

A046587

AD A046587

DRSAR/SA/N-68

SYSTEMS ANALYSIS DIRECTORATE

ACTIVITIES SUMMARY

JUNE 1977

TECHNICAL
LIBRARY

JULY 1977

Approved for public release; distribution unlimited.



US ARMY ARMAMENT MATERIEL READINESS COMMAND

SYSTEMS ANALYSIS DIRECTORATE

ROCK ISLAND, ILLINOIS 61201

DISPOSITION

Destroy this report when no longer needed. Do not return it to the originator.

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position.

WARNING

Information and data contained in this document are based on input available at the time of preparation. Because the results may be subject to change, this document should not be construed to represent the official position of the US Army Development & Readiness Command unless so stated.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DRSAR/SA/N-68	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SYSTEMS ANALYSIS DIRECTORATE ACTIVITIES SUMMARY - JUNE 1977		5. TYPE OF REPORT & PERIOD COVERED Note - Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Armament Materiel Readiness Command Systems Analysis Directorate (DRSAR-SA) Rock Island, IL 61201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Materiel Readiness Command Systems Analysis Directorate (DRSAR-SA) Rock Island, IL 61201		12. REPORT DATE July 1977
		13. NUMBER OF PAGES 135
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Additions or deletions of addresses to/from the distribution list are invited and should be forwarded to the address below. Inquiries pertinent to specific items of interest may be forwarded to Commander, ATTN: DRSAR-SA, Rock Island, IL 61201 (AUTOVON 793-4483/4628).		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Billet Crane Simulation COPPERHEAD M188E1 Propelling Charge EXBAL M551 Sheridan Wear-Out ZOT.14/ZOT.15 Guidance Simulation Provisioning System		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This monthly publication contains Memoranda for Record (MFR's) and other technical information that summarize the activities of the Systems Analysis directorate, US Army Materiel Readiness Command, Rock Island, IL. (The most significant MFR's and other data will be published as notes or reports at a later date.) The subjects dealt with are Exterior Ballistics of Boosted Rockets (EXBAL), SHAPE Technical Center, COPPERHEAD, Billet Crane Simulation, Provisioning System, M551 Sheridan, M188E1 Propelling Charge.		

DD FORM 1473
1 JAN 73

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS*

	Page
COPPERHEAD	
User's Guide for the Computer Program: Exterior Ballistics of Boosted Rockets (EXBAL)	5
Information for SHAPE Technical Center Relative to ZOT.14/ ZOT.15	65
Computer Simulation Study of the Relationship of the COPPERHEAD Footprint to Ceiling and Gun-to-Target Range	73
MISCELLANEOUS	
Scranton Billet Crane Simulation	85
Analysis of the Provisioning System	93
M551 Sheridan Wear Out	101
Statistical Methods Pertinent to a Potential Ignition Problem in the M188E1 Propelling Charge	109
DISTRIBUTION LIST	132

*Memoranda for Record and other technical information are grouped according to subject when applicable, and in chronological order.

13 JUN 1977

MEMORANDUM FOR RECORD

SUBJECT: User's Guide for the Computer Program: Exterior Ballistics of Boosted Rockets (EXBAL)

1. References:

a. Technical Report, DRSAR/SA/R-12, April 76, title: Dynamics of Liquid-Filled Projectiles.

b. MFR, DRSAR-SAM, 20 Apr 77, subject: An Improved Algorithm for the Glide Mode of Copperhead Used in a 3 DOF Flight Simulation.

2. A general purpose, point-mass (3 DOF) flight simulation program, EXBAL, has been used by DRSAR-SA and others for many years for a variety of applications. A recent special application is noted in Ref a. Each application has special requirements which often entail modifications to the basic program. Consequently, the program documentation must be updated frequently.

3. The purpose of this memorandum is to update EXBAL for the program user. Recent changes that were incorporated to treat the glide mode of Copperhead (Ref b) are discussed here. In Annex 1 (Incl 1) to this memo are contained the following: background, program structure, theory pertinent to recent changes, input and output data definition and format, flow charts for the major subprograms, and bibliographic citations. Annex 2 (Incl 2) contains the source program listing in Fortran 4 with an example.

2 Incl
as



GEORGE SCHLENKER
Operations Research Analyst
Methodology Division
Systems Analysis Directorate

Next page is blank.

ANNEX 1

DESCRIPTION OF THE COMPUTER PROGRAM: EXTERIOR BALLISTICS OF BOOSTED ROCKETS (EXBAL)

1. General

This program is a multi-purpose, point-mass flight simulation. It was conceived as a means of simulating trajectories for spin- and fin-stabilized projectiles and rockets in three-space. The principal intended application is to systems which can be assumed aerodynamically stable so that trailing or following behavior of fin-stabilized systems is exhibited and so that the equilibrium yaw of repose for spin-stabilized systems is quickly achieved. Important considerations in developing the program were:

- a. operating efficiency or speed of execution
- b. ease of use by unsophisticated users
- c. minimal input data requirements
- d. ability to generate multiple trajectories under program control for parametric analysis
- e. ability to treat a variety of system types via data changes and option switches
- f. modularity for ease of program modification.

The following sections will treat potential program applications, subprograms employed, execution options, input variables, output variables, and flow charts. Documentation for most of the theory is supplied in BRL Memorandum Report No. 1617, September 1964 [2] and BRL Report No. 1314, March 1966 [4].

2. Applications

This program was originally developed to analyze conceptual systems such as fin-stabilized gun-boosted

rockets in which the principal interest was in achievable range. However, subsequent applications involved conventional, purely ballistic systems in which significant variables were range, maximum ordinate, deflection due to spin, and time of flight. Other applications explored differential effects for error analysis associated with projectile inertial properties, meteorological conditions, and launch conditions. Recently, program changes were made to treat projectiles having wings, fins, and controls for a glide mode of flight.

3. Subprograms

The program is organized modularly into subprograms each of which performs a separate, discrete function.

The MAIN program performs such executive functions as input, control of plotting and printing output, change in time step as required, stepping thru parameter loops, and termination of run.

Subprogram RUNGE contains a fourth-order Runge-Kutta integration algorithm. The order of the equations is specified as is the number of independent variables in an entry point RUNGE1. The initial values of higher derivatives are computed on the occasion of the first call. Subsequent subroutine calls are made to entry point RUNGE2 at which the system state is updated from t to $t + dt$.

Subprogram SOUND contains all atmospheric data. This program generates the local speed of sound, local gravitational acceleration (exclusive of centrifugal acceleration), air density and viscosity.

Subprogram FLIGHT contains the differential equations

of flight which are evaluated by sequential calls from RUNGE.

Subprogram CDRAG develops the aerodynamic coefficient of drag and the drag increment due to wings (or other aerodynamic surfaces) deployed during flight. For accurate simulation of a specific system, tables of Mach number and coefficient of drag are read by MAIN and transferred thru COMMON to CDRAG. If a tabular drag coefficient is not provided as input, the program defaults to an internally supplied function.

Subprogram ACOEFS develops all the aerodynamic coefficients exclusive of drag necessary for treating spin-stabilized projectiles. An internally-supplied coefficient is used whenever tabular data for that coefficient is not entered as input. The coefficient values used in default are functional fits to the 155 mm (BAP) projectile T387.

4. Options

To be able to treat a variety of applications conveniently a number of program options are provided -- both explicitly as option switches and implicitly as parameter values of input variables. For example, a binary switch IOPTY is required as input. If this parameter value is omitted or set to 0 (zero), the program bypasses the computation of normal-body forces required for accurate simulation of spin-stabilized projectiles. Additionally, the program does not expect or read the input parameters needed for computing projectile spin and yaw. A considerable savings in execution time is obtained by omitting the spin option. If the spin option is desired, IOPTY is set to 1 and the values of

certain (required) variables are provided to implement this option.

Another major option is the choice of purely ballistic flight or flight with midcourse glide. This option is exercised by setting the switch IGLIDE to 1. The default option with IGLIDE set to 0 (zero) is ballistic flight. If IGLIDE is set to 1, several suboptions are provided/required. Since midcourse glide or body altitude hold applies exclusively (at present) to the Copperhead projectile, default tables of aerodynamic coefficients characterizing this system in glide are provided in a BLOCK DATA subroutine. To override these entries a switch IDFUFO is provided. With IDFUFO set to 1, the program expects user-supplied aero data; otherwise internal data are used. Several alternative means are provided for simulating the start of glide.

In suboption 1 a desired glide angle (GLIDE) is provided and the program calculates the body angle of attack required to hold body attitude after reaching the desired glide angle. A value of the tolerance, ϵ (EPSTHE) relative to the desired glide angle is also entered for this option. See Attachment 1 for details. Before altitude hold of the body is initiated an initial angle of attack is calculated such that the lift force equals the gravitational force normal to the velocity vector at that point in the flight. This option is useful when timer settings are unavailable.

In suboption 2 a time TENABL (in secs) is provided and GLIDE is set to -90 degrees. With this option the calculations for angle of attack to hold body attitude

start at TENABL. A value of TENABL equal to that at which the velocity angle $\theta = \text{GLIDE}$ produces a trajectory identical to that of suboption 1. Both suboptions 1 and 2 are exercised by omitting (or setting to zero) the value of MMCSW.

Suboption 3 requires the program user to provide time T_0 , called TMOMMC in the program. This is the time from launch at which the internal (MMC) timer sequence starts. This option is exercised by setting the switch MMCSW to unity and setting GLIDE to -90 degrees. Although internal degrees of freedom within the projectile are not simulated with a three-degree-of-freedom model, it is important to properly treat their kinematic effect. In contrast to other suboptions, suboption 3 faithfully simulates the effect of the events which occur after T_0 . These events are tabulated below:

SEQUENCE OF EVENTS IN COPPERHEAD TIMER

Event No.	Time (s)	Description
1.	T_0	timer sequence starts (main power at $\pm 30v$)
2.	$T_0 + 2$	roll control starts
3.	$T_0 + 3$	seeker gyro spinup initiated
4.	$T_0 + 4$	attitude-hold enable switch is closed
5.	$T_0 + 5$	start to extend wings, apply g bias, and free gyro

As far as projectile kinematics are concerned, the projectile remains ballistic until event number 4. When event number 4 occurs at $T_0 + 4(s)$, a control surface deflection in pitch, δ_p , is calculated continuously and

applied throughout the interval between events 4 and 5. This algorithm bases the calculation of δ_p upon the equilibrium behavior of the projectile airframe and autopilot between events 4 and 5. This behavior is approximately one in which pitch deflection of the fins and the associated trim angle of attack are proportional to the average turning rate of the velocity vector, $\bar{\dot{\theta}}$. Thus,

$$\delta_p = K \bar{\dot{\theta}} \quad (K, \text{ a constant}).$$

The turning rate $\dot{\theta}$ is calculated continuously by

$$\dot{\theta} = (\ddot{x}y - \ddot{y}x)/v^2.$$

An average value of $\dot{\theta}$ is calculated by exponential smoothing. This, of course, assumes that this system exhibits nearly first-order dynamics between the events 4 and 5.

Specifically,

$$\bar{\dot{\theta}} = \frac{\dot{\theta}}{1 + \tau s},$$

with τ a time constant (0.2 sec) and s the Laplace differential operator. Using exponential smoothing, this equation is solved implicitly by the recursive procedure:

$$\bar{\dot{\theta}}_i = c_0 \bar{\dot{\theta}}_{i-1} + c_1 \dot{\theta}_i$$

with

$$c_0 = e^{-h/\tau}$$

$$c_1 = 1 - c_0$$

where h is the integration time step, i.e.,

$$t_i = t_{i-1} + h.$$

For accurate simulation of this portion of the system

$$h \leq 0.1 \text{ sec.}$$

Having calculated δ_p , the trim angle of attack (α_t) is obtained by linear interpolation in the following table.

TRIM ATTACK* VERSUS MACH NUMBER AND CONTROL DEFLECTION

Entries are α_t (deg)

Mach Number	δ (deg)			
	0	5	10	15
0.5	0	7.4	12.1	17.7
0.8	0	7.2	11.8	17.2
0.9	0	7.4	11.6	17.1
- 1.0	0	7.1	11.3	17.1

With all program options the normal body force is calculated from the normal force coefficient at trim. This coefficient is a function of Mach number, M , and trim attack, α_t , i.e.,

$$C_N = C_N(M, \alpha_t) .$$

Values of C_N are obtained by two-way linear interpolation in a table as explained in Attachment 1.

* Reference: Wind Tunnel Data Analysis of 3/4 Scale Model for the XM712 Projectile, 27 Feb 76, pp. 72-75.

5. Input Variables

Program data input is supplied by punched cards whose content is described below in sequential order.

CARD	FORMAT	COLS	VARIABLE	CONTENT
1	20A4	1 - 80	TITLE	description of aerodynamic data, optionally supplied
2	2I2	1 - 2	NTBL	number of entries in drag table
		3 - 4	NARTBL	number of entries in each zero coefficient table. A zero or blank exercises default.
2a	8F10.0	1 - 10	XMTBL(1)	first entry in table of Mach numbers associated with drag. Points entered low to high.
		11 - 20	XMTBL(2)	
		.	.	
		71 - 80	XMTBL(8)	
2b	8F10.0	1 - 10	XMTBL(9)	continuation of Mach no. table
		.	.	
		.	XMTBL(NTBL)	last entry
2c	8F10.0	1 - 10	CDTBL(1)	first entry in coef. of drag table
		71 - 80	CDTBL(8)	
2d	8F10.0	1 - 10	CDTBL(9)	continuation of drag table
		.	.	
		.	CDTBL(NTBL)	last entry in drag table
2e	8F10.0	1 - 10	COTBL(1)	first entry in table of drag increment due to wings
2f	8F10.0	1 - 10	COTBL(9)	continuation of table of drag increments
		.	COTBL(NTBL)	last entry in drag increment table

CARD	FORMAT	COLS	VARIABLE	CONTENT
------	--------	------	----------	---------

If NARTBL \neq 0, additional cards must be supplied for each of the aerodynamic coefficients listed below.

			TMACH(I)	table of Mach numbers used for the additional aero data. Each table must have NARTBL entries with blank cards supplied for missing data. All aerodynamic coefficient values in the following tables are the ballisticians' values based upon caliber squared.
--	--	--	----------	---

			TKA(I)	table of spin damping moment coefficient
--	--	--	--------	--

			TKDYAW(I)	table of yaw drag coefficient
--	--	--	-----------	-------------------------------

			TKL(I)	table of lift force (derivative) coefficient
--	--	--	--------	--

			TKM(I)	table of overturning moment (derivative) coefficient
--	--	--	--------	--

			TCP(I)	table of center of pressure (in calibers aft of nose)
--	--	--	--------	---

			TKF(I)	table of Magnus force coefficient
--	--	--	--------	-----------------------------------

			TKT(I)	table of Magnus moment coefficient
--	--	--	--------	------------------------------------

			TKH(I)	table of damping moment coefficient
--	--	--	--------	-------------------------------------

			TKS(I)	table of pitching force coefficient
--	--	--	--------	-------------------------------------

3	3I1,7X, 3F10.0	1	IGLIDE	switch for glide option
---	-------------------	---	--------	-------------------------

CARD	FORMAT	COLS	VARIABLE	CONTENT
		2	IDFUFO	switch to input aero data for glide
		3	MMCSW	switch for glide suboption 3
		11 - 20	TMOMMC	timer setting, (sec), for suboption 3
		21 - 30	GLIDE	desired glide angle, (deg). Entered as a negative value.
		31 - 40	EPSTHE	tolerance in the de- sired glide angle, (deg)

If IDFUFO = 1, additional cards must be supplied for each of the aerodynamic coefficients listed below.

3a	4F10.0		TFMACH(I)	table of Mach numbers used to interpolate for normal body force during the midcourse glide phase of flight
3b	4F10.4		ALTRMM(I)	table of values of maximum trim angle of attack, (deg)
3c	4F10.4		AALTRM(I)	argument values of angle of attack, (deg), in table of normal force coeffi- cient versus Mach number and trim angle of attack
3d	4F10.4		TCN(I,J)	table of normal force coefficient with I indexed over Mach numbers and J indexed over trim angles of attack, (deg)
4	20A4	1 - 80	TITLE	description of run set
5	8F10.0	1 - 10	D	caliber or refer- ence diameter, (mm)
		11 - 20	EMO	initial projectile mass, (lb)

CARD	FORMAT	COLS	VARIABLE	CONTENT
		21 - 30	EMB	burnt or final mass, (lb)
		31 - 40	FC	nominal thrust, (lb)
		41 - 50	SPI	specific impulse, (sec)
		51 - 60	DELTA	rise time of thrust to nominal value, (sec)
		61 - 70	VO	initial velocity, (f/s)
		71 - 80	VWF	velocity of constant headwind, (f/s)
6	7F10.0, 3I3	1 - 10	HO	altitude ASL of launch point, (f)
		11 - 20	HTERM	altitude ASL of impact point, (f)
		21 - 30	FFCTR	form factor or ratio of ref. area used in est. aero. coefs. to ref. area used in input data
		31 - 40	QEO	initial value of quadrant elevation in parameter set, (deg)
		41 - 50	DQE	increment in QE, (deg)
		51 - 60	STEP	time step supplied for numerical inte- gration, (sec)
		61 - 70	TM	time programmed for start of thrust, (sec)
		71 - 73	NQE	number of steps in QE desired
		74 - 76	NPRINT	number of time steps per printout
		77 - 80	IOPTY	switch for spin option

CARD	FORMAT	COLS	VARIABLE	CONTENT
7	4F10.0	1 - 10	CADENS	correction factor for air density relative to NASA std. atmos.
		11 - 20	VCW	velocity of cross-wind from right to left facing down-range, (f/s)
		21 - 30	TENABL	time at which mid-course glide is enabled, (sec)
		31 - 40	THID	thrust-induced-drag factor applied during burning. Set to unity for standard case.

If IOPTY is zero, following cards are not required.

7a	6F10.0 I2	1 - 10	SPINO	initial spin, (rad/sec)
		11 - 20	XCG	position of the center of gravity aft of nose, (cal)
		21 - 30	CLONG	length of projectile, (cal)
		31 - 40	AMOM	axial moment of inertia, (kg/m ²)
		41 - 50	BMOM	trasverse moment of inertia thru cg, (kg/m ²)
		51 - 60	WTAREA	ratio of wetted area to reference area
		61 - 62	ISEP	switch for separate computation of skin friction drag
7b	6F10.0	1 - 10	VHXF	velocity of the launcher in the X-direction in inertial space, (f/s)
		11 - 20	VHYF	velocity of the launcher in the Y-(vertical) direction in inertial space, (f/s)

CARD	FORMAT	COLS	VARIABLE	CONTENT
		21 - 30	RCW	scale coefficient in rangewise windshear
		31 - 40	XCW	scale coefficient in crosstrack windshear

6. Output Variables

The definition of program outputs and echoed inputs is listed below.

FORTTRAN NAME	UNITS	DESCRIPTION
TENABL	sec	time at which midcourse glide is enabled
THID	nondimensional	thrust induced drag factor (nominally unity)
CADENS	nondimensional	correction factor to air density (nominally unity)
FFCTR	nondimensional	factor used to adjust drag coefficient for non-standard conditions, for example, when aero. coefs. were developed for a different reference area than that used for a run
VO	f/s	initial (muzzle) velocity
EMO	lb _m	initial mass of projectile
EMB	lb _m	final or burnt mass of projectile
D	mm	caliber or reference diameter of projectile
QE	deg	quadrant elevation or launch angle with respect to launcher
DT	sec	integration time step
FC	lb _f	nominal, constant level of thrust
SPI	lb _f sec/lb _m	specific impulse of rocket
VWF	f/s	velocity of headwind
HO	m	initial altitude above mean sea level (MSL)
HTERM	m	terminal or target altitude above MSL
VCW	f/s	velocity of crosswind (from right to left facing downrange)

FORTTRAN NAME	UNITS	DESCRIPTION
RWC	nondimensional	scale factor for windshear function for headwinds
XWC	nondimensional	scale factor for windshear function for crosswinds
T	sec	time after launch
X	m	rangewise projectile coordinate
HAG	m	height above ground impact
Z	m	crosstrack or deflection coordinate
XD	m/s	X-component of projectile velocity (Earth coordinates)
YD	m/s	Y-component of projectile velocity
V	m/s	projectile speed in the X-Y-Z inertial frame
CMACH	nondimensional	Mach number of projectile
RESIS	lb _f	drag force
THETA	deg	attitude of velocity vector of projectile in vertical plane
YAWDEG	deg	angle of attack (generalized yaw) of the projectile Zero is returned for IOPTY = 0.
SPIN	rad/s	projectile spin Zero is returned for IOPTY = 0.
DMY		Dummy variable is provided for convenience of user.
SUPVEL	m/s	maximum speed of the projectile
RANGE	m and nautical miles	range of projectile relative to surface of Earth
SUPALT	m	maximum altitude relative to MSL
PITCH	deg	pitch-plane angle of attack
BODYA	deg	pitch-plane body attitude in Earth coordinates

FLOW CHART FOR EXTERIOR
BALLISTICS OF BOOSTED ROCKETS

1. Read in constants and params.
2. Compute auxiliary constants and redimension input data.
3. Set constants for QE - loop.
4. Start QE - loop.
5. Print and label variables.
6. Set initial conditions for time loop, e.g., ISW = 0 & t, x, y, \dot{x} , \dot{y} .
7. Call RUNGE 1.
8. Initialize NPLØT.
9. Call subroutine of flight equations, FLIGHT, for evaluation of initial conditions.
10. Initialize a counter LINE for counting lines on a page for proper labeling of output at top of each page.
11. Skip to 16 and print initial conditions.
12. Start time loop.
13. Start print loop.
14. Test if burning has begun; if so set TØ = TIME and bypass 14 in future.
15. Call RUNGE 2 for solving flight equations.
16. Count lines printed and check if time to skip to new page and label.
17. Print time and dependent variables.

18. Increment NPLØT and store position of projectile in XPLØT and YPLØT. Save projectile position.
19. Check if time to stop integrating. Stop when y goes thru YTERM. If $y > YTERM$, return to step 12.
20. If $y < YTERM$, use past values of dependent variables to interpolate linearly for their values at YTERM.
21. Print out final values of dependent variables.
22. Call the plotting subroutine PPLØT and ask for a plot of the trajectory, represented by the x,y pairs saved in XPLØT and YPLØT. Label the plot with the run description, the quadrant elevation, initial velocity and nominal thrust level.
23. Return to 1 for another parameter set, otherwise
24. Stop.

Flow Chart for Subroutine FLIGHT

1. Test if ISW = 1.
2. a. If ISW = 0, omit thrust terms.
b. If ISW = 1, include thrust terms.
3. a. If ISW = 0, use initial mass
EM = EMO.
b. If ISW = 1, call subroutine BURN. CALL BURN(TIME,
XMASS, THRUST).

This generates the projectile mass in pounds mass and thrust in pounds force. Conversion of units occurs in the differential equations.

4. CALL SOUND (Y, A, G, RHO).

This generates speed of sound (A), gravity (G), and air density (RHO).

5. Relative wind speed computed: $VREL = \sqrt{(XDOT+VW)**2 + YDOT**2 + (ZDOT+VCW)**2}$
6. CMACH = VREL/A
7. a. If IOPTY = 0, omit spin and normal force calculations.
b. If IOPTY = 1, call ACOEFS and calculate spin and normal force derivatives.
8. a. If ISEP = 0, set FRICT to zero.
b. If ISEP = 1, compute skin friction drag (FRICT).

The subroutine CDRAG(CMACH, DRAG, CAD) generates the uncorrected coefficient of drag, DRAG, and the drag increment due to wings, CAD.

9. COFDRG = FFCTR * DRAG + XKDYAW * YAWSQ + FRICT + CAD.
10. a. If IGLIDE = 1 and NABLE = 1, compute normal force terms in GLIDE mode.
b. Otherwise, omit GLIDE calculations.
11. Solve differential equations for second derivatives of state variables.
12. Return.

REFERENCES

1. Barnhart, William. The Standard Atmosphere Used by BRL for Trajectory Computations, BRL Memorandum Report No. 1766, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., June 1966.
2. Lieske, Robert F. and Mc Coy, Robert L. Accuracy Analysis for a 155MM Rocket Boosted Artillery System, Memo. Report No. 1617, Ballistic Research Laboratories, September 1964.
3. Lieske, Robert F. and Mc Coy, Robert L. Equations of Motion of a Rigid Projectile, Report No. 1244, Ballistic Research Laboratories, March 1964.
4. Lieske, Robert F. and Reiter, Mary L. Equations of Motion for a Modified Point Mass Trajectory, Report No. 1314, Ballistic Research Laboratories, March 1966.
5. Gorn, S. and Juncosa, M. L. On the Computational Procedures for Firing and Bombing Tables, Report No. 889, Ballistic Research Laboratories, January 1954.
6. Nielsen, J. N. Missile Aerodynamics, Mc Graw - Hill, Inc., c. 1960.
7. Page, Leigh. Introduction to Theoretical Physics, D. Van Nostrand, Inc., c. 1935.
8. Rosser, J. B., Newton, R. R., and Gross, G. L. Mathematical Theory of Rocket Flight, Mc Graw - Hill, Inc. c. 1947.

