AD-A056 178 NAVAL WEAPONS CENTER CHINA LAKE CALIF F/G 19/5
COMMENTS ON AIRBORNE (AIR-TO-SURFACE) FORWARD FIRED LARGE CALIB--ETC(U)
NOV 74 R D COLE
UNCLASSIFIED NWC-TN-4070-51-74 NL

1 OF 1
AD
A056 178

END
DATE
FILMED
8 -78
DDC

AD A056178

AD No.____
DDC FILE COPY

(2)

UNCLASSIFIED

(14) NWC-TN-
TECHNICAL NOTE 4070-51-74
NOVEMBER 1974
COPY

LEVEL II

(6) COMMENTS ON AIRBORNE (Air-to-Surface)
FORWARD FIRED LARGE CALIBER GUN FIRE CONTROL.

by

(10) Roy Dale Cole (11) Nov 74
Weapons Systems Analysis Division
Weapons Development Department

(9) Technical note, (12) 41p.

78 07 03 172

This is an informal report containing preliminary information. It is not an official report of the Naval Weapons Center and must not be used as a basis for action unless enclosed in official correspondence in which the purpose of the transmittal is made clear.

NAVAL WEAPONS CENTER
China Lake, California

UNCLASSIFIED

403 019

TABLE OF CONTENTS

PREFACE

This report is written to record selected data from fire control work connected with a large caliber gun (air-to-surface) study. An informal and sometimes outline format is used for convenience and to minimize report preparation time and cost.

This limited fire control study was directed towards identifying problem areas and a more promising fire control system for this application. The primary risk of developing the required very accurate fire control is in (a) keeping system accuracy in the service (particularly combat) environment and (b) the probability of this in-service accuracy requirement leading to a high lifecycle cost.

INTRODUCTION

Figure 1 shows the coordinate system used in this report. Notation, with units normally used are as follows:

α	angle of attack, mils
β	angle of skid, mils
δ	initial gun projectile angle, degrees
θ	pitch angle, degrees
ϕ	roll angle, degrees
λ_g	gravity drop angle, mils
λ_e	elevation lead angle (aircraft coordinates), mils
λ_a	azimuth lead angle (aircraft coordinates), mils
ρ	air density, equivalent pressure altitude in feet
ν	gun angle relative to aircraft axis (elevation), mils
μ	gun angle relative to aircraft axis (azimuth), mils
ω_e	target LOS inertial angular rate (elevation), mils per sec
ω_a	target LOS inertial angular rate (azimuth), mils per sec
D	projectile deacceleration, ft per sec per sec
R	slant range to target, feet
V_m	muzzle velocity, ft per sec
v_a	true air speed, knots
t_f	time of flight of weapon, seconds
W_x	horizontal rangewind and target motion, knots
W_c	horizontal crosswind and target motion, knots

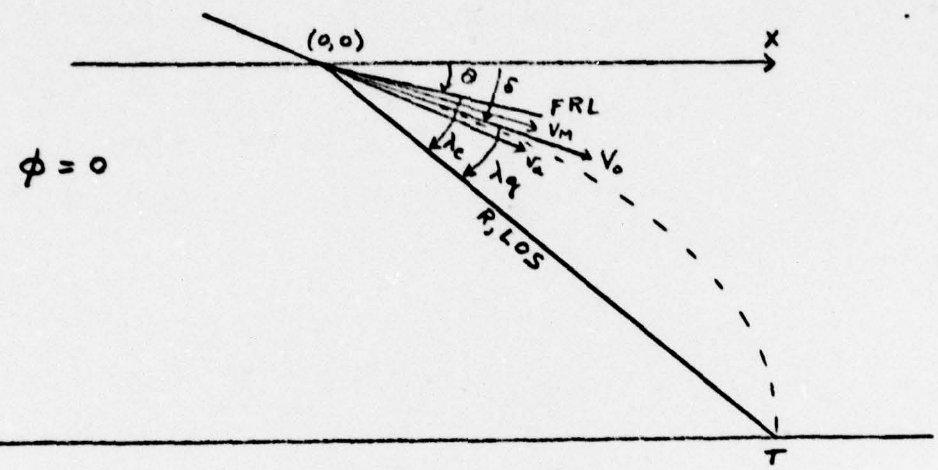

Figure 1.

In air-to-surface gun fire control major factors which can cause errors are listed below.

1. Alignment
   a. gun-sight boresight
   b. sensor boresight
   c. parallax
2. True airspeed effects
   a. as effective initial velocity direction change
   b. magnitude effect on gravity drop and time of flight
3. Gravity drop computation (or estimation)
   a. slant range
   b. dive angle
   c. air density
   d. muzzle velocity
   e. true airspeed
   f. drag coefficient (and variation)

g. roll resolution into sight coordinates

4. Wind and target motion

   a. time of flight accuracy (dependence functionally similar to gravity drop)

   b. angular rate of target LOS

   c. range rate

   d. true airspeed (magnitude and direction)

   e. inertial velocity (for wind only)

5. Miscellaneous factors

   a. pilot aim error

   b. sight unit error

   c. computer and interface errors

   d. other

In this report, except where specified otherwise, a gun system having approximately the muzzle velocity and projectile characteristics of the Rifle, 106mm, M40 firing standard ammunition is assumed. Appendix A gives the approximate ballistic data used in the error analysis and Appendix B gives data more firmly based on the above round. The variation between these two sources is minor and does not affect the error analysis. In an actual system, of course, the true ballistic characteristic must be known very accurately.

Figures 2-5 show in block diagram form five candidate fire control systems. Brief comments on these are given below. Later sections give a preliminary sensitivity error analysis on two selected concepts (The first is chosen to give a general feel for the problem and the last is directed toward specific problems of the more likely candidate scheme.).

Figure 2. This block diagram represents two concepts. The first accounts for only angle of attack (and perhaps skid) effects on direction of the effective firing line. The second system would add gravity drop based on baro-altitude, target altitude, angles, air density, and true airspeed. The latter would be the least expensive approach to give a full continuously computed impact point (CCIP) solution. It would not include wind or target motion and would require target altitude and atmospheric knowledge not generally known in changing combat conditions.

Figure 3. Here laser range replaces baro-ranging. Additionally a wind and target motion solution can be obtained by using the gyro stabilized laser pointing platform in a lead computing circuit. The accuracy of this wind solution depends on the pilot-aircraft tracking precision and time. While this crosswind lead computing has given acceptable

accuracy for short times of flight (short range, high velocity, low drag), it is not suitable for extremely accurate systems.

Figure 4. The addition of an automatic target tracker to furnish accurate angular rate data (as well as angles) gives the necessary information to use with laser slant range (and other data) to compute wind and target motion effects and thus the complete fire control solution. Only the variation in wind over the flight path is unaccounted for in this concept, and if the projectile drag is designed to be low this wind variation* (unlike wind at release) is a relatively small effect.

Figure 5. Doppler-inertial velocity can be used to compute wind effect--but not target motion. The wind information is there continuously (if there was time to align the platform). If this navigation and vertical information is available on the aircraft it's very stable data should be utilized even if an autotracker is also included.

*The wind does often vary by large amounts over the flight path (particularly at NWC, see Appendix C). Thus the projectile must be designed to have low drag characteristics for use with any extremely accurate fire control.

