AGARD-AG-300 Vol.10

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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD Flight Test Techniques Series Volume 10 on

Weapon Delivery Analysis and Ballistic Flight Testing

(L'Analyse du Largage d'Armes et les Essais en Vol Balistique)

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AGARDograph 300
Flight Test Techniques Series - Volume 10

Weapon Delivery Analysis and Ballistic Flight Testing

(L'Analyse du Largage d'Armes et les Essais en Vol Balistique)

by

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Preface

Since its founding in 1952, the Advisory Group for Aerospace Research and Development has published, through the Flight Mechanics Panel, a number of standard texts in the field of flight testing. Theoriginal Flight Test Manual was published in the years 1954to 1956. The Manual was divided into four volumes:

1 Performance
2 Stability and Control
3 Instrumentation Catalog, and
4 Instrumentation Svstems.

As a result of development in the field test instrumentation, the Flight Test Instrumentation Group of the Flight Mechanics Panel was established in 1968 to update Volumes 3 and 4 of the Flight Test Manual by the publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, the Flight Mechanics Panel decided that further specialist monograph should be published covering aspects of Volume 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group was established to carry out this task. The monographs of this series (with the exception of AG237 which was separately numbered) are being published as individually numbered volumes of AGARDograph 300.

At the end of each volume of both AGARDograph 160 and AGARDograph 300 two general Annexes are printed. Annex 1 provides a list of volumes published in the Flight Test Instrumentation Series and in the Flight Test Techniques Series. Annex 2 contains a list of handbooks that are on a variety of flight test subjects, not neccessarily related to the contents of the volume concerned.

The present Volume (Vol.10 of AGARDograph 300) covers 'Weapon Delivery Analysis and Ballistic Flight Testing', and treats the subject of stores ballistic modeling/testing from the overall system standpoint. All aspects of the ballistics testing design, data collection techniques, data reduction, analysis techniques, and finally the Operational Flight Program modeling techniques are addressed. Considerable effort has been expended to keep this report straightforward so that it can be understood by management as well as engineering personnel, but with sufficient engineering principles addressed so that a true ballistician could use it from an application perspective.

Preface

Depuis sa création el 1952, le Panel de la Mécanique du vol, sous l'égide du Groupe Consulratif pour la Recherche et les Rialisations Aerospatiales a publié, un certain nomhre de textes qui font autorité dans le domaine des essais en vol. Lc Manuel des Essais en Vol a ele publié pour la premihe fois dans les années 1954—1956. Il comportait quatre volumes a savoir:

1 Performances
2 Stabilité et Contrôle
3 Catalogue des appareils de mcsure, et
4 Systemes de mesure.

Les novations dans le domaine des appareils de mesure pour les essais en vol, ont conduit à recréer, en 1968, le groupe de travail sur les appareils de mesure pour les essais en vol pour permettre la remise à jour des volumes 3 el 4. Les travaux du groupe ont débouché sur l'édition d'une série de publications sur les appareils de mesure pour les essais en vol, I'AGARDographie 160. Les différents volumes de I'AGARDographie 160 publiés jusqu'à ce jour couvrent les derniers diveloppements dans le domdine.

En 1978, le Panel d la Mecanique du vol a signalé l'intérêt de monogrdphies supplementaires sur certains aspects des volumes I et 2 du Manuel initial et notamment les essais en vol des systl-mes avioniques. Ainsi, au mois de mars 1981, le groupe de travail sur les techniques des essais en vol a été recrée pour mener à bien cette tâche. Les monographies dans cette sirie (a I'exception de la AG 237 qui fait partie d'une série distincte) sont publiées sous forme de volumes individuels de l'AGARDographie 300.

A la fin de chacun des volumes de l'AGARDographie 160 et de I'AGARDographie 300 figurent deux annexes générales. L'annexe 1 fournit la liste des volumes publiés dans la série "Appareils de mesure pour les essais en vol" et dans le sirie "Techniques des cssais en vol". L'annexe 2 donne la liste des manuels disponibles sur les mêmes themes dans le domaine des essais en vol, qui ne sont pas forcement en rapport avec le contenu du volume en question.

Ce volume 10 de I'AGARDographie 300 décrit 'l'Analyse du Largage d'Armes et les Essais en Vol Balistique' et il traite de la *modélisation/essais balistiques* des armes externes du point vue global des systl-mes. Tous les aspects de la conception des essais balistiques, des techniques de collecte de données, de la reduction de données, des techniques d'analyse ct, enfin, des techniques dc modélisation du programme de *vol opérationnel y sont* abordes.

La rédaction a été particulièrement soignée, avec comme objectif d'éditer un rapport qui serait à la fois clair *ct compréhensible* pour les gestionnaires commc pour les ingénieurs, tout en traitant de suffisamment de principes d'ingéniérie pour intéresser de vrais ballisticiens du point de vue applications.

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In the preparation of the present volume the members of the Flight Test Techniques Group listed below took an active part. AGARD has been most fortunate in finding these competent people willing to contribute their knowledge and time in the preparation of this and other volumes.

La liste des membres du groupe de travail sur les techniques des essais en vol ont participe activement a la redaction de ce volume figure ci-dessous. UAGARD peut être fier que ces personnes compétentes aient bien voulu accepter de partager leurs connaissances et aient consacré le temps nécessaire a l'élaboration de ce et autres documents.

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Eglin Air Force Base
April 1992

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1.0 INTRODUCTION

For several decades, there has been an enormous increase in the emphasis and importance of carrying stores (both guided and unguided bombs, for example) externally on tactical fighter aircraft. In fact, many of today's aircraft carry so many stores and some stores have increased so much in size that pundits have remarked: "It'sthe stores that are carrying the aircraft!". Figure 1 shows an F-4 carrying **18** 800-pound-class cluster bombs. This is a heavy load, but there are heavier loads and much larger stores that can be carried in an almost endless array of configurations on most tactical fighter aircraft.

Tremendous amounts of time and money have been spent by the United States Air Force (USAF) and the supporting defense industrial infrastructure to establish safe carriage and separation envelopes for each aircraft/store configuration. As one can easily appreciate, the mounting of either a large number of small stores, or even a few large stores or any combination of these, can and usually does have significant ramifications on the aircraft in such areas as stability and control, structural loads, and flutter. On the other hand, the aircraft's environment can have serious detrimental effects on the stores themselves. For example, the store structure andlor internal functioning components may fail due to static and vibroacoustic loads imposed by the aircraft. Separation characteristics of stores are dependent on the aircraft's aerodynamic configuration, the store's physical and aerodynamic characteristics, and an array of other variables such as rack ejector forces. Nevertheless, analysis and test techniques for establishing safe aircraft/store carriage and store separation have reached a high level of maturity and are well documented in the literature.

However, successful completion of the preceding work only enables aircrews to carry and release stores safely in the vicinity of the target. Unless

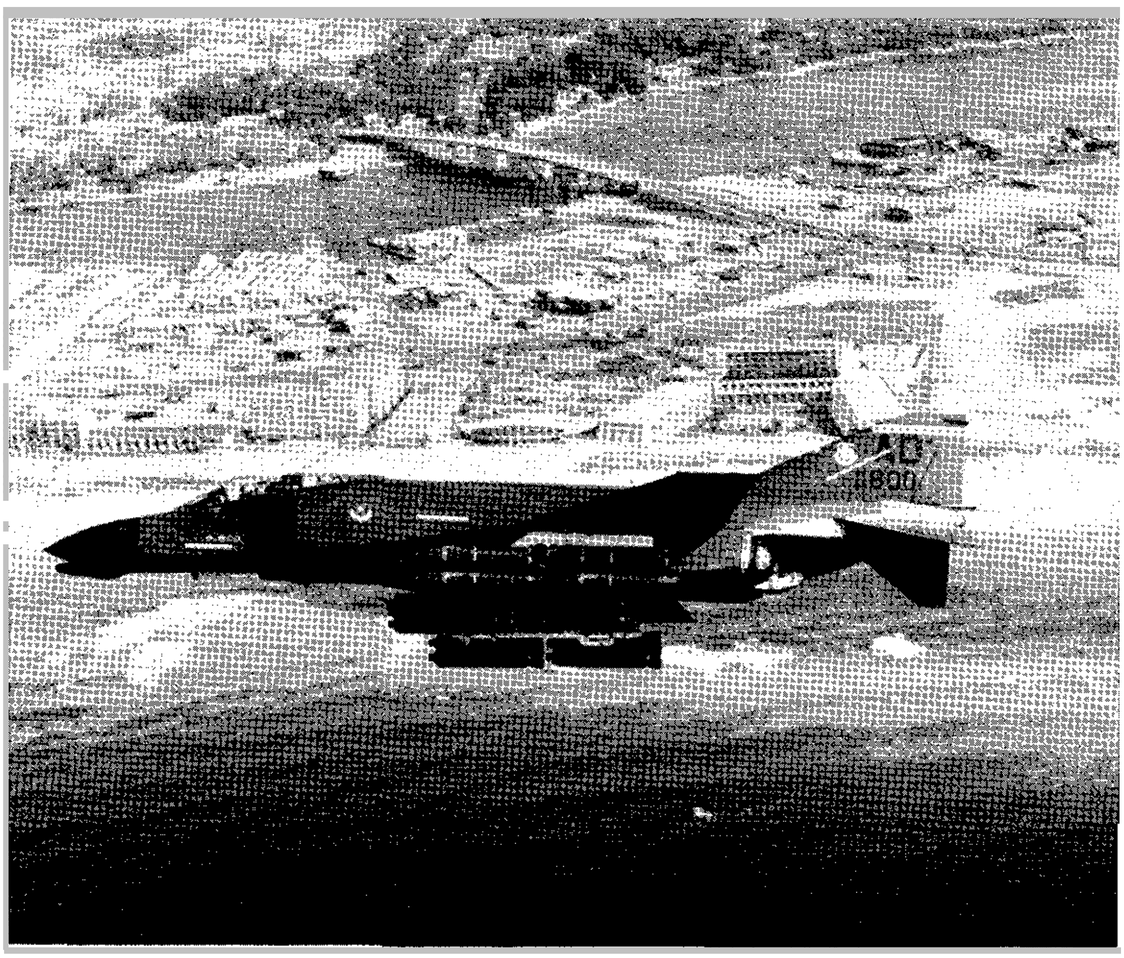


Figure 1. F-4 carrying 18 800-Pound-Class Cluster Bombs on Three Multiple Bomb Racks

stores can be released in such a manner as to put them on a trajectory so they will hit their intended targets, aircrews and aircraft will have been subjected to needless risk, and the mission and all of the work that was expended for it will have been to no avail.

In more recent years, data have become available which confirm that some aircraft have not been able to deliver stores with the accuracy that was originally expected. Quite naturally, this inability has led to concern from the operational community that its members could not achieve the "one target kill per pass" that they envisioned. First and foremost, there had been little emphasis during development testing to establish system ballistic accuracy for individual aircraft/store configurations. The testing that was done usually concentrated on establishing the overall delivery accuracy of the aircraft using small practice bombs such as the BDU-33. During operational evaluations, aircrews usually validated ballistic accuracy with these same practice bombs. For example, consider the following scenario: a pilot flies to a test range, releases a live bomb (for example, a MK 82 low-drag general-purpose bomb) against a ground target, looks over his or her shoulder after the release, and notes that the bomb bit the ground at some point relative to the target. The pilot might try to rationalize the miss due to aiming errors, a malfunctioning weapon delivery system, atmospheric conditions, a "bad" bomb, and the like. What the pilot never knew was that had man and machine been in perfect operational condition and harmony, the bomb might still have missed the target because of inadequate analysis and testing.

What really brought this situation to the attention of engineers was data obtained from one operational evaluation wherein most of the necessary variables were quantified. Live bombs were released against point targets, many of which missed their targets by very large distances. Expressed in another way, a person would have been very safe standing at target center! Bombs were released from an aircraft equipped with a weapons-delivery computer and were released in the automatic mode. Bomb mass properties were established before loading and were validated to be within acceptable tolerance. Atmospheric conditions were carefully measured before and after boinb releases. In short, bombs were released under very controlled conditions so that any errors (although none were expected) could be analyzed. It was subsequently determined that the primary source of ballistic error was due to the effect of the aircraft's flow field in disturbing the bomb's point mass trajectory, which had not been accounted for in the aircraft's weapon delivery system computer.

This experience, and others like it, served to dramatize the need for comprehensive ballistics analysis and testing in a systematic manner. Unfortunately, while the literature abounds with information on ways to establish safe carriage and separation of stores, a vast void exists on such information to establish ballistic characteristics. Accordingly, a key purpose of this volume is to open up the channels of communication by prompting others to expand and amplify on this initial effort. Within this context, this volume is intended for engineers and managers involved in ballistic analysis and test programs and for personnel, such as aircrews, in the operational community to foster a better understanding of what is involved in establishing ballistics accuracy.

By way of a disclaimer, it must be stated that this volume was assembled from the Eglin Air Force Base, Florida, perspective and specifically, from the perspective of the way ballistics analysis and testing are conducted and orchestrated by the Office for Aircraft Compatibility (3246th Test Wing/TY). However, this is not intended to imply that Eglin's way is the only way. This volume has been prepared at a general technical level. That is, technical details as to the inner workings of Eglin's various computer programs which are used to predict and analyze ballistics have been omitted in lieu of discussing approaches and procedures which may be evaluated and tailored for individual use by any test and evaluation organization.

When this volume was originally planned, it was hoped that substantive information from. other nations could be interwoven throughout the volume. While some information was obtained from a fact-finding trip to the United Kingdom, France, and Germany and from other sources, it **was** felt that it would be best not to incorporate inputs as planned so as to avoid the risk of any misquotes due to partial/incomplete information. However, as mentioned earlier, valuable information was obtained and the efforts of the people who pirepared and provided it are much appreciated. To keep the size of this volume to a reasonable length, all of this information cannot be documented herein. However, this author believes it would be of value to share representative inputs from Canada, Germany, and France. Appendix **A** contains a list of questions regarding how ballistic analysis and testing are performed in the host nation along with responses from Canada, Germany, and France. After reading this volume, it is suggested that these questions be reviewed from the standpoint of being able to understand how ballistic analysis and testing are performed in the reader's nation. If the reader is able to answer these questions, he or she will have the broad background necessary to perform detailed analyses.

Finally, it is hoped that this volume will stimulate others to add to the published database in this technical area. There is still much data that needs to be written and documented. Further efforts should have, as a goal, the standardization of procedures to the maximum extent possible in an effort to minimize resource expenditures while still delivering to the operational user the quality of data that bas the accuracy necessary to meet combat requirements.

2.0 HISTORICAL PERSPECTIVE

Long before the first flight of the Wright brothers, balloons were envisioned as a platform from which weapons could be dropped on an enemy. In early experiments, oranges and paper bags filled with flour were dropped overboard by hand from low altitudes, usually a few hundred feet, as the balloon drifted over a target outlined on the ground. However, it is wondered whether these early pioneers gave any thought to the fact that the enemy might be shooting back and the balloon would probably be shot down before reaching its target.

In the early days of World War I, the offensive use of the airplane was enhanced by dropping small bombs and other objects, such as quantities of steel darts and incendiary grenades. Bombs were thrown overboard by the aircrew (see Figure 2) at the perceived right time (by seat of the pants or by using eyeball judgment) to hit the target. From low altitudes of several hundred feet and at low airspeeds of less than 100 miles per hour, the results were considered very good against undefended area targets such as a fuel dump. However, this methodology changed when enemy defensive fire forced aircraft to release bombs from higher altitudes (usually above 1500 feet) and/or at night to minimize the possibility of getting shot down.

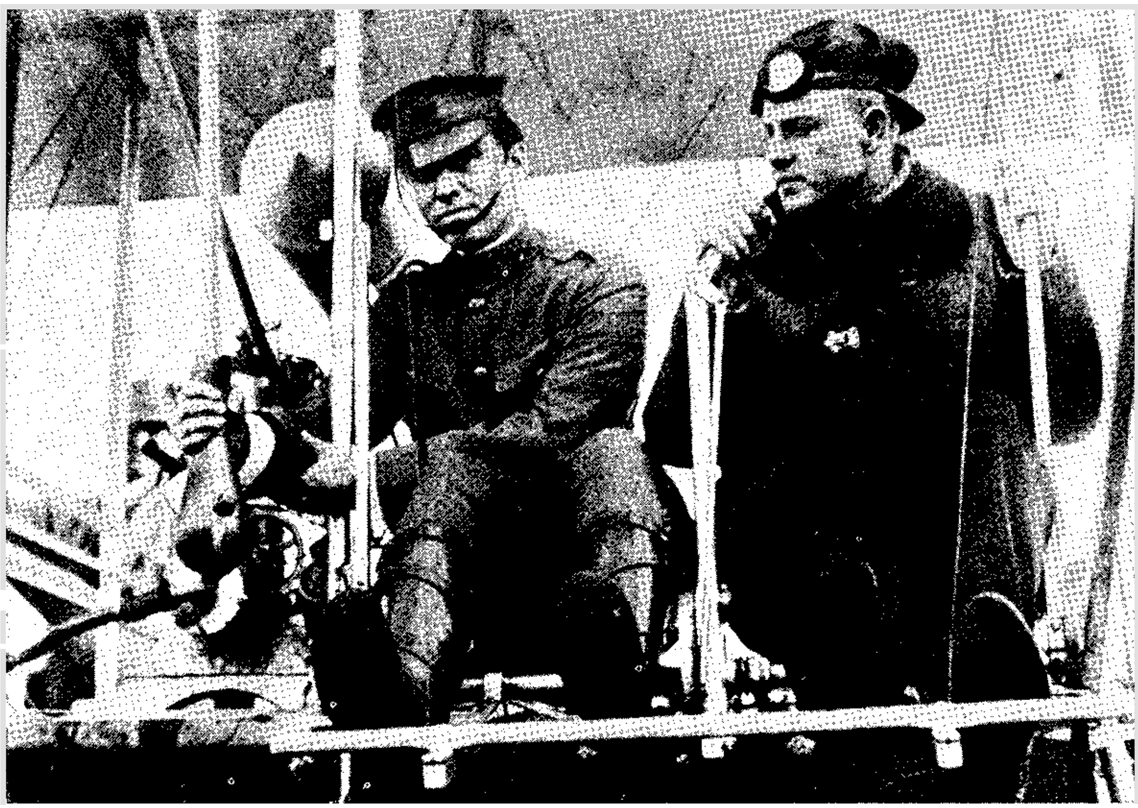


Figure 2. Aircrew Demonstrating Technique for Throwing a Small Bomb from an Aircraft

Under these conditions, the probability of hitting area targets declined substantially and the probability of hitting point targets, such as a bridge, became almost an impossibility except when a rare lucky hit is excluded.

The complex problem of hitting a target from a moving aircraft without even a bombsight to guide the aircrew was definitely underestimated at the beginning of World War I. As a result of combat experience during this war, the technical community slowly came to realize that there was only a single point in the vast airspace from which an aircraft could release its bombs and cause them to hit the target. These community members learned that aircraft motion and atmospheric conditions such as wind speed and direction all induced errors in the fall of bombs. As a result, considerable work was undertaken and significant technical progress was made in the area of aerial bombardment by the end of the World War I. For example, substantial improvements were made in the bombs themselves. They were specifically designed for aircraft use and equipped with stabilizing fins. The bombs had increased in *size*, too, (weighing up to several thousand pounds) as the payload of aircraft also increased. Primitive racks were developed to carry and release the bombs. Figure 3 shows

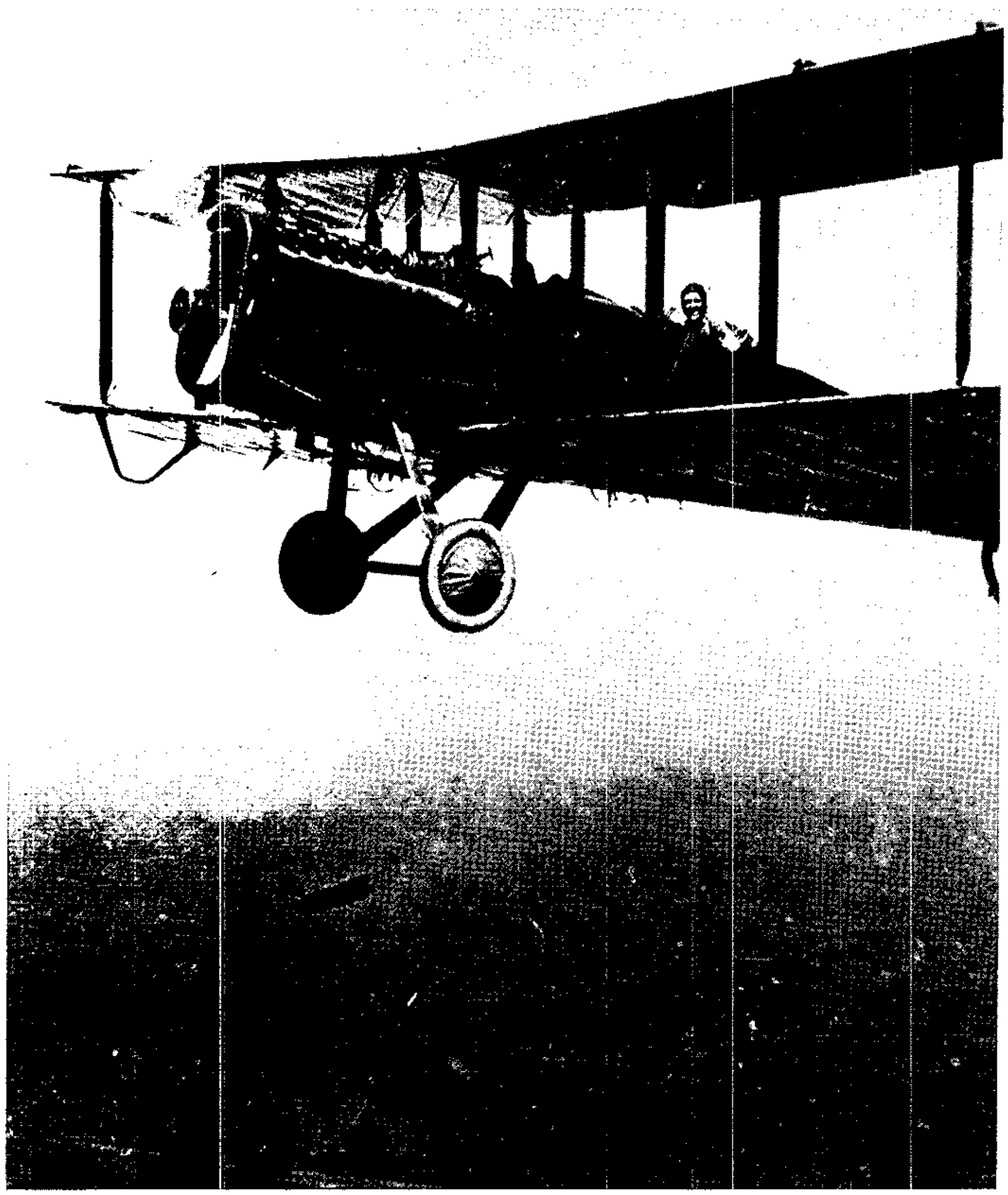


Figure 3. Four 25-Pound Bombs Just After Release from DH-4 Aircraft Using Strap Carriage Racks

several 25-pound bombs just after release from some of these primitive racks. Some of these racks consisted of nothing more than straps which were uncoupled when a cable was pulled by the pilot. Equally primitive aiming devices were developed. But, by the end of World War I, aircraft were still very ineffective in the bombardment mode. Most post-war histories agree that aerial bombardment had no effect on the war's outcome inasmuch as only a small percentage of the bombs hit the targets (Reference 1).

Between the world wars, the technical community focused on improving ballistic accuracy through the development and use of bombsights as well as efficient bomb release mechanisms. Bombsights were developed which used electric gyroscopes with stabilizing devices to maintain a true vertical reference line. The need for this true vertical reference line was one of the key lessons learned from the experience of World War I. Aircrews found that they could not maintain the vertical reference line needed for accurate bombing by relying on pendulum- or spirit-leveled instruments since these instruments only gave indications of an apparent vertical which varied with each turn, bump, pitch, or sideslip of the aircraft. In addition, aircrews could not even maintain a true and straight course. At best, they maintained a succession of curved paths in which errors were accumulated until they were observed and then corrected. The substantial impact of errors in the apparent vertical on ballistic accuracy was recognized in these early days. For example, one vintage test report from the **1920** era discusses the situation in which a bomb dropped from an aircraft traveling 100 miles per hour at 15,000 feet altitude would miss its target by 250 feet just from the effect of centrifugal force throwing off the apparent vertical by only one degree if the aircraft had been in a very slow turn of 360 degrees every half-hour (Reference **2).**

Integral to the development of a gyroscope-driven bombsight was the development of a sighting apparatus whose primary function was to indicate, at all times, the point on the ground where the bomb would hit if it were released at that instant. A complete bombsight was required to determine the speed **and** direction of the aircraft and of *the* wind, in relation to the ground, to arrive at an apparent direction to reach a given target. As one can surmise, these early pioneers were on the right track. But the result, then **as** today, was that even if the aircrew released the bomb at the precise moment required by the bombsight, this was no guarantee of hitting the target. Engineers studied the trajectories of bombs from the moment of release to ground impact, and made significant progress in quantifying bomb drag characteristics and determining the best geometric shape to control terminal velocities through wind tunnel and flight testing (Reference 3). But they were at a loss as to how to account for the very observable and unpredictable pitching and yawing motions of bombs as they separated from the aircraft (Reference *4).* These engineers knew that motions changed bomb drag and degraded ballistic accuracy. But, since they did not know how to account for these motions, they considered bombs as falling as a point mass using 3-degree-of-freedom (3DOF) equations of motion coupled with the most reliable freestream bomb drag they had. As will be shown, this procedure, for the most part, did not change for many years.

During the 1920s and 1930s, aircrews developed bombing techniques to effectively use the new bombsights and racks. Basically, two techniques were refined: dive-bombing and level-bombing. Dive-bombing consisted of making a high-altitude approach followed by a steep dive (up to 60 degrees or more) toward the target. During the dive, in which airbrakes are sometimes used to control speed, deviations in course were made to correct for initial aiming errors or wind. The bomb was released as close to the target **as** dive recovery would allow. Dive-bombing used a sighting device but not a bombsight. Yet accuracies were considered to be quite good. In fact, accuracies of 150-300 feet were regularly obtained by operational Army Air *Corps* squadrons (Reference *5).* In hindsight, this should not have been surprising since bomb times of fall were very small, thus minimizing induced errors from all sources. During peacetime, this technique may appear very appealing, but during wartime, against defended targets, this technique loses its appeal, as was proven by all combatants during World War II. For example, against undefended targets, the German Stuka was very effective. However, against defended targets and/or in the face of enemy fighters, the Stuka was easily shot down (Reference 5).

Level-bombing using bombsights received considerable publicity during the 1920 era with General Mitchell and his aircrews' sinkings of battleships. While this accomplishment bad significant ramifications on the future strategy of airpower, the fact was that General Mitchell and his aircrews practiced extensively by approaching and overflying ships at constant airspeeds and low altitudes (Figure 4). The ships were stationary, and they were big ships! Yet, even under such ideal conditions, ballistic accuracy was poor considering the fact that most bombs missed their targets (Reference 6). During one series of tests where bombs were released at high altitudes, not a single bomb hit a ship (Reference 7). Eventually, ships were sunk from low altitudes by the small percentage of bombs that did hit their targets.

Although bombsights, racks, and bombs had been considerably refined during the interlude from World War I to World War II, minimal progress had been made in improving overall ballistics accuracy, particularly in the level-bombing technique. Just as had occurred during World War I, aircrews were forced to high altitudes to minimize aircraft losses from enemy defensive fire. And, just as in World War I, ballistic accuracy was substantially degraded. For example, in 1938, just before World War II, a large-scale exercise was conducted by the Army Air *Corps* during which bombs were released at high altitudes (around 20,000 feet) against aircraft-carrier-size targets. Results showed average miss distances of over 1,000 feet (Reference 6). Precision daylight bombing by the USAF was, in reality, carpet or saturation bombing. For a target like a bridge, many aircraft were used to drop tons of bombs to achieve a high probability of hitting the target. Figure 5 shows a knocked-out bridge. But notice all the surrounding bomb craters and the relatively intact center span which was taken down by blast effects from a near miss.

The period from World War II through the Korean War and the beginning of the Vietnam War can be showcased by the design of aircraft that were able to carry heavier bomb loads faster and higher than before. The use of manual bombsights and simple bomb racks was still dominant. Bombs were released from aircraft using ballistics tables that were based on freestream drag characteristics only. That is, the effect of the aircraft on inducing bomb oscillations during separation was still not accounted

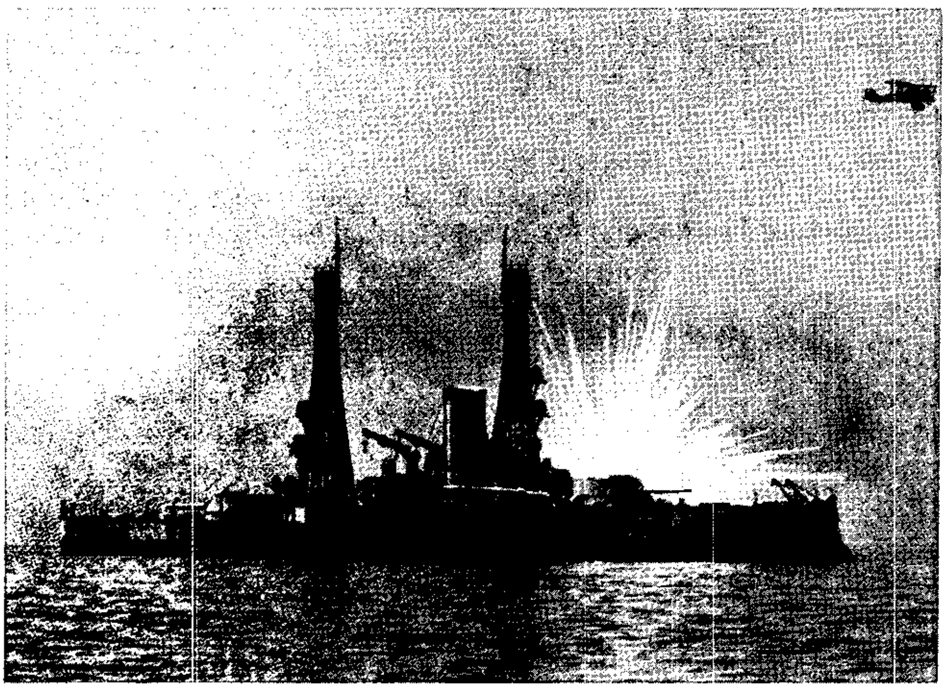


Figure 4. Martin Bomber Scoring Direct Hit on Battleship Alabama with 25-Pound Phosphorus Bomb

Figure 5. Bridge Destroyed Using Carpet Bombing

for. **As** a result, ballistic accuracy was still such that, to ensure killing a target, many bombs had to be released against a target. **A** factor in this number of bombs was that, since World War II, bombs had generally gotten smaller. Bomb weights predominately ranged from 250-750 pounds. It may be noted that, during World War II, bombs weighing 4,000 pounds, 12,000 pounds (Tallboy), and even 22,000 pounds (Blockbuster) were used to compensate, in part, for the inability to reliably score direct hits (Reference 8). During the Vietnam War, extensive use was made of the fighter-bomber. Again, to make up for shortcomings in ballistics accuracy, multiple bomb racks, such as the triple ejector rack (TER), which could carry up to three bombs, and the multiple ejector rack (MER), which could carry up to six bombs, were developed. Also, fighter-bomber aircraft were equipped with hardpoints to carry several of these racks. For example, with its six wing hardpoints and six multiple ejector racks, the A-7D could carry 32 MK 82 LDGP 500-pound bombs. The A-7D was one of the first fighter-bomber aircraft to be equipped with an automated weapon delivery system. With this system, the pilot could designate the target on his cockpit display and the bomb would be released automatically at the precise time needed to hit the target without the pilot having to physically push a release button. Whether bombs were released using level- or dive-bombing techniques, all of the bombs were usually dropped during one pass using a small time interval between bombs in an attempt to bracket the target because of the earlier mentioned use of freestream bomb drag characteristics. Figure 6 shows a typical release of bombs in the ripple mode. At best, a pilot could not expect to hit closer than 250-350 feet of a target on a regular basis with a single bomb (Reference 9). Reference 8 states that by the late 1960 period, no more than one-half the bombs released could be expected to hit within 300-500 feet of the target. Whichever figure is believable, both of them are too high in relation to the small size of most bombs used today. It is conjecture that from the 1950 period through the 1960 period, these errors did not concern the operational community inasmuch as nuclear weapons were available which did not need a high degree of accuracy. With the de-emphasis of nuclear weapons, the need for high accuracy is of renewed importance.

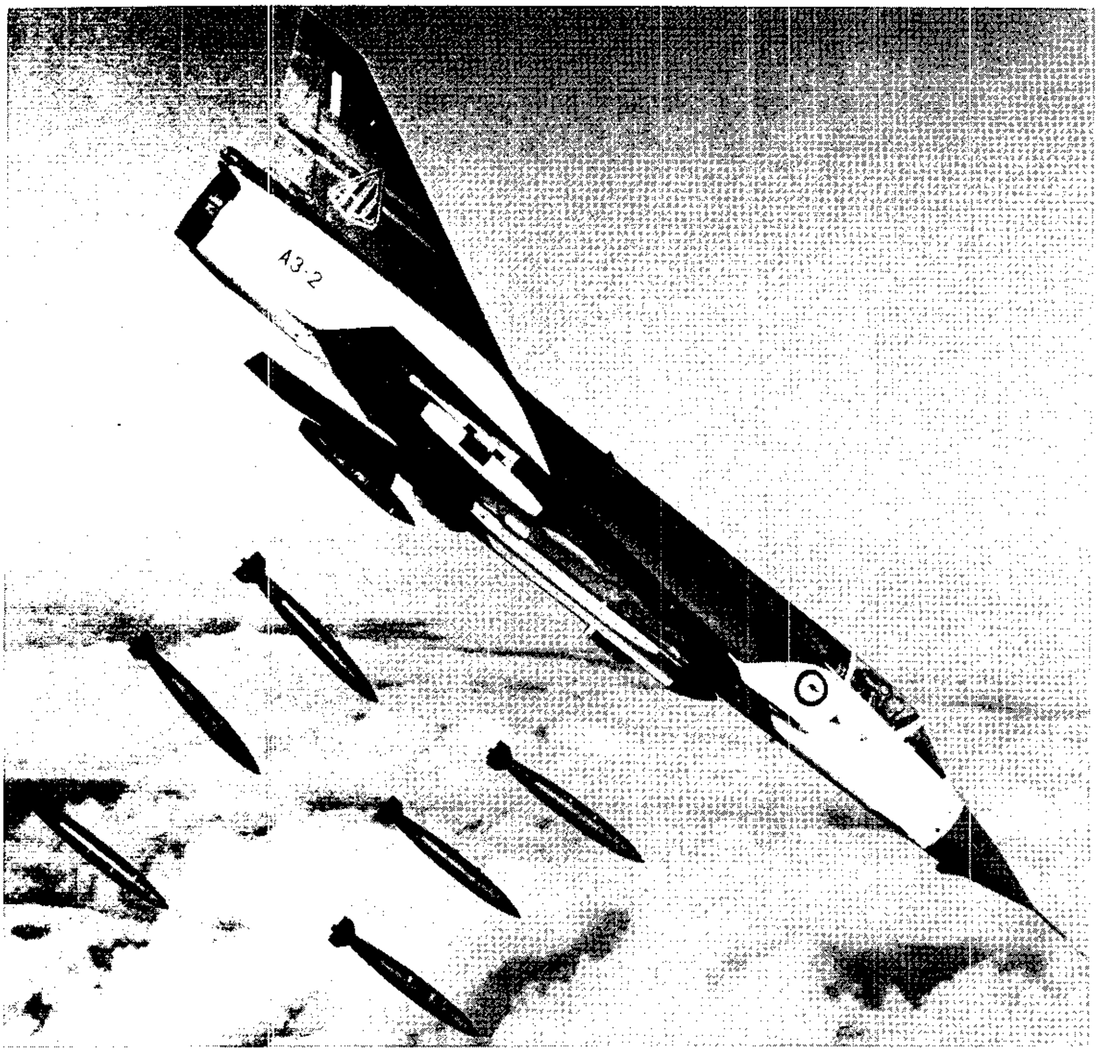


Figure 6. Ripple Release of Six MK 82 LDGP 500-Pound Bombs from Mirage Aircraft in a Dive

Most aircraft are now equipped with automated weapon-delivery systems and sophisticated supporting instrumentation/sensors such as laser rangefinders and altimeters and high-speed digital computers. This hardware, coupled with the technical knowledge and procedures to quantify and correct ballistic errors, offers the potential for significantly improving accuracy. In fact, for subsonic releases of bombs in the level and dive modes, bombing errors of under 50 feet and 20 feet, respectively, are suggested as an achievable goal. Using the right size stores, this would enable most targets to be killed with one bomb in one pass. This volume will now discuss some of the procedures utilized to make improved accuracy a reality.

3.0 POTENTIAL FOR REDUCING BALLISTIC ERRORS

In the early 1970 time period, analyses were performed to evaluate the effects of various error sources on miss distance (Reference 10). These analyses were among the first of their kind performed and therefore provided valuable insight into the sensitivity that various error sources have on ballistics accuracy. While analyses were somewhat simplistic by today's technical standards, the results are still relevant today and offer a good introduction to the volume on ballistics. Errors from four primary sources were analyzed:

(1) Errors associated with aircraft release conditions (50-foot altitude error, 10-knot airspeed error, 0.1-degree pitch attitude error, and 0.2-degree yaw error)
(2) Errors associated with bomb physical and geometric properties (20-pound bomb weight error, 0.5-inch bomb diameter error, 4-slug-ft^2 bomb inertia error, and 5-percent error in bomb freestream drag coefficient)
(3) Errors due to non-standard atmospheric conditions (5-percent error in density)
(4) Errors due to bomb-separation effects during release from the aircraft (5-degree error in bomb pitch attitude, 5-degree error in bomb yaw attitude, 50-degree/second error in bomb pitching motion, and 2-foot/second error in the end of stroke velocity imparted by the bomb by the aircraft's ejector rack).

Table I presents the raw data from the analyses for MK 82 LDGP 500-pound bombs at delivery conditions of 450 and 860 knots in level and 45-degree dives. Table II presents a concise summary of data grouped by each of the four error sources. Referring to Table II, at 450 knots for a level release, 57 percent of the total miss distance is due to aircraft release condition errors (287 feet out of 501 feet). Separation effects are the next biggest contributors to miss distance with 31 percent (150 feet), followed by bomb errors with 10 percent (53 feet), and atmospheric errors with 2 percent (11 feet). As may be noted, these percentages are representative of those for the 860-knot, level-release condition and the dive condition at both airspeeds with one exception. Note that the miss distance due to bomb errors increases rather substantially from 10 percent at 450 knots to 30 percent at 860 knots in the level-release mode, primarily due to increased bomb time of fall.

Presently, fighter-bomber aircraft are equipped with automatic weapon delivery systems. These highly sophisticated systems are capable of releasing bombs at the precise point required to put them on a trajectory *to* hit the target. In effect, there is no reason that the 57-percent error in miss distance due to aircraft release conditions cannot be reduced by an order of magnitude or more when bombs are released in the automatic mode. **A** reduction from 287 feet to less than 25 feet is postulated with proper attention to this error source.

Miss distance due *to* separation effects is clearly very significant. In an earlier AGARDoGraph (Reference 11), a statement was made to the effect that these errors were not correctable to any great extent. However, with modern weapon delivery systems, this statement is no longer true. If sufficient testing is performed, separation effects can be measured and modeled in the form of algorithms and stored in the weapon delivery system's high-speed digital computer. With accurate modeling, the computer signals the weapons release system to release bombs at adjusted conditions to account for separation effects. As explained in detail in later sections of this volume, the separation effects vary with aircraft release conditions, and are unique to each aircraft/store configuration. Thus, if separation effects were precisely measured, a very large computer would be required to store and process all of the necessary data. At this **time,** while modern aircraft have a substantial amount of computer storage capacity, they do not have enough capacity to store separation effects for all flight conditions and for all configurations, of which there are usually hundreds for each aircraft. Only land-based mainframe computers have this kind of storage capacity. However, aircraft computers do have the capacity to store separation effects data for a limited number of configurations at limited flight conditions. Thus, and most importantly, if the operational user defines primary go-to-war configurations along with combat delivery conditions", separation effects data can be modeled in the weapons delivery computer and be almost entirely accountable. A reduction from 150 feet to less than 10 feet is postulated with proper attention to this error source.

Miss distance due to errors in bomb physical and geometric properties (53 feet) cannot be ignored. Such a miss distance would reduce probability of kill by a significant amount. Until recently, **mass**-produced stores like the MK 82 formed a predominant portion of the USAF operational inventory. Manufacturing tolerances were rather loose to minimize cost. This accounted for large variations in weight, inertia, and even bombs being cast out of round. Low-cost stores will always be available, but a trend exists toward developing stores which, by their very nature, are manufactured with tighter tolerances. The new BLU-109 2000-pound-class warhead is a good example. The manufacturing tolerances for the forged version of this warhead are substantially **less** than tolerances for the **MK** 84 LDGP. Tighter tolerances also apply to other new stores like the CBU-87 and CBU-89 cluster bombs. The point is that if the operational **user** wants to kill **a** point target in one pass, a new class of bombs can be used that is manufactured

Table I. Predicted Miss Distances of MK 82 Low-Drag General-Purpose Bombs Due to Various Error Sources - Raw Data

	MISS DISTANCE M AIRCRAFT SOU				MISS DISTANCE FROM BOMB CES				MISS DISTANCE FROM ATMOSPHERE	MISS DISTANCE FROM SEPARATION EFFECTS			
DELIVERY CONDITION	50 FT ALTITUDE	10-KNOT AIRSPEED	0.1° PITCH	0.2° YAW	20-LB WEIGHT	0.5-IN DIAMETER	4-SLUG-FT² INERTIA	5% DRAG	5% DENSITY	5° PITCH	5° YAW	50°/SEC PITCH RATE	2 FT/SEC EJECTOR VELOCITY
LEVEL RELEASE/5000 FT													
450 KTAS	76	125	41	45	7	20	14	12	11	36	9	61	44
860 KTAS	117	130	127	80	67	170	14	90	90	83	19	68	68
45' DIVE RELEASE/8000 FT													
450 KTAS	33	25	5	29	2	3	4	3	2	18	1	25	24
860 KTAS	21	75	3	35	3	5	2	2	4	26	1	19	17

Table II. Predicted Miss Distances of MK 82 Low-Drag General-Purpose Bombs Due to Various Error Sources - Summary

DELIVERY CONDITION	TOTAL MISS DISTANCE	MISS DISTANCE (IN FEET) BY ERROR SOURCE			
		AIRCRAFT	BOMB	ATMOSPHERE	SEPARATION EFFECTS
LEVEL-RELEASE/5000 FT					
450 KTAS	501	287 (57%)	53 (10%)	11 (2%)	150 (31%)
860 KTAS	1123	454 (40%)	341 (30%)	90 (8%)	238 *(22%)*
45° DIVE-RELEASE/8000 FT					
450 KTAS	174	92 (53%)	12 (7%)	2 (1%)	68 (39%)
860 KTAS	219	140 (64%)	12 (5%)	4 (2%)	63 (39%)

with much tighter tolerances than in the past and that minimizes errors in miss distance. Further, using modern instrumentation to track bombs during their fall, systematic test procedures, and advanced data reduction techniques, bomb freestream drag coefficients can be established with a high degree of precision. An overall reduction from 53 feet to less than 5 feet is postulated with proper attention to this error source.

Finally, a miss-distance error of 11 feet was calculated due to an atmospheric density of 5 percent. One cannot control the atmosphere, so this error is accepted as a given fact.

The point of this discussion is that, with modern weapon delivery hardware and software and with proper testing and analyses, considerable reason exists for optimism that unguided stores can be released with near-pinpoint accuracy. If multiple stores are released against a point target, target kill will almost be a certainty.

4.0 OBJECTIVES OF BALLISTIC TEST PROGRAMS

There may be several objectives to a weapon system test program, but if ballistics are considered, there are three basic objectives:

(1) To obtain flight test data necessary to establish store freestream flight characteristics
(2) To obtain the flight test data necessary to establish separation effects
(3) To obtain the flight test data necessary to establish the weapon delivery accuracy of the aircraft's Operational Flight Program (OFP).

4.1 Freestream Testing

To aim a store so that it will hit a target, a knowledge of the flight characteristics of the store as it travels to the target is required. It is necessary to perform testing to obtain the data necessary to establish or verify the store's drag, event times, and other factors that affect the store's flight characteristics. Freestream drag characteristics are generally independent of aircraft and mode of delivery 1 to 3 seconds after release. Experience has shown that by this time, store motion is no longer influenced by the aircraft's flowfield. Subsequently, store motion is damped to steady-state conditions, and the store falls along a point-mass trajectory to its functioning point and/or target impact. Freestream testing is usually accomplished during the Development Test and Evaluation (DT&E) phase of a store program. During such testing, the contractor's drag and event times are verified. Because all drag prediction codes and wind tunnel test techniques have some limitations, no substitute exists for flight testing to validate drag and event times using actual hardware. The process of verifying or deriving freestream flight characteristics will be discussed in a subsequent section of this volume.

4.2 Separation-Effects Testing

Separation effects occur when a store is released from an aircraft and its motion is temporarily influenced by the interaction of the non-uniform flow of air between the aircraft and the store (Figure 7). Separation effects, for a given store are aircraft- and configuration-dependent. That is, the flowfield around an F-4 is not the same as it is around an F-16. In the same vein, the flowfield of an aircraft loaded with stores on a multiple bomb rack is different than that with stores mounted on the same aircraft, but on parent pylon raclts.

Separation-effects testing involves releasing stores from an aircraft, one at a time, under controlled test conditions. For example, time-space-position information (TSPI) is gathered for both the aircraft and the store from store release to store impact. Data are used, as explained later, to quantify changes in the store trajectory due to the aircraft flowfield. Once separation-effects data are established, they are mathematically modeled for use in the aircraft weapon-delivery algorithm of the Operational Flight Program (OFP). The OFP is used to compute the store range and time of flight to the target using onboard aircraft data sources. Incidentally, the thrust of this discussion revolves around the premise that all modern fighter-bomber aircraft are equipped with digital computerized weapon delivery systems rather than manual sights (that is, iron bombsight).

It is noteworthy that all store configurations need not be compensated for separation effects. For example, the stores released as shown in Figure 6 probably do not have measurable separation effects inasmuch as they separate with minimal angular perturbations, and hence, minimum variation in store freestream drag characteristics. When conducting a test program, it is prudent to make a few carefully selected drops at the user's prioritized combat delivery conditions to measure the accuracy of the aircraft using only store freestream

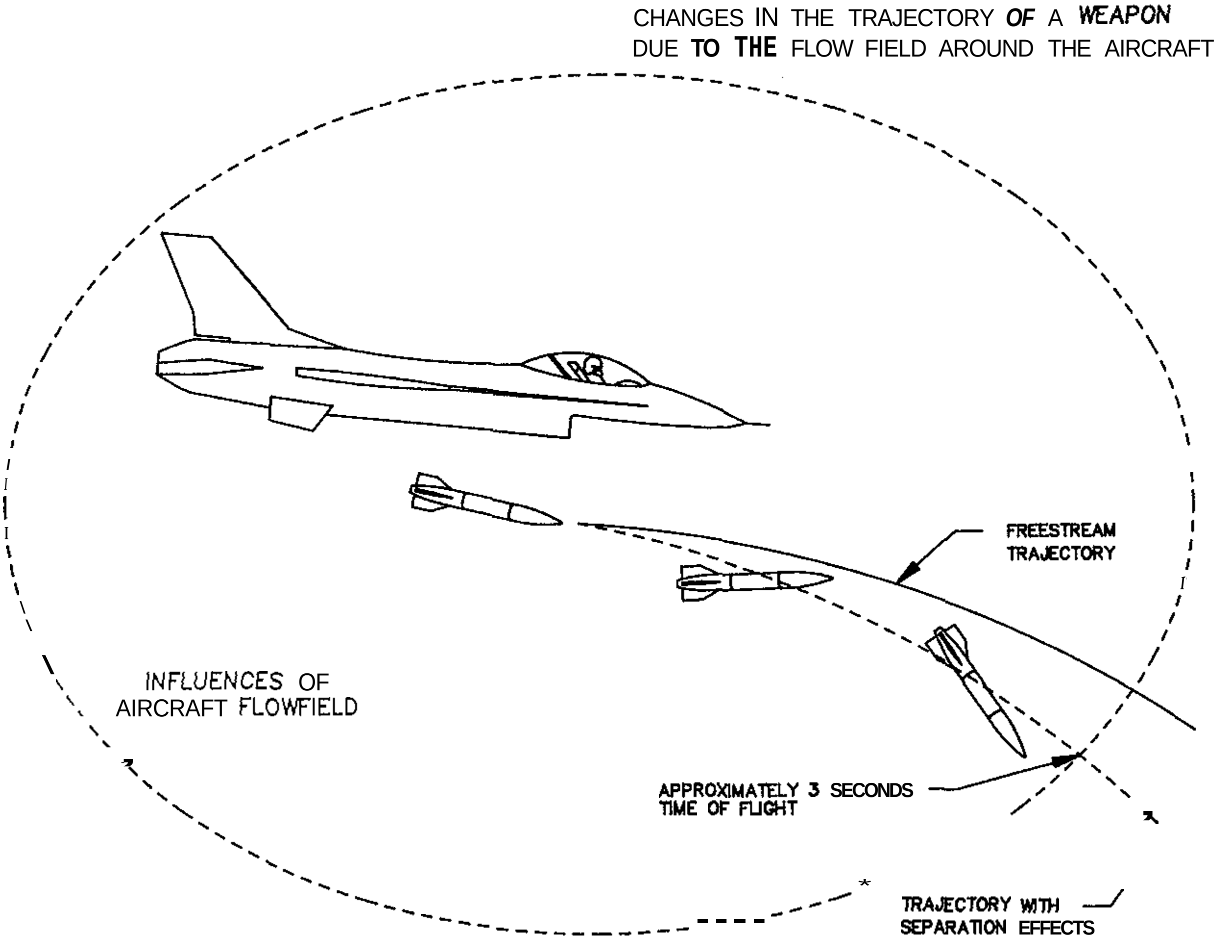


Figure 7. Separation Effects Defined

drag data in the OFP. This method has, in fact, been used for several aircraft in recent years. Test results have shown that, for some release conditions and for some store loadings, accuracy was sufficient without separation-effects compensation. Such testing can obviate the need for extensive test and analyses. However, sound engineering judgment must be used. It would be incorrect to assume that because a given store loadout displays negligible separation effects under one set of delivery conditions, there will not he large separation effects at different delivery conditions (for example, different airspeed, altitude, normal acceleration, and dive angle).

Separation effects are modeled in an aircraft OFP in various ways. In the F-16, these effects are modeled by adjusting the velocity vectors in the along-track and vertical directions (assumed time $t = 0$ at release) before they are fed to the air-to-ground integration routine contained in the OFP. Adjusted velocity vectors are then used to calculate the store trajectory. These velocity adjustments, or deltas, are derived from test drops and are curve-fitted to a function of Mach number and normal acceleration. The aircraft onboard computer uses these functions to compensate for separation effects for given store loadouts and delivery conditions. Obviously, the compensation is only as good as the separation-effects data. Because of computer storage limitations, modeling of data is not always precise. This is particularly true when there is a need to model several store loadouts over a broad band of delivery conditions. It cannot be overstated that the reason user prioritization of loadouts is so important is to ensure that the most important loadouts are modeled as perfectly as possible.

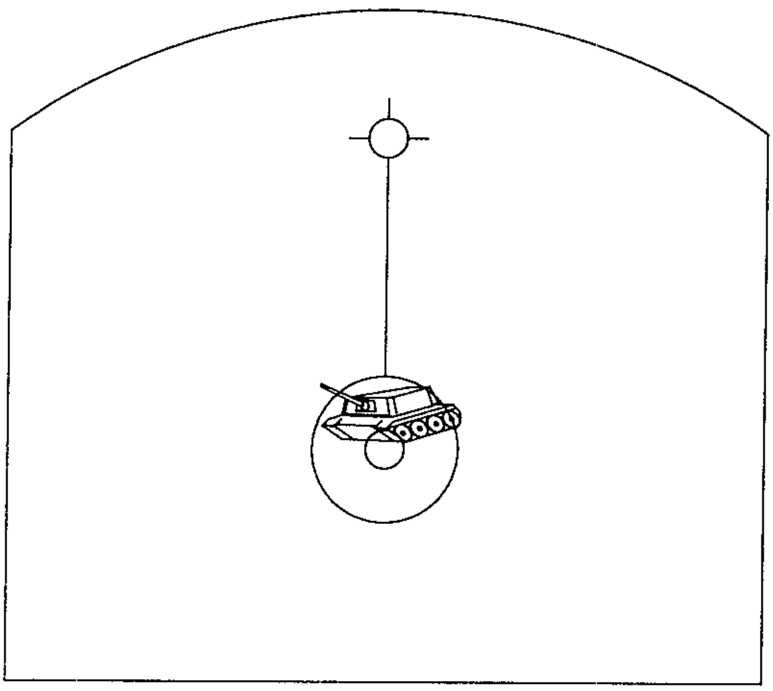
4.3 OFP Accuracy Testing

This testing provides data for analysis of the entire weapon delivery system. During testing, the pilot attempts to hit simulated targets using sensors from the aircraft weapon delivery system (for example, the Head-Up Display (HUD)). Tests are conducted in a very systematic manner using appropriate instrumentation to facilitate proper analysis. For example, the pilot attempts to designate the target precisely using HUD symbology (Figure 8). But if this is not the case, an error is introduced. Fortunately, by having the HUD instrumented, errors in designation can be detected and corrected for in the subsequent analyses. Results of testing are reported in terms of circular error probabilities (CEP) and range bias. CEP is the radius of a circle, centered on the target *or* mean point of impact, which contains 50 percent of all bombs dropped at a given set of delivery conditions for a specific loadout. Range bias is the distance that bombs hit long *or* short of the target. These two important measures are used to gauge the effectiveness of killing a target.

4.4 OFP Accuracy-Verification Process

If test results satisfy the user's accuracy criteria, testing is considered complete. However, if the user needs a higher degree of accuracy, additional testing would be required. Figure 9 describes the OFP accuracy-verification process. Basically, there are three phases. In the first phase, stores are released using validated store freestream drag characteristics modeled in the OFP. Usually a preproduction OFP is used which is called a "patch tape". In addition, any validated *or* even estimated separation effects (for example, from actual results from similar store loadouts on the same or other aircraft or from wind tunnel data) are included in the OFP modeling. A sufficient number of stores are then dropped to establish statistical confidence. This number has been the subject of considerable controversy and will be discussed in a later section of this volume. However, at this point, it is important to note that if results satisfy the user's criteria, OFP accuracy will have been verified and Phase I is then complete. (Note: These discussions assume you have an A/C whose avionics, etc., have been verified.)

ACCURACY ANALYSIS



DID THE BOMB REALLY GO THERE ???

Figure 8. Target Designation on Heads-Up-Display

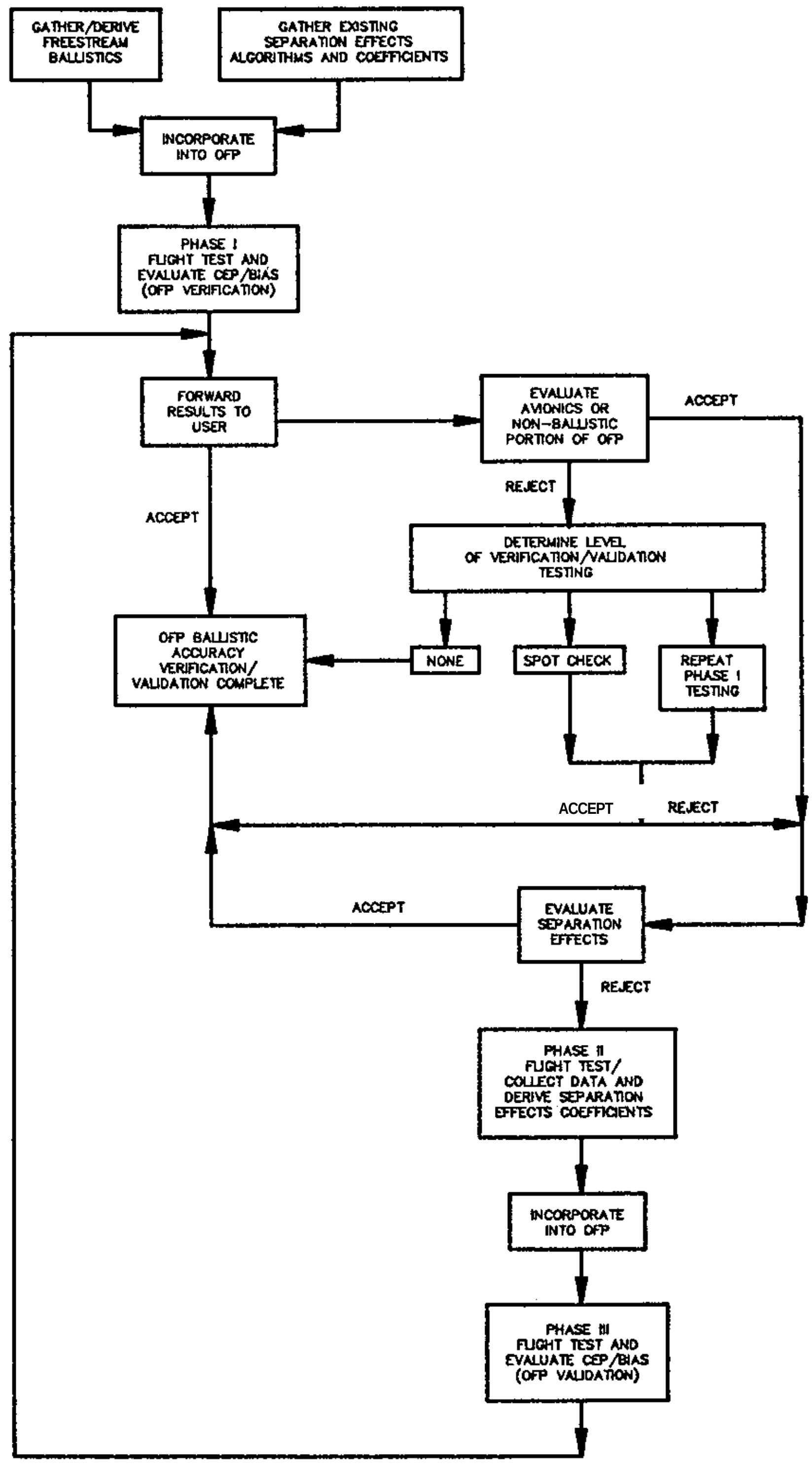


Figure 9. Ballistic Accuracy Verification Process

If the user is not satisfied with Phase I results. and after it has been validated that no aircraft avionics problems exist with the non-ballistic portion of the OFP, Phase II is conducted. In this phase, testing is performed to gather additional separation-effects data to refine modeling of coefficients in the OFP. Once the data have been analyzed and modeled, a new patch OFP tape is generated.