9. Sutton, George P. Rocket Propulsion Elements, John Wiley and Sons, Inc., c. 1956.
10. Design Engineering Handbook Series of AMC Pamphlets, Headquarters, U.S. Army Materiel Command,
 - (1) AMCP 706-242, Design for Control of Projectile Flight Characteristics, September 1966.
 - (2) ORDP 20-246, Section 3, Design for Control of Flight Characteristics, May 1957.
 - (3) AMCP 706-247, Section 4, Design for Projection, July 1964.
 - (4) AMCP 706-280, Design of Aerodynamically Stabilized Free Rockets, July 1968.

ATTACHMENT 1

Algorithm for Attitude-Hold Logic in Copperhead 3DOF Simulation

For simulations in which a preset-time option is not used, the program determines the time for commencement of attitude hold. Initially the glide angle θ will approach the desired glide angle θ_0 algebraically from above. (θ_0 is negative) When $\theta - \theta_0 \leq \epsilon$ (ϵ positive), an initial angle of attack, α_0 , is computed such that the associated lift component equals the component of gravity normal to the velocity vector, ie, such that

$$F_L = M_p g \cos \theta$$

with

$$F_L = F_N \cos \alpha_0$$

and

$$F_N = C_N(0) Aq$$

with projectile mass M_p and reference area A and dynamic pressure q .

Since α_0 is small--typically less than 10° --an iterative procedure is employed in which the first iteration assumes that $F_L = F_N$ so that

$$C_N^{(1)}(0) = \frac{M_p g \cos \theta}{Aq}$$

The value of $\alpha_0^{(1)}$ is obtained by interpolation in the tabular function $C_N(M, \alpha_t)$ with α_t the trim angle of attack.

Thus,

$$C_N^{(1)}(0) = C_N(M^*, \alpha_0^{(1)}),$$

where M^* is the local Mach number. The interpolation procedure is described below.

Then, form the second iterate for the normal force coefficient:

$$C_N^{(2)}(0) = \frac{M_p g \cos \theta}{Aq \cos \alpha_0^{(1)}}$$

The value of α_0 obtained by requiring that $C_N = C_N^{(2)}(0)$ is taken as the initial trim angle of attack at the start of attitude hold.

Interpolation Procedure

To calculate α_0 , interpolate on Mach number in the $C_N(M, \alpha_t)$ table obtaining $C_N(M^*, \alpha_t)$ at the local Mach number M^* for values of $\alpha_t = \{0, 5, 10, 15 \text{ (deg)}\}$. Then, α_0 is obtained by linearly interpolating with $C_N(0)$ as argument in this table.

The value of initial body attitude is given by

$$\theta_b(0) = \theta + \alpha_0.$$

For subsequent calculations during the attitude-hold trajectory, the value of angle of attack, α , is calculated which preserves body attitude, ie, for which $\theta_b = \theta_b(0)$.

Thus,

$$\alpha = \theta_b(0) - \theta.$$

If the above value of α satisfies

$\alpha < \alpha_{tm}(M)$, the maximum trim angle at M the instantaneous value of Mach number, the lift force is computed as

$$F_L = C_N(\alpha, M) Aq \cos \alpha$$

with C_N obtained by two-way interpolation. Otherwise, α is limited to $\alpha_{tm}(M)$ and lift is calculated as

$$F_L = C_N(\alpha_{tm}, M) Aq \cos \alpha_{tm}.$$

Induced drag due to lift is calculated as

$$F_{DI} = - C_N(\alpha, M) Aq \sin \alpha.$$

TABLE 1. MAXIMUM TRIM ANGLE OF ATTACK
VERSUS MACH NUMBER (AT $\delta = 12^\circ$)

Mach Number	α_t (max) (deg)
0.5	14.3
0.8	14.0
0.9	13.8
1.0	13.6

TABLE 2. NORMAL FORCE COEFFICIENT
VERSUS MACH NUMBER AT TRIM ATTACK
 $C_N(M, \alpha_t)$

Mach Number	α_t (deg)			
	0	5	10	15
0.5	0	1.1	2.1	3.1
0.8	0	1.2	2.1	2.9
0.9	0	1.3	2.2	3.0
1.0	0	1.3	2.5	3.7

Next page is blank.

ANNEX 2

SOURCE PROGRAM LISTING WITH EXAMPLE

FOR THE COMPUTER PROGRAM:

EXTERIOR BALLISTICS OF

BOOSTED ROCKETS (EXBAL)

Incl 2

```

C                                     00000100
C EXTERIOR BALLISTICS OF BOOSTED ROCKETS 00000200
C A THREE-DEGREE-OF-FREEDOM MODEL APPLICABLE WHERE 00000300
C TRAILING OR FOLLOWING BEHAVIOR CAN BE ASSUMED 00000400
C                                     00000500
C                                     00000600
C REAL RS(401),TS(401),VS(401),CJRT(11),CJVT(11) 00000700
C DIMENSION TITLE(20),U(12),WP(48),XMTBL(12),CDTBL(12),COTBL(12) 00000800
C 1, TMACH(11),TKA(11),TKDYAW(11),TKL(11),TKM(11),TKF(11), 00000900
C 2 TKT(11),TKH(11),TKS(11),TCP(11),TFMACH(4),ALTRMM(4),AALTRM(4), 00001000
C 3 TCN(4,4),WTGN(4) 00001100
C DIMENSION TCAD1(4),TCAD2(4),TDEL(4),TAT(4,4),WTAT(4) 00001200
C INTEGER *2 CHAR(1)/'*'/ 00001300
C DATA RF/6.378E6/,OMEGA/0.72915E-4/ 00001400
C DATA DTORAD/57.29578/ 00001500
C DATA TMCONG/0.2/ 00001600
C ASSIGN CONSTANTS NEEDED BY DIFFERENTIAL EQUATIONS TO COMMON 00001700
C                                     00001800
C COMMON EMO,EMR,SPI,FC,BRATE,DELT,TO,TB,ISW,V,THETA,FFCTR,CALSQ, 00001900
C 1 VW,VCW,ALT,R,IEND,CMACH,REYNLD,RESIS,CAL,DLONG,IOPTY,YAW,AMOM, 00002000
C 2 RMOM,PSI,WTAREA,ISEP,MACLE,IGLIDE,AWING,TENABL,AVTHD,CDEFL, 00002100
C 3 MMCSW,IMOMMC 00002200
C COMMON /SRCOR/TM 00002300
C COMMON/COFCOM/XCG,SMARG,EM,THID,PRNU,ALTRIM,CNATRM,GLIDE,EPSTHE 00002400
C 1 ,STAFAC,YAWNU,TKA,TKDYAW,TKL,TKM,TKF,TKT,TKH,TKS,TCP,FMACH, 00002500
C 2 NARTBL,TFMACH,ALTRMM,AALTRM,TCN,WTGN,TCAD1,TCAD2,TDEL,TAT,WTAT 00002600
C COMMON/WINCOM/RWC,XWC 00002700
C COMMON/DRGCOM/ XMTBL,CDTBL,COTBL,NTBL 00002800
C COMMON/SNDCOM/CADENS 00002900
C                                     00003000
C**** TABLES OF AERODYNAMIC COEFFICIENTS IS PARAM. SET INPUT SET -1. 00003100
C**** IF PARAMETERS NTPL AND NARTBL ARE BOTH ZERO, ENDOGENOUS 00003200
C**** FUNCTIONAL FITS TO THE AERODYNAMIC TABLES(WITH THE T387 FORM) 00003300
C**** WILL BE USED. SEE SUBROUTINE ACOEFS. 00003400
C**** IF ONLY NARTBL IS ZERO, THE ZERO-LIFT DRAG TABLE IS REQUIRED 00003500
C**** WITHOUT REQUIRING TABLES FOR THE OTHER AERO COEFFICIENTS. 00003600
C**** IF CERTAIN AERO COEFFICIENTS ARE DEFINED (KNOWN), THESE 00003700
C**** CAN BE READ WITH THE OTHERS LEFT BLA K. THE PROGRAM WILL 00003800
C**** USE THE TABULATED COEFFICIENTS AND DEFAULT TO THE ENDOGENOUS 00003900
C**** FUNCTIONS FOR THOSE ENTERED AS ZERO. 00004000
C D=PROJECTILE CALIBER, MILLIMETERS PARAMETER INPUT 1 00004100
C EMO=INITIAL PROJECTILE MASS, LBM INPUT 2 00004200
C EMR=BURNI MASS, LBM INPUT 3 00004300
C FC=NOMINAL THRUST LEVEL, LBF INPUT 4 00004400
C SPI=SPECIFIC IMPULSE OF ROCKET PROPELLANT, LBF/LBM/SEC INPUT 5 00004500
C BRATE=PROPELLANT BURNING RATE, LBM/SEC ENDOGENOUS VARIABLE 00004600
C DELT=THRUST RISE TIME, SEC INPUT 6 00004700
C TO=IGNITION TIME FOR ROCKET MOTOR ENDOGENOUS VARIABLE 00004800
C IN SUBROUTINE 'BURN' THE THRUST DECAY TIME IS ASSUMED 00004900
C EQUAL TO THE THRUST RISE TIME. A TYPICAL VALUE = 0.1 SEC. 00005000
C TB=EFFECTIVE BURNING INTERVAL, SEC ENDOGENOUS VARIABLE 00005100
C ISW= A SWITCH SIGNALING COMMENCEMENT OF BURNING ENDO. VARIABLE 00005200
C IEND=A SWITCH SIGNALING END OF BURNING ENDO. VARIABLE 00005300

```

```

C      V=PROJECTILE VELOCITY, M/SEC                      ENDO. VARIABLE00005400
C      VO=MUZZLE VELOCITY OF THE PROJECTILE, FT/SEC.    INPUT 7 00005500
C      THETA=ATTITUDE OF PROJECTILE, DEG                ENDO. VARIABLE00005600
C      CALSQ=CALIBER SQUARED, M**2                     ENDO. VARIABLE00005700
C      VW=VELOCITY OF HEADWIND, M/SEC (READ IN IN FT/SEC) ENDO. VARIABLE00005800
C      VWF=VELOCITY OF HEADWIND IN FT/SEC              INPUT 8 00005900
I) IEY033I COMMENTS DELETED *****
CONTINUE                                                00007000
C      ALT=TRUE ALTITUDE ABOVE SEA LEVEL, M             ENDO. VARIABLE00007100
C      R=RADIUS FROM CENTER OF EARTH TO PROJECTILE , M  ENDO. VARIABLE00007200
C      RE=NOMINAL RADIUS OF THE EARTH AT THE EQUATOR, M CONSTANT00007300
C      OMEGA=ANGULAR VELOCITY OF THE EARTH, RAD/SEC    CONSTANT00007400
C      IOPTY=A SWITCH INDICATING CHOICE OF YAW OPTION. INPUT 1800007500
C      IOPTY= 1 PRODUCES COMPUTATION OF YAW OF REPOSE FOR SPINNING PROJEC00007600
C      IOPTY= 0 SIGNIFIES A TRAILING PROJECTILE WITHOUT SPIN. FOR 00007700
C      THIS OPTION THE FOLLOWING INPUTS ARE UNNECESSARY. 00007800
C      SPINO=INITIAL SPIN, RAD/SEC                      INPUT 1900007900
C      XCG=POSITION OF CENTER OF GRAVITY AFT OF NOSE, CALIBERS INPUT 2000008000
C      XCP=POSITION OF CENTER OF PRESSURE AFT OF NOSE, CAL ENDO. VARIABLE00008100
C      CLONG=PROJECTILE LENGHT IN CALIBERS.            INPUT 2100008200
C      AMOM=LONGITUDINAL MOMENT OF INERTIA OF THE PROJECTILE, KG*M**2 INPUT 2200008400
C      BMOM=TRANSVERSE MOMENT OF INERTIA OF THE PROJECTILE, KG*M**2 00008500
C      INPUT 2300008600
C      VCW=VELOCITY OF CROSSWIND FROM RIGHT LOOKING DOWNRANGE(READ IN FT/00008700
C      INPUT 2400008800
C      WTAREA=WETTED AREA RATIO USED IN COMPUTING SKIN 00008900
C      FRICTION DRAG INPUT 2500009000
C      ISEP=A SWITCH INDICATING CHOICE OF SEPARATE 00009100
C      COMPUTATION OF SKIN FRICTION DRAG. INPUT 2600009200
C      = 1 IF FRICTION DRAG IS COMPUTED SEPARATELY AND ADDED TO FORM DRAG00009300
C      = 0 IF FRICTION DRAG IS INCLUDED IN DRAG FUNCTION. 00009400
C      SMARG=PROJECTILE STATIC MARGIN, CAL.            ENDO. VARIABLE00009500
C      PSI=ANGULAR ORIENTATION OF YAW VECTOR           ENDO. VARIABLE00009600
C      SRNG=SLANT RANGE TO PROJECTILE POSITION, M        ENDO. VARIABLE00009700
C      VHXF=VELOCITY OF LAUNCHER IN RANGEWISE DIRECTION. (FT/SEC) 00009800
C      VHYF=VELOCITY OF LAUNCHER IN VERTICAL DIRECTION. (FT/SEC) 00009900
C      CONTINUE                                         00010000
C      RWC IS HEADWIND COEF.                            00010100
C      XWC IS CROSSWIND COEF.                          00010200
C      PSI MAY BE COMPUTED BY REMOVING 'C' S FROM COMMENT CARDS 00010300
C      IN SUBROUTINE FLIGHT.                            00010400
C      CADEHS IS THE CORRECTION FACTOR FOR AIR DENSITY RELATIVE TO STANDAR00010500
C      00010600
C      EXTERNAL FLIGHT                                  00010700
C      EQUIVALENCE (U(1),X), (U(2),Y), (U(3),Z), (U(4),SPIN), 00010800
C      1 (U(5),XD), (U(6),YD), (U(7),ZD), (U(8),SPIND), 00010900
C      2 (U(9),XDD), (U(10),YDD), (U(11),ZDD), (U(12),SDO) 00011000
C      READ IN RUN DESCRIPTION, CONSTANTS IN FLIGHT EQUATIONS AND 00011100
C      INITIAL CONDITIONS.                              00011200
C      00011300
C      READ (5,256,END=30) TITLE,NTBL,NARTBL          00011400
256 FORMAT(20A4/2I2)                                  00011500
    
```

```

IF (NTBL.EQ.0) GO TO 255
READ (5,250) (XMTBL(1),I=1,NTBL)
READ (5,250) (CDTBL(1),I=1,NTBL)
READ (5,250) (COTBL(1),I=1,NTBL)
250 FORMAT(8F10.0)
WRITE (6,252) TITLE
252 FORMAT(1H1,20A4/1H0,10H MACH NO,10H COEF DRAG,10H DRAG INCR)
DO 253 I=1,NTBL
WRITE (6,254) XMTBL(I),CDTBL(I),COTBL(I)
253 CONTINUE
IF (NARTBL.EQ.0) GO TO 255
READ (5,250) (TMACH(I),I=1,NARTBL)
READ (5,250) (TKA(I),I=1,NARTBL)
READ (5,250) (TKDYAW(I),I=1,NARTBL)
READ (5,250) (TKL(I),I=1,NARTBL)
READ (5,250) (TKM(I),I=1,NARTBL)
READ (5,250) (TCP(I),I=1,NARTBL)
READ (5,250) (TKF(I),I=1,NARTBL)
READ (5,250) (TKT(I),I=1,NARTBL)
READ (5,250) (TKH(I),I=1,NARTBL)
READ (5,250) (TKS(I),I=1,NARTBL)
254 FORMAT(1H ,3F10.4)
WRITE (6,272)
272 FORMAT(1H0,10H MACH NO,8X,2HKA,5X,5HKDYAW,
1 BX,2HKL,8X,2HKM,10H CP, CAL)
DO 257 I=1,NARTBL
WRITE (6,251) TMACH(I),TKA(I),TKDYAW(I),TKL(I),TKM(I),TCP(I)
251 FORMAT(1H ,6F10.5)
257 CONTINUE
255 CONTINUE
C
C
C
GLIDE - FUFO - GLIDE - FUFO - GLIDE - FUFO - GLIDE - FUFO - GLIDE
C**** ATTITUDE HOLD LOGIC FOR NEARLY CONSTANT GLIDE ANGLE AP77
C**** THE SWITCH IGLIDE MUST BE SET TO 1 FOR AN ATTITUDE-HOLD TRAJECTORY
C**** THE SWITCH IDFUFO MUST BE SET TO 1 IF NORMAL FORCE AERO IS TO
C**** BE PROVIDED FOR GLIDE . OTHERWISE, DEFAULT AERO DATA ARE USED.
C**** THE PARAMETER MMCSW IS A SWITCH TO BE SET TO 1 WHEN AN ATTITUDE-HOLD
C**** OR GLIDE TRAJECTORY IS TO BE SIMULATED USING TIMER DATA SUPPLIED BY
C**** THE MARTIN MARIETTA CORP. (MMC) . IN USING THIS OPTION
C**** THE TIME PARAMETER TMOMMC REPRESENTS THE TIME IN SECS FROM
C**** LAUNCH AT WHICH THE 30 VOLT POWER BECOMES AVAILABLE.
C**** SUBSEQUENT EVENTS IN SEQUENCE ARE RELATED IN SUBROUTINE FLIGHT.
101 CONTINUE
READ (5,264,END=30) IGLIDE,IDFUFO,MMCSW,TMOMMC,GLIDE,EPSTHE
264 FORMAT(3I1,7X,3F10.0)
WRITE (6,1264) IGLIDE,IDFUFO,MMCSW,TMOMMC,GLIDE,EPSTHE
1264 FORMAT(1H0,4X,6HIGLIDE,4X,6HIDFUFO,5X,5HMMCSW ,10H TMOMMC (S),
1 10H GLIDE (D),11H EPSTHE (D)/3(9X,1I1),3F10.4)
IF (IDFUFO.NE.1) GO TO 1300
READ (5,1265) (TFMACH(1),I=1,4)
1265 FORMAT(4F10.0)
READ (5,1265) (ALTRMM(1),I=1,4)

```

	READ (5,1265) (AALTRM(I),I=1,4)	0^016900
	READ (5,1266) ((TCN(I,J),J=1,4),I=1,4)	00017000
1266	FORMAT(4F10.0)	00017100
1300	CONTINUE	00017200
	IF (IGLIDE.NE.1) GO TO 1	00017300
	WRITE (6,268)	00017400
268	FORMAT(1H0,8X,'MACH NO MAX TRIM (D)')	00017500
	WRITE (6,269) (TFMACH(I),ALTRM(I),I=1,4)	00017600
269	FORMAT(1H ,2F15.5)	00017700
	WRITE (6,270)	00017800
270	FORMAT(1H0,10X,'NORMAL FORCE COEFS AT TRIM ATTACK'/	00017900
	1 1H0,8X,25HMACH NO TRIM ATTACK (D): ,1H0,14X,1H5,13X,2H10,13X,	00018000
	2 2H15)	00018100
	WRITE (6,271) (TFMACH(I),(TCN(I,J),J=1,4),I=1,4)	00018200
271	FORMAT(1H ,F15.5,4X,4F15.5)	00018300
	1 READ (5,2,END=30) TITLE,D,EMO,EMB,FC,SPI,DELT,VO,VWF,H0,HTERM,	00018400
	1 EFCTR,QEQ,DQE,STEP,IM,NQE,NPRINT,IOPTY	00018500
	2 FORMAT(20A4/8F10.0/7F10.0,3I3)	00018600
C****	SWITCH NABLE IS SET FROM 0 TO 1 AT TIME TENABL	00018700
258	READ (5,260) CADENS,VCW,TENABL,THID	00018800
260	FORMAT(4F10.0)	00018900
	WRITE (6,262) TENABL,THID,CADENS	00019000
262	FORMAT(1H0,14HENABLE TIME = ,F10.4,5X,	00019100
	1 21HTHRUST DRAG FACTOR = ,F10.4,5X,10HHAIR DENS FACTOR = ,F10.4)	00019200
	IF (IOPTY.NE.1) GO TO 25	00019300
	READ 26,SPIND,XCG,CLONG,AMOM,BMOM,wTAREA,ISEP	00019400
	READ 26,VHXF,VHYF,RWC,XWC	00019500
26	FORMAT(6F10.0,I2)	00019600
	GO TO 27	00019700
25	SPIND=0.0	00019800
	XCG=0.	00019900
	CLONG=0.	00020000
	AMOM=0.	00020100
	BMOM=0.	00020200
	WTAREA=0.	00020300
	ISEP=0	00020400
	VHXF=0.0	00020500
	VHYF=0.0	00020600
	RWC=0.0	00020700
	XWC=0.0	00020800
	SMARG=0.0	00020900
	STAFAC=0.0	00021000
	YAWNU=0.0	00021100
	PRNU=0.0	00021200
	PSI=0.0	00021300
	DMY=0.0	00021400
C	START QUAD-ELEV LOOP	00021500
27	QE=QEQ-DQE	00021600
	SDD=0.0	00021700
	CAL=D*1.E-3	00021800
	DO 3 IQE=1,NQE	00021900
	QE=QE+DQE	00022000
	THETA=QE/57.29578	00022100

```

TO=1.E10                                00022200
EM=EMO                                    00022300
C IEND IS A SWITCH SIGNALLING END OF BURNING 00022400
IEND=0                                    00022500
C ASSIGN TIME INCREMENT FOR INTEGRATION.    00022600
C                                             00022700
C                                             00022800
C DT=STEP                                  00022900
C IWING IS A SWITCH INDICATING DEPLOYMENT OF WINGS 00023000
IWING=0                                    00023100
C NABLE IS A SWITCH SIGNALING CONTROLS DEPLOYED FOR GUIDED FLIGHT. 00023200
NABLE=0                                    00023300
C                                             00023400
C GLIDE - FUFO - GLIDE - FUFO - GLIDE      00023500
C**** CALCULATE WEIGHT CONSTANTS USED IN SMOOTHING THE PITCH RATE 00023600
C**** USED IN G-BIAS COMPUTATIONS          00023650
SMLSTP=0.1                                00023700
WTOUT1=EXP(-SMLSTP/TMCONG)                 00023800
WTIN1=1.0-WTOUT1                           00023900
TOGH=TMOMMC+3.9                             00024000
AVTHD=0.0                                    00024020
TM3=TMOMMC+3.0                              00024040
NTMSTP=61                                    00024060
KTM=0                                        00024100
C PRINT AND LABEL RUN DESCRIPTION, CONSTANTS, AND 00024200
C INITIAL CONDITIONS                        00024300
PRINT 9, TITLE, FFCTR, VO, EMO, EMB, D, QE, DT, FC, SPI, VWF, HO, HTERM, VCW
1, RWC, XWC                                  00024400
9 FORMAT(1H120A4/1H010X5HFFCTR13X2HV013X2HMO13X2HMR14X1HD/ 00024500
1 1H 5F15.6/1H0.                                00024600
2 6X9HQQUAD ELEV8X7HTM STEP9X6HTHRUST5X10HSP IMPULSE9X6HV-WIND/ 00024700
3 1H 5F15.6/1H04X11HINIT ALT,FT4X11HTERM ALT,FT15H VEL XWIND,FT/S, 00024800
4 12X,3HRWC,12X,3HXWC,/1H 5F15.6)           00024900
PRINT 91, VHXF, VHYF                         00025000
91 FORMAT(/8H VHXF = ,F12.2,20H FT/SEC        VHYF = ,F12.2,7H FT/SEC,/ 00025100
1/)                                           00025200
PRINT 92, DELT, TM                            00025300
92 FORMAT(1H 19HTHRUST RISE TIME = ,F12.4,5H SEC,8H TM = ,F12.4, 00025400
1 5H SEC)                                     00025500
C                                             00025600
C                                             00025700
C YO=INITIAL ALTITUDE, M                     00025800
C HO=ALTITUDE READ IN IN FT                  00025900
C YTERM=TERMINAL ALTITUDE, M                 00026000
C HTERM=TERMINAL ALTITUDE READ IN IN FT      00026100
IF(IOPTY.NE.1) GO TO 29                      00026200
PRINT 28, XCG, CLONG, AMOM, BMOM             00026300
28 FORMAT(1H0,11HLOC OF CG =,E10.4,2X,3HCAL,14H PROJ LENGTH =,E10.4, 00026400
1 2X,3HCAL,15H AXIAL M OF I =,E11.5,2X,7HKG M**2, 00026500
2 15H TRANS M OF I =,E11.5,2X,7HKG M**2)    00026600
29 IF(SPI.EQ.0.0) GO TO 60                   00026700
BRATE=FC/SPI                                 00026800
IF(BRATE.EQ.0.0) GO TO 60                   00026900
TR=(EMO-EMB)/BRATE                           00027000

