their time and insights; without their generous assistance, this research would not have been possible. I trust that in my sifting of their individual contributions, I have not distorted the events.

My colleagues at Rand have been of great assistance. The research has benefited from the stimuli and enthusiasm of Alvin Harman, Director of Rand's R&D and Acquisition Program, and Arthur Alexander. Don Palmer, Robert Perry, Ed Sharkey, and Ross Blachly have all been of considerable aid in offering both valuable corrections and avenues of research. John Koehler, Russell Shaver, and Giles Smith served as reviewers and provided cogent criticisms that were of immense value. Finally, Edmund Dews has continually sought to sharpen the report's perspectives; his contributions to this case study would be difficult to overstate.

Special mention must be made of my former Rand colleague, Douglas W. McIver. We conducted a majority of the personal interviews together

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*A record of all interviews is on file at The Rand Corporation as part of this report's documentation.

and were jointly responsible for an earlier draft of this report. I would be remiss were I not to acknowledge him a co-author, in spirit if not in fact.

Acknowledgments notwithstanding, all errors of fact or judgment are mine alone.

CONTENTS

I. INTRODUCTION

The introduction of air-to-ground precision-guided munitions (PGM) into the USAF munitions inventory has produced an extensive literature on the uses and implications of this new family of weapons;* there seems little doubt that PGMs permit previously unachievable ground attack capabilities for tactical aircraft. A computer simulation by Texas Instruments estimated that close to 21,000 unguided, manually-released 2000-lb bombs were needed to destroy 100 representative targets, compared with 4000 computer-released bombs or 100 laser-guided bombs.† Computer-released, unguided bombs improved target kill capability over unguided ordnance with manual release by a factor of 5 whereas the addition of a laser guidance unit improved target kill by a factor of 200.‡ These effectiveness calculations were borne out by the performance of PGMs in Southeast Asia and, later, in the Middle East.** Given these magnitudes of improvement in accuracy, proponents argue that PGMs vastly reduce both the number of bombs and sorties necessary to destroy a target, a reduction that would obviously have significant implications for the Air Force in terms of sorties, logistics, and overall costs. Most of the PGM literature and discussion concerns their present and potential characteristics, employment, and implications. This report examines the development and acquisition of one example of new weaponry.

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*For a compendium of such papers, see Gregory A. Carter, Compiler, *Seminar on the Implications of Precision-Guided Munitions: Vol. II. Proceedings* (U), The Rand Corporation, R-1248-ARPA, April 1973 (Secret).

†*United States Air Force, Paveway Laser-Guided Munitions*, Texas Instruments, Inc., January 1972, p. 15.

‡*United States Air Force, Paveway Laser-Guided Munitions*, Texas Instruments, Inc. (undated, approximately late 1972), p. 16. The figures for laser-guided bomb factor improvements are supported by unpublished Rand calculations; the Rand figures are for hard targets.

**See "U.S. Guided Bombs Alter Viet Air War," and Herbert J. Coleman, "Israeli Air Force Decisive in War," *Aviation Week and Space Technology*, 22 May 1972, pp. 16-17, and 3 December 1973, p. 21, respectively. Also see John W. Finney, "Guided Bombs Expected to Revolutionize Warfare," *The New York Times*, 18 March 1974, p. 1.

More specifically, this report describes the developmental history of a first-generation air-to-ground PGM, the laser-guided bomb (LGB) Development of the laser guidance kit for the M-117 (and, later, the MK-84) bomb will be described. The laser guidance kit is just one component of the laser-guided bomb system; other components--including the delivery aircraft, the laser designator, and the fuzing mechanism--will be addressed only as they relate to the development of the seeker kit.

Inevitably PGMs will have higher unit costs than the unguided ordnance they succeed. In addition, substantial research on new PGM developments and purchases are foreseen.* In a period of stringent defense budgets, aircraft, avionics, and munitions will be competing for the same scarce dollars. An analytical case study of this kind is worthwhile because of the importance of keeping PGM acquisition costs low while, simultaneously, encouraging major advances in design;† if PGM development and procurement costs per unit are too high, the potential of the new technology may be realized incompletely, too slowly, or only as a result of extremely difficult choices between expensive delivery systems and expensive munitions.

One way to ameliorate this dilemma is to attempt to understand the development strategies that might make the development of the PGMs more efficient in terms of money and time. In more general terms, the budgetary difficulties can be eased by employing development strategies that foster efficiency in each kind of development. Other Rand work has examined aircraft, missile, and major subsystem case histories and

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*Additional research and purchases are emphasized in the military budget for FY 1975. See Dr. Malcolm Currie, *The Department of Defense Program of Research, Development, Test, and Evaluation, FY 1975*, U.S. Senate, Committee on Armed Services, 93rd Congress, 2nd Session, 26-27 February 1974 (Washington, D.C.: Government Printing Office, 1974), pp. 4:51-52.

†Second-generation development of LGBs is already underway. See Clarence A. Robinson, Jr., "Air Force to Press Development of Laser Guidance for Maverick," and "Navy Backs New Laser Seeker," *Aviation Week and Space Technology*, 5 November 1973, p. 56, and 10 December 1973, pp. 44-51, respectively.

has suggested suitable development strategies.* Do these earlier findings apply to PGM acquisition? The present report makes a start at answering this question and, using the LGB development as an illustrative example, suggests that the answer is positive.

THE CASE HISTORY APPROACH

A general understanding of the development process and identification of preferred development strategies should be based, in part, on detailed case histories. Ideally, the analyst would have a large and variegated number of case histories illustrating several different development strategies for each of a range of different systems developed. But, in practice, he has to rely upon a limited number of case histories because few have been prepared from the point of view of the comparative analysis of development strategies and management procedures.† Moreover, each development is, in a real sense, a unique event; this is true even of two competing developments aimed at fulfilling the same general statement of desired operational characteristics.

Good case histories are an essential part of any serious and systematic attempt to understand and improve the R&D and acquisition process. They force analysis to remain close to reality and serve an important heuristic function by illuminating issues and suggesting conclusions; however, due to their inherent limitations, individual case studies cannot provide conclusive answers. This report is an addition to the case study literature.

To the author's knowledge, this is the first analytic case history of a PGM development. I have uncovered relatively little literature

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*For an overview of the cases Rand has recently investigated, see Robert Perry, Giles K. Smith, Alvin J. Harman, and Susan Henrichsen, *Systems Acquisition Strategies*, The Rand Corporation, R-733-PR/ARPA, June 1971. Also see, Thomas A. Marschak, *The Role of Project Histories in the Study of R&D*, The Rand Corporation, P-2850, January 1964. The Marschak study is also found in Thomas Marschak, Thomas K. Glennan, Jr., and Robert Summers, *Strategies for R&D: Studies in the Microeconomics of Development* (New York: Springer-Verlag, 1967).

†The two best examples of comparative weapons acquisitions studies are M. J. Peck and F. M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston: Harvard Business School, 1962), and Marschak, Glennan, and Summers, *op. cit.*

that directly addresses the issues of the developmental strategies and managerial procedures that characterized the development and acquisition of the laser-guided bomb. Therefore, the primary source of information for this report has been a series of personal interviews with the personnel who participated in the project throughout its history; their affiliations are listed in the Acknowledgments. These interviews have been substantiated wherever possible with data extracted from test documents published by the participating manufacturers and various organizations within the United States Air Force, especially the Armament Development and Test Center, Eglin Air Force Base, Florida. A bibliography appends this report; a record of interviews is on file at The Rand Corporation.

SCOPE OF STUDY

Azon and Razon were developed by the United States during World War II. A limited number of Azons, a 500-lb guided bomb, was used with some success in the Mediterranean and China-Burma-India Theaters.* Razon and the 12,000-lb Tarzon had limited deployment with mixed results during the Korean conflict.† These were the early guided-bomb developments, but this study focuses almost exclusively upon the development of the LGB in the mid-1960s. Although there are references to the later developments of the electro-optical and the infrared guided bombs, this report does not directly address those programs, nor does it examine the operational use of the laser-guided bomb as it was deployed in the Southeast Asia theater.‡ The time frame bounding this

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*See Hugh H. Spencer, "Azon and Razon," *Guided Missiles and Techniques*, National Defense Research Committee, Technical Report of Division 5, Vol. 1, *Summary*, Office of Scientific Research and Development, Washington, D.C., 1946, Chap. 2; also, "Azon Does a Job in Burma," *Radar*, No. 8, 20 February 1945, pp. 26-27.

†See Robert Futrell, *The United States Air Force in Korea, 1950-1953* (New York: Duell, Sloan, and Pearce, 1961).

‡For an examination of the effectiveness of laser and electro-optical guided bombs during Operation Linebacker in 1972, see R. L. Blachly, P. A. CoNine, and E. H. Sharkey, *Laser and Electro-Optical Guided Bomb Performance in Southeast Asia (Linebacker I: A Briefing)* (U), The Rand Corporation, R-1326-PR, October 1973 (Confidential).

study is 1962 to 1968, that is, the period beginning with Army experimentation with laser guidance technology and ending with the Operational Test and Evaluation of the laser-guided bomb system in Southeast Asia.

Finally, it should be noted that although this report emphasizes the development strategies of the Air Force, the various private contractors who participated in the LGB development were most responsive and acted with exemplary competence during the development. Their work is given less attention only because the purpose of the report is to examine Air Force R&D procedures.

ORGANIZATION OF REPORT

The report has two sections in addition to the Introduction. The first is a narrative that chronicles the important dates and events in the development. The second section analyzes the different developmental procedures employed and briefly reviews the major findings of the study in relation to other acquisition studies.

