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HUMAN ENGINEERING LABORATORY BATTALION  
ARTILLERY TESTS (HELBAT)

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1972

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## INTRODUCTION

The military needs information on the operational performance of conventional weapon systems. This information is needed by system analysts for assessing current and projecting future weapon capabilities, by military tacticians for structuring force compositions and force deployment, by weapon designers for developing future weapon systems, and by training agencies for determining training requirements and crew proficiency levels.

The Human Engineering Laboratory (HEL) has begun to develop this information through a series of field experiments superimposed onto Operational Readiness Tests (ORT) which Army units must undergo each year. Since the purpose of such tests is to evaluate a unit's ability "to perform its assigned mission under simulated combat conditions," they provide an ideal opportunity for combining field experiments with troop trials--and our experience has shown not only that such research can be piggybacked onto the tests without materially affecting the conduct or outcome of the tests, but also that our studies can assist the very evaluation for which the tests are conducted as well as generate the more general information needed by the analysts, tacticians, designers and training agencies.

Two of these field experiments, under the title of Human Engineering Laboratory Battalion Artillery Test (HELBAT), have already been completed and a third HELBAT has just been conducted. The artillery studies are scaled to battalion size. The battalion is the Artillery's basic operational unit and thus provides the greatest realism for operational study. It also provides a battalion-level Fire Direction Center equipped with the FADAC computer, as well as the redundancy of battery FDCs and organic meteorological sections.

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HELBAT I and HELBAT II were both conducted at Fort Hood, Texas, with battalions of M109 self-propelled 155mm howitzers from the 1st Armored Division. Agencies cooperating in the evaluations included the Army Materiel Systems Analysis Agency (AMSAA), Frankford Arsenal, the Joint Technical Coordinating Group for Munitions Effectiveness, and the Army Field Artillery Center at Fort Sill, Oklahoma.

Both tests were conducted over the same terrain, a tank maneuvering and firing area not familiar to the artillery. The same division artillery was used for both; however, the turnover of personnel during the two years intervening precluded any prior information that might contaminate the results of the second study.

## PURPOSE

While there were specific objectives stated for HELBAT I, its general purpose was to lay the groundwork for HELBAT II. U. S. Army studies as early as 1952 (Human Errors in Predicted Artillery Fire, ORO T-113, 1952) had indicated that human error contributed more to the total system error of artillery fire than all other sources of error combined. Since the ultimate goal of the HELBAT series was to isolate, quantify and reduce human error within the system, it was necessary first to measure total system accuracy, identify the sources of human error, and establish a priority for in-depth investigations of those human error sources.

Furthermore, it was necessary to develop a philosophy, establish procedures and determine the data-collection requirements for conducting systematic, repeatable and reliable studies of artillery operations on the battalion scale.

HELBAT I, therefore, was limited to the study of one type of artillery mission, surprise predicted fire, partly to simplify the attainment of the above objectives, and partly to generate information about a type of mission of immediate concern to the artillery. Fort Hood was chosen as the HELBAT test site because it provided four artillery battalions in a high state of training that were scheduled to undergo the annual Operational Readiness Tests. Moreover, since these battalions are assigned to an armored division, they are likely to be employed in conjunction with offensive armor, a role that would limit their use of extensive survey and pre-registration and at the same time place a premium on successful conduct of surprise predicted fire. Fort Hood itself provided relatively dry weather, vegetation offering adequate cover for armor, a large maneuver area, and a large impact area that would reduce the need for interrupting the operational flow of the tests for safety considerations.

The stated purpose of HELBAT I -- "to study the artillery's capability to deliver surprise massed fire accurately in the shortest

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possible time without adjustment" -- was selected because of the high priority the artillery places on surprise-fire missions. Data were collected on all sub-units of an artillery battalion that would affect the outcome of the mission's performance. Our objectives were to (1) determine the total system accuracy of a battalion using surprise-fire techniques, (2) determine what portion of the total system error is human error, and (3) determine the total time (survey to TOT) to deliver fire on the target.

We considered the results of HELBAT I to be especially significant, particularly with regard to the amount and sources of system error, since HELBAT I was conducted as a special exercise just four weeks after the battalions involved had conducted an Operational Readiness Test successfully and were therefore deemed to be in a high state of training and readiness. Our success in collecting a large volume of data without interfering with the normal conduct of an artillery mission convinced us we could superimpose such an evaluation onto a standard artillery ORT. HELBAT II was planned, therefore, to do just that.