Phase III, essentially a repeat of Phase I, is then performed. Stores are dropped to gather CEP and bias data. Data are reviewed by the operational user for acceptability. If results are acceptable, the OFP is considered to have been verified. If not, the cycle is repeated, usually at continuing and frequently substantial expenditure of resources.

4.5 Tradeoff Between Accuracy and Resource Expenditures

As a final part of this discussion, it should be pointed out that, although TSPI is not necessary to perform an OFP analysis, it is in the best interest of the Air Force to gather as much of this data as possible on every weapon released from an aircraft. The additional cost of adding TSPI and aircraft instrumentation readings to a mission is very small compared to other mission costs. Having these data available to the OFP analyst affords insight that would otherwise be lost as to the probable causes of biases and dispersions.

The tradeoff between increased accuracy and resource expenditures is visibly illustrated by the following red-world example. In the mid-1980's, an operational evaluation of the F-16 with CBU-58 stores showed that the stores hit short of the target by a large and unacceptable distance. The free-stream ballistics of the CBU-58 had been well established previously, and the aircraft weapon delivery system had passed all checks. After further analysis, it was determined that errors were primarily due to the separation effects not being modeled in the OFP. As a result, extensive testing was performed to gather separation-effects data. Data were analyzed and modeled, and a new OFP was prepared. Subsequent testing showed that errors were reduced by a very substantial 80 percent (see Figure 10). At this time, the operation user, satisfied with the large error reduction, asked

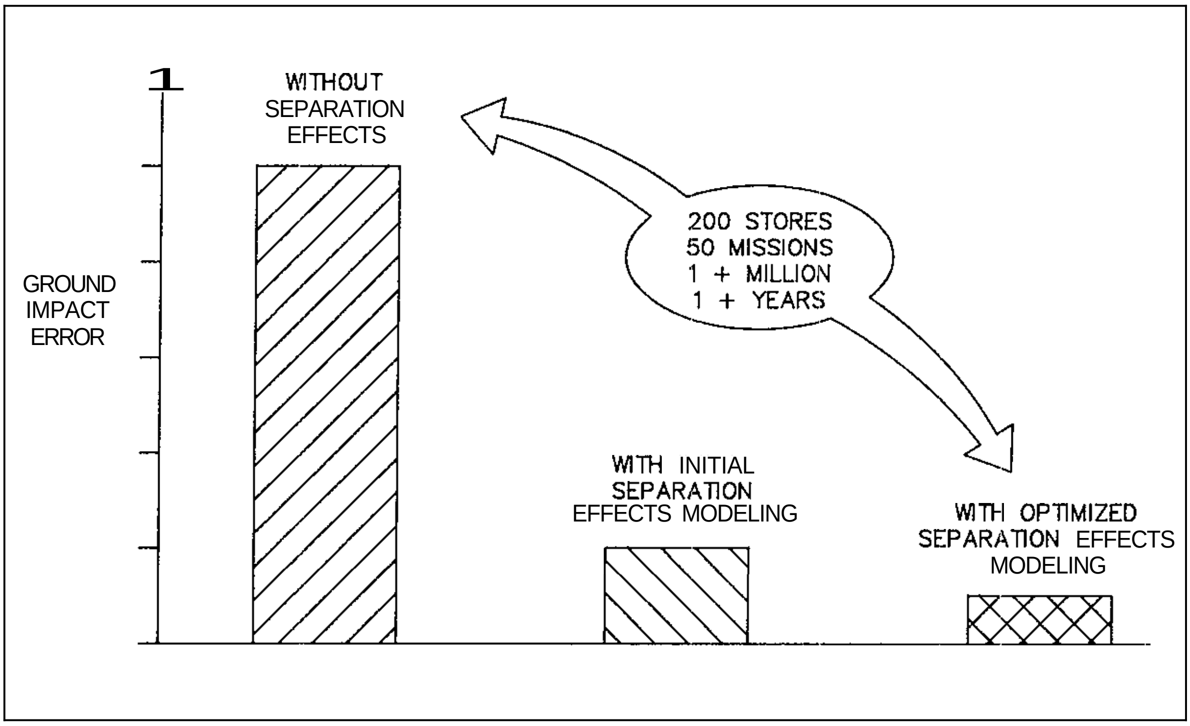


Figure 10. Tradeoff Between Accuracy and Resource Expenditures

that testing continue to further reduce errors. Consequently, another cycle of testing and analysis was performed, leading to a further reduction in error. However, on hindsight, it is questionable whether this additional cycle of testing and analysis was required considering the fact that the CBU-58 is a cluster weapon. The resources necessary to complete the three cycles required the expenditure of 200 stores in 50 flight test missions, took well over a year to complete, and cost over one million dollars. A lesson learned is that accuracy and resource expenditure tradeoffs should be considered before testing begins. This consideration would constrain a seemingly natural tendency on the part of the operational user (and this is not a criterion) to keep demanding more accuracy, irrespective of the resources required to achieve it.

5.0 GENERAL DESCRIPTION OF WEAPON DELIVERY SYSTEM

5.1 Data Sources

Several data sources onboard an aircraft affect the ability of the fire control system to calculate a weapon trajectory and to deliver that weapon on a target accurately and effectively. For purposes of illustration, F-16A/B data sources will be used in this discussion. Following are examples of identified major error sources, but are not necessarily all-inclusive.

Data sources are the Fire Control Radar (FCR), Central Air Data Computer (CADC), Inertial Navigation System (INS), and the Rate Sensor Unit (RSU). These and other systems communicate with the Fire Control Computer (FCC) on a serial digital multiplex (MUX) bus. It is interesting that, by installing a data recorder on the MUX bus, one can "listen in" on bus traffic, and this data can be saved for later evaluation. Other aircraft systems have similar types of data sources although the names may not be exactly the same.

The FCR provides essential radar ranging data **to** the FCC. In all visual delivery modes, the FCC slaves the radar to the desired aim point. The radar, in turn, provides the slant range to the aim point and the radar look-down angle. These inputs enable the FCC to solve the "bombing triangle", that is, to calculate both the aircraft height above and the distance along-track to the aim point. It may be noted that Low Altitude Target Navigation (LANTIRN) pods are planned to be used on later models of the F-16 and F-15E to provide primary ranging data to the target. These pods will **use** laser technology and are expected to significantly enhance the accuracy of ranging information.

Aircraft velocities are provided to the FCC by the CADC. The CADC takes pitot pressures and derives the aircraft velocities through the air mass. The CADC provides calibrated airspeed, ground speed, and true airspeed and then reports these velocities to the FCC. The FCC uses this data, along with INS data, to calculate wind speed and direction. Wind data is used in the FCC's trajectory calculations, but since wind data is only available at altitude, the FCC generally uses a linearly decaying function to calculate winds from the aircraft to the target altitude. The F-16 wind model assumes that the direction of the wind does not change and that the wind speed at an altitude of 4000 feet below the target altitude is zero. The FCC linearly models the wind from release altitude to target altitude and uses the average value in its trajectory calculations. The F-15E model, on the other hand, assumes a constant wind from release altitude to the target altitude. An interesting comparison would be the effect of each wind model on the overall weapon delivery system accuracy.

Accelerometers contained in the INS provide the data necessary to compute aircraft accelerations, velocities, altitudes, positions, and heading data. INS position data is used by the FCC's trajectory integration whenever accurate radar data (for example, slant range) is not available. For this reason, the INS becomes very important to aircraft bombing accuracy. Some drift is associated with any INS, and this drift is tolerated when it falls within specified limits. The rate of drift is measurable by visually observing movements of HUD symbols and by comparing position errors on return to a known point such as a hot pad or hanger. Drift **errors** can be removed from the INS in flight by using one of several INS update procedures. The most accurate procedure involves visually acquiring a known steerpoint on the HUD and manually changing the location of the steerpoint symbol to coincide with that steerpoint. These changes are fed back to the INS, and the aircraft position is updated accordingly.

The last system of interest **is** the **RSU.** This is the data source that provides the FCC with normal acceleration values (g's) for use in separation effect calculations. It has been shown that g's have a definite effect on the flowfield influences of a weapon at release. One reason is that different g's affect the time the store remains in the aircraft flowfield. Another reason is that g's change the aircraft angle of attack which, in turn, affects the flowfield.

5.2 Error Sources

Of all the external inputs to the FCC, errors associated with the FCR can have a profound effect on the air-to-ground accuracy. Essentially, the slant range and lookdown angle of the radar provide the basic starting point to the FCC air-to-ground integration routine. The FCC uses these inputs to calculate the aircraft height above the target. Therefore, if errors in this data are not detected, the value of the FCC integration can be greatly degraded. The same will hold true for data with LANTIRN when it becomes available.

The effects of errors in radar ranging are fairly straightforward. If the FCR reports a value which is smaller than it should be, the resulting bomb range calculated will also he shorter than it should be. This is true because the aircraft thinks it is closer to the ground than it actually is. Consequently, the aircraft will be allowed to travel closer to the target before release, and bombs will fall long of the aim point. Along the same line, a reported slant range which is larger than it should be results in the bombs impacting short of the target.

Since errors in the radar look-down angle are associated with the physical radar antenna mounts in the nose of the aircraft, the effects of these errors require study to understand. In all visual air-to-ground modes, the FCC commands the radar to look at a designated point on the ground. If the radar antenna is not aligned properly, the look-down angle value reported to the FCC will not reflect the true lookdown angle of the antenna. If, for instance, the antenna look-down angle reported is less than the actual angle, the radar will be slaved to a point further down range than it should be. In effect, it will give a higher value for the slant range. The resulting altitude calculations are, therefore, degraded not only as a function of the sine of the look-down angle error but also as a function of the aircraft speed and actual altitude as well. In addition to this, as the grazing angle (the angle at which the radar beam strikes the ground) decreases, the allowable tolerance in the radar slant range increases, adding further errors to the system. In summary, errors associated with false antenna look-down angle values are compounded and unpredictable unless specific cases are investigated. The worst case of all radar problems is when the look-down angle is off and radar ranging is bad. On the F-16, if the FCC detects three questionable radar slant range values in a row (for example, large jumps in value or no range data at all), it will use the last valid range value and revert to using INS position data and system altitude (a weighted average of INS and CADC altitudes as a function of vertical velocity) for its calculations.

Errors in the CADC affect velocity inputs to *the* FCC and introduce false wind data into the system. In many instances, CADC errors **are** a result of foreign objects getting into the pitot tubes and ports on the surface of the aircraft. Here the pilot and ground crew play major roles in preventing bad data from entering the air-to-ground calculations.

Since velocity and acceleration are important parts of the weapon delivery calculations, errors associated with the INS can also have a significant impact on bombing accuracy. INS errors are not as specific as radar errors, and many are caused by erroneous pilot inputs rather than hardware problems. If the system is not initialized properly, it will be inaccurate for the duration of the flight.

As with the INS, the RSU provides data relating the dynamics of flight to the FCC. Errors from the RSU are limited to the normal acceleration of the aircraft. This limitation directly affects the accuracy of any separation effect compensation computations since these computations are a function of normal acceleration.

Another error source, which is not due to external input hut which does have a direct effect on bombing accuracy, is the alignment of the HUD Pilot Display Unit (PDU). The steering and aiming symbols are projected on this surface. If this plate is not aligned at the proper angles, *the* HUD symbology will be improperly located and aiming errors will occur. For instance, if the plate is set too low, the pipper appears lower in the HUD field of view. This appearance causes the aircraft to be flown closer to the target before weapon release, resulting in an impact long of the aim point (see Figure 11). Along the same lines, a plate set too high will cause an impact short of the intended aim point.. Errors due io improper alignment are compounded by the fact that any symbology that has been corrected for canopy distortion is now being projected on a different area of the canopy and would require a different correction.

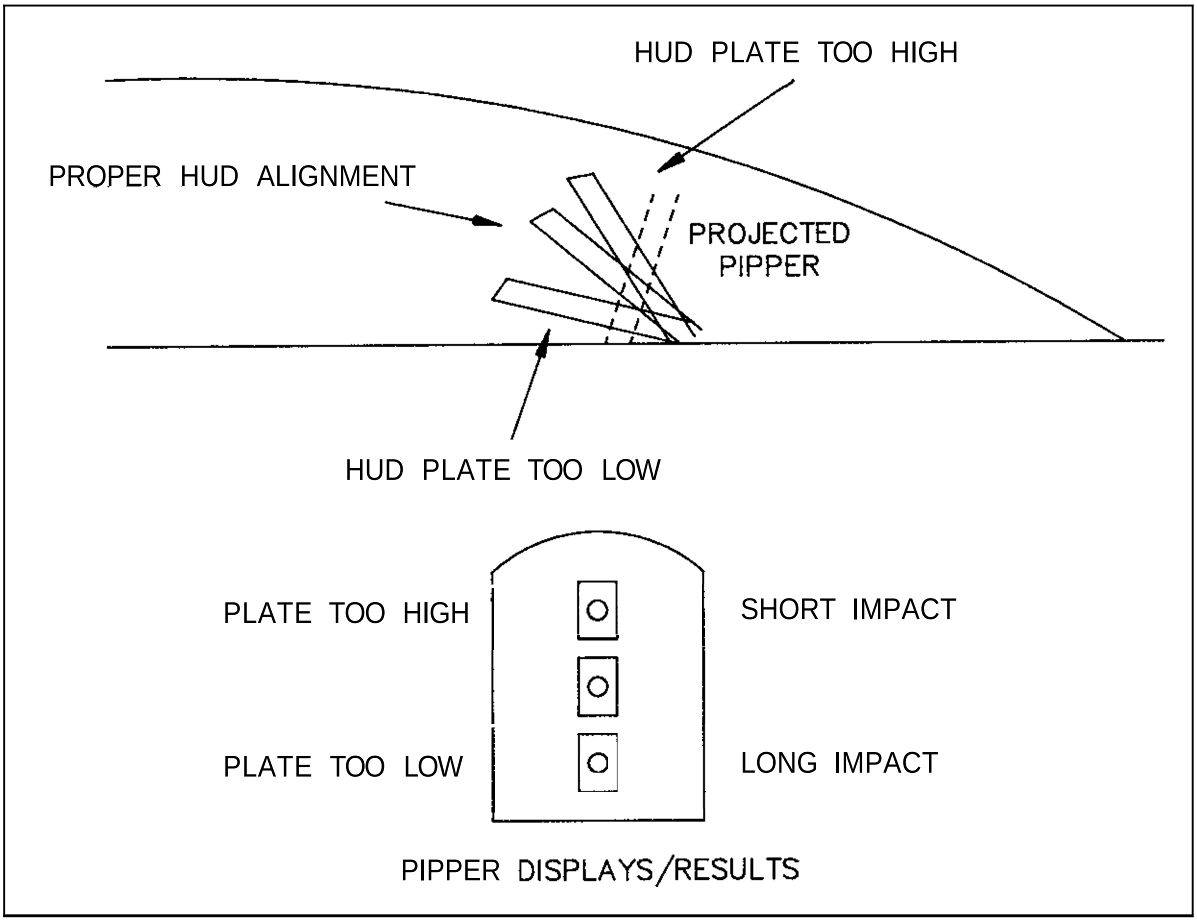


Figure 11. HUD Boresight

Separation-effects compensation has a significant bearing on the accuracy of any weapon-delivery system. Any errors which may have occurred during separation-effects testing or analysis and gone undetected will cause errors in bombing. Also, inadequate separation-effects testing can be an error source itself because under- or over-compensation of separation effects may result. Many difficult lessons have been learned in the past about the artificial savings of inadequate testing. As the saying goes, "There is never enough time (or money) to do the job right the first time, but there is always enough to do it again!" There is no substitute for careful, experienced engineering judgment in separation-effects analyses.

As a part of this discussion of error sources, two more factors need to be considered: design eye and HUD parallax errors. Design eye is defined as the position above the water line of the aircraft where the pilot's head must be to properly view the HUD.

However, at any given position, only a portion of the HUD is visible. At no time can the pilot see the entire field of view of the HUD. Therefore, the position of the pilot's head must change in order to view the desired portion of the HUD. If the HUD PDU has been properly aligned, the pilot is then, by definition, at design eye.

HUD parallax errors are not directly related with air-to-ground weapon delivery accuracy as they do not relate to the HUD but to the accuracy of the HUD video recorder. The pilot usually has the option of recording on video tape the view through the HUD at any given moment, and often this recording is used to determine where the pilot was aiming in relation to a target after the flight. Parallax errors are a result of optical distortions encountered in looking through the canopy of the aircraft. The canopy has a known and correctable optical distortion. This distortion is corrected by using a mathematical function in the FCC to place the symbols properly on the HUD to compensate for distortion errors. The problem arises when a recording is made. The position of the video camera may be lower than the pilot's head. Consequently, symbology which has been corrected for the pilot's viewpoint may not necessarily be in the correct location for the camera's viewpoint (see Figure **12).** It may be noted that parallax errors have only recently been acknowledged by the test community. Efforts are being made, however, such as by the F-16 community, to correct these errors on the ground **so** that when a video tape is viewed, the actual pilot input or view is seen rather than a misleading representation of what occurred. Parallax errors have also been uncovered on other aircraft types, and similar efforts are underway to solve the problem.

6.0 DEVELOPMENT OF A WEAPON SYSTEM TEST PROGRAM

6.1 Test Matrix Development

Factors to be considered when developing the matrix include the type of weapon, the weapon functioning envelope, and the number of weapons needed to satisfy test objectives.

6.1.1 Types of Weapons

Basically, there are two types of free-fall (unpowered) weapons: intact and functioning. **A** MK **82** LDGP bomb is an example of an intact weapon, and a **MK-20** Rockeye dispenser is an example of a functioning weapon (the dispenser separates, releasing submunitions at specified time or altitude). Both types **of** weapons may have components or events that alter the weapon flight characteristics. For example, the GBU-24 guided bomb is an intact weapon hut has stabilizing fins which deploy in two

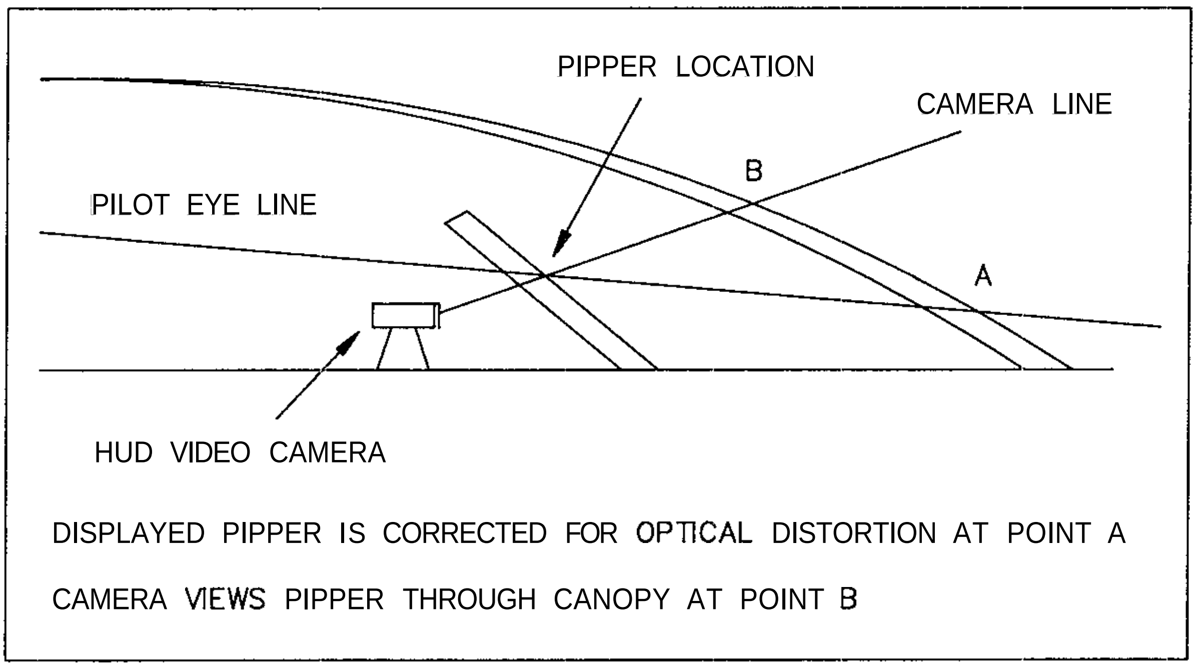


Figure 12. HUD Parallax Errors

stages after a period of time. This two-stage deployment affects the store trajectory and must be accounted for in ballistic calculations. Functioning weapons add even more complexity because submunitions form a pattern that must be modeled in order to predict pattern size. This pattern size is a function of release conditions and time of dispenser functioning which combine to form an almost unlimited combination of conditions that could be tested.

6.1.2 Weapon Functioning Envelope

The flight conditions at which the weapon will properly work as designed is the weapon functioning envelope. This envelope is usually defined during the Developmental Test and Evaluation (DT&E) phase of the weapon program and must be considered when designing a test matrix. For example, one horror story involves extensive testing of a weapon that was performed at low speeds even though it was known that the weapon fuze would not function at low speeds. (However, this information was not known by the test organization at the time of testing.) In another test program, cluster weapons were released at altitudes and speeds at which submunitions could not arm due to insufficient time of fall. The test matrix must be designed with a complete knowledge of the weapon functioning envelope in mind. Obviously, these are examples of weapon testing with lessons learned that must not be forgotten.

As mentioned earlier, the weapon functioning envelope is determined during store DT&E to validate design requirements. For example, a new cluster weapon recently placed in production was designed to function from 200 feet to 40,000 feet over an airspeed range of 200 knots to 700 knots. Here was a case where testing had to be performed using several different aircraft types because one aircraft could not cover the entire envelope. The point is that, when designing a test matrix, both store functioning envelopes and aircraft operating envelopes must be properly considered.

6.1.3 Number of Weapons Required for Store Freestream Testing

The number of weapons required not only depends on the type of weapon and functioning envelope but also on the type of testing to be performed.

For freestream testing of non-functioning weapons, a minimum of 36 stores is required to fully characterize ballistic performance. This figure is obtained as follows: one store should be released in level flight, a loft, and a dive. If the store is not designed to be released in one of these modes, testing is reduced proportionally. One store should also be released at the lowest operational speed, at medium speed, and at the highest operational speed. This release plan requires nine stores. However, to establish a reasonable level of confidence as to the results, a minimum of four releases at each test condition is recommended, bringing the minimum total number of stores required to 36.

For freestream testing of functioning weapons, a minimum of 216 stores is required to freely characterize ballistic performance. This figure is obtained by using the test points for nonfunctioning stores with these additions: three timer values for dispenser functioning (36x3=108) and three altitudes for dispenser functioning (36x3=108) should be tested at each condition. This additional testing is essential to validate that the store fuze functions as designed in the time and altitude (proximity) modes. If the fuze only has one or the other modes, testing time will be shortened. This testing is important because of the ramifications of timing/altitude errors on submunition pattern size. One might wonder why this testing cannot be conducted in the laboratory. The experience of analysts at Eglin indicates that there is no substitute for an end-to-end validation of the all-up store.

It cannot be overemphasized that the number of releases at each condition can either be determined by statistics or by analyst experience. The number determined by the analyst will usually be less than the number determined statistically. For example, if one wanted to establish ballistics (that is, freestream drag coefficient) to the 85 percent accuracy level with a confidence of 95 percent, 19 stores would be required. From a purely statistical standpoint, the confidence level drops to 50 percent with only four stores. However, the experience of analysts at Eglin has been that data from four stores yields fully adequate data. One way this has been validated is by the addition of data from subsequent releases to the original databases. Subsequent data was, and presently is, obtained from instrumented operational evaluations and from other DT&E tests wherein stores are released for other purposes and ballistics data are obtained on a piggyback @on-interference) basis.

To achieve the 95-percent accuracy level with a confidence of 95 percent, 60 stores would have to be dropped. To achieve 100-percent accuracy and confidence, all stores in the inventory would have to be released, and none would be left for combat. The point is that there is no substitute for experience and judgment when determining the number of stores to be released to establish reasonable confidence in the data. Establishing databases from a purely statistical standpoint must, therefore, be kept in perspective to minimize the expenditure of resources. This expenditure is doubly important because as stores get more complex, they are produced in more limited numbers and unit costs rise substantially. In fact, many stores have become so expensive that their costs dwarf the actual test costs.

One final note is necessary on the desired altitude for performing releases to gather freestream data. At Eglin, stores are generally released in the level and dive modes at altitudes ranging between 8,000 and 12,000 feet. For large stores, the altitude is adjusted higher, and for small stores, the altitude is adjusted lower. Ideally, stores are released at altitudes as high as possible, consistent with the ability to track them, so that data are obtained from release Mach to terminal Mach. For the loft mode, stores are usually released at altitudes lower than 500 feet. In this mode, data are obtained from release Mach to a minimum Mach as the store decelerates in its upward trajectory, and then increasing Mach, usually less than terminal velocity, before the store impacts the ground. In this way, with three delivery conditions and three speeds, the full Mach range is comprehensively covered.

6.1.4 Number of Weapons Required for Separation-Effects Testing

Store separation effects are highly dependent on the aircraft loadout. Therefore, because of aircraft OFP data storage capacity limitations, usually separation-effects testing is only performed for one or two loadouts of each store type (for example, a parent pylon and a multiple carriage configuration). In discussing how to structure a matrix, several examples will be used.

Consider an F-15E with 12 MK 82's loaded on fuselage conformal rack stations. Six bombs in two rows of three each are loaded on the left side of the aircraft, with the same number loaded symmetrically on the right side (see Figure 13). As in the case of freestream testing, data are required at a minimum of three airspeeds and at load factors that cover the g range sufficiently to permit modeling between data points. Since MK 82's are employed in the level-release mode (1 g), dive mode (as low as 0.5 g/cosine of 60-degree dive angle), dive toss mode (nominal 2.5 g), and loft mode (nominal 4.0 g), data must be obtained for each mode. Finally, at least four data points are required for each carriage station at each release condition. Since the loadout is symmetrical, two data points are automatically obtained for each station when all 12 bombs are released. Therefore, for each mode, stores required would be as follows:

1 (altitude) x 3 (airspeeds) x 1 (load factor)
x 4 (points) x 12 stations / 2) = 72 stores

For all four modes, 72 x 4 = 288 stores would be required.

Finally, consider an F-16 with Durandal runway attack bombs (symmetrical loading of two bombs on each side of the aircraft). For each mode, store required would be as follows:

1 (altitude) x 3 (airspeeds) x 1 (load factor)
x 2 (4 bombs in loadout) = 24 stores

Since Durandals are only employed in the level and shallow-dive modes, a total of 48 stores would be required.

To ensure obtaining adequate trajectory information for coefficient modeling for functioning stores, separation-effects testing should either be conducted with inert stores or with delayed fuzing to prevent dispenser functioning until at least 8-10 seconds after release. This arrangement is important because some dispensers function in less than 2 seconds.

Although testing at three airspeeds (low, medium, and high) is recommended, one must be aware that a risk is involved in modeling data for intermediate airspeeds and airspeeds beyond the tested envelope. This risk would be relatively high if the test designer did not have an historical database for guidance. This risk is illustrated in Figure 14. Assume that separation-effects data were obtained for configuration **A** at three airspeeds as shown. Because the magnitude of separation effects is relatively insensitive to airspeed, mathematical fit techniques would model a curve quite accurately. However, consider configuration **B.** The magnitude of separation effects is about the same at low

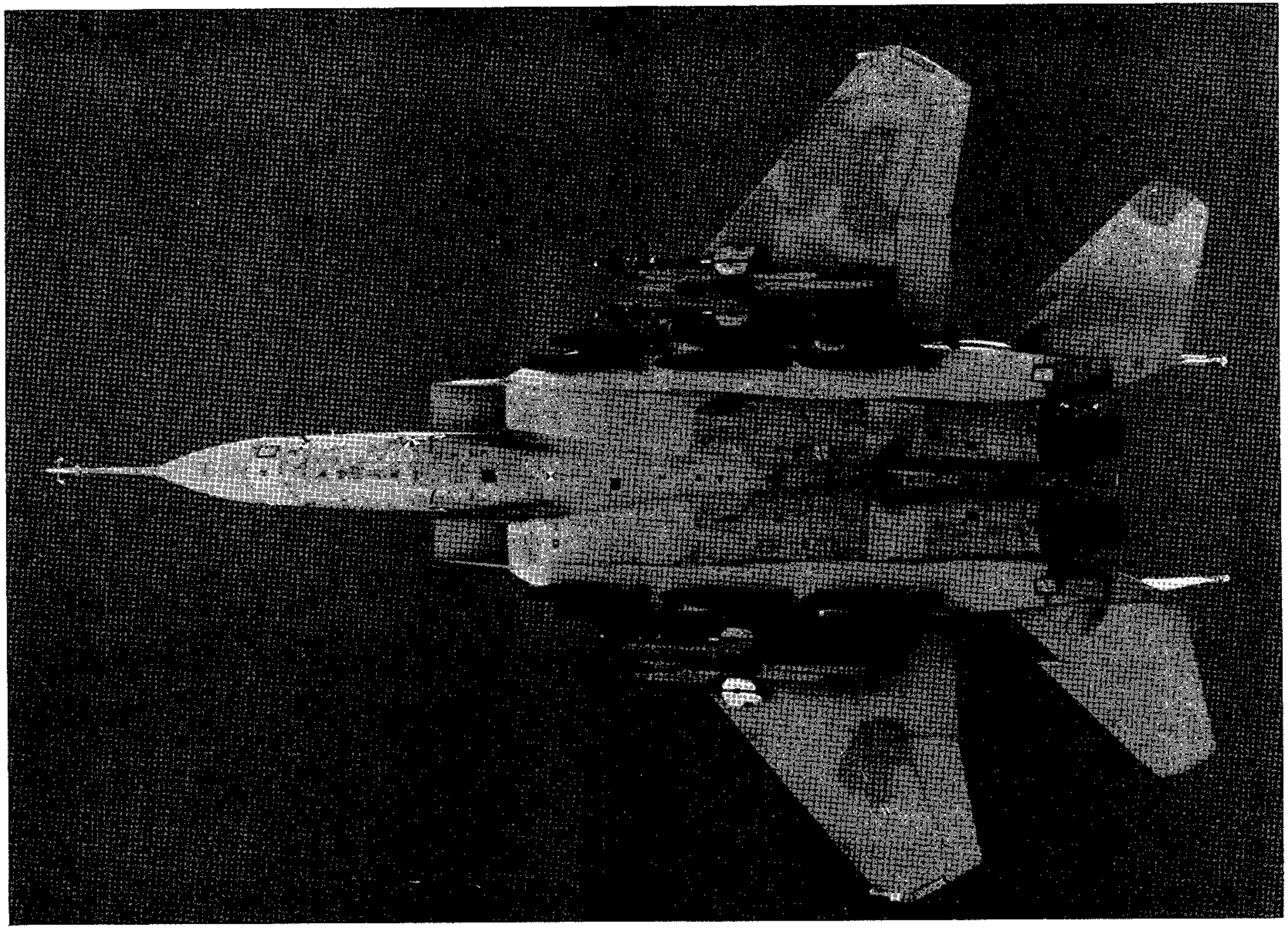


Figure 13. F-15E with Loadout of 12 MK 82 LDGP Bombs

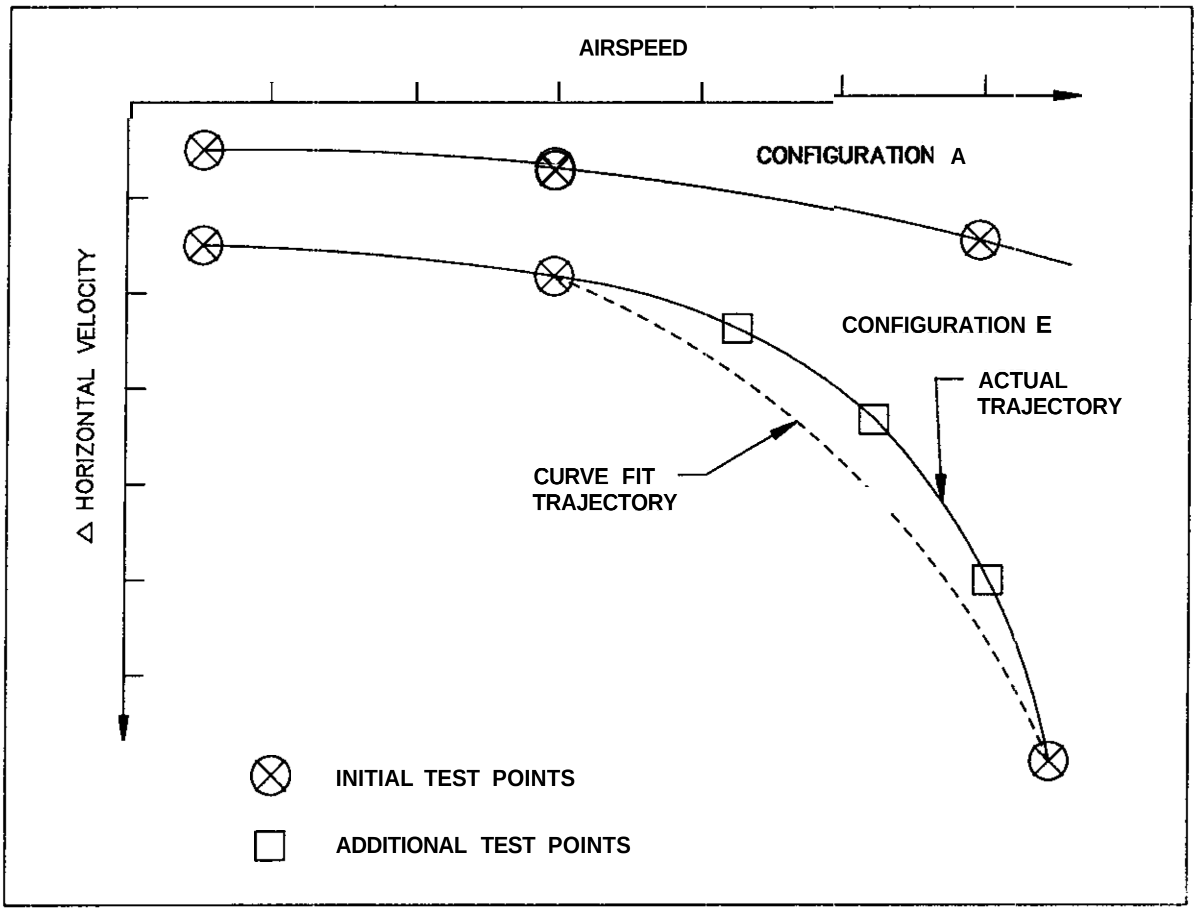


Figure 14. Effect of Airspeed and Configuration on Separation Effects

and medium airspeeds but is orders of magnitude larger at the highest airspeed. A mathematical fit of the three data points might yield the curve shown, which could be considerably different from actual results. This situation actually occurred. The aircraft OFP was modeled using three data points. Subsequent accuracy testing performed by operational users revealed substantial range errors in the airspeed regime covered by the medium and high airspeeds. Errors were subsequently traced to inaccurate separation-effects modeling. Range errors were eliminated by gathering additional data at intermediate speeds (shown by rectangles). Obviously, there is no substitute for experience in designing the test matrix, a verification that the workbook approach will not always work. With experience, the analyst has a good knowledge of the shape/trend of separation-effects data for various stores and loadouts. This information is used as a guide to select better test points for new stores and loadouts. With experience, and for configuration B, the analyst would undoubtedly shift the low speed data point to an intermediate speed (between the original medium and high speed points).

The need to obtain adequate test data to model g effects is equally important. Separation effects are affected by aircraft release g and can be substantial for some conditions and loadouts. As one may imagine, at low g (for example, 0.5), stores remain in the influence of the aircraft flowfield for a longer time than if stores are released at high g (for example, 6.0). If g effects are to be modeled in an accurate manner, at least three data points are required at each condition to be able to form a curve. The same precautions that were discussed relative to airspeed must also be observed for g.

Regarding the altitude for separation-effects testing, 3000-5000 feet is generally used at Eglin for level and dive/dive-toss modes if recovery altitude permits. This altitude range provides optimum film coverage for the Eglin arrangement of aircraft approach tracks and ground camera positions. At these altitudes, the cameras are able to record the initial stores trajectory in a manner that facilitates data analyses. Altitudes of less than 500 feet are usually used for loft modes.

Finally, one may wonder why stores have to be released for each carriage station. The answer is that separation effects are different for each station, and for that reason, each station must be characterized. What happens with data from each station? As unsophisticated as the procedure seems, data for all stations are averaged to arrive at one separation-effects modeling for a given loadout. In the future, software and hardware may allow each station to be modeled in the aircraft OFP, but at the present time, this is not being done on any USAF aircraft familiar to the authors.

6.1.5 Number of Weapons Required for OFP Accuracy Testing

Once separation-effects data have been gathered and modeled, it is necessary to perform testing to validate the OFP. This testing provides an end-to-end systems assessment of the overall accuracy of the weapons delivery system (which also includes freestream store drag data).

A minimum of 12 stores is recommended for each release mode. This means that, in the case of the 12-bomb F-15E configuration discussed previously, four missions would be required. That is, all 12 bombs would be released at combat airspeeds in each release mode. A CEP and range bias evaluation is then performed, and the results are compared to the accuracy criteria. If the criteria are met, then testing is terminated. If criteria are not met, the operational user decides whether further analysis/testing is required (which may involve rederivation of separation-effects modeling or modification to the aircraft weapon delivery system itself), whether less accurate results can, in fact, be accepted, or whether the loadout must be rejected.

A few comments are appropriate regarding the criteria for determining whether a range bias exists and the basis for recommending 12 stores per release condition.

At Eglin, a range bias is presumed not to exist for probabilities greater than 90 percent, using a one-tailed cumulative binominal test. This 90-percent value was arrived at based on the experience of engineers from several test agencies. Table III indicates that if 5 of 15 stores impact the ground long of the target, and the balance impact short of the target, then a probability of bias is assumed not to exist. If only 4 of 15 stores bit long or short, then a probability of bias is assumed to exist. Probabilities for other combinations of the number of stores dropped and those that hit long or short can he similarly derived from this figure. Clearly, the more evenly balanced the short versus long numbers are, the less likely there is for a bias to exist. Ideally, it would be desirable to assess CEP without a range bias. However, this is not a prerequisite. CEP can be assessed with a range bias. However, one would want to investigate the source of the range bias before rendering an overall assessment of system accuracy.

A final note is appropriate regarding the use of 12 stores to assess CEP. Figure 15 shows the number of stores required to estimate CEP as a function of confidence level and acceptable percentage error in CEP. This figure was formulated on the basis that range and deflection errors are independent. This approach is substantiated based on the work contained in References 12-14 and is quite important in that, if this were not the case, the number of stores required would be doubled. Note that 12 stores equate to a confidence level of 80 percent that the sample CEP is within 30-percent error of the true CEP. Again, why accept 80-percent confidence with 30-percent error of the true CEP? The answer lies in the experience and general acceptance of results by operational users over the years.

Another approach to determine the number of stores required has been developed by the USAF SEEK EAGLE Office. This approach is documented in Reference 15 and is based on the number of stores required to improve CEP by at least one percent for each additional store released. This approach can be compared to the law of diminishing returns in business or economics. Using this approach for the same confidence level of 80 percent in the earlier example, 16 stores with a CEP that would be within 25 percent of the true CEP would be required (see Figure 15). This approach has merit, but it requires more stores and a higher degree of CEP accuracy at comparable confidence levels than the analytical approach mentioned earlier. The reader must determine

Table III. Probabilities Associated with Values as Small as Observed Values of *X* in the Binomial Test
One-tailed probabilities under H_0 for the binomial test when P = Q = ½.

NUMBER OF BOMBS LONG OR SHORT OF AIMPOINT

NUMBER OF BOMBS DROPPED

N \ x	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	.031	.188	.500	.812	.969	***										
6	.016	.109	.344	.656	.891	.984	***									
7	.008	.062	.227	.500	.773	.938	.992	***								
8	.004	.035	.145	.363	.637	.855	.965	.996	***							
9	.002	.020	.090	.254	.500	.746	.910	.980	.998	***						
10		.011	.055	.172	.377	.623	.828	.945	.989	.999	***					
11		.006	.033	.113	.274	.500	.726	.887	.967	.994	***	***				
12		.003	.019	.073	.194	.387	.613	.806	.927	.981	.997	***	***			
13		.002	.011	.046	.133	.291	.500	.709	.867	.954	.989	.998	***	***		
14		.001	.006	.029	.090	.212	.395	.605	.788	.910	,971	.994	.999	***	***	
15			.004	.018	.059	.151	.304	.500	.696	.849	.941	.982	.996	***	***	***
16			.002	.011	.038	.105	.227	.402	.598	.773	.895	,962	.989	.998	***	***
17			.001	.006	.025	.072	.166	.315	.500	.685	.834	.928	.975	.994	.999	***
18			.001	.004	.015	.048	.119	.240	.407	.593	.760	.881	.952	.985	.996	.999
19				.002	.010	.032	.084	.180	.324	.500	.676	.820	.916	.968	.990	.998
20				.001	.006	.021	.058	.132	.252	.412	.588	,748	.868	.942	.979	.994
21				.001	.004	.013	.039	.095	.192	.332	.500	.668	.808	.905	.961	.987
22					.002	,008	.026	.067	.143	.262	.416	.584	.738	.857	.933	.974
23					.001	.005	.017	.047	.105	.202	.339	.500	.661	.798	.895	.953
24					.001	.003	.011	.032	.076	.154	.271	.419	.581	.729	.846	.924
25						.002	.007	.022	.054	.115	.212	.345	.500	.655	.788	.885

* Adapted from Table IV,B, of Walker, Helen, and Lev, J. 1953. Statistical inference. New York: Holt, p. 458

*** 1.0 or approximately 1.0

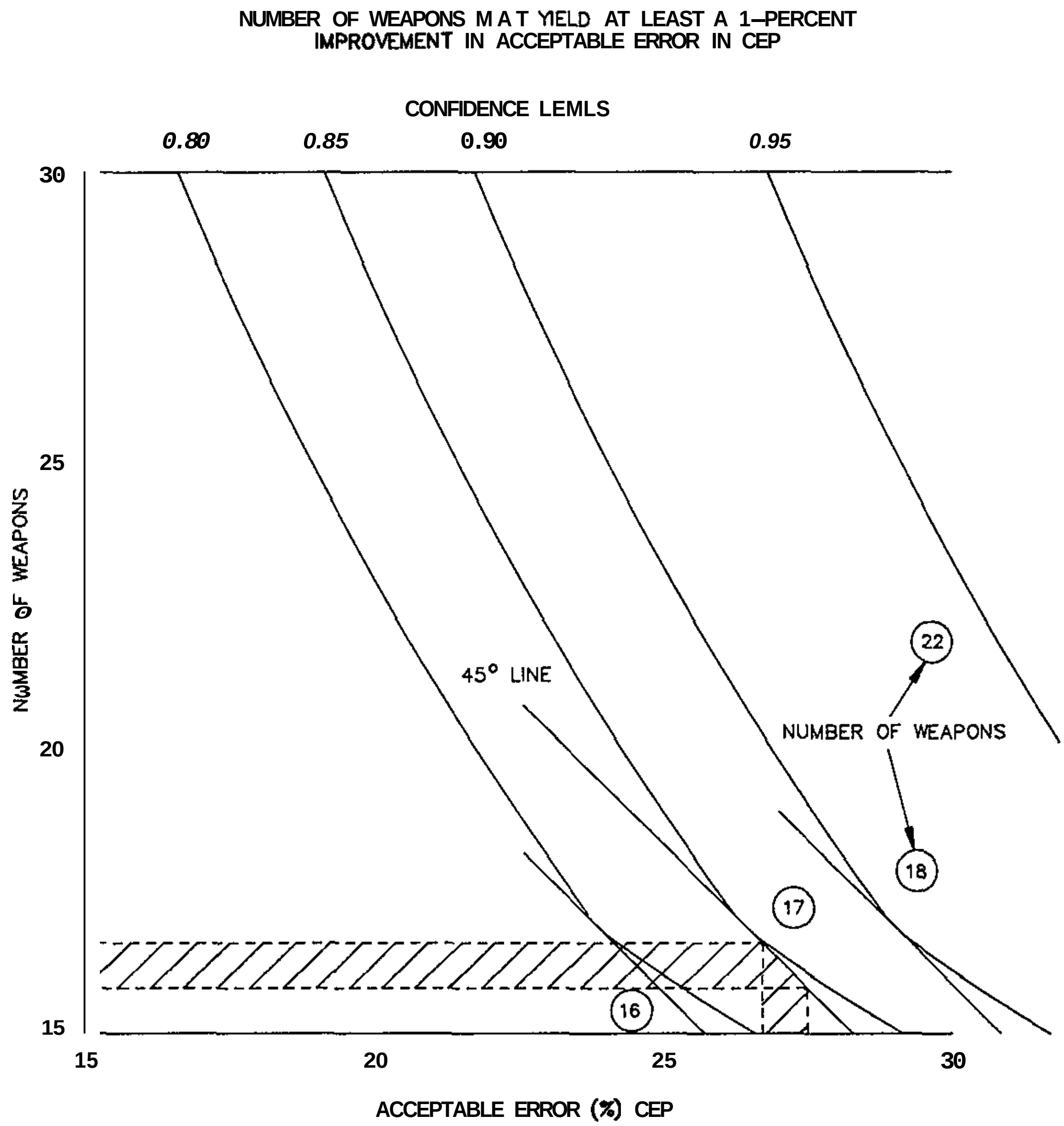


Figure 15. Recommended Number of Weapons

what approach best satisfies the test requirements and those of the operational user. This discussion should serve to bracket the approximate number of stores required for OFP accuracy testing.

7.0 FLIGHT TEST PREPARATIONS

7.1 Instrumentation Calibration and Verification

7.1.1 Aircraft Boresighting

Before any flight testing begins, the aircraft that is to be used in the test must he boresighted to ensure correct alignment of the radar antenna, the HUD PDU, the **INS** mounting brackets, and the RSU mounting brackets. For the ***sake*** of illustration, F-16A/B systems are used; however, calibration of other types of aircraft is very similar. Each of these systems plays a vital role in air-to-ground weapon delivery accuracy. Any errors associated with these systems will have a definite, and sometimes unpredictable, effect on bombing accuracy. Accuracy data can he a valuable by-product of both separation-effects testing and freestream ballistics testing. Therefore, it is essential that all aircraft systems he calibrated properly.

The actual boresighting procedure is straightforward. The radar antenna, HUD PDU, INS, and RSU are removed from the aircraft. An optical fixture is hung on the front of the aircraft in place of the antenna. The aircraft reference line, or water line, is then determined by using optical fixtures mounted on the nose and main landing gear. This reference line is determined by sighting from the main gear fixtures forward to the nose fixture. Once this reference line is established, the antenna, HUD PDU, INS, and RSU mounts are all aligned to it. Once these alignments are made, the fixtures are removed and the systems reconnected. Since the antenna mounts are usually held in place with an epoxy resin compound which must be allowed to cure, the total boresighting procedure requires several days to complete. In many cases, however, a boresight confidence check can be made in much less time. The confidence check measures the boresight but does not correct errors. If unacceptable errors are detected, a full boresight must be performed.

7.1.2 Aircraft Footprinting

In order to accurately assess the capabilities of an aircraft's OFP to deliver weapons on target, aircraft used in the test must be validated as being typical of those used in the operational inventory. Footprinting is one method used to determine whether a given test aircraft is a true representation of typical aircraft used every day by pilots throughout the USAF.

Footprinting is accomplished by using the test aircraft to drop a series of stores, usually BDU-33's, and observing the resulting impact patterns. More than one delivery mode is used, and the results are compared by delivery mode. Pilots flying the missions are briefed to fly the aircraft at specific delivery conditions of airspeed, altitude, and dive angle and to put the pipper on the target while flying the aircraft in a smooth and stable manner up to, and during, stores release. Incidentally, BDU-33's are generally used because they are cheap, mass properties are very consistent, freestream drag is very well defined, and separation effects are usually minimal.

After each mission, any pilot aiming errors are removed by reviewing the HUD video and comparing pipper position to the target. Aim-point-corrected impacts are then evaluated using pre-established guidelines. For example, analysts' experience at Eglin has determined the F-16 to have an approximate 33-foot-long range bias when releasing BDU-33's. This bias, coupled with a nominal 4- to 5-mil ballistic dispersion for the BDU-33, led to the following guidelines:

a. If the mean point of impact (MPI) is the point which has, as its range/deflection coordinates the arithmetic mean of the range and deflection coordinates of the impact points, is less than 50 feet from the target center, and there is random clustering about the target, the aircraft is accepted as having no system problems.

b. With a 50- to 60-foot MPI bias, the aircraft is accepted with skepticism, and in most cases retesting is required.

c. If the MPI is greater than 60 feet, reaccomplishment of footprinting is required following an investigation into aircraft hardware/software problems.

Once footprinting has been successfully accomplished, then the aircraft is considered to be truly representative of typical aircraft.

7.1.3 Aircraft Systems Check

Even though a specific aircraft has been boresighted and footprinted and found to be representative of operational aircraft, there is always a chance that errors can develop in the systems at any time. In order to ensure the absence of **errors** between the time the aircraft was boresighted and footprinted and the start of each mission, a series of maneuvers is made over the target prior to releasing any stores. This aircraft-systems check can detect radar-ranging errors, excessive INS drift errors, and accelerometer errors.

The check usually consists of a set of three diving passes made over the target. In the first pass, the aircraft is flown towards the target in a medium dive (usually 30 degrees). When approaching the target, the pilot designates the target visually on the HUD and confirms that the radar is ranging smoothly to the ground by watching the radar range indicator displayed on the HUD. At this point, gross radar-ranging errors become evident (Figure 16). As the aircraft nears the target, the pilot is instructed to pulse the stick to cause dynamic acceleration changes. If the Target Designator (TD) box displayed on the HUD jumps erratically, accelerometer errors are evident. At this point, the

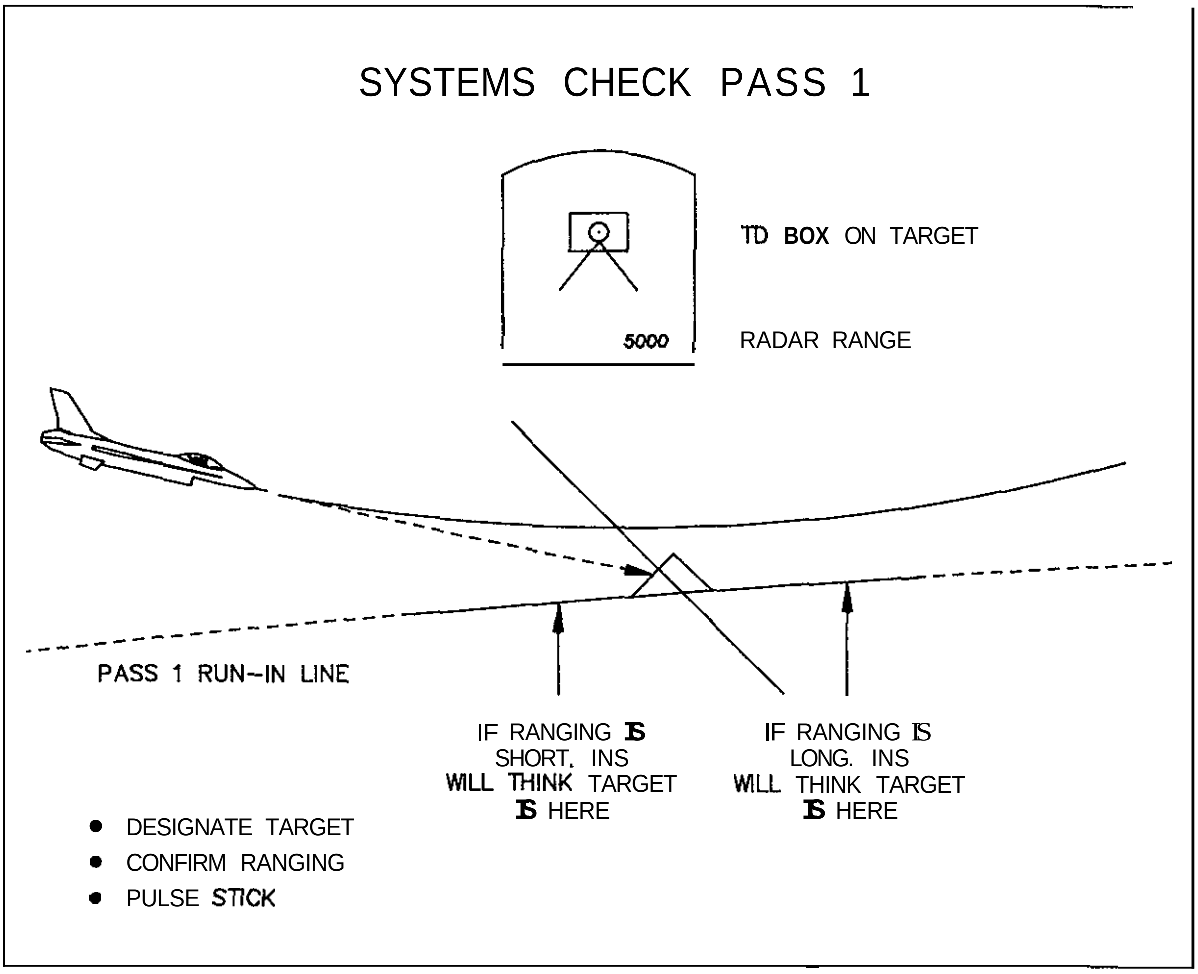


Figure 16. Systems Cheek — Pass 1

pilot is instructed to pull off the target, leaving the target designated. The INS, if it is functioning properly, will keep track of the target location and display the TD box on the HUD when the target is again in its field of view.

On the second pass, the aircraft is again flown in the same dive toward the target and along the same track used in the first pass. When approaching the target, the pilot is instructed to note the position of the TD box relative to the target. If the TD box has drifted off the target, it is slewed or manually moved through pilot input in the direction opposite the drift (approximately two-thirds of the amount of drift off the target), as shown in Figure 17. Again, the pilot pulls off the target. At this point, any large INS drift errors become apparent. Drift errors of one to two feet per second are usually within INS design specifications.

Upon target designation in the first pass, radar range to the target was determined. If there had been errors in the slant range reported to the FCC, the **INS** will have been given false target location data. Once these errors and drift errors from the second pass have been corrected and additional inputs are made to compensate for anticipated drift, a third pass is performed. The third pass is a run at the target at 90 degrees to the original attack heading, again in the same dive; however, the TD box is not slewed. Errors in radar slant range will be represented by an offset of the TD box from the target. If the TD box is displayed uprange of the target on the original run-in line, the radar is re-

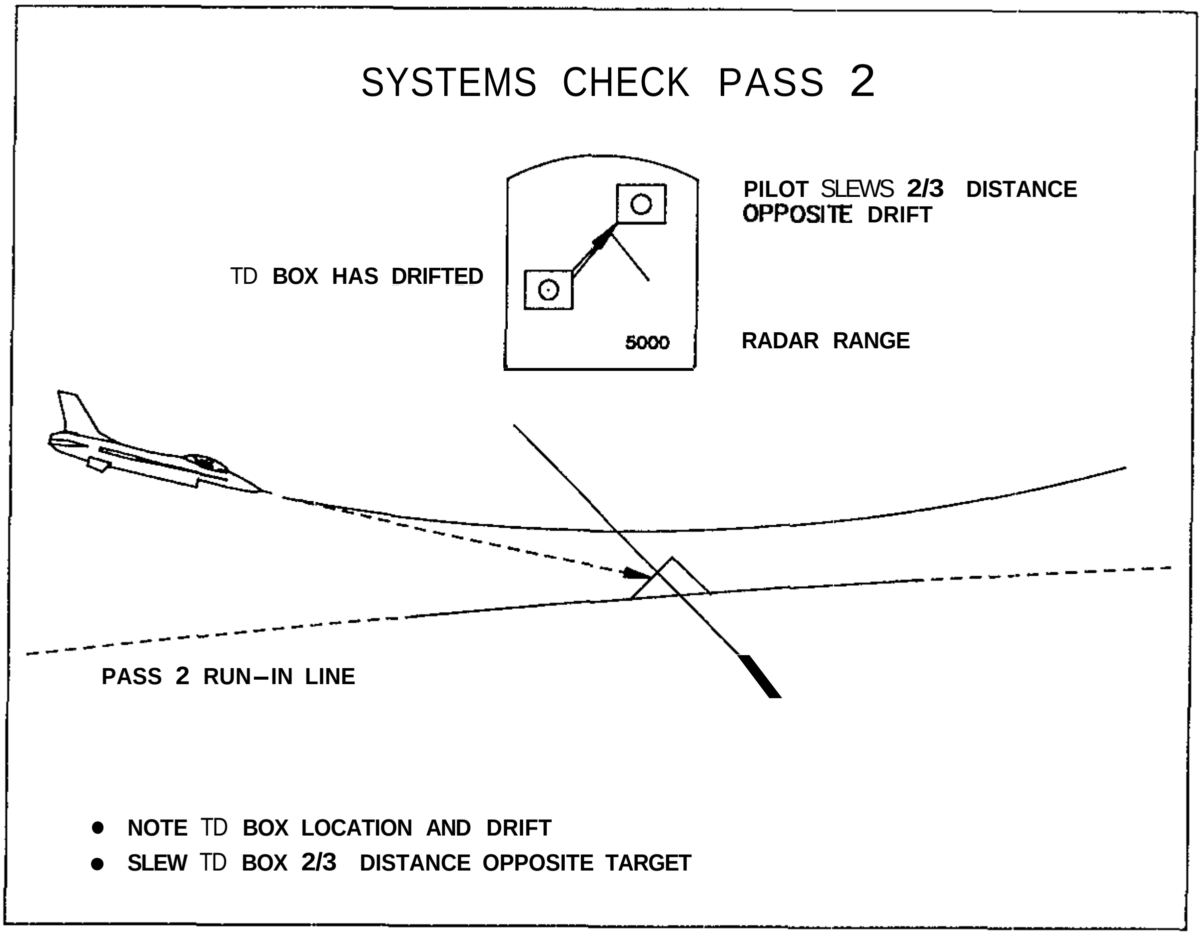


Figure 17. Systems Check — Pass 2

porting short slant range values. Conversely, if the TD box is displayed downrange of the target, the radar is reporting long slant range values (see Figure 18).