II. THE DEVELOPMENT OF THE LASER-GUIDED BOMB

ARMY RESEARCH ON LASER APPLICATIONS

The possibilities for laser application were recognized soon after the first operational laser was tested in 1960. Often referred to as "a solution looking for a problem," lasers were seen as applicable to as diverse a range of uses as communication conduits to death rays. The research staff of the U.S. Army's Missile Command (MiCom), at Redstone Arsenal in Huntsville, Alabama, was particularly interested in lasers as a possible guidance technology for over-the-hill (indirect) fire weapons and antitank use. Army engineers hoped to use a laser beam to "spot" or "illuminate" a tank and then design a seeker system for a missile head that could guide a missile in on the source of reflected light (e.g., the tank). The problem largely lay with the physical size of the laser. At the time, the laser required enormous amounts of energy, which made it too heavy for the 40 lb of weight that was the limit of what a foot soldier could carry and still retain combat mobility.

David J. Salonimer, a civilian engineer in the Missile Command was able to demonstrate mathematically in late 1962 that a seeker device could home in on a target illuminated by a *pulsed* laser beam; in effect, he proposed illuminating the target with regularly spaced short bursts of very high energy, arguing that there was no reason to illuminate the target continuously. In this system, the size of the power source and thus the laser could be reduced. In June 1963, MiCom granted contracts to North American-Autonetics and RCA-Burlington to investigate different technical approaches for developing seekers that could track or guide on pulsed laser radiation. The RCA contract, for approximately $58,000, utilized an image tube detector; the Autonetics approach, funded for about $98,000, used solid-state components. By the end of 1964, both contractors were able to demonstrate guidance units successfully under laboratory conditions. The RCA detector project was diverted to the Remote Target Designator Program (RTDP), which provided a television picture of a ground target that was being illuminated by a laser; the

RTDP was flight-tested in a twin-engine Beechcraft at the Redstone Arsenal in late 1964.

With the laboratory tests largely completed, MiCom began to develop and contract for hardware--seekers and illuminators--that could be put into the field, perhaps to improve the accuracy of artillery fire. Martin Marietta (Orlando Division) received a contract for pulse laser development in June 1964, and in May 1965 received a follow-on contract for two lightweight pulsed laser illuminators.

In September 1964, Texas Instruments engineers were asked by MiCom if they could adopt the Shrike (an antiradar, air-to-ground missile developed by Texas Instruments to home in on enemy radar transmissions) to track on the reflected pulsed laser radiation; Texas Instruments received a $50,000 contract to explore this possibility.

Thus, by the early part of 1965, MiCom had developed the conceptual basis and a portion of the hardware for what was to become the laser guidance system. The Army, however, decided to reduce the funding of the laser guidance research because of the immediacy of the Vietnam conflict and what the Army perceived would be Vietnam combat requirements. The laser guidance efforts at Huntsville had been nominally directed toward antitank warfare and, during the early stages of the Vietnam conflict, the enemy was simply not deploying tanks. There seemed to be an insufficient number of worthwhile targets for a ground-force laser-guided weapon system to illuminate and destroy, so the Army decided to concentrate its laser research on the RTDP system.

Salonimer and his colleague, Norman Bell, however, were advocates not easily dissuaded. When the Army chose to place the project on "the back burner," Salonimer and Bell, with the approval of their immediate superiors, offered the results of their research to the other services. Salonimer and Weldon Word (of Texas Instruments' Missile and Ordnance Division) approached John E. Short, a civilian project officer in the Limited War Deputate of Aeronautical Systems Division (ASD), in early 1965 with their research on laser guidance. Short recognized the general possibilities of laser guidance and, after a demonstration of the RTDP, asked MiCom to organize a tri-service meeting on laser applications. This meeting was held at Martin's Orlando facility in early April 1965.

PROJECT 1559: THE QUICK-REACTION CONCEPT

In early 1964, Lt. General James Ferguson, then Deputy Chief of Staff for Research and Development, Hq USAF, received a suggestion from a member of his staff that it would be efficacious to promote relatively small programs whose purpose would be to translate technological advances to possible weapons systems within a short time horizon--approximately six months to a year. At this time the Vietnam conflict was beginning to become serious, but it was not the only reason for setting up a contingency funding system for short-term R&D. A second reason was to develop weapons systems as quickly as possible with a minimum of procedural delays, in other words, to expedite procedures for low-cost developments. With the assent of the Director of Defense Research and Engineering (DDR&E) and the Air Force Chief of Staff, Project 1559, "Limited War Equipment Tests," was set up in FY 1965 as a virtual "petty cash" or Quick-Reaction fund for short development programs addressed to immediate requirements; the first funding level of $815,000 was to grow to over $8,700,000 in FY 1970.*

Continuing the same line of thought, General Ferguson approached General Bernard Schriever, then Commander of the Air Force Systems Command (AFSC), with the suggestion that AFSC sponsor a small research group under ASD, with Ferguson's staff assisting in the designation of the personnel. Although initially skeptical, General Schriever agreed and, in mid-July, the Directorate of Technical Assistance and Support--or, as it was more generally known, Detachment 5--was organized and stationed at Eglin AFB under the command of ASD's Deputy for Limited War.

Detachment 5 was chartered to provide "AFSC resident technical assistance and support to the commanders of the Tactical Air and Special Warfare Centers. Specifically, the directorate was to improve the System Command's response to immediate tactical operational needs, and identify the technological level required for future missions."†

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*A list and evaluation of the programs undertaken by Project 1559 is found in Raymond R. Stasiak, *History of Project 1559*, Technology Directorate, Deputy for Tactical Warfare (undated).

†Cited in Phillip H. Pollack, "Management Perspectives," *History of the Aeronautical Systems Division, January-December 1964* (U), Historical Division, Information Office, Aeronautical Systems Division, Wright-Patterson Air Force Base, Air Force Systems Command Historical Publication Series 65, ASE-20, 1965, p. 16 (Confidential).

Detachment 5 was commanded by a senior Air Force colonel, Joseph Davis, who had been a reconnaissance pilot in the Second World War, a fighter pilot in Korea, and Chief of the Air Force's Operational Readiness Inspection team in Europe before going into R&D.

Unofficially, Detachment 5's focus was originally to be on command and control problems. However, its staff expanded the scope to include virtually anything they considered interesting and that could be of immediate use. To illustrate their range of efforts, Detachment 5 personnel identified an assortment of R&D efforts ranging from forward-based command and control systems to new parachute extraction techniques.

AIR FORCE INTRODUCTION TO LASER GUIDANCE

Detachment 5 had been created by the Air Force to explore possible applications of new technology to developing new weapon systems or adopting and improving systems within the current inventory. Colonel Davis helped to implement this charter by visiting various aerospace and defense contractors to review their research. While at Martin-Orlando in late 1964 he witnessed a demonstration of the Martin pulsed laser illuminator and seeker and was immediately impressed by the laser tracking system. Returning to Eglin, he and members of Detachment 5 discussed potential applications of the system at length, especially the possibility of using the laser guidance system on a free-fall bomb. Therefore, when Salonimer and Bell briefed MiCom's work with laser seekers to the tri-service meeting in Orlando (1-2 April 1965), their findings were of particular interest to Colonel Davis. Colonel Davis asked about the status of laser guidance technology and if it could be employed for tactical bombing; specifically, was the available laser knowledge sufficient for the Air Force to initiate the development of a laser guidance system for missiles or bombs? Bell and Salonimer responded positively: the necessary technology was available and the laser seeker was capable of serving as a guidance device for missiles and artillery.

Davis envisioned a free-fall gravity bomb with a guidance system that could direct the bomb toward an illuminated target. The briefing of the Redstone research findings provided many of the necessary details required to confirm Davis' concept of a laser guidance mechanism attached to gravity bombs.

THE FEASIBILITY PROTOTYPE CONTRACTS

Colonel Davis returned to Eglin and indicated interest in receiving proposals for a feasibility prototype of a laser seeker unit compatible with an M-117 (the Air Force's standard 750-lb bomb) from Texas Instruments (TI), the Autonetics Division of North American Aviation (NA-A), the Orlando Division of Martin-Marietta, and Westinghouse-Baltimore, all of whom had been active in laser research. Colonel Davis advised them that he had authorization to release $100,000 with only ASD approval necessary for the most promising proposal of a laser seeker system. Westinghouse decided not to submit a proposal and Colonel Davis has described the Martin bid as inadequate. In May 1965, he forwarded the NA-A and TI proposals to the Deputy for Limited War, ASD, for approval, expressing a strong preference for the TI design (approximately $98,000).*

To help distinguish between the two prototypes, a brief review of the principles underlying laser-guided bombs is in order. A target is "illuminated" by a laser beam directed from an aircraft. The pilot of the munitions delivery plane must release his bomb within a "basket" (which is defined by the field of view of the laser sensor and the maneuverability of the bomb) in order for the guidance mechanism to operate correctly. Basically, both the TI and NA-A prototypes of the laser seeker unit were designed around an optical assembly that gathered and focused the reflected laser energy onto the surface of a detector that was divided into four quadrants. A preamplifier compared these quadrants to determine which received the most energy; this information was then used to initiate the bomb's guidance mechanism.

The basic mechanical differences between the TI and NA-A versions of the LGB feasibility prototypes were in the guidance mechanisms. (See Fig. 1 for the initial configurations of both models). The TI version included an aerodynamically stabilized seeker head (modified from their

*Detachment 5 was a research organization; it had no contracting authority.