```

```

PRINT 40, TB                                00027100
40 FORMAT(1H0,22HEFFECTIVE BURN TIME = ,F10.4,4H SEC) 00027200
GO TO 61                                     00027300
60 TB=0.                                     00027400
BRATE=0.                                     00027500
C                                             00027600
C COMPUTE AUXILLIARY CONSTANTS AND REDIMENSION INPUTS 00027700
61 CALSQ=D**2*1.E-6                          00027800
DLONG=D*1.0E-3*CLONG                        00027900
VELO=0.3048*V0                               00028000
C SUPVEL IS THE SUPREMIUM OF PROJECTILE VELOCITY. 00028100
SUPVEL=VELO                                  00028200
C SUPALT IS SUPREMIUM OF PROJECTILE ALTITUDE.     00028300
SUPALT=0.0                                   00028400
Vw=0.3048*VwF                               00028500
VCW=0.3048*VCW                              00028600
YO=0.3048*HO                                 00028700
YTERM=0.3048*HTERM                          00028800
RTERM=RE+YTERM                               00028900
C INITIALIZE TIME, X, X-DOT, Y AND Y-DOT.        00029000
C                                             00029100
T=0.                                         00029200
X=0.                                         00029300
Y=Y0                                         00029400
Z=0.                                         00029500
SPIN=SPINO                                   00029600
VHX=.3048*VHXF                               00029700
VHY=.3048*VHYF                               00029800
XD=VELO*COS(THETA)+VHX                      00029900
YD=VELO*SIN(THETA)+VHY                      00030000
THETA=57.29578*ATAN(YD/XD)                  00030100
V=SQRT(XD**2+YD**2)                          00030200
ZD=0.                                         00030300
SPIND=0.0                                    00030400
XDD=0.0                                       00030500
YDD=0.0                                       00030600
ZDD=0.0                                       00030700
YAW=0.0                                       00030800
ALT=Y0                                        00030900
SRNG=0.0                                     00031000
ISW=IBURN(T,ALT,THETA,V)                    00031100
IF (ISW.EQ.1) GO TO 70                       00031200
GO TO 71                                     00031300
70 TO=0.0                                     00031400
DT=STEP/4.                                   00031500
C                                             00031600
C INITIALIZE RUNGE-KUTTA SUBROUTINE          00031700
71 CALL RUNGE1(U,WP,4,2,FLIGHT)              00031800
C SOLVE FLIGHT EQUATIONS FOR INITIAL CONDITIONS. 00031900
C                                             00032000
CALL FLIGHT(T,U,4)                           00032100
C                                             00032200
C INITIALIZE COUNTER FOR DETERMINING NUMBER OF POINTS TO BE PLOTTED 00032300

```

C	AT END OF TRAJECTORY SOLUTION.	00^32400
C		00032500
	NPLOT=0	00032600
C		00032700
C		00032800
C	INITIALIZE COUNTER FOR COUNTING LINES PER PAGE.	00032900
C		00033000
	LINE=0	00033100
C		00033200
	IPRINT=-NPRINT	00033300
	YAWDEG=YAW*DTORAD	00033400
C	GO TO PRINT OUT INITIAL CONDITIONS.	00033500
C		00033600
	GO TO 4	00033700
C		00033800
C	START OF SOLUTION LOOP. SAVE LAST VALUES OF FLIGHT VARIABLES.	00033900
C		00034000
5	XP=X	00034100
	RP=R	00034200
	ZP=Z	00034300
	XDP=XD	00034400
	YDP=YD	00034500
	VP=V	00034600
	THE TAP=THETA	00034700
	CMACHP=CMACH	00034800
	RESISP=RESIS	00034900
	YAWP=YAWDEG	00035000
	SPINP=SPIN	00035100
	SMARGP=SMARG	00035200
	STAFAP=STAFAC	00035300
	PSIP=PSI	00035400
	SR:GP=SRNG	00035500
C		00035600
C	CALL RUNGE-KUTTA SUBROUTINE TO SOLVE FLIGHT EQUATIONS FROM	00035700
C	T TO T+DT.	00035800
C		00035900
C****	TO SHORTEN RUN TIME WHEN USING OPTION NMCSW, CHANGE TIME STEP TO	00035902
C****	SMLSTP FOR NIMSTP STEPS AND THEN RESUME INPUT STEP SIZE.	00035904
	IF (NMCSW.NE.1) GO TO 44	00035906
	IF (T+STEP.LT.TM3) GO TO 44	00035908
	IF (T.LT.TM3) GO TO 42	00035910
	KTM=KTM+1	00035912
	IF (KTM.GE.NIMSTP) GO TO 43	00035914
	DT=SMLSTP	00035916
	GO TO 44	00035918
42	DT=TM3-T	00035920
	GO TO 44	00035922
43	DT=STEP	00035924
44	CONTINUE	00035926
	CALL RUNGE2(T,DT)	00036000
C		00036100
C		00036200
C		00036300

```

C   SAVE POSITIONAL COORDINATES OF PROJECTILE FOR LATER PLOTTING OF   00036400
C   TRAJECTORY.                                                       00036500
C   00036600
C   SAVE RANGE AND FLIGHT TIME IN ARRAYS FOR SUBSEQUENT              00036700
C   POLYNOMIAL FIT                                                  00036800
C   00036900
C   SRNG=SQRT(X*X+(Y-Y0)**2+Z*Z)                                       00037000
C   IF(T .GE.TENARL) I WING=I                                         00037100
C   *****                                                             00037200
C   IF (NPLOT.EQ.400) GO TO 520                                       00037300
C   IF (SRNG.GT.SRNGEM) GO TO 520                                     00037400
C   NPLOT=NPLOT+I                                                    00037500
C   TS(NPLOT)=T                                                       00037600
C   RS(NPLOT)=SRNG                                                    00037700
C   VS(NPLOT)=V                                                       00037800
C   *****                                                             00037900
520 CONTINUE                                                         00038000
C   00038100
C   IF(IGLIDE.EQ.1) SPIN=CDEFL*DTORAD                                  00038200
C   YAWDEG=YAW*DTORAD                                                00038300
C   IF(IGLIDE.EQ.1) STAFAC=YAWDEG+THETA                              00038400
C   THD=(XD*YDD-YD*XDD)/V**2                                         00038500
C   AVTHD=WTIN1*THD+WTOUT1*AVTHD                                     00038600
C   IF(T.LT.TOGB) AVTHD=0.0                                          00038700
C   IF(V.GT.SUPVEL) SUPVEL=V                                          00038800
C   IF(ALT.GT.SUPALT) SUPALT=ALT                                      00038900
88  IF(ISW.EQ.0) GO TO 50                                             00039000
C   IF(IEND.EQ.1) GO TO 51                                             00039100
C   IF(T.GE.T0+Tb+DELT) GO TO 49                                     00039200
C   GO TO 51                                                         00039300
49  DT=STEP                                                           00039400
C   IEND=I                                                           00039500
C   CALL BURN(T,XMASS,THRUST)                                         00039600
C   PRINT 80, XMASS,THRUST,ALT,V,T                                    00039700
80  FORMAT(IH0,9H MASS = ,F10.4,11H THRUST = ,F10.4,                00039800
C   I 13H ALTITUDE = ,F10.2,10H SPEED = ,F10.2,10H TIME = ,F10.3) 00039900
C   GO TO 51                                                         00040000
50  ISW=IBURN(T,ALT,THETA,V)                                         00040100
C   IF(EMP.EQ.EMB) ISW=0                                             00040200
C   IF(ISW.EQ.0) GO TO 51                                             00040300
C   T0=T                                                             00040400
C   PRINT 20, T0                                                     00040500
20  FORMAT(IH0,15HBURN STARTS AT ,F10.4,4H SEC)                    00040600
C   DT=STEP/4.                                                       00040700
51  IPRINT=IPRINT+1                                                  00040800
C   IF(IPRINT.EQ.0) GO TO 53                                         00040900
C   GO TO 52                                                         00041000
53  IPRINT=-NPRINT                                                  00041100
C   00041200
C   ADVANCE LINES COUNTER AND CHECK IF TIME TO EJECT PAGE AND LABEL. 00041300
C   00041400
C   4 LINE=LINE+1                                                    00041500
C   DMY=THD*DTORAD                                                  00041600

```

```

C**** FOR COPPERHEAD FLIGHTS THE DUMMY VARIABLE IS THE ANGULAR          00041700
C**** PITCH RATE IN DEGREES/SEC.                                         00041800
C**** DMY IS A DUMMY VARIABLE USED FOR OUTPUT OF CHOICE                   00041900
IF (LINE.LE.0) GO TO 6                                                    00042000
LINE=-50                                                                    00042100
IF (IGLIDE.EQ.1) GO TO 116                                                00042200
WRITE (6,7) TITLE                                                         00042300
GO TO 6                                                                      00042400
116 WRITE (6,117) TITLE                                                    00042500
117 FORMAT (1H120A4/1H0,9HTIME,SECS,7X3HX,M,5X,5HHAG,M,7X,3HZ,M,2X,      00042600
1 8HXDOT,M/S,2X8HYDOT,M/S,5X5HV,M/S1X8HMACH NO.2X7HDRAG,LB,           00042700
2 9H THETA,D,9H PITCH,D,9H DELTA,D,9H BODYA,D,9H DTHE,D/S)           00042800
7 FORMAT (1H120A4/1H0,9HTIME,SECS,7X3HX,M5X5HHAG,M,7X,3HZ,M2X,        00042900
1 8HXDOT,M/S2X8HYDOT,M/S5X5HV,M/S1X8HMACH NO.2X7HDRAG,LB,           00043000
2 9H THETA,D,9H YAW,D,9H SPIN,R/S,9H STA FAC ,8H DUMMY V)           00043100
6 CONTINUE                                                                  00043200
HAG=ALT-YTERM                                                                00043300
PRINT R,T,X,HAG,Z,XD,YD,V,CMACH,RESIS,THETA,YAWDEG,SPIN,STAFAC,DMY    00043400
8 FORMAT (1H 1F9.3,3F10.1,3F10.1,F9.2,4F9.2,4F9.2)                     00043500
IF (T.GT.300.) GO TO 30                                                    00043600
C RULE FOR STOPPING SOLUTION - STOP WHEN PROJECTILE HITS GROUND.        00043700
C                                                                           00043800
C 52 IF (.NOT.(R.LE.RTERM.AND.THETA.LT.0.0)) GO TO 5                      00043900
C INTERPOLATE SOLUTION VARIABLES FOR R=RTERM                              00044000
C                                                                           00044100
YE=YTERM                                                                      00044200
TE=T-DT*(R-RTERM)/(R-RP)                                                    00044300
DEL=(T-TE)/DT                                                                00044400
XE=X-DEL*(X-XP)                                                              00044500
ZE=Z-DEL*(Z-ZP)                                                              00044600
XDE=XD-DEL*(XD-XP)                                                           00044700
YDE=YD-DEL*(YD-YP)                                                           00044800
VE=V-DEL*(V-VP)                                                              00044900
THETAE=THETA-DEL*(THETA-THETAP)                                             00045000
CMACHE=CMACH-DEL*(CMACH-CMACHP)                                             00045100
RESISE=RESIS-DEL*(RESIS-RESISP)                                             00045200
YAWDEG=YAWDEG-DEL*(YAWDEG-YAWP)                                            00045300
SPINR=SPIN-DEL*(SPIN-SPINP)                                                 00045400
STAFAC=STAFAC-DEL*(STAFAC-STAFAP)                                           00045500
SMARGE=SMARG-DEL*(SMARG-SMARGP)                                             00045600
PSI=PSI-DEL*(PSI-PSIP)                                                       00045700
SRNGE=SRNG-DEL*(SRNG-SRNGP)                                                 00045800
YE=YE-YTERM                                                                  00045900
C XPLOT(NPLOT)=XE                                                            00046000
C YPLOT(1,NPLOT)=YE                                                         00046100
C                                                                           00046200
C PRINT OUT SOLUTION VARIABLES FOR Y=YTERM.                                00046300
C                                                                           00046400
C PRINT R,TE,XE,YE,ZE,XDE,YDE,VE,CMACHE,RESISE,THETAE,YAWDEG,          00046500
1 SPINR,STAFAC,SRNGE                                                         00046600
C                                                                           00046700
C SUPVEL=SUPVEL/0.3048                                                       00046800
RANGE=SQRT(XE**2+ZE**2)                                                      00046900

```

G LEVEL 21

MAIN

DATE = 77143

17/22/29

```
RANGE=RANCE*(1.+(RANGE/RE)**2/6.)/1852. 00047000
C PRINT MAXIMUM VELOCITY, RANGE, AND ALTITUDE. 00047100
  PRINT 90, SUPVEL, RANGE, SUPALT 00047200
90 FORMAT(1H0,20HMAX PROJ VELOCITY = ,F15.4,4H F/S, 00047300
  1 3X,12HMAX RANGE = ,F15.4,11H NAUT MILES,3X,10HMAX ALT = , 00047400
  2 F15.4,8H METERS) 00047500
C 00047600
C PLOT THE TRAJECTORY JUST COMPUTED. 00047700
C 00047800
C LABEL PLOT WITH TITLE, QE AND VO. 00047900
C 00048000
C 00048100
  PRINT 10,TITLE,QE,VO 00048200
10 FORMAT (1H015X20A4/4H QE=F5.1,10H DEG, VO=F6.1,4H F/S) 00048300
  3 CONTINUE 00048400
C ***** 00048500
C CALL POLFIT(RS,TS,NPLOT,3,0,CJRT,G,U,.TRUE.,SDEV, 00048600
C 1 20HFLIGHT TIME VS RANGE) 00048700
C CALL POLFIT(RS,VS,NPLOT,3,0,CJVT,H,HINV,.TRUE.,SDEV, 00048800
C . 20HPROJ. VEL. VS. RANGE) 00048900
C RETURN FOR ANOTHER CASE. 00049000
C ***** 00049100
  GO TO 101 00049200
30 CALL EXIT 00049300
  END 00049400
```

```

SUBROUTINE SOUND(A,G,RHO,VISCO)
COMMON EMO,EMB,SPI,FC,BRATE,DELT,TO,TR,ISW,V,THETA,FFCTR,CALSO,
1 VW,VCW,ALT,R,IEND,CM-CH,REYNLD,RESIS,CAL,DLONG,IOPTY,YAW,AMOM,
2 BMON,PSI,WTAREA,ISEP,NABLE,IGLIDE,IWING,TENABL,AVTHD,CDEFL,
3 MMCSW,TMOMMC
COMMON/SNDCOM/CADENS
EQUIVALENCE (Y,ALT)
C
C SUBROUTINE COMPUTES THE SPEED OF SOUND IN M/SEC
C VERSUS ALTITUDE IN METERS. ALSO COMPUTED IS THE
C ACCELERATION DUE TO GRAVITY IN M/SEC/SEC AND THE
C AIR DENSITY IN KG/M**3 AND THE ABSOLUTE VISCOSITY
C OF THE AIR IN KG/M/SEC. NOTE THAT REYNOLD'S NUMBER
C PER METER IS GIVEN BY A*RHO*EMACH/VISCO.
C**** REFERENCE: BARNHART, W. THE STANDARD ATMOSPHERE USED BY BRL
C**** FOR TRAJECTORY COMPUTATIONS, MEMO. REPORT NO. 1766, JUNE 1966.
C**** DATA FOR THE FOLLOWING EQUATIONS WERE EXTRACTED FROM THE
C**** U.S. STANDARD ATMOSPHERE, 1962.
C
G=9.826*(6.378E6/(6.378E6+Y))**2
D=6.356766E6+Y
IF(Y.LE.11019.07) GO TO 1
IF(Y.LE.20063.12) GO TO 2
IF(Y.LE.32161.9) GO TO 3
IF(Y.LE.47350.09) GO TO 4
IF(Y.LE.52428.88) GO TO 5
IF(Y.LE.61591.03) GO TO 6
IF(Y.LE.79994.14) GO TO 7
RHO=0.4636*EXP(-0.12207E-3*Y)
C T=TEMPERATURE IN DEGRFES KELVIN
T=180.65
8 A=20.053*SQRT(T)
RHO=RHO*CADENS
VISCO=0.00467*(T+110.)*(T/217.78)**1.5
C THIS IS THE SUTHERLAND VISCOSITY LAW.
RETURN
1 RHO=1.224999+Y*(-.1176033E-3+Y*(.433719E-8+Y*(-.7461659E-13
1 +Y*(.5537603E-18-.9572727E-24*Y))))
T=(1.831702E9-4.103083E4*Y)/D
GO TO 8
2 RHO=1.490142+Y*(-.2940114E-3+Y*(.1993974E-7+Y*(-.7637263E-12
1 +Y*(.1615921E-16-.1476764E-21*Y))))
T=216.65
GO TO 8
3 RHO=1.81561+Y*(-.235749E-3+Y*(.130807E-7+Y*(-.3819651E-12
1 +Y*(.5798729E-17-.3626654E-22*Y))))
T=(1.250058E9+6.553416E3*Y)/D
GO TO 8
4 RHO=1.10944+Y*(-.1140029E-3+Y*(.4817401E-8+Y*(-.1039241E-12
1 +Y*(.1138793E-17-.5052135E-23*Y))))
T=(8.839083E8+1.7938E4*Y)/D
GO TO 8
5 RHO=.8974979E-1+Y*(-.417905E-5+Y*(.3529753E-10+Y*(.1177144E-14
00049500
00049600
00049700
00049800
00049900
00050000
00050100
00050200
00050300
00050400
00050500
00050600
00050700
00050800
00050900
00051000
00051100
00051200
00051300
00051400
00051500
00051600
00051700
00051800
00051900
00052000
00052100
00052200
00052300
00052400
00052500
00052600
00052700
00052800
00052900
00053000
00053100
00053200
00053300
00053400
00053500
00053600
00053700
00053800
00053900
00054000
00054100
00054200
00054300
00054400
00054500
00054600
00054700

```

G LEVEL 21

SOUND

DATE = 77143

17/22/29

1 +Y*(-.2567072E-19+.1449113E-24*Y)))	00054800
T=270.65	00054900
GO TO 8	00055000
6 RHO=.1029082E-1+Y*(.1081853E-5+Y*(-.8523619E-10+Y*(.2075003E-14	00055100
1 +Y*(-.2184824E-19+.860425E-25*Y)))	00055200
T=(2.381562E9-1.233888E4*Y)/D	00055300
GO TO 8	00055400
7 RHO=0.4636*EXP(-0.12207E-3*Y)	00055500
T=(3.157088E9-2.493041E4*Y)/D	00055600
GO TO 8	00055700
END	00055800

```

SUBROUTINE FLIGHT(TIME,U,KUTTA)                                00055900
DIMENSION U(12)                                                00056000
DIMENSION TMACH(11),TKA(11),TKDYAW(11),TKL(11),TKM(11),      00056100
1 TKF(11),TKT(11),TKH(11),TKS(11),TCP(11)                    00056200
DIMENSION TFMACH(4),ALTRMM(4),AALTRM(4),TCN(4,4),WTCN(4)     00056300
DIMENSION TCAD1(4),TCAD2(4),TDEL(4),TAT(4,4),WTAT(4)         00056400
DATA GGAIN/0.50/,DT4AH/4.00/,DT5AH/5.00/                     00056500
DATA DTORAD/57.29578/                                         00056600
DATA RE/6.3786/,OMEGA/0.72915E-4/,PIFOR/0.7853981/,TWOG/19.58418/00056700
C RE=NOMINAL RADIUS OF THE EARTH AT THE EQUATOR IN METERS    00056800
C OMEGA=ANGULAR VELOCITY OF THE EARTH IN RADIANS/SEC         00056900
C                                                             00057000
C TABLE OF EQUIVALENCES                                       00057100
C U(1) = X                                                       00057200
C U(2) = Y                                                       00057300
C U(3) = Z                                                       00057400
C U(4) = SPIN                                                    00057500
C U(5) = XDOT                                                    00057600
C U(6) = YDOT                                                    00057700
C U(7) = ZDOT                                                    00057800
C U(8) = SPIND                                                   00057900
C U(9) = XDDBL                                                   00058000
C U(10) = YDDBL                                                  00058100
C U(11) = ZDDBL                                                  00058200
C U(12) = DUMMY                                                  00058300
EXTERNAL CDRAQ                                                  00058400
COMMON EMO,EMB,SPI,FC,BRATE,DELT,TO,TR,ISW,V,THETA,FFCTR,CALSQ, 00058500
1 VWG,VXW,ALT,R,IEND,CMACH,REYNLD,RESIS,CAL,DLONG,IOPTY,YAW,AMOM, 00058600
2 BMOM,PSI,WTAREA,ISEP,NABLE,IGLIDE,IWING,TENABL,AVTHD,CDEFL,   00058700
3 MMCSW,IMOMMC
COMMON/COFCOM/XCG,SMARG,EM,THID,PRNU,ALTRM,CNATRM,GLIDE,EPSTHE 00058900
1 ,STAFAC,YAWNU,TKA,TKDYAW,TKL,TKM,TKF,TKT,TKH,TKS,TCP,TMACH, 00059000
2 NARTBL,TFMACH,ALTRMM,AALTRM,TCN,WTCN,TCAD1,TCAD2,TDEL,TAT,WTAT 00059100
COMMON/WINCOM/RWC,XWC                                         00059200
IF(ISW.EQ.0) GO TO 10                                          00059300
IF(TIME.GT.TO+TR+DELT) GO TO 9                                 00059400
CALL BURN(TIME,XMASS,THRUST)                                    00059500
EM=XMASS                                                        00059600
C THRUST-INDUCED DRAG                                          00059700
FFC=FFCTR*THID                                                 00059800
H=4.44823*THRUST                                               00059900
TERMX=H*U(5)                                                    00060000
TERMY=H*U(6)                                                    00060100
12 VSQ=U(5)**2+U(6)**2+U(7)**2                                  00060200
V=SQRT(VSQ)                                                     00060300
UP=RE+U(2)                                                      00060400
XSQ=U(1)**2                                                      00060500
YSQ=UP**2                                                        00060600
ZSQ=U(3)**2                                                      00060700
R=SQRT(XSQ+YSQ+ZSQ)                                            00060800
C                                                             00060900
C ALT=R-RE                                                       00061000
ALT=U(2)+XSQ/2./RE                                             00061100