7.2 Pilot Procedures

In addition to performing aircraft system checks, the pilot is instructed to fly strictly defined delivery conditions. Stores are generally released one at a time and in a specific release sequence. It is vital to a successful test that the release sequence be known to the analyst since ejection velocities and separation characteristics are station-dependent. **Also,** the pilot must have aircraft wings level and avoid any abrupt maneuvers at the time of release that would input dynamic data changes into the fire control system or introduce side forces which cannot be removed from the data after the mission. The pilot is further responsible for validating that all stores are properly loaded on the aircraft including lanyards, fuzes, timer settings, and the **like. A** walk around the aircraft prior to takeoff will usually reveal any loading errors to the thoroughly alert pilot. Once in the cockpit, the pilot ensures that all avionics equipment is properly functioning and that the correct weapon information has been loaded into the system. It is imperative that the pilot have a good understanding of both the aircraft and weapon systems being used.

7.3 Test Constraints/Tolerances

As with any test performed to measure specific parameters, it is essential to hold as many variables constant as possible. For this reason, constraints

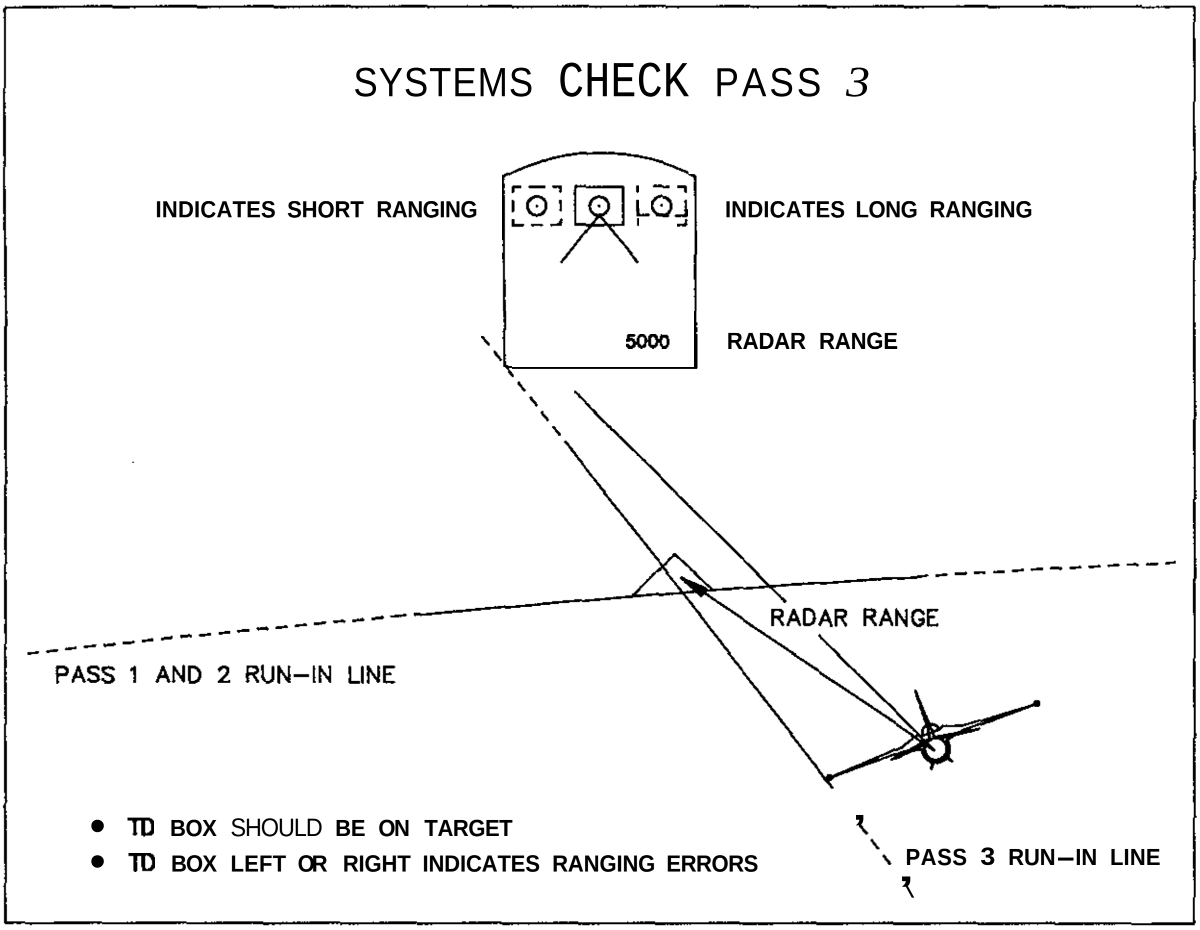


Figure 18. Systems Check — Pass 3

or tolerances should be placed on several different parameters. For example, there should be constraints covering airspeed, altitude, dive angle, normal acceleration, and weather conditions. These constraints must be designed to limit data errors and yet be practical for the pilot.

In general, flight condition tolerances should be set to correspond to the ability of test personnel. The author's experience has been that most pilots are able to control airspeed within ± *20* **KTAS,** altitude within ± 500 feet (except in loft deliveries in which case the limits are tighter on the positive side), and dive angle within ± 5 degrees. Naturally, some pilots are able to achieve a much higher degree of precision in their deliveries.

Limits on weather enhance the analyst's confidence in results of post-flight data analyses. Typically, weather conditions such as wind speed and direction, temperature, air pressure, and air density cannot be measured real-time during a mission. Data are gathered either prior to, or just after, the mission. Unfortunately, this can introduce errors into the data by virtue of the fact that weather conditions change, sometimes quickly, from the time they are measured to the time the mission is flown.

Of all the weather parameters, wind speed has the greatest effect on the accuracy of trajectory data. In most cases, wind speed is measured by launching a balloon with an instrumentation package either before or after a flight. Even if the average wind speed and direction do not change over the entire mission, the variable that cannot be held constant or accurately modeled is wind gusts. For these reasons, analysts at Eglin place restrictions on allowable wind speed and gusts measured at ground level. This approach is taken because experience has shown that as average wind speed increases, the frequency and magnitude of wind gusts also increase. Again, wind limits must be designed to be practical while, at the same time, providing a reasonable level of confidence in the data. At Eglin, surface wind speeds up to 20 knots with gusts not to exceed 10 knots are typically allowed. These are typical values and are frequently changed as mission requirements vary. For example, the effect of wind speed on a MK 82 LDGP bomb is much less than on a MK 82 Snakeye (high drag) because time of fall is less. So, a higher wind speed might be allowed for a MK 82 LDGP than for a MK 82 Snakeye. Similarly, wind affects lighter-weight stores more than heavier stores; cluster weapons, for example, are particularly sensitive to wind because of their submunitions. Therefore, lighter-weight stores may require lower wind limits. Thus, a thorough understanding of the weapons being tested is required to make effective decisions regarding wind tolerances. As can be seen, wind must always be considered as a go/no-go mission criteria. Finally, a mission obviously cannot be flown in weather that does not allow ground camera coverage. Therefore, the planned trajectory and flight path of the aircraft will dictate the allowable cloud cover and amount of precipitation.

8.0 WEAPON TEM TEST PRO DATA ENTS

8.1 Cinetheodolite Cameras

TSPI must be collected to help determine the store freestream drag and, when necessary, separation effects. These data can be obtained through the use of cinetheodolites equipped with low-, medium-, and high-speed film cameras (16mm, 35mm, 70mm, and 140mm) which generally operate at frame rates from less than 10 to 40,000 frames per second. Cameras must be capable of recording Inter-Range Instrumentation Group (IRIG) time code on film for subsequent analysis. IRIG time uses very high frequency (VHF), radio frequency (RF) transmissions in the 140-MHz range and is usable anywhere within the receiving range of the transmitter. Even though most major test sites are equipped with self-contained time code generators, IRIG time is still widely used to support airborne and land range missions. Eglin has five land test ranges and the Gulf of Mexico water ranges. An aerial view of a typical land range is shown in Figure 19. Approximately 120 land receivers are serviced by IRIG-transmitted time. Three Loran C synchronized time-code generators, which drive the transmitter, have identical accumulators and division circuits for reliability.

At Eglin, cinetheodolite cameras record encoded azimuth (angle measured clockwise from north to the tracked object) and elevation (vertical angle measured between the cinetheodolite and the tracked object) with the encoded frame number on each frame of film at 5, 10, 20, or 30 frames per second. Thirty-five-millimeter cameras are most frequently used to gather TSPI and to record such aspects as store-event times, fin opening, chute deployment, chute separation, weapon functioning, and impact.

Most cinetheodolites consist of four mechanically independent sections. The optical section contains a tracking telescope, digital measuring system for determining azimuth and elevation angles, a camera (usually 35mm), azimuth and elevation electronics, and sighting telescopes for azimuth and elevation measurements. The tracking drive control section contains all the equipment for driving and controlling the cinetheodolites in azimuth and elevation as well as the camera control system. The support section consists of a rotatable column with operator seats and a leveling device on which the cinetheodolites are mounted. The power and distribution unit contains a power transformer and audio equipment for communicating with the master control station. Some cinetheodolite cameras require two people to operate (one for azimuth tracking and one for elevation tracking) while others require only one person who does both the azimuth and elevation tracking. At the other end to the spectrum, Eglin has cinetheodolites which can be operated remotely during drops of live weapons.

Cinetheodolites are generally installed on isolated pedestals in concrete towers covered by astrodomes to protect the instruments and facilitate maintenance during inclement weather. A typical cinetheodolite installation is shown in Figure 20. An overall view of the cinetheodolite structure is shown in Figure 21. The exact position of each site is determined by a first-order geodetic survey. The cameras are located and oriented in a topocentric rectangular coordinate system. Precise camera orientation is accomplished and checked by on-site leveling procedures and calculations utilizing fixed boresight targets. Multiple station solutions for individual space position points are obtained. All

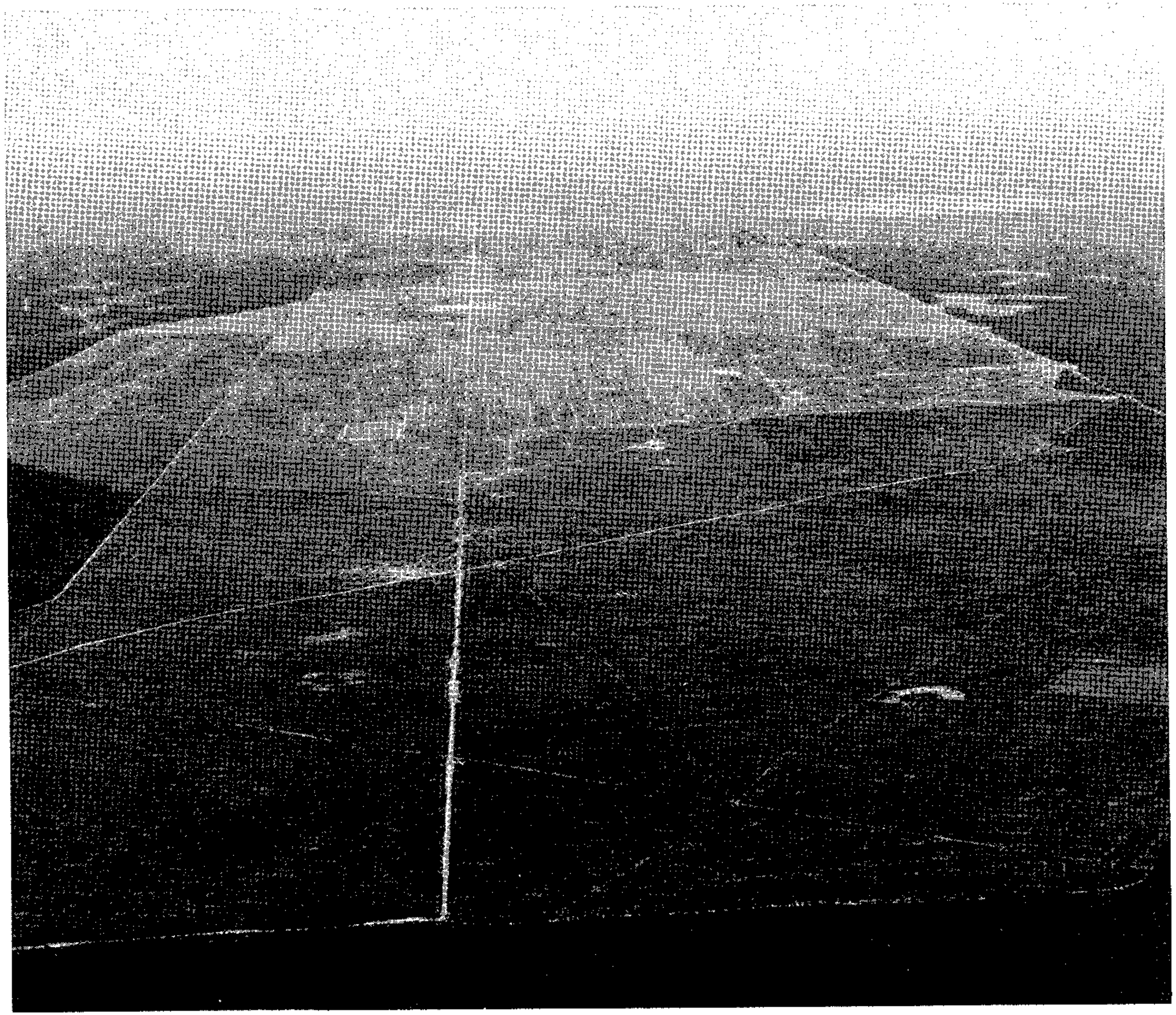


Figure 19. Typical Land Range

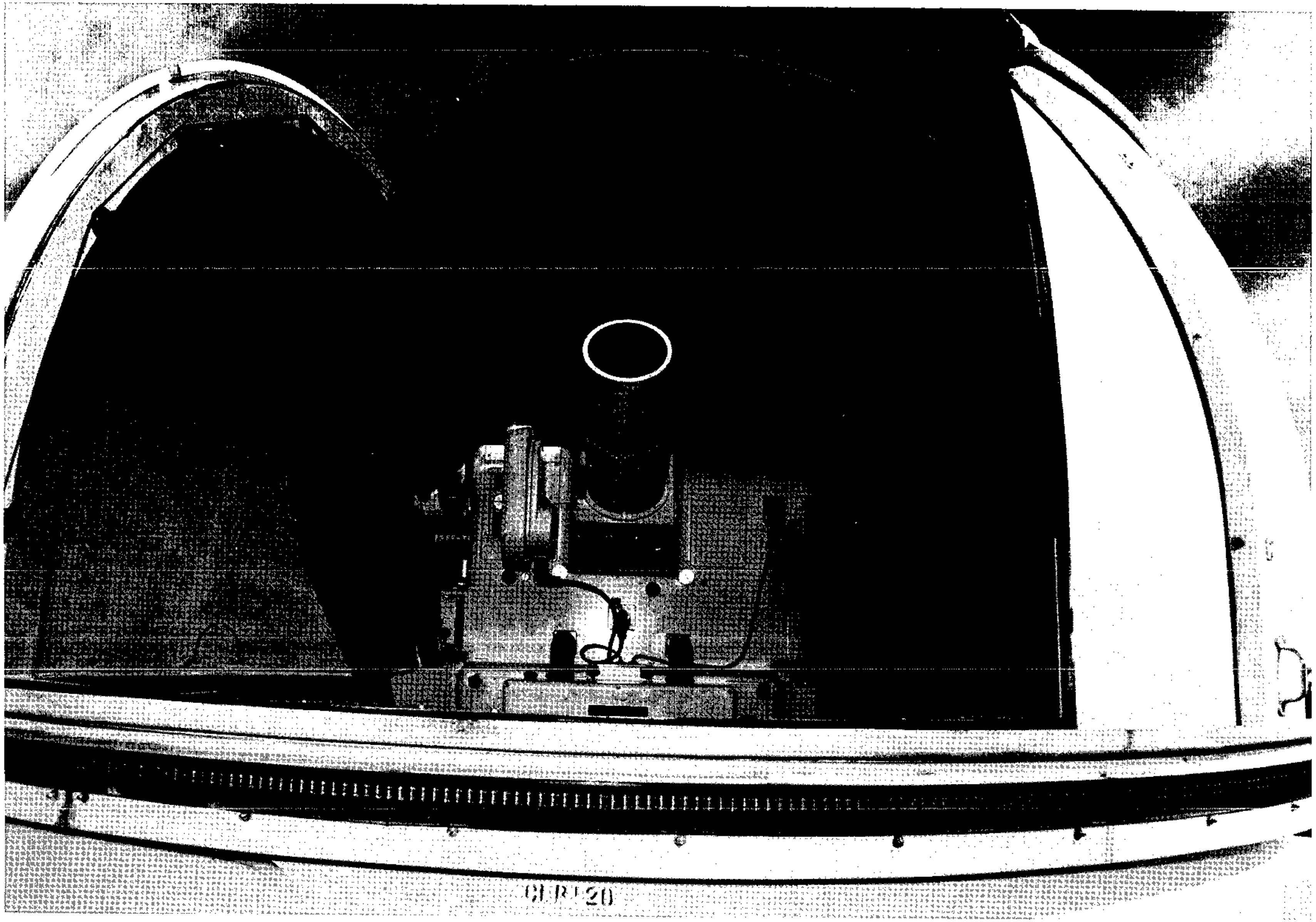


Figure 20. Cinetheodolite Inside Astrodome

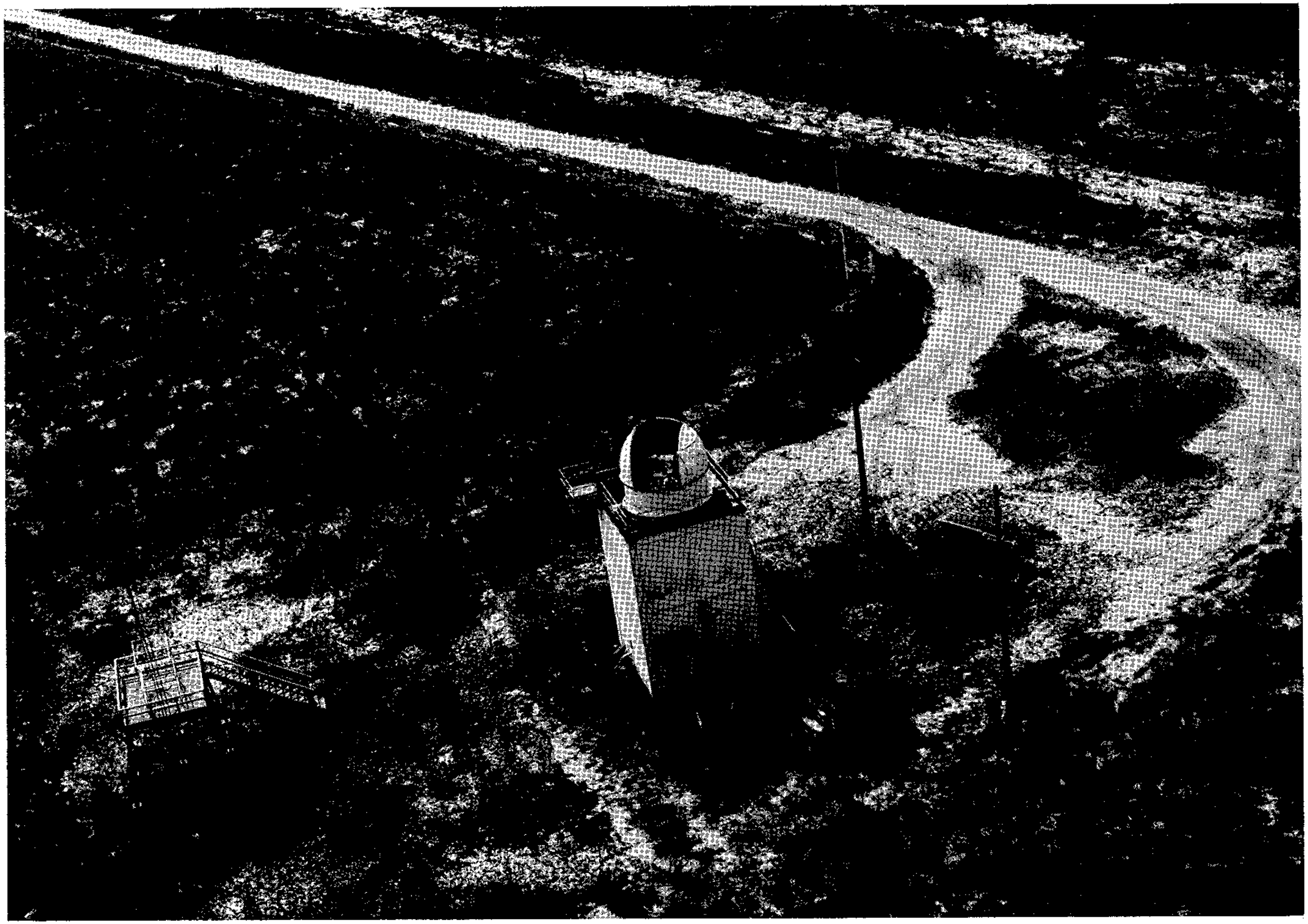


Figure 21. Cinetheodolite Structure

of Eglin's cinetheodolites are digitized models which, when combined with compatible Contraves semi-automatic film readers, reduce data reduction time.

At least three cameras should be used to avoid problems in geometry and to insure an accurate solution. A combination of six cinetheodolites has been shown to determine target position to ±1.5 feet, velocity to 1.5 feet per second, and acceleration to 2.5 feet per second squared in tests of specific aircraft. The majority of Eglin's ballistic tests use a minimum of four cameras. This arrangement allows for triangulation (see Figure 22), even in the event that one camera malfunctions or loses sight of the weapon during the tracking phase. As a rule of thumb, accuracies of at least 5 feet can be expected when using three to six cameras. Clearly, with good weather, complete camera coverage, and accurate film reading, cinetheodolites provide a very accurate means of tracking an object.

Using several different types of equipment at Eglin, TSPI is obtained from film and automatically transferred to a digitally-formatted computer tape through a PDP 11/34 microcomputer system. Figures 23(A) and 23(B) show typical frames from film that are reduced to obtain TSPI. It inay be noted that without an event time, it is very difficult to discern first store movement due to the small image of the store. Two Type 29 Telereader Systems (Figure 24) are used for reading all types of film with a sensitivity of 0.0003 to 0.00006 inch per count (depending on the magnification). One of these readers is also equipped with an angle-reading device which permits angles ranging from 0 to 360 degrees to be measured with an accuracy of 0.1 degree.

Two Contraves semi-automatic film readers (Figure 25) are utilized to read film from the digital Contraves cinetheodolites. Since the cinetheodolite camera operators cannot track an object in

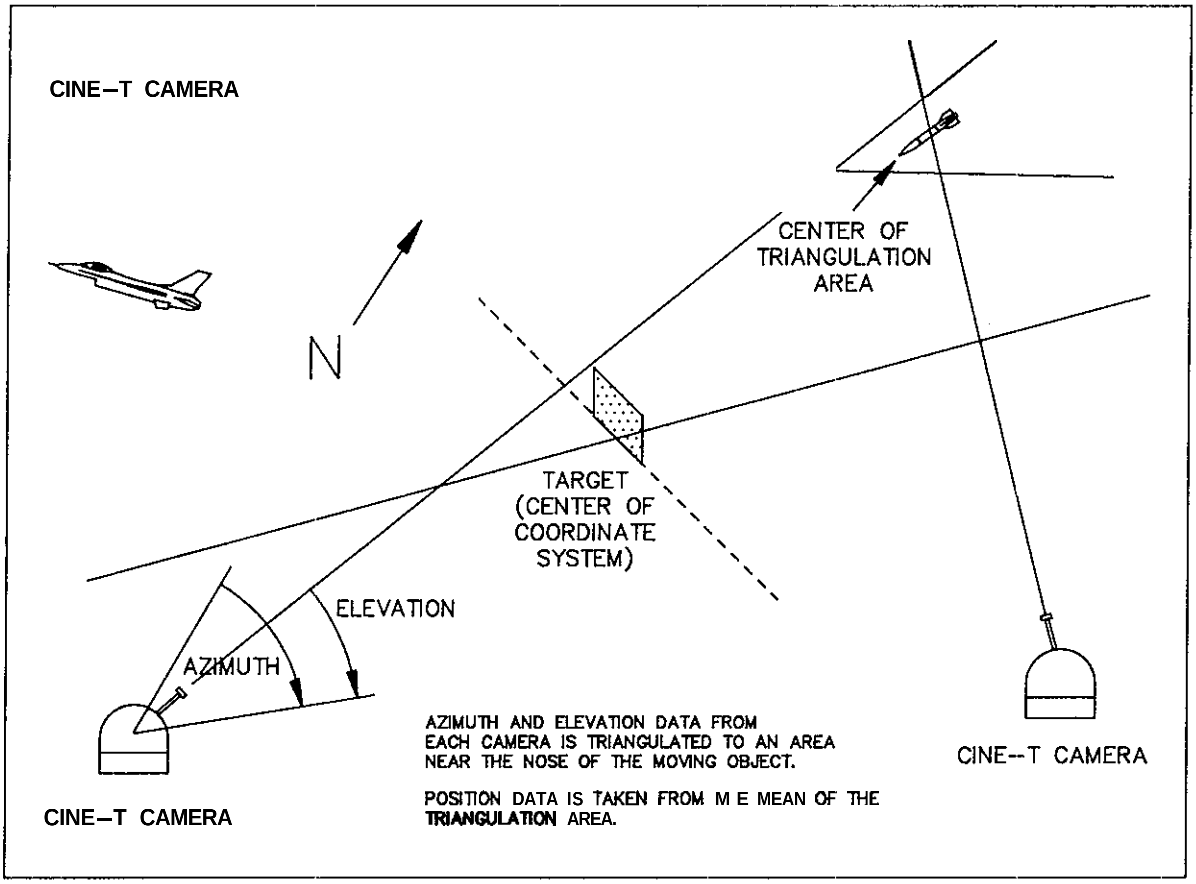


Figure 22. TSPI Raw Data Acquisition

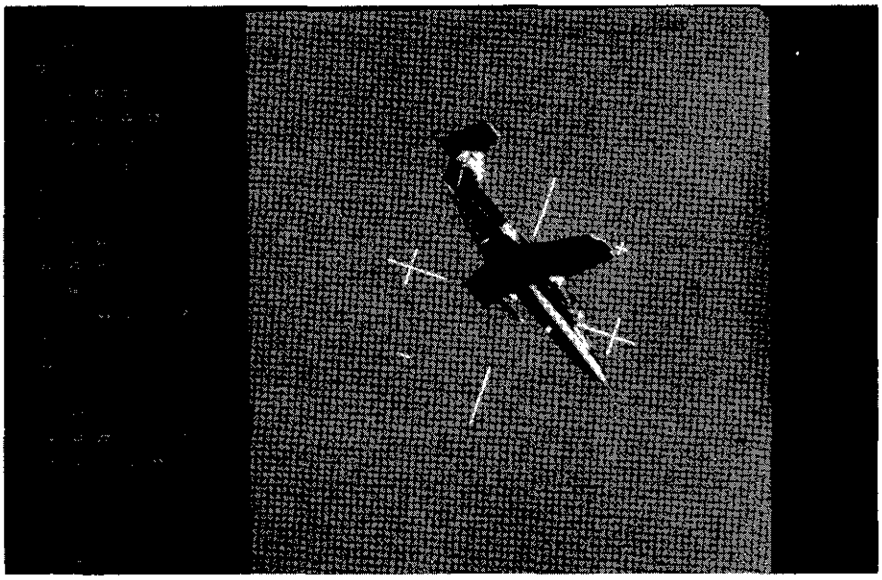


Figure 23(A). Cinetheodolite Photo Coverage of MK 82 Release

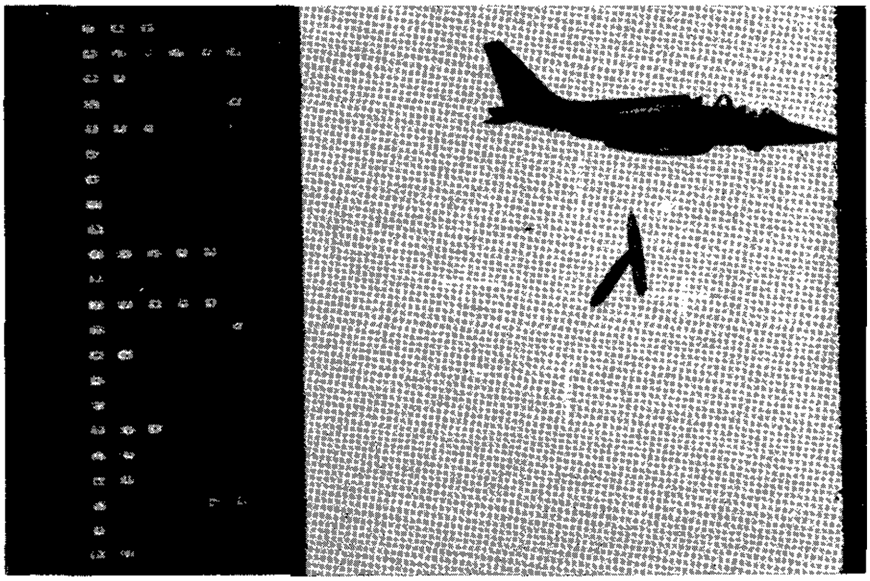


Figure 23(B). Cinetheodolite Photo Coverage of Alpha Jet

Figure 24. Type 29 Telereader System

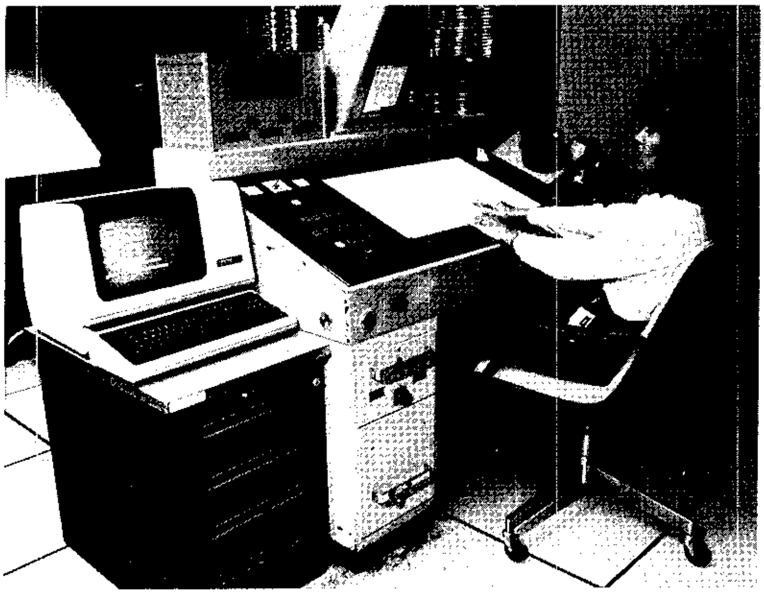


Figure 25. Contraves Semi-Automatic Film Reader

such a manner that the center of the optical axis of the camera lies directly on the nose of the object, it is necessary to determine the displacement between the optical axis and the nose or any other specified reference point on the object being tracked. This displacement is called the tracking error. Approximately *100 frames* per second can be read with a resolution of 0.0025 degree in azimuth and elevation and 0.2mm on the tracking correction.

At Eglin, cinetheodolite data are smoothed by using a least-squares curve fit. The trajectory of the aircraft or weapon helps determine the degree of the polynomial and the number of points that need to be used to smooth the cinetheodolite data.

A maximum of 39 points and up to a third-degree polynomial can be used. Typically, a 31-point quadratic equation is used to fit most standard weapon trajectories. When a weapon has a rocket motor firing or any other events that make it difficult to track, a cubic equation is used to obtain the smoothed data. The smoothed cinetheodolite data is reduced to generate TSPI. Smoothed data is usually reduced with the line of flight being the aircraft track at release and the origin of the coordinate system being the target. The smoothed TSPI is normally printed at 0.2-second intervals and contains parameters such as positions, velocities, accelerations, Mach numbers, dynamic pressures, and flight path angles correlated with time. A sample pass of TSPI is presented in Table IV.

During ballistic tests, the aircraft is tracked from a minimum of **3** seconds prior to release and for as long after release as the aircraft appears on the film of the cinetheodolites tracking the weapon. The weapon is usually tracked from release to cluster opening, fuze function, or impact. To record the time of weapon release as well as other event times, a medium-speed tracking camera, which operates at a nominal 96 frames per second with IRIG time and 35mm film, is also used at Eglin. Black and white film is typically used, except in those instances where color contrast is an important factor in determining the occurrence of events (for example, functioning fins).

Impact times, velocities, and angles for weapons and submunitions too small to track with cinetheodolite or medium-speed tracking cameras are determined by fixed Milliken or similar cameras along a grid impact area. Bowen ribbon-frame cameras, which operate at rates of 60, 90, 180, and 360 frames per second, may be synchronized to provide photographs of an item along a predetermined flight path.

8.2 Ground Impact Scoring

Ground impacts of large weapons, such as MK 84 bombs, are usually scored using the near edge of the weapon crater in polar coordinates oriented to the target and to the flightline downrange of the target. Figure 26 illustrates a sample impact plot. For functioning weapons released on grids, the origin of the coordinate system is typically the target. Submunitions are separated by type or dispenser to provide pattern data. Other data collected from the ground impact surveys include the number of submunitions located and the number of dud items. Scoring of initial impact locations is not always possible due to the fact that the weapons or submunitions may not possess sufficient velocity to dent the grid surface,

8.3 Aircraft Instrumentation

As a result of the increased interest in separation effects and system accuracy testing, a debate is ongoing within the technical community regarding the need to enhance aircraft instrumentation. At the present time, several types of instrumentation are used to gather data for use by analysts.

Eavesdropping on the MUX bus allows one to know what the aircraft is "thinking" during a weapon drop. This equipment is expensive, usually requires extensive down-time for modification, and requires specialized maintenance. Therefore, the number of aircraft with full instrumentation is small.

For an accurate analysis of TSPI, it is critical that the time for store release he precisely determined. Instrumented weapon racks offer **an** accurate source of actual time of weapon release, either by detecting end-of-stroke time of the ejector foot or recording cartridge fire. Both can be used to determine time of release or, at least, to verify the release time provided by TSPI. Radar Beacon System (RBS) tone is another way of recording actual release time, but care must be exercised or inherent system time delays may bias the analysis. Onboard cameras provide yet another way of determining actual release time by noting first store movement if the cameras are time-coded.

One type of instrumentation that is perhaps the most valuable to the analyst is the HUD recording.

Table IV. Sample TSPI Data

Weather Data

ALTITUDE FEET	ALTITUDE METERS	PRESS MB	TEMP DEG C	WD DEG	WV KTS	VS KTS	RHO GM/M3	NE	NO	DEW PT DEG C	V PR MB	RH PCT
67	20	1003.0	21.1	320	20	669	1185.0	293	270	0.9	6.5	26
201	61	998.4	20.3	310	21	667	1182.7	0	0	0.0	0.0	0
250	76	996.7	20.0	310	21	667	1181.9	0	0	0.0	0.0	0
300	91	995.0	19.7	310	21	667	1181.0	0	0	0.0	0.0	0
349	106	993.3	19.4	310	21	666	1180.2	0	0	0.0	0.00	0
394	120	991.8	19.2	310	22	666	1179.4	0	0	0.0		

Page 1: Position/Velocity Data

				TIME H M S	T-FREZ SEC	X FEET	Y FEET	Z FEET	VX F/S	VY F/S	VZ F/S	HT FEET
1	*	21	6	11.958	-4.950	-12480.203	8293.628	-100.298	791.517	-390.902	12.595	8440.288
1	*	21	6	12.156	-4.752	-12323.273	8216.054	-97.838	793.644	-392.671	12.251	8362.622
1	*	21	6	12.354	-4.554	-12165.820	8138.130	-95.447	795.771	-394.439	11.907	8284.606
1	*	21	6	12.552	-4.356	-12008.147	8059.856	-93.123	797.898	-396.208	11.562	8206.241
1	*	21	6	12.750	-4.158	-11849.953	7981.232	-90.868	800.025	-397.976	11.218	8127.526
1		21	6	12.948	-3.960	-11691.331	7302.287	-88.684	802.152	-389.765	10.848	8048.493

Page 2: Air Velocity Wind Data

		T-FREZ SEC	VT F/S	VA F/S	VWX F/S	VWZ F/S	WX F/S	WZ F/S	HT FEET	A G S
2	**	0.000	1065.054	1053.928	752.460	-46.329	16.844	36.839	1019.353	34.088
2		0.198	848.218	838.388	596.213	-43.216	15.278	35.707	888.239	34.087
2	*	0.396	263.371	250.522	181.561	-17.624	17.223	36.662	802.006	97.101
2	*	0.419	192.382	178.565	130.850	-14.246	17.303	36.624	798.644	97.401
2	*	0.517	184.016	169.988	124.366	-14.011	17.484	36.540	787.094	2.685
2	*	0.594	177.449	163.361	119.414	-13.893	17.484	36.540	178.407	2.685

Page 3: Acceleration, Mach, Drag, & Dive Data

		T-FREZ SEC	AN G G S	AD F/S/S	M	KD	CD	DA GR DEG	DA AIR DEG	HT FEET
3	**	0.000	0.461	-45.717	0.840	0.472	1.202	-26.098	-27.014	6434.290
3	*	0.198	0.474	-45.583	0.835	0.475	1.209	-26.601	-27.524	6351.374
3		0.396	0.380	-42.675	0.830	0.448	1.142	-27.095	-28.010	6267.500
3		0.594	0.021	-26.886	0.826	0.284	0.724	-27.494	-28.404	6182.821
3		0.792	0.209	-34.349	0.825	0.363	0.925	-27.874	-28.771	6097.280
3		0.990	0.286	-33.961	0.822	0.360	0.917	-28.141	-29.022	6011.362

Page 4: Acceleration, Horizontal Flight Path, & Dynamic Pressure Data

		T-FREZ SEC	AX F/S/S	AY F/S/S	AZ F/S/S	HV DEG	HVA DEG	Q LB/FT2	HT FEET	SR FEET
4	**	0.000	-797.289	750.768	10.003	63.865	61.048	1260.699	1019.353	1172.978
4		0.198	-797.289	750.768	10.003	63.868	60.426	799.460	888.239	984.287
4	*	0.396	-2201.353	2219.486	145.255	70.042	59.027	71.493	802.006	859.705
4	.	0.419	-2201.353	2219.486	145.259	73.161	58.358	36.323	796.644	854.564
4	:	0.517	-64.313	57.486	1.535	73.596	58.144	32.922	787.094	836.588
4	:	0.594	-64.313	57.486	1.535	13.165	57.535	30.409	778.407	823.054

VARIABLE	MEASUREMENT	UNITS
A	Acceleration	G
AD	Acceleration Due to Drag	F/S/S
ALTITUDE	Altitude	Feet or Meters
AN G	Normal Acceleration	G S
AX	X Acceleration	F/S/S
AY	Y Acceleration	F/S/S
AZ	Z Acceleration	F/S/S
CD	Drag Coefficient	
DA AIR	Dive Angle	Degrees
DA GR	Dive Angle	Degrees
DEW PT	Not Used	
HT	Height Above Sea Level	Feet
HVA	Heading from North	Degrees
KD	Drag Coefficient (Ballistics)	
M	Mach Number	
NE	Not Used	
NO	Not Used	
PRESS	Atmospheric Pressure	Millibars
Q	Dynamic Pressure	Lb/Ft^2
RH	Not Used	
RHO	Air Density	gms/cubic meter
SR	Slant Range	Feet
TEMP	Temperature	Degrees Celsius
TIME	Time of Day	Hrs/Mins/Secs
T-FREZ	Time from Freeze	Seconds
V PR	Not Used	
VA	Total Velocity in Air Mass	F/S
VS	Speed of Sound	Knots
VT	Total Velocity	F/S
VWX	X Velocity to Air Mass	XF/S
VWZ	Z Velocity to Air Mass	F/S
VX	X Velocity	F/S
VY	Y Velocity	F/S
VZ	Z Velocity	F/S
WD	Wind Direction	Degrees
WV	Wind Velocity	Knots
WX	Wind Velocity-X Component	F/S
WZ	Wind Velocity-2 Component	F/S
X	X Coordinate	Feet
Y	Y Coordinate	Feet

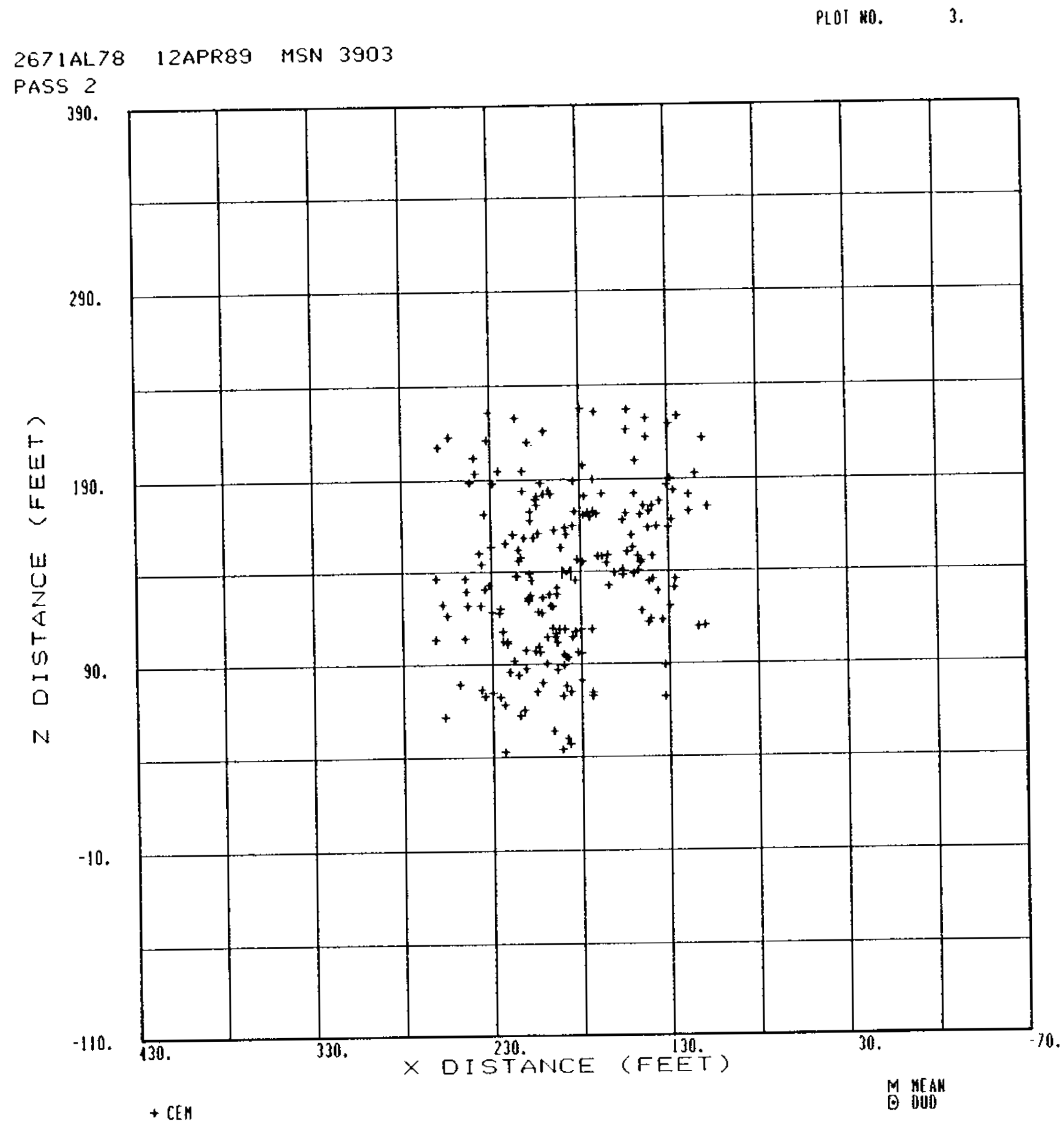


Figure 26. Typical Impact Plot

Unlike other types of instrumentation, HUD recordings are available as standard equipment on most aircraft. They can, in most cases, provide the analyst with data on airspeed, altitude, dive angle, g's, Mach number, and of primary importance in accuracy testing, the aim point.

As the need for instrumentation increases, some innovations are being utilized by the flight test community. For example, an interesting one is the use of small video cameras to record aircraft aft Multi-Purpose Displays (MPD's). At Eglin, this is being done in F-15E aircraft. Another example is the development of an OFP that will display data relating to weapon release on the MPD's for recording by these video cameras. This display amounts to a relatively inexpensive MUX recording. These same small cameras are also being used to record the pilot's view through the NUD, which will provide not only a color through-the-HUD image (HUD video today is black and white only) but also a delay-free image for accuracy analysis as well.

8.4 HUD Recordings

Pilots have been using cameras to record their activities ever since the invention of the airplane. Use of cameras to record engagements with other aircraft (kills) is a prime example. In fact, much of our present-day knowledge on the history of air warfare has come from cameras during actual battles in the sky. Air-to-air combat strategies were, and are, constantly being analyzed, scrutinized, and refined using gun camera footage and HUD video recordings. The gun cameras of the past have evolved into the HUD video recordings made every day by pilots. Present video technology allows very small cameras to record a flight and permits the recording to be reviewed as soon as the plane is back on the ground without having to wait for film to be developed. These procedures avoid the risk of losing the footage altogether due to improper handling.

It is doubtful that aircraft manufacturers ever intended for HUD recordings to be used in the exacting manner that analysts presently are attempting to use them. They were, first and foremost, designed to be used as recording devices for air-to-air combat, as training tools for pilots and weapon system operators, and perhaps for settling aircrew arguments as to "who shot down whom first." HUD recordings provide the analyst with an inside look at the intricacies of weapon delivery, and if the design of the recording system is known, they also provide a fairly accurate idea of weapon-release parameters. The analyst gets a pilot's-eye view of the weapon delivery system and an idea of its abilities and limitations.

Delays are evident in HUD recordings, since what is viewed on the video tape at a particular instant in time is not necessarily what happened at that time. The importance of these delays cannot be overemphasized. Analysts reviewing the tape of a mission have often accused pilots of making aiming errors, only to learn later that video recording delays had caused the appearance of pilot error.

These delays are caused by several different factors, but timing is a major one. For example, in most aircraft, video recordings are made at about 30 frames per second. HUD symbology is displayed at about 60 frames per second, but the software that updates the symbology is usually at 25 frames per second. Further, in the case of the F-15E, recordings are only made of every other symbology update cycle, which is 12.5 times per second. Thus, there is potential for large time lags in the recorded data on a HUD video recording. These time lags account for the innovative development of the camera modification to F-15E aircraft that was mentioned previously in this volume.

As is true with any data source, once the limitations of that source are known, it is then possible to make the most use of the data provided by the source. Once the limits and delays in a HUD video recording system are known, the analyst can put the recording to best use.

8.4.1 Use of HUD Video for Computerized Deliveries

The HUD video becomes most valuable in support of accuracy analysis testing. It provides the analyst with a real-time look at whether the pilot was able to attain the desired release parameters, allows the pilot to make real-time vocal notations as events/anomalies occur, and, most importantly, gives a good picture of pipper placement at the time of target designation. HUD video is not as vital to a separation-effects test as it is to an accuracy test, but it does afford the analyst with a quick look as to whether the pilot was on parameters. For this reason, it is recommended that HUD video be a required part of every flight test mission.

8.4.2 Use of HUD Video for Non-Computerized Deliveries

A non-computerized delivery **is** one in which the pilot sets the aiming reticle at a pre-selected mil depression that will, if the pilot is exactly on the predetermined delivery conditions, allow a weapon to be delivered on target. In this case, the HUD video allows the analyst to determine whether the pilot was on parameters, and if off parameters, by bow much. Again, it allows the analyst to relate aim point to the target.

8.5 Programmable Data Acquisition System (PDAS) Recordings

A PDAS is used at Eglin to provide MUX bus recordings to the analyst. It is installed on F-15E and F-16 aircraft and is a programmable device that can eavesdrop on the bus and can record and time tag, using IRIG-B time, pre-selected data words onto an analog tape. As these words appear on the bus, they are placed into an array of buffers for storage. When the buffer array is full, all data is time-tagged and written to tape.

As with the HUD recordings, the analyst must realize that a delay exists between the time the word appears on the bus and the time it is recorded. Instances of delays of up to ***200*** msec in PDAS data have been noted. PDAS should be used in conjunction with another data source so that timing differences can be resolved. Efforts are being made to correct time lags. One innovative solution was implemented on a system similar to PDAS at Edwards AFB, California. Data are simply stored in a buffer cell with its time tag in the next cell. This arrangement requires the buffer to be recorded twice **as** often since the buffer must now hold data and time tags for every word, but accurate time tags are now provided with the data.

An effort to **use** video tape to record the equivalent of MUX data in aircraft is underway at Nellis AFB, Nevada. The premise is a good one and will provide useful data to analysts, but it will have the same limitations **as** HUD video (that is, data will only be recorded at ***30*** frames per second).

8.6 Aircraft Data

The aircraft loadout must identify what is carried on each station of the aircraft **as** well **as** the specific station and rack combination associated with each pass. This information enables the analyst to **use** the proper ejection velocities and angles when modeling the drop. The release sequence must also be known in order to correlate TSPI for individual stores on a pass-by-pass basis. Finally, aircraft data must include the type and model and the latest software updates, if any, incorporated in the aircraft's OFP.

8.7 Store Data

The last pieces of data required to perform a ballistics analysis pertains to the weapons themselves. In order to accurately model a weapon trajectory, the following information must be available to the analyst: type of weapon and fuze, whether it **is** live or inert, measured mass properties (weight, center-of-gravity, and moments-of-inertia), and nominal functioning characteristics such **as** fin opening, dispenser opening, and fuze arming timer. In order to use these data in subsequent analyses, it is necessary to identify where each store is loaded on the aircraft.

8.8 Meteorological Data

In an earlier section of the volume, meteorological data were discussed **as** essential for ballistic analyses in that both the way a test is conducted and the performance of the test item can be affected by atmospheric conditions. For this reason, meteorological test criteria have been established for an increasing number of systems which are atmosphere-sensitive. Atmospheric conditions must satisfy these criteria before the test commences and must be measured during the testing phase. Because of the importance of meteorological data, the discussion that follows provider the reader with more information on this subject.

Instrumentation systems and components used for measuring, computing, displaying, and storing meteorological data fall into two broad categories: fixed measuring systems and mobile measuring systems. Fixed systems measure the distribution of meteorological parameters correlated to height by balloon sounders or by sensors on towers. Weather observers can also make meteorological measurements by operating portable meteorological equipment from various sites throughout the test complex.

Rawinsondes (for example, the AN/GMD-5 Rawin **Sets) are** used to make atmospheric soundings from the **earth's** surface to altitudes above 30 kilometers. This equipment and associated ground and flight equipment measure or derive data for pressure, temperature, relative humidity, wind direction and velocity, height, and density. Typically, routine soundings are made twice daily, and special soundings can be performed as required to support the testing environment.

At Eglin, temperature, which can be recorded in degrees Centigrade, Fahrenheit, or Rankin, is measured with An **ML-7** general-purpose, non-registering, mercury-in-glass thermometer. Dew point and relative humidity are measured with an ML-24 psychrometer. Pressure is measured by three types of instruments: the ML-102, a portable aneroid barometer that is individually calibrated for scale and temperature errors; an ML-512, which is a Fortin-type mercurial barometer with adjustable cistern; and an ML-563, which is a precision barograph that provides a continuous record for a 4day period. Density is recorded as grams per cubic meter, pounds per cubic foot, or slugs per cubic foot.

Wind direction and velocity data are obtained by tracking a Pilot Balloon (pibal) at the test site with cinetheodolite cameras. Wind measurements can be made in clear weather or in any portion of the atmosphere below cloud cover. Wind velocity is typically measured either in knots or feet per second. The wind direction and velocity pibal data are usually recorded at altitudes from the earth's surface to 3000 feet in 500-foot increments and from 3000 feet above the earth's surface to 1000 feet above release altitude in 1000-foot increments. Pibal recordings typically are taken in the vicinity of the release area within **30** minutes of the munition release time. The pibal can be tracked either by theodolites or, if released from suitable locations, by range cinetheodolites operating at 10 frames per second recording data with IRIG time in bursts of approximately 5 seconds each at one-half minute intervals. In the final product, the cinetheodolite pibal data is integrated into the reduced ballistics data printouts.

At Eglin, the ML-474 theodolite is used. This portable measuring device can be used singly or in pairs to make wind measurements from concrete pads with a known orientation. Measurements are made from the earth's surface through 10 kilometers by tracking a pibal. The theodolite used for this purpose is a right-angle telescope surveying instrument that records azimuth and elevation angles of the rising balloon at fixed time intervals. A typical ascent to 3 kilometers takes 10 minutes.

Single-theodolite Pibal wind measurements made at a requested location assume that the balloon has a known ascent rate. The estimated error of such measurements is usually 3 meters per second plus six percent of the wind vector. When the balloon passes through a temperature inversion or through other turbulent conditions, single-theodolite readings are unreliable.

For the greater precision required for most ballistic tests, pibals are typically tracked by a minimum of three cinetheodolites. Assuming five samples per second and smoothing to a 101-point linear equation, winds derived from this type of tracking have an estimated vector error of 0.5 meter per second and can be determined for vertical intervals as small as 75 meters.

8.9 Summary of Data Requirements for Ballistic Tests

Analysts at Eglin have prepared an Operating Instruction (OI) that defines ballistics requirements. Inasmuch as this OI is an unpublished/internal document, it is provided as Appendix B in order to provide the reader with quick and ready access to test requirements, data recording/collection requirements, meteorological requirements, and data reduction requirements.

9.0 DATA ANALYSIS

9.1 Freestream Analysis Methodology

A freestream ballistic analysis consists of the development of the weapon's freestream flight characteristics (drag coefficient, event times, and the like) for use in a mathematical model to predict the flight path of the weapon from release to impact. The methodology and necessary data to predict the impact pattern for functioning weapons are also developed during this analysis.

To predict the freestream performance of a weapon, analysts at Eglin compute theoretical trajectories using the computer program called Unguided Weapon Ballistic Analysis Program. This program has been used and refined for several years, but unfortunately, the program is documented for internal use only. The program is adaptable to any type of computer having the required memory and system routines. The program computes point mass three-degree-of-freedom (3DOF) trajectories using a modified Euler integration method with the following information:

1 Positions and velocities of the weapon at release (time zero) as determined from the reduced cinetheodolite TSPI for the aircraft (Incidentally, since cinetheodolite film position measurements at Eglin are made using the nose of the aircraft, a position correction factor is applied to obtain the true position of the weapon on the aircraft.)
2 Ejection velocity (that is, the velocity at which the weapon is ejected from the aircraft suspension rack)
3. Measured weapon weight and diameter
4. Drag coefficient as a function of Mach number, as furnished by the weapon contractor or as estimated based on a similar weapon
5. Meteorological data (such as air temperature, density, and wind direction and velocity)
6. Event times or altitudes that affect the weapon's drag
7. Measured range, cross range, and time of flight at weapon functioning and/or impact
8. The particle equations of motion (The particle equations of motion assume that the only forces acting on the weapon are the drag force, which acts in a direction opposite to that of the air velocity vector of the weapon, and gravity.)

The drag force (F) is expressed as follows:

$$F = MA = R(KD)(D^2)(V^2)$$

where

F = drag force (lb-ft/sec^2)
M = mass of bomb (lb)
A = acceleration of bomb due to drag (ft/sec^2)
R = air density (lb/ft^3)
KD = drag coefficient (dimensionless)
D = weapon diameter (ft)
V = air velocity of weapon (ft/sec)

CD, used by many aerodynamicists, is related to KD by the formula:

$$KD = (PI/B)(CD)$$

and drag force F may he expressed as:

$$F = 1/2(R)(CD)(S)(V^2)$$

where

S = ((PI)(D^2))/4 = cross-sectional area.