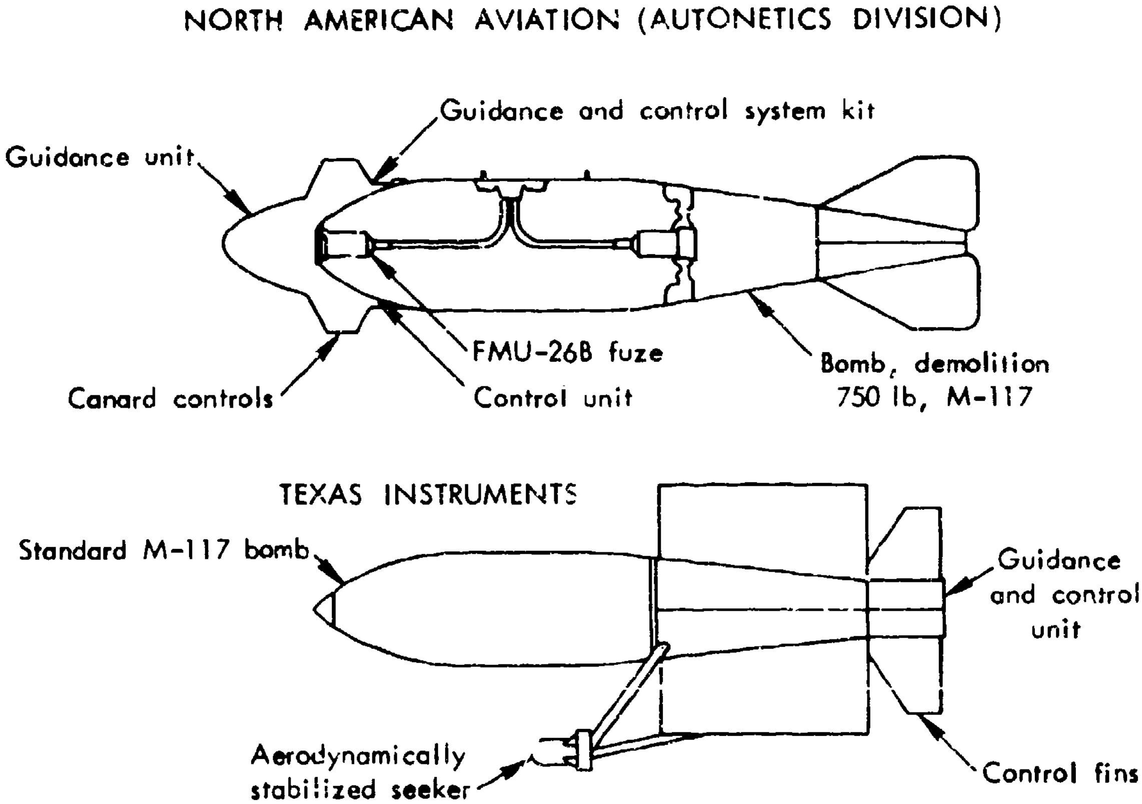

Fig. 1 — Initial configurations of LGB prototypes

Shrike missile) and a so-called "bang-bang" control system, both of which were outgrowths of TI's earlier work with the Army's pulsed laser system. The seeker head was mounted on a strut attached to the bomb's fin. The bang-bang guidance mechanism had no adjustment for the magnitude of the off-axis error; that is, the guidance mechanism's control fins were fully deflected when the seeker unit determined that corrective action was necessary. A bomb with the bang-bang control system would trace an undulating glide path rather than a smooth continuous arc toward the target. In addition to the aerodynamically stabilized seeker head and the bang-bang guidance, a third distinguishing TI feature was the rear control fins. These fins were supplied intact from TI's Shrike production line.

The initial Autonetics LGB test units employed a stabilized platform with a seeker head that had been adapted from the Sidewinder air-to-air missile. Based upon Autonetics' laser guidance research for MiCom, a "proportional control" guidance mechanism was used on the bomb in which the control fins can be set at a number of different angles depending on the magnitudes of the off-axis signal received during the bomb's descent. This would more closely approximate the continuous ballistic arc of an unguided bomb than one with bang-bang control mechanisms. Finally, the NA-A LGB had front canard control fins in conjunction with its stabilized seeker head.

There were thus two strikingly different laser-guided bomb prototypes proposed. The prevalent belief at the time among ASD and MiCom personnel was that proportional guidance was the more promising guidance system.* Earlier tests conducted by the Army and the Navy had suggested that efficient guidance could not be achieved if the seeker only generated directional information without magnitude. The Autonetics proposal was an extension of its work done with the Army and appeared to be a logical progression of the state of the art. However, although proportional guidance was considered more feasible, it was mechanically more complicated than the bang-bang system. Furthermore, the Autonetics model required roll stabilization in conjunction with its platform-mounted seeker. The TI bang-bang control system with the aerodynamically stabilized seeker was a less complex but unproved guidance system. In addition, the TI LGB prototype was markedly cheaper, costing only one-third as much per test unit as the NA-A counterpart. The choice between proposals was hardly clear-cut; put simply, ASD was presented with a high-cost/medium-risk (NA-A) design and a low-cost/high-risk (TI) design.

The proposals were reviewed by the Deputy for Limited War, with Salonimer of MiCom providing technical assistance. Rather than choose

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*This preference is implicit in ASD missile development programs. See *Development Plan: Advanced Air To Surface Missile Guidance Technology, 679A Program* (U), Directorate of Advanced Projects, Aeronautical Systems Division, Wright-Patterson Air Force Base, February 1969 (Secret).

between TI and NA-A on the basis of paper studies and proposals, ASD decided to conduct a prototype competition between the two designs. Revisions resulting from further discussions had now brought both contractors' proposals over the $100,000 threshold, so higher level approval was necessary. Short exercised his working relationship with the Southeast Asia Special Projects Division in DCS/R&D, which had access to Project 1559 funds and could provide money much quicker than the standard procurement sources. The Division Chief seconded Short's assessment of the potential of laser-guided bombs; Major General Andrew J. Evans, the Director of Development under DCS/R&D, Hq USAF, was similarly impressed, and allocated the necessary funding for both feasibility test programs. On 30 June, the Armament Laboratory at Eglin received permission to contract both the TI and NA-A feasibility prototype proposals; however, the fixed-price incentive contracts to conduct feasibility studies were not signed until 16 November 1965:

Table 1

FEASIBILITY STUDY CONTRACTS, 1965

Company	Dollar Amount (× 1000)		Test Bombs	
	Planned	Actual	Guided	Unguided
North American-Autonetics	442	450	5	3
Texas Instruments	264[a]	266	9	3

[a]Although the TI bid was originally about $98,000, the contract was substantially revised and adjusted upwards to include such additional factors as wind tunnel tests, recorders on the bombs, and flutter and divergence analyses.

THE FEASIBILITY PROTOTYPE TESTS

The testing of the prototype units began in mid-1966 and was performed at Eglin AFB by personnel at the Air Proving Ground Center (APGC) with the Air Force Armament Laboratory in charge of the project (both test series are summarized in Table 2). Detachment 5 had lost its personnel in a reorganization of ASD, but many were still stationed at

Table 2

FEASIBILITY PROTOTYPE TEST DROPS

NORTH AMERICAN-AUTONETICS

Date	Miss Distance (ft)	Remarks
5 Oct 66	975	Roll stability problem; control system changed.
14 Dec 66	82	Control section rotated on bomb inflight; change made to secure it.
17 Jan 67	24	Successful drop.
23 Jan 67	52	Error large probably because of high platform spring load rate.

SOURCE: 1st Lt. William N. Cooney, USAF, and 1st Lt. David R. Floyd, USAF, *Engineering Evaluation of the Autonetics' Laser-Guided Bomb*, Directorate of Tests, Air Proving Ground Center, Eglin Air Force Base, APGC-TR-67-52, May 1967, p. 13.

TEXAS INSTRUMENTS

Date	Miss Distance (ft)	Remarks
28 July 66	148	Boresight error; marginal maneuverability.
11 Aug 66	78	Low roll rate, marginal maneuverability; changed to larger fins and added roll tab.
26 Aug 66	488	Electronics failure.
4 Oct 66	190	Switch failure; seeker moved to nose on remaining test bombs.
28 Oct 66	27	Successful drop.
19 Nov 66	27	Seeker head rotated relative to control fins.
23 Nov 66	12	Ballistic aim-point offset on last two drops.
15 Dec 66	10	Crude airborne laser illuminator used.

SOURCE: 1st Lt. William N. Cooney, USAF, and 1st Lt. David R. Floyd, USAF, *Engineering Evaluation of Texas Instruments' Laser-Guided Bomb*, Directorate of Tests, Air Proving Ground Center, Eglin Air Force Base, APGC-TR-67-42, April 1967, p. 16.

Eglin AFB, including Colonel Davis, who was named the Director of Testing and later Vice Commander, APGC.

Autonetics began testing in October 1966. Their first drop suffered from roll stability problems and had a miss distance of 975 ft; as a result, the roll control system was redesigned. Two months later, the second Autonetics bomb was dropped and the miss distance was reduced to 82 ft. The results of this test were discounted, however, becsuse the bomb's guidance and control mechanisms became physically disengaged during its descent and the flight was essentially ballistic rather than guided. As a result, changes were made to the bomb's mechanical fastenings. The third Autonetics drop, considered completely successful, had a miss distance of approximately 24 ft. On the fourth and final Autonetics drop, there was a miss distance of 52 ft.* Autonetics engineers later posited that this error was due to a platform characteristic that had not yet been recognized.