HELBAT II examined all the missions specified for an Operational Readiness Test, but, because of the forward observer results in HELBAT I, the specific purpose of HELBAT II was "to do an in-depth study of existing as well as new forward observer techniques and equipment to provide the data base from which recommendations can be made to improve the accuracy and responsiveness of artillery fire." Fort Hood was again selected as the test site to minimize the test variables and facilitate correlation of data between the two tests by using the same terrain and same targets.

The nature of the HELBAT tests made it possible to conduct sub-tests. HELBAT I measured the warning sound of incoming volley fire and the time distributions of rounds striking the target area. HELBAT II assisted the Harry Diamond Laboratories in testing electronic fuzes and evaluated a photometric device developed by the Topographic Laboratories at the Engineer Center.

The data from HELBAT II confirm the forward observer results of HELBAT I and also provide a validation of our research approach to artillery accuracy studies.

#### PLANNING AND DATA COLLECTION

The HELBAT tests measured total system accuracy by recording the fall of shot around the target to determine the Mean Point of Impact (MPI) of the rounds in a volley and the distribution of rounds around the MPI. The relative percents of total system error contributed by the various subsystems within the artillery battalion were obtained by isolating the sources of error under five major

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headings: Survey, Metrological, Forward Observer, Fire Direction and Firing Battery.

Error sources measured under Survey included determining coordinates of battery centers and azimuths of orienting lines. Metrological errors were grouped under operations (including instrumental and procedural operations). Forward Observer error sources included map and compass reading, conventional ranging and ranging with the laser rangefinder. Errors in Fire Direction were made in map reading, photo restitution, and fire-direction operations (including instrumental, procedural and arithmetical operations). Firing Battery errors included laying errors, weapon emplacement errors within the battery and erratical ramming of ammunition.

HELBAT I fall-of-shot data were collected by cameras placed at a pre-surveyed position around the target area to record the impact of each round fired. HELBAT II collected similar camera data, supplemented by visual sightings by a flash platoon from Fort Sill's Target Acquisition Battalion and with trajectory tracking and plotting by the radar section organic to the artillery battalions undergoing the test. The HELBAT I system accuracy results indicate that surprise fire predicted by current methods has not become significantly more accurate than in World War II.