The positions and velocities of the computed trajectories are compared with the positions and velocities of the observed trajectories from TSPI for each weapon. This comparison is usually performed at 1.0-second intervals along the trajectory until impact or termination. If the delta range (which is the difference between the actual and computed ranges) and time-of-flight deviations for the individual trajectories are large and biased in one direction (see Figure 27), it must be determined whether the deviations are due to drag or separation effects. In order to make the distinction between drag and separation effects, additional trajectories are computed using the measured positions and velocities of the weapon at some time T(1). Time T(l) is usually 3 seconds after release but should be far enough along the measured weapon trajectory for the weapon to stabilize to steady-state flight. If the comparison of these trajectories with the measured trajectories produces large and biased deviations starting at T(1), the drag used to compute these trajectories must be adjusted or derived. If the comparison of these trajectories produces small deviations with an equal number of positive and negative values, then the drag that was used is considered to have been verified and is acceptable (see Figure 28).

Analysts at Eglin use two methods for adjusting or deriving store drag. The tried-and-true method is by manually adjusting the drag coefficient. This adjustment is accomplished by comparing the horizontal and vertical velocity components, usually at 1.0-second intervals, of each computed trajectory with those of the TSPI. This method can be used either with or without TSPI. If TSPI is not available, the comparison is made at impact using only bomb range and total time-of-fall (collected for ground instrumentation). When making the comparison, if the velocity differences are larger than 3 or 4 feet per second, the drag coefficient should be changed. In order to change the drag, the time or Mach number where the velocity comparisons begin to deviate from each other must be determined. Starting at this time or Mach number on the drag curve, the drag must be increased or decreased so that the computed velocities will better match those of the TSPI. A drag change in the portion of the trajectory where the horizontal velocity is large and the vertical velocity is small will affect down-range travel more than time of flight. A drag change in the portion of the trajectory where the vertical velocity is large and the horizontal velocity is small will affect the time of flight more than down-range travel. Additional

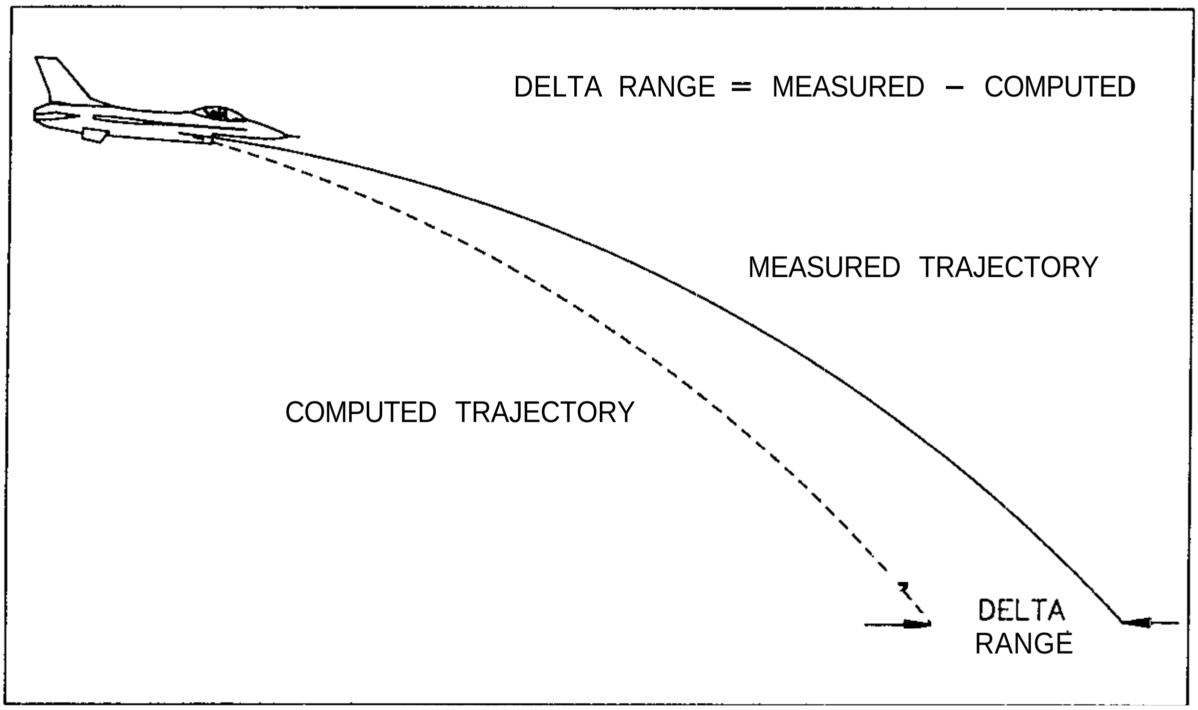


Figure 27. Delta Range

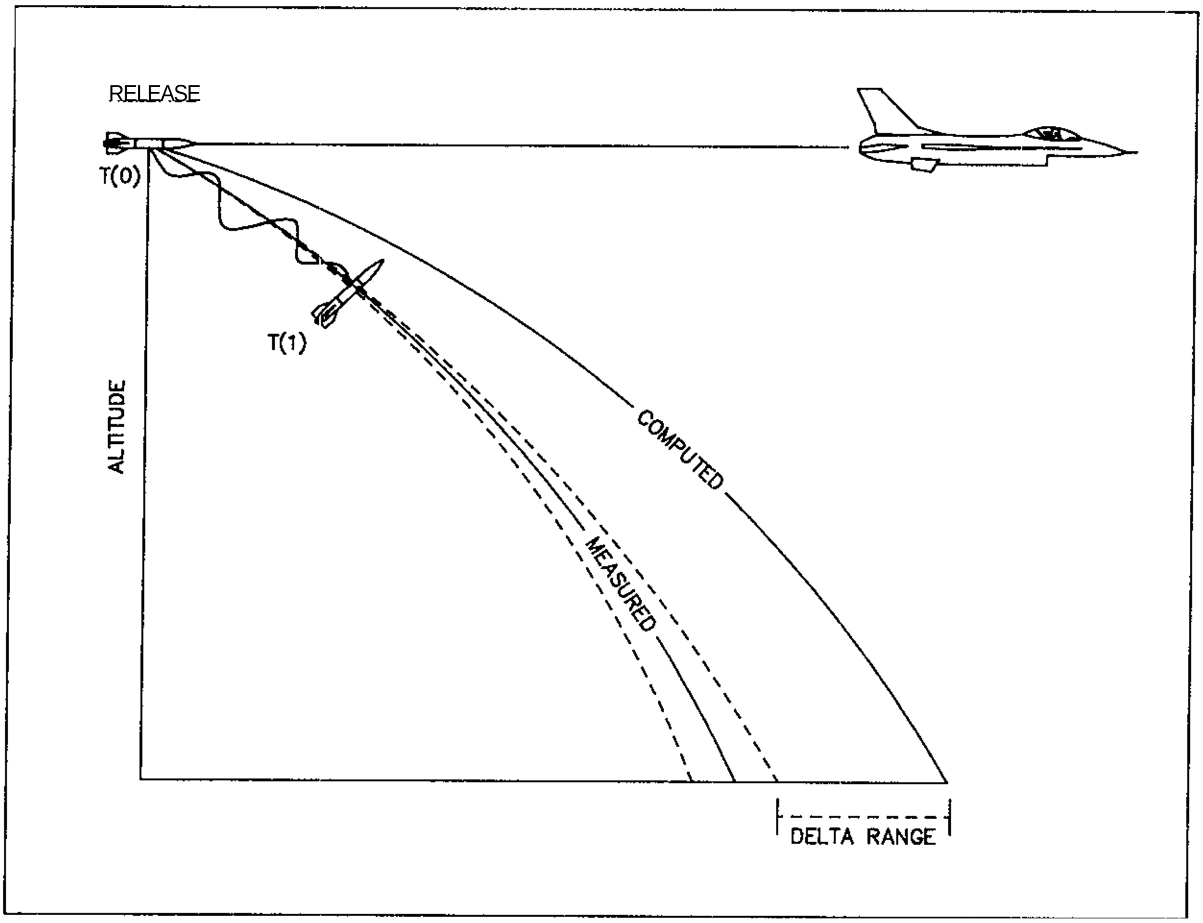


Figure 28. Validation of Freestream Drag

trajectories may be computed using the adjusted drag and the computed trajectories, and the TSPI can then be recompared. If these ttajectory comparisons are not favorable, another drag change should be made in the same manner as before, and more trajectories should be computed for comparison. This process should be repeated until the analyst determines that the drag is acceptable for the weapon. In summary, this method is adequate, but it is labor- and experience-intensive.

Another newer method involves the use of a drag extraction program called Drag Coefficient Extraction Methodology (KDEM). This program computes a drag value for each time interval from TSPI. It then sorts time intervals by Mach number and computes a weighted average drag for each Mach number. This drag is then the best available for the weapon being tested. The program was developed and validated at Eglin after years of research and testing. In the opinion of Eglin analysts, the program represents state-of-the-art drag-prediction methodology. The program is fully documented in Reference 16, and a summary of it forms part of Appendix C. Because the program is very user-friendly, it is not labor-intensive. Also, since the program is automated, it does not require analysts with extensive experience.

After adjusting or deriving the drag by using either of these methods, trajectories starting at time T(0) with the new drag are computed. If the comparison of these trajectories with the measured trajectories produces small deviations, the freestream drag analysis is complete, and it will not be necessary to do a separation-effects analysis. If the comparison of these trajectories with the measured trajectories produces large deviations, a separation-effects analysis must be accomplished. The methods for performing a separation-effects analysis will be discussed in a later section of this volume.

During the freestream drag analysis, weapon events such as drag chute deployment and fin opening must be modeled. An event may be modeled as a constant (straight line, polynomial, or some other equation). A review of test data provides the analyst with a guide as to the methodology to use to model events.

After the freestream ballistic analysis is complete, weapon ballistic dispersion should be computed. This is usually performed in the form of CEP. CEP is the radius of a circle which contains 50 percent of the weapons dropped at a given set of delivery conditions. The CEP is normally reported in milliradians in the normal plane.

9.2 Submunition Pattern Analysis

The type of weapon being tested will define the type of pattern analysis that must be performed as well as the type of data to be collected for the analysis. An impact pattern is defined as the geometric shape formed by the submunitions at impact. A pattern analysis must be accomplished to derive the methodology to define the pattern size and shape as well as to define the centroid of the pattern. It should be accomplished during the developmental phase of the weapon system testing in parallel with deriving the freestream drag.

The pattern is a function of the weapon conditions (altitude, velocity, and angle) at functioning and the type of method used to disperse the submunitions. The submunitions may be dispersed by such means as ram air, tangential velocity, submunition design, or a combination of submunition design with either ram air or tangential velocity. The ram air method assumes that, as the weapon functions and the submunitions are exposed to ram air, they slightly separate from each other and follow their individual trajectories. This trajectory pattern results in submunitions departing from the weapon opening with a characteristic angular displacement about the weapon velocity vector. This displacement does not provide for natural or designed dispersion of the submunitions induced during their free flight. The tangential velocity method of dispersion assumes that, at weapon functioning, submunitions are ejected perpendicular to the weapon velocity vector. The tangential velocity may be due to the weapon spinning or to some internal mechanism that ejects the submunitions from the weapon.

In order to perform a pattern analysis, the analyst must have a tabulation of the impact coordinates for each submunition within the pattern as well as a plot of the tabulated data. This plot gives the analyst a quick look at the shape and size of the pattern and will show those submunitions that are "outliers". (Outliers are those submunitions that may be several hundred feet from the main part of the pattern and will have little or no effect on target damage.) The plot also gives the analyst a quick look at defining the pattern centroid for use in determining the drag from function to impact. Impact time, velocity, and angle data are also helpful to the analyst when deriving the drag. The tabulated data should include statistical information such as the sum of the range and cross-range impact coordinates, the MPI, and the number of submunitions considered in the MPI. The MPI may differ from the geometric center of impact (GCI) or pattern centroid due to the density of the submunitions within the pattern. If applicable, the data should also include the number of live and dud submunitions within the pattern to determine the submunition reliability. The analyst may request other data such as a circle, ellipse, or some other geometric shape that contains 80 and/or 90 percent of the submunitions. Figure *26* shows a typical impact plot.

After reviewing the observed pattern data and the method of submunition dispersion, the analyst will have a working knowledge of the pattern shape. The pattern size will be determined by computing theoretical trajectories from function to impact using the appropriate dispersion method and the submunition drag. To define the pattern, four trajectories should be computed. These trajectories should simulate the short, long, right, and left submunitions that define the pattern boundaries and should then be compared with the observed points. The pattern analysis is complete if the trajectory comparisons are favorable. If the comparisons are not favorable, adjustments to the dispersion method values, such as velocity and angle, must be made and additional trajectories computed. These trajectories are compared with the measured trajectories, and the process is repeated until the comparison of the trajectories is favorable. At this point, the analysis is complete.

The analyst may want to take the pattern analysis one step further and determine the coefficients for an equation by using a regression program. The equation may be as follows:

$$\text{Pattern Size} = A + B\,(FA) + C\,(FV) + D\,(FH)$$

where A, B, C, and D are the coefficients from the stepwise regression program and FA, FV, and FH are the weapon functioning angle, velocity, and altitude, respectively. The equation may be used to compute the diameter of a circle, the major and minor axes of an ellipse, or the length and width of a rectangle.

9.3 Separation-Effects Analysis

A separation-effects analysis can be broken up into two distinct parts:

(1) Determining whether there is a need for separation-effects compensation for a given weapon loadout, and if compensation is required, the magnitude of the compensation
(2) Determining and implementing a methodology for separation-effects compensation.

The first part of a separation-effects analysis, determining the need, is straightforward. Using data provided from flight testing (for example, TSPI, release sequences, and event times), each individual weapon is modeled from at least two sets of initial conditions using earlier described freestream-modeling methods. The first set of initial conditions is taken at the time of weapon release from the aircraft. The results of this modeling are compared with the actual termination conditions of the dropped weapon. If separation effects exist and the freestream model of the weapon is a good one, the difference between the model and actual data will be significant. On the other hand, if few or no separation effects are present, the differences will be small. These differences or deltas are a good indication of the amount of compensation required. This first part of a separation-effects analysis is important because it provides insight into the magnitude of errors caused by separation effects. This insight helps in making decisions as to the cost-effectiveness of implementation of compensations. In many instances, improving a trajectory by a small amount does not measurably increase weapon effectiveness and, therefore, is not cost-effective.

The second set of initial conditions is taken from the actual trajectory some time after release. The ideal time is when all perturbations to the weapon during separation have stabilized. As previously mentioned, this condition normally occurs about 3 seconds after weapon separation. These initial conditions are used to model the weapon's trajectory again and are compared with the actual trajectory data of the weapon. Ideally, the difference between the model and the actual trajectory should, in this case, be zero. Again, if the freestream-modeling ability is good and no anomalies exist with the weapon, the difference will be very small. This second comparison of the weapon trajectory is valuable to the analyst because it tests the freestream model and allows bombs with anomalies to be identified and studied individually and possibly be removed from the sample set.

The second part of the separation-effects analysis is more complex than the first. Before any compensation for separation effects can be made, the decision must be made as to what methodology will be used onboard the aircraft. Without getting into the specifics of the many different methodologies, the methods in use today can all be labeled as "fudge factors". These fudge factors do not model the actual trajectory but make changes to the inputs of OFP trajectory calculations in order to, in effect, cheat the system into calculating the correct weapon freestream trajectory.

The basic analysis in compensation involves the same steps used in determining a need for compensation, that is, measuring the errors by comparing modeled trajectories to actual trajectories. These deltas are then used to determine the fudge factors needed, which are, in turn, curve fit to produce coefficients for equations contained in the aircraft OFP. Several different types of equations are presently used in aircraft OFP's. As previously stated, the equations contained in the F-16 and the F-15E discussion are functions of Mach number and g. The F-111 equation is a function of Mach number, **g,** and dynamic pressure.

Considerable effort has been devoted to quantifying separation effects by using wind-tunnelderived data instead of flight-test data. The thrust of this effort stems from the belief that an analytical method will enable separation effects to be established with more accuracy than is currently possible. But, in an austere budget environment, the biggest payoffs are projected to come in the form of less stores, less missions, and overall less cost and time needed to validate separation-effects models.

A program has been developed at Eglin called Separation-Effects Estimation Method (SEEM). This program uses a modified 3DOF ballistics model to emulate a 6DOF safe separation model. The 6DOF model uses wind-tunnelderived store force and moment coefficients during separation trajectories. Ideally, if the 6DOF model adequately predicts store separation effects, then OFP algorithms could be precisely modeled throughout the desired flight envelope for an endless array of loadouts. Parametric analyses could then be performed to identify worse-case flight conditions and loadouts and, subsequently, only limited flight testing would be necessary to validate predictions. The SEEM program is fully documented in Reference 17, and a summary of the program forms part of Appendix C.

It may be candidly noted that analyses performed using SEEM have not resulted in as accurate a comparison as expected between 6DOF wind-tunnel-derived data and TSPI. For example, drag force coefficients from TSPI were up to three times larger than those obtained from wind-tunnel-derived data. However, this difference may be explained in part by the wind tunnel test apparatus, which placed more emphasis on measuring store-normal forces and moments than drag forces. In addition, the small scale of the store models necessitated altering the store's geometry to facilitate mounting on support strings. This scale not only altered the store's aerodynamic characteristics but also altered its base drag. Nevertheless, a well-founded cause for optimism exists that SEEM is on the right track and will fulfill its expectations if given enhanced wind-tunnel-derived data (for example, by using larger store models).

The reader may also be interested in knowing that the use of Computational Fluid Dynamics (CFD) is being investigated for deriving separation effects. If SEEM represents the state-of-the-art, CFD represents the future. Considerable research has been performed by industry and government, and the results offer significant promise for using CFD to derive separation effects. For example, Arnold Engineering Development Center (AEDC) is performing work in this area that is on the cutting edge of technology. Analysts at AEDC have performed CFD analyses that have matched TSPI quite closely for certain flight conditions. It is hoped that a successive volume on ballistics will document a validated CFD program that can be readily used by test organizations world-wide.

9.4 Accuracy Analysis

In reality, the goal of tactical warfare is simple: kill targets. Therefore, the most important question asked by aircrews is, "How effective is my aircraft?". Knowledge of the effectiveness of an aircraft allows aircrews and mission planners to make the best use of that aircraft. For example, why risk sending a large number of aircraft against a target when a smaller number could do the job? Conversely, sending too few aircraft will unnecessarily risk men and machines while not accomplishing the goal of the mission. The ability to assess the accuracy of a weapon delivery system is invaluable to operational **users** and analysts. **Knowledge** of the limitations of a less-accurate aircraft weapon-delivery system will make that system more effective than a system with unknown abilities, even though it may be proven later to have a higher degree of weapondelivery accuracy.

The only essential data required to perform an accuracy analysis are the same aircraft release parameters used for CEP calculations (that is, altitude and slant range) and the location of the impacts of the weapons. Since impacts are measured to a common reference point on the ground such as a target, it must also be known where the pilot was aiming in reference to that point at the time of release (see Figure **29).** The reported impact locations must be corrected for aiming errors. For instance, assume an impact is measured 200 feet short of the intended target. If the analyst **makes** the assumption that there was no aiming error, a bias in the weapon delivery system would be indicated. But if it were known that the pilot aimed 175 feet short, the aim-point-corrected impact would be 25 feet short, probably well within the acceptable accuracy of the weapon.

The results of an accuracy analysis is reported in CEP or REP and DEP. REP and DEP are range error probable and deflection error probable, respectively. REP and DEP form a square which, as with CEP, contains 50 percent of the bomb impacts. REP and DEP can be reported in mils or feet but are usually reported in feet in the ground plane. For weapons released at low altitudes, REP and DEP are reported (in feel) as opposed *to* a CEP, because the angles used *to* calculate CEP decreases to the point where CEP becomes meaningless. REP and DEP are also reported for loft deliveries for the same reasons.

In accuracy analyses, CEP is reported from two different references: around the aim point and around the MPI. In this instance, MPI **is** the mean of all intact munition impacts and the mean of the pattern centroids for functioning weapons (see Figure **30). If** a bias in the system exists as a specified percentage of bombs falling either long or short of the target, the CEP around the MPI will be smaller than the CEP around the target. If no bias exists, the CEP around the MPI and target will be the same.

A detailed discussion of the equations for CEP, REP, and DEP can be found in other documents. However, for the convenience of the reader, the following paragraphs provide a further explanation of these terms. **A** CEP value is equal **to** the radius of a circle with its center at the desired mean point of impact, containing one-half of the impact points of independently aimed bombs *or* one-half of the MPI's resulting from independent aiming operations. CEP is associated with a circular normal distribution having a standard deviation (sigma). It is a meaningful measure of accuracy if the impact

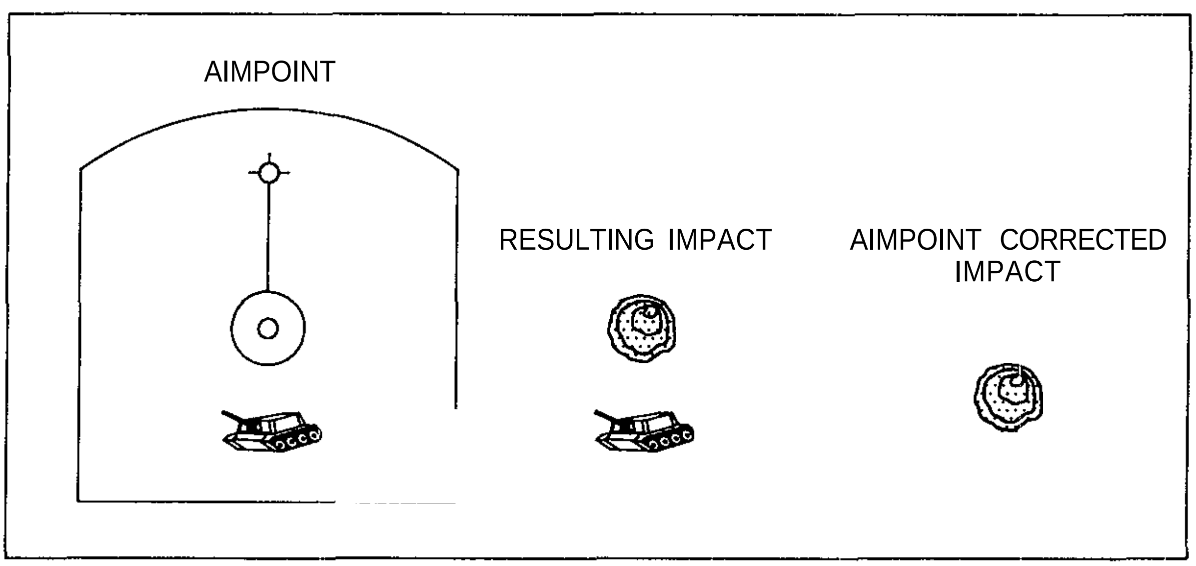


Figure *29.* Aimpoint-Correct4 Impacts

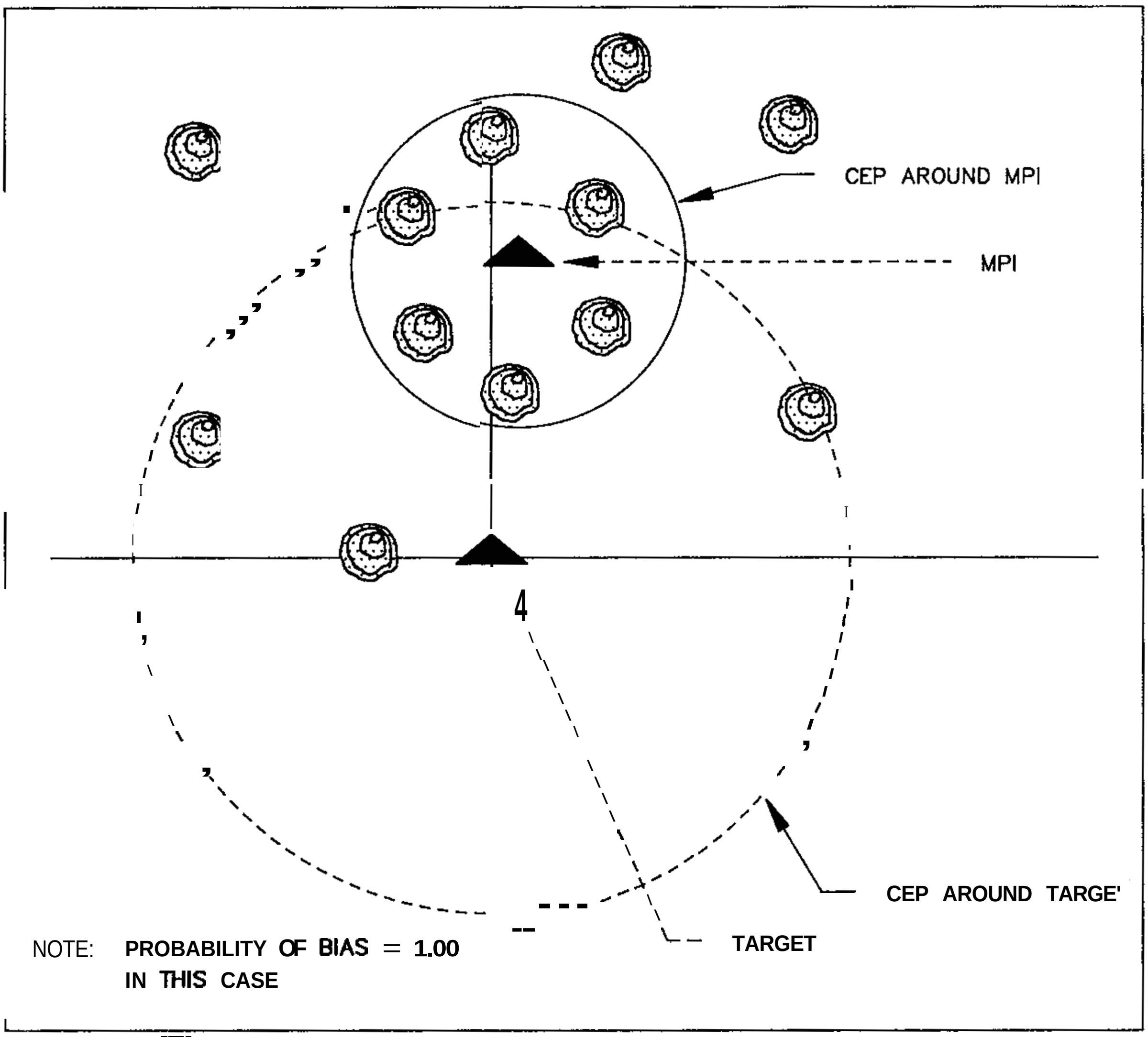


Figure 30. CEP Defined

group pattern is reasonably circular, at which time CEP = 1.774 sigma. As the group pattern becomes more elliptical, REP and DEP become more accurate descriptors of the pattern. A DEP value is equal to one-half the distance between two lines that are drawn parallel to the aircraft track, equidistant from the desired mean point of impact, and contain one-half the impact points or MPI's resulting from independent aiming operations. If the impact pattern is bivariate normal, as is usual, the delivery error standard deviation in deflection sigma is equal to 1.483 (DEP). Similarly, DEP = 0.6745 (sigma). REP is defined the same as DEP with the exception that its value is equal to one-half the distance between two lines that are drawn perpendicular to the aircraft track.

Many times a probability of bias is indicated by the grouping of impacts (aim points corrected) either long or short of the target. By assuming a binomial distribution, a bias evaluation can be accomplished. If the median is expected to be a certain point (for example, the target), then for any given sample, it would be expected that one-half of the bombs (aim-point-corrected) would impact long of the target and one-half would impact short if no bias were present. With the probability of long or short impacts equally being 50 percent, a binomial table (Table V) is used to evaluate bias. At Eglin, analysts use a bias criterion that is a combination of long or short impacts about the target, plus all worst-possible long or short possibilities that occur less than 10 percent of the time. Even though CEP, REP, and DEP, and if indicated, bias meas-

Table V. Ballistic Accuracy Without Separation-Effects Compensation

DATE	MSN NO	PASS	A/C	RACK POS	BOMB WT LBS	REL ALT MSL FT	REL MACH NO	REL ANG DEG	TRAJ ARC LENGTH FT	IMP ANG DEG	GROUND PLANE DELTA RANGE FT	GROUND PLANE DELTA DEFL FT	GROUND PLANE DELTA TIME SEC	NORMAL PLANE DELTA RANGE MILS	NORMAL PLANE DELTA DEFL MILS
8 MAY 86	4713	1	F-X	3 0	812.	3865.	0.74	0.1	12028.	35.61	-90.	30.	-0.14	-4.4	2.5
9 MAY 86	5008	2	F-X	7 0	813.	3918.	0.82	0.2	9007.	23.69	-139.	-17.	-0.24	-6.2	-1.9
9 MAY 86	5008	3	F-X	4 0	810.	3927.	0.82	0.1	9435.	24.82	-189.	22.	-0.30	-8.4	2.3
9 MAY 86	5008	4	F-X	6 0	812.	3910.	0.81	0.4	8956.	23.64	-247.	23.	-0.35	-11.0	2.5
12 MAY 86	1013	1	F-X	3 0	815.	3793.	0.73	0.0	8039.	25.31	-109.	-50.	-0.19	-5.8	-6.3
12 MAY 86	1013	2	F-X	7 0	809.	3803.	0.74	0.0	8030.	24.99	-116.	9.	-0.18	-6.1	1.2
12 MAY 86	1013	3	F-X	4 0	809.	3791.	0.73	0.0	8320.	26.18	-84.	-27.	-0.13	-4.5	-3.3
12 MAY 86	1013	4	F-X	6 0	815.	3791.	0.75	0.3	8227.	24.75	-174.	-20.	-0.28	-8.8	-2.5
14 MAY 86	3707	1	F-X	3 0	812.	4042.	0.93	-0.1	10778.	24.90	-1080.	56.	-1.10	-42.2	5.2
14 MAY 86	3707	2	F-X	7 0	811.	4050.	0.94	-0.1	10111.	23.01	-647.	32.	-0.74	-25.0	3.2
15 MAY 86	4014	1	F-X	3 0	817.	4890.	0.76	-14.9	6131.	30.50	-53.	0.	-0.07	-4.4	0.0
15 MAY 86	4014	2	F-X	7 0	814.	5004.	0.77	-19.1	6604.	35.01	-92.	-35.	-0.12	-8.0	-5.2
15 MAY 86	4014	3	F-X	4 0	813.	4769.	0.80	-18.7	7203.	35.02	-104.	-55.	-0.17	-8.3	-7.7
15 MAY 86	4014	4	F-X	6 0	817.	4997.	0.76	-23.3	6410.	38.08	-82.	13.	-0.10	-7.9	2.0
16 MAY 86	5015	1	F-X	4 0	813.	3964.	0.74	0.4	8801.	26.64	-69.	-61.	-0.13	-3.5	-6.9
22 MAY 86	4042	2	F-X	3 0	814.	5005.	0.82	-23.4	6853.	37.47	-7.	-52.	-0.03	-0.6	-7.6
22 MAY 86	4042	3	F-X	7 0	813.	4763.	0.82	-23.4	6690.	37.30	-51.	6.	-0.09	-4.6	0.8
22 MAY 86	4042	5	F-X	4 0	814.	4929.	0.84	-20.5	7046.	35.05	-126.	17.	-0.20	-10.3	2.4
22 MAY 86	4042	6	F-X	6 0	813.	4819.	0.85	-22.1	6998.	36.10	-31.	-1.	-0.08	-2.6	-0.1
23 MAY 86	5008	1	F-X	3 0	813.	5027.	0.90	-26.7	6967.	38.42	-55.	18.	-0.10	-4.9	2.6
23 MAY 86	5008	2	F-X	7 0	809.	4925.	0.92	-22.6	6527.	33.87	-113.	25.	-0.14	-9.6	3.8
23 MAY 86	5008	4	F-X	6 0	807.	5108.	0.95	-26.2	6988.	37.43	-86.	54.	-0.13	-7.4	7.7
27 MAY 86	2009	1	F-X	4 0	812.	3818.	0.74	0.3	8522.	24.89	-227.	11.	-0.30	-11.2	1.2
27 MAY 86	2009	2	F-X	6 0	811.	3740.	0.73	-0.1	8585.	26.01	-192.	73.	-0.24	-9.8	8.5
26 MAY 87	487	12	F-X	3 0	815.	4346.	0.81	-17.6	7026.	33.08	0.	-47.	-0.03	0.0	-6.6
26 MAY 87	487	13	F-X	7 0	815.	4259.	0.80	-19.6	6427.	33.62	-91.	43.	-0.14	-7.8	6.7
26 MAY 87	487	14	F-X	4 0	815.	4322.	0.80	-13.1	6215.	27.79	62.	-31.	0.04	4.6	-5.0
26 MAY 87	487	16	F-X	6 0	815.	4300.	0.81	-11.1	6435.	26.06	-177.	3.	-0.23	-12.1	0.5
9 JUN 87	1610	16	F-X	3 0	762.	1980.	0.91	-1.0	7456.	17.99	-490.	-38.	-0.58	-20.3	-5.1
9 JUN 87	1610		F-X	7 0	790.	2066.	0.90	-1.3	7525.	18.44	-450.	-28.	-0.54	-18.9	-3.7
10 JUN 87	1611	2	F-X	3 0	815.	4805.	0.78	-15.5	6522.	31.45	-81.	1.	-0.13	-6.5	0.1
10 JUN 87	1611	3	F-X	7 0	815.	4627.	0.80	-18.5	6632.	33.56	-14.	-5.	-0.06	-1.1	-0.7
10 JUN 87	1511	5	F-X	4 0	815.	4619.	0.80	-16.5	9717.	38.68	-72.	-47.	-0.10	-4.6	-4.8
10 JUN 87	1611		F-X	6 0	815.	5030.	0.77	-19.7	6387.	34.84	-30.	13.	-0.07	-2.7	2.0
22 JUL 87	5817	3	F-X	3 0	809.	5382.	0.81	-25.0	7027.	39.28	-168.	-43.	-0.20	-15.2	-6.1
22 JUL 87	5817	4	F-X	7 0	773.	5376.	0.75	-22.9	6007.	37.09	-143.	-41.	-0.18	-14.4	-6.8
22 JUL 87	5817	6	F-X	4 0	786.	4505.	0.79	-20.5	6865.	35.87	-136.	-38.	-0.20	-11.6	-5.6
22 JUL 87	5817	7	F-X	6 0	771.	4639.	0.79	-23.6	6186.	37.07	-102.	-2.	-0.15	-9.9	-0.3
24 AUG 87	47	5	F-X	7 0	771.	5152.	0.75	-19.9	6155.	33.56	96.	5.	0.38	8.6	0.9
24 AUG 87	47	6	F-X	4 0	798.	4923.	0.77	-20.6	6471.	34.20	-88.	-50.	0.19	-7.7	-7.7
10 SEP 87	1866	I	F-X	3 0	789.	4816.	0.81	-23.3	6432.	36.94	-72.	-15.	-0.09	-6.7	-2.3
10 SEP 87	1866	4	F-X	7 0	768.	5194.	0.76	-18.0	6032.	33.11	-129.	-10.	-0.16	-11.6	-1.6
18 SEP 87	2447	2	F-X	4 0	770.	4313.	0.78	-23.3	6612.	38.24	-24.	-22.	-0.08	-2.3	-3.4
18 SEP 87	2447	4	F-X	6 0	766.	4650.	0.79	-20.7	6522.	35.79	-94.	-14.	-0.15	-8.5	-2.1
						AVERAGE (N =	44)		7452.4		-144.7	-6.7	-0.18	-8.3	-1.1
						PE (FT)					131.7	22.2		5.3	2.9
						CEP (FT)					134.3				
						CEP (MILS)								7.2	

urements provide the insight necessary to plan effective missions, further insight can be gained into the causes of biases and dispersions by examining other data sources. PDAS data provides a look at what the aircraft is "thinking" at the time of weapon release. Factors such as airspeed, altitudes, system altitude and CADC altitude, dive angles, g loadings, and release times can be examined. If TSPI is available, these PDAS parameters can be compared with their equivalent TSPI parameters. TSPI gathered at the time of OFP testing can also be used in subsequent separation-effects analysis. Considerable time and money can be saved by wisely planning initial OFP testing to provide data for other analyses as well.

In the beginning of this volume, the potential for reducing ballistic errors was discussed. This discussion was based on the results of a theoretical sensitivity analysis using a 3DOF mathematical model. Additional sensitivity analyses have been performed using a state-of-the-art 6DOF mathematical model (Reference 18). The results indicate that the CEP for CBU-58 and MK 84 LDGP stores should be less than 6.9 and 2.3, respectively, when proper attention is given to compensating for (modeling) such factors as separation effects and ejector free. Appendix D provides a brief summary of these analyses for easy reference.

9.5 Actual Results of Freestream and Separation-Effects Analysis

Table VI presents a summary of actual flight test results for the accuracy of one 800-pound-class bomb in one loadout configuration released from an aircraft without any separation-effects compensation. Data in this table have been corrected for aim-point errors as necessary. Thus, if the pilot placed the pipper on the target, he could expect a bomb to hit 144.7 feet short of the target with a CEP of 134.3 feet. This is an average value over the range of flight test conditions (that is, range of release angles and Mach numbers).

Table VI presents a summary of predicted ballistic accuracy for the same missions using store freestream drag only. That is, separation effects were removed from the data using the procedures previously described. Ideally, if separation effects could be precisely modeled in the aircraft OFP, the pilot could expect a bomb to hit 4.6 feet short of the target with a CEP of 25.6 feet.

Table VII presents a summary of predicted ballistic accuracy with separation-effects modeling using the procedures previously described. In this case, separation effects were modeled into an equation for input to the aircraft OFP. Using this model, coupled with store freestream trajectory data, the pilot could expect a bomb to hit 4.2 feet long of the target with a CEP of 67.2 feet. The delta range is different, and the CEP is larger than the ideal values because the model optimized separation effects across a range of flight conditions.

9.6 Guided Weapons Analysis

The development of guided weapons simulation theory and analysis is beyond the scope of this volume. However, some of the major considerations should be identified. In the case of guided weapons, instead of working with a 3DOF simulation model and time-correlated position and velocity data, 6DOF is utilized to account for roll, pitch, and yaw over and above the point mass three-dimensional equations. For example, assume a short impact results at an actual test condition. Several variables could cause the problem; for example, the theoretical or predicated lift for the weapon could be greater than the actual, or the drag coefficient could be greater than the wind tunnel prediction. In the case of airborne illumination or designation of the target, the centroid of reflective energy could be short of the target and the weapon was really guiding to the short-connect point. All of these are major concerns which must be evaluated analytically in developing the final simulation model for use in operational employment for guided weapons. No one set of rules is available by which a guided weapon simulation analysis should be conducted. Rather, it is a subjective evaluation by the experienced analyst or engineer that must be incorporated into the final evaluation of the aerodynamic simulation model. Some of the general rules and guidelines for the data requirements for the analysis will be identified in subsequent paragraphs. For evaluating the guided weapons simulation model, several sources show the methods used in the past. Specifically, References 21, 22, and 23 contain detailed procedures that have been applied to guided munition simulation and analysis in the past.

With reference to guided weapons, testing occurs at two primary times within the system development phase. The first occurs throughout developmental test and evaluation. In this case, the specif-

Table VI. Ballistic Accuracy With Freestream Store Data

DATE	MSN NO	PASS	A/C	RACK POS	BOMB WT LBS	REL ALT MSL FT	REL MACH NO	REL ANG DEG	TRAJ ARC LENGTH FT	IMP ANG DEG	GROUND PLANE DELTA RANGE FT	GROUND PLANE DELTA DEFL FT	DELTA TIME SEC	NORMAL PLANE DELTA RANGE MILS	NORMAL PLANE DELTA DEFL MILS
8 MAY 86	4713	1	F-X			3780.	0.71	-5.2	10290.	35.54	13.	21.	0.03	0.8	2.0
S MAY 86	5008	2	F-X			3832.	0.78	-4.8	7049.	23.55	11.	6.	-0.01	0.6	0.9
9 MAY 86	5008	3	F-X			3833.	0.78	-5.0	7423.	24.69	11.	5.	-0.02	0.6	0.7
9 MAY 86	5008	4	F-X			3828.	0.77	-4.8	6947.	23.55	-25.	16.	-0.05	-1.4	2.2
12 MAY 86	1013	1	F-X			3710.	0.71	-5.2	6373.	25.22	-46.	-32.	-0.07	-3.1	-5.0
12 MAY 86	1013	2	F-X			3717.	0.71	-5.4	6314.	24.92	-13.	15.	-0.01	-0.9	2.4
12 MAY 86	1013	3	F-X			3703.	0.70	-5.3	6636.	26.12	-2.	-12.	-0.01	-0.1	-0.3
12 MAY 86	1013	4	F-X			3706.	0.72	-5.3	6388.	24.66	30.			1.9	-2.3
14 MAY 86	3707	1	F-X			3898.	0.84	-6.5	7745.	25.11	-8.	-1.	-0.02	-0.4	-0.2
14 MAY 86	3707	2	F-X			3929.	0.86	-5.7	7423.	22.97	34.	1.	0.02	1.8	0.2
15 MAY 86	4014	1	F-X			4387.	0.75	-19.7	4396.	30.59	-2.			-0.3	1.3
15 MAY 86	4014	2	F-X			4381.	0.76	-24.0	4837.	35.22	-16.	-36.	-0.03	-1.9	-7.2
15 MAY 86	4014	3	F-X			4129.	0.79	-23.5	5338.	35.20	-4.	-26.	-0.03	-0.4	-4.9
15 MAY 86	4014	4	F-X			4261.	0.76	-28.1	4640.	38.35	3.	-7.	0.00	0.4	-1.6
16 MAY 86	5015	1	F-X			3885.	0.72	-5.0	7053.	26.54	43.	-30.	0.05	2.7	-4.3
22 MAY 86	4042	2	F-X			4228.	0.81	-27.5	5025.	37.50	6.	-33.	-0.02	0.7	-6.5
22 MAY 86	4042	3	F-X			3980.	0.81	-27.8	4823.	37.46	7.			0.9	1.1
22 MAY 86	4042	5	F-X			4198.	0.82	-25.2	5070.	35.32	0.	16.	-0.03	0.0	2.2
22 MAY 86	4042	6	F-X			4048.	0.83	-26.3	5075.	36.19	20.	0.	-0.01	2.3	0.0
23 MAY 86	5008	1	F-X			4057.	0.87	-30.6	4915.	38.63	21.			2.7	0.1
23 MAY 86	5008	2	F-X			4068.	0.88	-26.6	4429.	34.13	-23.	6.	-0.04	-2.9	1.4
23 MAY 86	5008	4	F-X			4112.	0.90	-30.1	4844.	37.67	4.	-5.	-0.03	0.5	-1.1
27 MAY 86	2009	1	F-X			3732.	0.71	-5.1	6690.	24.83	-10.	47.	-0.08	-0.6	2.6
27 MAY 86	2009	2	F-X			3641.	0.70	-5.7	6755.	25.96	47.			3.1	6.4
26 MAY 87	487	12	F-X			4054.	0.80	-19.9	6121.	33.06	6.	-21.	-0.02	0.6	-3.5
26 MAY 87	487	13	F-X			3934.	0.79	-22.3	5452.	33.81	-1.	30.	-0.03	-0.1	5.5
26 MAY 87	487	14	F-X			4104.	0.79	-15.2	5398.	27.62	-15.	3.	-0.03	-1.3	0.5
26 MAY 87	487	16	F-X			4095.	0.80	-13.9	5404.	26.22	-43.	11.	-0.06	-3.5	2.0
9 JUN 87	1610	15	F-X			1924.	0.87	-4.5	5948.	18.02	8.	-2.	-0.01	0.4	-0.3
9 JUN 87	1610	16	F-X			2005.	0.86	-4.7	6072.	18.47	0.	-9.	-0.03	0.0	-1.4
10 JUN 87	1611	2	F-X			4553.	0.77	-18.3	5582.	31.53	-8.	-7.	-0.01	-0.8	0.3
10 JUN 87	1611	3	F-X			4329.	0.79	-21.0	5706.	33.57	16.			1.6	-1.2
10 JUN 87	1611	5	F-X			4348.	0.78	-19.2	8750.	38.78	9.	-32.	-0.01	0.7	-3.7
10 JUN 87	1611	7	F-X			4726.	0.76	-22.1	5512.	34.83	-15.	-13.	-0.05	-1.5	-2.4
22 JUL 87	5817	3	F-X			4980.	0.80	-27.9	6019.	39.65	-44.	-40.	-0.06	-4.6	-6.6
22 JUL 87	5817	4	F-X			5030.	0.74	-25.8	5094.	37.36	-57.	-40.	-0.07	-6.8	-7.8
22 JUL 87	5817	6	F-X			4171.	0.78	-23.6	5865.	36.18	-6.	-25.	-0.04	-0.6	-4.2
22 JUL 87	5817	7	F-X			4263.	0.78	-26.5	5209.	37.41	8.	-9.	-0.03	0.9	-1.6
24 AUG 87	47	5	F-X			4855.	0.75	-21.4	5428.	33.21	-43.	-2.	0.18	-4.4	-0.4
24 AUG 87	47	6	F-X			4598.	0.76	-23.1	5547.	34.48	-27.	-15.	0.19	-2.7	-2.7
10 SEP 87	1866	1	F-X			4440.	0.80	-25.8	5466.	37.14	-7.	31.	-0.05	-0.8	5.7
10 SEP 87	1866	4	F-X			4912.	0.75	-20.9	5106.	33.31	-50.	-22.	-0.08	-5.4	-4.3
18 SEP 87	2447	2	F-X			3956.	0.78	-25.8	5719.	38.23	-6.	-8.	-0.04	-0.7	-1.3
18 SEP 87	2447	4	F-X			4323.	0.78	-23.4	5582.	35.93	-28.	-26.	-0.06	-2.9	-4.6
						AVERAGE (N = 44)			5942.2		-4.6	-5.1	-0.01	-0.6	-1.0
						PE (FT)					16.1	13.2		1.5	2.3
						CEP (FT)					25.6				
						CEP (MILS)								3.3	

Table VII. Ballistic Accuracy With Separation-Effects Compensation

DATE	MSN NO	PASS	A/C	RACK POS	BOMB WT LBS	REL ALT MSL FT	REL MACH NO	REL ANG DEG	TRAJ ARC LENGTH FT	IMP ANG DEG	GROUND PLANE DELTA RANGE FT	GROUND PLANE DELTA DEFL FT	GROUND PLANE DELTA TIME SEC	NORMAL PLANE DELTA RANGE MILS	NORMAL PLANE DELTA DEFL MILS
8 MAY 86	4713	1	F-X	3 0	812.	3865.	0.74	0.1	11900.	35.53	37.	31.	0.06	1.8	2.6
9 MAY 86	5008	2	F-X	7 0	813.	3918.	0.82	0.2	8797.	23.58	66.	-17.	0.04	3.0	-1.9
9 MAY 86	5008	3	F-X	4 0	810.	3927.	0.82	0.1	9208.	24.71	32.	23.	0.00	1.5	2.5
9 MAY 86	5008	4	F-X	6 0	812.	3910.	0.81	0.4	8758.	23.52	-53.	24.	-0.08	-2.4	2.7
12 MAY 86	1013	1	F-X	3 0	815.	3793.	0.73	0.0	7893.	25.27	37.	-51.	0.01	2.0	-6.4
12 MAY 86	1013	2	F-X	7 0	809.	3803.	0.74	0.0	7895.	24.93	18.	9.	0.02	1.0	1.2
12 MAY 86	1013	3	F-X	4 0	809.	3791.	0.73	0.0	8179.	26.13	57.	-28.	0.07	3.0	-3.4
12 MAY 86	1013	4	F-X	6 0	815.	3791.	0.75	0.3	8098.	24.66	-45.	-20.	-0.09	-2.3	-2.5
14 MAY 86	3707	1	F-X	3 0	812.	4042.	0.93	-0.1	9969.	24.89	-280.	49.	-0.25	-11.8	4.9
14 MAY 86	3707	2	F-X	7 0	811.	4050.	0.94	-0.1	9240.	23.01	214.	24.	0.16	9.1	2.7
15 MAY 86	4014	1	F-X	3 0	817.	4890.	0.76	-14.9	6068.	30.56	14.	0.	0.05	1.2	0.0
15 MAY 86	4014	2	F-X	7 0	814.	5004.	0.77	-19.1	6549.	35.10	-32.	-35.	-0.01	-2.8	-5.3
15 MAY 86	4014	3	F-X	4 0	813.	4769.	0.80	-18.7	7137.	35.11	-32.	-55.	-0.04	-2.6	-7.8
15 MAY 86	4014	4	F-X	6 0	817.	4997.	0.76	-23.3	6362.	38.20	-27.	13.	-0.01	-2.6	2.0
16 MAY 86	5015	1	F-X	4 0	813.	3964.	0.74	0.4	8663.	26.57	67.	-62.	0.07	3.4	-7.1
22 MAY 86	4042	2	F-X	3 0	814.	5005.	0.82	-23.4	6796.	37.62	58.	-52.	0.07	5.2	-7.6
22 MAY 86	4042	3	F-X	7 0	813.	4763.	0.82	-23.4	6633.	37.46	13.	6.	0.00	1.2	0.9
22 MAY 86	4042	5	F-X	4 0	814.	4929.	0.84	-20.5	6977.	35.21	-50.	17.	-0.10	-4.1	2.5
22 MAY 86	4042	6	F-X	6 0	813.	4819.	0.85	-22.1	6929.	36.28	46.	-1.	0.02	4.0	-0.1
23 MAY 86	5008	1	F-X	3 0	813.	5027.	0.90	-26.7	6891.	38.72	37.	18.	-0.01	3.3	2.6
23 MAY 86	5008	2	F-X	7 0	809.	4925.	0.92	-22.6	6440.	34.17	-12.	24.	-0.04	-1.1	3.8
23 MAY 86	5008	4	F-X	6 0	807.	5108.	0.95	-26.2	6881.	37.88	44.	54.	-0.03	3.9	7.8
27 MAY 86	2009	1	F-X	4 0	812.	3818.	0.74	0.3	8387.	24.82	-86.	9.	-0.10	-4.3	1.1
27 MAY 86	2009	2	F-X	6 0	811.	3740.	0.73	-0.1	8439.	25.97	-42.	72.	-0.04	-2.2	8.5
26 MAY 87	487	12	F-X	3 0	815.	4346.	0.81	-17.6	6962.	33.18	72.	-47.	0.08	5.6	-6.7
26 MAY 87	487	13	F-X	7 0	815.	4259.	0.80	-19.6	6371.	33.74	-27.	43.	-0.04	-2.4	6.8
26 MAY 87	487	14	F-X	4 0	815.	4322.	0.80	-13.1	6146.	27.87	136.	-31.	0.16	10.3	-5.0
26 MAY 87	487	16	F-X	6 0	815.	4300.	0.81	-11.1	6356.	26.13	-93.	4.	-0.10	-6.4	0.6
9 JUN 87	1610	15	F-X	3 0	762.	1980.	0.91	-1.0	6855.	18.07	106.	-36.	0.05	4.8	-5.2
9 JUN 87	1610	16	F-X	7 0	790.	2066.	0.90	-1.3	6966.	18.54	106.	-26.	0.05	4.8	-3.7
10 JUN 87	1611	2	F-X	3 0	815.	4805.	0.78	-15.5	6462.	31.54	-18.	1.	-0.03	-1.5	0.1
10 JUN 87	1611	3	F-X	7 0	815.	4627.	0.80	-18.5	6568.	33.70	55.	-5.	0.03	4.7	-0.7
10 JUN 87	1611	5	F-X	4 0	815.	4619.	0.80	-16.5	9644.	38.74	6.	-47.	0.02	0.4	-4.9
10 JUN 87	1611	7	F-X	6 0	815.	5030.	0.77	-19.7	6334.	34.96	28.	13.	0.02	2.5	2.0
22 JUL 87	5817	3	F-X	3 0	809.	5382.	0.81	-25.0	6973.	39.44	-105.	-43.	-0.11	-9.6	-6.1
22 JUL 87	5817	4	F-X	7 0	773.	5376.	0.75	-22.9	5963.	37.22	-92.	-41.	-0.10	-9.3	-6.8
22 JUL 87	5817	6	F-X	4 0	786.	4505.	0.79	-20.5	6811.	35.99	-75.	-38.	-0.11	-6.5	-5.6
22 JUL 87	5817	7	F-X	6 0	771.	4639.	0.79	-23.6	6137.	37.23	-45.	-2.	-0.07	-4.4	-0.3
24 AUG 87	47	5	F-X	7 0	771.	5152.	0.75	-19.9	6103.	33.69	156.	5.	0.48	14.1	0.9
24 AUG 87	47	6	F-X	4 0	798.	4923.	0.77	-20.6	6415.	34.32	-25.	-50.	0.30	-2.2	-7.7
10 SEP 87	1866	1	F-X	3 0	789.	4816.	0.81	-23.3	6374.	37.10	-6.	-15.	0.01	-0.6	-2.3
10 SEP 87	1866	4	F-X	7 0	768.	5194.	0.76	-18.0	5979.	33.20	-71.	-10.	-0.06	-6.5	-1.6
18 SEP 87	2447	2	F-X	4 0	770.	4313.	0.78	-23.3	6561.	38.36	33.	-22.	0.01	3.1	-3.4
18 SEP 87	2447	4	F-X	6 0	766.	4650.	0.79	-20.7	6468.	35.90	-35.	-14.	-0.05	-3.1	-2.2
						AVERAGE (N =		44)	7307.6		4.2	-6.9	0.01	0.1	-1.1
						PE (FT)					55.2	21.8		3.5	2.9
						CEP (FT)					67.2				
						CEP (MILS)								5.6	

ic performance is evaluated against requirements for the weapon as specified in the developmental contract. The concern is with questions such as:

(1) Is the seeker head responding to the specified designator sensitivity requirements?
(2) Is the guidance and control unit responding in a manner appropriate to give maximum required design limits?
(3) Are actuator control points receiving sufficient energy?
(4) Is enough force available for control unit deflection movement throughout the flight profile?

During Development Test and Evaluation, care should be taken that a source for target designation is available. In this case, the designator or target illuminator should be a ground-based system. In addition to the target illuminator, the target area should be adequately covered with a detector to locate the centroid of reflective energy or target contrast. In all cases, guided weapons are designed to guide or maneuver to the center of contrast or of reflected energy. Without real-time measurement during the mission, questions will always be raised about designation operations position. Concerns always exist when a target miss occurs about whether the problem is within the weapon system or the energy source to which it is guiding. Since the designator's energy travels in a straight-line path, during testing it is better to have the orientation of the designator and the detector along the expected flight path or impact angle of the weapon. This orientation will assure that the centroid of reflective energy is equivalent to that seen by the weapon. With DT&E testing, the target will generally be elevated normal to the intended flight path angle; therefore, only a minimum detector area must be covered. However, during an operational test and evaluation, the entire weapon system is being evaluated, including the target illuminator source. Therefore, a wide-area target detector must be employed to ensure the centroid of reflective energy is recorded. Specifically, for a long-range designation for a laser designator, if even 5 percent of the energy source should spill over the intended target, a high probability exists that the centroid of the energy would be that area which is eliminated with a grass or other media surface. During operational evaluations, additional care must be taken to assure that the total possible illuminated surface can be identified and the center of reflectivity monitored. For example, with a monochromatic energy source, a small evaluation in the impact area surface can have a significant effect on the reflected energy. Specifically, in lasing a concrete runway, a 1- to 2-inch crack that gives a vertical development in the target would definitely reflect more laser energy than the general flat surface. Because the energy tends to reflect along an angle equal to the incidence angle, the energy reflects downrange from the energy source.

Within the weapon, the position of any moving part, the input/output of any transputer, and the exact orientation and location of any vector should be measured accurately. These measurements will generally require a telemetry package designed to ensure that the moments, center-of-gravity, and weight of the inert dummy bomb casing remains within design limits of the parent warhead. For most guided weapons, these measurements are broken into three distinct component areas: the seeker, the computer, and the canard or fin guidance control surfaces.

In the case of the **seeker,** its exact position relative to the bomb-body axis in roll, pitch, and yaw must be measured. This measurement allows for evaluation of the target detecting system to ensure that adequate guidance commands are processed for the guidance and control transputers. In addition to the attitude or orientation of the seeker, the centroid of reflected energy as seen by the weapon must be identified and recorded. This action will allow for evaluation of the control signal inputs into the computational portion of the guidance and control system. For example, if, based upon the telemetry data from the seeker, the target appeared in the lower half of the detector assembly for some period of time and the canards deflected to give a pitch-up command, then major problems exist between the seeker detector data processing and the canard deflection computer outputs. In this case, the real or correct weapon maneuver would be a pitch-down maneuver, which would center the reflected energy to the center of the detector screen. This action would have identified a problem, and, by evaluation of the computational computer within the system, one should be able to isolate more exactly the cause of a miss.

The second general area is the bomb-body axis orientation. Accurate measurement/evaluation of these vector space variables must be identified. This main axis system has all the aerodynamic coefficients and induced aerodynamic coefficients which are applied to simulate the aerodynamic characteristics of the weapon itself. An extreme example would be if a bomb body or a weapon body flew with a 15-degree angle of attack in a free steady-state flight. Then the induced drag due to angle of attack would be equal to; or greater than, the freestream aerodynamic drag for the clean body flying with zero-degree angle of attack. This type of aerodynamic characteristics will have drastic impact on such parameters as maximum range, weapon effectiveness, and impact velocity. These last two parameters are major concerns when evaluating total system design. For example, if the weapon is to be employed against a non-vertically developed target and the critical angle of ricochet is 15 degrees, then the 15-degree angle of attack requires that the airfoil group be given a dive direction prior to weapon impact. Otherwise, the weapon will ricochet, creating either minor damage or no damage. If the kinetic energy of the warhead is degraded significantly, the warhead becomes of minimum value against hardened targets. For instance, if the intended target array were covered by 4 feet of reinforced concrete but the weapon only retained sufficient energy to penetrate 2 feet of concrete, then the weapon would be without utility in this particular scenario.