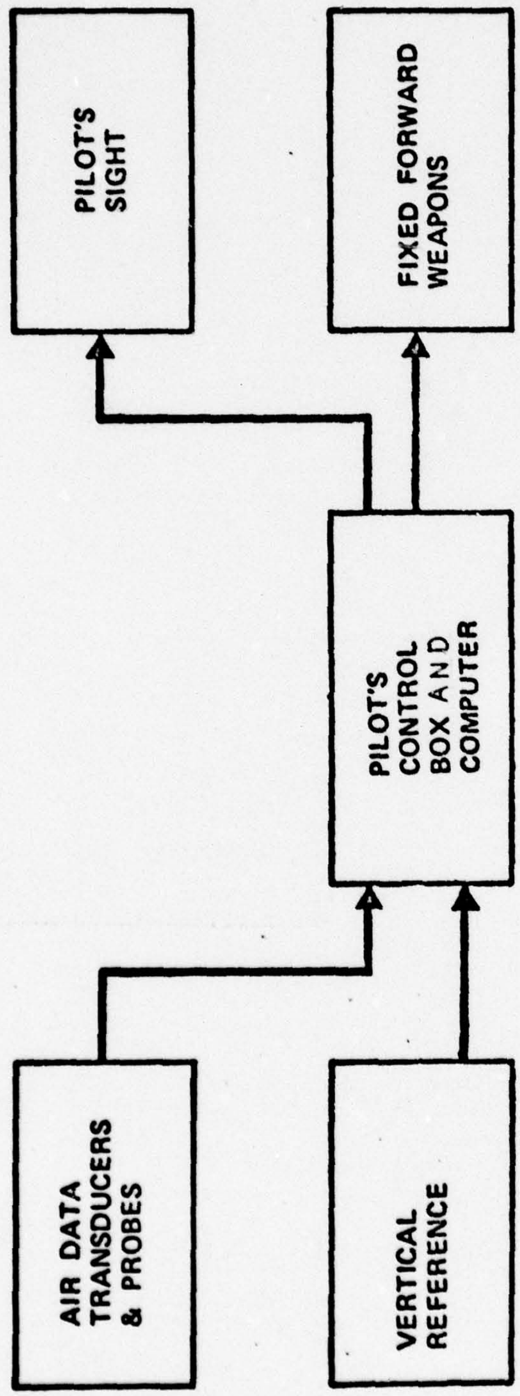

Figure 2. FIRE CONTROL SYSTEM

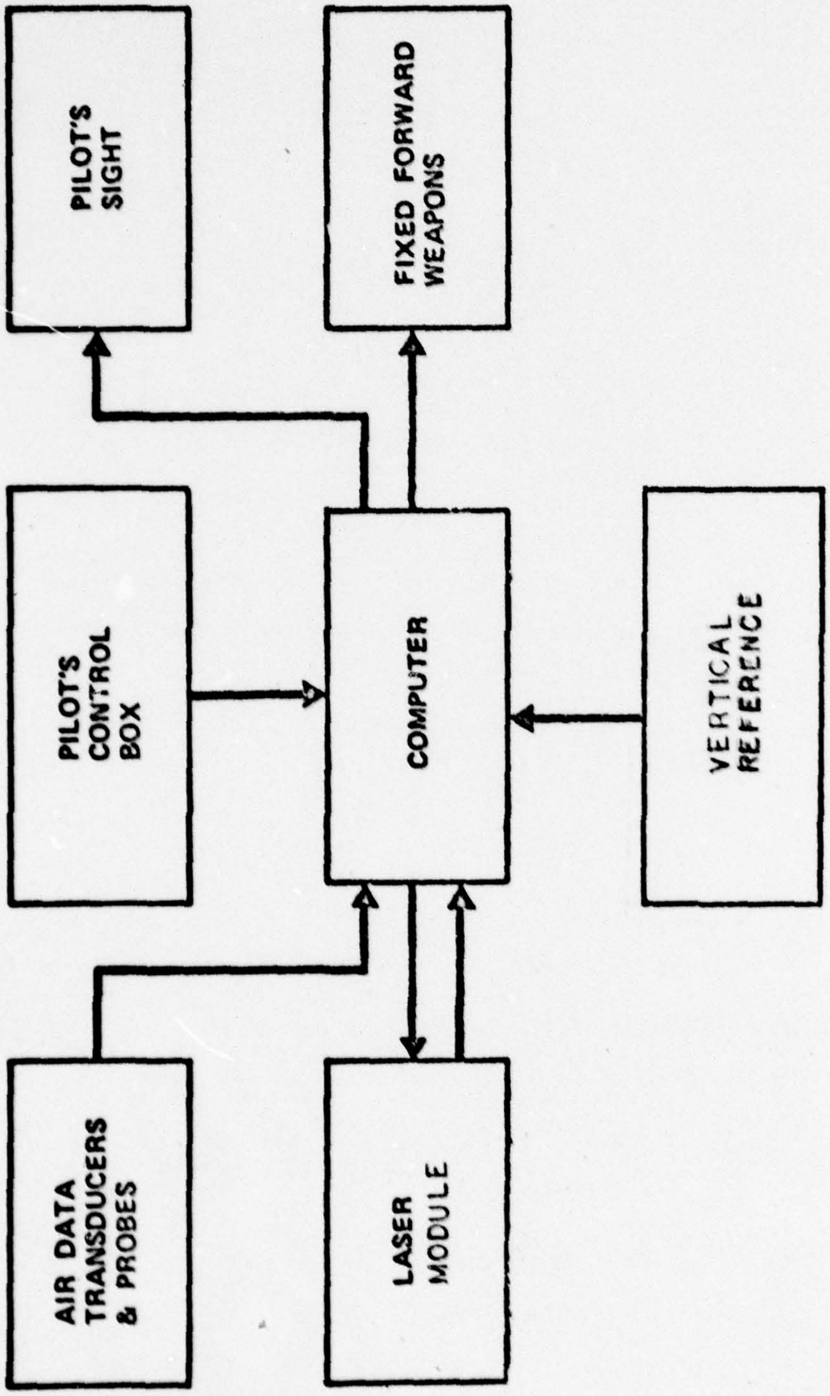

Figure 3. FIRE CONTROL SYSTEM

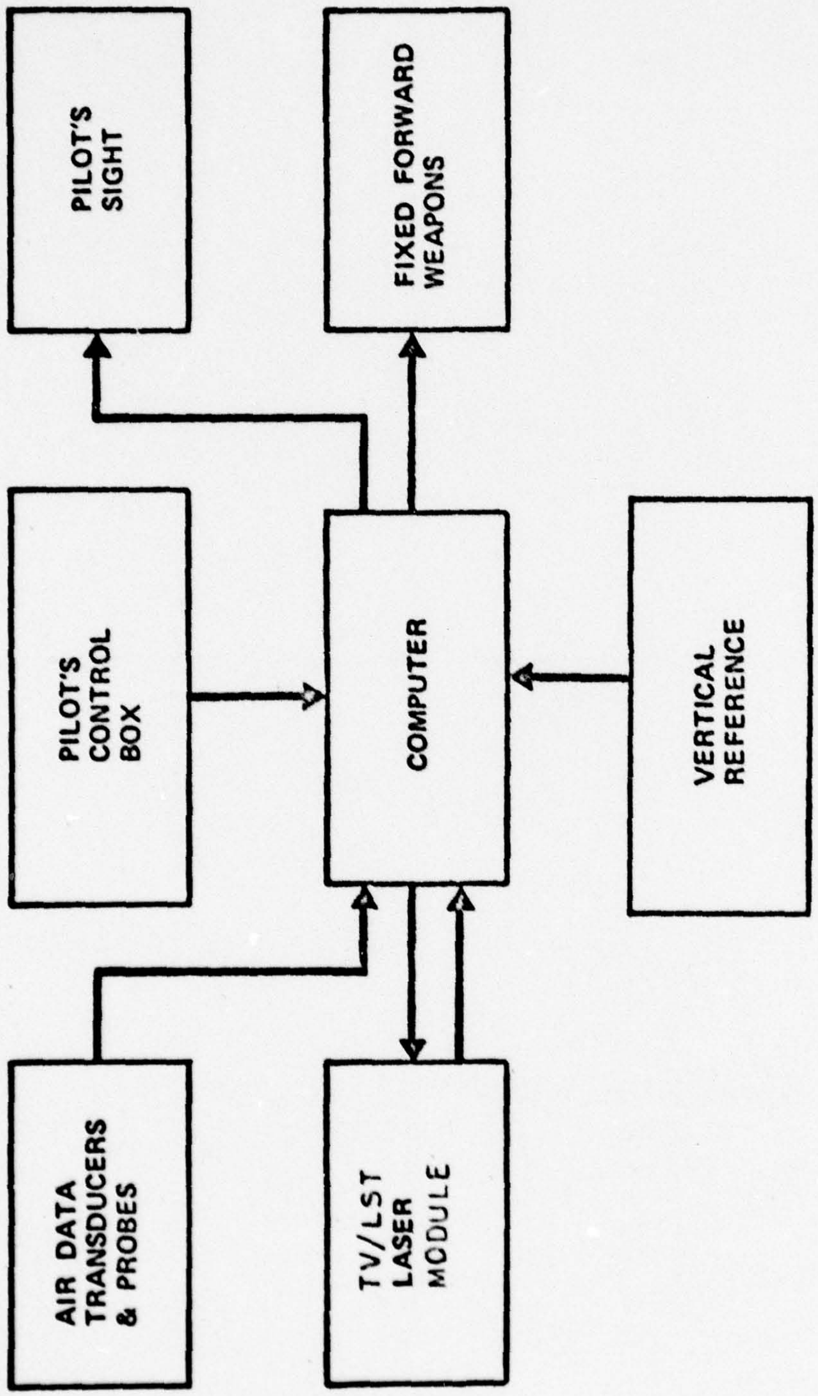

Figure 4. FIRE CONTROL SYSTEM

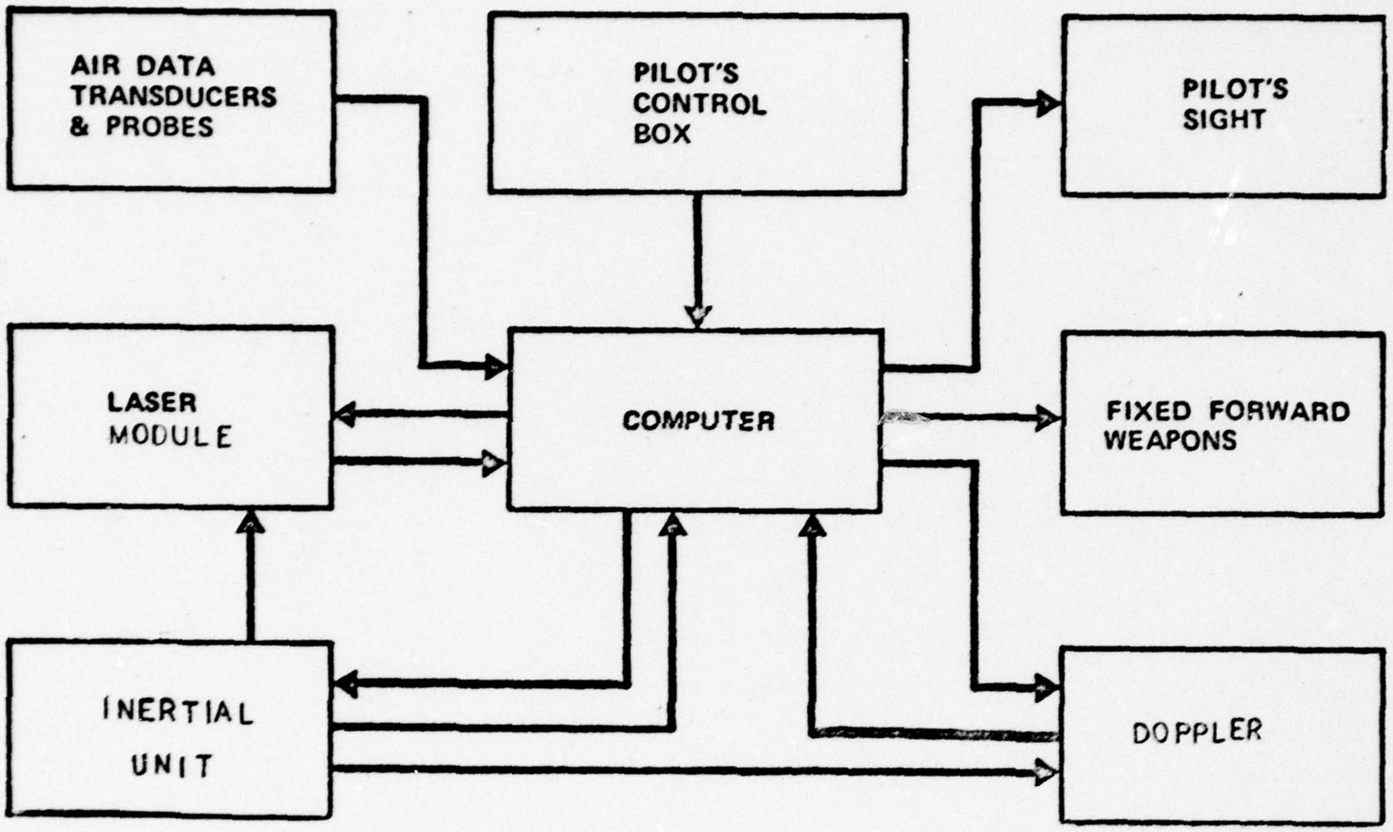

Figure 5. FIRE CONTROL SYSTEM

FIRST ORDER ERROR ANALYSIS - GENERAL CASE

The error analysis of this section is intended to show what sensors and quantities are the more critical factors in this application of gun fire control. As a basis for discussion a system such as shown in Figure 3 was used; however, no (lead computing) wind solution is included.

Table 1 gives major first order error sensitivities. Not included are computer error, interface errors, uncertainty of ballistic computation, etc. Table 2 applies Table 1 to a hypothetical system case. The assumed errors are total quantity errors whether bias or random. Concise comments on various inaccuracies and the use of the Tables 1 and 2 follow: (With few exceptions the comments apply to Tables 3, 4, and 5 of the next section.).

Gun boresight is present in any gun system. The error ratio varies from 1:1 depending on the muzzle velocity and aircraft speed.

Angle of attack error include boresight and corrections to convert local sensor angle to aircraft angle of attack as well as pure sensor error. The magnitude of lead error depends directly on the magnitude of muzzle velocity and the airspeed. Angle of attack (and skid) is a difficult quantity to measure accurately both in general flight and in flight calibration tests. Table 2 assumes the aircraft is very stable in yaw, and not requiring measurement. Thus in this type of a system the pilot should not skid the aircraft to correct aim error.

Slant range error includes pointing error, etc. In theory laser range can be better than shown in Table 2, however, it is not needed here.

In gun fire control pitch angle is not a critical factor, however, for large lead angles roll errors can result in moderate error in azimuth due to incorrect roll resolution. Often used flight maneuvers in test and repeated attacks can result in large roll error in the standard type vertical references. Proper flying to prevent this is necessary.

Air density is not a major problem as long as its measurement is included.

Baring major air flow problems, true airspeed measurement is not a major problem. (True airspeed is somewhat more sensitive a measurement in Tables 3, 4, and 5.)

If major errors are eliminated, muzzle velocity can cause a sizable error. It is particularly important in computing time of flight. Included in this error are effects of barrel wear, barrel temperature, propellant variations, etc.

Variation in or incorrectly used drag characteristics have also a major affect on on time of flight, and thus many second order effects. The gravity drop is little affected.

Wind (at aircraft position) and target motion that is not included in the lead computation causes an error directly proportional to time of flight. This is not only a large error source, but also gives a bias type error.

HUD errors are often two or three mils; however, here it is assumed only limited angles are used and that the sight (e.g. electromechanical servoed type) can be calibrated to a mil or so.