The Texas Instruments test series began in the summer of 1966. The first two TI drops had miss distances of 148 ft and 78 ft, respectively, which were attributed to boresight errors and marginal maneuverability. Before the third drop, quality control changes were made on the sensor itself to improve boresight precision, and larger control fins and roll tabs (to induce a higher roll rate) were added to provide greater maneuverability. The third and fourth TI drops experienced failures within their electronic circuitry, resulting in essentially no guidance to the bombs. After the fourth test, the TI engineers made a major structural change in their test units by removing the seeker head from the fin strut and placing it on the nose of the bomb; exterior cables were extended back from the seeker unit to the rear control fins. Although this necessitated an alteration in the fuzing arrangements, the test results of the remaining four units substantiated TI's modification decision. The fifth drop--with a miss distance of only 27 ft--was considered successful and produced no changes in kit design. After the

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*Autonetics did not test its fifth unit, nor did TI test its ninth unit. Although there was no official explanation, test personnel explained that they believed that they had sufficient data from the four Autonetics and eight TI drops and that the final unit tests thus were not considered necessary.

sixth drop (miss distance of 27 ft), the seeker head was rotated relative to the control fins; this improved the dynamic response of the control system and resulted in miss distances of only 12 and 10 ft on the last two drops. The final drop was of particular interest because it was the only drop in either series in which the target was illuminated by an airborne laser designator. (All previous drops had been designated by Martin ground lasers that MiCom had lent the APGC; they were tripod-mounted about 1000 ft downrange.) Carried aloft in an O1-E, the airborne laser successfully illuminated the target for an LGB delivered by an F-4; the miss distance was the smallest in the entire series.

Thus, by the end of the feasibility prototype test series, both the Texas Instruments and the Autonetics LGB prototypes had proven the feasibility of the laser guidance concept. This was particularly important for the lower cost but higher risk TI model. It should be noted that the first four drops in both manufacturers' tests provided little difference in bombing accuracy on which to choose between the two prototypes. The TI model was able to demonstrate its superior accuracy only in the additional four test drops that its lower unit cost made possible. It is also notable that the additional number of test units permitted the TI engineers a wider range of design options with which to experiment until a satisfactory design was achieved.

In addition to providing data for design modification, the feasibility tests provided valuable information on operational capabilities. For example, major delivery differences were recognized between the NA-A LGB and the TI version. The NA-A LGB gimbal configuration required the bomb to be carried on the aircraft with the seeker head caged and pointed along the bomb's longitudinal axis. This limited the aircraft's turning capabilities because seeker head damage could occur above a specified turn rate. Furthermore, in order for the NA-A seeker to acquire the illuminated target, it was necessary for the delivery aircraft to aim itself directly at the target until the seeker acquired the target and alerted the pilot to release the bomb. This not only required aircraft modification, but the launch sequence required at least 10 sec, thus necessitating special delivery tactics and presumably exposing the aircraft to prolonged ground fire.* In comparison, the TI gimbal-mounted sensor allowed an unmodified aircraft to deliver the weapon using the tactics that would be employed with conventional bombing because its seeker was able to acquire its designated target after it was released from the delivery aircraft.

THE ENGINEERING PROTOTYPE

By the end of 1966, the Texas Instruments and Autonetics laser-guided bombs had demonstrated their feasibility as weapon systems. The project was transferred from the Deputy for Limited War, ASD, to Hq USAF and Hq AFSC for further action. The engineering prototype contract was not signed with TI until May 1967. The feeling of some of the Eglin test personnel was that this delay, given the highly successful test evaluations, was unnecessarily lengthy; they suggested that it was due to a lack of support at Aeronautical Systems Division or problems in obtaining funding within the Air Staff. However, as we shall see, the primary reason for the delay was the transition from a quick-reaction, prototype project to the more standard acquisition procedures involving engineering development, contract definition, and operational requirements.

On 12 January 1967, Brig. General Joseph Cody (Chief of Staff, AFSC) recommended to Hq USAF that 50 additional TI bomb kits for the M-117 bomb be procured and that a kit for the M-118 (3000-lb) bomb be developed. This request was received by the Southeast Asia Special Projects Division for continued funding under Project 1559. However, it was decided that the laser guidance program was too far advanced in its development to continue to be funded under the Quick Reaction concept.

The Office of the Assistant Secretary of the Air Force for Research and Development had been informally advised of the progress of the LGB tests. Upon receiving a copy of Cody's letter, the Assistant Secretary's staff notified Lt. General Joseph Holzapple (then DCS/R&D) that $500,000 from current resources was to be allocated to the laser bomb

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*Cooney and Floyd, *Engineering Evaluation of the Autonetics' Laser-Guided Bomb*, p. 18.

project; the source was left unspecified. The project was continued under the direction of Major General Andrew Evans, who transferred the project supervision to the Armament Division of his Directorate. The $500,000 was reprogrammed from chemical/biological warfare monies and on 19 January, Hq AFSC was notified that the money had been assigned to the laser-guided bomb project for the purchase of the 50 TI seeker kits.

On 24 January, AFSC was directed by the Armament Division within Hq USAF to continue testing the TI seeker kit, to encourage North American-Autonetics to develop its model with its own funds, and to provide the Air Staff with development papers (form DD 1498) that would specify the number of items to be procured, a schedule for test and delivery, and a confirmation of the funds required. DD 1498 was an interim, abbreviated development plan and was the minimum essential documentation required by the Defense Department for the approval of development fund release. The formal reprogramming of the $500,000 was completed with notification of AFSC by the Assistant for R&D Programming, DCS/R&D, on 31 January 1967.

On 2 February, the Armament Division received the completed DD 1498 but was advised that the cost figures for the TI seeker kit were not yet confirmed. Furthermore, it was becoming clear within the Air Staff that the $500,000 would not cover the cost of the 50 TI kits and additional work by Autonetics. As one Air Staff participant recalled, "We at Headquarters suspected that there were major differences of opinion within the Systems Command agencies on how this program should be developed. It seemed apparent that more homework was needed within AFSC before TI would sign a contract." This suspicion was confirmed when, on 18 February, Major General Charles Terhune (Commander, ASD) recommended to AFSC that, in addition to the planned purchase of the 50 TI seeker kits, a Request for Proposal be issued to both TI and NA-A for 50 additional kits and that a Southeast Asia Operational Requirement (SEAOR)* be drafted and sent to the 7th Air Force for consideration.

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*In June 1965, Hq USAF coordinated many offices within the Air Force (e.g., the Deputy for Limited War and the Southeast Asia Special Projects Office) and initiated a system to insure that immediate attention was paid to operational requirements emanating from the Southeast

This was followed up three days later with an AFSC message to Hq USAF stating that AFSC was proceeding with contract talks with TI for the desired 50 kits needed for engineering development; it also recommended procuring 25 kits from Autonetics. The total cost of the procurement was projected to be $1.35 million for the TI kits and $550,000 for the Autonetics kits.

During the same time period, the Air Force had decided to put the MK-84 2000-lb bomb back into production. Tests at Holloman AFB had demonstrated that for targets in Southeast Asia, the MK-84 had a superior mix of destructive, delivery, and penetration capabilities compared to either the M-117 or M-118 munitions. On 2 March, Air Staff suggested to AFSC that the MK-84 be the munition used for the TI laser seeker unit following the 50 engineering development test items.

On 5 April, AFSC formally initiated contract talks with TI and on 20 May, a contract for $1.35 million was signed for 50 TI seeker kits for engineering and testing; these units were to be a mix of the M-117s and the MK-84s. The additional $850,000 had been reprogrammed from within the Armament Division in early April.

THE ACQUISITION DECISION

On 18-19 June 1967, personnel from Hq AFSC, ASD, Air Force Armament Laboratory, and the Tactical Air Warfare Center briefed members of the Air Staff. These briefings presented three alternatives for laser-guided bomb production that traded off varying degrees of developmental risk for operational dates. An early operational date had become especially important because an operational requirement from Southeast Asia (SEAOR 100) had been received in late March by ASD and the Air Staff that emphasized the need for greater bombing accuracy;

Asia theater. The 7th Air Force would prepare a Southeast Asia Operations Requirement (SEAOR) which would be sent to ASD and Hq USAF and AFSC where it would become a priority development item. By late 1967, the SEAOR had become very important for obtaining R&D money for small-scale, Vietnam-oriented developments. Therefore, it was not surprising that research personnel were very active in advising the operational commands in Southeast Asia what technology and applications were available and, on occasion, prepared draft SEAORs for the 7th Air Force to transmit back to AFSC requesting specific research projects.

it specifically suggested the laser guidance system as a possible solution.* This need was reinforced by pressure from the operations side of the Air Staff; Secretary of Defense McNamara was reluctant to grant additional targets in Vietnam because, as he pointed out, the Air Force had not been able to destroy all the ones he had allocated. The three procurement options were:

1. *Minimum Risk Delayed Operational Date.*† Purchase 50 TI plus 25 Autonetics laser kits and conduct an additional engineering prototype test period between September and December 1967. One contractor would be chosen in January and operational testing and development would begin immediately. Deployment in Vietnam would not be until October 1968.
2. *Medium Risk Early Operational Date.* TI would be granted a $17.5 million contract in July with authorization to produce to the limits of their existing plant capacity. An additional $1.5 million for tooling costs would be released in October and the full program would begin in December with an additional $8.5 million.
3. *Maximum Risk Earliest Operational Date.* TI would be immediately selected with an authorization to produce to the present plant capacity for two months. Long lead time and tooling costs ($1.5 million) would be released in July and full production would be scheduled to begin in October with the release of an additional $13.7 million.