The third general area is the airfoil or airfoil actuation measurement requirements. The internal kinetic energy within the guided system should be measured along with the actual control surface movement. In evaluating guided weapons, one should not assume that control surface movement will occur because direction to deflect to maneuver has been generated by the computer system itself. For example, a full pitchdown command may be given by the computer processing; however, if the pressure available for canard deflection is such that aerodynamic loading will not allow for deflection, then the canard will deflect so that the internal pressure is equal to the aerodynamic pressure on the canard. Additionally, the actual control surface deflection must be measured to evaluate the accuracy of the wind-tunnel-collected aerodynamic data. Aerodynamic influence of control surface deflection is usually measured in given increments by deflecting the control surfaces a predetermined angular amount and evaluating the induced roll, pitch, yaw, and drag faces due to canard deflections. The control surfaces would then be set at a different angle and the process repeated. By measuring the exact angular orientation during tests, non-linear trends between wind tunnel data points might be identified and corrected.

In summary, attempting *to* relate point mass ballistic analysis and simulation to guided simulation analysis is a major injustice to system evaluation. In ballistic analysis, primary concern is with the basic principles of physics relating to $F=ma$. However, in the case of 6DOF or guided weapons simulations, the concern is with a multitude of complex mathematical and engineering disciplines. To understand the total system concept, a full awareness is required of:

(1) the detector system principles relating to the electronics engineering discipline
(2) the computational capabilities of computer systems
(3) the aeromechanic, aerodynamic, and aeroengineering principles related to aeroelastic and freestream body mechanics.

In the development of a test plan to evaluate guided weapons, careful attention must be given to test measurements. Without accurate, precise, and time-correlated measurements of all possible parameters, major problems can be anticipated in trying to identify system performance, especially in trying to extrapolate and interpolate performance characteristics to conditions that will be a primary concern to the operational commands.

10.0 APPLICATION OF ANALYSIS/TEST RESULTS

10.1 Presentation of Results in Dash 25 and Dash 34 Series Technical Orders

Based on results of analysis/tests, ballistics tables are prepared for inclusion in technical orders (To's). In the USAF, there are Dash 34 Series To's for nonnuclear stores and Dash 25 Series To's for nuclear stores. The information presented in these To's provides aircrews with the technical data necessary to plan for weapons delivery.

Ballistic tables are developed for specific aircraft, weapon loadouts, and delivery modes using the validated freestream store drag and separation-effects databases. The ballistics for each weapon, together with the specific aircraft aerodynamic characteristics, are calculated on a mainframe computer for all required combat operations. Using mathematical models described earlier, calculations are made for bomb range, bomb time of fall, slant range, impact angle, sight depression, and wind correction factors as dictated by type of delivery, weapon, aircraft, and specific user needs. The ballistic tables are based on International Civil

Aviation Organization (ICAO) standard day conditions. Variations from the standard day are considered to have negligible effects on trajectory accuracy due to the usually short time of flight of weapons when released in level and dive modes at low/medium altitudes. However, since lofted weapons generally have longer times of flight, consideration of target density altitude is important for calculating accurate ballistic trajectory data. Table VIII is a typical presentation of ballistic tables as published in — 34 To's for the MK 84 Air Inflatable Retarder (low drag mode) released in the loft mode. Table IX presents ballistic tables for the same store released in the dive mode.

To effectively plan a mission to deliver weapons, consideration must also be given to safe escape, safe separation, vertical drop required for fuze arming, and the altitude lost during dive recovery. The lowest release altitude that provides the delivery aircraft with acceptable protection from weapon fragmentation is known as the safe escape value. This value is determined through computer analyses of weapon fragmentation envelopes when related to specified delivery profiles and specific escape maneuvers of the delivery aircraft. These values are based on normal functioning of weapons with detonation at ground impact (except for CBU's). In the case of CBU's, safe escape values are based on failure of the canister to open and detonation of the intact cluster at ground impact. The values presented in safe escape charts are based on various probabilities of hit. In the USAF, a probability of hit of less than, or equal to, 0.001 per pass is frequently used.

Safe separation values correspond to the minimum detonation times after release that provide the delivery aircraft with acceptable protection from early weapon detonation (airbursts). These values differ from safe escape values that deal with ground bursts. Safe separation requirements must be met when delivering proximity-fuzed, general-purpose bombs and CBU's with specific function times. Safe separation need not be considered for impact-fuzed, general-purpose bombs because of the small likelihood of early detonation at fuze arming. Safe separation requirements are met by using minimum fuze arming times that provide sufficient aircraft-to-weapon separation prior to the fuze arming.

Safe escape/safe separation charts provide safe escape/safe separation and vertical drop data required for fuze arming for various weapons and fuze combinations, delivery parameters, and escape maneuvers. These charts include time of fall, minimum release altitudes for safe escape, and vertical drop values required for fuze arming values. Time-of-fall values are the minimum times for release at which a weapon can detonate and satisfy the safe separation criteria. Minimum release altitude values represent the minimum altitude for release of a particular munition to ensure criteria for safe escape are satisfied. Vertical drop required for fuze arming values is based on all delays that affect *fuze* arming (wiring, retardation-device opening times, inherent *fuze* delays, and the positive tolerances on arming times). Table X shows a typical safe-escape chart as presented in Dash 34 Series TO's.

Dash 34 Series TO's can be quite voluminous for aircraft that are authorized to carry a wide variety of stores. The length of ballistic tables alone can be several hundred pages. In addition, the need for supporting information such as a description of the aircraft weapon delivery system, a description of the stores themselves, and safe escape data makes the *size* of Dash 34 To's for each aircraft quite large. In an effort to streamline and simplify the presentation of data for aircrews, a Dash 34 Standard Volume (SV) has recently be developed (Reference 19). The SV contains all of the generic, non-aircraft-specific information that aircrews need to plan their missions. For example, the SV contains needed information for all stores. Thus, the information for each store need not be repeated in each aircraft-specific Dash 34 TO. With the introduction of the SV, the Dash 34 TO for each aircraft need only contain the information that is unique for each aircraft.

10.2 Joint Munition Effectiveness Manuals (JMEM's)

JMEM are joint service authenticated weaponing manuals which present evaluations of the effectiveness of conventional weapons against selected targets. Also discussed are weapon characteristics, target vulnerability, delivery accuracy, methodology, reliability, and air-combat maneuvering with emphasis on weapons currently in inventory. Data is also included on some weapons which are programmed for future use. Use of these manuals is essential to ensure proper mission planning. JMEM's are divided into three categories of weapon applications. The major categories are: Air-to-Surface (61A1 Series), Anti-War (61B1 Series), and Surface-to-Surface (61S1 Series).

Table VIII. Ballistic Tables for MK 82 AIR (Low Drag) Released from an Aircraft in Loft Mode

45000 LBS GROSS WEIGHT

TGT DEN ALT	APPROACH ALT	APPROACH TAS	RELEASE ANG	RELEASE ALT	TIME PULL-UP TO REL	REL ATT	RANGE PULL-UP TO IMP	IMP PNG	TIME REL TO IMP	RANGE REL TO IMP	WIND CORR FACTORS H/T	WIND CORR FACTORS CROSS CRAB
FT	FT	KTS	DEG	FT	SEC	OEG	FT	DEG	SEC	FT	FT/KT	
0	200	500	10	328	2.5	14.8	9712	15	9.85	7588	21	1
			15	464	3.3	19.9	13004	21	14.02	10265	29	2
			20	650	4.0	25.0	15860	27	18.14	12533	37	3
			25	878	4.7	30.2	18188	34	22.07	14308	45	4
			30	1145	5.5	35.4	19961	40	25.76	15568	53	6
			35	1442	6.1	40.6	21172	46	29.16	16313	60	6
			40	1763	6.8	45.9	21832	51	32.25	16554	66	7
			45	2101	7.5	51.2	21966	56	35.01	16319	72	7
		550	10	350	2.7	13.9	11291	14	10.62	8826	22	1
			15	513	3.5	19.0	15116	21	15.19	11916	32	3
			20	733	4.3	24.1	18385	28	19.64	14486	40	4
			25	1005	5.1	29.3	21028	34	23.88	16473	49	6
			30	1320	5.9	34.5	23030	41	27.83	17969	57	7
			35	1671	6.6	39.7	24396	47	31.48	18683	64	8
			40	2049	7.3	45.0	25141	52	34.79	19935	71	9
			45	2448	8.0	50.2	25296	57	37.76	18655	77	9
		600	10	372	2.8	13.0	12823	14	11.33	10016	24	2
			15	561	3.7	18.1	17110	21	16.22	13451	34	3
			20	815	4.6	23.3	20718	28	20.95	16253	43	5
			25	1126	5.4	28.5	23610	35	25.41	18392	52	7
			30	1486	6.2	33.7	25792	41	29.58	19882	60	8
			35	1886	7.0	39.0	27281	47	33.42	20742	68	9
			40	2317	7.8	44.3	28094	53	36.91	20994	75	10
			45	2768	8.6	49.6	28260	58	40.03	20667	82	10
		650	10	392	2.9	12.8	14089	15	11.88	10968	25	2
			15	601	3.9	17.8	18674	21	16.98	14607	35	4
			20	881	4.8	22.9	22483	29	21.87	17529	45	5
			25	1221	5.7	28.0	25522	36	26.48	19745	54	7
			30	1614	6.5	33.2	27808	42	30.77	21276	63	9
			35	2048	7.3	38.5	29361	48	34.71	22146	71	10
			40	2515	8.2	43.7	30210	53	38.30	22387	78	11
			45	3004	8.9	49.1	30379	58	41.52	22022	85	11
	300	450	10	407	2.4	16.0	8561	16	9.61	6758	20	1
			15	519	3.1	21.1	11208	22	13.24	8901	28	2
			20	671	3.7	26.3	13558	28	16.90	10770	35	3
			25	858	4.4	31.4	15497	34	20.43	12256	42	4
			30	1076	5.0	36.7	16975	40	23.75	13314	49	4
			35	1320	5.7	41.9	17980	45	26.83	13935	55	5
			40	1584	6.3	47.2	18515	51	29.63	14128	61	5
			45	1861	6.8	52.6	18596	56	32.12	13906	66	5
		500	10	428	2.5	14.8	10082	16	10.36	7958	22	1
			15	564	3.3	19.9	13267	22	14.42	10527	30	2
			20	749	4.0	25.1	16056	28	18.46	12729	38	3
			25	978	4.7	30.2	18342	34	22.34	14462	46	5
			30	1245	5.5	35.4	20085	40	25.99	15693	53	6
			35	1542	6.1	40.6	21274	46	29.37	16416	60	6
			40	1863	6.8	45.9	21918	52	32.44	16640	66	7
			45	2201	7.5	51.2	22038	56	35.19	16391	72	7

Table PX. Ballistic Tables for MK 82 AIR (Low Drag) Released from an Aircraft in Dive Mode

DIVE ANG DEG	RELEASE ALT ABOVE TGT FT	RELEASE TAS KTS	BOMB RANGE FT	TIME OF FALL SEC	SLANT RANGE FT	IMPACT ANGLE DEG	SDFP DEP/ADJ MILS	WIND CORRECTION FACTORS H/T MILS/KT	WIND CORRECTION FACTORS CROSS DRIFT FT/KT
5	500	450	2622	3.57	2670	15	104/1.7	.4	6
		500	2808	3.44	2853	14	91/1.6	.4	6
		550	2980	3.33	3021	13	81/1.5	.3	6
		600	3137	3.22	3177	12	73/1.4	.3	5
		650	3281	3.12	3319	11	66/1.3	.2	5
5	600	450	2978	4.07	3038	16	114/1.7	.5	7
		500	3197	3.94	3253	15	100/1.6	.4	7
		550	3400	3.81	3453	14	89/1.5	.3	6
		600	3588	3.70	3638	13	80/1.4	.3	6
		650	3760	3.59	3808	12	73/1.3	.3	6
5	700	450	3308	4.53	3381	17	123/1.6	.5	8
		500	3559	4.40	3627	16	109/1.5	.4	7
		550	3792	4.27	3856	15	97/1.4	.3	7
		600	4008	4.15	4069	14	87/1.3	.3	7
		650	4208	4.04	4266	13	79/1.2	.3	7
5	800	450	3617	4.97	3704	18	132/1.6	.5	8
		500	3897	4.83	3979	17	117/1.5	.4	8
		550	4159	4.70	4236	16	104/1.4	.4	8
		600	4404	4.58	4476	15	94/1.3	.3	8
		650	4629	4.46	4698	14	85/1.2	.3	8
5	900	450	3908	5.39	4011	19	141/1.6	.5	9
		500	4217	5.25	4312	18	125/1.4	.4	9
		550	4507	5.11	4596	16	111/1.4	.4	9
		600	4777	4.99	4861	15	100/1.3	.3	8
		650	5028	4.87	5108	14	91/1.2	.3	8
5	1000	450	4185	5.78	4303	20	149/1.5	.5	10
		500	4521	5.64	4630	19	132/1.4	.4	10
		550	4837	5.51	4939	17	118/1.3	.4	9
		600	5132	5.37	5228	16	107/1.2	.3	9
		650	5407	5.26	5498	15	97/1.1	.3	9
10	800	450	2784	3.85	2896	21	108/1.8	.6	6
		500	2935	3.66	3042	19	94/1.7	.5	6
		550	3069	3.48	3171	18	83/1.6	.5	6
		600	3187	3.32	3286	17	73/1.5	.4	6
		650	3291	3.17	3387	16	66/1.4	.4	5
10	900	450	3045	4.22	3175	21	115/1.8	.6	7
		500	3217	4.02	3341	20	100/1.7	.6	7
		550	3370	3.83	3488	19	88/1.6	.5	6
		600	3506	3.66	3619	18	79/1.5	.4	6
		650	3625	3.51	3735	17	71/1.4	.4	6
10	1000	450	3295	4.58	3443	22	122/1.7	.7	8
		500	3488	4.37	3628	21	107/1.6	.6	7
		550	3660	4.17	3794	19	94/1.5	.5	7
		600	3813	3.99	3942	18	84/1.5	.4	7
		650	3949	3.83	4073	17	75/1.3	.4	6
10	1100	450	3535	4.92	3702	23	129/1.7	.7	8
		500	3748	4.71	3906	21	113/1.6	.6	8
		550	3939	4.51	4090	20	99/1.5	.5	8
		600	4110	4.32	4254	19	89/1.4	.4	7
		650	4261	4.15	4401	18	80/1.3	.4	7
10	1200	450	3767	5.26	3953	24	136/1.7	.7	9
		500	4000	5.04	4176	22	119/1.6	.6	9
		550	4209	4.83	4377	21	105/1.5	.5	8
		600	4397	4.63	4558	19	93/1.4	.5	8
		650	4564	4.46	4719	19	84/1.3	.4	8

Table X. Safe Escape Chart

MK-82 LDGP, SNAKEYE 1 LOW DRAG BOMBS DIVE RELEASE 5.0G TURNING MANEUVER TARGET DENSITY ALTITUDE ~ 5000 FEET									
RELEASE		SAFE ESCAPE/SAFE SEPARATION							
DIVE ANGLE	PAS	SINGLE		RIPPLE - 12 BOMBS					
		MINIMUM		10 MSEC		75 FEET		150 FEET	
		REL ALT	TIME OF FALL	MIN REL ALT	IMPACT SPACING	MIN REL ALT	INTV SET	MIN REL ALT	INTV SET
DEG	KNOTS	FEET	SEC	FEET	FEET	FEET	MSEC	FEET	MSEC
0	450	520	5.13	590	23	720	99	920	197
	500	480	4.90	540	25	640	89	810	178
	550	420	4.55	480	28	570	81	710	162
	600	390	4.38	440	30	510	74	620	148
	650	380	4.33	410	32	490	70	590	141
5	450	770	4.77	850	17	1120	129	1440	251
	500	750	4.55	840	18	1070	121	1360	235
	550	710	4.25	790	19	1030	115	1300	222
	600	690	4.05	770	20	960	110	1180	213
	650	700	4.00	770	20	950	106	1150	206
10	450	1070	4.74	1180	11	1610	159	2100	304
	500	1080	4.56	1190	14	1590	152	2050	290
	550	1040	4.23	1160	14	1580	147	2020	279
	600	1050	4.09	1150	14	1500	145	1880	276
	650	1070	4.01	1170	15	1490	141	1810	212
15	450	1380	4.77	1500	11	1130	188	2730	351
	500	1410	4.50	1530	11	1180	183	2760	342
	550	1390	4.29	1510	11	2200	180	2800	336
	600	1410	4.13	1510	11	1140	179	2700	334
	650	1460	4.08	1580	12	2100	178	2590	338
20	450	1680	4.78	1820	9	2660	215	1410	397
	500	1720	4.57	1870	9	2740	212	3480	395
	550	1730	4.32	1900	9	1800	211	3570	392
	600	1770	4.18	1910	9	2810	213	3570	396
	650	1830	4.11	1970	9	2740	215	3520	398

10.3 Mission Support System (MSS)

The goal of MSS is to provide the combat pilot with the computerized tools necessary to plan his missions in an efficient and timely manner while addressing the increasingly complex issues of modem air-to-air and air-to-surface combat. With the phenomenal growth in computer sophistication in the last several years, available hardware and software platforms exist that are capable of radically altering the manner and speed in which pilots plan their combat missions. The amount of time required to plan a routine air-to-ground mission by hand is probably not immediately obvious to the reader. The pilot must consult aircraft performance manuals, Dash 34 Series To's, **JMEM's,** and pertinent Air Force Regulations; perform various computations; interpret charts; and perform related **tasks.** This process may require many hours.

It is generally agreed that an acceptable MSS should have at least the following capabilities: flight planning, weapon delivery, and penetration-aids functionality (in combination with easily updated databases), and aircraft cartridge load. In terms of a hardware/software platform to support these areas, the following features are required: automatic data storage and retrieval including any necessary pre-entered databases, computational facilities, digital map access and display, and intuitive displays and controls mapped into a consistent madmachine interface. Essentially, these features provide the equivalent of a high-performance engineering workstation with a large on-line and secondary storage, a high-resolution color display, a mouse or trackball input device, and a keyboard.

A discussion of the flight planning and penetration aids portion of MSS is beyond the scope of this volume. Therefore, the following discussion is limited to the weapon delivery portion of MSS. Essentially, weapon delivery planning software supports the automation of the **tasks** specified in Dash 34 To's. Analysts at Eglin have produced two software products in this arena: a Microcomputer Weapon Delivery Program (MWDP) and a Mission Support System (MSS) Weapon Delivery Module (WDM).

10.3.1 Microcomputer Weapon Delivery Program

In 1981, based on the increasing demands from field units to automate the time-consuming process of the weapon delivery portion of mission planning, analysts initiated the development of the first **MWDP.** This program, in essence, adapted mainframe weapon delivery algorithms used in the generation of data in Dash 34 **To's** to a microcomputer platform. The program was written in the BASIC programming language and was released to the field in the summer of 1083. The program allows aircrews to select an aircraft maneuver and weapon for release from a menu of available databases. The program then allows for computation of the appropriate maneuver entry points (location, altitude, and time) for successful ballistics employment and informs the aircrew of any modifications necessary to the planned flight profile to ensure safe escape. The general goal of reducing the amount of time and individual references a pilot needs to accomplish weaponsdelivery planning exceeded expectations. The MWDP enables the aircrew to select maneuvers based on empirical aircraft performance information and to quickly utilize pre-computed ballistic and safe escape tables. This information is taken from data sources produced in support of Dash 34 To's. One MWDP limitation that was quickly identified was the burden imposed upon the significantly less powerful hardware platform (8-bit and 16-bit microprocessors) by the computation of store trajectories. However, this limitation was satisfactorily overcome by development of a variable step-size integration algorithm. Other limitations imposed by target hardware platforms impacted the relative ease in which databases could be modified and updated. The program has been enhanced and improved for several years and is now standardized by the USAF on Zenith 248 microcomputers.

10.3.2 MSS Weapon Delivery Module (WDM)

Work is currently underway for the development of a new MWDP that will offer even further enhancements. In 1986, analysts at Eglin were requested by the Tactical Air Command (TAC) to develop a weapon delivery capability for a new automated tactical mission planning system, MSS. This system is best described as the first organized, dedicated initiative on the part of TAC to develop a standard mission planning capability for all USAF combat aircraft. The MSS Weapon Delivery Module (WDM) effort was subsequently initiated as a separate and distinct software development program from the MWDP discussed earlier. The hardware platform was a Crornemco/UNIX system, which is a minicomputer platform offering considerably higher performance and capacities than the previous microcomputer platforms. This system was a dramatic departure from the platforms that the MWDP had executed on previously. The system configuration roughly corresponded to the MWDP. Initially, the program was converted from BASIC to PASCAL programming language, which is a more sophisticated and higher-level language. This translation was necessary to meet requirements regarding common USAF programming standards, While this conversion was taking place, modifications to the program logic were being made to accommodate a parallel flight planning capability development effort underway by **TAC.** This work was performed over a period of several years, with considerable improvement in the capabilities of the program being accomplished simultaneously. The capabilities of the current WDM include: the ability to perform ballistic calculations for single bomb or ripple releases based upon level, dive, loft/toss, and pop-up delivery profiles; the ability to calculate safe escape data for level and dive deliveries; and the ability to calculate CBU patterns. In addition to supplying improved functionality over the original microcomputer version in these areas, the WDM also incorporates the latest ripple safe escape data and store separation coefficient information, fuze timing capabilities, and an easy-to-use, text-based madmachine interface. The reader may be interested in Reference **20,** which contains a complete description of the computerized weapon planning software.

10.4 Future MSS

In recent years, significant advances have been made in tactical systems, especially with the introduction of the **F-15E** fighter and similar sophisticated aircraft and weapon systems. These advances have provided a tremendous impetus for improved mission planning systems. In both software and hardware, aircraft and weapon systems are leading the development of capable mission planning systems. In response to this situation, third-generation mission planning capability (MSS III) is under development. The system will probably include flight planning, penetration aids, weapon delivery planning, real-time data-gathering capability (threat information), and the like. This system will probably use large optical media devices to provide storage and on-line access to databases that essentially contain all the information currently stored in technical orders.

The madmachine interface of this system will probably follow current engineering workstation platforms in supplying a single, high-resolution monitor which displays all textual and graphic information on the same screen, and a keyboard and mouse for the input and manipulation of data significant to mission planning. Several capabilities have been identified that will probably find their way into the MSS 111 configurations. These configurations include:

(1) Refinement of aircraft flight path computations to more accurately support safe escape and ballistic issues
(2) Refinement of store ballistics trajectory computations (potentially resorting to the use of very high-fidelity **6DOF** simulation algorithms)
(3) Application of sophisticated, intelligent computations surrounding safe escape to support the capability of programmatic analysis of delivery options to allow alternative/improved safe escape criteria
(4) Complete encapsulation of weapon delivery planning with a "what-if' analysis capability so that pilots may easily implore the modification of weapon delivery parameters to support miscellaneous employment constraints, such as threat factors)
(5) Support for guided weapons
(6) Radical improvements in the madmachine interface to make weapon delivery mission planning easier and more intuitive.

While the details of MSS III are not finalized, the objectives of the system are clearly to provide pilots with an enhanced capability to efficiently plan combat missions in an increasingly complex environment.

The future of mission planning and, in particular, weapons delivery is on the threshold of entering an entirely new domain of extremely sophisticated, integrated scenarios. The future will undoubtedly see these systems being interwoven with theater-level battle management systems and high-volume, satellite information sources. It also seems likely that in an effort to provide unparalleled support for flexible weapon delivery planning, the systems flight and balance algorithms, in the form of complex software packages, will be incorporated into an MSS III. This incorporation would allow complete and extremely high-quality simulation capability, conceivably to the point of simulating the combined trajectories of all aircraft, weapons, and submunitions in a rigorous computational description of the entire air-to-surface environment. While this arrangement may sound unachievable, it is possible with today's hardware and software technology to construct platforms capable, at *least* in terms of "raw" computing capability, of doing exactly this type of simulation. In addition to the outright capabilities of such systems, we can expect to see madmachine interface becoming equally sophisticated. Judging from the likely initial operational capability of such a system, it is probable that pilots will communicate with the system using voice, true three-dimensional stereoscopic projection systems, and physical manipulation methods (such as light pens, joysticks, and mice). On an even broader horizon, it is likely that, with the growing integration of weapon system and aircraft avionics, weapon planning systems will probably become mandatory components in all onboard combat aircraft computer systems, including support simulation platforms.

11.0 EXAMPLES OF TEST PLANS AND ANALYSES RESULTS

11.1 Freestream Drag and Separation-Effects Example

The test plan for the BLU-107 in Appendix E is a good example of multi-purpose test integration. As stated earlier, there are two types of weapons: intact and functioning. This test plan is for an intact weapon, but the format is the same for both weapons. The only differences between an intact weapon test plan and that of a functioning weapon are the test objectives and the amount and type of data to be collected and reduced. The BLU-107 plan was originally designed for flight certification, but with careful planning, it was expanded to include freestream ballistics and separation-effects testing. The test plan consists of the Test Directive (TD), which lists background information pertinent to the test, the test objectives, and the method of test **(Mar).** This MOT provides as many exact details of the test as possible at the time of conception. The TD is a contract between the organizations conducting and analyzing the test, while the MOT is the detailed description of events that will occur. Attached to the MOT are detailed mission summaries that describe the exact aircraft loadout, data requirements, and delivery conditions for each mission of the test. By using mission summaries, the progress of the test can be tracked in greater detail and, if the need to change missions arises, mission summaries can be changed on an individual basis without having to change the TD or MOT. The mission summary is the day-byday working tool of the test engineers and analysts.

11.2 OFP Accuracy Test Example

The F-16 Z1 test plan found in Appendix F is a good example of how an OFP Accuracy 'Test can be accomplished. The TD and MOT are the same as described earlier.

12.0 FINAL REMARKS ON DATA COLLECTION

In any testing environment, all possible uses of the data should be considered before proceeding with the project. In general, adding a minimum effort in dafa collecting, will increase the utility of the data drastically. For example, with adequate preplanning of a freestream ballistics testing matrix, the information required to develop separation-effects coefficients for at least one aircraft can be collected. This collection will sometimes require coordination between the analyst and the weapon System Program Office (SPO). Specifically, the SPO has a requirement to develop freestream ballistics and demonstrate a capability of carriage and release of the weapon from several aircraft. In the past, this demonstration has prompted dropping of three to five weapons from each aircraft type and tracking these weapons to develop freestream ballistics. By restructuring the test and releasing **all** weapons from one aircraft type, sufficient data can be collected to develop separation effects for the one aircraft/weapon combination as well as to develop freestream ballistics.

Likewise, for OFP testing, the only required data are aircraft positioning, pipper placement, and ground impact. However, if separation-effects adjustments are required after verification and without TSPI having been collected on the weapon, the expenditure of additional stores will be required. This effort will always be more expensive than collecting the data during the first test. Aircraft avionics input into the Stores Management System is not absolutely required but has been found to be valuable. The aircraft computes a weapon range based upon space vector inputs from the INS and the weapon aerodynamics. It is entirely possible for a mission to be accomplished with the wrong weapon code identified in the computer. With the **INS** inputs, this error is easily identifiable; without this data, many hours may be spent trying to determine what caused a gross miss.

Another use for the INS input data is for an analytical evaluation of system accuracy after the final ballistics equations are identified. Given that a weapon is released at point A, it will impact at point B consistently except for a small ballistics dispersion. The only difference a change in drag coefficients or the addition of separation effects is going to have is a change in weapon range and time-of-fall. When these changes are the case, one can analytically model on a mainframe, using the avionics inputs and updated drag coefficients or separation effects, what the sight-picture would have been had the OFP used the updated data. The results should then be compared with follow-up OFP accuracy testing and be included in the accuracy database for increased precision in estimating system capabilities. In the case where an old weapon is being added to a new aircraft, separation-effects testing or freestream ballistic testing can be used for accuracy assessment if the pipper placement is recorded. This is especially true for older weapons which have a large database for freestream ballistic development and a rigid-wing, slow-speed airframe. Experience has shown that, in this case, release disturbance is highly unlikely to be a major factor in trajectory modeling.

In summary, it is highly encouraged that all possible information such as aircraft TSPI, weapon TSPI, INS inputs, and HUD video he collected when conducting ballistics testing. This procedure allows the use of data in a multitude of different applications and will ultimately result in lower total system development cost than piece-meal testing with data being collected to satisfy only one test objective at one time.

13.0 CONCLUSION

Until recent years, the techniques for performing ballistics analyses/testing have not changed appreciably. Now, however, every day seems to herald new technical advances that touch every aspect of this subject. It is earnestly hoped that publication of this volume will be of value in introducing the reader to this most important subject and stimulating reader contributions that enhance/enlarge the documented database for all to share.

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APPENDIX A

QUESTIONS ON BALLISTIC ANALYSES AND TESTING

WITH RESPONSES FROM CANADA, FRANCE, AND GERMANY

EUROPEAN FACT-FINDING TRIP
FOR
AGARDOGRAF'H ON BALLISTIC ANALYSES AND TESTING

Purpose: To obtain details as to how European nations perform ballistic analyses and flight testing. European inputs will enhance completeness of AGARDOGRAPH. Inputs will also highlight areas that could he standardized to streamline this work among all allied nations.

Information Sought: The following is a list of some of the major questions to he asked. Naturally, during the course of conversations, other questions will he asked:

1. **Provide a historical perspective on your nation's involvement in ballistic analyses and flight testing.**
   For example, how has this work evolved over the years? Provide a brief synopsis of how this work was performed in the past as compared to how it is being performed now.

2. **How are ballistic accuracy requirements established?**
   Presumably, these are established by the military. Specifically, what is the process by which criteria **are** established for a given store to impact a given distance from the intended target? What is the criteria?

3. **Once accuracy requirements are established, what are the demonstration criteria and how are the criteria established?**
   For example, once the military specifies an accuracy criteria, how many stores are required to be released against a target during a test program to establish statistical confidence as to the results?

4. **Who specifies aircraft/store configurations to be tested and aircraft release parameters?**
   Does the military determine this or is this left to the discretion of the test organization? For example, if there is a requirement to establish accuracy for a MK **82** bomb from an F-16, and there are dozens of configurations involved (e.g., with and without fuel tanks, ECM pods, multiple or single carriage, etc.), who decides what the release envelope to be tested should be? For example, should stores be released at multiple aircraft dive angles and at all airspeeds/altitudes that are authorized? This would take a lot of stores!

5. **Provide a brief synopsis of the types of aircraft and stores used by your nation for which ballistic analysis and testing is required and performed,**
   For example, do aircraft have optical sights and/or weapon delivery computers? Are stores generally of the iron bomb type (non-functioning) or do they have functioning fins or other functioning parts that affect ballistic analyses and testing?

6. **Summarize ground and airborne test requirements/capabilities to support ballistic analyses and flight testing.**
   For example, how do you track aircraft to obtain exact release conditions/position and how do you pinpoint store impact coordinates? What type of ground cameras are used (frame rate and other technical characteristics)? Describe your overall range procedures for ballistic testing (e.g., procedures for various data sources). Are smoothing procedures used for time-space-position-information (TSPI)? What are your camera requirements? What are your data format requirements? What are your telemetry requirements?

7. **Describe pretest preparations.**
   For example, are store mass properties determined? Are aircraft boresighted (and if so, how regularly)? Are cameras and other equipment calibrated (and if so, what equipment)?

8. **Are aircrews given any special procedures to follow during ballistics flight testing?**
   If so, what are they (and why were they derived)?

9. Describe your ballistic analysis and prediction tools/codes.
Are you satisfied with their results?

10. When stores do not hit their intended targets, what do you do about it?
Accept results? What are considered to he sources of error for stores not hitting their intended targets? Once the weapon freestream ballistics have been derived/verified, do you have any further analysis (is., in support of overall system accuracy assessment)?

11. Provide examples as to how ballistics data is provided to aircrews.

12. What improvements do you plan to make in the coming years to improve ballistic analysis/prediction tools, range capabilities, aircraft instrumentation capabilities, etc.?

13. Have you had any particular problems in the area of ballistic analysis and testing that you would care to discuss?

14. Once requirements are defined, how are ballistic flight test programs developed?
Specifically, who developed the test matrix and how is it developed?

15. Is ballistics data ever gathered in conjunction with a store separation test program?

16. Clarify the role of the military and industry in ballistic analyses and flight testing.
For **example,** does the military/government perform all work or is part of (or all) work performed by industry?

17. What portion, if any, of ballistics-related analysis and testing is classified?
If classified, what is your classification level?

18. Can a list of references be provided on the subject covered by the AGARD report being prepared?
It would be most helpful to obtain a copy of those reports which are considered to be especially informative in describing your nation's capabilities in the subject area.

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RESPONSE FROM CANADA

HISTORICAL

The Canadian Forces (CF) have just recently established an air weapon ballistics methodology policy which is integrated in the stores clearance process in a manner similar to the USAF SEEK EAGLE Program. The reason for absence of such a policy in the past was primarily due to lack of full-time staff assigned to CF ballistics matters.

1. Historical perspective on Canada's involvement in ballistic analyses and flight testing

   Prior to establishment of the CF air weapon ballistics methodology policy, ballistic analyses and testing were conducted somewhat independently, under National Defence Headquarters (NDHQ) cognizance, by the Defence Research Establishment in Valcartier (DREV) and the CF Aerospace Engineering Test Establishment (AETE). DREV was used as a scientific agency to determine weapon components physical and aerodynamic data, to develop algorithms to calculate weapon trajectories, and to produce ballistic tables. AETE was used as a flight test establishment to verify predicted weapon trajectories.

   A recent reorganization within the air weapons section of NDHQ allowed the CF to now have full-time personnel working on CF air weapon ballistics and to provide configuration control of CF air weapons ballistics activities.

   AETE was then tasked by NDHQ to act as the CF source of engineering excellence, with respect to air weapon ballistics, to support the NDHQ air weapon ballistics personnel. This tasking is a standing project which tasks on a continuing basis. AETE ballistic engineers have established air weapon validation and accuracy procedures for Canadian 2.75-inch rockets (CRV-7) and practice bombs.

2. How are ballistic accuracy requirements established?

   These requirements are established by CF operational and technical staffs. In establishing an aircraft weapon delivery system accuracy, direct and indirect limitations must be considered. Direct limitation could be errors in the aircraft sight setting, aiming errors, and angle-of-attack errors. Indirect limitations such as the accuracies of the attitude indicator, the altimeter, and the wind corrections must also be considered. Also the human factor is considered with respect to how close to the desired release conditions the pilot will, on average, release the weapon.

3. Once accuracy requirements are established, what are the demonstration criteria and how are the criteria established?

   For verification and validation of the CRV-7 rockets ballistic algorithms, an accuracy requirement of 2.0 mils between predicted and actual impact points is required by CF operational and technical staffs. The sample *size* required to validate ballistic algorithms is not constant, and the method used to determine this sample size is described in the AETE Technical Memorandum No. 545.

   Once a weapon ballistic algorithm has been validated, the overall accuracy of this weapon when released from different types of aircraft must be estimated and validated. To estimate an aircraft weapon system overall accuracy when releasing a specific weapon, circular error probable (CEP) values are determined within ***20*** percent of their true values with a 95-percent confidence level. This means that at least **47** independent statistically successful weapon releases are necessary to achieve such an estimation.

   Once this specific aircraft/weapon CEP has been estimated, the number of test points required to validate it is calculated following the procedure outlined in the AETE Technical Memorandum No. 597. In short, a test of hypothesis approach is followed to ensure the weapon system meets the claimed accuracy. This means each case under consideration may require a different number of weapon releases to establish the correctness of the estimation.

4. **Who specifies aircraft/store configurations to be tested and aircraft release parameters?**

NDHQ operational and technical staffs specify aircraft/store configurations to be tested and release parameters to AETE via flight test Project Directives. Normally, releases are conducted at numerous points in the weapon-release envelope in order to best cover this envelope. As well, all wing stations may be used to release the weapons and to study weapons trajectories after launch. Weapons are also released under selected dive angle, altitude, and airspeed conditions. **As** an example, for the production of MK 82 bomb delivery tables from the CF-5, an extensive flight trials program was conducted where 150 bombs were dropped in high and low drag configurations. The bombs were dropped at each of four selected combinations of dive angle, altitude, and airspeed from the centerline and the four wing pylon stations.

5. **Brief synopsis of the types of aircraft and stores used by Canada for which ballistic analysis and testing is required and performed**

The CF fighter aircraft that carry weapons are the CF-18 and the CF-5; both aircraft have optical sights and the CF-18 has an integrated fire control system. These fighters are cleared for the following CF air-to-ground weapons: MK **82** LD and HD (Snakeye), MK 20, BL-755, and CRV-7 (C-14 and C-15 versions). These aircraft are also cleared to employ other weapons that are not in Canadian inventory. The CF-18 computer system contains all the ballistic data needed to release these weapons. The CF has manual ballistic tables for all weapons cleared on the CF-5, and for the BL-755 and CRV-7 for the CF-18. However, CF-18 BL-755 manual ballistic tables have not been verified.

6. **Summarize ground and airborne test requirements/capabilities to support ballistic analyses and flight testing.**

The phototheodolite tracking system is normally the primary data acquisition source used by the CF at AETE. Of the nine Contraves Model F phototheodolites available at AETE, five are normally used to track the aircraft and stores. Data from a minimum of three phototheodolite sites are required for a solution, but five are used to allow for equipment or tracking failures. The phototheodolites are all synchronized and are normally run at 30 frames/second. The azimuth, elevation, IRIG B time code and tracking error are read from each film and are computed to produce time-space-position-information. No smoothing of the phototheodolite data is necessary to produce TSPI, but five-point moving arc smoothing is applied to the computed TSPI if velocity or acceleration is to be derived. High speed (400 frames per second) motion picture cameras (IPL photosonics) might be used **as well** as over-the-shoulder cameras in single-seat CF-18 to record the Head Up Display (HUD).

The following information on the instrumentation used by AETE to support ballistic analysis is also provided:

a. **A** pickle-tone generator is actuated by the weapon release button and a UHF signal is transmitted to all instrumentation systems for correlation purposes;

b. Telemetry is used to give a backup source of aircraft parameters at release, which are also displayed in real time at a ground station, to assist in the conduct of the test;

c. Radar is used to generate coarse TSPI as a backup to the phototheodolites and also as an input to the ground station CRT situation display. The test aircraft are normally equipped with C Band transponders for radar tracking, but the aircraft can be skin-tracked with a lesser certainty of maintaining lock; and

d. Meteorological data are acquired by tethersodes or radiosondes, just before or after the test flights and normally from the ground to the release altitude at intervals specified by the AETE Project Officer. These data are used for ballistic wind corrections and the calculation of true airspeed.

7. Pretest preparations

A weight and balance check of large stores is always performed by AETE prior to flight testing to ensure center of gravity location, weight, and moments of inertia are within the tolerances specified in MIL-STD-1763. Smaller stores, such as Modular Practice Bombs (MPB's) and rockets, are not checked. None of the measurements are entered into ballistic algorithms when comparing actual and predicted trajectories. Prior to accuracy test flights, the gunsight is harmonized. If aircraft-mounted cameras were to be used (normally they are not), they would be calibrated using a grid board prior to the start of testing.

8. Are aircrews given any special procedures to **follow** during ballistics flight **testing?**

For ballistic validation flight tests conducted at AETE, the aircraft is flown at specified conditions (dive angle, airspeed, height above target) and as long as it is in a fairly stabilized profile prior to release, the test point is accepted. As AETE is not concerned with hitting a "target" on ballistic missions, any stable release condition is acceptable. Prior to calculations by the AETE Project Officer, the data are subjected to a normality test as all assumptions are based on having a normally distributed population.

9. Describe your ballistic analysis and prediction tools/codes.

CF basic ballistics prediction tools are a six-degree-of-freedom (6DOF) computer program or a 2DOF computer program. A 6DOF program is a full aerodynamic simulation allowing three translational and three rotational degrees of freedom. A 2DOF program treats the body as a point mass with two translational degrees of motion. This means that a 2DOF does not simulate any motion related to forces due to angle of attack or the dynamic response of the body. However, even if a 6DOF program provides a better simulation, it cannot be used to produce ballistics tables, since it needs too much computer time and memory space. This is the reason why the CF uses 2DOF programs to simulate store trajectories, but a 6DOF program can be used in certain cases to introduce launch factors into the 2DOF program. Launch factors are correction factors used to account for pitching moments at the release of a rocket.

10. When stores **do** not hit their intended targets, what do you do about it?

AETE conducts flight testing for the CF and produces a report for NDHQ. These reports describe the flight test procedures and contain results plus recommendations. Based on these reports, NDHQ decides the actions to be taken in order to improve the results.

When flight tests are conducted to establish air weapon ballistic characteristics, AETE engineers do not consider if the weapons bit the target. Once the weapon ballistic characteristics are determined and introduced in its trajectory-predicting algorithm, failure of the weapon to fall within an acceptable distance of the target will be investigated for pilot aiming and aircraft sensor inputs to the mission computer.

11. Provide examples as to how ballistics data is provided to aircrew.

Ballistics data are provided to aircrew via the publication of manual ballistics tables in Aircraft Operating Instructions (AOI's). As an example, for the CF-5, the AOI's contain manual rocket ballistics tables which provide the aircrew the sight setting, rocket impact angle, and horizontal and slant ranges. The tables cover a wide delivery envelope with release conditions varying from 0" to 60° dive angles and 360 to 520 KTAS.

For "smart" aircraft like the CF-18, the information is contained as algorithms in the aircraft mission computer and ballistic tables are used as a backup in case of a mission computer failure and for training purposes only.

12. **Planned improvements to improve ballistic methodology**

The first and immediate improvement planned by the CF is the accuracy of CF-5 and CF-18 rocket ballistics tables and codes. Also the CF has to update the CF-18 mission computer with the most recent store physical and aerodynamic input data. It is planned to improve the 2DOF and 6DOF computer programs currently in use in the CF by providing aircrew with more accurate wind correction factors.

13. **Particular problems in the area of ballistic analysis and testing**

The main problem encountered by the CF was the absence of full-time personnel as air weapon ballistics OPI. This delayed the normal evolution and development of a Canadian ballistics methodology.

14. **Once requirements are defined, how are ballistic flight test programs developed?**

As discussed previously, NDHQ tasks AETE with a Project Directive which details the objectives of the flight tests. Considering these directives, AETE develops the ballistic flight test program and test matrix according to their resources and experience.

15. **Are ballistics data ever gathered in conjunction with a store separation test program?**

The CF often gathers ballistic data in conjunction with a store separation program. It was done for the MK 82 bombs and for the CRV-7 rockets for the CF-5 aircraft. However, normally stores clearance safe separation data have priority over ballistic data.

16. **Clarify the role of the military and industry in ballistic analyses and flight testing.**

In the CF, all the flight testing is performed by the military at AETE. With respect to the ballistic analyses, all work is normally performed by the Department of National Defence (DND). However, in some exceptional cases, industry performs ballistic analyses for the CF. As an example, Hunting Engineering Ltd (HEL) has been contracted lately to produce BL-755 manual ballistic tables based on flight test trials conducted by the CF. The reason for this contract award to industry was that the BL-755 bomb is a two-phase weapon type and that the CF does not possess an accurate mathematical model to predict impact points of BL-755 bomblets.

17. **What portion, if any, of ballistics-related analysis and testing is classified?**

Currently, computer programs to calculate stores trajectories, all the input data to run this program, as well as manual ballistic tables are not classified. The only classified material on ballistic-related analysis is the material which contain CEP results of actual live firing/release of stores. This material is classified either CONFIDENTIAL or SECRET.

18. **References**

A general reference document on Canadian air weapon ballistics that we can recommend was published by DREV in Canada under The Technical Cooperation Program (TTCP) and titled Comuendium of Ballistic Table Methodologies. This compendium was written by Mr. B. Cheers and Mr. J.F. Teague and could be found in file: 36212-003 under DREV Memorandum 2846/87, July 1987. Twenty copies of this compendium were sent to Dr. D. Daniel, AFATL Eglin AFB, U.S. National Leader, WTP-2.

AETE engineers have recently produced two technical memorandums to standardize air weapons ballistic procedures within the CF organizations. Draft copies **of** these technical memorandums were passed to 3246 Test Wing TYD Ballistics Branch on 13 September 1989 for information. The following are the references of these technical memorandums:

a. AETE Technical Memorandum No. 595, **A** Procedure to Validate Rocket Ballistic Tables,

b. AETE Technical Memorandum No. 597, **A** Procedure to Estimate and Validate Weauon Accuracy.

RESPONSE FROM GERMANY

Preliminary Remark:

Attached please find excerpts of the GE Ammunition Assessment Manual "Bombs". These excerpts cover all important aspects of bomb ballistics as viewed by the Meppen Engineering Center. The answers below contain references to this document.

Answer 1

Not much can be said about the history of bomb ballistics in Germany before 1945 since only a few documents are available and bomb ballistics is only a side issue in textbooks.

With the buildup of the German Federal Air Force and the introduction of U.S. weapon systems (F-84, F-86), the ballistic documents of the **USAF** were adopted too. Our efforts did not begin before the procurement of conventional weapons for the weapon systems F-104G and Fiat G-91 in the late sixties. The responsibility for bomb ballistics was assigned to Engineering Center 91 (E-91) which was also responsible for the testing of air-dropped ammunition. Since then, release clearance trials have been carried out on the site of E-91 using aircraft of Engineering Center 61 (Manching) and of the Federal Air Force.

In the field of bomb ballistics, use could be made of ballistics for artillery, anti-tank and air defense guns where similar trajectory models are used. Additional information in evaluation methods and model philosophy became available during development and procurement of Cluster Bomb BL-755 (produced by Hunting).

The evaluation methods were modified and refined during the years in order to achieve the highest possible precision using simple ballistic models.

Answers 2 and 3

Since the Federal Air Force has so far not commissioned the development of any new bombs, such as the MK 82 type, no specific ballistic accuracy requirements have been formulated. So far, the military have only established accuracy requirements for the overall system (sensors, ballistics, and aircrew). For level or dive bombing, the system accuracy is given as relative accuracy in milliradians; for loft deliveries, it is given in meters or feet.

The ballistic accuracy or the ballistic dispersion is essentially determined by the release behavior and the free-flight phase. For multistage systems (parachute-retarded bombs, cluster bombs, runway-denial bombs), the time tolerances for the actuation of the various stages must also be considered. It is the task of the ballistics engineer to develop suitable ballistic models which describe the release behavior and the free-flight phase as accurately as possible over the entire operational range. The ballistic model can then be used to establish the ballistic dispersion which will be either accepted or rejected. Importance should be attached to the requirement that the ballistic dispersion and the errors of the sensors and of the aircrew are reasonably balanced.

The number of releases is often determined by the procurement cost for inert bomb bodies, since the dropping of live ammunition is prohibited in Meppen. As an example, no more than 25 bombs are available for trials with a five-bomb configuration (Tornado), which must cover everything, even the determination of minimum ripple intervals. Of course, this is not enough for a reliable statistical statement. On the other hand, training bombs are available in sufficient numbers.

Answer 4

The store configurations to be tested are specified by the military. Normally there is a standard test configuration for each bomb type. Experience shows that it is not necessary to test all configurations, particularly since the aircraft computers often use only one ballistic model for one bomb type. The airspeed is the main release parameter which is subject to variation. Release angle and altitude are selected from a tactical point of view. Because of the possible different release behavior, separate trials are conducted for loft deliveries.

Answer 5

The Federal Air Force currently flies three weapon systems:

F4F Phantom	- automatic release possible
Alpha Jet	- CCIP mode
PA-200 Tornado	- automatic release standard

High-explosive bomb MK **82** with retarder system BSU 49 B is to be adapted to all weapon systems. Delivery trials using runway denial bombs BAP 100 and Durandal have been completed for the F-4F. Furthermore, trials with modified training bombs are being conducted and/or prepared.

Answer 6

Only ground measurement equipment is used in Meppen for the determination of ballistic characteristics. The airborne instrumentation (cameras) is used primarily to record event times like bomb release, actuation of the fins, and opening of the parachute. **A** telemetry system is not used with bomb delivery trials.

Reference:
Ammunition Assessment Manual "Bombs"
Para. 2.7.1 Measurement Requirements during Release Trials

Answer 7

Determination of the mass properties and of the bomb center of gravity falls under pre-flight test preparations. In addition, colored markers are added to establish the number of revolutions and to ensure identification during ripple releases. Calibration of the airborne instrumentation is performed by Engineering Center 61 (WTD 61) in Manching.

Answer 8

There are no special procedures for aircrews. They are responsible for meeting the release requirements.

Answer 9

The ballistic analysis tools used in Meppen have proved valuable for the determination of ballistic characteristics. A detailed description is given in paragraph 2.7 "Determination of Ballistic Characteristics" of the Ammunition Assessment Manual "Bombs". Under the heading of "Preliminary Remarks", this paragraph also contains a comment on the prediction tools used by industry.

Answer 10

We are often confronted with this problem. System engineers and aircrews often tend to blame delivery errors on the ballistics engineers. Of course, miss distances caused by faulty ballistics are possible. For example, one of our weapon systems experienced problems with training bomb BDU **33,** the characteristics of which were determined in level deliveries and the bomb subsequently used for loft deliveries. Such errors can only be found if the complete system is investigated, and the sensor errors and ballistics errors are dealt with separately.

Some of the miss distances can be explained with the poor state of the bombs themselves:

We found, for example, sand and wood debris instead of the specified filling in inert bombs MK 82, used for system tests. Due to the changed mass distribution, these bombs showed a different pendulum behavior which, in turn, led to higher drag. Short throws were the result. Great delivery errors, in particular with training bombs, are often caused by bent fins.

Despite the availability of support in the form of sensors and onboard computers, the aircrews have produced the greatest errors with in-service weapon systems. Only thorough training will remedy this problem.

Answer 11

The ballistic data are handed over to the aircrew in the form of ballistic tables, the format of which essentially corresponds to that of the USAF. The aircrews have indirect access to the ballistic data via the onboard computer.

Answer 12

WTD 91 is planning to improve, in the coming years, its external ballistic measurement capabilities (cinetheodolites) which will afford greater flexibility for the planning of bomb delivery trials. An upgrade of the analysis tools is intended. The use of prediction models will be reserved for industry.

Answer 13

Unfortunately, very few persons in West Europe are studying bomb ballistics. However, a number of model and analysis philosophies do exist. It would be useful if these model philosophies were discussed and standardized by a working group as has already been achieved within NATO for artillery ballistics.

Answer 14

The flight test program (test matrix) is normally prepared by a ballistics expert and a trials engineer. The release conditions are determined by the tactical requirements, although they should, at the same time, cover the entire release area.

Since the number of actual releases is often very small, a lot of experience is needed to select the proper trials conditions. A formal procedure does not exist.

Answer 15

The ballistic trials will, whenever possible, be conducted together with release trials for cost reasons.

Answer 16

Due to the organization of the GE MOD Armament Division, the conduct and analysis of the trials belong to the responsibilities of civilian personnel. The GE Air Force provides the jump-off base. Normally, industry is not involved in the analysis of test data.

Answer 17

Ballistic data are only classified "VS-Nur fur den Dienstgebrauch" (equivalent US Restricted).

Answer 18

1. BWB-WMIV6
Handbuch der Munitionsbewertung "Bomben" 1988
(Ammunition Assessment Manual "Bombs")

2. Ballistisches Institut der Luftkriegsakademie Formelsammlung zur Bombenballistik 1941
(Ballistic Institute of the Air Warfare Academy, Collection of Formulas for Bomb Ballistics)

3. WTD 91 Arbeitsbereich Flugbahnvermessung un Telemetrie Aufgabenbeschreibung und Gerateausstattung 1985
(WTD 91 Trajectory Tracking and Telemetry Division Terms of Reference and Equipment Allotment)

H. Nie

RESPONSE FROM FRANCE

1. Historical Overview

1.1 How We Did

a. Theoretical calculation of Cbx $= \frac{S.Cx}{m}$ as a function of Mach number, from which tables are derived

b. Implementation of these tables in the weapon delivery system

c. Test deliveries providing experimental ballistics (on paper)

d. Derivation of experimental Cbx values from these trajectories

e. Modification of the theoretical calculus (i.e., return to a)

No corrections were made for delivery conditions nor for aircraft aerodynamic field-induced movements of store. Hence, this led to a "mean Cbx" adapted to a single aircraft.

1.2 How We Do

a. and b. as in 1.1
c. Wind tunnel tests for safe separation tests

Presently **only** store behavior respective to aircraft is analyzed. These tests are meant to demonstrate that the delivery process will cause no harm to the aircraft.

Since Reynolds numbers of such wind tunnel tests which are used are not proper, modeling of the store behavior in the aircraft aerodynamic field is not derived.

d. Tests deliveries with cinetheodolite-derived trajectories

e. Introduction of actual deliveries conditions as initial values of a store's ballistic model

Elaboration of an experimental Cbx by matching the model-derived trajectory with the measured one, which has been corrected for wind effect.

1.3 How We Should Do in the Future

Add in that process a modeling of the initial release phase using instrumented stores (sensors and solid state recording devices).

2. Establishment of Ballistic Accuracy Requirements

a. *The* military asks the DGA for a store that could cause a desired damage level to a defined target (expression of a need).

b. The DGA calls the industry for proposals on that base.

c. Development of store(s) is then conducted. (Industry may propose a store to be developed without being called for. Then the military will be asked if they are interested.)

d. Ground tests of store then shall establish its effectiveness pattern. This will confirm or modify weapon delivery system accuracy requirements.

e. The store is flight tested on testbed aircraft. It is then "qualified," that is, it reputedly fills the development objectives.

f. The store is then adapted to the mission aircraft through two types of flights:
- separation tests usually flown over sea in safe conditions
- delivery tests to demonstrate the accuracy of the overall system.

Criteria are:
- impact point versus actually designed point (CEP) for ballistics calculation certification
- impact point with respect to that point which the crew tried to designate for overall system evaluation.

After the development phase, a "government evaluation" takes place. A minimum of 3 to 10 stores are then delivered, depending on the delivery envelope and the store's cost.

Afterward, a military experimentation will he conducted by "CEAM" (Centre d'Expérimentations Aériennes Militaire, a service of French Air forces), the result of which are part of the final statistic.

4. Who specifies aircraft/store configuration to be tested?

a. The military list their wishes with respect to:
- store configurations
- flight envelope
- separation envelope (including jettison)
- delivery conditions envelope

b. Calculations and wind tunnel tests allow for captive flight envelope projection.

c. Wind tunnel tests provide data to assess/adapt delivery items desired characteristics. Limitations to the separation envelope may he derived.

From these tests, generally held by industry in government-owned facilities, flight test programs are derived:

- for captive flight envelope demonstration
- for separation envelope demonstration.

These programs, generally proposed by industry, are discussed with the government test organization.

5. Aircraft and Stores foir Which Ballistic Analysis is Used:

5.1 Type of Aircraft presently flight tested with stores:

- Jaguar (delivery computer-electro-optical HUD)
- F1 CR (delivery computer-electronic HUD)
- MIRAGE 2000 (delivery computer-electronic HUD)

5.2 Stores currently adapted to aircraft:

- 250-kg bombs (clean and decelerated)
- BAT 120 - BAP 100
- MATRA BELUGA
- MATRA DURANDAL
- US MK 20 and CBU-58 Bombs

6. Test Facilities Needed to Flight Test Ballistics:

6.1 Ground Facilities:

- Radars for real-time guidance of aircraft (typical accuracy = 15m)
- Cinetheodolites (film 35mm focal 1000 to 2000mm - 5 to 10 frames/second. Accuracy: 1m at 5-km range; 5m at 10-km range)
- Film cameras (100 frames/second) for sequence identification
- TV camera for safety monitoring of flights
- Film cameras (200 to 400 frames/second) to determine store dive-angle at impact point of accelerated stores
- Trajectories are calculated by three-point smoothing of cinetheodolite results

6.2 Onboard Instrumentation:

- Release cameras (6 to 10 typically): 50 to 100 frames/second; film 16mm; focal: 10mm
- HUD color camera: 16 frames/second; film 16mm; focal: 50mm
- Acquisition and recording devices to collect flight conditions at release point, and inputs and outputs of any weapon delivery system device involved (radar, baro altitude, INU)
- Time base, synchronizing every instrumentation device

7. Re-Test Preparation:

7.1 Store Preparation:

- Determination of mass and center of gravity position
- Inertial momentum for guided weapons only
- Use of "never released before" stores

7.2 Aircraft

- Boresighting of:
  - weapon delivery system sensors
  - cameras
- Calibration of instrumentation
- Identification of delays (system instrumentation)

8. Test Procedures:

Special procedures are usually given to:

- achieve the desired test conditions as closely as possible
- locate the release point at the optimal point with respect to:
  - ground instrumentation accuracy
  - test range safety regulation

Hence, crew actions may occur in unusual (or nonoperational) sequences, using special commands to cope with the testbed aircraft.

10. Errors:

Error sources accounted for:

- pilot's designation
- sensors
- algorithms (HUD reticles accuracy - ballistics simplified calculation)

- wind variation between release point and target
- store manufacturing process deviations
- atmosphere deviation from that used in the computers

11. Improvements Forecast:

- Use wind tunnel tests to identify store changes influence from one stage of development to another
- Collect more accurate TSPI
- Modelize the initial release movements of store influence on its future trajectory
- Improve manufacturing processes to minimize store deviation from standard
- Develop realtime ground aids to assist the test engineer in his decision process during flights.

(12-13. No Responses)

14. Development of Test Programs:

- Industry is generally responsible for the development programs and associated tests.
- Official testing organization is responsible for certification programs and associated tests. These combine analytical and operational type tests.

15. Is ballistics data ever gathered in conjunction with a store separation test program?

- Usually not, but it should be.