Pilot aim can be almost any value depending on experience, wind gusts, aircraft, combat conditions, etc., etc. On test range the average can be about three mils.

BASIC SYSTEM

[Error Required to Cause one Milliradian Lead Angle Error][1]

CONDITION (400 Knots & →	10°/3000 Ft	25°/6000 Ft	45°/7500 Ft
Error Source, Units ↓			
Elevation			
Gun Boresight, ν, mils	1.4	1.4	1.4
Angle of Attack, α, mils	3.4	3.4	3.4
Slant Range, R, feet	220	160	170
Pitch Angle, δ, degrees	25	4.2	1.9
Density, ρ, 1000 ft p. altitude	14	2.6	1.9
True Airspeed, v_a, knots	63	26	24
Muzzle Velocity, V_m, fps	100	43	40
Drag Variation, D, percent	83	8.0	5.7
Rangewind[2], W_x, knots	6.3	2.2	1.3
HUD, λ_e, mils	1	1	1
AIM, λ_e, mils	1	1	1
Azimuth			
Gun Boresight, μ, mils	1.4	1.4	1.4
Angle of Skid, β, mils	3.4	3.4	3.4
Crosswind[2], W_c, knots	1.2	1.0	0.9
Roll Angle, θ, degrees	5.3	2.3	2.1
HUD, λ_a, mils	1	1	1
AIM, λ_a, mils	1	1	1

Table 1. Inverse Lead Angle Error Sensitivities. [1]More correctly the inverse of the sensitivities, [2]wind includes target motion, no vertical wind is assumed.

BASIC SYSTEM

CONDITION (400 Knots & →	10°/3000 Ft	25°/6000 Ft	45°/7500 Ft
Error Source ↓			
Elevation			
Gun Boresight, 1 mil	0.7	0.7	0.7
Angle of Attack, 8 mils	2.4	2.4	2.4
Slant Range, 30 feet	0.1	0.2	0.2
Pitch Angle, 1 degree	0.0	0.2	0.5
Density, [illegible]00 ft p. altitude	0.0	0.0	0.1
True Airspeed, 5 knots	0.1	0.2	0.2
Muzzle Velocity, 25 fps	0.2	0.6	0.6
Drag Variation, 2 percent	0.0	0.2	0.3
Rangewind*, 10 knots	1.6	4.5	7.9
HUD, 1 mil	1.0	1.0	1.0
Pilot Aim, 3 mils	3.0	3.0	3.0
Azimuth			
Gun Boresight, 1 mil	0.7	0.7	0.7
Angle of Skid, 4 mils	1.2	1.2	1.2
Crosswind*, 10 knots	8.5	10.1	11.0
Roll Angle, 1 degree	0.2	0.4	0.5
HUD, 1 mil	1.0	1.0	1.0
Pilot Aim, 3 mils	3.0	3.0	3.0

Table 2. Sample System Accuracy. These errors all optimistic values. *Wind includes target motion. Second order terms not included. Since these errors are part bias and part random they must be combined accordingly.

FIRST ORDER ERROR ANALYSIS - ANGULAR RATE CASE

If accurate target LOS inertial angular rate and LOS slant range is available two of the major errors discussed in the last section--angle of attack (and skid) and wind and target motion are nearly eliminated. Of course, an error dependence on angular rate and a change in other error sensitivities occurs. Table 3 and 4 shows the results of this type fire control concept.

The primary error sources in an autotrack system for a fixed forward gun are: (1) boresight, particularly between HUD and gun; (2) HUD pip placement; and (3) pilot aim.

The HUD error can be eliminated, the aim error reduced, and the boresight made an easier task by using a direct (mechanical and/or optical) coupling between a trainable gun and the autotracker.* This allows the pilot (or observer) to lock the tracker on the target and the gun aimed independently of small aircraft steering variations. If extreme accuracy (i.e. a few mils) is required this approach is the most feasible concept for the gun-fire system. (Table 5). More comments on this are in a later section.

---

*With a fixed gun the effect of the HUD errors and the pilot aim error can be decreased by firing automatically (if the trigger is depressed) as the elevation lead angle is approached. This lets the pilot concentrate on azimuth steering. (The tracker must be locked on the target.)

AUTOTRACKER-LASER SYSTEM

[Error Required to Cause One Milliradian Lead Angle Error][1]

CONDITION (400 Knots & →	10°/3000 Ft	25°/6000 Ft	45°/7500 Ft
Error Source, Units ↓			
Elevation			
Gun Boresight, ν, mils	1.4	1.4	1.4
Angle of Attack, α, mil	20	25	30
Slant Range, R, feet	310	250	233
Pitch Angle, δ, degrees	25	4.2	1.9
Density, ρ, 1000 ft p. altitude	14	2.6	1.9
True Airspeed, v_a, knots	74	11	7.3
Muzzle Velocity, V_m, fps	100	43	40
Drag Variation, D, percent	83	8.0	5.7
Range Rate, $\dot{R}$, fps	110	36	25
Angular Rate, $\dot{\omega}_e$, mils/sec	0.66	0.28	0.21
HUD, λ_e, mils	1	1	1
AIM, λ_3, mils	1	1	1
Azimuth			
Gun Boresight, μ, mils	1.4	1.4	1.4
Angle of Skid, β, mils	0.0	0.0	0.0
Roll Angle, θ, degrees	1.2	1.0	0.9
Angular Rate, ω_a, mils/sec	0.66	0.28	0.21
HUD, λ_a, mils	1	1	1
AIM, λ_a, mils	1	1	1

Table 3. Inverse Lead Angle Error Sensitivities. [1]More correctly the inverse of the sensitivities.

AUTOTRACKER-LASER SYSTEM

CONDITIONS (400 Knots & →	10°/3000 Ft	25°/6000 Ft	45°/7500 Ft
Error Source ↓			
Elevation			
Gun Boresight, 1 mil	0.7	0.7	0.7
Angle of Attack 8 mils	0.3	0.3	0.3
Slant Range, 30 feet	0.1	0.1	0.1
Pitch Angle, 1 degree	0.0	0.2	0.2
Density, 100 ft p. altitude	0.0	0.0	0.1
True Airspeed, 5 knots	0.1	0.5	0.7
Muzzle Velocity, 25 fps	0.2	0.6	0.6
Drag Variation, 2 percent	0.0	0.2	0.3
Range Rate, 30 fps	0.3	0.8	1.2
Angular Rate, 1/4 mil/sec	0.4	0.9	1.2
HUD, 1 mil	1.0	1.0	1.0
Pilot Aim, 3 mils	3.0	3.0	3.0
Azimuth			
Gun Boresight, 1 mil	0.7	0.7	0.7
Angle of Skid, 4 mils	0.0	0.0	0.0
Roll Angle, 1 degree	0.2	0.4	0.5
Angular Rate, 1/4 mil/sec	0.4	0.9	1.2
HUD, 1 mil	1.0	1.0	1.0
Pilot's Aim, 3 mils	3.0	3.0	3.0

Table 4. Sample System Accuracy. These errors all optimistic values. Second order terms not included. Since these errors are part bias and part random they must be combined accordingly.