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*The genesis of SEAOR 100 was, as suggested, ASD. In order to expedite LGB development, the ASD staff prepared a draft SEAOR which was personally delivered to the Commander of the 7th Air Force in Vietnam. Although there were serious reservations within the 7th Air Force on the efficacy of a laser guidance system, a short time later Hq USAF and Hq AFSC received SEAOR 100.

†The headings are those of Clarence J. Geiger, "Project Pave Way," *History of the Aeronautical System Division, January 1967-June 1968* (U), Volume 1, *Narrative* (U), Historical Division, Information Office, Aeronautical Systems Division, Wright Patterson AFB, Air Force Systems Command Historical Publication Series 69, ASE-3, 1969, pp. 117-118 (Confidential).

It is notable that the first option called for additional testing of both contractors' prototypes even though the TI model had demonstrated superiority in the first feasibility test and additional funds had been contracted to TI.

Major General Andrew Evans selected the second alternative and forwarded the selection to the Chief of Staff of the Air Force (CSAF) for final approval. The laser-guided bomb was assigned an extremely high funding priority rating and designated Project Paveway. A series of Project Paveway liaison officers were designated within AFSC, ASD, TAC, and the relevant offices within the Air Staff to monitor the project; their work was coordinated within General Evans' Directorate.

On 17 July, the CSAF ordered that all further contractual work by North American-Autonetics on their laser-guided bomb models be discontinued. At the same time, AFSC was directed to prepare technical development plans including consideration of combat deployment for laser, electro-optical, and infrared guidance systems. Finally, CSAF confirmed General Evans' choice of the second procurement strategy for the laser system. On 20 July, AFSC formed the Paveway project office within ASD. There are two items of particular interest in the CSAF directive. First, the family of guidance systems under consideration had been tripled. The Air Staff was now considering two types of guidance seekers in addition to the laser: infrared and electro-optical. This was largely in response to fears voiced within the Air Staff Directorate of Operations that because laser guidance required the designating aircraft to loiter over the target, the aircraft would be exposed to prolonged antiaircraft fire. The electro-optical and infrared guided bombs offered a launch-and-leave capability, thus reducing aircraft exposure without sacrificing bomb guidance. Therefore, development of the electro-optical and infrared guided bombs was initiated. Also, the Air Force was willing to delay the definition of the technical specifications and operational requirements for the laser-guided bomb system until July 1967--a full year and a half after the original feasibility contracts were signed.

A short time later (24 July), the Assistant Secretary of the Air Force for R&D, Dr. Alexander H. Flax, wrote a memorandum* to the Chief

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**Ibid.*, p. 119.

of Staff of the Air Force recommending that developmental emphasis be placed on the laser-guided bomb and that the LGB program should not be integrally tied to the development of the other guided munitions. Assistant Secretary Flax added that although he recognized that the weapon system was needed immediately, a complete and thorough program of aircraft and weapon integration tests should be undertaken and all certifications met. In other words, the usual planning and coordination processes were now considered desirable in order to assure an early operational date for the LGB. These recommendations were forwarded as directives from CSAF to Hq AFSC on 2 August; the CSAF especially emphasized that each mode of guidance should be considered as a separate--albeit related--development program. At the same time, CSAF sanctioned the use of special expeditious procedures if normal channels and methods were considered to be too slow.

On 24 August, USAF revised AFSC's procurement authorization for the production phase of the laser-guided bomb program. Procurement was directed towards obtaining a large number of MK-84 laser guidance kits in conjunction with a number of M-117 kits; the M-118 bomb was considered too limited in supply and potential usage and its seeker kit was de-emphasized. The purchase of eight laser illuminators and three modified F-4 aircraft canopies was deleted. A $3.25 million funding ceiling was placed on the development program.

On 21 September, Hq USAF issued the Requirements Action Directive (RAD) that listed the desired performance characteristics of guided bombs--two and a half years after MiCom had briefed the Air Force on the feasibility of a laser guidance mechanism, almost two years since the signing of the feasibility prototype contracts, and nearly nine months since the tests demonstrating the feasibility of the system had been completed. The CEP was to be no greater than 25 ft; the bombs with modification kits would be compatible with both the F-4 and F-111;* guidance reliability was to be at least 80 percent; delivery could take place from either a dive mode or a level run; and operational deployment

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*The F-111 compatibility requirement was later dropped.

would be no later than June 1968.* Not only were the requirements defined months after the initial testing had demonstrated feasibility, but development and major procurement decisions had gone so far that the acquisition directive stated the system was to be operational within nine months.

In late 1967, a series of cost effectiveness analyses for laser-guided bombs was prepared by the Operations Analysis Office, Hq USAF (AFGOA), on the data from the Eglin tests. The analyses, based on the preference criteria of least dollar cost and fewest sorties, demonstrated that the LGB was more cost effective (in terms of targets destroyed per dollar cost) than unguided ordnance and that it required the fewest number of sorties for 23 out of 25 target categories (the two exceptions were supporting a rifle company in South Vietnam and destroying revetted aircraft in North Vietnam).

On 15 January 1968, Hq USAF issued Development Directive Number 69, which approved a production program of $4.7 million for 293 seeker kits for fiscal year 1968, at a unit price of approximately $16,000. This was well within the limits of the budget option chosen by the Air Force the previous July. These funds were from the Air Force's munitions budget. Because of the shortage of munitions resulting from the growing Vietnam involvement, approval for the LGB purchase had to be secured from the highest levels of the Air Force and the Office of the Secretary of Defense. The AFGOA analyses were presented in the course of securing the necessary approvals.

The approval of the production contract, in effect, marks the termination of the research and development process that resulted in the laser-guided bomb, although Texas Instruments effected a series of modifications on the basic seeker and control design during the production of the kits using Value Engineering Change Proposals (VECP); for example, VECP procedures were used to substitute aluminum components for the original Shrike stainless steel parts. The VECP alterations, of

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*Ibid., pp. 120-121.

course, were intended to drive the production cost down rather than to basically reconfigure the system.*

ENGINEERING PROTOTYPE DEVELOPMENT AND DEPLOYMENT

The Texas Instruments LGB system began the engineering prototype test series at Eglin AFB in November 1967. Both the M-117 and the MK-84 were included in these tests, which consisted of over 50 drops. This series was to be more than a brief test of production line items. Significant problems were identified and corrected, and a major reconfiguration--the use of canard control fins--was tested and adopted. Furthermore, beginning in April 1968, pilots from the Tactical Air Warfare Center (TAWC) participated in the formal Operational Test and Evaluation process; the participation of TAWC pilots meant that delivery tactics could be devised and practiced prior to theater evaluation so that when the laser-guided M-117s and MK-84s began to undergo evaluation in Southeast Asia, the crews were already trained in the use of the system.

Major design modifications were continued into the engineering prototype test phase.† Air Staff's request that the MK-84 be used had been relayed to the Texas Instruments engineers, who had already been experimenting with adopting the laser guidance kit to the M-118. The emphasis on the MK-84 led TI to significantly alter the design. The rear control fins were removed and replaced by front canard control fins: this change eliminated the necessity of exterior cabling running along the length of the bomb from the seeker unit to the guidance mechanism since they were now both in the front of the bomb. This reconfiguration was possible on the TI version because the aerodynamically

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*Mass production and a number of VECPs have been successful in reducing the unit cost. *Aviation Week* cites a $3100/unit cost for the laser guidance system in 1972 ("U.S. Guided Bombs Alter Viet Air War," *Aviation Week and Space Technology*, 22 May 1972, p. 17); this cost figure has been reduced since then.

†The tests beginning in November 1967 consisted of 36 M-117 tail control kit drops, and 2 M-117 and 16 MK-84 canard control fin drops; they were conducted at Eglin AFB and Southeast Asia.

stabilized seeker head did not require roll control. Locating the entire guidance package in the front of the bomb also made the laser seeker kit adaptable across a wide range of standard Air Force munitions.

The two major problems that were corrected during these tests concerned the internal wiring of the seeker and multiple laser reflection. The first problem was traced to a premature battery activation of the seeker system by an arming wire and was relatively easy to correct. The problem created by multiple laser reflection, however, was more difficult to remedy. A portion of the laser beam directed from the aircraft through the canopy was reflected from the canopy's outer surface back to the inner surface and then to the ground. This reflection produced a second, albeit weaker, laser-illuminated spot (a "satellite") on the ground that might cause the seeker to acquire and track the satellite instead of the illuminated target. The identification of this phenomenon was the most difficult aspect of this problem. Once the satellite spot was identified as the source of the trouble, it was corrected by reducing the sensitivity of the seeker so that it would no longer acquire the satellite spot.

Only a very few MK-84s were tested at Eglin prior to being sent to Southeast Asia for theater evaluation, which took place from May to August 1968.* These evaluations substantiated the increased accuracy and destruction claims made for the use of the canard fins and the MK-84. The evaluations also argued for the discontinuation of the M-117 in favor of the MK-84; the underlying rationale was that if a target were important enough to warrant the use of an expensive laser guidance unit, the bomb with the greater destructive and penetration capabilities was preferable. As a result of the SEA evaluations, the Air Force contracted to purchase 1000 MK-84 laser kits in addition to the January 1968 production order. Due to Presidents Johnson's and Nixon's restrictions on American bombing of military targets within North Vietnam from 1968 through 1971, LGBs found only limited use from the time they were added to the Air

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*The Southeast Asia evaluations are described in Melvin F. Porter, *Second Generation Weaponry in SEA* (U), Project CHECO Division, Pacific Air Forces, 1970 (Secret); and Col. A. W. Blizzard, USAF, *Paveway Laser-Guided Bomb System: Final Report* (U), USAF Tactical Air Warfare Center, Eglin Air Force Base, TAC Test No. 67-92, January 1969 (Secret).