16. Generally the industry is responsible for the development of the store.

Government services are to control security aspects, performances, and effectiveness of the store. This work is conducted throughout the development phase, and after it has been completed.

17. Classification:

Store effectiveness characteristics and weapon system measured accuracy and its influence on future use by the military are CONFIDENTIAL or SECRET depending on the store and/or the mission.

(18. No Response)

Le REDACTEUR
L'INE BOICHOT

APPENDIX B

BALLISTICS REQUIREMENTS

Department of the Air Force
Headquarters 3246th Test Wing (AFSC)
Office for Aircraft Compatibility
Eglin Air Force Base, Florida 32542-5000

This Operating Instruction covers test requirements, data reduction requirements, and factors to be considered in a comprehensive ballistic and Operational Flight Program (OFP) deliver accuracy analysis for unguided non-self-propelled weapons.

1. Test Requirements

a. For a standard ballistic lest, a minimum of three weapons is required for each test point. Normally, one-third of the weapons will be dropped at the maximum speed the aircraft is capable of flying, one-third dropped at the minimum speed, and one-third in the medium range. Normally, weapons will be dropped in level, dive, and loft deliveries. Aircraft loadouts and delivery conditions will be optimized for the user's go-to-war configurations. Consideration should be given to "footprinting" a particular aircraft with inexpensive munitions (e.g., BDU-33/B) prior to testing with expensive or scarce assets. For each pass, the following data will be provided:

(1) Aircraft Data

(a) Aircraft type
@)Aircraft tail number
(c) Complete aircraft loadout
(d) Aircraft/rack station associated with each pass for weapons that were released
(e) Which OFP block software update is incorporated in the aircraft

(2) Weapon Data

(a) Weapon type (include if item is live or inert)
@)Weapon weight associated with each pass for weapons that were released
(c) Center of gravity (CG) and moments of inertia
(d) Fuze type (if applicable)
(e) Fuze setting (time or altitude, and RPM if applicable)

(3) Rack data

(a) Rack type
@)Ejection cartridges and orifice settings

b. An Operation Flight Program (OFP) delivery accuracy analysis requires, in addition to the data listed above, avionics/sensor data and the pipper location associated with each pass.

(1) Aircraft Sensor Data (Actual Release Parameters from HUD, **etc.)**

(a) Prior to starting a series of computer-aided releases, the aircraft avionics and weapon delivery system should be recalibrated. **A** white vertical 16-foot by 16-foot panel with a black cross should be erected as a target marker to facilitate early target acquisition during level and low-angle deliveries (this is also an aid in data reduction). Stabilized flight conditions are to be maintained on each weapon delivery run. Prescribed tolerances for planned release conditions *are* ± 50 KTAS, ± 10 degrees climb/dive, ± 500 feet MSL, and ± 0.5 g's. While pipper placement on the target during bomb release run-in is important, execution of an abrupt maneuver at the last instant before weapon release in an attempt to keep the pipper on the target is to be avoided. Collect the following data from aircraft instruments at the moment of release:

1. Airspeed (KTAS/Mach number)
2. Flight Path Angle (deg)
3. Altitude AGL/MSL (ft)
4. Slant Range to Aim Point (ft)
5. Load Factor (g's)

6. Dynamic Pressure (Q)
7. Winds at Altitude from INS
8. Delivery Mode
9. Pilot's Inputs to OFP

(2) Pipper (Release)/Weapon (Impact) Location

(a) To facilitate assessment of aim point error from the optical sight camera film or video tape, distinguishable markings surrounding the target are required. The range markings should be concentric about the target center at 50-foot intervals to a distance of 200 feet. Using these procedures, the following distances should then be determined (uprange/short distance is negative, downrange/long distance is positive, cross-range right is positive, and cross-range left is negative):

	Range	Cross-Range
Weapon Impact Relative to Target (ft)	____	____
Aim Point (Pipper) Relative to Target (ft)	____	____
Weapon Impact Relative to Aim Point (ft)	____	____

2. Data Recording/Collection Requirements:

a. The aircraft and weapon will be tracked by a minimum of three cinetheodolite cameras operating at a nominal 30 frames per second with 35mm black and white film and Integrated Range Instrumentation Group (IRIG) time to provide the following coverage:

(1) Of the aircraft from a minimum of 3 seconds prior to release to as long after release as the aircraft appears on the film of the cinetheodolites tracking the weapon.

(2) Of the weapon from release to either cluster opening, fuze function, or impact (whichever is longest).

b. Time of weapon separation from the aircraft will be determined as available from the following data sources:

(1) By means of instrumentation installed on racks which either transmit the data to be recorded by ground telemetry systems or from a magnetic tape recorder on the rack with IRIG time with 1-millisecond accuracy.

(2) By medium-speed tracking cameras on 35mm black and white film operating at a nominal 96 frames per second with IRIG time with 5-millisecond accuracy.

(3) By the tracking cinetheodolite cameras to within ,0167-second accuracy. Note: This accuracy is acceptable for ballistic computations only when weapons are released at velocities less than or equal to 300 knots.

c. Any special event times such as fin opening, chute deployment, chute separation, weapon functioning, and impact will be recorded by the instrumentation described in subparagraph 2.b.(1),(2), or (3) above to accuracies as stated. Thirty-five-millimeter film will be used to record these data. Color film will be used to record events where color contrast is an occurrence. Otherwise, black and white film will be used. For events requiring timing accuracies higher than those specified above (i.e., 1-millisecond or greater), 16mm cameras operating at nominal frame rates of 1000 frames per second or greater and IRIG time may be required.

d. Impact times, velocities, and angles for submunitions or a weapon too small to be tracked by cinetheodolites or the medium-speed tracking cameras described above will be determined by CZR-1, fixed Milliken, or similar grid cameras with black and white film and IRIG time.

e. Weapon fuze function heights will be determined as follows:

(1) For function heights from approximately 500 to 4000 feet, to ±10-foot accuracy, using cinetheodolites and medium-speed tracking cameras (nominal 96 frames per second frame rate) and 35mm black and white film with IRIG time, the function point will be projected vertically to the range surface. This method is used primarily for determining *the* fuze function heights of clusters or submunition dispensers.

(2) For function heights from approximately 10 to 50 feet, to ± 1-foot accuracy, using cinetheodolites and 16mm high-speed cameras (nominal 1000 frames per second frame rate, black and white film and IRIG time), and a flag of known height at the impact points to be photographed post-impact by the cinetheodolites.

(3) For function heights of **4** inches to 10 feet, to accuracies of ±3-6 inches using 16mm film, high-speed cameras operating at 2000 to 4000 frames per second with color film, and IRIG time. These cameras are mounted on mounts modified to enable these cameras to track in azimuth only. Suitable lenses will be used as necessary to provide the required vertical weapon terminal trajectory coverage. Up to two 2-foot x 8-foot x %-inch colored fuze function height reference panels are located post-impact at the impact points and photographed by these cameras.

(4) If the fuze function is not clearly apparent on the film (that is, as apparent as in the case of a dispenser), the weapon must be modified to provide a clear manifestation of the fuze function, either by the installation of instrumentation such as strobe lights for camera frame rates of over 400 frames per second, or by fuzes with boosters installed in weapons drilled to permit the fuze function explosion products to be evidenced outside the weapon, or the equivalent.

f. Weapon or submunition impact and scoring data:

(1) Ground impacts of large weapons such as the MK **82** will be scored (Cor example, with Photo-T/flag) using the near edge of the weapon crater and polar coordinates oriented to the target and to the flightline downrange of the target.

(2) For submunitions and other weapons released on grids (separated by item types or dispensers), measurements along track and cross track ± 1 foot should be oriented to the target to provide the following pattern data:

(a) Standard grid coordinate scoring will be used for either the submunition initial or final impact locations. Scoring by initial impact locations may not be practical if the submunitions do not possess sufficient velocity to dent the grid surface.
@)Number of items located
(c) Number of duds

3. Meteorological Data Requirements

a. Atmospheric properties (temperature, density) associated with corresponding altitude will be obtained from standard base upper air (Rawinsonde) observations (taken, ideally, within 30 minutes of mission). Temperature can be measured in either degrees Centigrade, degrees Fahrenheit, degrees Rankin, or sonic velocity input. Density can be measured in grams per cubic meter, pounds per cubic foot, or slugs per cubic foot.

b. Wind direction and velocity data (measured in knots or feet per second) associated with corresponding altitude will be obtained by tracking a pilot balloon (pibal) within 30 minutes of weapon release time in the vicinity of the release area. These data are required for altitudes from the earth's surface to 3000 feet AGL at 500-foot increments, and from 3000 feet to 1000 feet above the release altitude at 1000-foot increments. The pibal may be tracked either by theodolites operating under standard conditions or range cinetheodolites. The cinetheodolites will operate at a nominal 10 frames per second, recording **IRIG** time in bursts of approximately ***5*** seconds each at ½-minute intervals. This data will be incorporated into the final reduced ballistics data printouts.

4. Data Reduction Requirements

a. Cinetheodolite data will be smoothed by fitting a moving arc polynomial to the Cartesian coordinates. Typically, a 31-point quadratic equation is used to fit most standard weapon drops. If, however, a weapon bas rocket motors firing or any other anomalies that make it difficult to track, a cubic equation is used to obtain the smoothed data.

b. Smoothed cinetheodolite data will be reduced to generate time-space-position-information (TSPI). The **TSPI** will be printed out at 0.2-second intervals and will correspond to the following format:

(1) Title Page

PROJECT NUMBER	DATE (dd/mm/yy)	MISSION NUMBER	A/C OR ITEM

LINE 2

# OF POINTS SMOOTHED	DEG OF POLYNOMIAL USED IN SMOOTHING THE DATA

LINE 3

OUTPUT ORIGIN	LATITUDE	LONGITUDE	HT OF TGT	FLIGHTLINE

LINE 4

RELEASE TIME (hh/mm/ss)	SOURCE OF RELEASE TIME (a/c UHF **tone, cameras, cine-t,** or a/c **rack** instrumentation)

LINE 5

GAMMA

(2) Data Pages

PAGE 1

ZULU TIME	TIME SINCE RELEASE	POSITION COORDINATES (X,Y,Z)	VELOCITY COORDINATES (VX,VY,VZ)	HEIGHT OF TARGET ABOVE MSL

TIME SINCE REL	TOTAL VELOC	TOTAL VELOC IN AIR MASS	HORIZ VELOC WITH RESPECT TO AIR MASS	VERT VELOC WITH RESPECT TO AIR MASS	WIND VELOC COMPNTS	HT OF TARGET ABOVE MSL

PAGE 3

TIME SINCE REL	NORMAL ACCEL	ACCEL DUE TO DRAG	MACH	KD	**DIVE** ANGLE	HEIGHT OF TARGET ABOVE MSL

TIME SINCE REL	HORIZ ACCEL	VERT ACCEL	CROSSRANGE ACCEL	HEADING FROM NORTH (DEG)	DYNAMIC PRESSURE	HT OF TARGET ABOVE MSL

a. In the reduction of smoothed data:

(1) The line of flight will be aircraft track at release.
(2) The origin of the coordinate system will be the target.

b. TSPI printouts will be hand-annotated by the organization in charge of the reduction of the cinetheodolite data to indicate events such as fin opening, chute start out and chute completely open, fuze arm and function, etc.

c. Impact data will be collected as required.

(1) Plots of impact data will specify the location of each weapon (or submunition) for each release. Plots will be annotated with line-of-flight, release point, and other pertinent parameters.

(a) The mean point of impact (MPI) will be computed either per release for multiple releases or cumulatively for sequential passes as specified.

@)The location of each weapon or submunition will be tabulated with respect to the established coordinate system. The origin of the coordinate system will be the target.

(c) For submunitions, impact pattern statistical data (CEP, sigma X, sigma Y) and other parameters will be computed.

d. TSPI **will** be provided on both magnetic tape and hardcopy outputs as specified in the Test Directive.

APPENDIX C

FUTURE TRENDS IN BALLISTIC TESTING AND ANALYSES

Office for Aircraft Compatibility
3246th Test Wing/TY
Eglin Air Force Base, Florida 32542-5000

January 1990

Three-Degree-of-Freedom (3DOF) Ballistic Improvements

The Office for Aircraft Compatibility (TY) will he using two computer programs for developing store separation effects and freestream drag coefficients for use in 3DOF trajectory computations. One program will be used to determine the store freestream drag coefficient (that is, when the store is no longer under the aerodynamic influence of the aircraft), **K„** as a function of Mach number. The other program will determine the store drag, lift, and side force coefficients during the separation phase of the trajectory (that is, when the store is under the aerodynamic influence of the aircraft). These programs, combined with a semi-automated data file generator, will significantly reduce the man-hours required to develop 3DOF ballistics data and, more importantly, will increase data accuracy.

Freestream K_D

The computer program which determines freestream store drag is called K, Estimation Method (KDEM). The program uses an optimal estimation method where the objective or cost function is to minimize the sum of the squares of the residuals between measured and modeled trajectory parameters. Since the 3DOF model is nonlinear with respect to K, (a function of Mach), a linearization about an initial estimate for K, is made and an iterative procedure is used to determine a converged estimate of K,. The details of this method are developed below.

TSPI measurements are coordinates of position and velocity as a function of time. For N measurements or time intervals, a measurement vector, Z, is developed such that

$$Z = [X \ Y \ Z \ \dot{X} \ \dot{Y} \ \dot{Z}]^T \tag{1}$$

The position measurements are X, Y, and Z and the velocity measurements are $\dot{X}$, $\dot{Y}$, and $\dot{Z}$. The measurement vector is a column matrix where each coordinate measurement is expanded for N measurements. Thus,

$$Z = (X_1 \ X_2 \ ---X_N \ ------\dot{Z}_1 \ ---\dot{Z}_N)^T \tag{2}$$

The Z matrix is a 6N x 1 (6N rows and 1 column) matrix.

The 3DOF equations of motion are used to compute corresponding values for each measurement. These differential equations for the freestream portion of the trajectory are (Coriolis and centripetal acceleration are omitted here but not in KDEM).

$$\begin{aligned} \ddot{x} &= -K_D \, \rho \, d^2 V \frac{\dot{X}}{m} \\ \ddot{Y} &= -K_D \, \rho \, d^2 V \frac{\dot{Y}}{m} \\ \ddot{z} &= -K_D \, \rho \, d^2 V \frac{\dot{z}}{m} + g \end{aligned} \tag{3}$$

where

ρ = air density
V = total velocity
d = weapon diameter
m = weapon mass
g = gravity acceleration.

If the correct K_D is used and the measurements are perfect, then

$$Z = H(K_D) \tag{4}$$

where $H(K_D)$ is a 6N x 1 matrix representing the 3DOF model output for each measurement. However, the correct K, is not known and the measurements are not perfect. Thus,

$$Z = H(K_D) + E \tag{5}$$

where E is a column vector of errors (6N x 1) presenting measurement errors and K_D errors.

The objective is to minimize the sum of the squares of the residuals (SSR) which is

$$SSR = [Z - H(K_D)]^T [Z - H(K_D)] = E^T E \tag{6}$$

If the model was linear with respect to K„ linear least squares could be used to find the value of Kr which minimizes SSR. In the linear case, SSR is minimized by taking the derivative of **SSR** with respect to K„ setting it to zero, and solving for K_D. The result would be, in matrix form,

$$K_D = (H^T H)^{-1} H^T Z \tag{7}$$

where H replaces the $H(K_D)$ notation. The model may be linearized by a Taylor series expansion about an initial estimate of K, which is noted as k,. **Thus,**

$$Z = Z(\hat{K}_D) + \frac{\partial H(\hat{K}_D)}{\partial K_D} (K_D - \hat{K}_D) + \textit{higher order terms} + E \tag{8}$$

If the estimate, $\hat{K}_D$, is sufficiently close to K„ the higher order terms may be dropped. The linearized form of equation (5) becomes

$$Z - Z(\hat{K}_D) = \frac{\partial H(\hat{K}_D)}{\partial K_D} (K_D - \hat{K}_D) + E \tag{9}$$

In the above equation the difference between K, and $\hat{K}_D$ may be determined by developing a form of equation (7) since equation (9) is now linear with respect to the difference or delta K,. Note that the difference between the measured value and the computed value using the estimate has been formed on the left-hand side of equation (9). This difference or residual is treated as the measurement in equation (7). Thus,

$$\Delta K_D = \left[\left(\frac{\partial H}{\partial K_D}\right)^T \left(\frac{\partial H}{\partial K_D}\right)\right]^{-1} \left[\left(\frac{\partial H}{\partial K_D}\right)\right]^T \left(Z - Z(\hat{K}_D)\right) \tag{10}$$

Equation (10) provides an estimate of the change in $\hat{K}_D$ that has minimized (linear least squares) the residuals. When $\Delta\hat{K}_D$ is added to $\hat{K}_D$, a better estimate ***of*** $\hat{K}_D$ is obtained. The process of determining updated estimates may continue until further deltas would be less than an arbitrary small value.

K_D is a function of Mach number and cannot be assumed constant for any trajectory. For simplicity, assume that K_D may be modeled as

$$K_D = C_1 + C_2 M + C_3 M^2 \tag{11}$$

where M is the Mach number. The estimation process now is to estimate the constants in the above polynomial which will minimize SSR. Equation (9) becomes

$$Z - Z(\hat{C}) = \frac{\partial H(\hat{C})}{\partial C_1}\left(C_1 - \hat{C}_1\right) + \frac{\partial H(\hat{C})}{\partial C_2}\left(C_2 - \hat{C}_2\right) + \frac{\partial H(\hat{C})}{\partial C_3}\left(C_3 - \hat{C}_3\right) + E \tag{12}$$

Where $\hat{C}_1$, $\hat{C}_2$, and $\hat{C}_3$ are estimates of the polynomial coefficients and $\hat{C}$ is the vector of these estimates. From equation (11), the differences or delta coefficient changes may be determined similar to equation (9) as

$$\Delta C_i = \left[\left(\frac{\partial H}{\partial C_i}\right)^T \left(\frac{\partial H}{\partial C_i}\right)\right]^{-1} \left(\frac{\partial H}{\partial C_i}\right)^T \left(Z - Z(\hat{C})\right) \tag{13}$$

where i = 1, 2, and **3.** These equations provide improved estimates over the initial estimates and iterations may continue until an arbitrary small delta in each coefficient is obtained.

The solution of equation (13) is dependent on the proper development of the sensitivity matrix, $\partial H / \partial C_i$. The elements of the sensitivity matrix are the partial derivatives of the 3DOF output with respect to the coefficients or parameters being estimated. For the second-order polynomial containing three coefficients, the matrix is

$$\frac{\partial H}{\partial C_i} = \begin{bmatrix} \frac{\partial X_n}{\partial C_1} & \frac{\partial X_n}{\partial C_2} & \frac{\partial X_n}{\partial C_3} \\ \cdot & \cdot & \cdot \\ \frac{\partial Y_n}{\partial C_1} & \frac{\partial Y_n}{\partial C_2} & \frac{\partial Y_n}{\partial C_3} \\ \cdot & \cdot & \cdot \\ \frac{\partial Z_n}{\partial C_1} & \frac{\partial Z_N}{\partial C_2} & \frac{\partial Z_N}{\partial C_3} \\ \cdot & \cdot & \cdot \\ \frac{\partial \dot{X}_n}{\partial C_1} & \frac{\partial \dot{X}_n}{\partial C_2} & \frac{\partial \dot{X}_n}{\partial C_3} \\ \cdot & \cdot & \cdot \\ \frac{\partial \dot{Y}_n}{\partial C_1} & \frac{\partial \dot{Y}_n}{\partial C_2} & \frac{\partial \dot{Y}_n}{\partial C_3} \\ \cdot & \cdot & \cdot \\ \frac{\partial \dot{Z}_n}{\partial C_1} & \frac{\partial \dot{Z}_n}{\partial C_2} & \frac{\partial \dot{Z}_n}{\partial C_3} \end{bmatrix} \tag{14}$$

The dashed line denotes a partition where each partition contains n rows or a row for each measurement. TSPI measurements are provided as a function of time. The time intervals between measurements are nominally 0.1 or ***0.2*** seconds. It is computationally convenient if the intervals are constant for all measurements being processed. These intervals must be known in advance because the elements in the sensitivity matrix must be determined and synchronized with the TSPI.

The elements of the sensitivity matrix are determined from a set of differential equations developed by taking the partial derivative of each equation of motion with respect to each coefficient. For the stated example, nine differential equations are developed. For example, both the ∂x/∂ C, and the ∂x/∂ C, are obtained from the equation

$$\frac{\partial}{\partial C_1}(\ddot{x}) = -\frac{\partial K_D}{\partial C_1}\left(\frac{\rho d^2 V\dot{X}}{m}\right) - \frac{\partial V}{\partial C_1}\left(\frac{K_D \rho d^2 \dot{X}}{m}\right) - \frac{\partial \dot{x}}{\partial C_1}\left(\frac{K_D\ \rho d^2 V}{m}\right) \tag{15}$$

This equation may be further expanded since

$$\frac{\partial K_D}{\partial C_1} = 1 \tag{16}$$

and

$$\frac{\partial V}{\partial C_1} = \frac{\left(\frac{\dot{x}\partial\dot{x}}{\partial C_1} + \dot{y}\frac{\partial\dot{y}}{\partial C_1} + \dot{z}\frac{\partial\dot{z}}{\partial C_1}\right)}{V} \tag{17}$$

Since the partial derivatives are continuous, the order of the differentiation may be reversed so that

$$\frac{\partial}{\partial C_1}(\ddot{x}) = \frac{d^2}{dt^2}\left(\frac{\partial x}{\partial C_1}\right) \tag{18}$$

and

$$\frac{\partial}{\partial C_1}(\dot{x}) = \frac{d}{dt}\left(\frac{\partial x}{\partial C_1}\right) \tag{19}$$

Thus, equation (15) may be expressed as a second-order differential equation in the variable ∂ x/∂ C,. **All** nine differential equations developed in this manner are integrated along with the equations of motion to produce the elements of ∂ H/∂ C and the elements of $Z(\hat{C})$.

Convergence of the iterative process is dependent on the accuracy of the initial estimate of the parameters or coefficients to be estimated. Too large an error in the initial estimate will cause divergence because the higher order terms in the series expansions could become significant. To eliminate novice error in providing an initial guess for the coefficients in the drag model, a computed mean drag is derived from TSPI. This mean drag estimate is further refined by repeated trajectory calculations using

$$C_1(I) = C_1(I-1) + \frac{X - x\ (I-1)}{\frac{\partial x}{\partial C_1}} \tag{20}$$

where I denotes the iteration step, **X** is the measured range, and x is the 3DOF model output. In usually fewer than four iterations, the range error (X - x) is less than 50 feet. An accurate initial estimate for C_1 is obtained. The other coefficients, which add the effect of Mach number variation, are set to zero. This initialization scheme produces convergence of the K_D procedure for both low-drag and high-drag bombs.

Another problem that the computer program solves for the user is that it selects a **K,** model based on the Mach number level and variation for each drop. The selections include a first-order polynomial for low Mach variation, a third-order polynomial for large variations in the transonic region, and the following model for all subsonic conditions with some Mach variation during the drop.

$$K_D = C_1 + \frac{C_2}{2 - M^2} \tag{21}$$

In the above equation, M is Mach number. The TSPI for the bomb drop is processed first to determine these variations.

The coefficients for the K, versus Mach model or equation is determined to less than a 3-percent change in their value from one iteration to the next. This level of convergence is achieved, in most cases, in fewer than three iterations. The derived model is only valid for that particular drop. It is used only to predict the K, for a specific Mach number, which must be within the Mach interval of the test data. Similar data from other drops in the same Mach region may have significantly different coefficients but predict about the same K,. For a small interval ($\pm$ 0.005) about a given Mach number, K_D predictions are made using the equations developed from drops that have the given Mach in its Mach variation range. These Mach number "bins" may have KD values from several drops. The mean K_D for each Mach bin is the estimate of the **K,** for that Mach number.

These **K,** values are plotted in Figure C-1 for three different bombs. Note that two bombs have the same shape but different physical properties. The computer program determined that, although the shape is the same for both bombs, the 3DOF ballistics are slightly different. The K_D curves labeled as STDTAPE are the data approved for use by the Air Force and represent the results from a large number of test drops. It is used as a standard to validate the computer program.

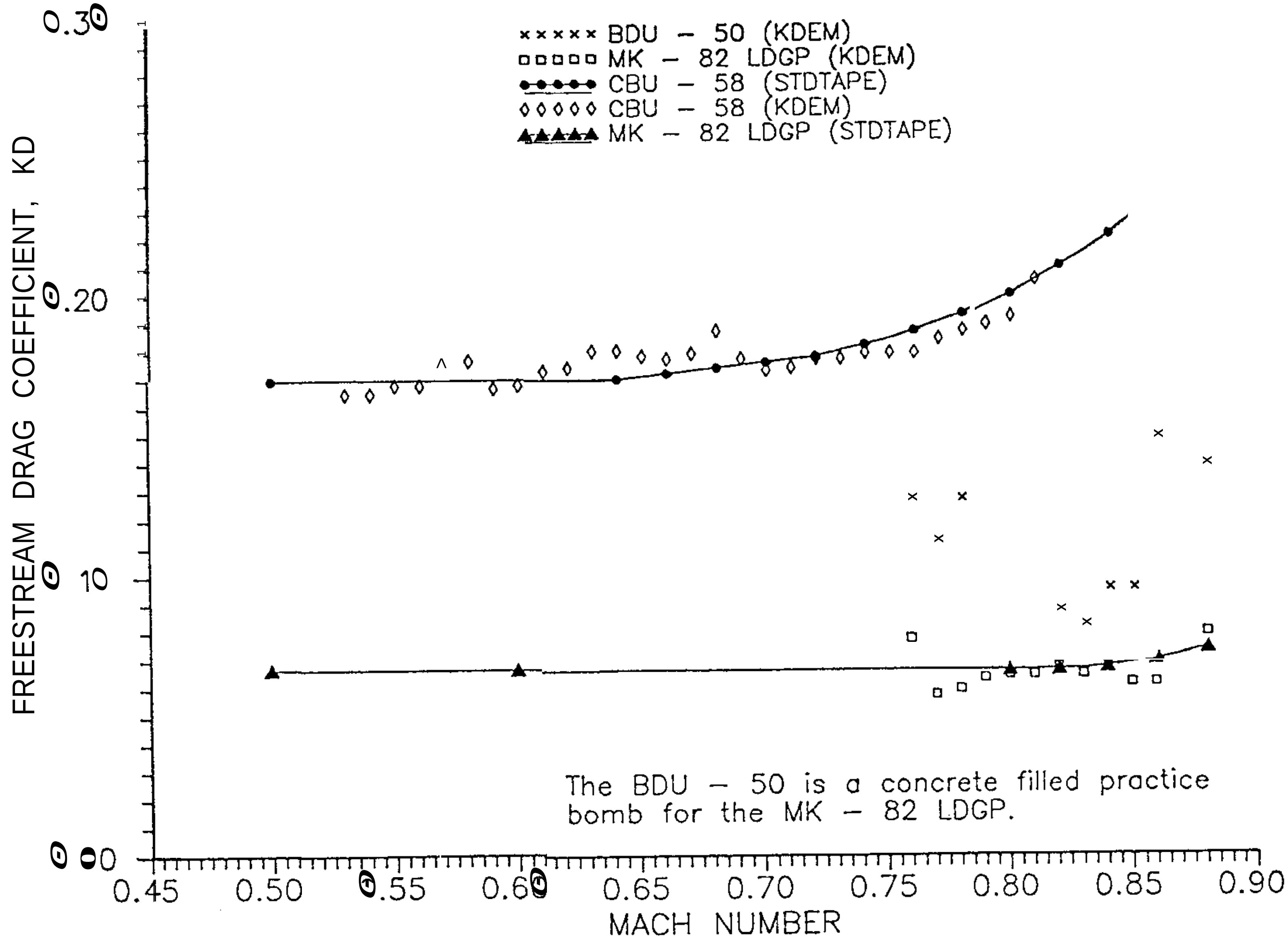
Separation Effects

A computer program called Separation Effects Estimation Method (SEEM) uses similar techniques to those developed in KDEM to determine the drag, lift, and side force coefficients to predict the bomb trajectory while the bomb is under the influence of the aircraft's flowfield. The 3DOF equations are written to include these forces. The equations are

$$\begin{aligned}
\dot{V} &= \frac{-\pi \rho V^2 d^2 C_D}{(8m)} - g\,SIN\,\gamma \\
\dot{\psi} &= \frac{\pi \rho V d^2 C_S}{(8m) COS\,\gamma} \\
\dot{\gamma} &= \frac{\pi \rho V d^2 C_L}{(8m)} - \frac{(g\,COS\,\gamma)}{V}
\end{aligned} \tag{22}$$

where

C_D = drag coefficient = $8/\pi\ K_D$
C_S = side force coefficient
C_L = lift coefficient
γ = velocity vector pitch angle
ψ = velocity vector heading or yaw angle.



C-1. KDEM K_D Estimates Versus Mach Number

The forces are illustrated in Figure C-2. These equations are written in the wind axis system. The same equations in the earth's axis system are

$$\ddot{x} = K_b \left(C_D \dot{x} - C_L \frac{\dot{z}\dot{x}}{V_H} + C_s \frac{V\dot{y}}{V_H} \right.$$

$$\ddot{y} = K_b \left(C_D \dot{Y} - C_L \frac{\dot{z}\dot{y}}{V_H} - C_s \frac{V\dot{x}}{V_H} \right) \qquad (23)$$

$$\dot{z} = K_b \left(C_D \dot{z} + C_L V_H \right) + g$$

where

$$K_b = \frac{-\pi \rho \, V d^2}{8m}$$

$$V_H = \sqrt{\dot{x}^2 + \dot{y}^2}$$

Note that when the lift coefficient (C_L) and the side force coefficient (C_s) are zero, these equations reduce to the freestream equations given in equation set **(3).**

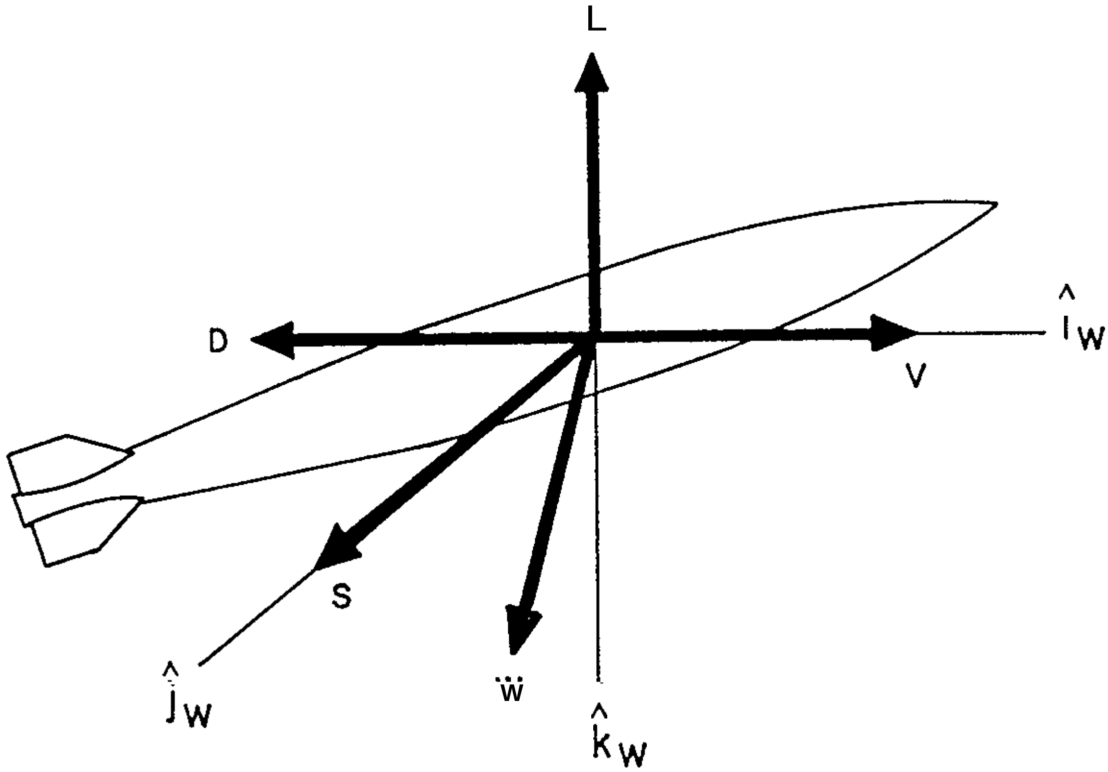
Force coefficient variations during the separation phase are due largely to the angular motion of the weapon. Small changes in weapon total yaw angle induce large changes in the force coefficients. The yawing motion of the weapon is characterized as a damped oscillation which seems to have been initiated by forces in addition to the ejection mechanism forces. The weapon usually yaws to its maximum amplitude within the first half cycle which is characteristic of damped oscillation.

If damped harmonic motion represents the angular motion of the weapon, the variation in forces proportional to the yaw (angle of attack and sideslip) should also exhibit the same nature. The variation in any general force coefficient, C_F, should be characterized by the differential equation for damped harmonic motion which is

$$\ddot{C}_F + K_1 \dot{C}_F + K_2 C_F = F(t) \qquad (24)$$

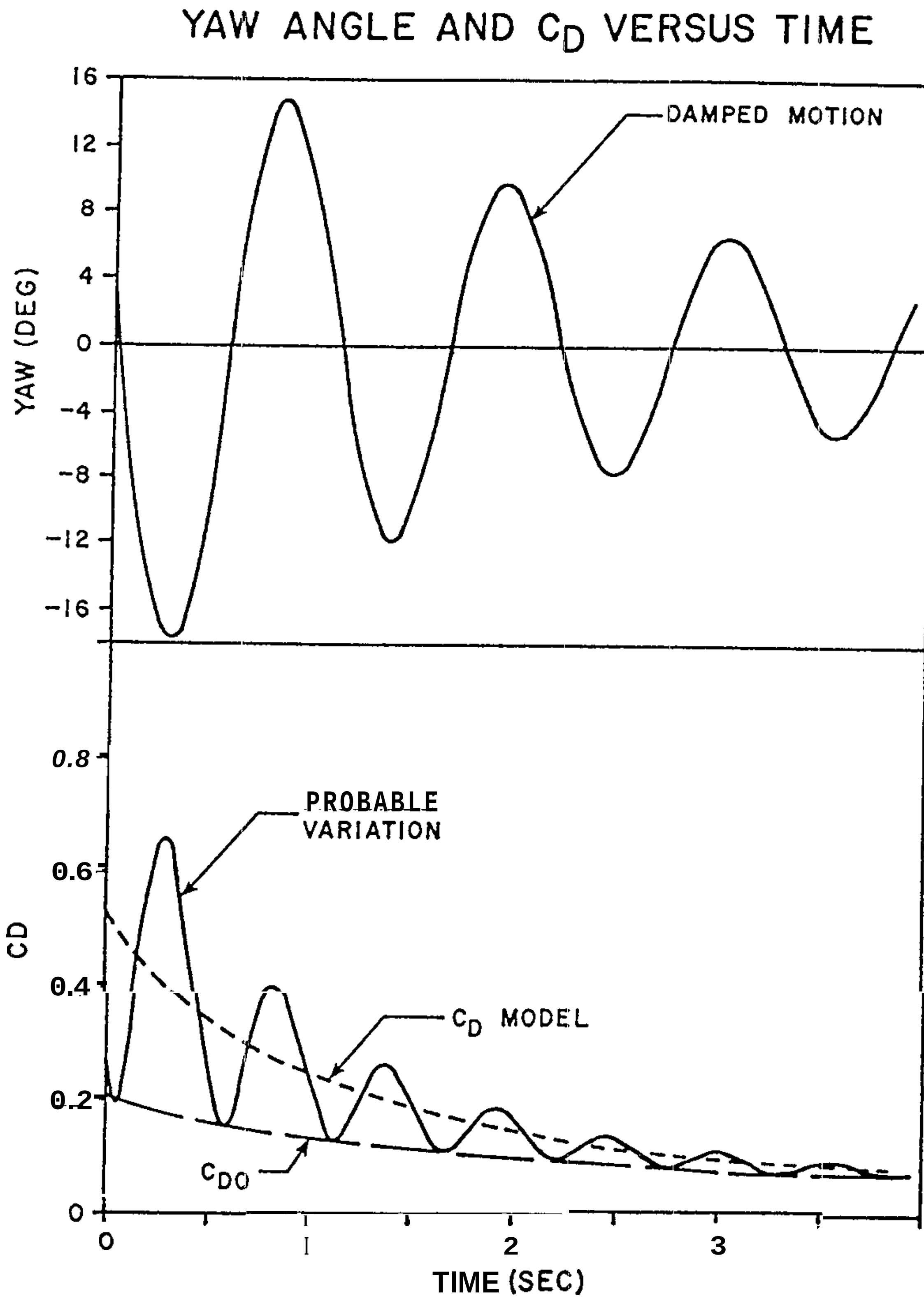
where K_1 acts as a damping coefficient and K_2 acts as a restoring force coefficient. The term on the right-hand side represents an external influence such as the induced flow about the aircraft. The constants should be related to the physical and aerodynamic properties of the weapon. The form and value of the influence term representing separation effects should be dependent on aircraft/weapon configuration and the release conditions. This term as well as the constants could be estimated from **TSPI** if the data were accurate enough to observe the short duration effect of the forces on displacing the weapon. Such an approach would require **TSPI** accuracy of less than an inch at time intervals less than **5** milliseconds apart.

Figure C-3 represents a possible yaw angle time history curve in the upper window. The lower window represents the corresponding variation in drag coefficient, C_D. Note that the minimum C'_D occurs when the yaw angle is zero. **A** curve connecting the minimum values is actually a curve for the zero-yaw drag coefficient. Since this coefficient does not vary with time, the variation seen is a reflection of Mach number variation with time. The maximum C_D value occurs at maximum absolute yaw angle. Thus, the time between consecutive maximums gives the half period of oscillation which provides additional information on the aerodynamic nature of the weapon. Since state-of-the-art **TSPI** accuracy is not adequate to implement



V = VELOCITY
L = LIFT FORCE
D = DRAG
S = SIDE FORCE
W = WEIGHT

C-2. Wind ***Axes*** **Force System**



C-3. **Typical Yaw Angle and Drag Coefficient Time** such a force coefficient model, several alternate models were investigated. The following model seems to represent the mean C_D as a function of time (T).

$$C_D = C_1 + \frac{C_2}{1 + T} \tag{25}$$

This equation form is also applicable to lift (C_L) and side (C_S) force coefficients. Figure C-4 illustrates a possible angle-of-attack time history for an undamped and a damped motion. If the motion is undamped, the net lift force sums to zero since the lift force, unlike drag, is equally positive and negative. For the damped motion, the net lift does not sum to zero because the half yaw cycle produces so much lift, regardless of the direction, that the summation is biased in that direction. The effect of the lift and side force models is to bias the forces in the proper direction. The bias is initially large and decays to near zero in 2 to 3 seconds after release. This type of model gives a smooth transition to freestream motion. Thus,

$$C_S = C_3 + \frac{C_4}{1 + T} \tag{26}$$

$$C_L = C_5 + \frac{C_6}{1 + T} \tag{27}$$

The coefficients, C_1 through C_6, become the parameters or constants to be estimated so that the computed trajectory closely matches the TSPI trajectory.

The measurement vector for determining these coefficients is

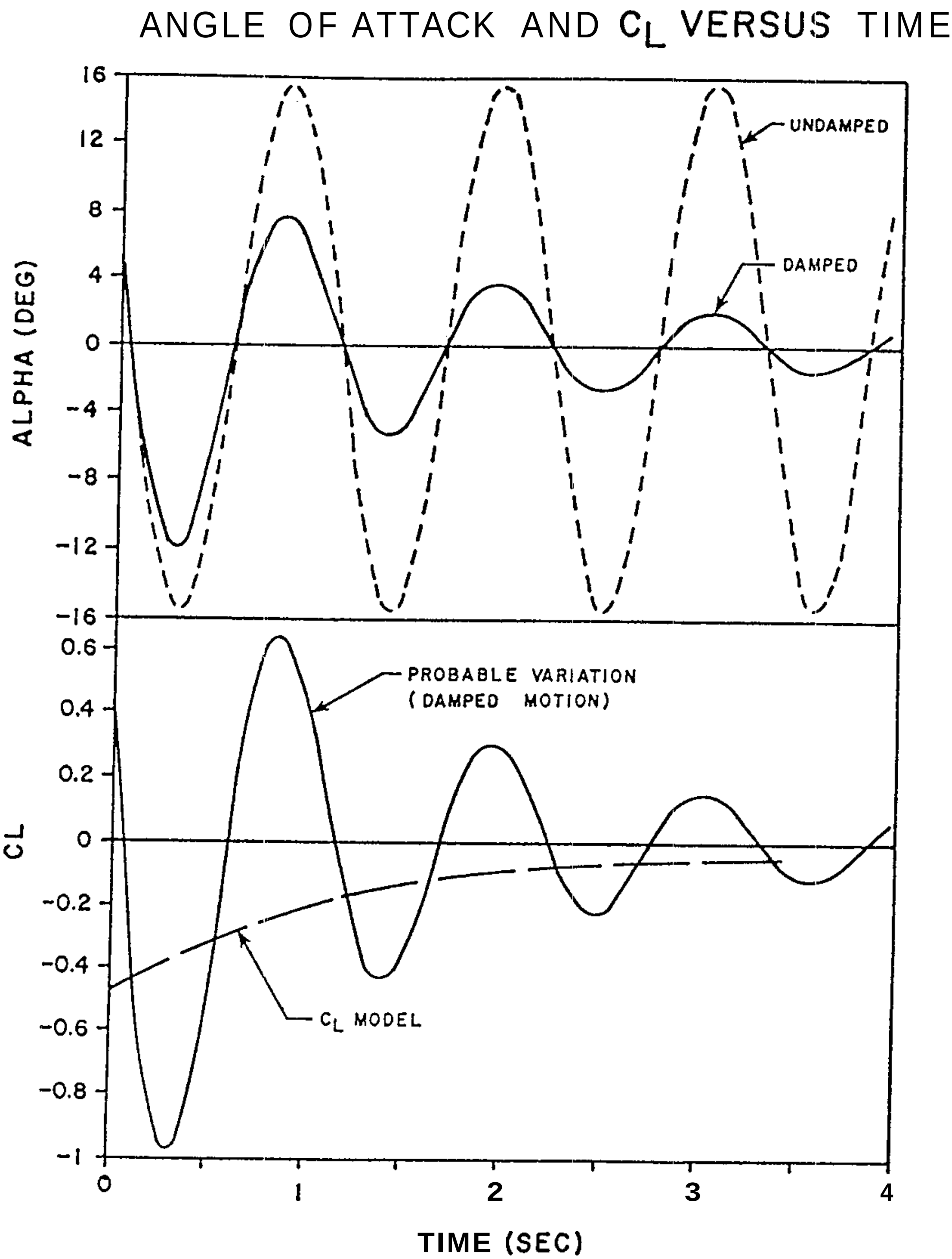
$$Z = [V \psi \theta]^T \tag{28}$$

which is derived from the measurements of x, y, and z. The expanded sensitivity matrix is

$$\frac{\partial H}{\partial C} = \begin{bmatrix} \frac{\partial V_m}{\partial C_1} & \frac{\partial V_m}{\partial C_2} & \cdots & \frac{\partial V_m}{\partial C_6} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial \psi_m}{\partial C_1} & \frac{\partial \psi_m}{\partial C_2} & \cdots & \frac{\partial \psi_m}{\partial C_6} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial \theta_m}{\partial C_1} & \frac{\partial \theta_m}{\partial C_3} & \cdots & \frac{\partial \theta_m}{\partial C_6} \end{bmatrix} \tag{29}$$

Initial estimates for C_1, C_3, and C_5 are obtained by solving for C_D, C_S, and C_L (22) and using average values of V, ψ, and θ from the TSPI. Initial estimates for C_2, C_4, and C_6 are set to zero. These initial estimates are sufficiently accurate to assure convergence of the estimation process.

The set of coefficients, C_1 through C_6, serve only to predict the drag, lift, and side force coefficients for a given bomb drop. Bomb-to-bomb variations and release variations will produce significantly different coefficient values. An analysis of the coefficients derived from approximately 50 CBU-58 bombs dropped



C-4. **Typical Damped and Undamped Angle of Attack Time Histories and the Effect on Lift** from an F-16 aircraft exhibited a strong correlation between the force coefficients initial values at time equal to zero and the release Mach number and the release angle of attack. At approximately 3 seconds time of flight, the correlation with angle of attack was weak, but the force coefficients strongly correlated with expected freestream values.

The following equations provide the initial force coefficient values

$$\begin{aligned} C_{DO} &= C_1 + C_2 \\ C_{SO} &= C_3 + C_4 \\ C_{LO} &= C_5 + C_6 \end{aligned} \tag{30}$$

The subscript "O" denotes initial values. The initial values may be related to release Mach (M) and release angle of attack (α) by

$$\begin{aligned} C_{DO} &= M^r\left(a_1 + \frac{a_2}{\alpha} + \frac{a_3}{\alpha^2}\right) + a_4\,\alpha^2 \\ C_{SO} &= M^r\left(b_1 + \frac{b_2}{\alpha} + \frac{b_3}{\alpha^2}\right) + b_4\,\alpha^2 \\ C_{LO} &= M^r\left(d_1 + \frac{d_2}{\alpha} + \frac{d_3}{\alpha^2}\right) + d_4\,\alpha^2 \end{aligned} \tag{31}$$

The coefficients in these equations are determined by linear least squares regression. The results obtained from the CBU-58 test data are shown in Figures C-5 to C-7. These results are plots of the initial coefficients derived from flight test data and the same coefficients predicted by the above equations after the regression. Mach number is the "hidden" variable in these plots.

Additional equations are developed by regressing (linear) C_1 versus C_2, C_3 versus C_4, and C_5 versus C_6. Using the drag force coefficients as an example, the following equations

$$C_D = C_1 + \frac{C_2}{1 + T} \tag{32}$$

$$C_{DO} = C_1 + C_2 \tag{33}$$

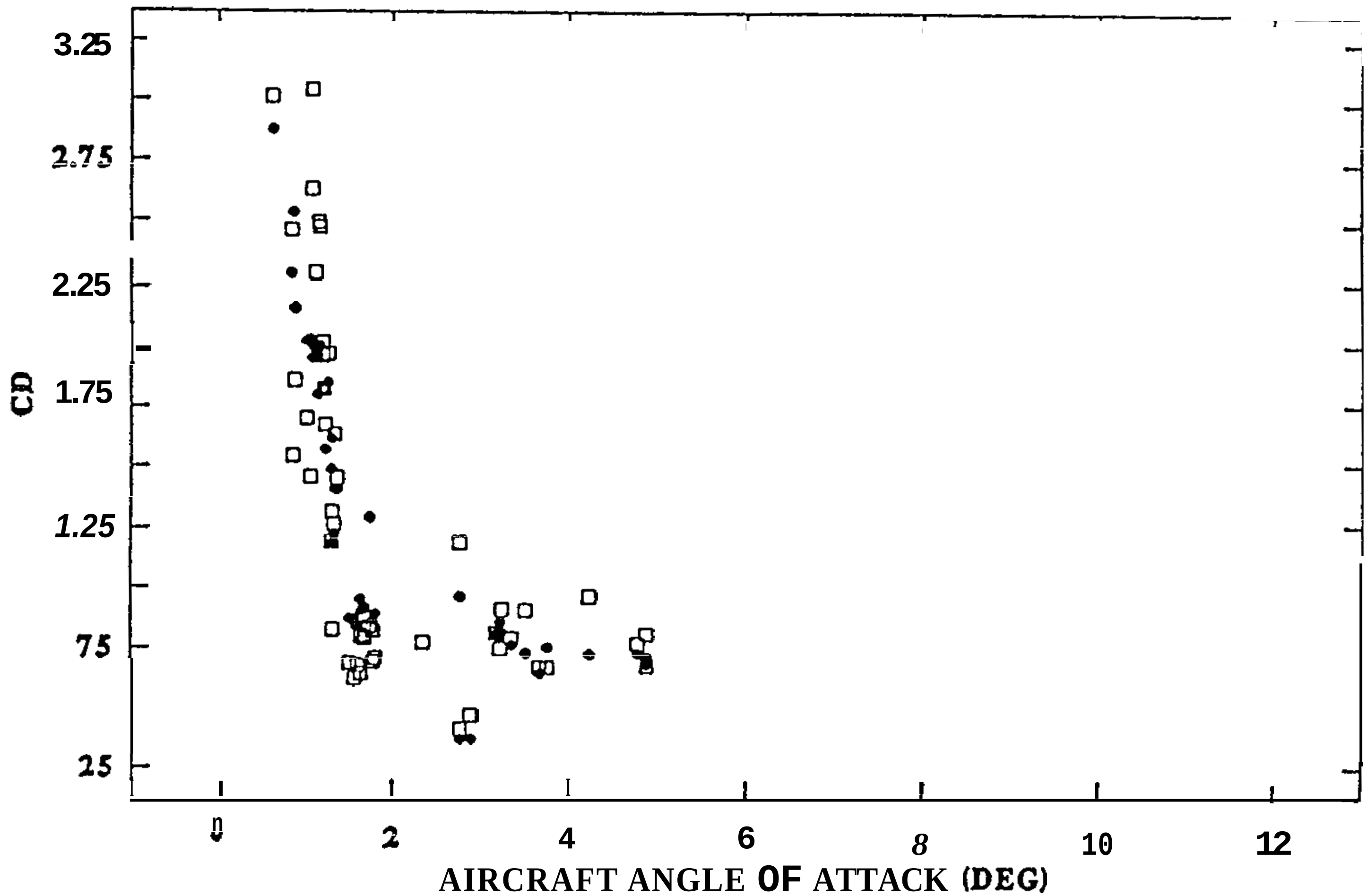
and

$$C_1 = a_5 + a_6\,C_2 \tag{34}$$

have three unknowns, C_D, C_1, and C_2. a_5 and a_6 come from the linear regression of C_1 versus C_2. C_D, derived from the above equations, is

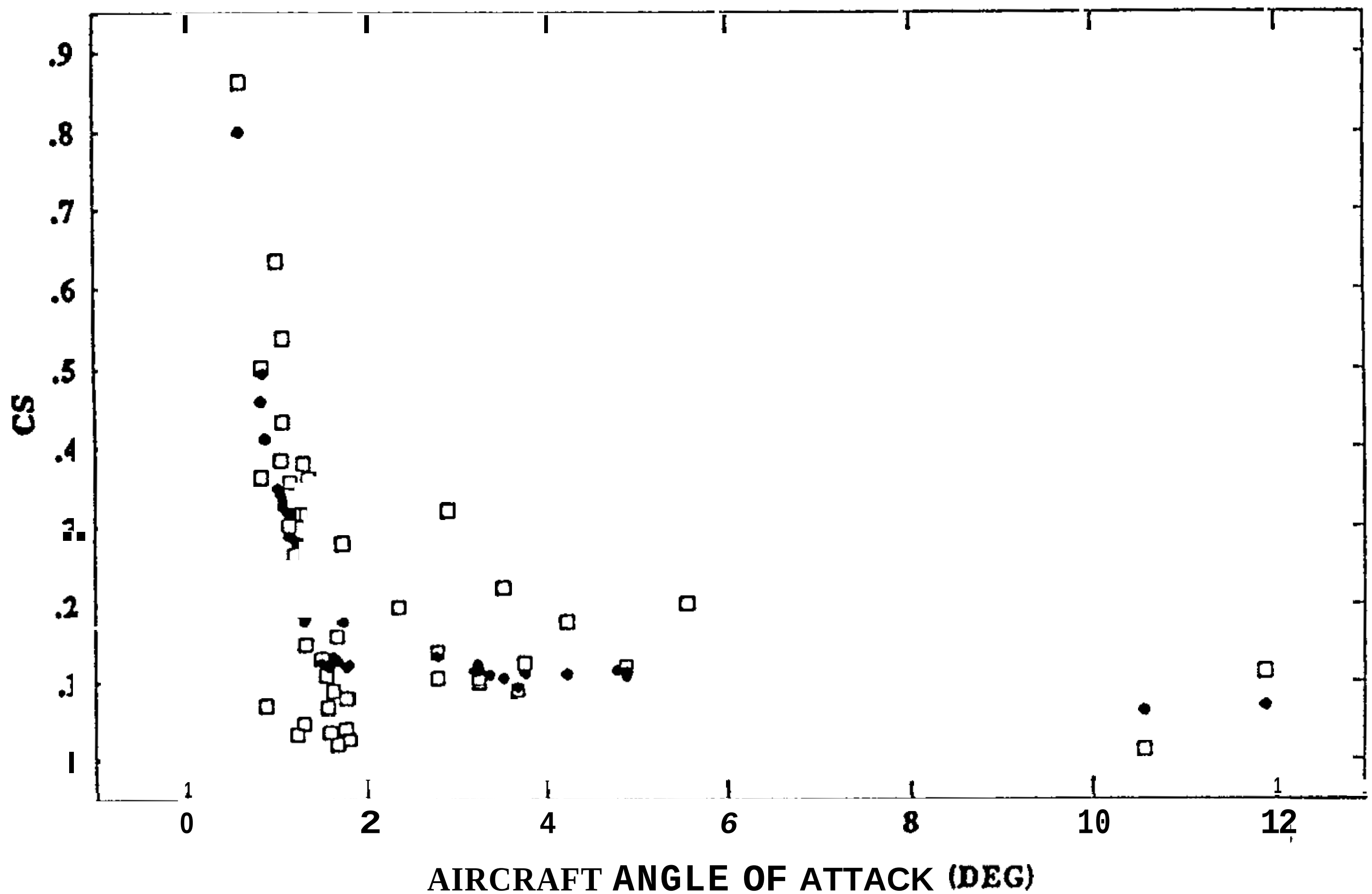
$$C_D = C_{DO} - \frac{C_{DO} - a_5}{1 + a_6}\,\frac{T}{1 + T} \tag{35}$$

INITIAL DRAG COEFFICIENT vs ALPHA



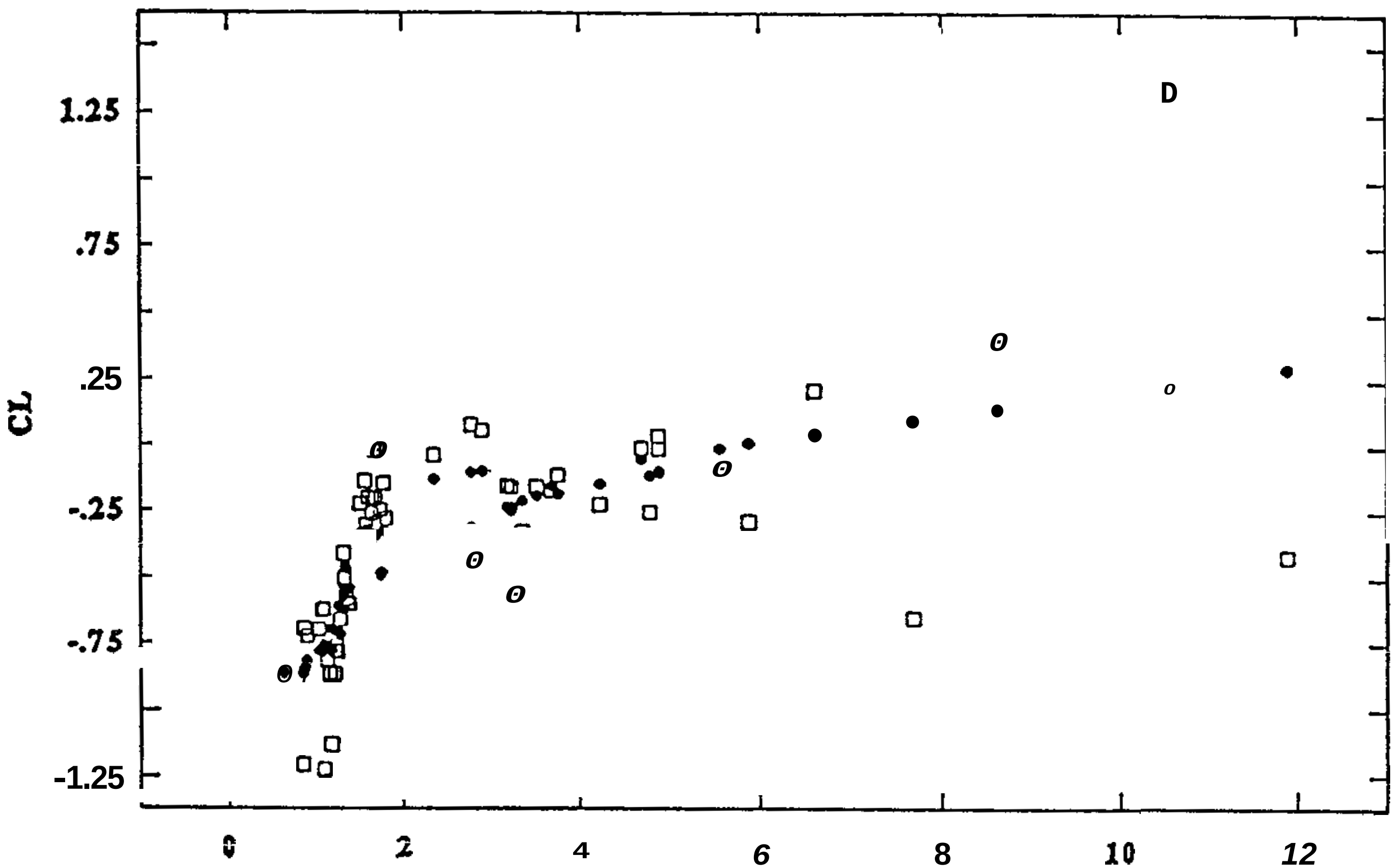
C-5. SEEM Initial Drag Coefficient Versus Angle of Attack

INITIAL SIDE COEFFICIENT vs ALPHA



C-6. SEEM Initial Side Force Coefficient Versus Angle of Attack

INITIAL LIFT COEFFICIENT vs ALPHA



C-7. SEEM Initial Lift Coefficient Versus Angle of Attack

Likewise,

$$C_S = C_{SO} - \frac{C_{SO} - b_5}{1 + b_6} \frac{T}{l + T} \tag{36}$$

$$C_L = C_{LO} - \frac{C_{LO} - d_5}{1 + d_6} \frac{T}{l + T} \tag{37}$$

where b, and b, come from the linear regression of C_3 versus C_4. The coefficients d_5 and d, come from the regression of C_5 versus C_6.