TRAINABLE GUN-AUTOTRACKER DIRECT COUPLED SYSTEM

CONDITIONS (400 Knots & →	10°/3000 Ft	25°/6000 Ft	45°/7500 Ft
Error Source ↓			
Elevation			
Gun Boresight, 1 mil	0.7	0.7	0.7
Angle of Attack, 8 mils	0.3	0.3	0.3
Slant Range, 30 feet	0.1	0.1	0.1
Pitch Angle, 1 degree	0.0	0.2	0.2
Density, 100 ft p. altitude	0.0	0.0	0.1
True Airspeed, 3 knots	0.0	0.3	0.4
Muzzle Velocity, 25 fps	0.2	0.6	0.6
Drag Variation, 2 percent	0.0	0.2	0.3
Range Rate, 30 fps	0.3	0.8	1.2
Angular Rate, 1/4 mil/sec	0.4	0.9	1.2
Pilot Aim, 0.3 mil	0.3	0.3	0.3
Servo, 0.5 mil	0.5	0.5	0.5
Azimuth			
Gun Boresight, 1 mil	0.7	0.7	0.7
Angle of Skid, 4 mils	0.0	0.0	0.0
Roll Angle, 1 degree	0.2	0.4	0.5
Angular Rate, 1/4 mil/sec	0.4	0.9	1.2
Pilot's Aim, 0.3 mil	0.3	0.3	0.3
Servo, 0.5 mil	0.5	0.5	0.5

Table 5. Sample System Accuracy. These error values are not necessarily representative, instead they represent a goal such as to approach the desired system results. Computer, interface, etc. errors must be similarly small. (Second order terms not included.)

EXPLORATORY DEVELOPMENT SYSTEM COMMENTS

The generalized system shown in Figure 4 with a trainable* gun directed directly by an autotracker is the only apparent concept which could approach the desired accuracy in a fire control.

The initial tracker lock-on technique could be similar to those used with the A-4M IWDS (ARBS) fire control. For example, a roll in towards the target and using the HUD (boresighted to the tracker axis) lock on to the target or nearby; then using the hand controller and viewing the TV monitor change the lock on point to the desired location.**

After lock on the computed lead angle is inserted between the tracker axis and the effective gun axis by servo control of the trainable gun. Then the pilot may fire at will.

Accuracy is the primary problem in this fire control design. Thus as seen in the error sensitivities sections, all sensors must be chosen or designed with this a prime concern. Boresight, particularly between the autotracker and gun, must be insured at all times. This will require special automatic or semi-automatic optical techniques designed into the equipment.

Self test and service test equipment must be a basic part of the design from the start of development if service use is to approach test results.

Gun-projectile ballistics must be known very accurately and the projectile must have low drag characteristics. Service use muzzle velocity variations will likely represent a major error source.

---

*An alternate system is one using a fixed gun (again, directly coupled to the tracker) which is fired in like manner as bombs are dropped in automatic release from A-4M IWDS (ARBS) or the A-7E. The firing is automatic (if allowed by pilot trigger depression) based on elevation lead. Azimuth lead is presented on the HUD as an error signal which is nulled. If the target is being tracked (by the autotracker) this scheme eliminates the HUD errors (position & boresight) and allows the pilot to concentrate on azimuth steering. This approach would avoid the complexity of a trainable gun at the expense of some loss of azimuth accuracy. The CCIP symbol can be displayed for alternate use. Its use gives the advantage of tracking one point and shooting at a nearby target (no target motion correction).

**If a laser spot tracker (LST) is used the pilot would not adjust lock point unless he wished to switch to TV mode.

APPENDIX A

TRAJECTORY DATA USED IN ERROR ANALYSIS

Trajectories were computed on a HP 9100A/9101A calculator based on drag data of the 20mm M56 round and a multiplicative factor 0.4. This factor was determined by fitting trajectories to table values for ground firing for the Rifle, 106mm, M40, firing cartridge, HEP-T, M346. This method was used because it was available immediately, and was sufficiently accurate for error analysis use. Table A-1 compares one case computed this way and by more precise methods used for Appendix B. Table A-2 gives the trajectory data used in the error analysis.

METHOD	R	V_m	δ	v_a	λ_g	t_f
HP 9100A	7575	1650	45	400	27.4	4.88
1108	7575	1650	45	400	27.2	4.83

Table A-1. Comparison of Appendix A and Appendix B data. The derivatives used in error sensitivities vary less than the angle and time of flight.

TRAJECTORY DATA

v_a(fps)	δ(deg)	R(ft)	λ_g(mils)	t_f(sec)	$\dot{\xi}_i$(fps)	$\dot{\eta}_i$(fps)
675	10	3,000	10.91	1.521	1,682	42.1
675	10	2,800	10.02	1.404	1,720	39.2
675	12	3,000	10.83	1.520	1,683	41.8
700	10	3,000	10.67	1.504	1,703	41.6
675	25	6,000	25.47	3.599	1,222	78.6
675	25	5,800	24.21	3.438	1,250	75.8
675	27	6,000	24.99	3.596	1,225	77.3
700	25	6,000	24.89	3.557	1,237	77.8
675	45	7,500	27.60]	4.866	1,062	77.7
675	45	7,300	26.41	4.681	1,084	75.4
675	47	7,500	26.56	4.861	1,065	74.9
700	45	7,500	26.97	4.809	1,076	76.8
675*	10	3,000	10.77	1.507	1,716	41.9
675*	25	3,000	9.85	1.502	1,726	38.6
675*	25	6,000	24.71	3.524	1,270	78.4
675*	45	7,500	26.54	4.736	1,118	76.9
675	0	3,000	11.13	1.524	1,675	42.7
675	0	6,000	28.91	3.652	1,181	88.2

Table A-2. $\dot{\xi}$ and $\dot{\eta}$ are velocity components along and perpendicular to the initial projectile velocity. The muzzle velocity was used as 1,625 feet per second.* These computed for an air density change of 2,000 feet in pressure altitude or a 6.07 percent drag decrease.

APPENDIX B

TRAJECTORY DATA FOR REFERENCE

This data was compiled by John Peterson, NWC, Code 5115. It represents more precise data than that of Appendix A. It is included here for later convenience. The round is the 106mm M346A1.

LEGEND

TIME	TIME OF FLIGHT, SECONDS
X	HORIZONTAL RANGE, FEET
DIST	SLANT RANGE, FEET
V	VELOCITY, FEET/SECOND
DH	GRAVITY DROP, FEET
CMA	STATIC MOMENT COEFFICIENT
ENG	ENERGY, FOOT-POUNDS
THETA	IMPACT ANGLE, DEGREES
Z	ALTITUDE, FEET
DRAG	DRAG, POUNDS
YAW	YAW OF REPOSE, DEGREES
MACH	MACH NUMBER
SPIN	REVOLUTIONS/SECOND
SG	GYROSCOPIC STABILITY FACTOR (disregard)
TEMP	SURFACE (MSL) TEMPERATURE
Q.E.	DIVE ANGLE, DEGREES

BALLISTIC DATA

PROJECTILE DIAMETER	106.00 MILLIMETER
PROJECTILE LENGTH	3.8 CALIBERS
PROJECTILE WEIGHT	17.35 POUNDS
AXIAL MOMENT OF INERTIA	.0091800 POUND-INCH SQ.
TRANSVERSE MOMENT OF INERTIA	.0675000 POUND-INCH SQ.
AXIAL RADIUS OF GYRATION	.3752641 CALIBERS
TRANSVERSE RADIUS OF GYRATION	1.0175775 CALIBERS
CENTER OF GRAVITY, FROM BASE	1.502 INCHES
MUZZLE VELOCITY	1650.0 FEET/SECOND
BARREL TWIST	14.86000 CALIBERS/TURN
RIFLING EXIT ANGLE	7 DEGREES 3 MINUTES
YAW-DRAG COEFFICIENT, PER RADIAN SQUARED	5.8
ROLL DAMPING MOMENT COEFFICIENT, PER RAD/SEC	-.0100

DRAG COEFFICIENT AND STATIC MOMENT COEFFICIENT TABLE

MACH	CDO	MACH	CMA
.10	.232	.10	2.970
.60	.174	.90	3.100
1.25	.604	.97	3.190
1.45	.604	1.00	3.110
1.60	.591	1.20	2.850
1.75	.573	1.50	2.590
2.05	.532	1.70	2.460
2.10	.532	1.99	2.290
2.20	.532	2.25	2.160
2.30	.532	2.50	2.040
2.40	.532	3.00	1.890
2.50	.532	3.60	1.830