```

V G LEVEL 21

FLIGHT

DATE = 77143

17/22/29

```
DRCOSX=U(1)/R                                00061200
DRCOSY=UP/R                                    00061300
DRCOSZ=U(3)/R                                  00061400
CALL SOUND(A,G,RHO,VISCO)                      00061500
C                                                00061600
C THIS GENERATES SPEED OF SOUND, GRAVITY, AIR DENSITY, AND VISCOSITY. 00061700
C IF(V.EQ.0.0) GO TO 13                        00061800
C TERMX=TERMX/V                                00061900
C TERMY=TERMY/V                                00062000
C**** COMPUTE VELOCITY OF WIND AS A FUNCTION OF ALTITUDE. 00062100
C HARG=1.000*U(2)                              00062200
C VW=VWO+RWC*VWC(HARG)                        00062300
C VCW=VXW+XWC*VWC(HARG)                      00062400
C VW=VWO                                        00062500
C VCW=VXW                                        00062600
C VRELSQ= ((U(5)+VW)**2+U(6)**2+(U(7)+VCW)**2) 00062700
C VREL=SQRT(VRELSQ)                            00062800
C CMACH=VREL/A                                  00062900
C COMPUTE REYNOLD'S NUMBER AND SKIN FRICTION COEFFICIENT (SFC). 00063000
C FRICT=0.0                                     00063100
C IF(DLONG.EQ.0.0) GO TO 48                    00063200
C REYNLD=DLONG*A*RHO*CMACH/VISCO              00063300
C ALR=ALOG10(REYNLD)                           00063400
C PWR=0.05*ALR                                  00063500
C SFC=0.455/ALR**2.58/(1.+0.2*CMACH**4)**PWR 00063600
C IF(ISEP.EQ.0) GO TO 48                       00063700
C FRICT=WTAREA*SFC                             00063800
C DENOM=MASS OF PROJECTILE IN KG.             00063900
48 DENOM=0.4536*EM                             00064000
C DYNPRS=0.5*RHO*VRELSQ                        00064100
C IF(IOPTY.EQ.1) GO TO 20                      00064200
C YAW=0.0                                       00064300
C YAWSQ=0.0                                     00064400
C XKDYAW=0.0                                   00064500
C XTERMS=0.0                                   00064600
C YTERMS=0.0                                   00064700
C ZTERMS=0.0                                   00064800
C U(8)=0.0                                     00064900
21 CALL CDRAG(CMACH,DRAG,CAD)                  00065000
C COFDRG=FFC*DRAG+XKDYAW*YAWSQ+FRICT+CAD      00065100
C THIS GENERATES THE CORRECTED COEFFICIENT OF DRAG 00065200
C                                                00065300
C DIFFERENTIAL EQUATIONS                      00065400
22 CONTINUE                                    00065500
C FORM=PI*OFOR*CALSQ*DYNPRS                    00065600
C DRG=-COFDRG*FORM                            00065700
C                                                00065800
C RESIS IS AIR RESISTANCE IN POUNDS.          00065900
C RESIS=DRG /4.44823                          00066000
C                                                00066100
C**** GLIDE - FUFO - GLIDE - FUFO - GLIDE - 00066200
C IF(IGLIDE.NE.1) GO TO 60                    00066300
C**** ATTITUDE HOLD LOGIC FOR COPPERHEAD AP77 00066400
```

```

THE=ARSIN(U(6)/V)*DTORAD                                00066500
IF(MMCSW.NE.1) GO TO 1260                                00066600
C**** NOTE THAT OTHER OPTIONS FOR MECHANIZING ATTITUDE-HOLD 00066700
C**** CALCULATIONS MAY BE EMPLOYED. THESE ARE FOUND AFTER LOC. 1260. 00066800
T4AH=TMOMMC+DT4AH                                        00066900
C**** T4AH IS THE TIME AT WHICH THE ATTITUDE-HOLD SWITCH IS THROWN. 00067000
IF(TIME.LT.T4AH) GO TO 60                                00067100
IF(NABLE.EQ.1) GO TO 1390                                00067200
T5AH=TMOMMC+DT5AH                                        00067300
C**** T5AH IS THE TIME AT WHICH THE GYRO IS FREED, WINGS 00067400
C**** ARE EXTENDED, AND THE BODY IS COMMANDED TO FOLLOW THE GYRO. 00067500
IF(TIME.LT.T5AH) GO TO 1200                              00067600
NABLE=1                                                  00067700
IHING=1                                                  00067800
TENABL=T5AH                                              00067900
GO TO 1390                                               00068000
1200 CONTINUE                                           00068100
C**** CALCULATION OF CONTROL DEFLECTION FOR G BIAS 00068200
CDEFL=GGAIN*ABS(AVTHD)*DTORAD                            00068300
C**** SET UP INTERPOLATION ARRAYS TO DETERMINE TRIM ATTACK FOR GIVEN CON 00068400
IF(CMACH.LT.TFMACH(1)) GO TO 1230                        00068500
DO 1210 I=2,4                                           00068600
IF(CMACH.LT.TFMACH(I)) GO TO 1220                       00068700
1210 CONTINUE                                           00068800
C**** LOCAL MACH NUMBER IS BEYOND THE TABLE 00068900
TRIMMX=ALTRMM(4)                                        00069000
C CAD1=TCAD1(4)                                          00069100
C CAD2=TCAD2(4)                                          00069200
DO 1212 J=1,4                                           00069300
WTAT(J)=TAT(4,J)                                        00069400
WTCN(J)=TCN(4,J)                                        00069500
1212 CONTINUE                                           00069600
GO TO 1244                                               00069700
1220 FRACT=(CMACH-TFMACH(I-1))/(TFMACH(I)-TFMACH(I-1)) 00069800
DO 1214 J=1,4                                           00069900
WTAT(J)=TAT(I-1,J)+FRACT*(TAT(I,J)-TAT(I-1,J))        00070000
WTCN(J)=TCN(I-1,J)+FRACT*(TCN(I,J)-TCN(I-1,J))        00070100
1214 CONTINUE                                           00070200
TRIMMX=ALTRMM(I-1)+FRACT*(ALTRMM(I)-ALTRMM(I-1))      00070300
C CAD1=TCAD1(I-1)+FRACT*(TCAD1(I)-TCAD1(I-1))          00070400
C CAD2=TCAD2(I-1)+FRACT*(TCAD2(I)-TCAD2(I-1))          00070500
GO TO 1244                                               00070600
1230 TRIMMX=ALTRMM(1)                                    00070700
C CAD1=TCAD1(1)                                          00070800
C CAD2=TCAD2(1)                                          00070900
DO 1240 J=1,4                                           00071000
WTAT(J)=TAT(1,J)                                        00071100
WTCN(J)=TCN(1,J)                                        00071200
1240 CONTINUE                                           00071300
1244 CONTINUE                                           00071400
C**** BEGIN INTERPOLATION FOR TRIM ATTACK 00071500
DO 1246 J=2,4                                           00071600
IF(CDEFL.LT.TDEL(J)) GO TO 1250                         00071700

```

G LEVEL 21

FLIGHT

DATE = 77143

17/22/29

```
1246 CONTINUE 00071800
C**** CONTROL SURFACE DEFLECTION REQUIRED EXCEEDS CAPABILITY. 00071900
C**** WRITE ERROR MESSAGE. 00072000
WRITE (6,1248) 00072100
1248 FORMAT(1H0,'ERROR: CONTROL DEFL. CALCULATED FROM G BIAS EXCEEDS 00072200
1LIMIT') 00072300
CALL EXIT 00072400
1250 CONTINUE 00072500
FRACT2=(CDEFL-TDEL(J-1))/(TDEL(J)-TDEL(J-1)) 00072600
ALTRIM=WTAT(J-1)+FRACT2*(WTAT(J)-WTAT(J-1)) 00072700
C**** CALCULATE THE NORMAL FORCE COEFFICIENT 00072800
DO 1252 J=2,4 00072900
IF(ALTRIM.LT.AALTRM(J)) GO TO 1256 00073000
1252 CONTINUE 00073100
C**** TRIM ANGLE CALCULATED IS BEYOND THE TABLE. WRITE ERROR 00073200
C**** MESSAGE AND STOP. 00073300
WRITE (6,1254) 00073400
1254 FORMAT(1H0,'ERROR: TRIM ANGLE CALCULATED IS BEYOND THE TABLE') 00073500
CALL EXIT 00073600
1256 CONTINUE 00073700
FRACT3=(ALTRIM-AALTRM(J-1))/(AALTRM(J)-AALTRM(J-1)) 00073800
CNO=WTGN(J-1)+FRACT3*(WTCN(J)-WTCN(J-1)) 00073900
C**** UPDATE INITIAL BODY ATTITUDE 00074000
ABODYO=THE+ALTRIM 00074100
C**** GO CALCULATE AERO FORCES 00074200
GO TO 1500 00074300
1260 CONTINUE 00074400
IF(TIME.LT.TENABL) GO TO 66 00074500
IF(NABLE.NE.1) GO TO 1300 00074600
GO TO 1390 00074700
66 CONTINUE 00074800
C**** TIME .GE. TENABL 00074900
IF(NABLE.EQ.1) GO TO 1390 00075000
GPEPS=GLIDE+FPSTHE 00075100
IF(THE.GT.GPEPS) GO TO 60 00075200
C**** CALCULATION FOR INITIAL CONDITIONS FOR ATTITUDE HOLD 00075300
C**** ATTITUDE HOLD STARTS WITH ENABLE SET TO 1. ENTER ONLY ONCE FOR IC 00075400
1300 NABLE=1 00075500
C**** FIRST ITERATE FOR CNO AND ALTRIM 00075600
KOUNT1=1 00075700
CNO=DENOM*TWOG*U(5)/V/2.0/FORM 00075800
C**** THIS IS THE REQUIRED NORMAL FORCE COEF. TO PRESERVE GLIDE ANGLE. 00075900
C**** COMPUTE MAX TRIM ANGLE 00076000
IF(CMACH.LT.TFMACH(1)) GO TO 1330 00076100
DO 1310 I=2,4 00076200
IF(CMACH.LT.TFMACH(I)) GO TO 1320 00076300
1310 CONTINUE 00076400
C**** LOCAL MACH NUMBER IS BEYOND THE TABLE 00076500
TRIMMX=ALTRMM(4) 00076600
C CAD1=TCA01(4) 00076700
C CAD2=TCA02(4) 00076800
DO 1312 J=1,4 00076900
WTCN(J)=TCN(4,J) 00077000
```

```

      WTAT(J)=TAT(4,J)                                00077100
1312 CONTINUE                                         00077200
      GO TO 1350                                       00077300
1320 FRACT=(CMACH-TFMACH(I-1))/(TFMACH(I)-TFMACH(I-1)) 00077400
      DO 1314 J=1,4                                    00077500
      WTCN(J)=TCN(I-1,J)+FRACT*(TCN(I,J)-TCN(I-1,J)) 00077600
      WTAT(J)=TAT(I-1,J)+FRACT*(TAT(I,J)-TAT(I-1,J)) 00077700
1314 CONTINUE                                         00077800
      TRIMMX=ALTRMM(I-1)+FRACT*(ALTRMM(I)-ALTRMM(I-1)) 00077900
C      CAD1=TCAD1(I-1)+FRACT*(TCAD1(I)-TCAD1(I-1)) 00078000
C      CAD2=TCAD2(I-1)+FRACT*(TCAD2(I)-TCAD2(I-1)) 00078100
      GO TO 1350                                       00078200
1330 TRIMMX=ALTRMM(I)                                 00078300
C      CAD1=TCAD1(I)                                   00078400
C      CAD2=TCAD2(I)                                   00078500
      DO 1340 J=1,4                                    00078600
      WTCN(J)=TCN(I,J)                                 00078700
      WTAT(J)=TAT(I,J)                                 00078800
1340 CONTINUE                                         00078900
1350 CONTINUE                                         00079000
C**** INTERPOLATE IN WTCN(J) FOR THE INSTANTANEOUS TRIM, ALTRIM 00079100
C**** AND CONTROL SURFACE DEFLECTION AT TRIM.         00079200
      DO 1360 J=2,4                                    00079300
      IF(CNO.LT.WTCN(J)) GO TO 1370                   00079400
1360 CONTINUE                                         00079500
C**** REQUIRED NORMAL FORCE EXCEEDS CAPABILITY. PRINT NOTICE AND SET 00079600
C**** ALTRIM TO TO MAXIMUM.                           00079700
      ALTRIM=TRIMMX                                    00079800
      WRITE (6,1366)                                   00079900
1366 FORMAT(1H0,'INITIAL NORMAL FORCE REQUIRED FOR DESIRED GLIDE EXCEEDS 00080000
      IS CAPABILITY')                                00080100
C**** REPLACE CNO WITH MAX REALIZABLE                 00080200
      CNO=WTCN(3)+(TCN(4)-WTCN(3))*(TRIMMX-AALTRM(3))/ 00080300
      1 (AALTRM(4)-AALTRM(3))                        00080400
      GO TO 1374                                       00080500
1370 CONTINUE                                         00080600
C**** INTERPOLATE FOR INITIAL TRIM ANGLE REQUIRED FOR NORMAL FORCE. 00080700
      FRACT2=(CNO-WTCN(J-1))/(WTCN(J)-WTCN(J-1))    00080800
      ALTRIM=AALTRM(J-1)+FRACT2*(AALTRM(J)-AALTRM(J-1)) 00080900
1374 CONTINUE                                         00081000
C**** INTERPOLATE FOR CONTROL SURFACE DEFLECTION     00081100
      DO 1376 J=2,4                                    00081200
      IF(ALTRIM.LT.WTAT(J)) GO TO 1378               00081300
1376 CONTINUE                                         00081400
C**** ALTRIM IS BEYOND THE TABLE. WRITE ERROR MESSAGE AND STOP. 00081500
      WRITE (6,1377)                                   00081600
1377 FORMAT(1H0,'ERROR. ALTRIM BEYOND THE TABLE. CHECK INPUT PARAMS') 00081700
      CALL EXIT                                        00081800
1378 CONTINUE                                         00081900
      FRACT3=(ALTRIM-WTAT(J-1))/(WTAT(J)-WTAT(J-1)) 00082000
      CDEFL=TDEL(J-1)+FRACT3*(TDEL(J)-TDEL(J-1))    00082100
      KOUNT1=KOUNT1+1                                  00082200
      IF(KOUNT1.GT.2) GO TO 1375                       00082300

```

G LEVEL 21

FLIGHT

DATE = 77143

17/22/29

```

      CNO=CNO/COS(ALTRIM/DTORAD)
      GO TO 1350
1375 CONTINUE
C**** END OF CALCULATION OF INITIAL TRIM ANGLE FOR GLIDE OPTION 1.
C**** NOW CALCULATE INITIAL BODY ATTITUDE.
1380 ABOYO=THE+ALTRIM
      CN=CNO
      GO TO 1500
1390 CONTINUE
C**** SUBSEQUENT CALCULATION OF ALTRIM FOR ATTITUDE HOLD
      ALTRIM=ABOYO-THE
      IF (CMACH.LT.TFMACH(1)) GO TO 1430
      DO 1410 I=2,4
      IF (CMACH.LT.TFMACH(I)) GO TO 1420
1410 CONTINUE
C**** LOCAL MACH NUMBER BEYOND THE TABLE
      TRIMMX=ALTRMM(4)
C      CAD1=TCAD1(4)
C      CAD2=TCAD2(4)
      DO 1412 J=1,4
      WTCN(J)=TCN(4,J)
      WTAT(J)=TAT(4,J)
1412 CONTINUE
      GO TO 1450
1420 FRACT=(CMACH-TFMACH(I-1))/(TFMACH(I)-TFMACH(I-1))
      DO 1414 J=1,4
      WTCN(J)=TCN(I-1,J)+FRACT*(TCN(I,J)-TCN(I-1,J))
      WTAT(J)=TAT(I-1,J)+FRACT*(TAT(I,J)-TAT(I-1,J))
1414 CONTINUE
      TRIMMX=ALTRMM(I-1)+FRACT*(ALTRMM(I)-ALTRMM(I-1))
C      CAD1=TCAD1(I-1)+FRACT*(TCAD1(I)-TCAD1(I-1))
C      CAD2=TCAD2(I-1)+FRACT*(TCAD2(I)-TCAD2(I-1))
      GO TO 1450
1430 TRIMMX=ALTRMM(1)
C      CAD1=TCAD1(1)
C      CAD2=TCAD2(1)
      DO 1440 J=1,4
      WTCN(J)=TCN(1,J)
      WTAT(J)=TAT(1,J)
1440 CONTINUE
1450 CONTINUE
C**** INTERPOLATE IN WTCN(J) FOR THE NORMAL FORCE COEF. CN.
      DO 1460 J=2,4
      IF (ALTRIM.LT.AALTRM(J)) GO TO 1470
1460 CONTINUE
C**** REQUIRED TRIM ANGLE EXCEEDS MAX TABULATED VALUE. TRIM WILL
C**** BE LIMITED TO TRIMMX.
      ALTRIM=TRIMMX
      CN=WTCN(3)+(WTCN(4)-WTCN(3))*(ALTRIM-AALTRM(3))/
      1 (AALTRM(4)-AALTRM(3))
      GO TO 1474
1470 CONTINUE
C**** INTERPOLATE FOR CN WITHIN THE TABLE
```

```

FRACT2=(ALTRIM-AALTRM(J-1))/(AALTRM(J)-AALTRM(J-1))          00J87700
CN=WTCN(J-1)+FRACT2*(WTCN(J)-WTCN(J-1))                        00087800
1474 CONTINUE                                                  00087900
C**** INTERPOLATE FOR CONTROL SURFACE DEFLECTION              00088000
DO 1476 J=2,4                                                  00088100
IF(ALTRIM.LT.WTAT(J)) GO TO 1478                               00088200
1476 CONTINUE                                                  00088300
C**** ALTRIM IS BEYOND THE TABLE. WRITE ERROR MESSAGE AND STOP. 00088400
WRITE (6,1377)                                                00088500
CALL EXIT                                                       00088600
1478 CONTINUE                                                  00088700
FRACT3=(ALTRIM-WTAT(J-1))/(WTAT(J)-WTAT(J-1))                00088800
CDEFL=TDEL(J-1)+FRACT3*(TDEL(J)-TDEL(J-1))                    00088900
C**** END OF NORMAL FORCE COEFFICIENT CALCULATIONS            00089000
C**** PROGRAM REENTRY FOR ATTITUDE-HOLD CALCULATIONS          00089100
1500 CONTINUE                                                  00089200
C**** CONVERT ANGLE TO RADIANS                                  00089300
CDEFL=CDEFL/DTORAD                                             00089400
ALTRIM=ALTRIM/DTORAD                                           00089500
C**** PLACE TRIM ANGLE IN YAW POSITION FOR PRINTOUT.           00089600
YAW=ALTRIM                                                      00089700
FN=CN*FORM                                                       00089800
SINAL=SIN(ALTRIM)                                               00089900
COSAL=COS(ALTRIM)                                               00090000
C**** CALCULATE AXIAL FORCE INCREMENT PRODUCED BY FIN DEFLECTION AT TRIM 00090100
C DELCA=CAD1*(0.4*ALTRIM-CDEFL)**2-CAD2*ALTRIM**3              00090200
DELCA=CDEFL/6.0                                                 00090300
FDI2=DELCA*FORM                                                  00090400
FL=FN*COSAL-FDI2*SINAL                                          00090500
FDI=-FN*SINAL-FDI2*COSAL                                        00090600
SINTH=U(6)/V                                                     00090700
COSTH=U(5)/V                                                     00090800
TERMX=TERMX-FL*SINTH+FDI*COSTH                                   00090900
TERMY=TERMY+FL*COSTH+FDI*SINTH                                   00091000
60 CONTINUE                                                      00091100
IF(NABLE.EQ.1) IWING=1                                          00091200
C**** END OF ATTITUDE-HOLD CALCULATIONS                        00091300
C                                                                 00091400
C                                                                 00091500
U(10)=(DRG*U(6)/VREL+TERMY)/DENOM-G*DRCCOSY+0.53166E-8*UP     00091600
I *2.*OMEGA*U(7)+YTERMS                                         00091700
U(9)=(DRG*(U(5)+VW)/VREL+TERMX)/DENOM-G*DRCCOSX+XTERMS        00091800
U(11)=-2.*OMEGA*U(6)-G*DRCCOSZ+ZTERMS+DRG*(U(7)+VCW)/VREL/DENOM 00091900
U(12)=0.0                                                       00092000
C AC IS THE ACCELERATION OF THE PROJECTILE ALONG THE TRAJECTORY. 00092100
C AC=(U(5)*U(9)+U(6)*U(10)+U(7)*U(11))/V                       00092200
IF(IOPTY.EQ.0) GO TO 14                                         00092300
U(8)=-RHO*CALSQ**2/AMOM*XKA*U(4)*V                             00092400
14 IF (KUTTA.EQ.4) THETA=ARSIN(U(6)/V)*57.29578                00092500
RETURN                                                            00092600
13 U(9)=0.                                                       00092700
U(10)=-G                                                         00092800
THETA=90.                                                        00092900

```

G LEVEL 21

FLIGHT

DATE = 77143

17/22/29

```

RETURN
9 EM=EMB 00093000
GO TO 11 00093100
10 EM=EMO 00093200
11 TERMX=0. 00093300
TERMY=0. 00093400
FFC=FFCTR 00093500
GO TO 12 00093600
20 CALL ACOEFS(CMACH,YAW,XKA,XKDYAW,XKL,XKM,XKF,XKT,
1XKH,XKS,XCP) 00093700
VXRL=U(5)+VW 00093800
VZRL=U(7)+VCW 00093900
VRLSQ=VXRL**2+U(6)**2+VZRL**2 00094000
VRL=SQRT(VRLSQ) 00094100
C TEST FOR DYNAMIC STABILITY. 00094200
BOTTOM=8.0*BMON*DYNIPRS*CAL**3*XKM 00094300
STAFAC=(U(4)*AMOM)**2/BOTTOM 00094400
IF (STAFAC.LE.1.0) GO TO 25 00094500
C**** COMPUTE THE YAWING FREQUENCY 00094600
YAWNQ=AMOM/BMON*SQRT(1.-1./STAFAC)*U(4)/6.2832 00094700
C**** COMPUTE THE OVERTURNING MOMENT AND PRECESSIONAL FREQUENCY 00094800
OTNMOM=2.*XKM*CAL**3*DYNIPRS 00094900
PRNU=OTNMOM/AMOM/U(4)/6.2832 00095000
C COMPUTE YAW OF REPOSE. 00095100
ALPHAB=RHO*CAL*VRLSQ*(XKL*XKM*VRLSQ+CALSQ*XKF*XKT*U(4)**2) 00095200
IF (ABS(ALPHAB).LT.1.E-20) GO TO 25 00095300
ALPHAA=AMOM*XKL*U(4)/CALSQ/ALPHAB 00095400
ALPHAB=DENOM*XKT*U(4)/ALPHAB 00095500
AMB=ALPHAB-ALPHAA 00095600
ALPHAX=AMB*(U(6)*U(11)-VZRL*U(10))-ALPHAB*VZRL*G 00095700
ALPHAY=AMB*(VZRL*U(9)-VXRL*U(11)) 00095800
ALPHAZ=AMB*(VXRL*U(10)-U(6)*U(9))+ALPHAB*VXRL*G 00095900
YAWSQ=ALPHAX**2+ALPHAY**2+ALPHAZ**2 00096000
YAW=SQRT(YAWSQ) 00096100
IF (YAW.GT.1.5708) GO TO 25 00096200
ARG=(VXRL*ALPHAZ-VZRL*ALPHAX)*VRL 00096300
ARG1=(VXRL*ALPHAY-U(6)*ALPHAX)*VXRL-(U(6)*ALPHAZ-VZRL*ALPHAY)*VZRL 00096400
IF (ABS(ARG1).LE.1.0E-20) GO TO 50 00096500
PSI=57.3*ATAN(ARG/ARG1) 00096600
GO TO 53 00096700
50 IF (ARG*ARG1) 51,52,52 00096800
51 PSI=-90. 00096900
GO TO 53 00097000
52 PSI=90. 00097100
53 CONTINUE 00097200
C 00097300
C PSI=ORIENTATION OF YAW. THIS IS THE ANGLE BETWEEN THE PLANE 00097400
C CONTAINING BOTH THE VELOCITY AND YAW VECTORS AND A VERTICAL 00097500
C PLANE CONTAINING THE VELOCITY VECTOR. IT IS MEASURED 00097600
C CLOCKWISE FROM THE VERTICAL PLANE. 00097700
C 00097800
C 00097900
C 00098000
C END OF COMPUTATION OF YAW. 00098100
DKFN=CAL*XKF*U(4) 00098200

```

G LEVEL 21

FLIGHT

DATE = 77143

17/22/29

```
XKLVSQ=XKL*VRLSQ                                00098300
RDSQ=RHO*CALSQ/DENOM                             00098400
XTERMS=RDSQ*(XKLVSQ*ALPHAX+DKFN*(ALPHAY*VZRL-ALPHAZ*U(6))) 00098500
YTERMS=RDSQ*(XKLVSQ*ALPHAY+DKFN*(ALPHAZ*VXRL-ALPHAX*VZRL)) 00098600
ZTERMS=RDSQ*(XKLVSQ*ALPHAZ+DKFN*(ALPHAX*U(6)-ALPHAY*VXRL)) 00098700
XKDYAW=2.54647*XKDYAW                             00098800
*****                                             00098900
C IF(YAW.LT.0.69) GO TO 21                          00099000
  PRINT 55,RHO,XTERMS,YTERMS,ZTERMS                 00099100
55 FORMAT(1H ,1P4E10.5)                             00099200
C *****                                             00099300
  GO TO 21                                           00099400
25 PRINT 26,STAFAC                                   00099500
26 FORMAT(1H0,40HUNSTABLE PROJECTILE STABILITY FACTOR = ,F10.4) 00099600
  CALL EXIT                                          00099700
  END                                               00099800
```

```

SURROUTINE CDRAG(EMACH,DRAG,CAD)                                00099900
C                                                                00100000
C PROGRAM COMPUTES THE COEFFICIENT OF DRAG VERSUS MACH NUMBER  00100100
C AND THE COEFFICIENT INCREMENT DUE TO WINGS.                 00100200
C                                                                00100300
DIMENSION XMTBL(12),CDTBL(12),COTBL(12)                       00100400
DATA CDOKD/2.546479/                                           00100500
COMMON EMO,EMH,SPI,FC,HRATE,DELT,TO,TB,ISW,V,THETA,FFCTR,CALSO, 00100600
1 VW,VCW,ALT,R,IEND,CMACH,REYNLD,RESIS,CAL,DLONG,LOPTY,YAW,AMOM, 00100700
2 BMON,PSI,WTAREA,ISEP,HABLE,IGLIDE,IWING,TENABL,AVTHD,CDEFL,  00100800
3 MMCSW,TMOMMC                                                 00100900
COMMON/DRGCOM/ XMTBL,CDTBL,COTBL,NTBL                         00101000
CAD=0.0                                                         00101100
IF(NTBL.NE.0) GO TO 5                                          00101200
IF(EMACH.LE.0.80) GO TO 1                                       00101300
IF(EMACH.LE.1.10) GO TO 3                                       00101400
IF(EMACH.LE.3.0) GO TO 4                                       00101500
EM3=EMACH-3.0                                                  00101600
DRAG=0.09+EM3*(-0.02+0.002*EM3)                                00101700
DRAG=CDOKD*DRAG                                               00101800
RETURN                                                         00101900
1 DRAG=0.0589                                                  00102000
DRAG=CDOKD*DRAG                                               00102100
RETURN                                                         00102200
3 C=10.*(EMACH-0.8)                                           00102300
DRAG=0.07736*C**3*EXP(-C)+0.0589                               00102400
DRAG=CDOKD*DRAG                                               00102500
RETURN                                                         00102600
4 DRAG=0.21547+EMACH*(-0.05134+0.00317*EMACH)                00102700
DRAG=CDOKD*DRAG                                               00102800
RETURN                                                         00102900
5 DO 6 J=1,NTBL                                                00103000
IF(EMACH.LT.XMTBL(J)) GO TO 8                                    00103100
6 CONTINUE                                                     00103200
8 JL=J-1                                                       00103300
IF(JL.LE.0) GO TO 12                                           00103400
FRAC=(EMACH-XMTBL(JL))/(XMTBL(J)-XMTBL(JL))                   00103500
CD=CDTBL(JL)+(CDTBL(J)-CDTBL(JL))*FRAC                        00103600
CAO=0.0                                                         00103700
IF(IWING.NE.1) GO TO 10                                         00103800
CAO=COTBL(JL)+(COTBL(J)-COTBL(JL))*FRAC                       00103900
10 CONTINUE                                                    00104000
DRAG=CD                                                         00104100
CAD=CAO                                                         00104200
RETURN                                                         00104300
12 CONTINUE                                                    00104400
DRAG=CDTBL(1)                                                  00104420
CAD = 0.                                                         00104450
IF (IWING.EQ.1) CAD = COTBL(1)                                 00104500
RETURN                                                         00104700
END                                                             00104800