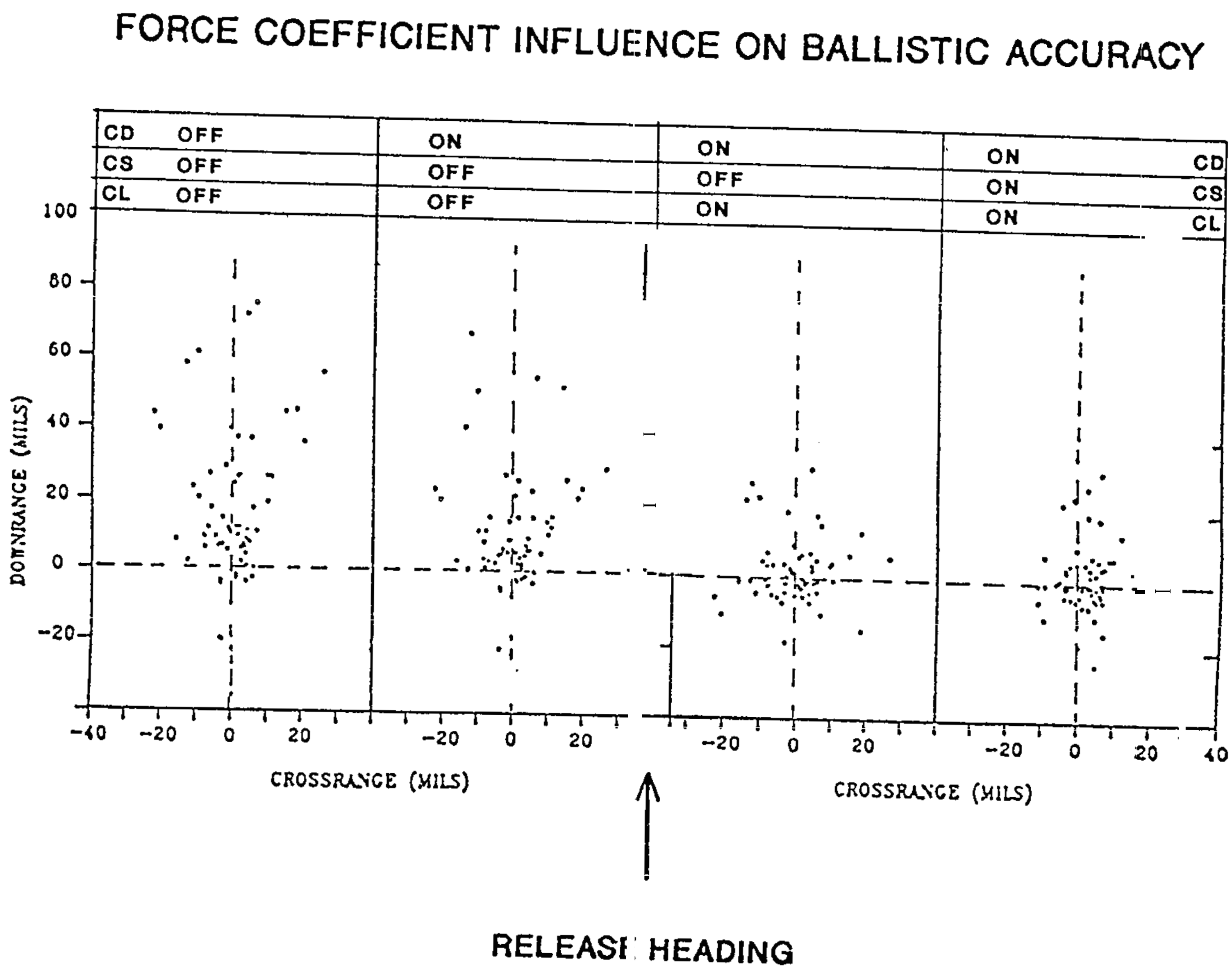
Equations (31), (35), (36), and (37) are used to determine the drag, side force, and lift coefficients for a 3DOF simulation of a bomb trajectory. The role of each force coefficient in improving the 3DOF simulation accuracy is illustrated in Figure C-8. Each dot on the plot is the difference between the 3DOF output and the TSPI at the point of trajectory termination. The first or left-hand frame compares a 3DOF using only freestream drag from release to termination. C,, C_S, C_L indicated as "OFF" means no additional forces are added during separation. The next frame shows the addition of the drag due to separation effects and related conditions.

The maximum payoff from KDEM and SEEM **is** obtained when the programs are used to develop 3DOF ballistics for a new bomb. With sufficient TSPI and bomb diameter and weight data, a user can determine both separation effects force coefficients and freestream drag coefficients. Inputs from similarity analysis or wind tunnels are not needed. Given the TSPI on magnetic tape, a user should be able to complete a 50-bomb drop analysis in less than two working days. The computer program execution time, on a modern mainframe computer, for a SO-bomb drop file is less than 25 seconds. Most of the time required in completing the analysis is used in preparing the input files.

The accuracy of the 3DOF simulations using the KDEM and SEEM coefficients should be on the order of 7.0 mils or less for dispensers like the CBU-58 and 3.0 mils or less for low-drag bombs like the MK 82 LDGP. The following accuracies have been obtained from 3DOF simulations using coefficients derived by SEEM:

AIRCRAFT	BOMB	RACK	BIAS ERROR		RANDOM ERROR (CEP)
			X(mils)	Y(mils)	mils
F-16	CBU-58	TER	0.60	-0.60	7.11
F-16	MK 82 LDGP	TER	0.68	0.90	4.13
F-16	MK 82 LDGP	PYLON	0.88	0.38	2.77
F-4	CBU-52	TER	0.63	0.09	2.64
F-4	MK-20	TER	1.10	0.62	3.81

KDEM produces a high-fidelity estimate of K_D because the process attempts to match the entire freestream trajectory. The convergence criteria is less than a 3-percent change in K_D from the previous iteration. This criteria is much better than adjusting a K_D versus Mach curve until all drops are predicted with less than a given range error of $\pm$SO feet evenly distributed. The miss-distance adjustment criteria had previously shown that the BDU-50 had the same ballistics **as** the MK 82 LDGP. Indeed, the range error difference between BDU-50's and MK 82 LDGP's appear low and insignificant. However, the BDU-SO K_D was at least **23** percent higher. While this difference is insignificant for low-altitude release, it would become significant for high-altitude release.



C-8. SEEM Force Coefficient Influence on Ballistic Accuracy

Impact on Test Requirements

KDEM and SEEM were developed to use the current TSPI. There are three areas where improvements in testing could produce better data not only for these computer programs but for TSPI users in general. The areas of improvement are:

1. On-site and on-time weather measurements.
2. Accurate measurements for the first second of flight.
3. Accurate measurements for aircraft G, Mach number, and angle of attack.

Some tests are conducted with weather measurements from some other site several miles away and several hours prior to, or after, the test. TSPI on a bomb for the first second of flight is usually poor. In fact, SEEM has to ignore any TSPI until 1.2 seconds into the trajectory. The algorithms relating separation effects to bomb release conditions need accurate measurement. Angle-of-attack measurements are critical at low angles of attack. There is considerable force coefficient sensitivity in the low angle-of-attack region as shown previously in Figures C-5 to C-7.

On the other hand, KDEM and SEEM may not reduce the number of bomb drops required to develop an accurate 3DOF model. With perfect measurements, KDEM will determine a **K,** curve that will match the TSPI trajectory from the onset of freestream conditions to impact with little or no error. However, a different drop will produce a different K_D curve because the bomb exhibits its ownunique trajectory. Bombs and bomb trajectories are like snowflakes; no two are identical. Several drops are still required to predict the "average" bomb. Testing must also produce sufficient data to predict the "average" bomb rack and the "average" flowfield effect.

OFP Considerations

The C„, C„, and C_L equations were developed for possible addition to the Onboard Flight Program (OFP). There are no transcendental functions or non-integer exponents in the equations. However, the number of terms or coefficients may be prohibitive. The SEEM computer program also performs linear least squares regression of alternate equation forms for the initial force coefficients. The following forms are also regressed where C_{DO} is used as the example:

$$a.\ C_{DO} = M^r\,(a_1)$$

$$b.\ C_{DO} = M^r\left(a_1 + \frac{a_2}{\alpha}\right)$$

$$c.\ C_{DO} = M^r\left(a_1 + \frac{a_2}{\alpha} + \frac{a_3}{\alpha^2}\right)$$

$$d.\ C_{DO} = M^r\left(a_1 + \frac{a_2}{\alpha} + \frac{a_3}{\alpha^2}\right) + a_4\alpha^2$$

The prediction accuracy of each form is also provided to aid the user in selecting the form to use. Since a, and a_6 are always used, the use of form "a" requires 9 coefficients, form "b" requires 12 coefficients, form "c" requires 15 coefficients, and form "d" requires 18 coefficients. The value of "r" is parametrically set to 0, 1, 2, and 3 to find the best power of Mach.

Another concern of OFP developers is computation time and the number of integration steps needed to accurately integrate the trajectory. Accelerations due to separation forces are high in some cases and may require less than a 0.2-second integration step size for accurate results. Current OFP computers may not be able to accurately compute these high accelerations.

OFP mechanization of these equations may not be the best approach in developing an accurate OFP ballistics model. Another approach is to replace the 3DOF model and integration technique in SEEM with a model of the actual OFP trajectory routine. Modeling errors, mechanization errors, and integration errors would be absorbed in the regressed coefficients.

6DOF Ballistics Development

Several attempts have been made to develop methods to estimate 6DOF aerodynamic coefficients from flight test data. Some of these procedures have been successful in their particular limited application. Aerodynamic parameter estimation techniques are applied in ballistic ranges for gun projectiles, in the wind tunnel for drop model testing, and in aircraft flight testing. In each case the vehicle's flight is at a near-constant Mach number and atmospheric condition. These controlled tests eliminate the need to model the Mach number variation of the aerodynamic coefficients during a flight test. In the case of a free-fall bomb, neither the bomb's Mach number nor the atmospheric conditions can be controlled. The aerodynamic parameter estimation procedure is mathematically more complex. There is no known operational 6DOF ballistics analysis procedure being used for free-fall bombs.

The need to develop a 6DOF ballistic analysis capability is driven by the need to reduce the number of bomb drops and to improve the prediction accuracy of the resultant ballistic models. This need can be met by measuring more of the bomb's state variables and measuring them more accurately. For example, current TSPI measures only translational motion to determine a total K_D which varies from bomb to bomb because atmospheric and physical variations cause each bomb to exhibit a unique total yaw time history. If total yaw angle could be measured in addition to translational motion, then the following drag model could be used.

$$K_D = K_{DO} + K_{D\delta}\,\delta^2$$

K is the drag coefficient at zero yaw angle. $K_{D\delta}$ is the induced drag coefficient caused by the bomb's total yaw angle, 6. The K and $K_{D\delta}$ values should be the same for each bomb drop, given the same Mach number variation during the drop. Thus, only a few bombs are required to determine the ballistic coefficients. However, several more bombs may be required to find the average 6 although a 6 of zero is expected for the "average" bomb.

There is no need to develop a 6DOF ballistic analysis capability if instrumentation capabilities do not exist to measure a state variable from each degree of freedom of the bomb's motion.

Instrumentation

Major advances in instrumentation have occurred in the past ten years. There are technology programs that will produce even more advances within the next ten years. Yet, ballistic analysis procedures are limited to the use of ground-based tracking devices. Even these devices could be enhanced to give better than a 3-foot bomb position measurement accuracy. However, adapting instruments to measure the required state variables is not a straightforward task.

The most desired measurements are the bomb's center of gravity acceleration and the bomb's angular acceleration about each body axis. Instruments to make these measurements must be precisely located at the bomb's center of gravity and precisely aligned with each body axis. Thus, a special modified bomb with the embedded instruments is needed. These instrumented bombs would he costly and, therefore, may he undesirable. Instruments located elsewhere in or on the bombs are subject to coupling effects of angular and translational motion. That is, a fixed point in a translating and rotating reference frame (bomb body axes) has an inertial acceleration of

$$a = a_o + \omega \times (\omega \times r)$$

where a_o is the inertial translational acceleration of the axis system origin, ω is its angular rate, and r is the position vector to the point. If a linear accelerometer is placed with its input axis parallel to the x-body axis, then the accelerometer would measure

$$a = a_{xo} - x\left(q^2 + r^2\right) + y\left(pq - \dot{r}\right) + z\left(pr + \dot{q}\right)$$

where

a = accelerometer output
a_x = the non-gravitational **x** component of the bomb's acceleration
p,q,r = components of the angular velocity; roll, pitch, and yaw respectively
x,y,z = location coordinates of the accelerometer

This measurement could not be used as the acceleration of the bomb's center of gravity directly. With measurements of the angular rates and acceleration, a derived center-of-gravity acceleration can be obtained. An alternate technique may locate two linear accelerometers on the x-axis at different points. The two measurements permit a derivation of the x-component of the center-of-gravity acceleration.

Instrumentation location and subsequent derivation of the desired state variables from these measurements can be determined. Most instrumentation locations will be in a modified nose fuze, a tail fuze, and in the tail/fin assembly. With solid-state microcircuitry, some very small and reliable linear and angular accelerometers and gyros are likely available for this application. One ongoing technology program is developing a very thin wafer than contains inertial sensing devices. This program may produce a "peel and stick" inertial sensor.

Instrumentation performance requirements are to be defined. Some requirements are severe while some are relatively benign. Gyro drift rate errors may be tolerated at large values since measurement durations will likely be less than 5.0 seconds. An extreme duration would be 30 seconds. Scale factory error or g sensitivity for linear accelerometers may have to be extremely low. The highest angular rate of a bomb is its spin rate which could be as high as 600 rpm. **A** point on the surface of the bomb where an accelerometer could be located may have as much as 100 g's acceleration.

Analysis Methods

Analytical methods to estimate 6DOF aerodynamic coefficients from the measured motion of the bomb are being developed. Most of the software needed can be readily developed. However, there are software interfaces needed with the instrumentation suite. The software must interface with the variables that are being measured. There are numerous combinations of state variables in either earth-fixed axes or in body-fixed axes that are suitable for the estimation process. For example, it is possible to use current TSPI and body-fixed strap-down gyros to obtain position data in the earth axes and angular rate data in the body axes. Any combination is suitable as long as there are measurements from each degree of freedom of body motion.

The analytical methods should be similar to the 6DOF parameter estimation procedures in use today. However, for free-fall weapons, the aerodynamic coefficient must be modeled as a function of Mach number, angle of attack, and angle of yaw for each drop. **A** mathematical model having three independent variables may be too difficult to construct. A reasonable approach is to model the time variation of the aerodynamic coefficient as a polynomial and, given the polynomial, correlate the coefficient with Mach, angle of attack, and of yaw at the same time marks.

Regardless of the technique used, the mathematics are complex but not impossible. Although large *size* matrices are involved, there are sufficient computer memory and computing speed to solve the problem.

The primary focus of both the instrumentation and the analytical methods is to determine and model the bomb motion during the first **2** to **3** seconds of flight. The resultant ballistics model at the 6DOF level may be suitable for computer mainframe applications such as generating bombing tables. Much less sophisticated ballistics modeling is needed for OFP applications, at least until much larger and faster OFP computers are available. Such models can be developed from the more sophisticated 6DOF model.

Impact on Test Requirements

The number of flight tests should be significantly reduced, but the number of personnel involved during bomb loading will increase. The number of personnel will be approximately the same number as required by any instrumented weapon that is released from an aircraft. In addition to the regular ground crew, instrumentation checks will have to be made by instrumentation technicians.

The loading time will be increased by the amount of time required to complete the instrumentation checklist. Data reduction time may be reduced if phototheodolites are not part of the instrumentation suite. Film reading is a time-consuming task.

Payoffs

The highest expected payoff is more accurate ballistic models. The ballistic prediction error should have a **zero** mean and a CEP no larger than the natural ballistic CEP of the weapon.

The next payoff should be in the number of bomb drops required. The complete freestream 6DOF ballistics can be determined with a few bombs. However, separation variations could increase this number four-fold. The problem here is that the 6DOF capability cannot account for the variations in the hardware. It only determines the aerodynamic coefficients needed to predict the measured bomb motion.

Payoffs in time are likely because most of the analyses will be accomplished on a computer, and there will be fewer flight tests.

A cost savings may be the least expected payoff. While flight costs, personnel costs, and data reduction costs are expected to be lower, the instrumented bomb cost will be higher. How much higher depends on the types of instruments and their accuracy requirements. Instrument price is usually proportional to instrument precision.

APPENDIX D

BALLISTIC SENSITIVITY ANALYSES STUDY FOR CBU-58 AND MK 84 LDGP STORES

Office for Aircraft Compatibility
3246th Test Wing/TY
Eglin Air Force Base, Florida 32542-5000

January 1990

Introduction

A ballistic sensitivity analysis determines the impact error caused by an error in the nominal value of a bomb input parameter or a release parameter. The magnitude of the impact error divided by the magnitude of the parameter error is the error's ballistic sensitivity. Such analyses are performed by using a GDOF computer program and by inputting incremental changes to those input parameters identified as having an error. These parameters may include bomb weight, moments of inertia, aerodynamics, ejection velocity, release timing error, and numerous others. If the input parameter can have an error, it is referred to as an error source. Virtually all inputs are potential error sources, but some are prone to occur more often than others. It is the random combination of these errors from bomb to bomb that produces the bomb's ballistic dispersion. If the magnitude of the error sources is known, a large number of random combinations (Monte Carlo trials) should produce a theoretical estimate of the bomb's ballistic dispersion.

Theoretical estimates of a bomb's dispersion are beneficial during the design phase and production phase of the bomb. Using ballistic sensitivity analyses, a bomb may be designed to have minimum dispersion when released from a specific aircraft. The GDOF methodology, in this case, must have aircraft flowfield interference methods. In general, design specifications can be set so that the freestream dispersion will be less than a given value.

If a production bomb exhibits an undesired level of dispersion, a ballistic sensitivity analysis could identify the error sources most likely to be causing the undesired dispersion. Such an analysis can also evaluate a proposed product improvement to minimize or eliminate a given error source. While the sensitivity to one error source may be large, its removal from the possible combinations of errors may have little effect on reducing the bomb's dispersion.

If a new bomb is being certified for release from a particular aircraft, a ballistic sensitivity study should be performed using design specification tolerances for error source magnitude. Excessively large dispersions could indicate that the design tolerances, in combination with the aircraft's flowfield, may produce erratic and possibly dangerous separation dynamics. If the theoretical dispersion estimates appear acceptable, the dispersion value may be used in test planning to determine the number of bomb drops required to realistically determine the bomb's dispersion.

In developing ballistic coefficients and other ballistic algorithms, the process continues until a minimum ballistic prediction error is reached. The random component of ballistic prediction error cannot be less than the bomb's natural dispersion. When developing ballistics for a new bomb, this limiting value can be useful. If the ballistics data and algorithm produces a ballistic prediction error that is several magnitudes above the theoretical estimate, the ballistician needs to seek alternate algorithms and possibly request other tests.

The following sections present data from a recent ballistic sensitivity analysis study. Data were generated using the Ballistic Error Assessment Model (BEAM) computer program. Results of this study indicate that the CEP for the CBU-58 when released from a modern tactical fighter aircraft should be less than 6.9 mils, and the CEP for the MK 84 should be less than **2.3** mils.

Weapon Manufacture Errors

These errors are primarily errors in the bomb weight, center of gravity location, and the moments of inertia. This group of errors could be responsible for as much as 4.6 mils CEP for the CBU-58, but only 0.10 mil CEP for the MK 84 LDGP. The most sensitive error source in this group is the transverse location of *the* center of gravity. An error of 0.3 inch (standard deviation) in either the y- or z-axis components produces a 4.0-mil CEP. For dispenser-type bombs, this type of error may be prevalent because the submunitions may shift during storage and carriage.

Aircraft/Rack Errors

This group of errors includes release timing errors, pylon alignment errors, and ejection rack errors. The timing error is the error in time from the cockpit switch to the ejection cartridge ignition. The pylon alignment error is an error in the bomb's initial pitch and yaw angles relative to the aircraft. The ejection rack errors include a lengthy list of possible errors because the BEAM computer program includes a fairly detailed simulation of the ejection rack interior ballistics and resulting forces and moments imparted to the bomb. These error sources could contribute 0.9 mils for the CBU-58 released from a multiple bomb rack (i.e., the TER-9) and 3.4 mils when released from a parent pylon bomb rack (i.e., MAU-12). The MK 84 LDGP's CEP could be 0.7 mil when released from the MAU-12.

The most sensitive source of error in this group is the ejection rack. The MAU-12 sensitivity is higher than the TER-9 because the MAU-12 imparts larger forces and moments and has more components included as error sources. The MAU-12-induced CEP is 3.3 mils for the CBU-58 and 0.66 mil for the MK 84 LDGP.

Atmospheric Errors

Atmospheric errors include errors in air density, air temperature, wind magnitude, and wind direction. This group of errors in the real world are correlated and quite variable. The BEAM computer program includes a weather model which generates a typical weather profile as a function of altitude for a random day of the year. Thus, the sensitivity defined here is the sensitivity to day-to-day weather change. The sensitivity was determined from 75 random days or weather files. These files were used to compute 75 trajectories having the same initial conditions. The dispersion obtained was 3.25 mils CEP for the CBU-58 and 1.75 mils CEP for the MK 84 LDGP.

Aerodynamic Errors

This group of errors include aerodynamic force, restoring moment, and damping moment variations. These errors are due to body shape variations, fin and nose misalignments, surface texture variations, and lug height variations. In the BEAM computer program, any aerodynamic force variation that does not act through the center of gravity also produces a moment variation. Rather large aerodynamic forces can act through the center of gravity and cause little variation in the dispersion. A force standard deviation equivalent to 6.7 pounds (5 percent of freestream) acting through the CBU-58 center of gravity and parallel to the x-axis produces a 1.0-mil CEP. Only a 0.32-pound force variation acting normal to the x-axis and on the surface of the bomb produces a 3.0-mil CEP. Similar forces on a percentage basis produces only a fraction of a 1.0-mil CEP for the MK 84 LDGP.

Another source of error is the aircraft's flowfield. The causes of variations in the flowfield are speculative because the problem is complex. Given the same atmospheric conditions, the same aircraft altitude, and the same aircraft configuration, there should be no variation in the flowfield. Wind tunnel testing would prove this statement. However, no two aircraft are identical, stores are suspended with variations, and pilots fly the aircraft differently. Regardless, the study shows that if there is a 5-percent variation in the aerodynamics describing the flowfield, the effect on CEP is 0 S mil for the CBU-58 and 1.33 mils for the MK 84 LDGP,

Impact on Testing

This ballistic sensitivity study shows:

a. Dispenser-type stores are sensitive to transverse center-of-gravity errors, MAU-12 releases, aerodynamic moments, and the weather.

b. Low drag heavy bombs are insensitive to expected variations in their aerodynamics and physical properties. Most of the sensitivity comes from the weather, the flowfield, and the MAU-12.

The study could recommend changes to *the* testing procedures which could reduce the level of ballistic dispersion. But this measured dispersion would not represent *the* real world and could only be referred to as a "test" dispersion.

The study does show that the **MAU-12** needs to be serviced **and** inspected to reduce its effects on *the* test CEP. The weather should be measured accurately and timely to reduce its effects on *the* test CEP. Transverse measurements of *the* bomb's center of gravity may eliminate some "wild" dispensers like *the* **CBU-58** before they are dropped. Such eliminations would reduce *the* test **CEP.**

APPENDIX E

METHOD OF TEST ANNEX

TEST DIRECTIVE 2671AL71

BLU-107/B PARENT CARRIAGE ON F-16A/B AIRCRAFT

Office for Aircraft Compatibility
3246th Test Wing/TY
Eglin Air Force Base, Florida 32542-5000

25 July 1988

1.0 INTRODUCTION

This Method of Test (MOT) Annex identifies test procedures and related data collection, reduction, and analysis requirements to accomplish stated test objectives. The 3246 Test Wing, Eglin AFB, Florida, is the designated RTO. The test is designed in response to 3246 TESTW/TY letter, dated 26 May 1988, subject: Work Request (WR) for **BLU-107/B** Parent Carriage on F-16A/B Aircraft. An AD technical report will be required.

1.1 Background/Overview

1.1.1 Headquarters Tactical Air Command has identified a requirement (TAC Certification Request 4-86) to certify the BLU-107 (Durandal) parent carriage on F-16A/B aircraft. The testing to be accomplished under Test Directive (TD) 2671AL71 will provide data to support certification for carriage and employment of the BLU-107 on the F-16 parent pylons. The certification recommendations will be made by 3246 TESTWRY.

1.1.2 The scope of testing under TD 2671AL71 will encompass assessment of sway brace pad torquing, captive compatibility flights, flutter investigations, and aircraft/munition separation demonstrations. Time-Space-Position-Inforation (TSPI) will also be collected on BLU-107 munitions released from F-16 aircraft.

1.1.3 The test missions to be conducted are outlined in the mission summary attached to this MOT Annex (Attachment 1). Applicable flight test configurations and related flight clearance/limits are as established by 3246 TESTWRY.

1.1.4 The AD Airborne Test Review/Safety Board (ATR/SB) will act as final authority (ref. ADR 127-2) on the safety aspects of the flight test missions associated with the test. The flight tests will be conducted over authorized AD test areas using standard flight profiles.

1.2 Test Objectives

1.2.1 Evaluate the new loading procedure for torquing sway brace pads one half turn beyond initial contact.

1.2.2 Demonstrate captive carriage compatibility of BLU-107/B munitions on F-16 aircraft to be prescribed flight limits using a specified aircraft/weapon flight test configuration and flight profile.

1.2.3 Collect flutter flight test data on specified F-16/external store configurations involving the carriage of BLU-10703 munitions.

1.2.4 Demonstrate the release and separation of BLU-10703 munitions released from F-16 aircraft using specified aircraft flight test configurations and munition release conditions.

1.2.5 Collect ballistics data (TSPI) on BLU-107/B munitions released from F-16 aircraft.

2.0 TEST ITEM DESCRIPTION

2.1 Primary Test Aircraft. A detailed description of the basic F-16 aircraft may be found in USAF Technical Order 1-F-16A/C-1. Specific requirements related to this test are identified below.

2.1.1 Captive Carriage Investigations. Any F-16 aircraft may be used other than instrumented F-16 flutter flight test aircraft.

2.1.2 Flutter Investigations. An AD F-16 aircraft with an operable onboard instrumentation system for flutter flight tests will be required. PDAS and HUD recording capability (selected aircraft performance parameters) will also be required. NOTE: All BLU-107 flutter missions must he performed on the same flutter instrumented F-16.

2.1.3 **Aircraft/Munition** Separations. The F-16 aircraft used for the conduct of this phase of the test (F-16 flutter-instrumented aircraft excluded) must have an appropriate onboard motion picture capability, i.e., AIM-9 camera pods and strake/chaff cameras to provide photographic coverage of the aircraft/munition separation events. NOTE: It will be essential that TFOA personnel keep the GADS office (KRT) informed of camera/lens combination changes that occur after the initial setup and calibration of the F-16 onboard camera system.

2.2 **BLU-107/B** Munition. The BLU-107/B is a parachute retarded, rocket boosted, concrete penetration bomb designed for low-level release against airfield targets. Physical properties pertaining to the BLU-107/B are reflected in Attachment 2 to this MOT Annex. The BLU-107/B munitions provided for this test are to be configured with inert warheads and live rocket motors.

3.0 INSTRUMENTATION (Ground and Airborne Facility Requirements)

Existing facilities/capabilities identified in AD Technical Facilities Manuals, Vol 1 and Vol 2, are adequate to support this flight test. Applicable technical requirements/procedures are detailed in the Technical Support Annex (Annex B) to this Test Directive.

4.0 OBJECTIVES, PROCEDURES, AND DATA

4.1 Captive Carriage Investigations. (Ref. Para. 1.2.1 and 1.2.2, Test Objectives.)

4.1.1 Purpose. An abbreviated captive compatibility test mission is conducted primarily to demonstrate the structural integrity aspects of a given flight test configuration. The structural integrity of the MAU-12/BLU-107 combination during flight after being subjected to a decreased torquing of bomb rack sway brace pads (one half turn after initial contact versus one full turn, normally) will be an area of particular interest on the first captive flight test mission (ref. Msn No. 1, Atch 1 to this MOT Annex).

4.1.2 Method

4.1.2.1 Procedure

4.1.2.1.1 It is to be noted that on the first captive test flight (Msn No. 1) the effectiveness of a non-standard sway brace tightening procedure is to be evaluated. The BLU-107 is to be loaded on the MAU-12 bomb rack with the sway braces tightened only one half turn after initial contact. Loading checklists are to he coordinated through 3246 TESTW/TYDD prior to scheduling any flying missions.

4.1.2.1.2 Mass properties measurements will he made and recorded as part of the test records with respect to the weight, c.g. location, and moments of inertia (pitch and yaw) of the BLU-107 munitions provided for the test. Mass properties measurements for other external stores will also be accomplished as needed and the results recorded as part of the test records. Items with mass properties different from those indicated in the 3246 TESTW/TY Flight Clearance letter must be cleared by 3246 TESTW/TY prior to scheduling a flight test mission.

4.1.2.1.3 The specific aircraftlexternal store flight test configurations and pertinent test conditions (ref. Mission Detail column, Mission Summary) for the planned captive flights are outlined in Atch 1 to this MOT Annex. The assigned **3247th** Test Pilot will construct and fly an appropriate captive flight profile to accomplish the flight requirements outlined for these missions.

4.1.2.1.4 After each captive carriage flight, the munition/aircraft combination will be visually inspected for indications of looseness, cracking, or material failure. The physical security of arming and/or fin release lanyards will he checked during the inspection. Any discrepancies will be documented photographically. (NOTE: 3246 TESTWITY will be presented when the aircraft munition loading is inspected prior to and after each captive test flight.)

4.1.2.1.5 The pilot conducting the captive compatibility investigation will provide, as part of the test records, a written report describing the actual flight profile performed, including maneuvers, airspeeds, and g-loads demonstrated during flight. Any aircraft-handling problems peculiar to the flight test configuration flown or aircraft system malfunctions that adversely affected the outcome of the flight test mission will also be documented in the report.

4.1.2.1.6 The pilot of the chase aircraft will be responsible for advising the pilot of the primary test aircraft of any problems observed with the F-16/external store configuration during captive carriage. As part of the test records, the chase pilot will provide a written report of his observations should problems be encountered with the F-16 flight test configuration.

4.1.2.1.7 As part of the test records, the aircraft flight test configuration for captive carriage investigations will be documented by still photographs as requested by the test engineer.

4.1.2.2 **Criteria.** Acceptance criteria for captive compatibility flights will be in consonance with Para. 250.4, Test 250, MIL-STD-1763. Criteria for success of the sway brace tightening procedure will be on the basis of observations by test personnel that during flight all sway brace pads remained tightened/intact and that the physical integrity of the sway-brace pads was not adversely affected, i.e., no fractures or breakage.

4.1.2.3 **Resources Required.** Principal resource requirements related to captive carriage flight test investigations will include:

4.1.2.3.1 F-16 aircraft and assigned 3247th flight test pilot

4.1.2.3.2 Safety chase aircraft

4.1.2.3.3 Tanker aircraft

4.1.2.3.4 BLU-107/B test munitions

4.1.2.3.5 Munition loading checklists

4.1.2.3.6 3246th Munition Maintenance Squadron support (load crews)

4.1.2.3.7 Munition handling/uploading equipment

4.1.2.3.8 Water test area

4.1.2.3.9 CCF (monitor/communications with primary test aircraft)

4.1.2.3.10 Still documentary photography

4.1.2.3.11 Mass properties measurement facility (Bldg 990)

4.1.2.4 **Data Records.** Pertinent test records (data sources) will be:

4.1.2.4.1 Test pilot's flight test mission report (1 copy to 3246 TESTW/TY)

4.1.2.4.2 Test engineer's flight test mission records, including results of postflight inspection of aircraftlmunitionslswaybraces and any related photography.

4.1.2.4.3 Still documentary photographs (flight test configurations). Two sets of prints to 3246 TESTWRY.

4.1.2.4.4 Mass property records (munitions). 1 copy to 3246 TESTW/TY.

4.1.2.5 **Data Reduction:** None

4.1.2.6 **Data Analysis.** Pilot's test mission reports and test engineer's test mission notes will be reviewed and assessed for evidence of adverse physical integrity of the MAU-12 rack/BLU-107 munition combination as the result of captive carriage flight. The adequacy of the sway brace tightening procedures employed for the captive flights will be evaluated. Evidence of any conditions that may have adversely affected aircraft handling characteristics or safety of flight as a result of the captive carriage of the BLU-107 munitions on the F-16 aircraft will also be ascertained.

4.1.2.7 **Summary of Missions.** Ref. Mission No. 1 and Mission No. 2, Atch 1 to this MOT Annex.

4.1.2.8 **Potential Hazards.** No safety hazards are envisioned that would elevate risks above those normally associated with captive flight investigations, i.e., not categorized **as** high risk flight test mission (ref. ADR 127-2).

4.2 **Flutter Test Flights. (Ref.** Para. 1.2.3, **Test Objectives)**

4.2.1 **Purpose.** To collect quantitative flight test data *to* establish Limit Cycle Flutter (LCF) onset and decay for selected F-16/BLU-107 flight test configurations flown within a prescribed flight envelope.

4.2.2 **Method.**

4.2.2.1 **Procedure.**

4.2.2.1.1 Mass properties measurements will be made and recorded as part of the test records with respect to the weight, c.g. location, and moments of inertia (pitch and yaw) of the BLU-107 munitions provided for the test. Mass properties measurements for other external stores will also be accomplished as needed and the results recorded as part of the test records. Items with mass properties different from those indicated in the 3246 TESTW/TY Flight Clearance letter must be cleared by 3246 TESTWITY prior to scheduling a flight test mission.

4.2.2.1.2 Approved munition loading checklists (ref. AFSCR 66-1 and ADR 136-3) and aircrew preflight/postflight checklists (ref. ADR 127-2 and AD Sup 1 to AFSCR 80-33) must be available prior to the start of flight testing.

4.2.2.1.3 Use of a safety chase aircraft in support of flutter test flights will be commensurate with ATR/SB requirements. Aerial tanker support may be used to extend flight duration for primary and/or chase aircraft.

4.2.2.1.4 The pertinent flight test configurations and related data points for the flutter investigations are shown in Attachment 1 to this MOT Annex.

4.2.2.1.5 The Centralized Control Facility (CCF/TELEMAG), Bldgs 380/381, will be required to receive and record time correlated telemetry (TM) signals. Selected TM parameters will be required to be displayed in real time for analysis by 3246 TESTW/TY flight test specialist. A dedicated radio frequency will be required for mission control purposes. Direct and frequent communication between mission controller/flight test specialists and the pilot of the F-16 primary test aircraft is essential ***for an*** instant abort notification on a test point. All test related ground/aircraft communications will be recorded (time correlated) for subsequent playback in conjunction with post mission data analysis, if required.

4.2.2.1.6 Ground-based radar will be used as required to vector/control and/or track the **F-16** primary test aircraft during the conduct of the flutter investigations. Requirements for primary TSPI data recording and/or secondary radar pen plots will be as specified by the test engineer.

4.2.2.1.7 The **F-16** primary test aircraft will be prepositioned at a prebriefed altitude and airspeed over the authorized AD test area prior to execution of the first flight test maneuver in the flight test mission profile. Initiation of an investigation at a given test point will be communicated by the TZG Test Engineer at the CCF. Upon assessment of the real-time displays during the execution of a test point, the flight test specialists at the CCF in conjunction with pilot qualitative assessments will determine whether the pilot of the **F-16** primary test aircraft will repeat a test point or proceed to another selected test point in the flight test mission profile. Until the go-ahead is given to establish the next test point, the pilot of the **F-16** primary test aircraft will loiter at his discretion at a safe airspeed/altitude. NOTE: TY flight test specialist will require hard copies of CRT displays when critical performance limits are approached.

4.2.2.1.8 An abort of a test point will be based on the judgment of the pilot and/or the flight test specialists at the CCF observing real-time displays of the frequency and amplitude of selected parameters. If an abort is called, the pilot is to immediately cease the test maneuver and enact the appropriate abort procedure established at the pilot preflight briefing. The **F-16** primary test aircraft may then loiter until further instructions are received. If a radio failure occurs, the flight test mission will be stopped and the **F-16** primary test aircraft will return to base within the safe return airspeed envelope.

4.2.2.1.9 Upon landing after each **F-16** flutter test mission, the aircraft/external store flight test configuration will be visually inspected for indications of external store looseness/structural integrity. Inspection results will be documented by the test engineer as part of the test records.

4.2.2.1.10 The TY flight test specialists who will be working at the **CCF** during the flight tests must participate in the preflight briefing of the pilot of the primary **F-16** test aircraft. Test pilot briefings will include the specific flight maneuvers to be accomplished, the identificalion and discussion of the critical data points to be attempted, pertinent flight envelope restrictions, and test procedures/decision criteria. Concise terminology for executing an abort of a test point will be established also. **A** postflight debriefing of the **F-16** test pilot for flight test engineering personnel will be established by the test engineer as deemed necessary.

4.2.2.1.11 As part of the test records, the test pilot of the **F-16** primary test aircraft will provide the test engineer with a written flight test report upon completion of each test flight. Any problems with aircraft handling qualities/characteristics will be identified. Awareness/evidence of uncharacteristic oscillations, vibrations, noise, buss, flutter, or other dynamic aeroelastic instabilities during the accomplishment of **test** points will be noted and reported. Deviations between actual and briefed test points will be documented. Weather or air turbulence conditions that adversely affect the results of the test flight will be identified. Any problems experienced with respect to the operation of onboard instrumentation, ground/air communication, or test mission control procedures will be identified also.

4.2.2.1.12 The TZ test engineer will maintain a flight test log to include a record of the flight test configuration, related munition mass properties, total flight time, and test points completed. Pilot flight test mission reports will be included as part of the flight test log. Any deficiencies occurring in airborne systems or ground support that adversely affected the conduct of the missions will be recorded. As part of the test records, still descriptive photographs will be made to document flight test configurations and test setup, including aircraft instnunentation installations and supporting test site equipment/displays used in the conduct of the test.

4.2.2.2 Criteria. Acceptance criteria with respect to the outcome of the flutter investigations will be in consonance with paragraph **210.4,** Test **21, Flutter Tests, MIL-STD-1763.**

4.2.2.3 Resources Required. Principal resource requirements related to acquisition of flutter flight test data will include:

4.2.2.3.1 Flutter-Instrumented F-16 aircraft and assigned 3247th flight test pilot

4.2.2.3.2 BLU-107 munitions

4.2.2.3.3 Associated external stores (inert AIM-9P, L missiles; external fuel tanks)

4.2.2.3.4 External stores loading checklists and external store handling/loading equipment

4.2.2.3.5 3246th MMS support (load crews)

4.2.2.3.6 3246 TESTW/TFES support (airborne instrumentation)

4.2.2.3.7 Penthouse (Bldg 130) telemetry support

4.2.2.3.8 CCF/TELEMAG (telemetry recordingldisplay)

4.2.2.3.9 Computer Sciences Directorate (KRB) support (data reduction)

4.2.2.3.10 AD Water Test Area

4.2.2.3.11 Ground radar monitor/control (primary test aircraft)

4.2.2.3.12 Chase aircraft

4.2.2.3.13 Aerial tanker support

4.2.2.3.14 Precision Measurements Facility (Bldg 990)

4.2.2.3.15 Still documentary photography

4.2.2.4 **Data Records.** Pertinent test records (data sources) will he:

4.2.2.4.1 Aircraft onboard recording (PDAS/HUD)

4.2.2.4.2 Telemetry/Recording (ground TM site)

4.2.2.4.3 Telemetry **real** time stripout records

4.2.2.4.4 Hard copies of CRT displays

4.2.2.4.5 Ground/air communications recordings

4.2.2.4.6 Radar monitoring/tracking plots (if applicable)

4.2.2.4.7 Test pilot's flight test mission reports

4.2.2.4.8 Test engineer's flight test records

4.2.2.4.9 Mass Properties records (munitions/external stores) 1 copy to 3246 TESTW/TY

4.2.2.4.10 Still descriptive photography

4.2.2.5 **Data Reduction**

4.2.2.5.1 Format and time intervals for telemetry data reduced from magnetic tapes will be as established by TY and/or TFE. (NOTE: The real-time displays of the selected parameters during flight should normally suffice for the flight investigations. Otherwise, reduction of data from the magnetic tape would be limited to selected TM stripouts for instrumentation checks to verify that all parameters were recorded during flight. Copies of reduced telemetry data are to be made available as follows: 2 copies to TY, 2 copies to TFES.)

4.2.2.5.2 Primary radar TSPI (if applicable) will be reduced only at the request of the test engineer. Any secondary data pen plots will be forwarded to the test engineer as part of the test records.

4.2.2.5.3 PDAS recordings will he reduced as necessary to verify selected aircraft performance parameters.

4.2.2.6 Data Analysis

4.2.2.6.1 Real time displays of flutter data and any related data will be used by 3246 TESTW/TY is assessing flight test values with respect to analytical predictions for each respective aircraft test configuration. Lack of aeroelastic stability/damping at a given test point will be identified. Limiting airspeeds for a given aircraft/external store configuration will be established, as required. Certification recommendations related to safe carriage of BLU-107 munitions of F-16 aircraft will be the responsibility of 3246 TESTW/TY.

4.2.2.6.2 The test engineer's flight test records and test pilot's flight test reports will be used to identify/corroborate test item deficiencies or aircraft system or instrumentation malfunction that adversely affected test results.

4.2.2.6.3 Playback of voice recordings or HUD video will be accomplished as necessary in resolving data assessment problems.

4.2.2.7 Summary of Missions. Reference Mission No. 3 and Mission No. 4, Atch 1 to this MOT Annex.

4.2.2.8 Potential Hazards. Flight hazards which are normally associated with flutter investigations will be minimized by adherence to the existing 3246 Test Wing letter, dated 12 November 1985, Subject: Uniform Abort Policy for F-16 Limit Cycle Flutter (LCF) Flight Testing. This letter imposes flight parameter limits related to limit cycle phenomena during F-16 flutter testing.

4.3 Aircraft/Ordnance Separation Missions (Re. Para 1.2.4 and 1.2.5, **Test Objectives)**

4.3.1 Purpose. The conduct of aircraft/ordnance separation test missions is to demonstrate the separation characteristics of a given ordnance when released/launched/jettisoned from the aircraft under prescribed flight conditions. Time-Space-Position Information (TSPI) on the aircraft prior to weapon release and on the weapon at release and during separation/fallaway from the aircraft will be used in addressing ballistic/trajectory characteristics.

4.3.2 Method

4.3.2.1 Procedure

4.3.2.1.1 Weight, center of gravity location, and moment of inertia (pitch and yaw) will be verified and recorded as part of the test records for those munitions used in the conduct of aircraft/munition separation flight test investigations NOTE: Items with mass properties different than those prescribed by 3246 TESTW/TY within their related flight clearance letter must be cleared by TY prior to scheduling for upload on the aircraft.

4.3.2.1.2 Meteorological records will be required as part of the ballistic data acquisition effort. The required meteorological data are to be provided as outlined in TZP Standard **76-01.**

4.3.2.1.3 Boresights of onboard cameras for documenting aircraft/munition separation events must be checked and maintained during this phase of the flight test. NOTE: It is essential that the GADS office (KRB) be informed by TFOA instrumentation personnel of camera/lens combination changes that occur after the initial setup and calibration of the camera system of the **F-16** primary test aircraft.

4.3.2.1.4 Aerial tanker support will be used as required to extend flight duration for the primary andlor chase aircraft on selected test missions.

4.3.2.1.5 Under this phase of the test, the release of **BLU-107** munitions from the **F-16** primary test aircraft will be accomplished. The specific flight test configurations and munition release conditions are outlined in the Mission Summary (ref Attachment **1** to the MOT Annex). Tolerances (unless specified otherwise) for flight test conditions are: Airspeed: ±10 KCAS (except Mission No. **6, -10** KCAS only); Mach: ±0.2 (except Mission No. **6, -0.2** Mach only); G's: ±0.2; Altitude: ±100 ft; Angle: ±5 deg. NOTE: Pilot may use onboard recording of HUD displays to provide supplementary record of flight parameters for post-mission reviews of ordnance release events. The Programmable Data Acquisition System (PDAS) may also be used to record aircraft flight parameters.

4.3.2.1.6 F-16 onboard motion picture coverage and photo-chase motion picture coverage will be scheduled as required to document munition separation characteristics on each airdrop. Continuous motion picture coverage is needed for release events from just before the munition is released and until it clears the aircraft on fallaway. Color film at **200** frames/second is required. Processed airborne photographic film will be reviewed by the test pilot, the test engineer, and the TY separation engineer after each aircraft/munition separation mission for evidence of unsafe separation Characteristics. The decision to conduct the next flight test mission in the series will be determined at this film review. NOTE: Quantitative film assessment (GADS) may be required before building up to the next release condition for munition separation test points where simulations/analysis reflect caution, i.e., possible collision with aircraft. Such test points will be identified by **3246** TESTW/TY.

4.3.2.1.7 Tracking of the aircraft/munition combinations by time-correlated cinetheodolites (B&W, **30** *fps)* and ground-based tracking cameras (color 96 fps) will be required to obtain TSPI during the munition trajectory. Tracking of the aircraft/munition combination should commence a minimum of **3** seconds prior to the munition release event. The munition will be tracked from just before the instant of release, through fallaway, to ground impact. Ground-based radar may be used to monitor, track, or position the bomb-releasing aircraft on approved flight profiles. Radar also may be used to aid cinetheodolite acquisitions for aircraftlmunition tracking purposes. NOTE: HARP support may be used when appropriate to aid the pilot to establish release conditions.

4.3.2.1.8 Upon landing after a bomb release mission, the **F-16** primary test aircraft will be visually inspected for evidence of any adverse effects on aircraft skin, bomb racks, or adjacent external stores. Observed discrepancies will be documented photographically.

4.3.2.1.9 As part of the test records, the pilot of the **F-16** primary test aircraft will provide the test engineer with a complete flight test report upon completion of each aircraft/ordnance separation mission. Deviations between briefed and actual release conditions (airspeed, altitude, dive angle, and g load) will be included in the report. Any problems experienced in the carriage or release of the test munitions or with aircraft handling characteristics will also be included in the report.

4.3.2.1.10 The **test** engineer's flight test record will include a complete description of each flight test configuration, including bomb rack loading and related ordnance mass properties, rack orifice opening, type ejector cartridges, and ordnance release mode. Munition separation problems, test support problems, or aircraft malfunctions that adversely affected the outcome of a mission should be documented. Still descriptive photographs will be made as directed by the test engineer to document the aircraft flight test configuration for a given test flight.

4.3.2.2 Criteria. Acceptance criteria with respect to the outcome of the aircraft/munition separation flight tests will be as set forth in paragraph **271.4, MIL-STD-1763,** Aircraft/Stores Certification Procedures.

4.3.2.3 Resources Required. Principal resource requirements related to aircraft/munition separation flight test investigations will include:

4.3.2.3.1 F-16 with onboard camera capability and assigned **3247th** flight test pilot

4.3.2.3.2 Photo-chase aircraft with motion picture photographer

4.3.2.3.3 BLU-107 munitions and associated loading checklists

4.3.2.3.4 *3246th* MMS Load Crews

4.3.2.3.5 Munition handling/uploading equipment

4.3.2.3.6 Munition **PMF** (Bldg **990)**

4.3.2.3.7 Authorized land test area with cinetheodolite and associated ground high speed motion picture coverage. HARP support

4.3.2.3.8 Meteorological support (ref TZP Standard **76-01)**

4.3.2.3.9 CCF/TELEMAG (monitor/communication primary test aircraft; real time PDAS telemetry display/recording, as required)

4.3.2.3.10 Ground radar monitor/control (primary test aircraft)

4.3.2.3.11 GADS support

4.3.2.3.12 Still documentary photography

4.3.2.4 Data Records. Pertinent test records (data sources) will be:

4.3.2.4.1 * **F-16** onboard camera film (2 prints **3246** TESTW/TY; **2** prints McAir)

4.3.2.4.2 * Photochase film **(2** copies **3246** TESTW/TY)

4.3.2.4.3 Cinetheodolite **film (TSPI)**

4.3.2.4.4 Ground tracking camera film

4.3.2.4.5 Munition mass properties records **(1** copy AD/KR; **1** copy **3246** TESTWRY)

4.3.2.4.6 Meteorological records **(1** copy AD/KR; **1** copy **3246** TESTWRY; **1** copy McAir)

4.3.2.4.7 Test pilot flight test mission report **(1** copy **3246** TESTW/TY)

4.3.2.4.8 Test engineer test records

4.3.2.4.9 Still documentary photographs **(2** sets if prints **3246** TESTWRY)

4.3.2.4.10 HUD recordings (when applicable)

4.3.2.4.11 PDAS recordings (including telemetry recordings; where applicable)

* The following identification data should be on each roll of film: Msn No., date, type A/C, type munition, and actual ordnance release parameters.

4.3.2.5 Data **Reduction/Analysis.**

4.3.2.5.1 Cinetheodolite and related ground-based tracking camera film will be reduced to provide ballistics data in accordance with AD/KR procedure and format, as related to TZP Standard 76-01, dated 2 **Sep** 86. (Output origin axis should be rotated to align with aircraft ground tracking at munition release.) Three copies of reduced data to be provided to 3246 TESTW/TYDB.

4.3.2.5.2 3246 TESTW/TY will select film footage for GADS reduction. Separation data will be plotted in standard **GADS** format to depict munition pitch, yaw, roll characteristics upon ejection and fallaway from the aircraft. Two copies of reduced GADS data will be provided to 3246 TESTWITY.

4.3.2.5.3 **All** airborne photography will be reviewed to ascertain the presence of any aircraft/external store separation characteristics that pose safety hazards with respect to the release of BLU-107 munitions from F-16 aircraft.

4.3.2.5.4 Test pilot's flight test reports, HUD, andlor PDAS recordings, and engineer's test records will be used **as** necessary to provide inputs for data assessments and to corroborate test item deficiencies, aircraft system malfunctions, or test support/range problems that adversely affected the outcome of a given test mission.

4.3.2.5.5 Final analysis **of** test data with respect to the carriage and employment of BLU-107/B munitions using the F-16 aircraft will be the responsibility of 3246 TESTW/TY. The routing and/or integration of pertinent test data into the freestream database related to T.O. 1F-16-34 ballistics tables will also be the responsibility of 3246 TESTWITY.

4.3.2.6 **Summary of** Missions. Ref. Mission No. 5 and Mission No. 6, Atch 1 to this MOT.

4.3.2.7 Potential Hazards. For planning purposes, 3246 TESTW/TY initially estimates aircraft/munition separation risks **as** indicated below. Elevation of any flight test missions designated as Category 1 into a high-risk regime must be accomplished in accordance with procedures set forth in ADR 127-2.

a. Category 1 - Likely collision between released store and aircraft.
b. Category 2 - Possible but unlikely collision between released store and aircraft.
c. Category 3 - Unlikely collision between released store and aircraft.

5.0 Interim Test Reviews (Ref. TZ 01 80-4). Test program reviews should be accomplished by the test engineer if any one of the following events occur: unsatisfactory data acquisition, safety problem, or test items deficiencies which dictate that testing should be suspended or discontinued.

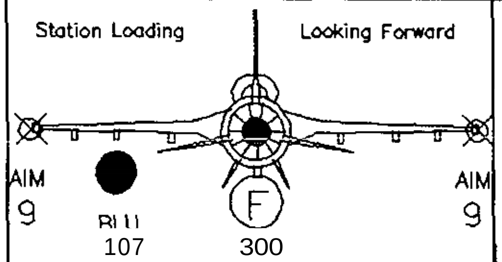
AIRCRAFT/MUNITION MISSION SUMMARY

Prepared by: Stephen J. Huntley, TYMA, 2-8941

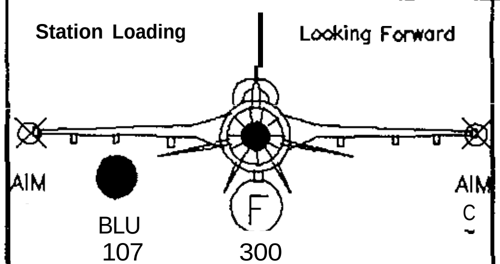
Date: 21 Mar 88

oject Title: BLU-107/B Parent Carriage on F-16 A/B Aircraft

Test Directive Number:

<table>
<tr><th>Msn No.</th><th>Test Articles and Configurations</th><th>Test Conditions</th><th>nstrumentation Requirements</th><th>Mission Details</th></tr>
<tr><td>1</td><td>

AIM-9s stations 1,9
BLU-107 station 3
300 Gal Tank station 5
Line 1</td><td>AIRSPEED (KCAS): 500
MACH: 0.9
ALTITUDE: Below 1000 ft MSL
LOAD FACTOR ("G"): +5.5/-1.0</td><td>NA</td><td>Conduct a minimum 30 minute captive profile IAW MIL-HNBK-244 paras 6.2.1.7.6.2 (f). (g), (h). This is to verify non-standard swaybrace tightening procedure of BLU-107 on MU-12.

If swaybrace pads crack or fail, TYM program manager must be contacted prior to flying subsequent mission.</td></tr>
<tr><td>2</td><td>

AIM-9s stations 19
BLU-107 station 3
300 Gal Tank station 5
Line 1</td><td>AIRSPEED (KCAS): 600
MACH: 1.2
LOAD FACTOR ("G"): SYM +6.0/-2.0
ROLL +4.8/-1.0</td><td>Safety Chase</td><td>CAPTIVE COMPATIBILITY: Conduct a captive compatibility flight test IAW MIL-HNBK-244, paras 6.2.1.7.6.2 (f), (g), (h). and 6.2.1.7.7. Handling qualities are not an issue. The minimum total flight time should be 1.5 hours as specified by para 6.2.1.7.8 to ensure complete structural evaluation.

Contingent on Mission 1

Do not exceed 600/1.2 for this configuration.

Atch 2 page 1 of 3</td></tr>
</table>

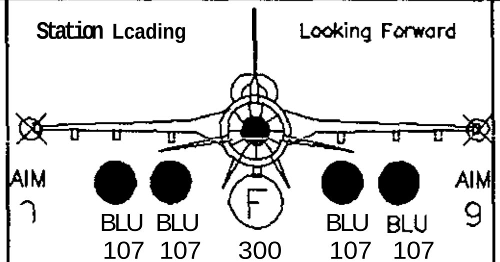
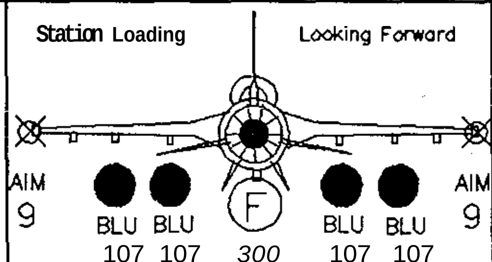
AIRCRAFT/MUNITION MISSION SUMMARY	Prepared by: Charles Denegri. NEF. 2-3017	Date: 22 FEB 88	Page 2 of 3

Project Title: BLU-107 Parent Carriage	Test Directive Number:

Msr No.	Test Articles and Configurations	Test Conditions	Instrumentation Requirements	Mission Details
3	AIM-9P Stations 2,8 BLU-107 Stations 3,4,6,7 OPT 300 gal tank Station 5 Line 2	10K: .80, .85, .90, .95, .98, 1.05 (600 KCAS) 5K: .80, .85, .90, .95, .98 (600 KCAS) 17.5K: 1.20 (600 KCAS)	Standard flutter flight test instru- mentation with telemetry	Flutter Flight Test Profile order will be determined by N E flutter test director. The following may be performed at each test point. 1) Stick raps 2) Random data 3) Frequency sweep 4) Excitation system bust 5) 6.0 g wind-up turn Contingent on Mission 1.
4	AIM-9L Stations 2,8 BLU-107 Stations 3,4,6,7 OPT 300 gal tank Station 5	Same as mission 3		Some as mission 3 Contingent on missions 1 and 3. Atch 2 Page 2 of 3

E-14

AIRCRAFT/MUNITION MISSION SUMMARY	Prepared by Lt Dovid T. Roberts. TYEA, 2–3017	Date 22 Apr aa	
Project Title F-16/BLU-107 SEEK EAGLE Flight Test	Test Directive Number		

Msn No.	Test Articles and Configurations	Test Conditions	Instrumentation Requirements	Mission Details
5	 AIM–9s stations 1,9 BLU–107 stations 3,4,6,7 *300* Gal Tank station **5** Line 4	AIRSPEED (KCAS): 540 ALTITUDE (FT MSL): 1000 LOAD FACTOR ("G"): SIM: 1.0 UNSYM: NA RELEASE MODE SINGLE INTERVAL (ms): NA TOLERANCES: Airspeed: +/– 10 **KCAS** Mach: +/– 0.02 Gs: +/– 0.1 Altitude: +/– 100 ft	Onboard and chose camera required. Gather TSPI IAW TZP STD 76–01	Pass 1: Release one BLU–107 from station 3. Pass 2 Release one ELU–107 from station 7. Pass 3 Release one BLU–107 from station 4. Pass 4: Release one BLU–107 from station 6. SEPARATION CATEGORY IIIB NOTE TYEA must review onboord and chose film along with actual conditions. Only upon TYE's approval may the next mision be flown. Contingent on Mission 1.
6	 AIM–9s stations 1,9 BLU–107 stations 3,4,6,7 300 Gal Tank station **5** Line **4**	AIRSPEED **(KCAS):** 600 ALTITUDE (FT MSL): 1000 LOAD FACTOR ("G"): SIM: 1.0 UNSYM: NA RELEASE MODE: SINGLE INTERVAL (ms): NA TOLERANCES: Airspeed +/– 10 **KCAS** Mach: +/– 0.02 Gs: +/– 0.1 Altitude: +/– 100 ft	Onboord and **chase** camera required. Gather TSPI IAW TZP STD 76–01	Pass 1: Release one BLU–107 from station *3.* Pass 2 Release one BLU–107 from station 7. Pass 3 Release one BLU–107 from station **4.** Pass 4 Release one BLU–107 from **station** 6. SEPARATION CATEGORY IIIB NOTE TYEA must review onboard and chase film along with actual conditions. Only upon TYE's approval may the next mision be **flown.** Contingent on Mission 1 Atch **2:** page 3 of 3

MASS AND PHYSICAL PROPERTIES DATA	DATE 20 Mar 86

WEAPON

BLU-107/B (Durandal-French)

TYPE

Bomb (Parachute Retarded, Rocket Motor Accelerated)

WEIGHT FULL *(Lbs.)*	WEIGHT EMPTY *(Lbs.)*
483 lbs (219.1 kg)	N/A

LENGTH *(Inches)*

98.07 (2491 mm)

DIAMETER *(Inches)*

Warhead and rocket motor section- 8.35 (212mm) Parachute Section 8.78 (223 mm)

FIN

Four fins.