TRAJECTORY TABLE NUMBER 1

ALTITUDE: 500.0 FEET DE: -10.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME	X	DIST	V	CD	CMA	ENG
THETA	Z	DRAG	YAW	MACH	SPIN	SG
.00	0.	0.	2325.6	.532	2.24	1457569.
-10.00	500.	319.806	.0307	2.09	1492.	2.68
.10	226.	230.	2268.3	.534	2.27	1384658.
-10.08	460.	305.847	.0325	2.04	1486.	2.76
.20	447.	454.	2213.5	.541	2.29	1320497.
-10.16	421.	295.316	.0344	1.99	1679.	2.84
.30	662.	673.	2160.7	.547	2.32	1258152.
-10.24	382.	285.126	.0364	1.94	1673.	2.92
.40	872.	886.	2109.6	.554	2.35	1199413.
-10.33	344.	275.279	.0384	1.89	1667.	3.00
.50	1077.	1095.	2060.4	.560	2.37	1144040.
-10.41	306.	265.774	.0406	1.85	1661.	3.09
.60	1277.	1298.	2012.8	.566	2.40	1091832.
-10.50	269.	256.609	.0429	1.81	1655.	3.18
.70	1473.	1497.	1966.9	.571	2.42	1042593.
-10.59	233.	247.780	.0453	1.76	1650.	3.27
.80	1664.	1692.	1922.6	.576	2.45	996138.
-10.69	197.	239.088	.0478	1.72	1644.	3.36
.90	1851.	1882.	1879.8	.581	2.47	952329.
-10.78	161.	230.672	.0504	1.69	1639.	3.46
1.00	2034.	2068.	1838.6	.585	2.49	911008.
-10.88	127.	222.608	.0531	1.65	1634.	3.55
1.10	2212.	2250.	1796.8	.590	2.52	872014.
-10.98	92.	214.885	.0559	1.61	1629.	3.65

TRAJECTORY TABLE NUMBER 1 (CON'T)

ALTITUDE: 500.0 FEET   DE: -10.0 DEGREES

VELOCITY: 400.0 KTAS   TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
1.20 -11.08	2387. 58.	2427. 207.207	1760.4 .0589	.593 1.58	2.54 1624.	835195. 3.76
1.30 -11.19	2558. 24.	2602. 199.773	1723.4 .0619	.596 1.54	2.56 1619.	800458. 3.85

TIME,SEC	RANGE,FT	VEL,FPS	THETA	SPIN	SG
1.37	2726.8	1687.8	-11.3	1614.	3.85

TRAJECTORY TABLE NUMBER 2

ALTITUDE: 2000.0 FEET   QE: -20.0 DEGREES

VELOCITY: 400.0 KTAS   TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
.00	0.	0.	2325.6	.532	2.23	1457568.
-20.00	2000.	304.818	.0308	2.10	1692.	2.82
.10	216.	230.	2271.5	.532	2.26	1390538.
-20.08	1921.	291.534	.0325	2.05	1686.	2.90
.20	427.	454.	2219.8	.538	2.28	1327934.
-20.15	1844.	282.479	.0342	2.00	1680.	2.97
.30	633.	674.	2169.7	.545	2.31	1268681.
-20.23	1768.	273.680	.0360	1.96	1674.	3.05
.40	834.	888.	2121.2	.551	2.33	1212595.
-20.31	1694.	265.126	.0379	1.91	1668.	3.12
.50	1031.	1098.	2074.2	.557	2.36	1159502.
-20.39	1621.	256.819	.0398	1.87	1663.	3.20
.60	1223.	1303.	2028.8	.562	2.38	1109237.
-20.48	1549.	248.764	.0419	1.83	1657.	3.28
.70	1411.	1504.	1984.8	.568	2.41	1061642.
-20.56	1479.	240.960	.0440	1.79	1652.	3.37
.80	1595.	1700.	1942.2	.573	2.43	1016565.
-20.65	1410.	233.398	.0462	1.75	1646.	3.46
.90	1774.	1893.	1900.9	.578	2.45	973865.
-20.74	1342.	225.848	.0486	1.71	1641.	3.54
1.00	1950.	2081.	1861.1	.582	2.48	933449.
-20.83	1275.	219.579	.0510	1.68	1636.	3.63
1.10	2122.	2265.	1822.5	.586	2.50	895178.
-20.93	1210.	211.583	.0535	1.64	1631.	3.72

TRAJECTORY TABLE NUMBER 2 (CON'T)

ALTITUDE: 2000.0 FEET QE: -20.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
1.20	2291.	2445.	1785.2	.590	2.52	858926.
-21.02	1145.	204.852	.0561	1.61	1627.	3.82
1.30	2456.	2622.	1749.2	.593	2.54	824571.
-21.12	1081.	198.072	.0588	1.57	1622.	3.91
1.40	2617.	2795.	1714.3	.596	2.56	792050.
-21.22	1019.	191.526	.0616	1.54	1617.	4.01
1.50	2775.	2965.	1680.7	.599	2.58	761255.
-21.32	957.	185.266	.0645	1.51	1613.	4.11
1.60	2930.	3131.	1648.2	.601	2.61	732078.
-21.42	897.	179.278	.0675	1.48	1608.	4.20
1.70	3082.	3294.	1616.7	.604	2.63	704415.
-21.53	837.	173.547	.0704	1.45	1604.	4.29
1.80	3231.	3455.	1586.3	.604	2.65	678174.
-21.64	778.	167.443	.0735	1.43	1600.	4.39
1.90	3377.	3612.	1557.0	.604	2.68	653357.
-21.74	720.	161.616	.0766	1.40	1596.	4.48
2.00	3521.	3766.	1529.8	.604	2.70	629874.
-21.86	663.	156.093	.0799	1.37	1592.	4.58
2.10	3661.	3917.	1501.6	.604	2.72	607631.
-21.97	606.	150.854	.0832	1.35	1588.	4.68
2.20	3799.	4066.	1475.3	.604	2.74	586543.
-22.08	550.	145.879	.0867	1.33	1584.	4.78
2.30	3935.	4213.	1449.9	.604	2.76	566535.
-22.20	495.	141.152	.0902	1.30	1580.	4.88

TRAJECTORY TABLE NUMBER 2 (CON'T)

ALTITUDE: 2000.0 FEET QE: -20.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
2.40 -22.32	4068. 441.	4356. 136.656	1425.4 .0938	.604 1.28	2.78 1576.	547534. 4.98
2.50 -22.44	4198. 397.	4498. 132.377	1401.7 .0975	.604 1.26	2.80 1573.	529475. 5.08
2.60 -22.56	4327. 334.	4637. 126.501	1378.7 .1013	.596 1.24	2.82 1569.	512299. 5.19
2.70 -22.69	4453. 281.	4773. 120.018	1356.9 .1051	.582 1.22	2.84 1565.	496185. 5.29
2.80 -22.81	4577. 229.	4908. 114.089	1336.2 .1089	.570 1.20	2.85 1562.	481175. 5.39
2.90 -22.94	4699. 177.	5040. 108.651	1316.6 .1124	.558 1.18	2.88 1559.	467159. 5.48
3.00 -23.07	4820. 126.	5171. 103.649	1298.0 .1158	.547 1.16	2.90 1555.	454043. 5.56
3.10 -23.20	4938. 76.	5300. 99.036	1280.3 .1193	.536 1.15	2.92 1552.	441742. 5.64
3.20 -23.33	5055. 25.	5427. 94.770	1263.4 .1227	.526 1.13	2.94 1549.	430183. 5.72