```

```

SUBROUTINE ACOEFS (EMACH, YAW, XKA, XKDYAW, XKL, XKM, XKF, XKT, XKH, XKS, XCP)
1) DIMENSION TMACH(11), TKA(11), TKDYAW(11), TKL(11), TKM(11), TKF(11),
1) TKT(11), TKH(11), TKS(11), TCP(11)
DIMENSION TCAD1(4), TCAD2(4), TDEL(4), TAT(4,4), WTAT(4)
COMMON/COFCOM/XCG, SMARG, EM, THID, PRNU, ALTRIM, CNATRM, GLIDE, EPSTHE
1) STAFAC, YAWNU, TKA, TKDYAW, XKL, TKM, TKF, TKT, TKH, TKS, TCP, TMACH,
2) NARTBL, TFMACH, ALTRMN, AALTRM, TCM, WTCN, TCAD1, TCAD2, TDEL, TAT, WTAT
C EMACH = MACH NUMBER
C XKA = SPIN DAMPING MOMENT COEFFICIENT
C XKDYAW = YAW DRAG COEFFICIENT
C XKL = LIFT FORCE COEFFICIENT
C XKM = OVERTURNING MOMENT COEFFICIENT
C XKF = MAGNUS FORCE COEFFICIENT
C XKT = MAGNUS MOMENT COEFFICIENT
C XKH = DAMPING MOMENT COEFFICIENT
C XKS = PITCHING FORCE COEFFICIENT
C XCP = CENTER OF PRESSURE AFT OF NOSE IN CALIBERS
C
C FOR DEPENDENCE OF ACOEFS UPON YAW SEE BRL MEMO. RPT. NO. 2023
C RELATIVE TO T387 TYPE PROJECTILE.
C XKT=-0.14+0.0576*(EMACH-1.25)**2
C XKT=0.0
C XKF=0.157
C SYAW=SIN(YAW)**2
C GO TO 50
51 CONTINUE
DO 60 J=1, NARTBL
IF (EMACH.LT.TMACH(J)) GO TO 70
60 CONTINUE
70 JL=J-1
FRAC=(EMACH-TMACH(JL))/(TMACH(J)-TMACH(JL))
IF (TKA(J).EQ.0.0) GO TO 52
XKA=TKA(JL)+(TKA(J)-TKA(JL))*FRAC
52 IF (TKDYAW(J).EQ.0.0) GO TO 53
XKDYAW=TKDYAW(JL)+(TKDYAW(J)-TKDYAW(JL))*FRAC
53 IF (TKL(J).EQ.0.0) GO TO 54
XKL=TKL(JL)+(TKL(J)-TKL(JL))*FRAC
54 IF (TKM(J).EQ.0.0) GO TO 55
XKM=TKM(JL)+(TKM(J)-TKM(JL))*FRAC
55 IF (TKF(J).EQ.0.0) GO TO 56
XKF=TKF(JL)+(TKF(J)-TKF(JL))*FRAC
56 IF (TKT(J).EQ.0.0) GO TO 57
XKT=TKT(JL)+(TKT(J)-TKT(JL))*FRAC
57 IF (TKH(J).EQ.0.0) GO TO 58
XKH=TKH(JL)+(TKH(J)-TKH(JL))*FRAC
58 IF (TKS(J).EQ.0.0) GO TO 59
XKS=TKS(JL)+(TKS(J)-TKS(JL))*FRAC
59 IF (TKM(J).EQ.0.0) GO TO 62
IF (XKL.EQ.0.0) CALL EXIT
SMARG=-XKM/XKL
XCP=XCG+SMARG
RETURN
00105000
00105100
00105200
00105300
00105400
00105500
00105600
00105700
00105800
00105900
00106000
00106100
00106200
00106300
00106400
00106500
00106600
00106700
00106800
00106900
00107000
00107100
00107200
00107300
00107400
00107500
00107600
00107700
00107800
00107900
00108000
00108100
00108200
00108300
00108400
00108500
00108600
00108700
00108800
00108900
00109000
00109100
00109200
00109300
00109400
00109500
00109600
00109700
00109800
00109900
00110000
00110100

```

G LEVEL 21

ACOEFS

DATE = 77143

17/22/29

62	IF (TCP(J).EQ.0.0) GO TO 63	0^110200
	XCP=TCP(JL)+(TCP(J)-TCP(JL))*FRAC	00110300
63	SMARG=XCP-XCG	00110400
	XKM=-XKL*SMARG	00110500
	RETURN	00110600
50	CONTINUE	00110700
	IF (EMACH.LE.0.8) GO TO 10	00110800
	IF (EMACH.LE.0.9) GO TO 20	00110900
	IF (EMACH.LE.1.0) GO TO 30	00111000
	IF (EMACH.LE.1.1) GO TO 35	00111100
	IF (EMACH.LE.1.30) GO TO 40	00111200
	IF (EMACH.GT.1.5) GO TO 45	00111300
C	VALID FOR EMACH GTR 0.8 AND LT 1.5	00111400
5	XKA=0.0038+0.002*EXP(-1.5*(EMACH-0.8))	00111500
C	VALID FOR EMACH GTR 0.9	00111600
6	EM9=EMACH-0.9	00111700
	HOLD=1.-EXP(-5.*EM9)	00111800
	XKL=0.5507+0.4*HOLD	00111900
	XKL=XKL+6.6*SYAW	00112000
	XCP=0.237+1.57*HOLD	00112100
C	VALID FOR EMACH GTR 1.0	00112200
7	XKS=-4.0+1.78*(EMACH-1.)	00112300
C	VALID FOR EMACH GTR 1.1	00112400
	XKDYAW=1.5+2.38*EXP(-2.72*(EMACH-1.1))	00112500
C	VALID FOR EMACH GTR 1.3	00112600
	XKH=3.7	00112700
C	VALID FOR ALL EMACH	00112800
9	SMARG=XCP-XCG	00112900
	XKM=-XKL*SMARG	00113000
	IF (NARTBL.NE.0) GO TO 51	00113100
	RETURN	00113200
10	XKA=0.0058	00113300
	XKDYAW=1.5	00113400
11	XKL=0.62-0.077*EMACH	00113500
	XKL=XKL+4.3*SYAW	00113600
	XCP=1.2-1.07*EMACH	00113700
12	XKS=-4.0	00113800
13	XKH=0.71+2.3*EMACH	00113900
	GO TO 9	00114000
20	EM8=EMACH-0.8	00114100
	XKA=0.0038+0.002*EXP(-1.5*EM8)	00114200
	XKDYAW=1.5+2.5*SIN(6.283*EM8)	00114300
	GO TO 11	00114400
30	EM8=EMACH-0.8	00114500
	XKA=0.0038+0.002*EXP(-1.5*EM8)	00114600
	XKDYAW=1.5+2.5*SIN(6.283*EM8)	00114700
	EM9=EMACH-0.9	00114800
	HOLD=1.-EXP(-5.*EM9)	00114900
	XKL=0.5507+0.4*HOLD	00115000
	XKL=XKL+5.5*SYAW	00115100
	XCP=0.237+1.57*HOLD	00115200
	GO TO 12	00115300
35	EM8=EMACH-0.8	00115400

G LEVEL 21

ACOEFS

DATE = 77143

17/22/29

XKA=0.0038+0.002*EXP(-1.5*EM8)	00115500
XKDYAW=1.5+2.5*SIN(6.283*EM8)	00115600
EM9=EMACH-0.9	00115700
HOLD=1.-EXP(-5.*EM9)	00115800
XKL=0.5507+0.4*HOLD	00115900
XKL=XKL+5.5*SYAW	00116000
XCP=0.237+1.57*HOLD	00116100
XKS=-5.78+1.78*EMACH	00116200
GO TO 13	00116300
40 EM8=EMACH-0.8	00116400
XKA=0.0038+0.002*EXP(-1.5*EM8)	00116500
XKDYAW=1.5+2.38*EXP(-2.72*(EMACH-1.1))	00116600
EM9=EMACH-0.9	00116700
HOLD=1.-EXP(-5.*EM9)	00116800
XKL=0.5507+0.4*HOLD	00116900
XKL=XKL+6.6*SYAW	00117000
XCP=0.237+1.57*HOLD	00117100
XKS=-5.78+1.78*EMACH	00117200
GO TO 13	00117300
45 XKA=0.0038+0.002*EXP(-1.5*(EMACH-0.8))	00117400
GO TO 6	00117500
END	00117600

G LEVEL 21

RUNGE1

DATE = 77143

17/22/29

```

SUBROUTINE RUNGE1(V,W,NEQ,NORD,DIFEQ)
DIMENSION V(12),w(48)
NV=NEQ*NORD
N=NV+NEQ
RETURN
C
ENTRY RUNGE2(T,DT)
DT2=DT*.5
DT6=DT/6.
DO 1 I=1,N
1 W(I)=V(I)
DO 2 J=1,3
  NJM=NEQ+N*(J-1)
  JDECK=N*J
  IF (J-3)3,4,4
3 DTW=DT2
  GO TO 5
4 DTW=DT
5 TW=T+DTW
  DO 6 I=1,NV
    K=I+JDECK
    L=I+NJM
    W(K)=W(I)+W(L)*DTW
6 V(I)=W(K)
  CALL DIFEQ(TW,V,J)
  DO 2 I=1,N
    K=I+JDECK
2 W(K)=V(I)
  DO 7 I=1,NV
    K1=I+NEQ
    K2=K1+N
    K3=K2+N
    K4=K3+N
7 V(I)=W(I)+DT6*(W(K1)+2.*(W(K2)+W(K3))+W(K4))
  T=TW
  CALL DIFEQ(T,V,4)
RETURN
END
00117700
00117800
00117900
00118000
00118100
00118200
00118300
00118400
00118500
00118600
00118700
00118800
00118900
00119000
00119100
00119200
00119300
00119400
00119500
00119600
00119700
00119800
00119900
00120000
00120100
00120200
00120300
00120400
00120500
00120600
00120700
00120800
00120900
00121000
00121100
00121200
00121300
00121400
```

G LEVEL 21

VWC

DATE = 77143

17/22/29

	FUNCTION VWC(Y)	00121500
	IF(Y.GE.6700.)GOTO3	00121600
	VWC=5.1816+4.972E-5*Y+1.3494E-7*Y*Y	00121700
	RETURN	00121800
3	VWC=10.058+3.9624*COS(.42946E-3*(Y-9448.8))	00121900
	IF(Y.GT.13700.) WRITE(6,1)	00122000
	RETURN	00122100
1	FORMAT(28H ALTITUDE ABOVE 13700 METERS)	00122200
	END	00122300

```

SUBROUTINE BURN(TIME,XMASS,THRUST)                                00122400
C  SUBROUTINE COMPUTES PROJECTILE MASS IN POUNDS MASS AND        00122500
C  ROCKET THRUST IN POUNDS FORCE                                  00122600
C  TO=TIME AT WHICH BURNING COMMENCES                            00122700
C  EMO=INITIAL MASS, LBM                                         00122800
C  EMB=BURNED MASS, LBM                                          00122900
C  TIME=TIME AFTER LAUNCH ,SEC                                   00123000
C  SPI=SPECIFIC IMPULSE, LBF/LBM/SEC                             00123100
C  FC=CONSTANT NOMINAL THRUST LEVEL, LBF                         00123200
C  IBURN= INDICATOR OF COMMENCEMENT OF BURNING (IBURN=1)        00123300
C  DELT=RISE TIME OF THRUST--ASSUMED EQUAL TO DECAY TIME , SEC  00123400
C  BRATE=FC/SPI=BURNING RATE, LBM/SEC                           00123500
C  TB=(EMO-EMB)/BRATE=EFFECTIVE BURNING TIME, SEC               00123600
C                                                                00123700
COMMON EMO,EMB,SPI,FC,BRATE,DELT,TO,TR,ISW,V,THETA,FFCTR,CALSQ,  00123800
1 VW,VCW,ALT,R,IEND,CHACH,REYNLD,RESIS,CAL,DLONG,IOPTY,YAW,AMOM,  00123900
2 HMOM,PSI,WTAREA,ISEP,NABLE,IGLIDE,ISWING,TENABL,AVTHD,CDEFL,  00124000
3 MMCSW,TMOMMC                                                  00124100
IF (TIME.LE.TO) GO TO 1                                         00124200
IF (TIME.LE.TO+DELT) GO TO 2                                     00124300
T2=TO+TB                                                         00124400
IF (TIME.LE.T2) GO TO 3                                         00124500
IF (TIME.LT.T2+DELT) GO TO 4                                     00124600
THRUST=0.                                                         00124700
XMASS=EMB                                                         00124800
RETURN                                                            00124900
1 XMASS=EMO                                                       00125000
THRUST=0.                                                         00125100
RETURN                                                            00125200
2 XMASS=EMO-BRATE*(TIME-TO)**2/(2.*DELT)                         00125300
THRUST=(TIME-TO)/DELT*FC                                         00125400
RETURN                                                            00125500
3 XMASS=EMO-BRATE*(TIME-TO-DELT/2.)                             00125600
THRUST=FC                                                         00125700
RETURN                                                            00125800
4 XMASS=EMO-BRATE*((TB-DELT/2.)+(TIME-T2)*(1.-(TIME-T2)/DELT/2.)) 00125900
THRUST=FC*(1.-(TIME-T2)/DELT)                                     00126000
RETURN                                                            00126100
END                                                                00126200

```

G LEVEL 21

IBURN

DATE = 77143

17/22/29

	FUNCTION IBURN(TIME,ALT,QE,VELO)	00126300
C		00126400
C	FUNCTION PRODUCES INDICATION OF COMMENCEMENT OF	00126500
C	BURNING--IBURN=1.	00126600
C	IBURN=0 UNTIL BURN BEGINS	00126700
C	USER CHOOSES TO FROM CURRENT TIME OR ALT (ALTITUDE) OR	00126800
C	QE (LOCAL QUADRANT ELEVATION) OR VELO (VELOCITY)	00126900
	COMMON /SRCOM/TH	00127000
	DATA ALTMAX/30000./,VMIN/0.0/	00127100
	IF (TIME.GE.TM) GO TO 3	00127200
	IF (ALT.GE.ALTMAX) GO TO 3	00127300
	IF (VELO.LE.VMIN) GO TO 3	00127400
C	IF (QE.GT.45.0) GO TO 2	00127500
	IBURN=0	00127600
	RETURN	00127700
C	2 IF (QE.LT.46.0) GO TO 3	00127800
C	4 IBURN=0	00127900
C	RETURN	00128000
	3 IBURN=1	00128100
	RETURN	00128200
	END	00128300

```

BLOCK DATA                                00128400
DIMENSION TKA(11),TKDYAW(11),TKL(11),TKM(11),TKF(11),    00128500
1 TKT(11),TKH(11),TKS(11),TCP(11),TMACH(11)              00128600
DIMENSION TFMACH(4),ALTRMM(4),AALTRM(4),TCN(4,4),WTCN(4)  00128700
DIMENSION TCAD1(4),TCAD2(4),TDEL(4),TAT(4,4),WTAT(4)    00128800
COMMON/COFCOM/XCG,SMARG,EM,THID,PRNU ,ALTRIM,CNATRM,GLIDE,EPSTHE 00128900
1 ,STAFAC,YAWNU,TKA,TKDYAW,TKL,TKM,TKF,TKT,TKH,TKS,CPC,TMACH, 00129000
2 NARTBL,TFMACH,ALTRMM,AALTRM,TCN,WTCN,TCAD1,TCAD2,TDEL,TAT,WTAT 00129100
C**** DEFAULT VALUES FOR AERO DATA USED IN GLIDE CALCULATIONS 00129200
DATA TFMACH(1)/0.50/,TFMACH(2)/0.80/,TFMACH(3)/0.90/,TFMACH(4)/1./00129300
1,ALTRMM(1)/14.30/,ALTRMM(2)/14.00/,ALTRMM(3)/13.80/,ALTRMM(4)/13.600129400
2 0/,AALTRM(1)/0.0/,AALTRM(2)/5.0/,AALTRM(3)/10.0/,AALTRM(4)    00129500
3/15.0/,TCN(1,1)/0.0/,TCN(1,2)/1.10/,TCN(1,3)/2.10/,TCN(1,4)/3.10/,00129600
4TCN(2,1)/0.0/,TCN(2,2)/1.20/,TCN(2,3)/2.10/,TCN(2,4)/2.90/,    00129700
5TCN(3,1)/0.0/,TCN(3,2)/1.30/,TCN(3,3)/2.20/,TCN(3,4)/3.00/,    00129800
6TCN(4,1)/0.0/,TCN(4,2)/1.30/,TCN(4,3)/2.50/,TCN(4,4)/3.70/    00129900
DATA TCAD1/4.0,5.0,5.75,6.50/,TCAD2/5.0,5.0,4.5,4.0/,        00130000
1 TDEL/0.,5.0,10.0,15.0/,TAT/0.,0.,0.,0.,7.4,7.2,7.4,7.1,    00130100
2 12.1,11.8,11.6,11.3,17.7,17.2,17.1,17.1/                    00130200
END                                                                00130300

```

COPPERHEAD AERO DATA USED BY RODMAN LABS (MAY 77)

MACH NO	COEF DRAG	DRAG INCR
0.0	0.3250	0.0350
0.5000	0.3286	0.0374
0.7000	0.3300	0.0400
0.8000	0.3650	0.0390
0.9000	0.4420	0.0420
0.9400	0.4950	0.0850
1.0000	0.6120	0.1130
1.0400	0.6900	0.0670
1.1000	0.7107	0.0943
1.1500	0.7280	0.0770
1.3000	0.7280	0.0770
2.0000	0.6480	0.1570

IGLIDE 1 IDFUFO 0 MCMCSW 1 16.5000 TOMMC (S) GLIDE (D) EPSTHE (D) 0.0

MACH NO	MAX TRIM (D)
0.50000	14.30000
0.80000	14.00000
0.90000	13.80000
1.00000	13.60000

NORMAL FORCE COEFS AT TRIM ATTACK

MACH NO	TRIM ATTACK (D): 0	5	10	15	THRUST DRAG FACTOR =	AIR DENS FACTOR =
0.50000	0.0	1.10000	2.10000	3.10000	1.0000	1.0000
0.80000	0.0	1.20000	2.10000	2.90000		
0.90000	0.0	1.30000	2.20000	3.00000		
1.00000	0.0	1.30000	2.50000	3.70000		

ENABLE TIME = 100.0000

SPECIAL COPPERHEAD GLIDE FLIGHT FOR ROD. LABS. 20 MAY MV=1538 F/S

FFCTR	VO	MO	MB	D
0.970000	1538.00000	137.199997	137.199997	155.000000
QUAD ELEV	TM STEP	THRUST	SP IMPULSE	V-WIND
22.500000	0.200000	0.0	0.0	0.0
INIT ALT,FT	TERM ALT,FT	VEL XWIND,FT/S	RWC	XWC
4010.00000	4010.00000	0.0	0.0	0.0

VHXF = 0.0 FT/SEC VHYF = 0.0 FT/SEC

THRUST RISE TIME = 0.0 SEC TM = 200.0000 SEC

SPECIAL COPPERHEAD GLIDE FLIGHT FOR ROD. LABS. 20 MAY MV=1538 F/S

TIME SECS	X,M	HAG,M	Z,M	XDOT,M/S	YDOT,M/S	V,M/S	MACH NO.	DRAG,LB	THETA,D	PITCH,D	DELTA,D	BODYA,D	DTHEAD/S
0.0	0.0	0.0	0.0	433.1	179.4	468.8	1.40	-352.55	22.50	0.0	0.0	0.0	0.00
2.000	823.1	322.0	-0.0	391.6	143.6	417.1	1.25	-274.45	20.13	0.0	0.0	20.13	-1.26
4.000	1572.0	577.7	-0.2	358.6	112.7	375.9	1.13	-214.97	17.45	0.0	0.0	17.45	-1.42
6.000	2262.1	775.8	-0.3	332.5	85.6	343.4	1.03	-164.83	14.44	0.0	0.0	14.44	-1.58
8.000	2907.0	922.9	-0.6	313.6	61.7	319.6	0.96	-112.29	11.14	0.0	0.0	11.14	-1.72
10.000	3519.9	1024.6	-0.8	299.9	39.9	302.6	0.91	-84.74	7.58	0.0	0.0	7.58	-1.84
12.000	4108.5	1083.9	-1.1	289.0	19.2	289.6	0.87	-71.03	3.80	0.0	0.0	3.80	-1.93
14.000	4676.6	1102.7	-1.3	279.5	-0.7	279.5	0.84	-62.35	-0.14	0.0	0.0	-0.14	-2.01
16.000	5226.9	1082.4	-1.5	271.0	-19.9	271.7	0.82	-56.38	-4.21	0.0	0.0	-4.21	-2.06
18.000	5761.0	1024.2	-1.8	263.3	-38.7	266.1	0.80	-52.45	-8.35	0.0	0.0	-8.35	-2.09
19.700	6203.3	945.7	-1.9	257.1	-54.2	262.7	0.79	-50.87	-11.90	0.0	0.0	-11.90	-2.09
20.700	6458.6	887.3	-2.0	253.6	-65.8	261.3	0.78	-50.38	-13.92	0.86	0.60	-13.06	-1.62
21.700	6710.7	821.5	-2.1	250.7	-69.1	260.0	0.78	-55.64	-15.41	1.36	0.95	-14.05	-1.34
22.700	6959.9	750.4	-2.2	248.0	-73.2	258.6	0.78	-55.16	-16.45	2.40	1.66	-14.05	-0.78
23.700	7206.7	676.2	-2.2	245.8	-75.4	257.1	0.77	-54.70	-17.06	3.01	2.08	-14.05	-0.46
24.700	7451.5	600.5	-2.3	243.8	-76.5	255.6	0.77	-54.23	-17.42	3.37	2.33	-14.05	-0.28
25.899	7742.9	508.6	-2.3	241.8	-77.0	253.8	0.76	-53.67	-17.67	3.62	2.50	-14.05	-0.15
27.899	8223.3	355.1	-2.3	238.7	-77.0	250.8	0.75	-52.76	-17.87	3.82	2.64	-14.05	-0.07
29.899	8697.8	202.3	-2.3	235.8	-76.5	247.9	0.74	-51.90	-17.97	3.92	2.71	-14.05	-0.04
31.899	9166.7	50.6	-2.3	233.1	-75.9	245.2	0.73	-51.08	-18.03	3.98	2.74	-14.05	-0.03
32.562	9320.8	0.0	-2.2	232.3	-75.7	244.3	0.73	-50.82	-18.04	3.99	2.75	-14.05	9320.83

MAX PROJ VELOCITY = 1537.9995 F/S MAX RANGE = 5.0328 NAUT MILES MAX ALT = 2324.9587 METERS

SPECIAL COPPERHEAD GLIDE FLIGHT FOR ROD. LABS. 20 MAY MV=1538 F/S
 QE= 22.5 DEG, VO=1538.0 F/S

8 8 JUN 1977

MEMORANDUM FOR RECORD

SUBJECT: Information for SHAPE Technical Center Relative to ZOT.14/
ZOT.15

1. Reference is made to Technical Note, DRSAR/SA/N-58, Description of a Computer Program (ZOT.14) for Guidance Simulation of Cannon-Launched Guided Projectiles (AD #A036663), Jan 77.
2. DRSAR-SA is preparing, for transmittal to SHAPE Technical Center, a set of data including the source program for ZOT.15, the guidance simulation program currently used by DRSAR-SAM. This memorandum provides a guide to use of this program.
3. User information required for use of this program may be classified as (a) information relative to conversion of the source from IBM S-360 extended FORTRAN to ANS FORTRAN for UNIVAC, and (b) methodological background with input/output descriptions.
4. Relative to the first category (conversion), the following items need be pointed out:
 - a. Precision need not be double in the UNIVAC version due to longer word length. IMPLICIT statements are to be deleted, and variables declared simply REAL or INTEGER.
 - b. Certain I/O formats will require change--fields specified as D should be changed to E, literal (Hollerith) fields should be rewritten in H-format (the "quote" format has been used), and the lengths of some A-formatted fields may require change (A8 has been used).
 - c. Numeric literals (constants) written D-format throughout the program should be changed to E- or F-format as required.
 - d. Multiple-entry subroutines may not be allowed. If not, such a subroutine may be separated into several subroutines sharing common storage, or alternatively, may be converted to a single-entry subroutine with a parameter in the call list specifying which segment is to be performed (DODGER is an example).
 - e. Subroutine RANDMM is the pseudo-random number generator used in this program. It is a slight re-code of RANDU of the IBM S-360 Scientific

8 2 JUN 1977

DRSAR-SAM

SUBJECT: Information for SHAPE Technical Center Relative to ZOT.14/
ZOT.15

Subroutine Package (SSP). This code is applicable only to the 360 and must be replaced by code applicable to whatever machine is to be used.