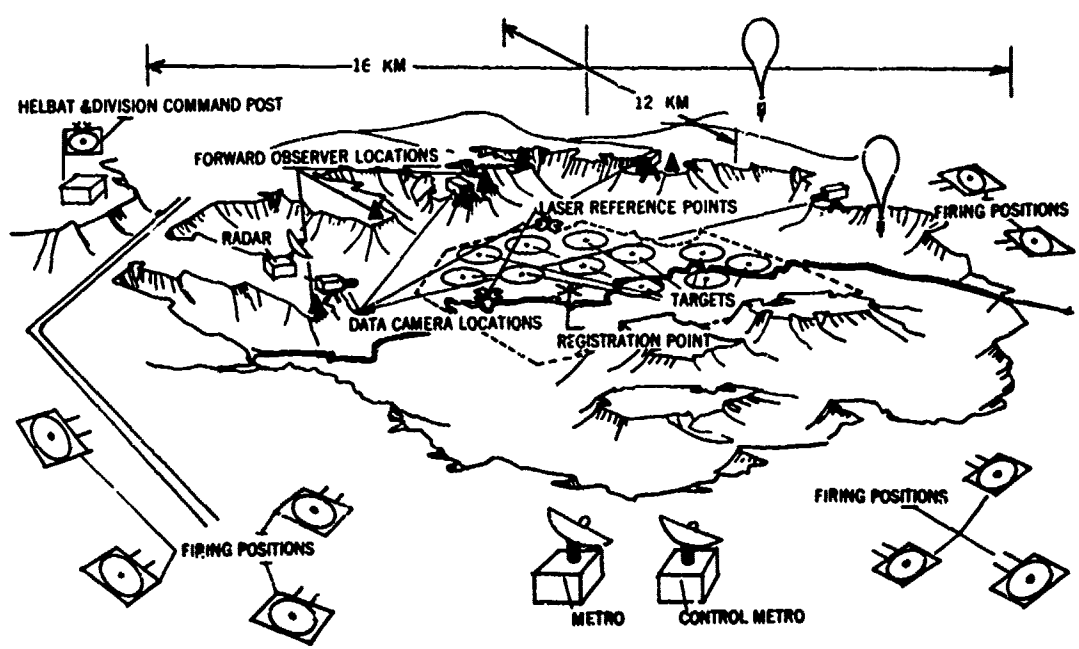


Figure 1. HELBAT Test Site

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Subsystem errors were measured at each point within the artillery battalion where information is acquired, processed or communicated.

Survey error was measured by comparing the performance of the battalion survey with a higher-order survey performed by a control survey team.

Metrological error was estimated by comparing the performance of the battalion's metrological section with a control metrological section which simultaneously duplicated all metrological flights.

Error at the Firing Battery was measured by interrupting each mission when the weapons were laid and ready to fire so safety officers could check and record the sight picture of each weapon. In HELBAT II an additional control on Firing Battery performance was obtained by having an independent survey team make a transit check of the lay of the center piece of one battery in each battalion.

Several methods were used to obtain measures of the error at the Fire Direction Center. In both HELBAT I and HELBAT II, an HEL controller was stationed at the FDC and all communications to and from the FDC were tape-recorded. In HELBAT I the performance of the battalion FDC was compared with that of an independent control FDC receiving and processing the same information; In HELBAT II, since all missions were computed with the FADAC, the control FDC was eliminated. In both tests the ultimate measure of Fire Direction error was obtained by an electronic computer solution to the information processed by the FDC.

Forward Observer error in location, direction and distance was measured by means of pre-surveyed observation points and target locations. The measurement of Forward Observer error also provides a good example of how an operational evaluation like HELBAT can be conducted without interfering with the requirements of an Operational Readiness Test. The ORT directive says that "all forward observer locations will be tactically sound and will be occupied in accordance with the tactical situation." In HELBAT the observer is allowed to select his own observation point in accordance with his own tactical judgment; that point is marked and later surveyed. The operational conditions of the ORT are thus faithfully observed, while an objective measure of observer performance is nevertheless obtained. The other HELBAT measures are similarly obtained with little or no effect on the normal conduct of the ORT.

In HELBAT I, the laser rangefinder was employed by the forward observer, in accordance with Army usage and training at the time, only for determining ranges to target. When HELBAT I results revealed significant errors in forward-observation location and target direction, new procedures were developed to use the laser for

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those tasks, as well as ranging, in HELBAT II.

The results of HELBAT I revealed that forward observer errors in range to target, location and azimuth accounted for more than half--53 percent--of the total system error. The Fire Direction Center produced 26 percent of the total error through errors in computing met correction, registration and firing data and in plotting. Metro Section, Survey and Firing Battery taken together produced the remaining 21 percent of the total error.

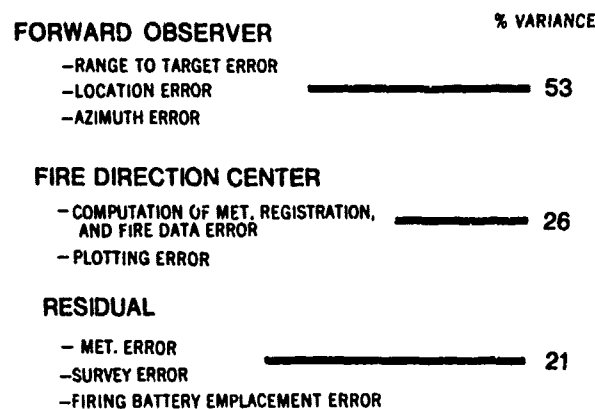


Figure 2. HELBAT I Errors

Forward observer procedures include three methods for locating targets: (1) by grid coordinates, (2) by polar plot (combining Forward Observer location, target direction and target range), and (3) by shifting from a known point. HELBAT II, which examined all three methods, showed that the grid-coordinate method--when the terrain provides no dominant features, as may be the case in combat--produces an extremely large error in target location. It was precisely that absence of dominant features on the Fort Hood terrain that had led the HELBAT I battalion commanders to the tactical decision to use polar plot exclusively for that test.