TIME,SEC	RANGE,FT	VEL,FPS	THETA	SPIN	SG
3.25	5491.2	1247.3	-23.5	1546.	5.72

TRAJECTORY TABLE NUMBER 3

ALTITUDE: 3000.0 FEET QE: -30.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
.00	0.	0.	2325.6	.532	2.23	1457568.
-30.00	3000.	295.218	.0294	2.11	1692.	2.92
.10	199.	230.	2273.7	.532	2.25	1393224.
-30.07	2885.	283.227	.0309	2.06	1686.	2.99
.20	394.	455.	2223.9	.537	2.28	1332912.
-30.14	2772.	274.416	.0324	2.02	1680.	3.06
.30	584.	675.	2175.8	.543	2.30	1275798.
-30.21	2662.	266.583	.0340	1.97	1675.	3.13
.40	770.	890.	2129.0	.549	2.33	1221559.
-30.29	2553.	258.927	.0356	1.93	1669.	3.20
.50	952.	1101.	2083.6	.555	2.35	1170051.
-30.36	2447.	251.456	.0373	1.89	1664.	3.28
.60	1129.	1307.	2039.6	.560	2.37	1121138.
-30.44	2342.	244.174	.0391	1.85	1658.	3.35
.70	1303.	1509.	1996.9	.566	2.40	1074685.
-30.52	2240.	237.085	.0409	1.81	1653.	3.43
.80	1473.	1706.	1955.5	.571	2.42	1030566.
-30.60	2140.	230.192	.0429	1.77	1648.	3.51
.90	1640.	1900.	1915.3	.575	2.44	988658.
-30.68	2041.	223.362	.0449	1.73	1643.	3.59
1.00	1803.	2089.	1876.4	.580	2.46	948869.
-30.76	1944.	216.648	.0470	1.70	1638.	3.68
1.10	1963.	2275.	1838.7	.584	2.49	911100.
-30.85	1849.	210.160	.0492	1.66	1633.	3.76

TRAJECTORY TABLE NUMBER 3 (CON'T)

ALTITUDE: 3000.0 FEET QE: -30.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME	X	DIST	V	CD	CMA	ENG
THETA	Z	DRAG	YAW	MACH	SPIN	SG
1.20	2119.	2457.	1802.1	.588	2.51	875239.
-30.94	1755.	203.894	.0519	1.63	1628.	3.95
1.30	2272.	2636.	1766.7	.592	2.53	841176.
-31.02	1664.	197.759	.0537	1.59	1624.	3.93
1.40	2422.	2811.	1732.4	.594	2.55	808827.
-31.11	1573.	191.586	.0562	1.56	1619.	4.02
1.50	2568.	2982.	1699.2	.597	2.57	778135.
-31.21	1485.	185.663	.0587	1.53	1615.	4.12
1.60	2712.	3150.	1667.1	.600	2.59	749000.
-31.30	1397.	179.980	.0613	1.50	1610.	4.21
1.70	2853.	3316.	1636.0	.602	2.61	721329.
-31.40	1311.	174.525	.0638	1.47	1606.	4.30
1.80	2992.	3478.	1605.9	.604	2.64	695034.
-31.49	1227.	169.158	.0664	1.45	1602.	4.38
1.90	3127.	3637.	1576.8	.604	2.66	670054.
-31.59	1144.	163.514	.0691	1.42	1598.	4.47
2.00	3260.	3793.	1548.7	.604	2.68	646385.
-31.69	1062.	158.153	.0719	1.39	1594.	4.56
2.10	3391.	3947.	1521.6	.604	2.70	623938.
-31.79	981.	153.056	.0748	1.37	1590.	4.65
2.20	3519.	4097.	1495.4	.604	2.72	602634.
-31.90	901.	148.207	.0777	1.35	1586.	4.74
2.30	3645.	4246.	1470.0	.604	2.74	582397.
-32.00	823.	143.590	.0807	1.32	1582.	4.84

TRAJECTORY TABLE NUMBER 3 (CON'T)

ALTITUDE: 3000.0 FEET   QE: -30.0 DEGREES

VELOCITY: 400.0 KTAS   TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
2.40 -32.11	3768. 745.	4391. 139.191	1445.6 .0837	.604 1.30	2.76 1578.	563159. 4.93
2.50 -32.22	3890. 669.	4535. 134.997	1421.9 .0869	.604 1.28	2.78 1574.	544857. 5.03
2.60 -32.33	4009. 594.	4676. 130.996	1399.0 .0901	.604 1.26	2.80 1571.	527433. 5.12
2.70 -32.44	4126. 519.	4814. 125.282	1376.8 .0934	.595 1.24	2.82 1567.	510833. 5.22
2.80 -32.56	4241. 446.	4951. 119.124	1355.6 .0967	.582 1.22	2.84 1564.	495255. 5.32
2.90 -32.67	4355. 373.	5086. 113.479	1335.6 .0999	.570 1.20	2.85 1560.	480723. 5.41
3.00 -32.79	4466. 302.	5218. 108.290	1316.6 .1029	.559 1.18	2.87 1557.	467133. 5.49
3.10 -32.91	4576. 231.	5349. 103.506	1298.5 .1059	.548 1.16	2.90 1554.	454399. 5.56
3.20 -33.03	4684. 161.	5478. 99.085	1281.3 .1088	.537 1.15	2.92 1551.	442443. 5.64
3.30 -33.15	4791. 91.	5605. 94.989	1264.9 .1117	.527 1.13	2.94 1547.	431195. 5.71
3.40 -33.27	4896. 22.	5731. 91.186	1249.3 .1146	.518 1.12	2.95 1544.	420596. 5.78

TIME,SEC	RANGE,FT	VEL,FPS	THETA	SPIN	SG
3.43	5771.2	1234.3	-33.4	1541.	5.78

TRAJECTORY TABLE NUMBER 4

ALTITUDE: 5500.0 FEET   QE: -45.0 DEGREES

VELOCITY: 400.0 KTAS   TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
.00	0.	0.	2325.6	.532	2.22	1457568.
-45.00	5500.	272.521	.0261	2.13	1692.	3.18
.10	163.	230.	2278.4	.532	2.24	1398959.
-45.06	5337.	262.929	.0272	2.09	1687.	3.24
.20	322.	456.	2232.9	.533	2.26	1343631.
-45.11	5177.	254.215	.0284	2.05	1681.	3.30
.30	478.	677.	2188.9	.539	2.28	1291273.
-45.17	5021.	248.159	.0296	2.00	1676.	3.37
.40	631.	894.	2146.1	.544	2.31	1241226.
-45.23	4867.	242.185	.0308	1.96	1671.	3.43
.50	780.	1106.	2104.3	.549	2.33	1193396.
-45.29	4716.	236.300	.0321	1.92	1666.	3.50
.60	927.	1315.	2063.6	.555	2.35	1147692.
-45.36	4568.	230.513	.0334	1.89	1661.	3.56
.70	1070.	1519.	2024.0	.560	2.37	1104025.
-45.42	4422.	224.830	.0348	1.85	1656.	3.63
.80	1211.	1719.	1985.4	.565	2.39	1062307.
-45.48	4279.	219.257	.0362	1.81	1651.	3.70
.90	1349.	1916.	1947.8	.570	2.42	1022453.
-45.55	4139.	213.797	.0377	1.78	1646.	3.77
1.00	1484.	2109.	1911.2	.574	2.44	984381.
-45.62	4001.	208.395	.0392	1.74	1642.	3.85
1.10	1616.	2298.	1875.6	.578	2.45	948021.
-45.68	3866.	202.980	.0408	1.71	1637.	3.92

TRAJECTORY TABLE NUMBER 4 (CON'T)