5. Relative to the second category (methodology and I/O), the referenced technical note provides the basis for understanding the present program. The key difference between the two programs is in subroutine TRACK, which was totally changed, in order to provide a more faithful representation of the logical states of the seeker. Other changes are generally of the nature of an added option. These are discussed in the input guide, attached (Incl 1), which also describes the input data required to run the program.



RICHARD D. HEIDER
Operations Research Analyst
Methodology Division
Systems Analysis Directorate

1 Incl
as

USER'S INPUT GUIDE TO ZOT.15

The following input list is provided as an amendment to the corresponding list found in Appendix A of the tech note referenced in the body of this memorandum.

CARD 1: Identical to CARD 1 of ZOT.14

CARD 2: Identical to CARD 2 of ZOT.14

CARD 3: Identical to CARD 3 of ZOT.14

CARD 4, required, format (8F10.0), contents by field:

(1) THETGY elevation angle of gyro (optical) axis [deg], ignored unless IGLIDE is equal to 2 (see CARD 9)

Remaining fields are not used.

CARD 5: First seven fields identical to corresponding fields of CARD 4 of ZOT.14. Field (8) contains

(8) CANT gyro (optical) axis cant or lookdown angle [deg], applicable to ballistic mode. (Do not use this variable to account for hangoff as suggested with ZOT.14, since this effect is now properly modeled.)

CARD 6: Identical to CARD 5 of ZOT.14

CARD 7: Identical to CARD 6 of ZOT.14

CARD 8, required, format (8F10.0), contents by field:

(1) CSMA1 as in ZOT.14

(2) CSMA2 as in ZOT.14

(3) ROLRAT as in ZOT.14

(4) CTERM control parameter--specify 0.0 to terminate the run upon any impact for which acquisition had failed to occur; specify 1.0 to continue the run to the next replication regardless.

(5) TMAX control variable--specify 0.0 to exercise the internally-defined time limit (standard with ZOT.14); specify a positive clock time [sec] (greater than maximum expected impact time) to exercise option of user-specified time limit.

(6) KLDOT as in ZOT.14 except that it is now applicable to both glide and ballistic modes.

Incl 1

(7) GSBAR range of gimbal angle (abs. val.) within which the gimbal saver output is zero [deg]

(8) KGS gain of gimbal saver [dimensionless]

CARD 9, required, format (7F10.0, 2I2, 2I3), contents by field:

(1-7) identical to corresponding fields of CARD 8 of ZOT.14

(8) IGLIDE projectile mode control parameter--0 for ballistic, 1 for glide trim, 2 for attitude-hold with user-specified attitude. Note: 1 and 2 are both glide options-- IGLIDE = 1 causes projectile and gyro attitudes to be internally defined such that the initial acceleration of the projectile lateral to the velocity is zero (standard with ZOT.14), while IGLIDE = 2 causes projectile and gyro attitude to be as specified by THETGY on CARD 4

(9) ICAGE gyro cage control parameter for action of gyro after loss of acquisition--ICAGE = 0 for free gyro or 1 for caged gyro

(10) NLAST output option--NLAST = 0 to ignore, or 1 to 100 to average the positions of the last NLAST spots and compute and report the miss distance with respect to this average position in addition to the miss distance with respect to the nominal aimpoint (pitch, yaw, and modulus)

(11) NEWAER new aero option--specify 0 to use the aero tables currently stored (defined by BLOCK DATA, if this is the first run of the job, or by input from a previous run), or specify 1 if any changes are to be made.

CARD 10, optional, format (16I5), contents by field:

(1) N1 option parameter for vector VMACH--N1 = 0 for no change, N1 = 1 thru 7 for a changed vector VMACH having NMACH = N1 elements

(2) N2 similar parameter for VMCAO, NMCAO

(3) N3 similar parameter for VDELTA, NDELTA

(4) N4 similar parameter for VALPHA, NALPHA

(5) I1 option parameter for table TKA--I1 = 0 for no change, 1 for change

- (6) I2 similar parameter for TCNA
- (7) I3 similar parameter for TCND
- (8) I4 similar parameter for TCAD
- (9) I5 similar parameter for TXSM
- (10) I6 similar parameter for TCA0

Remaining fields are not used.

CARDS 11-i, optional, format (8F10.0), contents: Each vector or table for which a change is required is punched in the order of mention in the above description of CARD 10; each vector or table begins a new card; for tables TKA and TCNA, mach number varies before varying alpha or delta, as appropriate. See the listing of subroutine AEROIN for further information on using this option.

CARD 12: Identical to CARD 9 of ZOT.14

CARD 13: Identical to CARD 10 of ZOT.14

CARD 14: Identical to CARD 11 or ZOT.14

CARD 15, required, format (8F10.0), contents by field:

- (1) BMDIVG as in ZOT.14
- (2) AGCLD same as DYRANG of ZOT.14
- (3-7) identical to corresponding fields of CARD 12 of ZOT.14
- (8) KC gyro electrical cage gain [sec^{-1}]

CARD 16, required, format (8F10.0), contents by field:

- (1) AGCSR max rate [db/pulse] at which detector automatic gain control (AGC) can shift (up or down)
- (2) WLE nominal width of leading edge of detector glimpse gate [microsec]. This is the time between opening of the gate and expected arrival of the pulse from the target.
- (3) WGATE(1) width of gate during correlation sequence [microsec]. Time from opening to closing of gate if no pulse is received.
- (4) WGATE(2) width of gate after correlation is established (during tracking).

- (5) WTRUNC time from reception of first pulse in gate to gate closure [microsec]. Supersedes closure time scheduled by WGATE
- (6) GATESR max rate [microsec/pulse interval] at which the leading edge (opening) of the glimpse gate can be shifted relative to nominal pulse period.
- (7) SLOPE slope of intrapulse dynamic threshold [db/microsec]
- (8) not used

CARD 17, required, format (8F10.0), contents by field:

- (1-5) identical to corresponding fields of CARD 13-1 of ZOT.14
- (6) XINCR if CRELOC = 0.0, XINCR is the x-wise increment as defined for ZOT.14; if CRELOC = 1.0, XINCR is the standard deviation of a circular-normal distribution of target locations [m;ft]
- (7) ZINCR if CRELOC = 0.0, ZINCR is as defined for ZOT.14; if CRELOC = 1.0, XINCR is a positive odd integer value used as the seed for random target relocation (number of digits should be less than the number of significant decimal places allowed by machine word size for a real variable of the precision used).
- (8) CRELOC option code as explained above.

CARD 18: Identical to CARD 13-2 of ZOT.14

CARD 19: Identical to CARD 14 of ZOT.14

CARDS 20: Identical to CARDS 15 of ZOT.14

CARD 21, optional, format (8F10.0)--used only when MODESM = 3--contents by field:

- (1) RDB distance [m] from designator to nearest point of background, which is modeled as a vertical plane of infinite extent
- (2) AZDB azimuth [deg] from designator to the same point
- (3) AZDES azimuthal direction [deg] of designator's beam
- (4) ELDES elevation [deg] of the same
- (5) REFL2 reflectivity of background

CARD 22: Identical to CARD 16 of ZOT.14

CARD 23, optional, format (9X,5F8.2)--used only if MODESM = 2 or 3, then NSPOTS cards required--contents by field:

- (1) YV(1) as in ZOT.14
- (2) YV(2) as in ZOT.14
- (3) YV(3) as in ZOT.14
- (4) CROSS same as BRITE of ZOT.14
- (5) PCTEBG percent of beam energy spilling over onto background.

This completes the data deck.

Next page is blank.

8 JUL 1977

MEMORANDUM FOR RECORD

SUBJECT: Computer Simulation Study of the Relationship of the COPPERHEAD Footprint to Ceiling and Gun-to-Target Range

1. References:

- a. Conversation between Mr. George Schlenker, DRSAR-SAM, and COL Robert Nulk, DRCPM-CAWS-GP, 24 Mar 77, subject as above.
- b. Memorandum for Record, DRSAR-SAM, 31 Jul 76, subject: Computer Simulation Study of COPPERHEAD (CLGP) for Guidance Accuracy and Footprint.
- c. Technical Report, Rodman Lab, R-TR-77-007, Jan 77, title: A Comprehensive Digital Flight Simulation of the Cannon Launched Guided Projectile.

2. Introduction.

This memorandum documents a study performed by the undersigned, with the guidance of G. Schlenker, during Apr-Jun 77 at the request of COL Nulk (Ref 1a), to further explore the dependence of footprint size upon the ceiling and the gun-to-target range (GTR). The most recent previously-developed estimates of footprints for COPPERHEAD (Ref 1b) included two levels of ceiling (3000 and 2000 feet) and three GTR's (6, 12, 18 kilometers). The intent of this study was to generate footprints for unlimited ceiling and for ceilings from 3000 feet to zero, by decrements of 500 feet, for the same set of three GTR's. At the same time, certain of the projectile's design parameters were to be updated, in order that the estimates might be as current as possible.

3. Parameter Changes.

Many of the seeker and autopilot parameters were altered since the previous study (Ref 1b). Those which one might expect to affect the footprint include: K_B , K_C , K_A , K_{GS} and \overline{GS} .* In addition, flight tests performed in Mar 77 indicated a larger drag coefficient than previously estimated.

*These parameters are:

K_B gain of g-bias computation circuit	K_{GS} gain of gimbal saver
K_C gain of gyro electrical cage circuit	\overline{GS} threshold of gimbal saver
K_A gain of attitude-hold circuit	

DRSAR-SAM

SUBJECT: Computer Simulation Study of the Relationship of the COPPERHEAD Footprint to Ceiling and Gun-to-Target Range

4. Procedures.

a. Zoning Solutions

The EXBAL exterior ballistic program was used to generate unguided trajectories for the projectile using new aerodynamic drag estimates. From this set, appropriate trajectories for the three GTR's were selected (Table 1).

b. Footprint Definition

The ZOT.15 guidance simulation* was then used to generate the footprints shown in Figures 1-3 and listed in Table 2.

c. Experiments for Stretch Range Dependence

Further ZOT.15 experiments were performed to define the stretch range of COPPERHEAD, given the stated 12-km trajectory, as a function of ceiling and meteorological visibility. Results are displayed graphically in Figures 4 and 5.

Figure 4 shows the dependence upon visibility, and Figure 5 shows the dependence upon ceiling. For any given combination of ceiling and visibility, the stretch range is the lesser of the two stretch ranges indicated from these figures.

5. Analysis of Results.

Generally, the dependence of the footprint upon ceiling and upon GTR is similar to that seen previously (Ref 1b). For low ceilings, however, the size of the footprint shrinks extremely rapidly, due to the very short time available for proportional-navigation (PN) guidance. Note that the footprint has, for all practical purposes, vanished at the 1000-foot level. In fact, before reaching the 500-foot level, the footprint vanishes totally, because the time remaining to impact is insufficient for the seeker to sequence to PN guidance or to arm the warhead. The fly-to-seeker guidance (FTS) is inadequate for purposes of hitting the target; an interval of several seconds of PN guidance is essential.

The footprints generated during these experiments agreed well with those of Ref 1b except in the stretch, which is significantly reduced in

*This program is the successor to ZOT.14, documented in Technical Note DRSAR/SA/N-58 (AD# AO 36663), January 1977, Description of a Computer Program (ZOT.14) for Guidance Simulation of Cannon-Launched Guided Projectiles. The supplementary documentation for the current ZOT.15 is contained in MFR, DRSAR-SAM, 22 Jun 77, subject: Information for SHAPE Technical Center Relative to ZOT.14/ZOT.15.

DRSAR-SAM

SUBJECT: Computer Simulation Study of the Relationship of the COPPERHEAD Footprint to Ceiling and Gun-to-Target Range

each case. Further experiments were performed using ZOT.15 to identify the parameter responsible for the reduction, with the result that the gimbal-saver circuit was isolated as the cause. ZOT.15 estimates of miss distance vs range with and without the gimbal-saver are displayed in Figure 6. The reason for the degraded performance is that the gimbal-saver effectively reduces the navigation gain whenever the projectile axis is steered more than \overline{GS} away from the gyro axis.

6. Verification of Gimbal-Saver Effect.

It was desired to cross-check between simulation models on the validity of the effect of the gimbal-saver upon the stretch range as indicated by ZOT.15. Therefore, a series of runs of the Rodman six-degree-of-freedom model (Ref 1c) were made for DRSAR-SAM for a slightly different 12-km nominal GTR trajectory (Rodman aero being slightly different from that used in the preceding portion of this study). ZOT.15 matching runs were produced using exact-match inputs, with the results displayed in terms of miss distance vs range displayed in Figure 7. These results do verify the existence of the effect of the gimbal-saver, but there is a disagreement between the two simulation models as to the stretch point, which is presently unexplained. However, there is adequate agreement between these models as to the tuck point. Further analysis* of differences is required.

7. Conclusions and Recommendations.

a. For ceilings much below 2000 feet, an adequate footprint is not achievable using the desired 20-degree glide; a shallower glide might provide the required footprint, but one must accept decreased lethality if that approach is taken. Trade-off studies along this line are recommended.

b. The effect of the gimbal-saver requires further study, preferably using all available flight models. Based upon the results of this study, I recommend a review of the choice of the parameter values of the gimbal-saver with a view to restoring the gimbal-saver to its original design or its possible elimination.

*Additional runs would be required of the Rodman model, but at present the turnaround would be excessive due to the demands imposed by the transfer-of-function process currently underway.

SIGNED

9 Incl
1-7. Figures
8. Table 1
9. Table 2

RICHARD HEIDER
Operations Research Analyst
Methodology Division
Systems Analysis Division

Figure 1
Footprints for 6 Kilometer
Nominal Gun-Target Range
DRSAR-SAM April 1977

CEILING
(ft)

2500 +
2000

1500

1000

BIP

Incl 1

DEFLECTION (km) →

RANGE (km) →

9

8

7

6

0

76

1

2

5

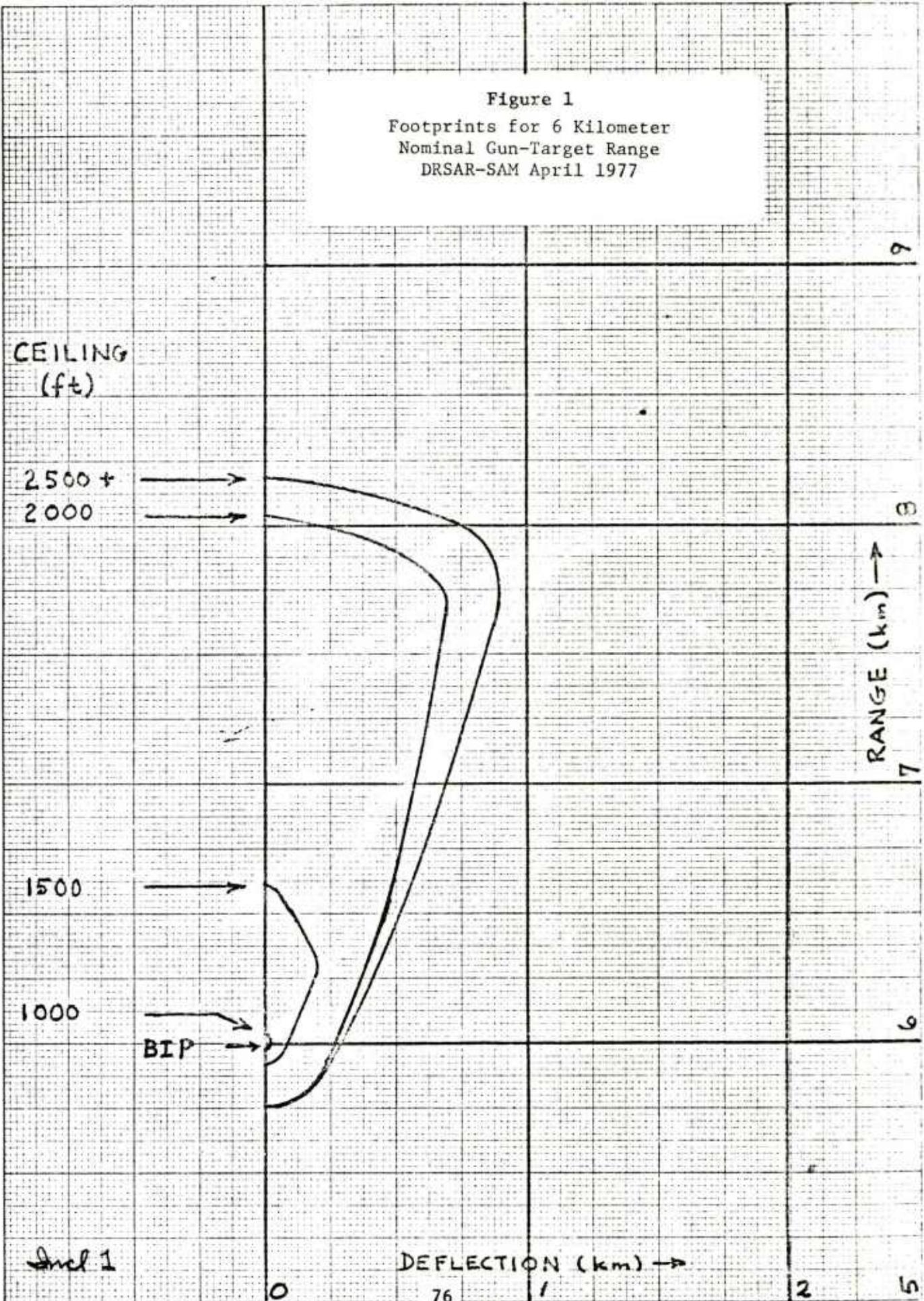


Figure 2
Footprints for 12 Kilometer
Nominal Gun-Target Range
DRSAR-SAM April 1977

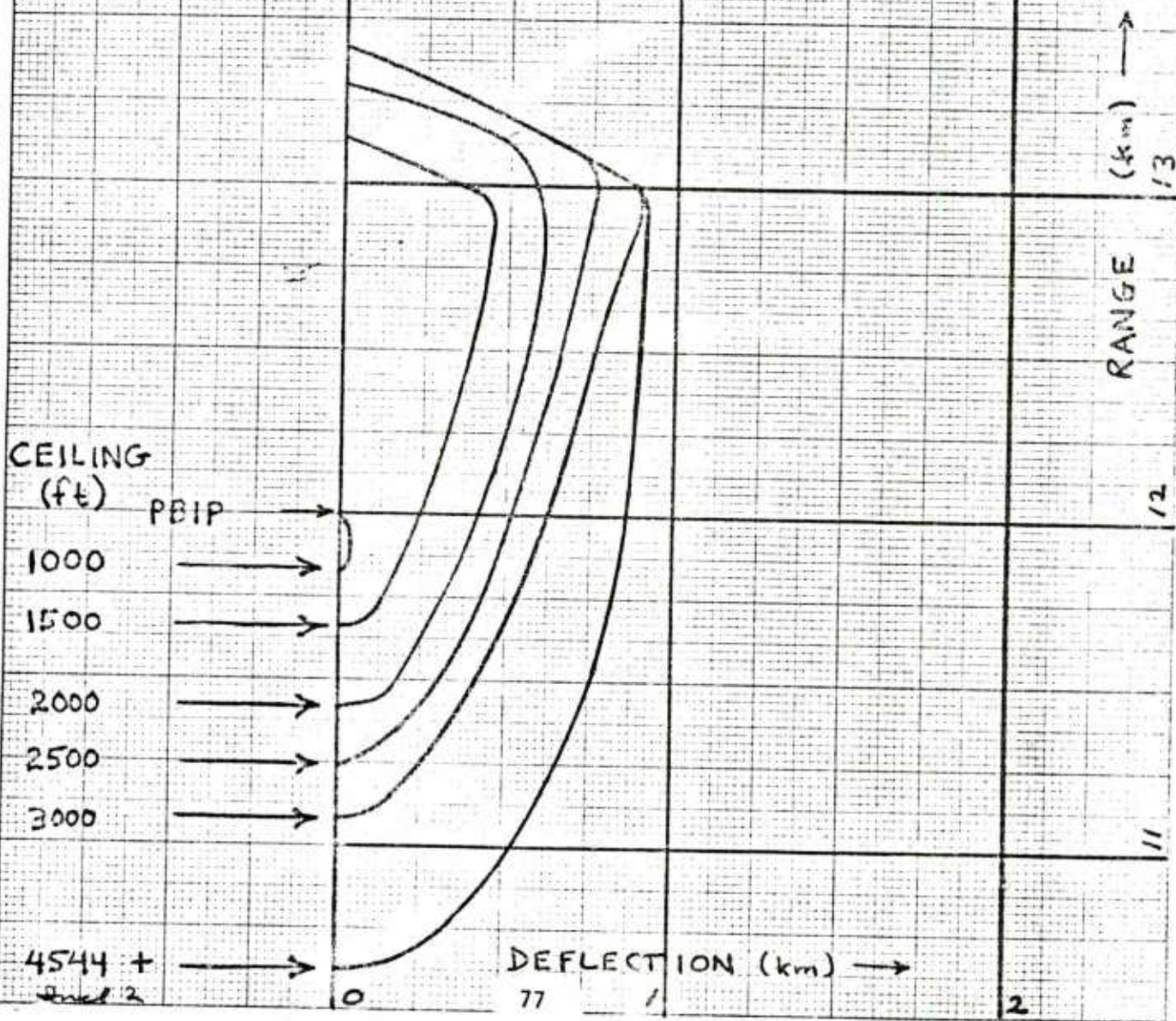
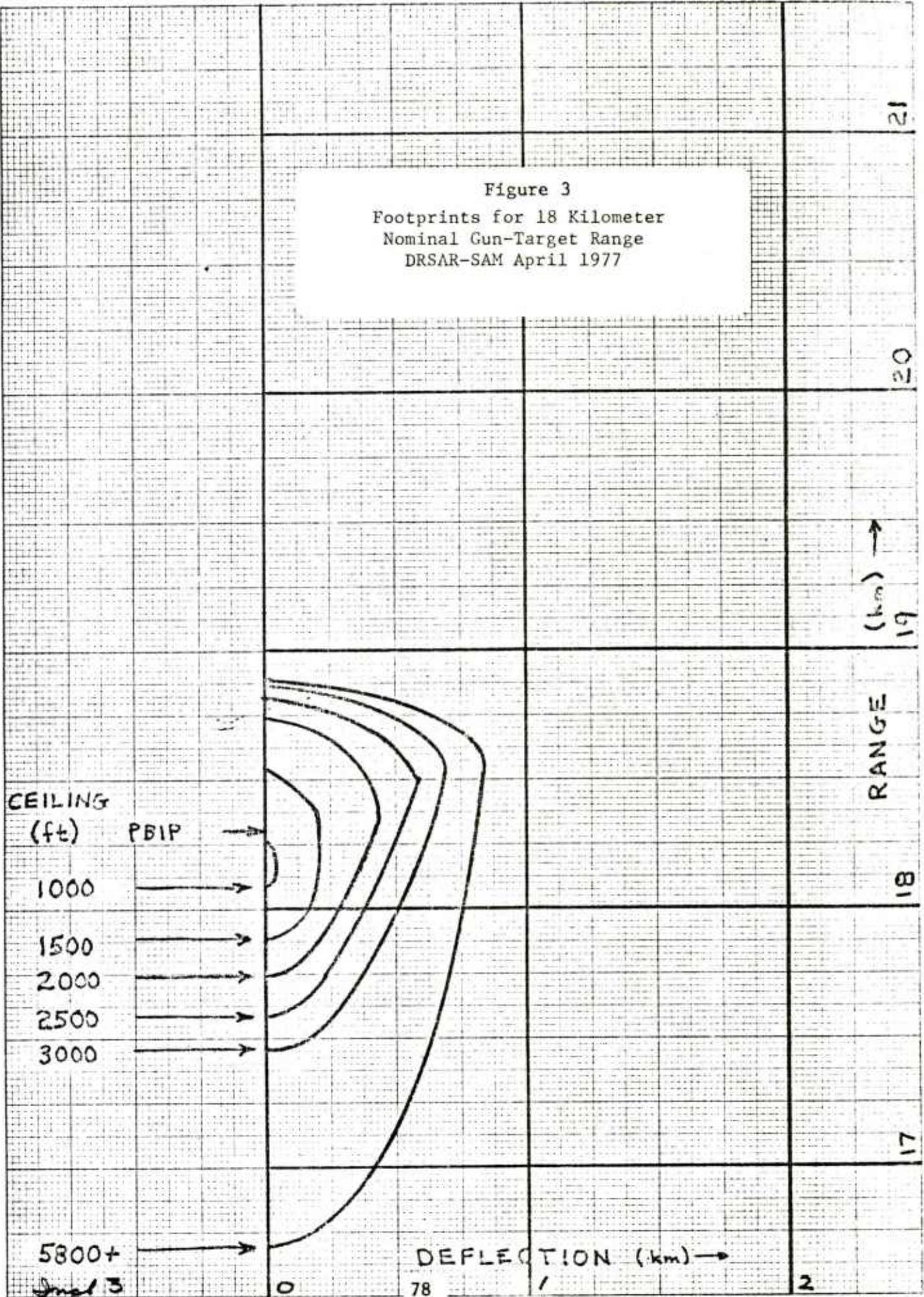