Force inventory; this was also true for the electro-optical guided bombs. Because of the scarcity of high-value point targets outside North Vietnam, the precision-guided bombs were used mostly for interdiction and the suppression of enemy antiaircraft fire. However, once President Nixon removed many of the restrictions limiting bombing of targets within North Vietnam in 1972, the accuracy provided by laser and electro-optical guided bombs and their resultant effectiveness became public knowledge.* Referred to by the press as "smart bombs," they provided the Air Force with a precision bombing capability to strike and destroy virtually any target that could be seen by the pilot and acquired by the seeker.†

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*See "U.S. Guided Bombs Alter Viet Air War," and "'Smart' Bombs Wreck Viet Bridges," *Aviation Week and Space Technology*, 22 May 1972, pp. 15-16, and 27 May 1972, p. 17, respectively.

†See Ted Sell, "The Smart Weapons--Landmark in Accuracy," *The Los Angeles Times*, 9 July 1972, Section J, p. 4; this article is mostly on the electro-optical guided bomb.

III. OBSERVATIONS

Before summarizing the study's major findings, it is important to reemphasize that this report is basically a case history, with all the inherent strengths and weaknesses of that genre. As Marschak has pointed out, a "strong subjective element often enters into the interpretation of a history....\"* However, it is possible to highlight the main factors that made the laser-guided bomb a successful development and, in conjunction with other R&D case studies, contribute to the empirical evidence basis for a better understanding of general R&D processes. Also, the procedures used in the LGB development might prove to be directly applicable to future generations of PGM development.

There is another caveat to the findings. The LGB development was relatively low cost and, for the first part of its history, seemingly enjoyed a low profile. These combined to give the development personnel exceptional freedom of action; indeed, some would argue that this low profile was the key to the entire development. However, this was not the case. The project did appear to have a low profile and was low cost, but other inexpensive projects with low profiles have been a great deal less successful; i.e., a low profile is not, by itself, sufficient to guarantee a successful development. While these were not irrelevant factors, as we shall see, they were not the primary reasons for the expeditious manner in which this weapon system was developed.

The research suggests that there were at least six features of the development that contributed in an important way to its success. These are are:

- Competitive prototype development
- Early and repeated testing of system hardware
- Technology/requirements interaction
- Incremental development

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*Marschak, "The Role of Project Histories...," in Marschak, Glennan, and Summers, *op. cit.*, p. 49.

- Delegation of development decisions
- Availability of contingency development funds.*

It should be emphasized that these features are highly interrelated and mutually reinforcing: e.g., one cannot have prototyping without testing; reconfiguration of a design would be an arduous process unless the relevant decisions can be made on the spot; and test results are necessary for incremental development. Although each will be discussed individually, it should be recognized that, with the partial exception of the last item, they should be viewed as a developmental policy package.

COMPETITIVE PROTOTYPE DEVELOPMENT

Prototype development is not novel to the Department of Defense. Employed before and during the Second World War and endorsed recently as a desirable acquisition strategy by the Fitzhugh Blue Ribbon Committee and by Rand researchers,† prototyping is being at least partially reintroduced. In the past, it has been generally characterized by high priority projects requiring major technological advances.‡ In testimony delivered before the Senate, former Deputy Secretary of Defense David Packard distinguished between two types of prototyping:

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*With the exception of the last item, these form the thrust of the so-called "Five Rules of a Good Development Policy"; see B. H. Klein, W. H. Meckling, and E. C. Mesthene, *Military Research and Development Policies*, The Rand Corporation, R-333-PR, December 1958, pp. 4-5.

†Blue Ribbon Defense Panel, Appendix E, "Staff Report on Major Weapon Systems Acquisition Process," *Report to the President and the Secretary of Defense on the Department of Defense* (Washington, D.C.: Government Printing Office, July 1970), p. 5; see also Perry *et al.*, *op. cit.*, Sec. IV.

‡See Thomas K. Glennan, Jr., "Issues in the Choice of Development Policies," Marshall, Glennan, and Summers, *op. cit.*, p. 47. Rand has an extensive literature on prototype development; see Klein, Meckling, and Mesthene, *op. cit.*; B. H. Klein, T. K. Glennan, Jr., and G. H. Schubert, *The Role of Prototypes in Development*, The Rand Corporation, RM-3467/1-PR, 1971; and Robert L. Perry, *A Prototype Strategy for Aircraft Development*, The Rand Corporation, RM-5597-1-PR, July 1972.

> The first is the *advanced development* prototype, where a proposed new weapon would be designed, built, and tested to confirm that the technology is feasible and that the design does indeed have utility against a requirement. In our approach, an advanced development prototype would be completed and evaluated before a commitment is made to full-scale development and, of course, to production. The second kind is a production, or an *engineering* prototype. This type of prototype is intended both to assure that we have the engineering problems solved and also to permit thorough testing and evaluation of a system.*

Competitive prototyping differs from the standard prototype procedures in that there are at least two competitive systems being concurrently developed for testing and a specific decision has to be made as to which system will be chosen for continued development and/or production. Frederick Scherer underlines the importance of the development of competing systems within the general strategy of prototype development by pointing out that "this competition between substitutes affords the government two main benefits ... the statistical benefits and the behavioral benefits."† The first serves as insurance against the uncertainties inherent in weapon system development:

> By sponsoring the more or less concurrent development of two or more competing weapon systems or key subsystems which represent potential substitutes for filling a presumed military need, the government can hedge against these uncertainties, reducing the risk of being committed to an unsatisfactory approach and increasing the probability of obtaining an acceptable end product.‡

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*Testimony before the Committee on Armed Services, U.S. Senate, *Advanced Prototype*, 92nd Congress, 1st Session (Washington, D.C.: Government Printing Office, 9 September 1971), p. 3; emphasis added. Also see Deputy Secretary Packard's testimony to the Subcommittee of the Committee on Appropriations, U.S. House of Representatives, *Hearings, Department of Defense Appropriations, Use of Prototypes in the Development and Procurement of Weapon Systems*, Part 9, 92nd Congress, 1st Session (Washington, D.C.: Government Printing Office), pp. 515-547.

†F. M. Scherer, *The Weapons Acquisition Process: Economic Incentives* (Cambridge: Harvard University Press, 1964), p. 19.

‡*Ibid.*, p. 19.

The behavioral benefits of competition occur when the bidders "recognize that only one may be rewarded with further development and/or production contracts."* This, Scherer argues, should motivate contractors to mobilize their best efforts, thus assuring a superior product.

The initial test phase of the LGB development--what has earlier been referred to as the feasibility phase and what Packard termed the advanced development prototype--is an excellent example of competitive prototyping. Two distinct prototypes were juxtaposed and tested against each other to assess their utility in reference to a perceived need. Presented with a high-cost/medium-risk (NA-A) design and a low-cost/high-risk (TI) design choice, ASD opted to conduct a prototype competition rather than to choose between the two designs on the basis of their paper proposals.

Competitive prototyping produced valuable data for the continuance of the program as well as serving as a hedge against the uncertainties in the development (Scherer's "statistical advantage"). The greater uncertainty of TI's high-risk/low-cost design was balanced by NA-A's model, which was more of an extension of the technology. More specifically, the performance of the relatively untried bang-bang guidance system and aerodynamically stabilized seeker head was compared to the performance of proportional guidance and the stabilized platform.

In addition to providing an examination of the general concept as well as a specific comparison of the two systems' performances, the competitive prototype approach provided an opportunity for the Air Force to compare designs and possibly cross-fertilize the respective designs. For example, after the initial feasibility tests, TI adopted NA-A's use of canard control fins and NA-A altered its design by adopting tail control fins similar to those on the TI test model. The primary reason behind these modifications was that the NA-A model required roll stabilization, which was difficult to maintain with canard fins, and TI's aerodynamically stabilized head did not require roll stabilization and was therefore able to employ the canard fins.

**Ibid.*, p. 20.

Scherer's "behavioral" advantage is more difficult to assess in respect to this project. Although intuitively plausible, there is no concrete evidence in this case study either for or against the proposition. It would probably be safer to amend Scherer's "behavioral" advantage hypothesis to apply mainly to those projects which are viewed by the company as potentially large profit makers. The low-cost LGB development was never viewed by TI as a large profit producer, so it would not have received the full benefits ascribed to Scherer's "behavioral" advantage.

Competitive prototyping is increasingly accepted within the research community as a desirable strategy for a project in which the uncertainties are significant and the cost of building multiple models is not prohibitive. Major Air Force developments--such as the A-X and the light-weight fighters--have been competitively prototyped. This case study suggests that the procedure is applicable to weapon systems at the lower end of the cost spectrum whose technology is still undemonstrated.