Accuracy in locating targets by polar plot depends on the effectiveness of methods for locating the forward observer, establishing the target direction, and estimating target distance. Accordingly, HELBAT II evaluated the performance of these three functions under two conditions: by conventional methods and by new methods employing the laser rangefinder. HELBAT I had already demonstrated that the laser was far more effective than conventional estimation for determining distance; for HELBAT II we devised methods by which the laser could also be used in locating the forward observer and in establishing target directions.

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In the conventional condition, the forward observer located his position by conventional map spot using grid coordinates, established target directions by means of the M2 compass and estimated target ranges.

In the laser condition, the forward observer lased to two mapped reference points to determine distance to them from his position and measured the angle between the two sightings; the Fire Direction Center then located his position by intersecting arcs of the lased distances from the two reference points on the map, solved for the angle at the observer location, and checked this measurement against the angle measured by the forward observer with the laser mount. The FDC then gave the observer a true azimuth to one of his reference points from which directions to targets could be established. Distances to targets were obtained directly from the laser.

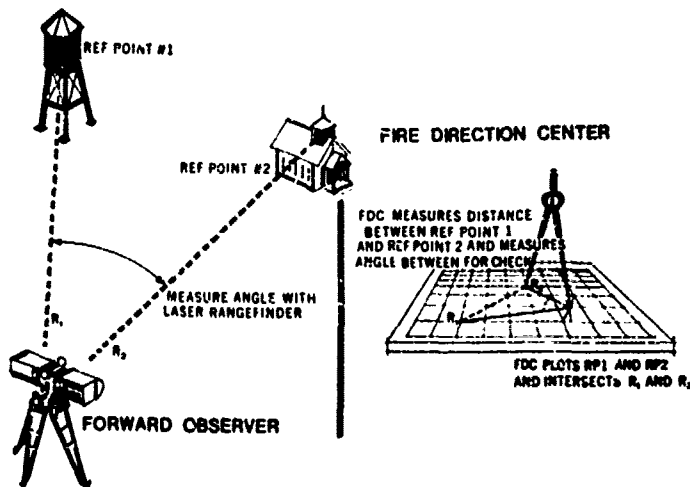


Figure 3. Laser Condition

In a variation of the laser condition, forward observer position was located with only one reference point by using the laser to establish its distance and ARK-1, azimuth indicator, a device which references true North, to establish its true azimuth from the observer. The FDC could then locate the forward observer on the map simply by reading off the reported distance from the map reference point along the azimuth opposite to the reported azimuth. Reference azimuths were established directly from the ARK-1, and ranges were obtained directly from the laser.

The laser was also used to locate forward observer position by lasing to two air bursts of white phosphorus or illuminating



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rounds. In this procedure, a laser at the firing battery measured distance and direction to the bursts, while the forward observer lased for distance to the same bursts. The Fire Direction Center then plotted the resulting readings and computed battery and forward observer triangles to locate the observer's position. This technique was not used to fire actual missions.