Figure 3
Footprints for 18 Kilometer
Nominal Gun-Target Range
DRSAR-SAM April 1977



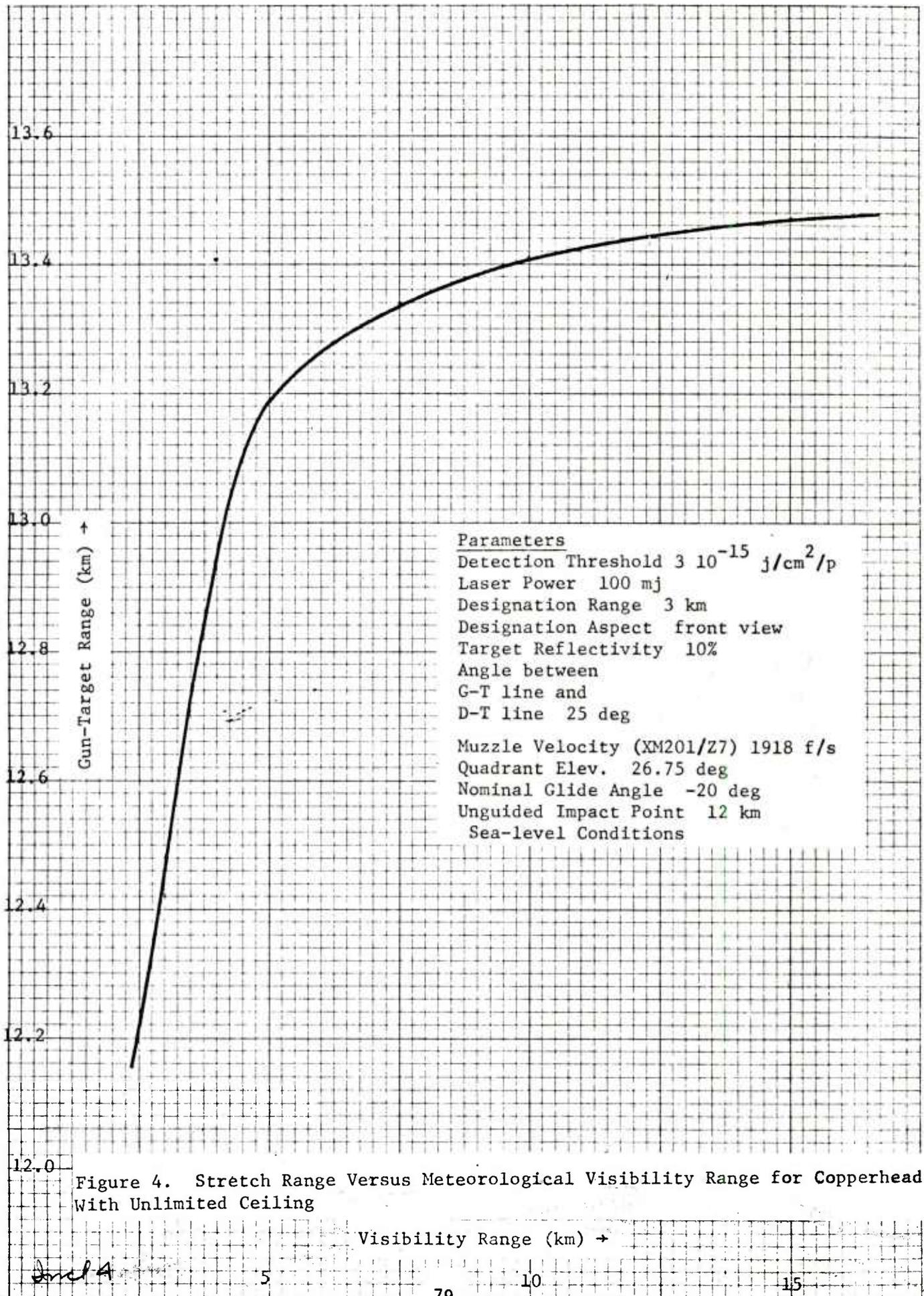


Figure 4. Stretch Range Versus Meteorological Visibility Range for Copperhead With Unlimited Ceiling

Incl A

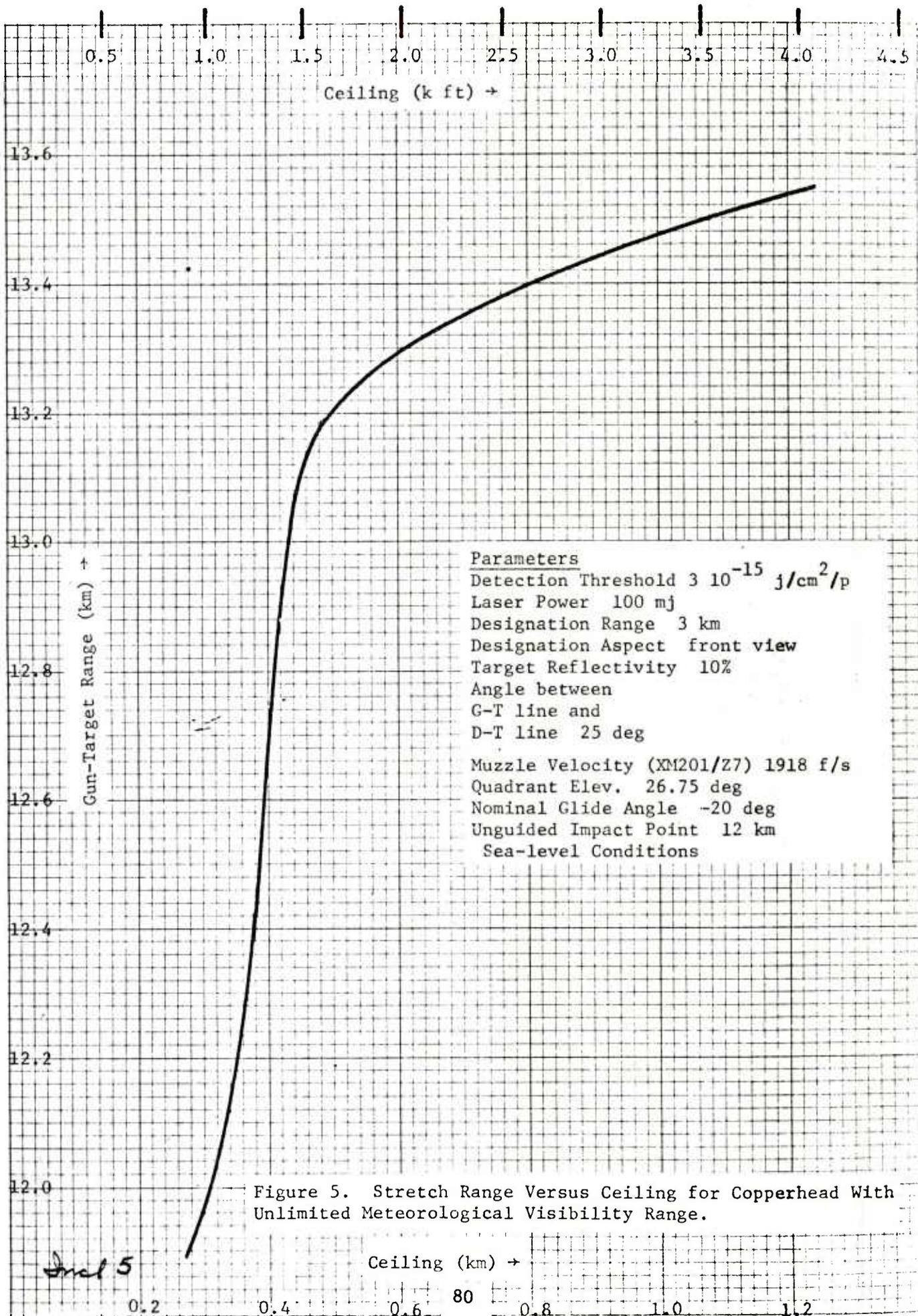


Figure 5. Stretch Range Versus Ceiling for Copperhead With Unlimited Meteorological Visibility Range.

Incl 5

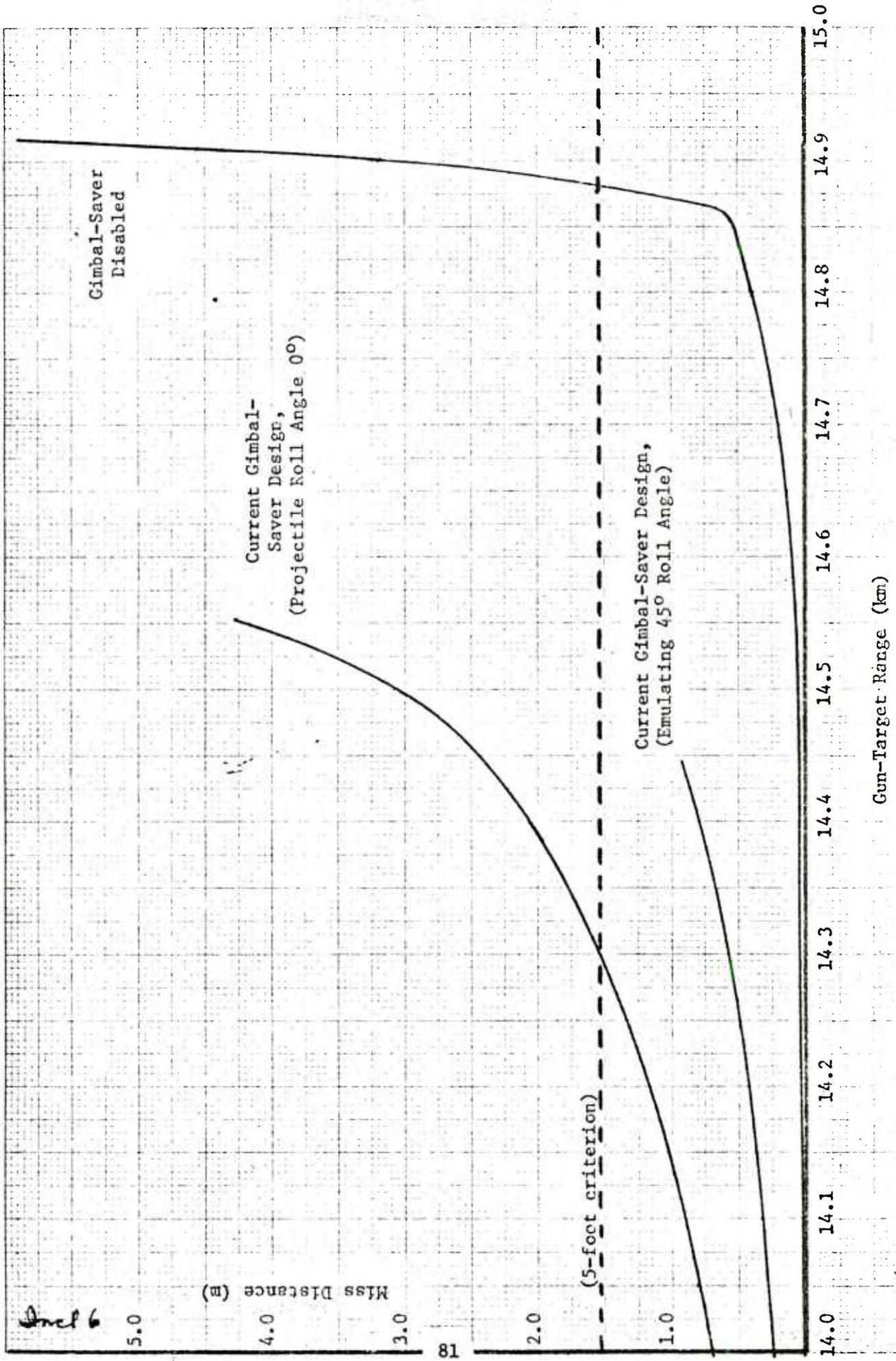
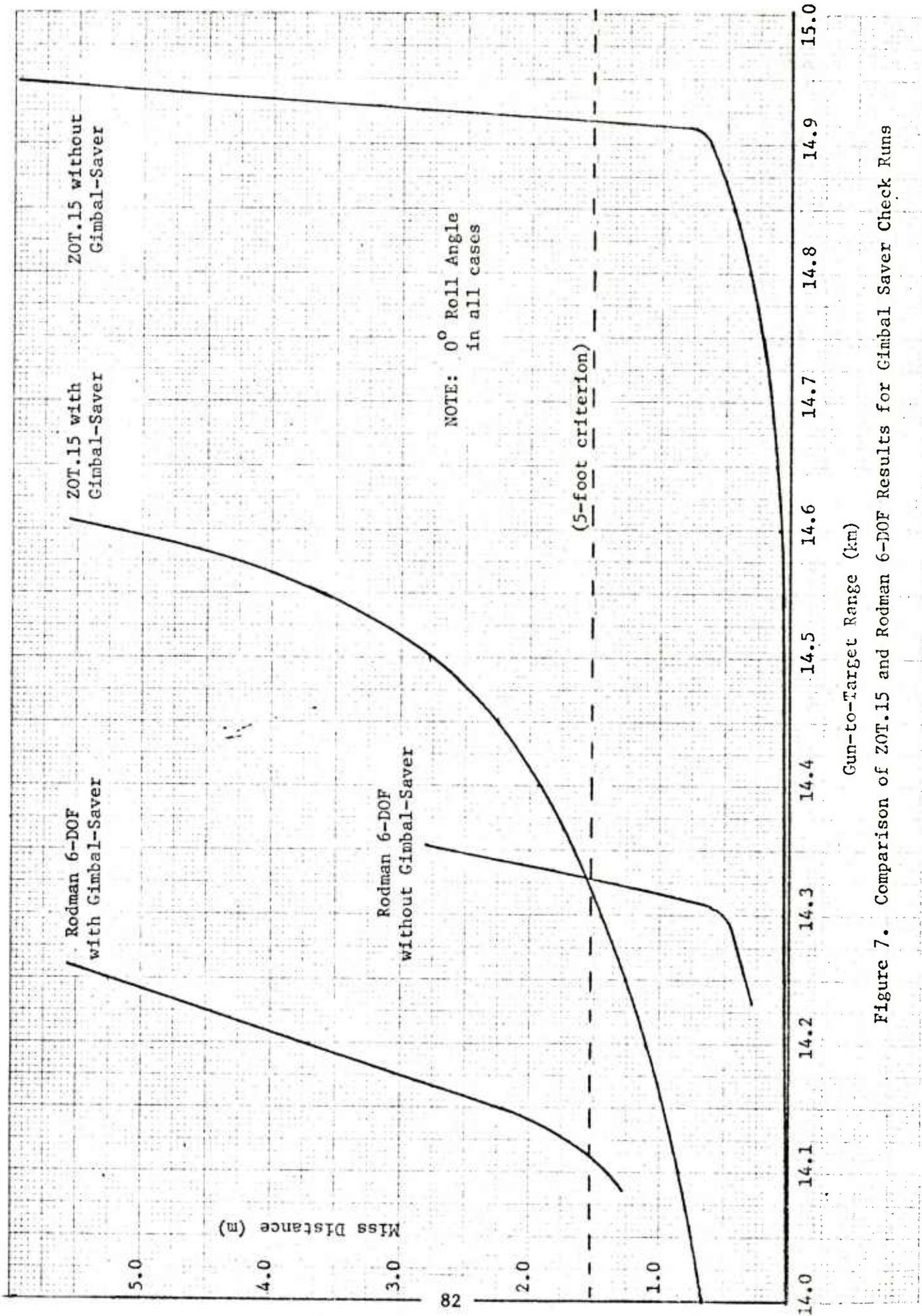


Figure 6. ZOT.15 Estimates of Miss Distance vs Gun-to-Target Range as a Function of Gimbal-Saver Characteristics

Incl 6



NOTE: 0° Roll Angle
in all cases

(5-foot criterion)

Figure 7. Comparison of ZOT.15 and Rodman 6-DOF Results for Gimbal Saver Check Runs

Incl 8

TABLE 1
SCENARIO FOR DR SAR-SAM APRIL 1977 FOOTPRINTS

GROUND PLANE ALTITUDE	SEA LEVEL
VISIBILITY RANGE	10 KM
PRECIPITABLE WATER VAPOR CONCENTRATION	7.84 MM/KM
LASER POWER	100 MJ/PULSE
DESIGNATION RANGE	3 KM
DESIGNATION ASPECT	FRONT VIEW (0°)
GUN-TARGET-DESIGNATOR ANGLE	25°
GUN-TARGET RANGES	6, 12, 18 KM
MUZZLE VELOCITY	1061, 1918, 1918 FPS
QUADRANT ELEVATION	26.0, 26.75, 44.0°
GLIDE ANGLE (NOMINAL)	(BAL.), -20, -20

PROJECTILE DESIGN - CURRENT (APR 77) EXCEPT DRAG INCREASED OVER
WIND TUNNEL RESULTS PER MAR 77 TEST FIRINGS

Incl 9

TABLE 2
FOOTPRINT AREAS (sq KM)

CEILING (FT)	NOMINAL GTR (KM)		
	6	12	18
500	0	0	0
1000	0.00	0.02	0.02
1500	0.18	0.91	0.21
2000	2.21	1.65	0.61
2500	2.92	2.23	0.96
2700+	2.92	---	---
3000	2.92	2.70	1.37
4544+	2.92	3.93	---
5800+	2.92	3.93	2.72

07 JUN 1977

MEMORANDUM FOR RECORD

SUBJECT: Scranton Billet Crane Simulation

1. After the Scranton billet crane simulation project was completed in August 1976, Chamberlain Manufacturing Corporation obtained a copy of the report and wrote a letter to ARRCOM listing their objections to the assumptions made in the study. The letter was forwarded to this office for comments. Several of their objections were judged valid. At the request of DRSAR-IMB changes were made in the program and the simulation was rerun to answer the valid objections. This memo details the changes made and the analysis performed.

2. In summary, the simulation results indicate that the 200 feet-per-minute maximum velocity recommended by the Corps of Engineers for the Scranton AAP billet crane is adequate.

3. The following new information was supplied by DRSAR-IMB:

a.	<u>billet size</u>	<u>mult wt.</u>	<u>number mults/mo.</u>
	5 1/4"	107 lbs	147,000
	6 3/4"	172 lbs	21,000
	7 3/8"	220 lbs	63,000

b. An automatic squaring table is being procured.

c. The crane has a hoist speed of 90 ft/min.

d. The maximum stacking height is 15 ft.

4. The following information was obtained from Chamberlain's letter or from phone conversations with Mr. Bernie White, Scranton AAP:

a.	<u>billet size</u>	<u>billet weight</u>	<u>number billets/ht</u>	<u>no. billets per charge</u>
	5 1/4"	1874 lbs	170	10
	6 3/4"	3091 lbs	103	8
	7 3/8"	3698 lbs	87	6

7 JUN 1977

- b. The average load per rail car is 60 tons.
- c. There are 500 work hours per month, including coffee and shift breaks.
- d. Rail car delivery is restricted to 16 hours per day.
- e. Breaker line capacity is 340 mults/line/hr.

5. The following is an explanation of the changes made in the assumptions and data inputs used by the simulation. Most of the data used in the simulation was collected at the time of the original study.

a. Assumption 5. Billets are stored and charged into the feeders in heats which are assumed to be groups of 170, 103, and 87 each for 5 1/4", 6 3/4", and 7 3/8" billets, respectively.

b. Assumption 12. The crane operator has sufficient skill and is allowed to operate the crane at maximum speed. He could, thus, begin x and y movement of the crane simultaneously, after lifting the load above the rail car sides or bay stock-piles.

c. The random number generator has been changed to use a separate string of random numbers for each stochastic item. Therefore, the first six input cards contain 42 seeds in an 8110 format.

d. Item 1. Chamberlain states that under mobilization conditions they will work 500 hours per month, including coffee and shift breaks. Since there are 45 minutes of breaks plus 35 minutes for lunch per 8 hour shift, the actual number of work hours per month is:

$$(500 \text{ hr/mo}) \left(\frac{480 \text{ min/shift} - 35 \text{ min lunch} - 45 \text{ min break}}{480 \text{ min/shift} - 35 \text{ min lunch}} \right) = 449.44 \text{ hrs/mo}$$

The mean time between charges for the 5 1/4" billets is determined by:

$$\begin{aligned} \text{number of mults per billet} &= \frac{1874 \text{ lbs/billet}}{107 \text{ lbs/mult}} \\ &= 17 \text{ mults/billets} \end{aligned}$$

mean time between charges =

$$\frac{(17 \text{ mults/billet})(10 \text{ billets/chg})(449.44 \text{ hrs/mo})(60 \text{ min/hr})}{(147,000 \text{ mults/mo})}$$

$$= 31.19 \text{ min/chg}$$

7 JUN 1977

DRSAR-SAL
SUBJECT: Scranton Billet Crane Simulation

To create some manufacturing variability, it will be assumed that this 31.19 minutes between charges is the mean of a normal distribution having 95% of its area within 15% of its mean. Thus, the standard deviation is:

$$\sigma = \frac{(.15)(31.19)}{1.96}$$
$$= 2.39$$

Cut-offs are set at 3 std dev or 24.02 minutes and 38.36 minutes.

e. Item 2. The distribution of the time between charges for the 6 3/4" billet table is as follows:

$$\text{number of mults per billet} = \frac{3091 \text{ lbs/billet}}{172 \text{ lbs/mult}}$$
$$= 18 \text{ mults/billet}$$

mean time between charges =

$$\frac{(18 \text{ mults/billet})(8 \text{ billets/chg})(449.44 \text{ hr/mo})(60 \text{ min/hr})}{(21,000 \text{ mults/mo})}$$
$$= 184.91 \text{ min/chg}$$
$$\sigma = \frac{(.15)(184.91)}{(1.96)}$$
$$= 14.15$$

limits = 142.46 minutes, 277.36 minutes

f. Item 3. The distribution of the time between charges for the 7 3/8" billet table is as follows:

$$\text{number of mults per billet} = \frac{3698 \text{ lbs/billet}}{220 \text{ lbs/mult}}$$
$$= 16 \text{ mults/billet}$$

mean time between charges =

$$\frac{(16 \text{ mults/billet})(6 \text{ billets/chg})(449.44 \text{ hr/mo})(60 \text{ min/hr})}{(63,000 \text{ mults/mo})}$$
$$= 41.09 \text{ min/chg}$$

7 JUN 1977

DRSAR-SAL
SUBJECT: Scranton Billet Crane Simulation

$$\sigma = \frac{(.15)(41.09)}{1.96}$$
$$= 3.14$$

limits = 31.67 minutes, 50.51 minutes

g. Item 4. Since the arrival of heats is not affected by breaks, it must be based on the number of hours per month that the plant is operating:

$$(500 \text{ hr/mo}) \left(\frac{480 \text{ min/shift}}{480 \text{ min/shift} - 35 \text{ min lunch}} \right) = 539.33 \text{ hr/mo}$$

The mean time between arrivals of 5 1/4" heats is determined by:

$$\frac{(147,000 \text{ mults/mo})}{(17 \text{ mults/billets})} = 8647.06 \text{ billets/mo}$$

$$\frac{(8647.06 \text{ billets/mo})}{(170 \text{ billets/ht})} = 50.865 \text{ hts/mo}$$

$$\frac{(539.33 \text{ hrs/mo})(60 \text{ min/hr})}{(50.865 \text{ hts/mo})} = 636.19 \text{ min/ht}$$