FIN SPAN *(Inches)*

17.03 (432.5 mm)

FIN ANGLE FROM LUGS *(Degrees)*	SUSPENSION *(Inches)*
Selectable at 15"	14 (355.5 mm)

FORWARD MOUNTING LUG *(Inches all of nose) – STA. 0.00*

26.77 (679.95 mm) See Note 3

ITEM	FULL	EMPTY
CG AFT OF FWD LUG *(Inches)*	9.45 ± 0.5	
I PITCH AND YAW (SLUG FT2)	71.0 ± 10%	
I ROLL (SLUG FT2)	0.98 ± 10%	

OUTLINE AND MOUNTING DRAWING OR REFERENCE

Matra Ourandal Dwg, 14 May 79

FUZE

Time delay impact.

REMARKS *(Continue on reverse if necessary)*

1. BLU-107/B Bomb stock #1325-14-398-7137.
2. Properties represent all-up live configuration.
3. When FWO pair of mounting lug holes are used, the following dimensions apply:

   FWO mounting lug: 24.27 in.
   CG aft of FWD lug: 11.95 ± 0.5 in.

Atch 3 DO 1 f 3

AD FORM JAN 81 694 PREVIOUS EDITION WILL BE USED

APPENDIX F

METHOD OF TEST ANNEX

TEST DIRECTIVE 2671AL78

F-16/Z-1 OPERATIONAL FLIGHT PROGRAM (OFP) FOR SPECIFIED WEAPONS

Office for Aircraft Compatibility
3246th Test Wing/TY
Eglin Air Force Base, Florida 32542-5000

21 December 1988

1.0 INTRODUCTION

This Method of Test (MOT) Annex identifies test procedures and related data collection, reduction, and analysis requirements to accomplish the test objectives. The 3246th Test Wing is the designated responsible test organization. The test is being conducted in response to 3246 TESTW/TY letter, **Work** Request for the F-16/Z-1 Operational Flight Program (OFP) for Specified Weapons, Test Directive Number 2671AL78, dated 23 November 1988. A final test report is required.

1.1 Background,

1.1.1 There is a **Hq** TAC requirement to verify the accuracy of the F-16/Z-1 OFP for all weapons having updated ballistics and/or separation coefficients. Table F-1 lists weapons and configurations to be tested at Eglin AFB under this effort:

Table F-1. Data **on** Weapons and Configurations **for** Test at Eglin

Munitions	Suspension	**F-16** MCL **No.**	Quantity
CBU-87	TER	132	20
CBU-87	MAU	132	22
CBU-89	TER	127	24
CBU-89	MAU	125	24
BLU-107	TER	107	6
BLU-107	MAU	164	4

1.1.2 All configurations have been flight tested and certified in T.O. 1F-16A-1 except for the BLU-107/MAU configuration which will be covered by TY Flight Clearance 88-092. Attachment 1 contains the mission summaries, and Attachment 2 contains the data reduction worksheets to document and coordinate flight test data. Attachment 3 contains the acceptable mass and physical properties for munitions to be used during this test program.

1.1.3 All testing will be consistent with existing T.O. 1F-16A-1 aircraft operating procedures. Standard -33 loading procedures and -34 aircrew procedures will be used, except for the BLU-107/MAU configuration. A local loading procedures checklist will be developed and approved for the BLU-107IMAU configuration.

1.2 Test Objectives.

1.2.1 Collect munitions impact, dispersion, time-space-position-information (TSPI), and pilot aiming error data on specified munitions released from F-16 aircraft with OFP Block Z-1 software.

1.2.2 Collect data to develop a footprint database on Armament Division (AD) F-16 aircraft for BDU-33 Continuously Computed Impact Point (CCIP), Dive Toss (DTOS), and Continuously Computed Release Point (CCRP) delivery modes for OFP Block Z-1 Software.

2.0 TEST ITEM DESCRIPTION

2.1 **F-16** Primary Test Aircraft. F-16 primary test aircraft will he equipped with OFP Block Z-1 software and the Programmable Data Acquisition System (PDAS). A detailed description of the basic F-16 aircraft is contained in T.O. 1F-16A-1.

2.2 Test Munitions. Detailed descriptions of test munitions are contained in T.O. 1F-16A-33-1-1. Inert-filled warheads and dispensers with inert submunitions will be used if available. Live fuzing will not be required except for dispenser openings.

3.0 INSTRUMENTATION.

No unique or special purpose instrumentation is required in support of this test. Existing ground and airborne facilities and the capabilities identified in AD Technical Facilities Manuals (Vol 1 and Vol 2) are adequate. Applicable technical support requirements and procedures are detailed in the Technical Support Annex (Annex **B** to the Test Directive).

4.0 OBJECTIVES, PROCEDURES, AND DATA

4.1 Objectives

4.1.1 **Objective 1.2.1.** Collect munitions impact, dispersion, time-space-position-information (TSPI), and pilot aiming error data on specified munitions released from F-16 aircraft with OFP Block Z-1 software.

4.1.2 **Objective 1.2.3.** Collect data to develop a footprint database on AD F-16 aircraft for BDU-33 Continuously Computed Impact Point (CCIP), Dive Toss (DTOS), and Continuously Computed Release Point (CCRP) delivery modes for OFP Block Z-1 software.

4.2 **Purpose.** Time-space-position-information will be used to address weapons ballistics/trajectory characteristics. Weapons scoring will facilitate quantification of weapon delivery performance with respect to a particular munition and a related delivery mode.

4.3 Method.

4.3.1 Testing will be in accordance with the attached Mission Summary. The flight parameters listed in the Mission Summary have the following tolerances. Test tolerances are ± 20 KTAS, ± 200 feet MSL (must ensure safe escape), ± 0.5 g, and ± 5 degree dive. Do not exceed T.O. 1F-16A-1 limits. Testing will occur in two phases: Production Representative Demonstration and Operational Verification.

4.3.1.1 **Production Representative Demonstration.** F-16A-0609 and F-16A-0761 (if available) will be footprinted to determine total system bias. Footprinting will be accomplished by flying CCIP, DTOS, and CCRP profiles specified in the Mission Summary (see Mission No. 1). Upon completion of Mission Nos. 1 and 2, 3246 TESTW/TY personnel must review and analyze the data before proceeding to subsequent missions.

4.3.1.2 **Operational Verification.** F-16 specific operation profiles have been coordinated with **Hq** TAC for each configuration. Data will be collected to determine the total system accuracy for each profile of the F-16 aircraft.

4.3.2 Aircrew executing weapon deliveries will use aircraft onboard recording to document pipper/cursor location with respect to the target at the time of the weapon release event. Aircrew will attempt to keep the pipper/cursor aligned with the target; however, the aircrew should not aggressively maneuver the aircraft immediately prior to release. This will permit the weapon release computer system to function with stabilized parameters during computations prior to weapon release. Other operational considerations for pilots participating in this test follow.

4.3.2.1 **Dive Toss (DTOS).** Release altitudes refer to the altitude at which the pilot initiates the g pull-up maneuver.

4.3.2.2 **Continuously Computed Impact Point (CCIP).** The aircrew should initiate a smooth pull at briefed range to 4 g's within 2 seconds. The aircraft should be kept in a steady 4-g pull with wings level following the steering cues. Wings will be level one second prior to release. Radar ranging will be used.

4.3.2.3 **Continuously Computed Release Point (CCRP).** The aircrew should initiate a smooth pull at briefed range, to 4-gs within two seconds. The aircraft should be kept in a steady 4-g pull with wings level following the steering cues. Wings will be level one second prior to release. Radar ranging will be used.

4.3.3 Weight, center of gravity, and moments of inertia (pitch and yaw) will be verified and recorded as part of the test records for test items released from the F-16 test aircraft. Items with mass properties different from those specified must be cleared by 3246 TESTW/TY prior to scheduling for upload on the aircraft.

4.3.4 Approved munitions loading checklists (ref. AFSCR 66-1 and ADR 136-3) and aircrew preflight/postflight checklists (ref. ADR 127-2 and AD Sup 1 to AFSCR 80-33) must be available prior to the start of flight testing.

4.3.5 Meteorological records will be required as part of the ballistic data acquisition effort. The required meteorological data are to be provided as outlined in TZP Standard 76-01. Pibal data is required within one-half hour of actual munition releases.

4.3.6 The test flights will be conducted over authorized AD test areas using standard flight profiles under supervision of the AD Airborne Test Review/Safety Board (ATR/SB).

4.3.7 Use of safety chase aircraft in support of weapon delivery test missions will be commensurate with ATR/SB requirements. Aerial tanker support will be used as required to extend flight duration for the primary andlor chase aircraft on selected test missions. Aerial photography of impact is desired to satisfy impact data requirement.

4.3.8 An AD land test area with appropriate cinetheodolite coverage will be required for the acquisition of ballistics data. Ground-based radar will be used as necessary to monitor, track, or position the bomb-releasing aircraft on approved flight profiles. Radar also may be used to aid cinetheodolite acquisition for aircraft/munition tracking purposes.

4.3.9 Tracking of the aircraft/external store combinations by time-correlated cinetheodolites (B&W, 30 *fps)* and ground-based high-speed tracking cameras (color, 96 *fps)* will be required to obtain TSPI during the munition trajectory. Tracking of the aircraft/munition combination should commence a minimum of 3 seconds prior to the munition release event. The munition will be tracked from release, through fallaway, to bomb ground impact or dispenser opening event, as applicable.

4.3.10 A white vertical 16-foot x 16-foot panel with radar reflector will be erected as a target marker to facilitate early target acquisition ducing level and low angle deliveries. To facilitate assessment of aimpoint error from optical sight camera (KB-25/A) film, distinguishable markings surrounding the target are required. The range markings should be concentric about the target center at 50-foot intervals to a distance of 200 feet. **NOTE:** Distinguishable target markings must be maintained to aid aircrew and AD/KR personnel in assessing aiming error.

4.3.11 Cluster munitions should be dropped one weapon per target, four targets **per** grid. A radar reflector will be installed in the center of each target.

4.3.12 When appropriate, the test engineer may request spotting tower reports or BDU-33 bomb impacts points. Pertinent target center coordinates are also to be provided to the test engineer.

4.3.13 In addition to safety of flight considerations, factors which are to be considered in aborting test missions are identified below. In general, abort if any of the following conditions exist:

4.3.13.1 Wrong OFP's

4.3.13.2 If impact scores are unreasonably far from target (greater than 1,000 feet from target) and/or outside range safety footprint.

4.3.13.3 If winds gust by more than 10 knots, i.e., 5 knots gusting to 15 or if wind condition is judged to be too severe by the test engineer. Surface wind conditions will be determined by the Range Automated Weather System (RAWS) Site 01.

4.3.13.4 If onboard systems are inaccurate, i.e., poor radar ranging, or bad **INS** with high drift rate of accelerometer vertical channel not properly compensating during DTOS mode.

4.3.13.5 If EOD considerations apply, e.g., sequential failures (non-opening) of two dispensers filled with submunitions will cause termination of a drop mission over a given target area.

4.3.14 The F-16 primary test aircraft will be visually inspected upon landing for evidence of any adverse effects on bomb racks, pylons, or aircraft skin resulting from the release of munitions. Observed discrepancies will be documented photographically.

4.3.15 As part of the test records, the pilot of the primary F-16 test aircraft will provide the test engineer with a written flight test report upon completion of each bomb drop mission. Each report should include, but not necessarily be limited to, information/comments on the following:

4.3.15.1 Identification of F-16 primary test aircraft, OFP software installed, flight test configuration, including type of munitions uploaded and respective fuze/time settings.

4.3.15.2 Deviations between planned and actual munitions release conditions, including release mode.

4.3.15.3 Apparent aiming error (HUD film review).

4.3.15.4 Problems with aircraft subsystems.

4.3.15.5 Problems with carriage and/or release of munitions, including related problems with aircraft handling characteristics.

4.3.15.6 Postmission inspection of aircraft.

4.3.15.7 Incidents which may adversely affect aircraft/avionics boresight alignments.

4.3.16 The test engineer will maintain flight test mission records which will include a complete description of each aircraft flight test configuration, including bomb rack loadings, rack orifice openings, type ejection cartridges, and munition release conditions/mode. Munition identifications will include mass properties, the type fuzes installed, and fuze/timer settings. Results of boresight checks will be included as part of the test records as well as results of aircraft postflight inspections after completion of a bomb drop mission. Aircraft malfunctions, munition separation problems, or test support problems that adversely affected the outcome of a test mission will be documented. Copies of reduced TSPI as well as copies of plots of munition impact coordinates/patterns and related target center coordinates should be included as part of the test records. Still descriptive photographs will be made as directed by the test engineer to document test munitions and aircraft flight test configurations. Copies of onboard recordings will also be included as part of the test records.

4.3.17 The 3247th Test Squadron aircrew will:

4.3.17.1 Ensure that safety-of-flight issues are resolved prior to flight.

4.3.17.2 Review safe escape data found in T.O. 1F-16A-34-1-1, Section 4, for each mission. Primary release parameters are airspeed and dive angle while release altitude is driven by safe escape and tactical considerations.

4.3.17.3 Perform a 13-minute INS alignment prior to taxi.

4.3.17.4 Perform in-flight INS and radar ranging systems checks prior to releasing munitions.

4.3.17.5 Complete the Pilot/Test Engineer Mission Summary Report. Review HUD video immediately after flight and complete the Data Reduction Worksheet, AFSC Form 4772, and draw a target area sketch depicting aimpoint and estimated impacts per release. The exact configuration, OFP software installed, munition fuze and timer settings, aiming error, etc., must be accurately documented. Approximate impact scores from spotting towers or test/support aircraft will be included in the AFSC Form 4772 and updated by the test engineer once more when accurate data is available.

4.3.17.6 Report to the test engineer any hard landings which may misalign the aircraft's boresight.

4.3.17.7 Report any aircraft system errors, especially **INS** anomalies, on the data reduction worksheet and to the test engineer. Include **INS** debrief data with report, if applicable.

4.4 **Criteria,**

4.4.1 A pass condition for a weapons delivery mission is defined as all events related to a particular weapon delivery mode function in accordance with pre-defined sequence. A fail condition **results** if:

4.4.1.1 All events do not occur.

4.4.1.2 All events occur but are not in proper sequence.

4.4.1.3 More events occur than should have (even if there is no adverse system impact).

4.4.2 The criteria for success of the overall weapon delivery flight test is the acquisition of sufficient quantitative data and qualitative information to establish baseline weapon system delivery performance for the selected munitions and test conditions.

4.5 **Resources Required.** Principal resource requirements related to acquisition of ballistics data on munitions release from F-16 primary test aircraft will include:

4.5.1 F-16 primary test aircraft equipped with PDAS. Technical Order -99 **INS** calibrations must **be** performed monthly. Also, it must be verified that camera control and RBS beacon tone circuitry do not alter the standard release pulse timing sequence generated by the OFP and FCC.

4.5.2 Chase aircraft (commensurate with ATR/SB requirement).

4.5.3 Aerial tanker support.

4.5.4 Test munitions and associated equipment as listed in the attachments.

4.5.5 3246th MMS Load Crews

4.5.6 Munition handling/uploading equipment.

4.5.7 Munition PMF (Bldg 990).

4.5.8 Authorized land test area with cinetheodolite and associated ground high speed motion picture coverage. Spotting tower support. Bomb scoring.

4.5.9 Targets (white, 16-foot x 16-foot vertical panels with radar reflectors) including target coordinates (latitude and longitude).

4.5.10 Meteorological support (ref. TZP Standard 76-01).

4.5.11 CCF (test engineer - Ground/air test communications/control).

4.5.12 Still documentary/descriptive photography.

4.6 Data Records. Principal test records (data source) will be:

4.6.1 Cinethwdolite film.

4.6.2 High speed ground camera film.

4.6.3 Radar TSPI (when applicable).

4.6.4 Munitions ground impact measurements (copy to KR).

4.6.5 Target center coordinates (copy to KR).

4.6.6 Onboard recordings (copy to KR).

4.6.7 Postmission inspection results (aircraft).

4.6.8 Meteorological records (copy to KR).

4.6.9 Munition mass properties records (copy to TYDB).

4.6.10 F-16 pilot flight test mission reports (copy to TY).

4.6.11 Test engineer test records.

4.6.12 Still descriptive photographs.

4.6.13 F-16 PDAS printout (copy to TY).

4.7 Data Reduction/Analysis. Principal requirements follow:

4.7.1 Cinetheodolite and related high-speed ground camera film will be reduced to provide ballistics data in accordance with AD/KR procedure and format, **as** related to TZP Standard **76-01,** dated **2** Sep **86.** (Output origin axis should be rotated to align with aircraft ground track at munition release.) Three copies of reduced data will be provided to **3246** TW/TYDB. NOTE: Cinethwdolite and related high-speed ground camera film associated with gross misses (± 1000 feet) should be retained for purpose of flow field assessment.

4.7.2 Onboard recordings will require assessment to establish pipper placement with respect to ground target (aim point error) at bomb release event.

4.7.3 In conjunction with the reduced ballistics data, **3246** TW/TYDB requires a data worksheet for each bomb release event. AD/KRTTR, the test engineer and the test pilot will provide timely inputs for completion of data sheets.

4.7.4 The test engineer's flight test records and **F-16** pilots flight test reports will be used as required to provide inputs for the data reduction and to corroborate test item deficiencies, aircraft system malfunctions, or test support problems that adversely affected test results.

4.7.5 Final analysis of collected test data to validate the performance of the **F-16** weapon delivery system using **F-16** Z-1 OFP ballistics software by correlation and analysis of munition impacts, dispersion, and pilot aiming error will be the responsibility of **3246** TW/TY. The integration of pertinent test data into the freestream database related to T.O. **1F-16-34** ballistics tables will also be the responsibility of the **3246** TW/TY as well as assessments of any effects due to the position of a given munition in the aircraft's flowfield.

4.8 Summary **of Mission.** Ref. Attachment **1** to this **annex.**

4.9 Potential **Hazards.** No safety hazards are envisioned that would elevate risks above those normally associated with aircraft/munition separation flight test investigations, i.e., not categorized as high risk flight test missions (ADR **127-2).**

5.0 Interim **Test Reviews (Ref. TZ OI** ***80-4.*** Test progress reviews will be accomplished by the test engineer if any one of the following events occurs: unsatisfactory data acquisition, safety problems, or test item deficiencies which dictate that testing should be suspended or discontinued.

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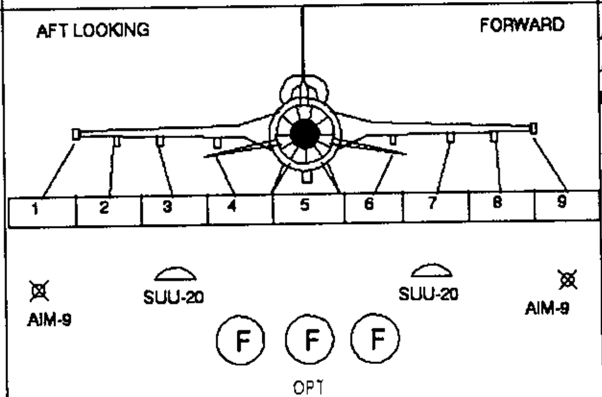
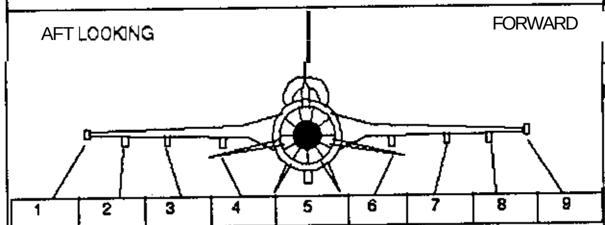
PROJECT TITLE
F-16 Z1 OFP VERIFICATION FLIGHT TEST — **2671AL78**

MSN NO.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
1	 BDU-33/SUU-20	A/S (KTAS): 540 ALT(AGL): 4000' DIVE ANGLE: -30 LOAD FACTOR: 0.86g DEL. MODE: CCIP SINGLE RELEASE	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	RELEASE 12 BDU-33's FROM SUU-20 IN CCIP MODE TO FOOT PRINTNC NOTE: MISSION MUST BE FLOWN BY EVERY AIRCRAFT USED FOR Z1 TESTING
2	 SEE MISSION 1	(KTAS): 540 ALT(AGL): 3500' DIVE ANGLE: -30 LOAD FACTOR: 4g DELMODE DTOS SINGLE RELEASE	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	RELEASE 12 BDU-33's FROM SUU-20 IN CCIP MODE TO FOOT PRINT A/C NOTE: MISSION MUST BE FLOWN BY EVERY AIRCRAFT USED FOR Z1 TESTING DO NOT PROCEED WITH FURTHER MISSIONS UNTIL MSNS 1 AND 2 HAVE BEEN ANALYZED BY TYDB

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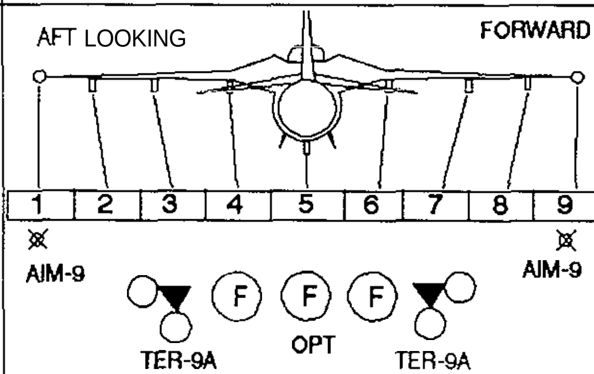
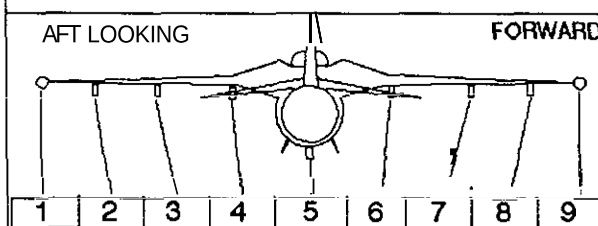
'ROJECT TITLE -16Z1 OFP VERIFICATION FLIGHT TEST	WORK DIRECTIVE NO. 2671AL78		

ISN O.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATIO REQUIRED	MISSION DETAILS
3	 CBU-87/TER SLANT 2	A/S (KTAS): 480 ALT(AGL): 2000' DIVE ANGLE: 0 LOAD FACTOR: 1g DEL MODE: CCIP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS
4	 SEE MISSION 3	A/S (KTAS): 550/0.95 mach ALT(AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 0.94g DEL MODE: CCIP SINGLERELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 7601 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS

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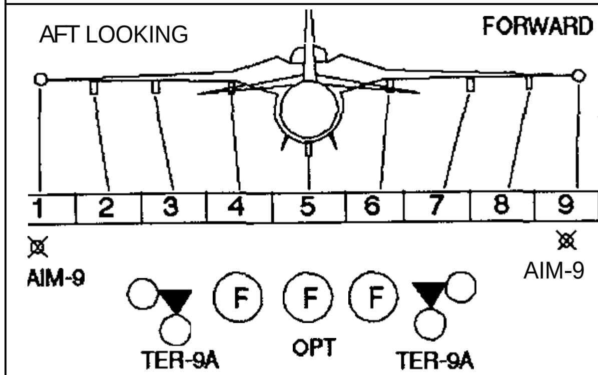
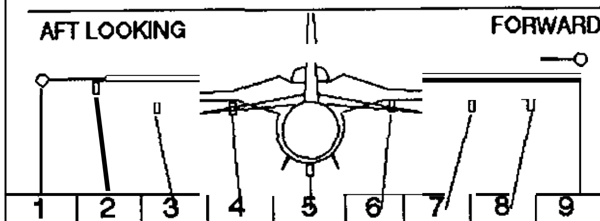
PROJECT TITLE F-16 Z1 OFP VERIFICATION FUGHT TEST	WORK DIRECTIVE NO. 267' 78

MSN NO.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
5	 CBU-87/TER SLANT 2	A/S (KTAS): 480 ALT (AGL): 1000' DIVE ANGLE: +35 LOAD FACTOR: 4g DELMODE CCRP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS REO AVTR	AIR PHOTOS OF IMPACTS REQUIRED VEAPONS TO BE DROPPED ON SEPARATE GRIDS 000' RUN-IN ALTITUDE
6	 SEE MISSION 5	A/S (KTAS): 520 ALT (AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 4g DELMODE DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 78-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED W O N S TO BE DROPPED ON SEPARATE GRIDS

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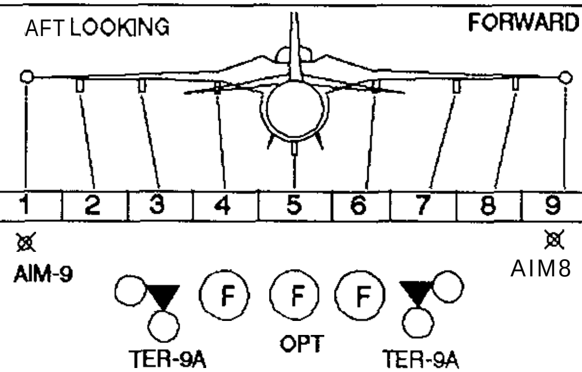
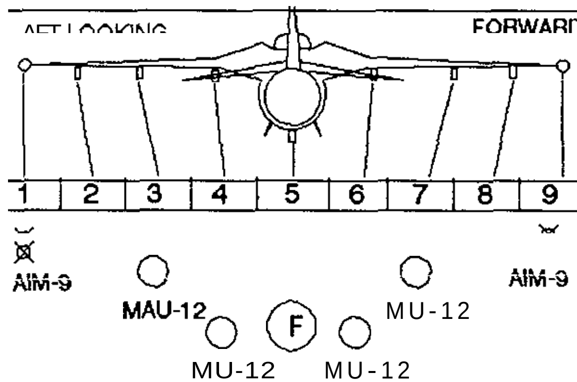
ROJECT TITLE -16 Z1 OFP VERIFICATION FLIGHT TEST	**WORK** DIRECTIVE NO. **2671AI 78**		

SN 3.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
7	 :BU-87/TER SLAM 2	A/S (KTAS): 550/0.95 mach ALT(AGL): 4000' DIVE ANGLE: -30 LOAD FACTOR: 4g DEL. MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 78-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS
8	 CUB-87/MAU-12	A/S (KTAS): 480 LT(AGL): 2000' IVE ANGLE: 0 OAD FACTOR: 1g EL MODE: CCIP SINGLE RELEASE TIMER SETTING 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS

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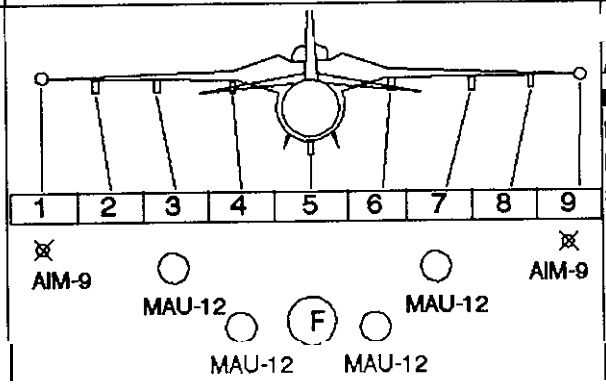
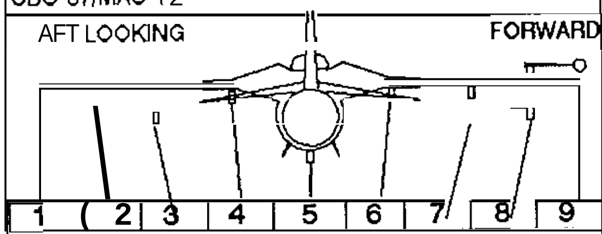
			INSTRUMENTATIC REQUIRED	MISSION DETAILS
-10		ALT(AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 0.94g DEL. MODE: CCIP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED W O N S TO BE DROPPED ON SEPARATE GRIDS
1	CBU-87/MAU-12  SEE MISSION 9	A/S (KTAS): 480 ALT(AGL): 1000' DIVE ANGLE: +35 LOAD FACTOR: 4g DELMODE CCRP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS REO AVTR	AIR PHOTOS OF IMPACTS REQUIRED NEAPONS TO BE DROPPED ON SEPARATE GRIDS 1000'RUN-IN ALTITUDE

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MIKE JOHNSON</td><td>DATE
18 NOV 88</td><td>PAGE 6
OF 14</td></tr>
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2671AL78</td></tr>
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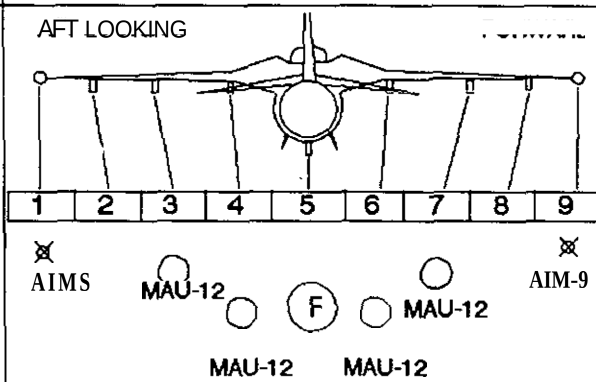
<tr><td>12</td><td>

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TIMER SETTING: 4.0 SEC</td><td>TSPI IAW
TZP STD
76-01
REQUIRED
PDAS
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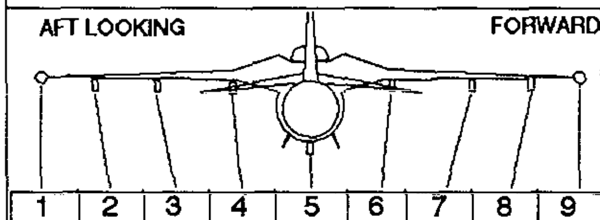
<tr><td>13</td><td>

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76-01
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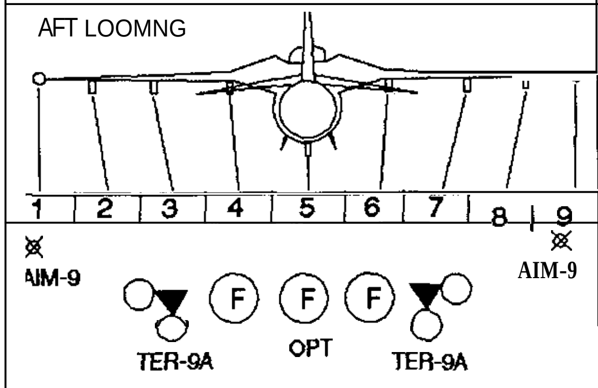
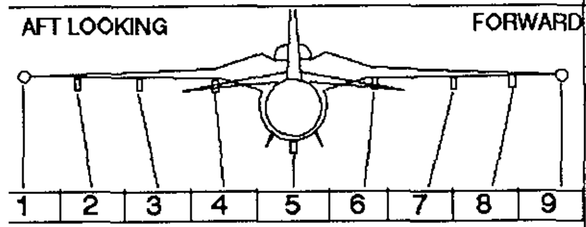
PROJECT TITLE Z1 OFP VERIFICATION FLIGHT TEST	WORK DIRECTIVE NO. 2671AL78

MSN	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
	 ;BU-89/TER SLANT 2	A/S (KTAS): 480 D LOAD FACTOR:1g SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS
	 SEE MISSION 14	A/S (KTAS): 550/0.95 mach ALT(AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 0.94g DEL MODE: CCIP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS

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'ROJECT TITLE
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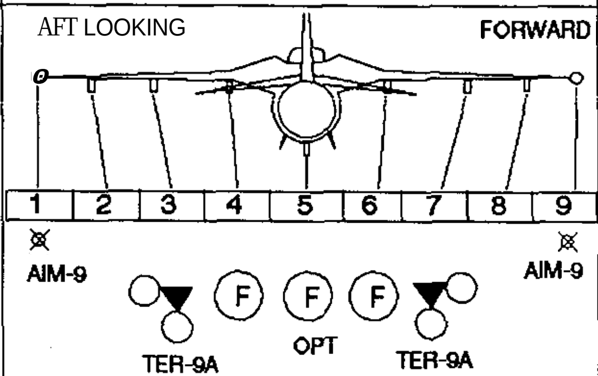
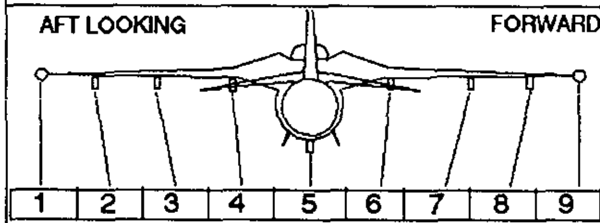
ISN !O.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATIC REQUIRED	MISSION DETAILS
16	 ;BU-89/TER SLANT 2	A/S (KTAS): 480 ALT(AGL): 1000' DIVE ANGLE: +35 LOAD FACTOR: 4g DEL MODE: CCRP SINGLE RELEASE ITIMERSETTING: 4.0 SEC	TSPI IAW TZP STD 78-01 REQUIRED PDAS REO AVTR	AIR PHOTOS OF IMPACTS REQUIRED VEAPONS TO BE DROPPED)N SEPARATE GRIDS 1000' RUN-IN ALTITUDE
17	 SEE MISSION 16	A/S (KTAS): 520 ALT(AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 4g DEL. MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED VEAPONS TO BE DROPPED)N SEPARATE GRIDS

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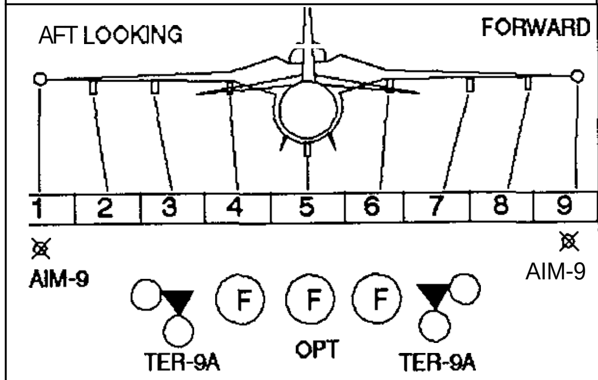
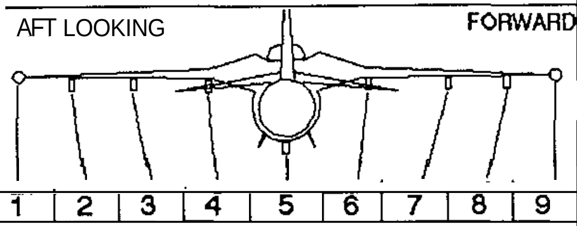
MSN NO.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATIO REQUIRED	MISSION DETAILS
18a	 BU-89/TER SLANT 2	A/S (KTAS): 520 ALT (AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 4g DEL MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS DROP FROM STATIONS 3/1 AND 7/1 (FIRST TWO STORES)
18b	 SEE MISSION 18a	A/S (KTAS): 550/0.95 mach ALT (AGL): 4000' DIVE ANGLE: -30 LOAD FACTOR: 4g DEL. MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS DROP FROM STATIONS 3/2 AND 7/3 (LAST TWO STORES)

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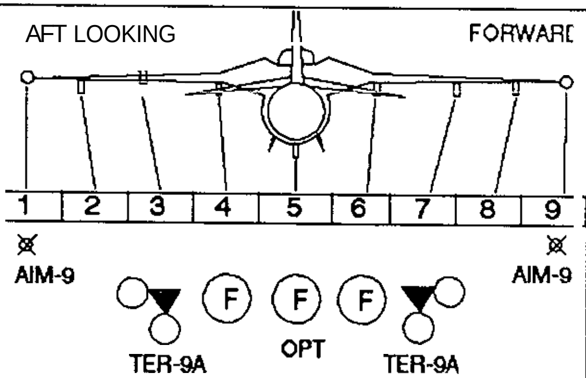
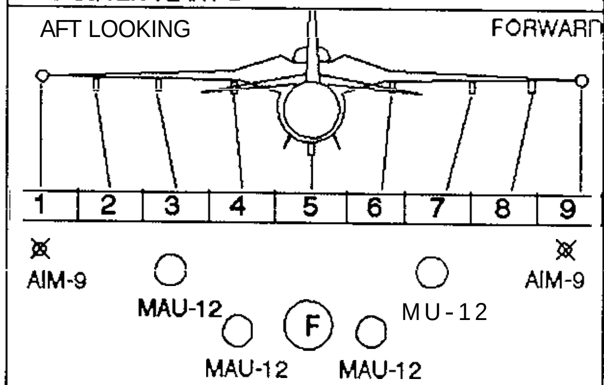
PROJECT TITLE F-18 Z1 OFP VERIFICATION FUGHT TEST	WORK DIRECTIVE NO. 2671 L78		

TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
 CBU-89/TER SLANT 2	VS WAS): 550/0.95mach LT(AGL): 4000')IVE ANGLE: -30 .OAD FACTOR: 4g)EL MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED W O N S TO BE DROPPED ON SEPARATE GRIDS
 CBU-89/MAU-12	VS WAS): 480 LT(AGL): 2000' IVE ANGLE: 0 OAD FACTOR 1g)EL MODE: CCIP INGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS

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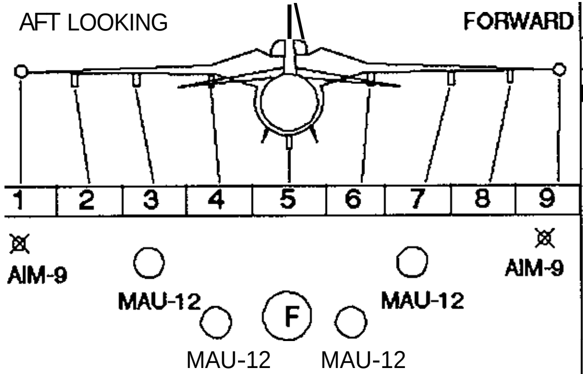
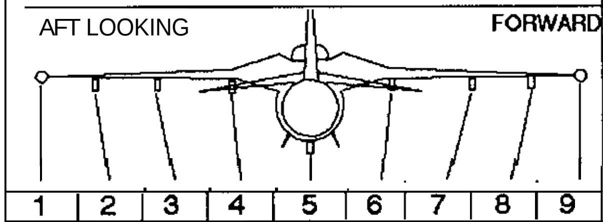
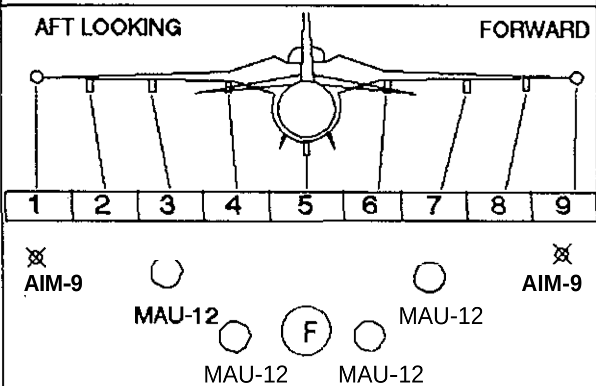
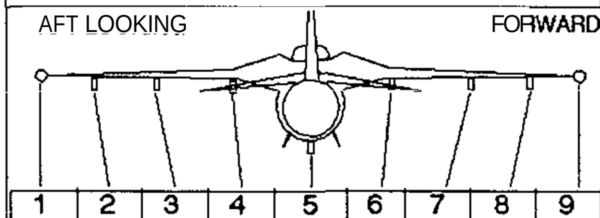
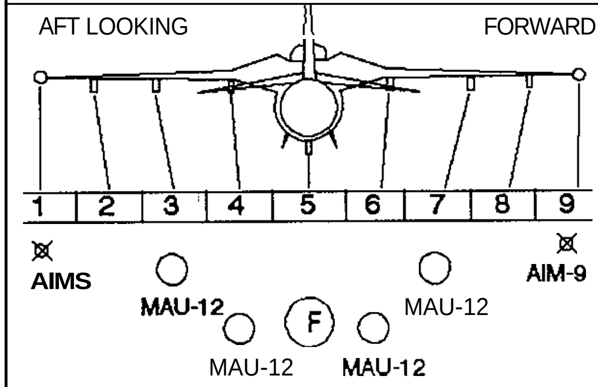
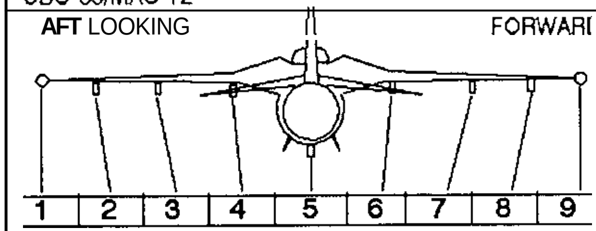
ISN O.	TEST ARTICLES ANC CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATIO REQUIRED	MISSION DETAILS
21	 :BU-89/MAU-12	A/S (KTAS): 600 ALT(AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR: 0.94g DEL MODE: CCIP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED /VEAPONS TO BE DROPPED ƆN SEPARATE GRIDS
22		A/S (KTAS): 480 ALT(AGL): 1000' DIVE ANGLE: +35 LOAD FACTOR: 4g DEL MODE: CCRP SINGLERELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD *78-01* REQUIRED PDAS REO AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ƆN SEPARATE GRIDS 1000' RUN-IN ALTITUDE

	PREPARED BY MIKE JOHNSON	DATE 18 NOV 88	PAGE 12 OF 14
PROJECT TITLE F-16 Z1 OFP VERIFICATION FUGHT TEST	WORK DIRECTIVE NO. 2671AL78		

MSN NO.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
23	 CBU-89/MAU-12	A/S (KTAS): 540 ALT(AGL): 3500' DIVE ANGLE: -20 LOAD FACTOR:4g DEL. MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS
24	 SEE MISSION 23	A/S (KTAS): 600 ALT(AGL): 4500' DIVE ANGLE: -30 LOAD FACTOR:4g DEL. MODE: DTOS SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS

	PREPARED BY MIKE JOHNSON	DATE 18 NOV 88	PAGE 13 OF 14

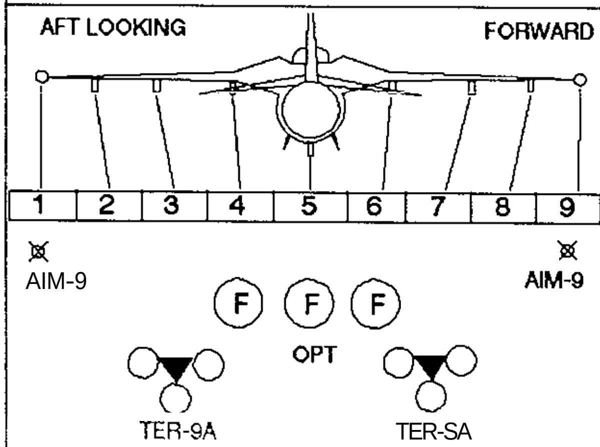
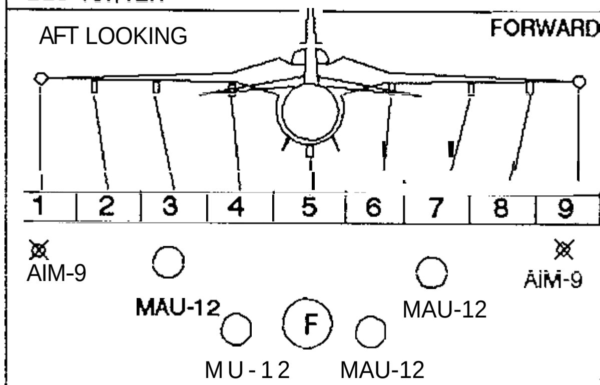
2671 AL78

MSN NO.	TEST ARTICLES ANCCONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATIO REQUIRED	MISSION DETAILS
25a	 CBU-89/MAU-12	S (KTAS): 540 .T (AGL): 3500' VE ANGLE: -20)AD FACTOR: 4g EL MODE: DTOS NGLE RELEASE IMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED 3N SEPARATE GRIDS DROP FROM STATIONS 3 AND 7 (FIRST TWO STORES)
25b	 SEE MISSION 25a	'S (KTAS): 600 .T (AGL): 4500' MANGLE: -30)AD FACTOR 4g ELMODE: DTOS NGLE RELEASE IMER SETTING 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	AIR PHOTOS OF IMPACTS REQUIRED WEAPONS TO BE DROPPED ON SEPARATE GRIDS DROP FROM STATIONS 4 AND 6 (LAST TWO STORES)

	PREPARED BY MIKE JOHNSON	DATE 18 NOV 88	PAGE 14 OF 14

'ROJECT TITLE
'-16 Z1 OFP VERIFICATION FLIGHT TEST

WORK DIRECTIVE NO.
2671AL78

ISN O.	TEST ARTICLES AND CONFIGURATIONS	TEST CONDITIONS	INSTRUMENTATION REQUIRED	MISSION DETAILS
26	 BLU-107/TER	A/S (KTAS): 540 ALT(AGL): 500' DIVE ANGLE: 0 LOAD FACTOR: 1g DEL. MODE: CCIP SINGLE RELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	
27	 3LU-107/MAU-12	A/S WAS): 540 ALT(AGL): 500' DIVE ANGLE: 0 LOAD FACTOR: 1g DEL. MODE: CCIP SINGLERELEASE TIMER SETTING: 4.0 SEC	TSPI IAW TZP STD 76-01 REQUIRED PDAS HUD AVTR	

TECHNICAL SUPPORT ANNEX
TEST DIRECTIVE NO. 2671AL78
F-16/Z-1 OFP VERIFICATION

1. General. This test program is to verify the delivery accuracy of the Z-1 OFP while employing CBU-87, CBU-89, and BLU-107 munitions. Support will be required from these organizations: Photographic Support (Photolab Contractor), Operations Support (DOUP), Meteorological Support (ADNE), Mathematical Computation (AD/KR), Engineering Support (TFR, TFE), and the Range O&M Contractor.

2. Support Requirements and Responsibilities.

   a. Photographic Support. The Photolab Contractor will:

      (1) Provide a still photographer to expose up to 200 color negatives of selected aircraft/weapon configurations and make **up** to four 8- x 10-inch prints of selected negatives.

      (2) Mount and service the onboard cameras on the F-16 aircraft to cover munitions release and fallaway. No GADS data are required.

      (3) Receive and process the aerial film exposed by DOUP and the high-speed tracking camera film and cinetheodolite film exposed by the Range O&M Contractor.

   b. Oaerations Suuuort. DOUP will provide a photographer in the photochase plane and/or the UH-1 helicopter to photograph the munitions release and fallaway from the mission F-16 aircraft and photograph the submunition impact pattern in the target area. Operate these cameras with color film at 200 frames per second and/or a frame rate from the helicopter to obtain good resolution of the impacts.

   c. Meteorological Support. AD/WE will:

      (1) Provide the weather parameters from the readings nearest the mission time to include wind speed and direction, temperature, humidity, pressure, and density.

      (2) Coordinate the release of a pibal for track by the Contraves cinetheodolites within 30 minutes post mission.

   d. Engineering Support.

      (1) TFE will preflight the PDAS and HUD video on the scheduled F-16 aircraft.

      (2) TFR will provide the 16-foot x 16-foot vertical white target panels with a radar reflector centered on each panel facing the aircraft approach heading. The target for submunition drops should be marked with concentric circles at 50-foot intervals out to 200 feet from target center.

   e. Mathematical Comautation. AD/KR will reduce and analyze the cinetheodolite film to obtain TSPI on the delivery aircraft to release and the munition from release to function and/or impact. Rotate the data to aircraft ground track at munition release. Reduce the pibal track to obtain wind data for the ballistic calculation. Provide plot and orientation data for the submunition patterns scored by the O&M Contractor.

   f. Range Support. The O&M Contractor will:

      (1) Provide range support with safety and communications for the scheduled test **ares.** On test areas where available, provide spotting tower support to determine munition impact position relative to the target.

(2) Operate up to four cinetheodolites to track the mission aircraft to release and the munition from release to function and/or ground impact. Operate the cameras at 30 frames per second for this portion of the track and track a pibal to mission altitude plus 500 feet within 30 minutes post mission at 10 frames per second.

(3) Set up a tracking mount with two 35mm cameras operation at 96 frames per second with color film, one camera with an 80-inch lens and one with a 32-inch lens, to track the mission aircraft to release and the test item from release to function andlor impact.

(4) Provide target support as requested by TFR to assure a good 16-foot x 16-foot target with radar reflector for each munition release.

*(5)*Operate the low-level-sounder weather equipment on the RHAWS when scheduled to provide wind data within **30** minutes of the scheduled mission time. Winds at the mission altitude are required. Wind gusts are of interest when in excess of 10 knots. Calculate deviations in wind speed and direction using RHAWS data at 60 samples per minute (spm) with outputs each minute.

(6) Provide scoring relative to the target for all munitions released when requested by the Test Engineer. Score submunition patterns.

3. <u>Data Classification</u>. Authority: F-16 Security Classification Guide.

a. Tracking Accuracy: Air-to-Ground - detection range of the AN/APG-68 radar - CONFIDENTIAL, declassify on OADR.

b. Any data (TSPI, etc) which reveals "a" above - CONFIDENTIAL, declassify on OADR.

c. Specific frequency and frequency band, frequency separation between channels, wide-band- or narrow-band-commanded frequencies, and first local oscillator frequency of AN/APG-68 radar - SECRET, declassify on OADR.

RALPH L. PARRETT
Chief, Technical Support Branch

Annex 1

AGARD Flight Test Instrumentation and Flight Test Techniques Series

1. Volumes in the AGARD Flight Test Instrumentation Series, AGARDograph 160

Volume Number	*Title*	*Publication Dare*
1.	Basic Principles of Flight Test Instrumentation Engineering by A.Pool and D.Bosman (under revision)	1974
2.	In-Flight Temperature Measurements by F.Trenkle and M.Reinhardt	1973
3.	The Measurement of Fuel Flow by J.T.France	1972
4.	The Measurement of Engine Rotation Speed by M.Vedrunes	1973
5.	Magnetic Recording of Flight Test Data by G.E.Bennett	1974
6.	Open and Closed Loop Accelerometers by I.Mclaren	1974
7.	Strain Gauge Measurements on Aircraft by E.Kottkamp, H.Wilhelm and D.Kohl	1976
8.	Linear and Angular Position Measurement of Aircraft Components by J.C. van der Linden and H.A.Mensink	1977
9.	Aeroelastic Flight Test Techniques and Instrumentation by J.W.G. van Nunen and G.Piazzoli	1979
10.	Helicopter Flight Test Instrumentation by K.R.Ferrell	1980
11.	Pressure and Flow Measurement by W.Wuest	1980
12.	Aircraft Flight Test Data Processing — A Review of the State of the Art by L.J.Smith and N.O.Matthews	1980
13.	Practical Aspects of Instrumentation System Installation by R.W.Borek	1981
14.	The Analysis of Random Data by D.A.Williams	1981
15.	Gyroscopic Instruments and their Application to Flight Testing by B.Stieler and H.Winter	1982
16.	Trajectory Measurements for Take-off and Landing Test and Other Short-Range Applications by P. de Benque d'Agut, H.Riebeek and A.Pool	1985
17.	Analogue Signal Conditioning for Flight Test Instrumentation by D.W.Veatch and R.K.Bogue	1986
18.	Microprocessor Applications in Airborne Flight Test Instrumentation by M.J.Prickett	1987
19.	Digital Signal Conditioning for Flight Test by G.A.Bever	1991

2. Volumes in the AGARD Flight Test Techniques Series

Number	Title	Publication Date
AG237	Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK)	1979

The remaining volumes are published as a sequence of Volume Numbers of AGARDograph 300.

Volume Number	Title	Publication Date
1.	Calibration of Air-Data Systems and Flow Direction Sensors by J.A.Lawford and K.R.Nippress	1983
2.	Identification of Dynamic Systems by R.E.Maine and K.W.Iliff	1985
3.	Identification of Dynamic Systems — Applications to Aircraft Part 1: The Output Error Approach by R.E.Maine and K.W.Iliff	1986
4.	Determination of Antenna Patterns and Radar Reflection Characteristics of Aircraft by H.Bothe and D.McDonald	1986
5.	Store Separation Flight Testing by R.J.Arnold and C.S.Epstein	1986
6.	Developmental Airdrop Testing Techniques and Devices by H.J.Hunter	1987
7.	Air-to-Air Radar Flight Testing by R.E.Scott	1988
8.	Flight Testing under Extreme Environmental Conditions by C.L.Henrickson	1988
9.	Aircraft Exterior Noise Measurement and Analysis Techniques by H.Heller	1991
10.	Weapon Delivery Analysis and Ballistic Flight Testing by R.J.Arnold and J.B.Knight	1992

At the time of publication of the present volume the following volumes were in preparation:

Identification of Dynamic Systems. Applications to Aircraft
Part 2: Nonlinear Model Analysis and Manoeuvre Design
by J.A.Mulder and J.H.Breeman

Flight Testing of Terrain Following Systems
by C.Dallimore and M.K.Foster

Reliability and Maintainability
by J.Howell

Testing of Flight Critical Control Systems on Helicopters
by J.D.L.Gregory

Flight Testing of Air-to-Air Refuelling of Fixed Wing Aircraft
by J.Bradley and K.Emerson

Introduction to Flight Test Engineering
Edited by F.Stoliker

Space System Testing
by A.Wisdom

Annex 2

Available Flight Test Handbooks

This annex is presented to make readers aware of handbooks that are available on a variety of flight test subjects not necessarily related to the contents of **this** volume. It is not necessarily a full listing of such documents.

Requests for A & AEE documents should be addressed to the Defence Research Information Centre, Glasgow (see back cover). Requests for US documents should be addressed to the Defence Technical Information Center, Cameron Station, Alexandria, VA 22314 (or in one case, the Library of Congress).

Number	***Author***	*Title*	*Dute*
AFFTC-TIH-88-004	Hendrickson, C.L	Flight Testing Under Extreme Climatic Conditions	1988
AFFTC-TIM-75-11	Pihlgren, W.D.	Aircraft Vertical Center of Gravity Determination Using the Ground Inclination Method	1975
AFFTC-TIH-84-1	Lush, KJ.	Electrical Subsystems Flight Test Handbook	1984
AFFTC-TIH-83-2	Lush, K.L.	Hydraulic Subsystems Flight Test Handbook	1983
AFFTC-TIH-82-2	Lush, K.L.	Environmental Control Subsystems Flight Test Handbook	1982
AFFTC-TIH-81-6	Jones, L.W.	Development of Curves for Estimating Aircraft Arresting Hook Loads	1982
NATC-TM-79-33SA	Chapin, P.W.	A Comprehensive Approach to ln-Flight Thrust Determination	1980
NATC-TM-79-3SY	Schiflett, S.G. Loikith, G.J.	Voice Stress Analysis as a Measure of Operator Workload	1980
NASA-CR-3406	Bennett, R.L. and Pearsons, K.S.	Handbook **on** Aircraft Noise Metrics	1981
–	–	Pilot's Handbook for Critical and Exploratory Flight Testing. (Sponsored by AIAA & SETP – Library **of** Congress Card No.76-189165)	1972
–	–	**A** & AEE Performance Division Handbook of Test Methods for assessing the flying Qualities and Performance of Military Aircraft. Vol.1 Airplanes (A/L 9 1989)	
A & AEE Note 2111	Appleford, J.K	Performance Division: Clearance Philosophies for Fixed Wing Aircraft	1978
A & AEE Note 2113 (Issue *2)*	Norris, E.J.	Test Methods and Flight Safety Procedures for Aircraft Trials Which May Lead to Departures from Controlled Flight	*1980*
A & AEE ARM 1014/03	–	A & AEE Armament Division Handbook of Test Methods	

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7. Presented at

8. Author(s)/Editor(s) R.J. Arnold and J.B. Knight

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OFP Ballistic testing

14. Abstract

This volume in the AGARD Flight Test Techniques series treats stores ballistic modeling/testing from the overall system standpoint. All aspects of the ballistic testing design, data collection techniques, data reduction, analysis techniques, and finally the Operational Flight Program modeling techniques are addressed. Considerable effort has been expended to keep this report straightforward so that it can be understood by management as well as engineering personnel, but with sufficient engineering principles addressed so that a true ballistician could use it from an application perspective.

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AGARDograph 300 Volume 10	AGARD-AG-300 Volume 10
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