ALTITUDE: 5500.0 FEET QE: -45.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	FNG SG
1.20 -45.75	1746. 3733.	2484. 197.710	1840.9 .0425	.582 1.68	2.48 1633.	913320. 4.00
1.30 -45.82	1873. 3602.	2667. 192.596	1807.2 .0441	.586 1.64	2.50 1628.	880195. 4.08
1.40 -45.90	1998. 3474.	2846. 187.604	1774.5 .0459	.590 1.61	2.52 1624.	849571. 4.16
1.50 -45.97	2120. 3347.	3021. 182.581	1742.6 .0477	.593 1.58	2.54 1620.	818374. 4.24
1.60 -46.04	2240. 3223.	3194. 177.605	1711.6 .0496	.595 1.56	2.55 1615.	789564. 4.32
1.70 -46.12	2358. 3101.	3364. 172.801	1681.6 .0515	.598 1.53	2.57 1611.	762089. 4.40
1.80 -46.20	2473. 2980.	3530. 168.163	1652.4 .0535	.600 1.50	2.59 1607.	735875. 4.49
1.90 -46.27	2586. 2862.	3694. 163.686	1624.1 .0554	.602 1.47	2.61 1603.	710857. 4.56
2.00 -46.35	2698. 2746.	3855. 159.263	1596.6 .0574	.604 1.45	2.64 1599.	686971. 4.64
2.10 -46.43	2807. 2631.	4014. 154.544	1569.9 .0594	.604 1.42	2.66 1595.	664173. 4.72
2.20 -46.51	2914. 2518.	4169. 150.035	1544.0 .0615	.604 1.40	2.68 1592.	642471. 4.80
2.30 -46.60	3019. 2407.	4322. 145.725	1519.0 .0636	.604 1.38	2.70 1588.	621800. 4.89

TRAJECTORY TABLE NUMBER 4 (CON'T)

ALTITUDE: 5500.0 FEET   DE: -45.0 DEGREES

VELOCITY: 400.0 KTAS   TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CNA SPIN	ENG SG
2.40	3123.	4473.	1494.7	.604	2.72	602097.
-46.68	2297.	141.603	.0658	1.35	1584.	4.97
2.50	3225.	4621.	1471.2	.604	2.74	583305.
-46.77	2190.	137.659	.0681	1.33	1581.	5.05
2.60	3324.	4767.	1448.4	.604	2.76	565371.
-46.85	2083.	133.882	.0703	1.31	1577.	5.14
2.70	3423.	4911.	1426.3	.604	2.77	548244.
-46.94	1978.	130.263	.0727	1.29	1574.	5.22
2.80	3519.	5053.	1404.8	.604	2.79	531880.
-47.03	1875.	126.794	.0750	1.27	1570.	5.31
2.90	3614.	5192.	1384.0	.604	2.81	516235.
-47.12	1773.	123.417	.0774	1.25	1567.	5.40
3.00	3708.	5329.	1363.8	.591	2.82	501276.
-47.21	1672.	117.755	.0799	1.23	1563.	5.48
3.10	3800.	5465.	1344.7	.580	2.84	487280.
-47.30	1572.	112.543	.0823	1.21	1560.	5.57
3.20	3890.	5598.	1326.4	.568	2.86	474159.
-47.40	1474.	107.732	.0847	1.20	1557.	5.65
3.30	3979.	5730.	1309.1	.558	2.88	461833.
-47.49	1377.	103.280	.0868	1.18	1554.	5.72
3.40	4067.	5860.	1292.5	.547	2.90	450233.
-47.59	1281.	99.152	.0890	1.16	1551.	5.78
3.50	4154.	5988.	1276.7	.538	2.92	439298.
-47.68	1186.	95.316	.0911	1.15	1547.	5.85

TRAJECTORY TABLE NUMBER 4 (CON'T)

ALTITUDE: 5500.0 FEET　　　　QE: -45.0 DEGREES

VELOCITY: 400.0 KTAS　　　　TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
3.60	4239.	6115.	1261.6	.528	2.93	428973.
-47.78	1092.	91.741	.0932	1.14	1544.	5.91
3.70	4323.	6241.	1247.2	.520	2.95	419209.
-47.88	999.	88.407	.0952	1.12	1541.	5.97
3.80	4406.	6365.	1233.4	.511	2.97	409963.
-47.98	907.	85.289	.0973	1.11	1539.	6.03
3.90	4488.	6487.	1220.1	.503	2.98	401194.
-48.08	816.	82.370	.0992	1.10	1536.	6.09
4.00	4569.	6609.	1207.4	.495	3.00	392868.
-48.18	726.	79.632	.1012	1.09	1533.	6.14
4.10	4649.	6729.	1195.2	.487	3.01	384953.
-48.28	636.	77.059	.1031	1.07	1530.	6.20
4.20	4728.	6847.	1183.4	.480	3.03	377419.
-48.39	547.	74.639	.1050	1.06	1527.	6.25
4.30	4806.	6965.	1172.1	.473	3.04	370240.
-48.49	459.	72.359	.1069	1.05	1524.	6.30
4.40	4884.	7082.	1161.2	.467	3.06	363393.
-48.59	372.	70.207	.1087	1.04	1522.	6.35
4.50	4960.	7197.	1150.7	.460	3.07	356854.
-48.70	285.	68.175	.1105	1.03	1519.	6.40
4.60	5036.	7312.	1140.6	.454	3.08	350606.
-48.81	199.	66.253	.1123	1.02	1516.	6.45
4.70	5110.	7425.	1130.8	.448	3.09	344628.
-48.91	113.	64.433	.1140	1.01	1514.	6.49

TRAJECTORY TABLE NUMBER 4 (CON'T)

ALTITUDE: 5500.0 FEET DE: -45.0 DEGREES

VELOCITY: 400.0 KTAS TEMP: 59.0 DEG F

TIME THETA	X Z	DIST DRAG	V YAW	CD MACH	CMA SPIN	ENG SG
4.80 -49.02	5184. 28.	7538. 62.709	1121.4 .1157	.442 1.00	3.10 1511.	338905. 6.54

TIME,SEC	RANGE,FT	VEL,FPS	THETA	SPIN	SG
4.83	7575.1	1112.3	-49.1	1508.	6.54

APPENDIX C
SELECTED WIND DATA, NWC ARBS FLIGHT TESTS

Table 1 gives wind data taken before an ARBS bomb drop flight test. Table 2 gives wind data before and after particular flights (of approximately 1-hour duration). Note the variation in both magnitude and direction. The rangewind is approximately North-South. This data is a small sample of summer afternoon NWC weather conditions. Good bombing results were obtained in these conditions with NWC's ARBS.

TABLE 1. Wind Components (ft/sec) as a Function of Altitude.

Date	6-9-71		6-22-71		6-24-71		6-25-71		6-28-71		6-29-71	
AGL	CW	RW	CW	RW	CW	RW	CW	RW	CW	RW	CW	RW
500	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-15	10
1,000	-0	24	5	20	37	-5	40	15	0	10	-12	8
2,000	-5	16	2	23	30	5	34	11	2	3	-2	-24
3,000	-7	20	0	20	40	-12	20	-5	5	5	-7	-20
4,000	-7	15	17	22	40	-12	35	-30	4	8	-19	-20
5,000	-5	20	17	22	30	-10	35	-22	0	0	-28	-20
6,000	-5	7	NA	NA	25	-10	40	-13	-8	5	-29	-21

Ground level altitude approximately 2,200 ft MSL.

CW Crosswind
RW Rangewind
NA Not available

TABLE 2. Wind Components (ft/sec) Before and After an ARBS Test Flight (nominally 12 bomb drops per flight).

Date	6-10-71				6-11-71			
Wind	CW		RW		CW		RW	
AGL	B	A	B	A	B	A	B	A
1,000	-7	NA	7	NA	0	5	0	5
2,000	-5	6	7	5	5	-3	-25	10
3,000	-15	0	20	9	-5	-6	-20	-4
4,000	-3	4	10	5	-15	-5	-10	0
5,000	-12	-4	13	15	-15	-8	0	-4
6,000	-15	-5	10	16	-15	-10	0	-5

Ground level altitude approximately 2,200 ft MSL.

CW Crosswind
RW Rangewind
NA Not available
B Preflight conditions
A Post flight conditions