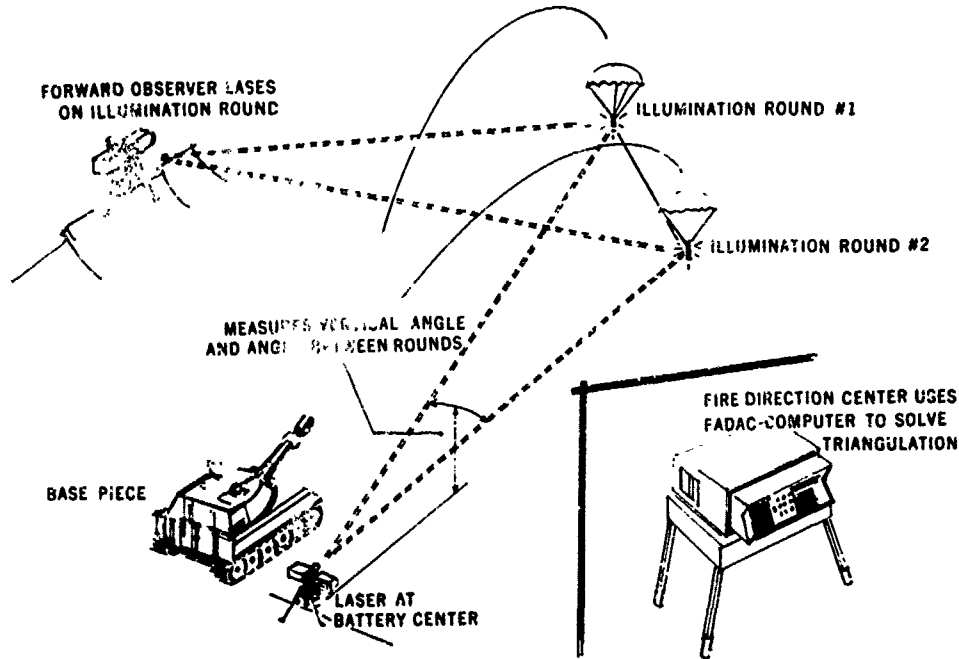


Figure 4. Illumination Condition

Once the forward observers' positions were located, they could then locate targets with the laser by polar plot, conduct laser registration and adjust fire by lasing on round signatures.

There were problems in collecting time data for both HELBAT I and HELBAT II, because it was difficult (1) to coordinate precisely the measurement of a variety of simultaneous events occurring at widely separated points within a large area, especially without affecting the performance of the units under test, and (2) to separate out the times of single events within a continuous process. Occasional halts in the tests for safety checks and adjustments interrupted the time measurements.

It was also difficult to collect data on the lay of individual weapons within each battery before a mission was fired, information that would contribute significantly to the assessment of the accuracy of fire. Limitations of control personnel allowed us to

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record transit data on the lay of only one battery base piece per battalion. Needed but not now available is instrumentation for recording data simultaneously on all batteries, regardless of their location.

In HELBAT II, which involved the performance of multiple tasks by each forward observer, conventional observations without the laser rangefinder were placed first in the sequence to provide individual baseline data for each observer, since counterbalancing the observers' tasks would have interfered with the conduct of the ORT. Multiple tasks also tended to confound observer time data, since information accrued from earlier observations unavoidably speeded up the completion of later observations within a given trial.

There was some direct feedback into the test program from field analyses performed while the tests were in progress. For example, it was quickly apparent that forward observers on airburst registration missions could lase against illumination rounds more effectively than they could against white phosphorous rounds, even in daylight. The illumination round provided a point source that was either lased successfully or missed altogether; the billowing of the white phosphorous round allowed different observers to lase against different portions of the clouds with resulting discrepancies in their direction data. And the slow descent of the illuminating round under its parachute allowed a common countdown before lasing, so that the sightings could be coordinated better in time.

Field analysis also suggested that the current standard U. S. laser mount configuration would make it difficult to lase against moving targets, a finding that had implications not only for HELBAT II, but also for HELBAT III.

## ANALYSIS

In order to account for sources of error other than human error, all the weapons used in HELBAT I were calibrated for velocity error before the test. Two years later, before HELBAT II, the same weapons were calibrated for the same reason, and comparison of the calibration data revealed a startling fact--the HELBAT II calibration showed an increase in muzzle velocity for all weapons across all charges, a trend directly contrary to the normally expected decrease in muzzle velocity. Further analysis is planned on the data from individual gun tubes and rounds, lot average velocities, lot testing, storage, chronographing, etc., in an attempt to account for an apparently atypical result.

Analysis of the test data showed that, in all cases, individuals performed better when the missions they processed were actually fired. The consistency of this finding suggests that feedback from the rounds fired and an awareness of being measured motivates individuals to higher performance, whereas lack of feedback and

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measurement apparently tends to reduce motivation and consequently to reduce performance. There is, therefore, the further suggestion that studies of individual tasks within a total mission are of only limited value in evaluating total mission performance. Such a conclusion supports the basic philosophy of operational testing and research.

Data collection and analysis did reveal at least one drawback to the operational approach, although the HELBAT experience also demonstrated this problem can be overcome by proper planning and management of operational tests. When experimental observations are superimposed on a continuing process like an Operational Readiness Test, a trial continues even when data collection equipment and procedures fail, thus losing data. Delaying the ORT to restart a trial or repair equipment would reduce the operational reality of the test and tend to invalidate the results, but careful planning and sufficient redundancy in data collection can minimize data loss without interfering with the events being observed. So, for example, when camera data were lost in HELBAT because cameras malfunctioned, the data could often be rescued by comparing the records of the flash ranging team and radar observers.