EARLY AND REPEATED TESTING OF THE SYSTEM HARDWARE

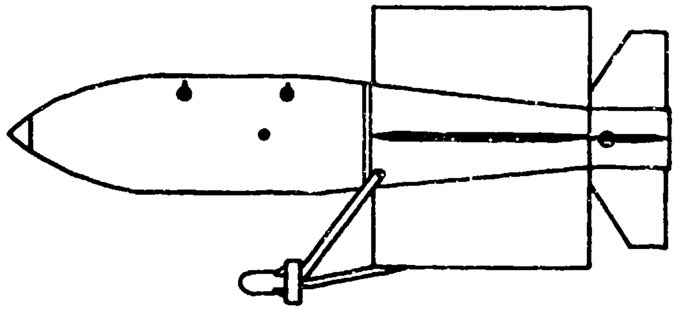
The testing of the two competing systems was important for two reasons. First, the relatively rapid testing of the systems encouraged an iterative design process directed toward a functioning weapon system at an early date. Second, the tests provided data upon which subsequent requirements and production decisions could be based. This subsection will examine the former benefit; the latter will be discussed in a succeeding subsection.

The test series of the NA-A and TI prototype laser-guided bombs are excellent examples of the value of early and repeated testing. With the use of careful monitoring, both major and minor errors were identified and corrected within relatively short time periods. Only once was more than five weeks spent between drops in a contractor's test series. The failure of the fastenings on NA-A's second test item is an example of a relatively minor flaw that might be difficult to detect in a system's blueprint or design but that was quickly apparent upon testing the model. A more major shortcoming in the LGB system was the satellite spot caused by multiple laser reflection. Without extensive testing of the engineering prototype, this problem could have been extremely difficult to isolate and correct; if the seeker's sensitivity threshold had not been adjusted, the LGB might have received a much lower theater evaluation and never generated the enthusiasm that it did.

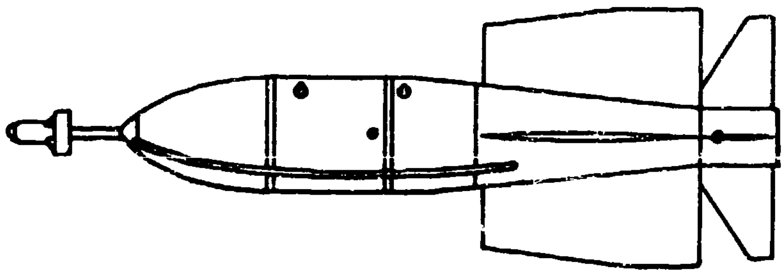
These tests, then, were the basis of a series of both small and significant design modifications. The evolution of the TI prototype, as shown in Fig. 2, best demonstrates the iterative nature of these changes. After four tests, the TI seeker was removed from the fin strut and placed on the nose. After the eighth test drop, TI engineers considered placing the control fins on the nose of the bomb since they had observed no roll stabilization problems. In addition, having the entire control kit on the front of the bomb made the laser system more modular so that it could be utilized on a large number of standard Air Force munitions. In both of these major system modifications, the reconfigurations were based upon and then validated by early and repeated testing of the system and its component hardware.

An ancillary feature of the iterative design process was the immediate access to the Eglin test facilities that Colonel Davis, as Director of Tests, provided the TI and NA-A test personnel. The ready access to test facilities expedited the development of an acceptable system because there was little time spent waiting in the queue for test facilities. TI and NA-A were able to operate on their own test schedule instead of being constrained by the usual "first in, first out" rule.

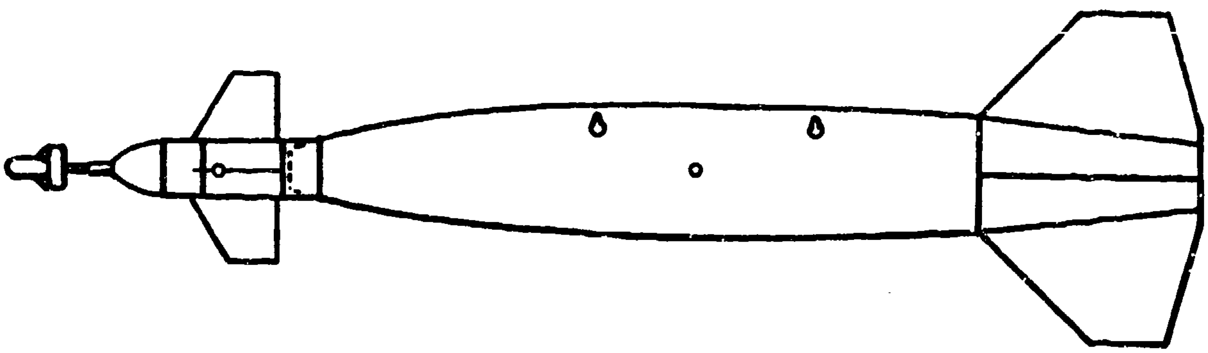
The LGB development demonstrated the advantages of early and repeated testing of the system hardware in order to obtain test data on which to base design alternation, thus permitting a rapid evolution of system design. Unfettered by detailed contractual specifications, TI engineers developed a significantly different design for their LGB within a relatively short time frame. In summary, the rapid development of the LGB system hardware into an operational weapon system would not have occurred without the data obtained through the two test periods, without the immediate access to APGC test facilities, and without the willingness on the part of the TI engineers to make significant design modifications.



(a) M-117 guided bomb with fin seeker
(July 1966)



(b) M-117 guided bomb with nose seeker and rear control fins
(Oct. 1966)



(c) Mk-84 guided bomb with nose seeker and canard control fins
(late 1967)

Fig. 2— Evolution of Texas Instruments laser-guided bomb

TECHNOLOGY/REQUIREMENTS INTERACTION

One of the notable features of the laser guidance development was the late imposition of the design specifications and operational requirements. The technology of the system development was allowed to define the component development until hardware testing could demonstrate feasible system performance parameters (e.g., attainable CEP). "Mil specs" were not imposed until very late in the program, and the standard set of world-wide qualifications tests was not met until *after* the system had been deployed in the Southeast Asia theater.

During the early laser guidance work of the U.S. Army Missile Command, technology, not requirements, dictated and motivated the development of the system. The initial work with laser guidance at the Redstone Arsenal was nominally directed toward antitank action but was so basic in its research aims that combat requirements were not a primary consideration. In fact, RCA-Burlington's laser research was later diverted into the Army's Remote Target Designation Program and never did address the earlier antitank requirement. Although the laser guidance project was antitank in its research goal, MiCom's laser guidance work was basically driven by technology rather than by requirements.

Relatively general requirements can also be seen during the early Air Force-sponsored work toward a laser-guided bomb within Detachment 5. Although Detachment 5 was more applications-oriented than was MiCom and its funding came from special Quick Reaction funds set aside for Vietnam-related systems, the original motivation behind Colonel Davis' proposal was the very general goal of improving bombing accuracy. The original contracts with Texas Instruments and North American-Autonetics were only slightly more precise; they specified that the bombs use a laser designation system to achieve a 30-ft CEP. Modifications in the prototypes during the first test series were designed to meet that standard rather than a specific operations requirement. As we have seen above, these modifications were dictated by the test results. Technology was still motivating the development although the ultimate operational uses were now more clearly seen than during the early MiCom research.

It was not until March 1967, close to two years after Colonel Davis originally proposed the concept of a laser-guided bomb to the Deputy for Limited War, that operational requirements began to be formally stated.

The first such document was SEAOR 100 from the 7th Air Force in Southeast Asia; because it had been prepared by ASD staff and was based upon the results of recently completed tests of feasibility prototypes, SEAOR 100 was not a theater-generated operations requirement in the strict sense of the word. The official Requirements Action Directive (RAD) was not issued until the following September, two months after a production strategy had been chosen. It was not until late in the development process, when LGB technology was well in hand, that specific, documented requirements (in this case, SEAOR 100 and the RAD) began to influence the development. By delaying the definition of the operational requirements until relatively late in the R&D process, the Air Force greatly increased the probability that the performance standards obtainable by the available technology and the desired operational requirements would be convergent.

Air Force restraint in not imposing early requirements on the LGB or insisting upon designing to Mil Specs permitted the TI engineers and the Air Force R&D personnel a maximum amount of design leeway and development discretion. The late imposition of specifications and requirements thereby assured the Air Force that the technology would provide the system it desired within both the immediate time frame and projected cost. There was, in short, a convergence of technology and requirements. Lacking this union, the development might have taken much longer in pursuing requirements that might never be obtained or obtained only at higher costs. As Perry, *et al.*, have pointed out,

> In the course of development of a new weapon system it may become apparent that the performance goal need not be precisely that originally specified or, alternatively, that the performance originally specified can be attained only at a cost much greater than originally proposed ... The maximum speed of the F-106, the range of the B-58, and the supersonic range capability of the F-111 are relatively recent instances of originally specified performance that could not be attained at an acceptable cost.*

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*Perry, *et al.*, *op. cit.*, p. 44.

In this particular case, the technology/requirement convergence was a significant factor in the successful attainment of the specified operations requirements.