Forward observer location error with conventional map spot techniques produced a Mean Radial Error (MRE) of 97 meters from 42 trials in HELBAT II, results which compare closely with the MRE of 110 meters obtained with conventional techniques in HELBAT I. The HELBAT II technique employing the laser rangefinder and two map reference points produced an MRE of 2 meters from 10 trials, while the combination of the laser with the ARK-1 and one reference point resulted in an MRE of 7 meters from 12 trials. The consistency of the conventional location error in HELBATs I and II validates the procedures used to collect the data from both, and HELBAT II clearly demonstrates the superiority of the laser techniques suggested by HELBAT I for locating the forward observer.

Forward observer to target distance errors in HELBAT I and HELBAT II demonstrated a similar superiority for the laser rangefinder, and the consistency of the results between the two studies. Conventional estimating of distance in HELBAT I produced an error that was 22 percent of the range, while conventional ranging in HELBAT II produced an error that was 16 percent of range--nearly identical results. Laser ranging in HELBAT I produced an error of 3 percent of range which is identical to that found in HELBAT II.

The laser techniques employed in HELBAT II also significantly reduced the error in establishing target directions demonstrated in both HELBAT I and HELBAT II by conventional means. In HELBAT I the standard deviation in direction error produced by using the M2 compass in the conventional manner was 78 mils; for HELBAT II it was 69 mils--again nearly identical results. The HELBAT II technique combining the forward observer's laser with FDC plotting produced a

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standard deviation of 7 mils, and the technique combining the laser with the ARK-1 azimuth device also produced a standard deviation of 7 mils in establishing reference azimuths.

In HELBAT II the laser rangefinder was also evaluated for speed and accuracy of laser registration as compared with precision registration by conventional means. Conventional precision registrations took an average of 14 minutes to complete, firing an average of 11.7 rounds to obtain a 67-meter Mean Radius of Error in the fall of shot around the registration point. Laser registration averaged 9 minutes to complete with 7.7 rounds fired and an MRE of 34 meters.

The comparison of distances between actual targets and assumed targets (target location error) produced by conventional techniques and the laser techniques of HELBAT II is similarly striking. (Actual target locations had been determined before the HELBAT tests began; "assumed targets" were the target locations produced by the forward observer reports and Fire Direction Center computations.) The MRE of the distance between real and assumed targets in HELBAT I was 224.5 meters. It is important to note, however, that this result was obtained from missions where FO location was determined by conventional map spot and target direction was conventionally established with the M2 compass--but distance was obtained from the laser rangefinder rather than by conventional estimation. The advantages of the new laser techniques developed from HELBAT I and applied in HELBAT II are better demonstrated by the baseline location, direction and distance data obtained by fully conventional FO procedures in HELBAT II where the target location MRE was 400 meters. The laser and super-laser techniques applied in HELBAT II, on the other hand, produced an MRE of only 24 meters.

HELBAT II demonstrated that it is possible to conduct operational evaluations of artillery accuracy during standard Army Operational Readiness Tests without materially affecting the specified conduct of a test and with significant gains in information of both short-term value to the units involved and long-term value to designers, analysts, tacticians and training agencies.

The ORT provides a vehicle wherein operational troop units playing combat scenarios can fulfill the requirements for any kind of operational evaluation. The HELBAT studies not only show that artillery units can be evaluated operationally, but also suggest that the operational approach can be applied to units located elsewhere than in the Continental United States. Such application could, for example, provide an objective comparison of the relative readiness of units stationed in the U. S. and overseas that would be of current interest to the Army and might provide information on the future training and deployment of artillery units. It would also, of course, broaden the HELBAT data base, with the consequent strengthening of all their implications for future design, training and tactics.

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The purpose of HELBAT III, conducted in the spring of 1972, was to measure current techniques and investigate new procedures for delivering effective indirect fire against moving targets.

The basic question to be tested in HELBAT III was whether the artillery could obtain adequate target data and process a fire mission effectively during the relatively brief time a moving target is available for tracking and firing. The improvement in the speed and accuracy of locating stationary targets in HELBAT II indicated that moving targets could be dealt with effectively if the burden of making tactical decisions on target behavior and intercept points were removed from the forward observer team, leaving it only with the responsibility for obtaining target data and feeding it to the Fire Direction Center.

Such was the plan adopted for HELBAT III. The forward observer was located by the laser technique developed in HELBAT. When the target (a tank or tank formation) appeared, the observer began a continuing series of laser sightings taken at regular intervals as long as the target was in view. The laser rangefinder was mounted on a tracking mount especially designed to provide instant and clearly legible readouts of distance, direction, vertical angle and time. These data were continuously transmitted to the FDC by the reconnaissance sergeant.

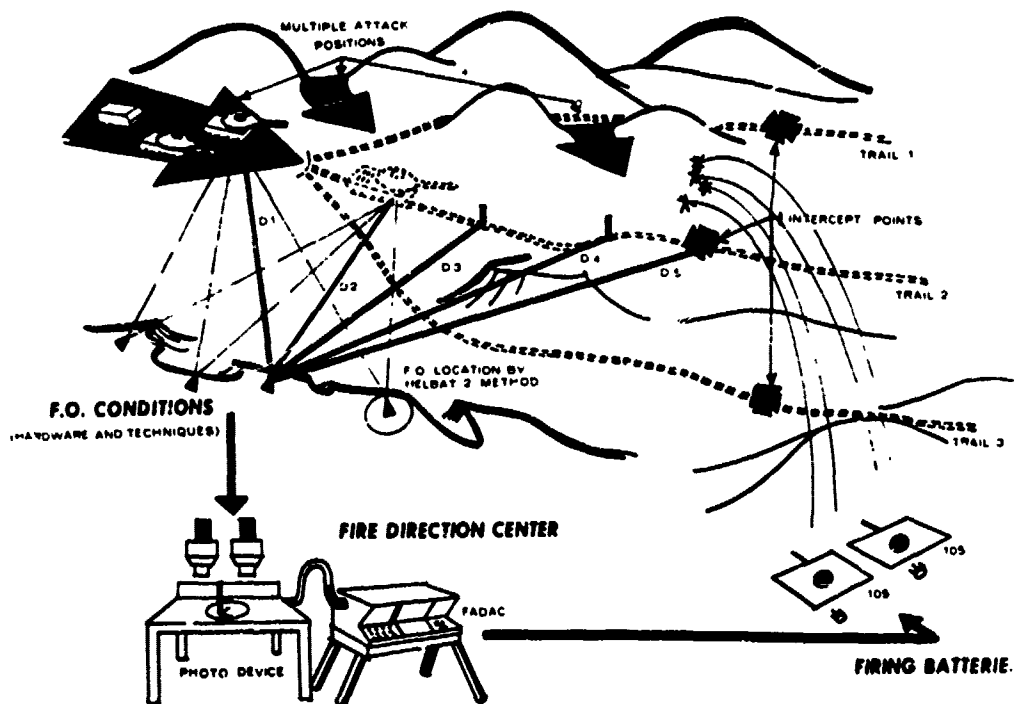


Figure 5. Schematic of HELBAT III

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There are two important factors that must be kept in mind with operational units in a testing environment. The first is that they are not tailor-made units composed of above-average people. Rather, they are common, everyday units subject to all the variables of such units--high personnel turnover, widely varying skill levels, misassigned personnel, and chronic personnel shortages. Such conditions can impede the orderly flow of test procedures, but they do provide a more realistic evaluation of overall system performance.

The second is the motivation and morale of the units. Operational testing cannot duplicate the combat environment with the will to survive and the underlying individual motivation that goes with it. This motivation is directly related to how well a unit will perform. The high motivation in both HELBAT I and II was attributed to the competition between the three or four battalions (one being rated best) and to the idea that they were contributing to new techniques which would improve the capability of their artillery.

The HELBATs also contributed directly to the Operational Readiness Tests. The systematic and controlled collection and analysis of performance data add an important objective dimension to the subjective evaluation applied by ORT umpires, and, as the HELBAT forward observer results dramatically demonstrate, objective measures assist significantly in the identification of areas of weakness in training and performance that are a prime objective of the ORT. Artillery units are, after all, designed for combat, not for measuring performance. The HELBAT evaluation provides the tools and techniques for isolating problems and for assigning relative weight to specific areas of weakness with the total system performance. And, as both HELBAT tests showed, they can enhance the training value of the ORT itself by providing additional motivation for the troops under test.