This experience and its success are not unique to the LGB. Other examples of low-cost developments with this relationship are the Sidewinder air-to-air missile developed by the Navy and some types of radar, such as the APQ-56.*

INCREMENTAL DEVELOPMENT

An incremental development is characterized by a number of discrete phases--including advanced and engineering development as well as production--linked by decision nodes. Perry, *et al.*, have described such a strategy:

> Basically, such an approach would require separating the development of systems from the subsequent production of those systems; furthermore, it would call for first conducting those aspects of development aimed at demonstrating the performance potential of the system and later addressing such issues as verifying reliability and maintainability of the system and providing for the special constraints imposed by service support requirements. Finally, an incremental strategy could, and ordinarily would, include periodic reassessment, redefinition, and readjustment of program constituents....†

Although there was apparently no predetermined policy to do so, this incremental approach characterized the development of the laser-guided bomb. The first decision point occurred in mid-1965 when the Air Force chose to develop a laser guidance system. Colonel Davis did not propose the feasibility tests of the laser guidance system until he had some assurance from the MiCom laser research effort that such a concept was technically feasible. The data that MiCom's Salonimer and Bell presented were gathered from hardware tests and were persuasive enough to convince not only Davis but personnel in Limited War and the

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*See the case histories of the Sidewinder and radar systems in Marschak, "The Role of Project Histories...," in Marschak, Glennan, and Summers, *op. cit.*, Chapter 3.

†Perry, *et al.*, *op. cit.*, pp. 41-42.

Air Staff as well. A second decision was that favoring TI for the advanced development prototype. Based on the evidence of TI and NA-A prototype tests, the decision to proceed to the engineering development phase was precisely consistent with the test findings. The prototype evaluation of the TI LGB model recommended that this "laser-guided bomb should be developed to be placed in operational use as soon as possible."* The evaluation of the Autonetics LGB suggested that "further development ... should continue."† As a result, TI was given a further development contract and Autonetics was permitted to continue work on laser-guided bombs until advised to terminate efforts in mid-1967.

A second feature of an incremental development is the priority of demonstrating a system's feasibility before "addressing such issues as verifying reliability and maintainability of the system..." This was evidenced in the LGB development when the Air Force postponed the verification of reliability standards and world-wide qualification tests until *after* the system was deployed in Southeast Asia. The Air Force was willing to delay the imposition of service and logistic requirements until after the system had proven its performance in order to expedite its combat deployment.

Another facet of this development approach is that a thorough testing of the system's feasibility is conducted before production decisions were made or operations requirements set. No decision was made on the future LGB development nor were performance parameters defined until the data from the feasibility prototype tests were assimilated. These data gave the decisionmakers within AFSC and Hq USAF high-quality information so that the product could meet the specifications that would be defined, such as those set down in the September 1967 RAD.

Finally, the incremental development provides the decisionmakers with a series of discrete check points at which they may judge if the project is proceeding as planned. In the case of the LGB, progress was generally considered acceptable. However, if a development is not proceeding according to plan or schedule, or if the perceived requirements

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*Cooney and Floyd, *Engineering Evaluation of Texas Instruments' Laser Guided Bomb*, p. 27.

†Cooney and Floyd, *Engineering Evaluation of the Autonetics' Laser Guided Bomb*, p. 21.

have been changed, the decisionmakers can make adjustments, including the cancellation of the entire project. For example, the Air Force cancelled North American's Hornet (an electro-optical guided antitank air-to-surface missile) after its relatively successful feasibility tests in 1967--Hornet's projected antitank mission was deemphasized and North American was directed to apply Hornet's technology to developing an electro-optical guided bomb (the future Hobos).

The incremental approach is more suitable when the technology and/or threat are uncertain than when they are better known. In either case, however, the "periodic reassessment implied by application of an incremental strategy suggests recurrent evaluation not only in terms of its intrinsic promise, but also of its advantages over competing systems also in development or already in the force."*

This approach was mirrored by the sequential funding arrangements that characterized the LGB development; these will be discussed subsequently.

DELEGATION OF DEVELOPMENT DECISIONS

The LGB development program was characterized by a delegation of development decisions to various levels within the Air Force R&D hierarchy. These decisions were generally made at the level that had the most information pertaining to a specific decision without the necessity of exercising the entire R&D decisionmaking loop (from Eglin AFB up to the Chief of Staff and including DDR&E). This decisionmaking discretion was particularly notable at the lower levels of the development chain of command. A chief advantage of this delegation of decisionmaking authority was the shortened time of development.

From the very beginning of the LGB concept, R&D personnel at lower organizational levels were permitted to exercise considerable discretion. Colonel Davis is a particular case in point. As Commander of Detachment 5, he was receptive to proposals from North American-Autonetics and Texas Instruments for an LGB prototype. During the feasibility test period, Colonel Davis, as Director of Tests and then Vice Commander of APGC, gave both NA-A and TI virtually immediate access to test facilities,

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*Perry, *et al.*, *op. cit.*, p. 43.

thereby reducing time spent in the queue for test facilities and shortening the development time. Because the contracts were written to a simple performance standard as opposed to detailed design specifications, major system modifications were proposed and approved by the Air Force Armament Laboratory at Eglin without necessitating a rewrite of the contracts, thus saving additional time.

Concomitantly, the development personnel had the support of their superiors from the early stages of the development. APGC Commander, Major General Andrew Kinney, was completely supportive of Colonel Davis' efforts to develop the LGB as quickly as possible. The Deputy for Limited War within ASD was given financial support above his discretionary allowance for the initial TI and NA-A contracts by the Director of Development under DCS/R&D.

Major decisions were made within the Air Staff when the relevant information was centered there. These decisions concerned such options as engineering development, procurement alternatives, and the formation of a project office within ASD. Funds were reprogrammed within the Air Force budget instead of the time-consuming submission of a supplementary budget request to DDR&E. The MK-84 was introduced at the specific instruction of DCS/R&D personnel who had access to ordnance comparisons tests conducted at Holloman AFB. Although development on electro-optical and infrared guided bombs was initiated at the request of the Air Staff, it was made clear that the LGB development should be especially emphasized and pursued independently.

Some might argue that a major reason for the delegation of authority to people relatively low in the chain of command who possessed relevant information was that the LGB development was low profile and very low cost during its initial stages. The argument is not persuasive because the LGB was not a low profile development even though it was low cost. Personnel within the Air Staff, the Assistant Secretary of the Air Force for R&D, and Hq AFSC were all being directly advised of test results in late 1967-early 1968. It is more probable that this decisionmaking discretion was the result of permitting test officers to exercise development options and the absence of a contract with detailed specifications.

The fact that decisions were made at the level where the pertinent information was found often meant a significant delegation of authority to the development officers at Eglin.

In a more general sense, the success enjoyed by the delegation of authority in the LGB development is to be expected. It is almost axiomatic in the organizational behavior literature that decisions should be made at the point where there is the greatest concentration of relevant information.* The experience of the LGB development is confirmed by many other developments, such as Lockheed's Agena-D booster.†

CONTINGENCY DEVELOPMENT FUNDS

The manner of funding was important for two reasons. First, the fact that there were no dedicated line-item funds present throughout the program life meant that research personnel had to apply for funding at distinct intervals in the development. Project 1559--Quick Reaction funds--were tapped for the feasibility prototype models, and monies had to be reprogrammed to pay for the engineering development prototypes. The LGB was not to receive line-item funding until after its first production contract. The fact that money had not been requested for the entire project at its inception forced the decisionmakers within the Air Staff to evaluate the LGB project carefully at least twice before production money was allocated. This reinforced the incremental approach discussed above.

The second point is that there were funds available for the initial LGB development. Had Project 1559 not provided contingency funds, the project might conceivably never have been initiated. These contingency funds added a certain amount of flexibility to the development process. This most pointedly applies, of course, to relatively low-cost developments. Even though the development of the LGB produced a successful weapons system, a review of the various projects initiated by Project 1559 reveals that, of the 304 tasks funded by Quick Reaction funds, over

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*For example, see Robert Thompson, *Organizations in Action* (New York: McGraw-Hill, 1967).

†The Agena-D program is described in Perry, *et al.*, *op. cit.*, Section III.

40 percent were considered "highly successful"; full-scale production occurred in close to 33 percent of the tasks.* Thus we can assume that the advantages of contingency funding were not restricted to the laser-guided bomb development.

It should be recognized, however, that contingency funds and reprogramming do have their limits. Although there were no formal guidelines on distributing the Quick Reaction monies, the Southeast Asia Special Projects Division placed a $500,000 ceiling on requests with the rationale that anything over that amount would require more than a year's development time as well as curtailing the number of proposals that could be funded. This ceiling was occasionally exceeded but was generally adhered to. DoD regulations at the time permitted a maximum of $1.9 million to be reprogrammed without authorization from DDR&E. Therefore, it is apparent that the segmented nature of the funding is most applicable for relatively low-cost developments; the more expensive developments must obtain funds via the standard budgetary channels.

FLEXIBILITY

If one were to characterize the development of the LGB in a single word, that word would be "flexibility." The six features of the development which were identified earlier in this section served interactively to present multiple design and managerial alternatives. The availability of two competing prototype models, the lack of strict design specifications or operations requirements until testing had determined what specifications and performance parameters were obtainable, the ability of the project managers to make significant design alterations without having to make contract modifications, and the incremental manner in which the development progressed all contributed to this flexibility. The funding arrangements also contributed to that flexibility but in a different manner. If the entire project's funding had been granted at the outset, the contract probably would have been written in a manner that would make changes relatively difficult. There

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*Raymond R. Stasiak, *History of Project 1559*, Technology Directorate, Deputy for Tactical Warfare, undated.

is nothing inherent in the LGB project funding arrangements that would dictate a flexible approach except that the different phases entailed a number of project reviews. In cases in which a project did not progress as well as did the LGB, these decision points would give the decisionmakers an opportunity to revise or even cancel the project. Thus, the disjointed funding arrangement could be viewed as providing an additional element of flexibility to a developmental program.

These features, then, were the keys that produced the laser-guided bomb within 36 months of the original contract at, in the words of many of the participants interviewed, a "significant cost and time savings."

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