The long-term value of the HELBAT studies is amply documented by the results produced so far. The forward observer has been clearly identified as the major source of error in achieving accurate artillery fire, and new forward observer procedures and equipment have demonstrated a significant improvement in forward observer performance. The laser rangefinder not only reduces ranging error by a factor of ten, but it also reduces forward observer location error, direction error and, ultimately, target location by the same factor. Even lasing against air bursts produces a forward observer location that is 50 percent better than that achieved by conventional means, and laser registration improves registration accuracy by nearly 50 percent with fewer rounds and shorter time than required by conventional precision registration.

The order-of-magnitude improvement in forward observer location error achieved by the new techniques of HELBAT II made it possible, in HELBAT III, to attack a problem that has always haunted the artillery--the successful engagement of moving targets--a capability the artillery now possesses only in a very limited degree.

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As the target data arrived at the FDC, distance, direction and vertical angle data were fed into the FADAC computer, which converted them to target coordinates. The coordinates were then transferred to a three-dimensional topographical display capable of plotting target location and measuring distance travelled and distance to intercept points. Time and distance travelled were combined by a calculator to produce a rate of travel. Once probable intercept points were determined by the fire direction officer in consultation with an experienced armor officer, the intercept coordinates were fed back into the FADAC to produce fire directions for each intercept point, and target times to intercept points were continuously updated as forward observer reports flowed in. The fire direction officer then called for a mission as the target reached an intercept point.

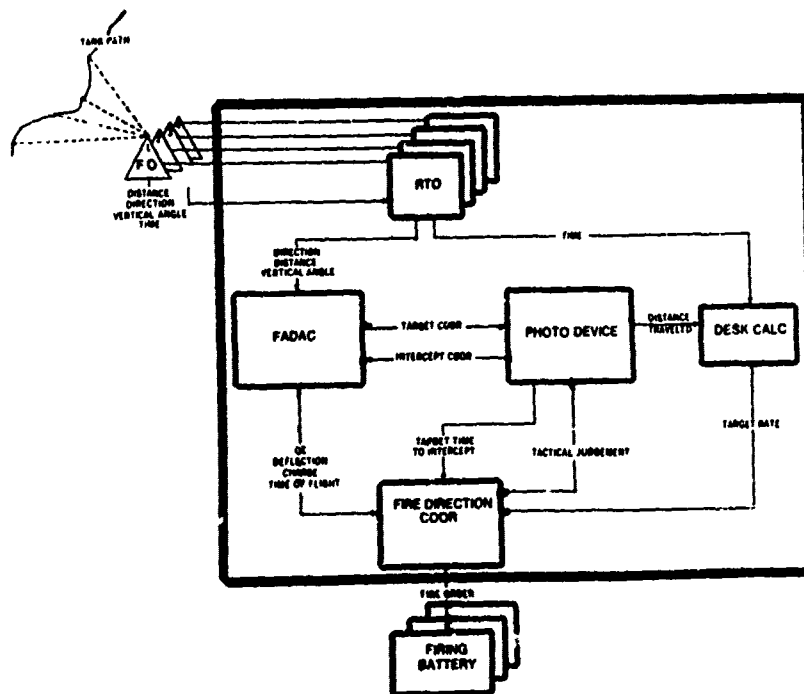


Figure 6. Schematic of Data Processing

By applying these new procedures and comparing them with conventional procedures, HELBAT III provided an evaluation of indirect-fire techniques for engaging moving targets. The test also allowed an evaluation of forward observer laser tracker for ranging and illumination, and measurement of moving-target responses to artillery fire.

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The HELBAT experience so far suggests implications even for something so basic as the very doctrine by which the Army designs, trains, deploys and employs its artillery. Doctrine is traditionally derived from the Army's combat experience; but because the nature of combat precludes the systematic collection of performance data, that doctrine's objective base has always been slender. Combat experience will always play a part in evolving Army doctrine, of course, but the HELBAT experience strongly indicates that operational evaluation will also play an increasingly important role in developing the doctrine by which today's Army prepares for tomorrow's battles.