Since most arrivals are Poisson, it will be assumed that this arrival is also Poisson distributed. Further, since these arrivals are not completely random, cut-offs at 3 standard deviations will be employed. For a Poisson distribution, the standard deviation is equal to the square root of the mean. Thus the limits are 560.52 and 711.86. Chamberlain indicated that rail cars are delivered during a 16 hour period each day and heats arriving during the remaining 8 hours are delayed. The program has been changed to delay any arrivals which occur in the last 8 hours of any 24 hour period.

h. Item 5. Arrival of 6 3/4" heats.

$$\frac{(21,000 \text{ mults/mo})}{(18 \text{ mults/billet})} = 1166.67 \text{ billets/mo}$$

$$\frac{(1166.67 \text{ mults/mo})}{(103 \text{ billets/ht})} = 11.33 \text{ hts/mo}$$

DRSAR-SAL
 SUBJECT: Scranton Billet Crane Simulation

$$\frac{(539.33 \text{ hrs/mo})(60 \text{ min/mo})}{(11.33 \text{ hts/mo})} = 2856.91 \text{ min/ht}$$

$$2856.91 \pm 3(2856.91)^{1/2} = 2692.56, 3017.26$$

Thus the limits are 2692.96 and 3017.26.

i. Item 6. Arrival of 7 3/8" heats.

$$\frac{(63,000 \text{ mults/mo})}{(16 \text{ mults/billet})} = 3937.5 \text{ billets/mo}$$

$$\frac{(3937.5 \text{ billets/mo})}{(87 \text{ billets/ht})} = 45.26 \text{ hts/mo}$$

$$\frac{(539.33 \text{ hrs/mo})(60 \text{ min/hr})}{(45.26 \text{ hts/mo})} = 715 \text{ min/ht}$$

$$715.00 \pm 3(715)^{1/2} = 634.78, 795.22$$

Thus the limits are 634.78 and 795.22.

j. Item 11. The time required to pick billets out of a rail car is entered as a triangular distribution having a minimum time of .40 minutes, a maximum time of 1.65 minutes, and a most-likely time of .90 minutes. This is an increase of 9 seconds to insure that the load is lifted clear of the car sides, i.e., to lift an additional 13.5 feet.

k. Item 15. The number of 5 1/4" billets picked out of a rail car per unit pick is entered as a triangular distribution having 1 as the minimum, 12 as the maximum, and 10 as the most-likely number of billets.

l. Item 16. The number of 6 3/4" billets picked out of a rail car is entered as a triangular distribution with 1, 8, and 6 as the minimum, maximum, and most-likely number of billets, respectively.

m. Item 17. The number of 7 3/8" billets picked out of a rail car is entered as a triangular distribution with 1, 8, and 6 as the minimum, maximum, and most-likely number of billets, respectively.

n. Item 22. The time required to pick billets off of the storage pile in the bays was entered as a triangular distribution, having a minimum time of .40 minutes, a maximum time of 1.15 minutes and a most-likely time

DRSAR-SAL
SUBJECT: Scranton Billet Crane Simulation

7 JUN 1977

of .65 minutes. This is an increase of 9 seconds to insure that the load can be lifted clear of the bay stacks.

o. Items 23-25. The number of 5 1/4", 6 3/4", and 7 3/8" billets picked off of a storage pile. Since the billets are not processed in any manner while in the storage bays, the distributions are assumed to be identical to items 15-17 respectively.

p. Item 29. DRSAR-IMB has indicated that automatic squaring tables are being procured. Therefore, the crane is not used for squaring and the time required is entered as a constant zero.

q. Item 36. The size of a typical 5 1/4" heat is entered as a constant 170 billets.

r. Item 37. The size of a typical 6 3/4" heat is entered as a constant 103 billets.

s. Item 38. The size of a typical 7 3/8" heat is entered as a constant 87 billets.

t. Item 39. The typical number of 5 1/4" billets on a rail car is entered as a constant 60 billets.

u. Item 40. The typical number of 6 3/4" billets on a rail car is entered as a constant 32 billets.

v. Item 41. The typical number of 7 3/8" billets on a rail car is entered as a constant 32 billets.

6. A bay priority scheme in which those bays which are closest to the work areas are used most, was established. This tends to minimize the overall distance traveled by the crane, and thus allows more time for other operations. The simulation was run three times with different seeds for the random number generators. Each run was for 400,000 minutes. The variation in travel, idle, and billet handling times from the three runs was determined, and in all cases the maximum variation was less than .5% of its mean. This indicates that 400,000 minutes is long enough to establish a steady state condition for the time percentages. The results of these runs indicate that the crane would be idle at least 33% of the time with a certainty of .995+. This does not include coffee, shift, and lunch breaks which constitutes an additional 16.66%. In addition, there is a .99 probability that the maximum lead times required to assure that the feed tables are never empty are 9.97 minutes, 8.92 minutes, and 8.83 minutes for the 5 1/4", 6 3/4", and 7 3/8" billet tables, respectively.

DRSAR-SAL

7 JUN 1977

SUBJECT: Scranton Billet Crane Simulation

7. A bad bay priority scheme, i.e., the bays which are used the most are located at the far end of the yard from the work areas, was then established and the simulation was again repeated three times. The variability between runs was less than 3% and the results indicate that the crane would be idle at least 9% of the time with a probability of .995+. The .99 probability lead times required by the feed tables are 11.13 minutes, 12.97 minutes, and 14.88 minutes for the 5 1/4", 6 3/4", and 7 3/8" billet tables respectively.

8. Chamberlain objected to the distributions used for the time between charges, because they did not allow for peaks of activity. Therefore, one run was made with these distributions changed to consist of a peak at the mean time between charges when the lines were operating at 340 mults-per-hour and a tail to the right to account for downtime. The results indicated that the idle time of the crane dropped from 33% to 31%. A single run was judged to be sufficient since the previous multiple runs had shown less than 3% variation in the results.

9. Additional sensitivity analysis was performed by varying the maximum speed of the crane. These runs were made with both good and bad bay priority schemes, normally distributed time between charges, and constant acceleration at 1 foot per second squared. The maximum velocity was varied from 80 feet per minute to 400 feet per minute, and the results are plotted in Figure 1. If a good bay priority scheme is used, then top speeds in excess of 200 feet-per-minute only increase the reserve capability from 33% to 41%. Figure 2 is a plot of the average speed of the crane as a percentage of its maximum speed. With a good bay priority scheme, the maximum usage of the crane's capabilities occurs at approximately 160 ft/minute and with a bad bay priority scheme, the maximum occurs around 240 ft/minute. Outside of this range, the percent utilization of the crane's speed capability drops off.

10. The third case reported in the original report, i.e., shock-loading the rail car queue with a month's supply of billets and determining the time required to unload it, was not performed since this is clearly a situation in which both cranes would be used and the computer model does not have provisions for simultaneous operation of the two cranes.

David Hoehn

DAVID HOEHN
Operations Research Analyst
Logistics Systems Analysis Division

Next page is blank.

DRSAR-SAA
DRSAR-MA
DRSAR-MM

Analysis of the Provisioning System
DRSAR-SA

7 JUN 1977

CPT Krueger/jls/6370

1. Reference:

- a. MFR, DRSAR-MA to DRSAR-SA, 9 Feb 76, subject: VADS PIP Provisioning.
- b. FONECONS between DRSAR-MM, Mr. Crouch, DRSAR-MA, Mr. Stehn, and DRSAR-SA, CPT Krueger, Mar 76 - Dec 76, subject as above.
- c. MFR, DRSAR-MM, 10 Mar 76, subject: Initial Provisioning.

2. The Systems Analysis Directorate was tasked (ref 1a) to analyze the provisioning system as applied at HQ, ARRCOM. The attached MFR (Incl 1) contains the analysis of the provisioning system. An estimate of the provisioning time was developed in March 1976 (ref 1b) and used to validate the developed simulation. A summary of the various time frames simulated is shown below:

<u>SIMULATION</u>	<u>DAYS</u>	<u>DIFFERENCE</u>
a. Current Process	265	-
b. Increase Provisioning Personnel	261	-4
c. Reduce DLSC and DSA/GSA Time	179	-86
d. LSA	235	-30
e. Combinatorial (b&d)	230	-30

The time estimates provided by provisioning and cataloging personnel (ref 1b and 1c) were used as input for the simulation. Even though the above changes to the current process show reductions in processing time, they should not be implemented until cost savings can be identified.

3. Point of contact is CPT Krueger, extension 6370.

1 Incl
as

~~DRSAR~~

M. RHIAN
Director, Systems Analysis Directorate

DRSAR-SAA

MEMORANDUM FOR RECORD

2 JUN 1977

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

1. Reference:

- a. Minutes of CG, ARRCOM Weekly Staff Meeting, 29 Jan 76.
- b. DRSAR-MA MFR to DRSAR-SA, subject: VADS PIP Provisioning, 9 Feb 76.
- c. Army Regulation 700-18, Provisioning of US Army Equipment, 21 Sep 73.
- d. Technical Manual 38-715-1, Provisioning Techniques, Oct 65.
- e. Commodity Command Standard System Operating Instructions, Vol 1, No. 18-700-13, Provisioning System, Oct 75.
- f. Standard Operating Procedure No. 700-MA-26, Commodity Command Standard System Provisioning System, 9 Dec 74.
- g. DRSAR-MM MFR, subject: Initial Provisioning, 10 Mar 76.
- h. Numerous FONECONS between Mr. Crouch, DRSAR-MM, Mr. Stehn, DRSAR-MA, and CPT Krueger, DRSAR-SAA, subject: Ref 1a, above, period of time - Mar 76 through Dec 76.
- i. SAO Note 2, "Secondary Items Administrative Lead Time Simulation Study, Mr. R. Banash, etal, June 74.
- j. Military Standard No. 1388-1, Logistical Support Analysis, 15 Oct 73.

2. Introduction. This Directorate was tasked initially (ref 1a) to analyze the VULCAN Air Defense System (VADS) Product Improvement Program (PIP) provisioning effort. This tasking was subsequently broadened to become an analysis of the overall provisioning system as applied at HQ, ARRCOM, (ref 1b).

3. Background. Provisioning is the process for determining and acquiring the range and quantity of support items (repair parts, special tools, technical manuals, etc) necessary to operate and maintain a weapon system for an initial period of service. Provisioning planning begins early in the life cycle of a new system or early in the design phase for product

DRSAR-SAA

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

improvements. However, adequate guidelines for starting this planning and establishing the sensitivity of the provisioning process to procedural factors in the system are unknown. The purpose of this study was to analyze and simulate the provisioning system as prescribed in references 1c-1g and perform a sensitivity analysis on identified system factors.

4. Methodology. The procedures for accomplishing provisioning actions were described in a procedural flow format utilizing major contributions from the Maintenance and Materiel Management Directorates (ref 1g and 1h). The network developed related activities and decision points within the provisioning process. This network was then simulated using the General Purpose Simulation System (GPSS) developed by the Science Research Associates, Inc., a subsidiary of IBM. The purpose of this step was to obtain an automated representation of the provisioning process in order to quantitatively assess the current process. After verification of the process simulation, proposed changes and identified problem areas were analyzed. All results have been rounded to whole days, and the days refer to calendar days.

5. Discussion of Data. No historical data existed for times to complete a provisioning process; however, a generalized time estimate was developed in March 1976 by the provisioning and cataloging personnel of the Maintenance and Materiel Management Directorates (ref 1g). This estimate was later refined (ref 1h). This refined estimate was used to verify the simulation results. It should be noted that this study covered the provisioning process from the point in time that the Maintenance Directorate receives the initial provisioning input from the developer until that point in time that all National Stock Numbers (NSN) are assigned. A separate study (ref 1i) simulated the administrative lead time (ALT) for the procurement of secondary items.

6. Current Process Analysis. The current process was simulated using the GPSS computer program. GPSS utilizes three basic entities: Facilities, Storages, and Queues. A facility is an entity that can handle only one transaction at a time, for example, the Configuration Control Board reviews only one Engineering Change Proposal at a time. A storage entity is one that can handle up to and including a specified number of transactions at one time, for example, the provisioning branch can handle as many transactions as it has personnel available. The final entity, Queues, is an entity in which a transaction waiting to enter a facility or storage resides until space is available for it to be processed.

These three entities were combined in a logical manner that described the actual flow process for provisioning transactions. The system simulation was allowed to reach a steady state to reflect the average number of days to complete a transaction. Table 1 compares the simulation results with the original March 76 estimate.

DRSAR-SAA

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

TABLE 1

Current Process

Simulation	265 (Calendar Days)
Estimate (March 1976)	239
Difference	26

The 26 day difference between the simulation result and the original estimate was discussed with the concerned representatives (ref 1h). It was concluded that the March 76 estimate did not fully allow for the time needed to correct errors noted when the Provisioning Master Data Record was received from the ALPHA system and reviewed. Also, the possible re-submission to the Defense Logistics Service Center (DLSC) and Defense Supply Agency/General Services Administration DSA/GSA for NSN's was not fully taken into account. It was felt, therefore, that the simulation run was a more viable time estimate and would serve as the standard against which the sensitivity analyses would be compared.

7. Sensitivity Analyses. The sensitivity of the following system factors to change was investigated.

a. Six unfilled positions in the Provisioning Branch of the Maintenance Directorate had been identified. The opinion was that this shortage created a backlog situation.

b. A reduction of the minimum required process time at DLSC (DSA/GSA) from 60 to 30 days was investigated.

c. Exclusive use of LSA, Logistical Support Analysis was investigated.

d. A combination of using LSA and increasing the number of provisioning to personnel by six was investigated.

No increase in the number of personnel in the Cataloging Division was considered since no unfilled positions were indicated and no queue time developed in the simulation that would indicate the possible need to increase personnel.

8. Sensitivity Results.

a. Increase of the Number of Personnel in the Provisioning Branch. The Chief of the Provisioning Branch reported six unfilled slots existed

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

within his organization. This fact, coupled with existence of Queue time for his organization, indicated that an increase in personnel may have a potential to decrease the provisioning time frame. The number of personnel for the Provisioning Branch was increased by six for this simulation run and no other changes were made to the simulation process. The results of the run are shown in Table 2.

TABLE 2

Increased Number of Provisioning Personnel

Current Process	265	(Calendar Days)
Increased Number	261	
Difference	4	

While the addition of six personnel to the Provisioning Branch did decrease the time frame by four days, it is doubtful that the additional personnel would be warranted. To further substantiate this, the increased number of personnel was varied from six down to two and the reduction in provisioning time was only changed from four days to three. The addition of only one person resulted in a reduction of approximately one day.

b. Reduction in DLSC and DSA/GSA Process Time. It was pointed out that DLSC and DSA/GSA are allowed 60 days to process requests for stock numbers. This is virtually a fixed time delay and if some stock number data were found to be in error, an additional 60 days would be allowed DLSC or DSA/GSA upon resubmission of the data. While a reduction in this time frame is not within HQ, ARRCOM's control, the results shown in Table 3 may assist in causing revision of this 60 day allowance. The reduction used in this simulation was a cut of one-half, 60 to 30 days, and all other portions of the simulation remained unchanged.

TABLE 3

Reduced Process Time DLSC and DSA/GSA

Current Process	265	(Calendar Days)
Reduced DLSC and DSA/GSA Time	179	
Difference	86	

The reduced times made a significant contribution to reducing the time required to properly provision a weapon system. If the 60 day limit is absolute, time still could be saved in provisioning if error resubmission could be placed in a category that waived the mandatory 60 day process time.

DRSAR-SAA

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

c. Logistical Support Analysis (LSA). A Logistical Support Analysis (LSA) was to be required on all newly developed weapon systems and major modifications. This requirement, however, is not being fully implemented because of some difficulties in the bridging program that converts the LSA input to the CCSS format, and because of the need to thoroughly familiarize personnel with the use of LSA, i.e., a developer (military and civilian) personnel and provisioning and cataloging personnel. The procedures to use LSA in the provisioning process were simulated and the results are shown in Table 4.

TABLE 4

Use of Logistical Support Analysis

Current Process	265 (Calendar Days)
LSA Process	235
Difference	30

The use of LSA is completely within ARRCOM's control to implement and training in the use of LSA is available. If cost savings can be identified with this 30 day reduction, then this alternative may warrant implementation.

d. Combinatorial. The use of LSA and an increase of six in the current number of provisioning personnel was simulated next. This combination was chosen because of the ability of HQ, ARRCOM to readily implement these changes.

TABLE 5

Combinatorial

Current Process	265 (Calendar Days)
Combinatorial	235
Difference	30

The results of this simulation run are identical with just using LSA. Further investigation revealed that the Provisioning Branch realized no queue time under just LSA procedures and the processes needed to conduct a provisioning effort still require the same amount of time. Thus, increasing the available number of personnel when no backlog exists would not create a reduction in time.

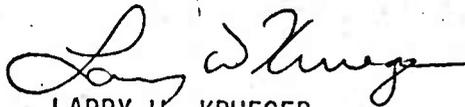
9. Summary. The above results indicate that the least effective means of reducing provisioning time frames is to fill all or a portion of the unfilled positions in the Provisioning Branch. The most effective means of reducing the provisioning time is to have DLSC and DSA/GSA's mandatory time frame reduced; however, this is not an immediate solution, since

DRSAR-SAA

JUN 19

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

it is an action required at DOD level. The combinatorial alternative is not a reasonable solution since the addition of personnel resulted in no change over using LSA alone. The most viable solution is to use LSA. To do this may require special effort to insure the bridging program problems are solved and that the largest possible number of personnel are trained to use LSA.



LARRY W. KRUEGER

CPT, OrdC

Systems Assessment Division

Systems Analysis Directorate

DRSAR-SAA
DRSAR-MA
DRSAR-MM

M551 Sheridan Wear-Out
DRSAR-SA

8 JUN 1977
CPT Krueger/jls/6370

1. Reference:

- a. DF w/incl, DRSAR-MA to DRSAR-SA, 1 Nov 76, subject: Trip Report - USAREUR Visit 11-25 Oct 76, DCG, Dir of Maintenance and Ch, DRSAR-MMP, Part II.
- b. Demand Return Disposal Files, 15 Dec 74 - 15 Dec 76.
- c. Order of Merit List, M551 Sheridan, 6 Oct 76.

2. The Systems Analysis Directorate was tasked (ref 1a) to conduct a failure rate analysis on European based Sheridans and additionally, to determine if the component buy policy for ARRCOM managed M551 Sheridan components and repair parts need to be revised to accommodate a rapidly increasing wear-out rate. As discussed in the attached MFR (Incl 1), no rapidly increasing wear-out rate was indicated. As a result, this study indicates that no alteration of the component buy policy is needed.

3. In regard to the processes for collecting data on parts demand history, two important changes need to be made. First, the Demand Return Disposal Files (ref 1b) only contain the past two years demand history. The number of years of demand history retained at HQ, ARRCOM on magnetic tapes needs to be extended to a minimum of at least four years. Second, the weapons codes (per AR 725-50) used in the DRD files are not used in Europe and are not a required entry of CONUS. The lack of these codes hinders the use of the DRD files as an accurate data base. The feasibility of making the use of those weapons codes prescribed in AR 725-50 a mandatory Army wide entry should be investigated.

4. Point of contact is CPT Krueger, extension 6370.

1 Incl
as

~~SECRET~~
M. RHIAN
Director, Systems Analysis Directorate

Incl 1

SMIF

DRSAR-SAA

MEMORANDUM FOR RECORD

SUBJECT: M551 Sheridan Wear-Out

1. Reference:

- a. DRSAR-MA DF w/incl to DRSAR-SA, 1 Nov 76, subject: Trip Report - USAREUR Visit 11-25 Oct 76, DCG, Dir of Maintenance and Ch, DRSAR-MMP, Part II.
- b. Demand Return Disposal Files, 15 Dec 74-15 Dec 76.
- c. Order of Merit List, M551 Sheridan, 6 Oct 76.

2. Introduction. The Systems Analysis Directorate was tasked to conduct a failure rate analysis on European-based Sheridans and additionally, to determine if the component buy policy for ARRCOM managed Sheridan related items need be revised to reflect an accelerated failure rate for Sheridan turret components and repair parts.

3. Background. During a visit to USAREUR (ref 1a), it was reported to the DCG, ARRCOM that the age of the Sheridans in USAREUR was a factor causing a rapidly increasing component wear-out rate. This study was approached from the viewpoint that if the European-based Sheridans, all having varied ages, were, in fact, wearing out at a rapid rate, the component buy policy should be adjusted accordingly.

4. Discussion of Data. In order to show that the varied aged Sheridans were wearing out rapidly, it would be necessary to group the Sheridans by age and then identify specific failure rates by age group. This data was not available in a processible form. Thus, the study focused on reviewing the available demand history files (ref 1b). The required demand data was requested from the ALPHA system; however, the system could not provide the needed information. Copies of the December 1976 ALPHA Demand Return Disposal (DRD) files were obtained. The files are on seven magnetic tapes and contain the past two years' demand history (15 Dec 74-15 Dec 76) for all ARRCOM managed NSN's. The DRD files presented an additional problem. The European Materiel Management Center does not use the Weapon Systems codes listed in AR 725-50. For that matter, it is not a required entry for CONUS based units. This necessitated using the Sheridan Weapon System Order of Merit List (OML) dated 6 Oct 76 (ref 1c) to obtain all Sheridan Stock Numbers and then screen the DRD files for those NSNs to obtain the required information.

DRSAR-SAA

SUBJECT: M551 Sheridan Wear-Out.

5. Methodology. The rationale for using the DRD files was that if the variably-aged Sheridans were rapidly wearing out, this would be reflected in a corresponding rapid increase in the number of demands and/or quantities demanded. A COBOL program was written that would first screen the DRD files for the stock numbers obtained from the OML and then further screen the remaining stock numbers for recurring European-generated demands. This last screening process reduced the stock numbers to be analyzed to as close to the using unit level as possible.

The resultant European-identified Sheridan stock numbers were then subjected to four analyses to determine if a rapid increase had occurred in the number of demands and/or quantity demanded.

a. The stock numbers were first ordered by total cost per NSN from high to low. The top 90% of the cumulative total cost were then subjected to a trend analysis. This trend analysis consisted of comparing first and second year demands.

b. The total demands per month and total quantity demanded per month were each graphed (Incl 1 & 2) and again a trend analysis performed on the data.

c. The average quantity per demand was graphed (Incl 3) by month and again a trend analysis was performed on the data.

d. The average cumulative quantity demanded per month was calculated, graphed (Incl 4) and a trend analysis performed.

6. Results of Analyses.

a. After the European stock numbers were identified and subsequently ranked by cost from high to low, the stock numbers comprising the top 90% of the total cost were separated for analysis. The number of NSN's in this category was 111 or 11.6% of all the stock numbers considered. In addition, these stock numbers accounted for 35.4% of the total demands for all stock numbers considered. The number of demands for the first and second years for each stock number was determined and a linear regression performed in order to determine the trend from the first year to the second year. The linear regression yielded a positive slope which would indicate an increase from one year to the other and the correlation factor (a measure of how close the data points conform to a straight line) was moderately high, which indicates a close fit. However, it was felt that further investigation was warranted. This need became more obvious when a closer examination of the data was made. First, the demands were grouped by years as opposed to months, in addition, there were many anomalies in the data, i.e., demands greatly increased or decreased from the first to the second year. Second, upon examination of specific stock numbers that exhibited a large increase in demands for the second year, it was found

DRSAR-SAA

SUBJECT: M551 Sheridan Wear-Out

1 JUN 1977

that this increase was due a great extent to Maintenance Letters that had been sent to the field directing various maintenance or inspection actions. These letters invariably lead to a temporary increase in demands. In addition, almost all the increased second year demand stock numbers were included in pending Engineering Change Proposals (ECPs) for the Sheridan. In all, no conclusions could be made as to any indication of rapid wear-out.

b. The total demands and total quantity demanded were graphed by month in an attempt to determine where and when the above noted fluctuations occurred and also to gain a better insight into the nature of the demands i.e., was there a rapid increase in demands. Because this data was a time series analysis, the series was decomposed to eliminate many of the anomalies described above, such as the seasonal and cyclical fluctuations in order to arrive at the secular trend (the secular trend indicates the long-run growth or decline of the series). Upon analyzing the secular trend, no indication of rapid increase was detected.

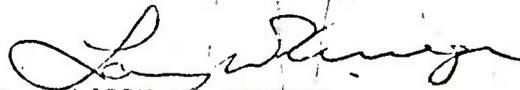
c. The average quantity per demand was plotted by month and again a secular trend analysis was made to determine if a rapid rise was indicated. This attempt again failed to indicate anything other than a slight increase.

d. The average cumulative quantity demanded per month was calculated and graphed. This was another means of trying to discern a rapid increase in demand for parts. Upon reviewing the results, again there was no indication of rapid rise in demands or quantity demanded.

7. Summary.

a. All attempts to demonstrate that the European-based Sheridans were wearing out rapidly failed to indicate any such pattern. A gradual increase was detected; however, this increase is basically inconclusive because of the availability of only two years of demand data to analyze. The largest benefit to be realized from this effort is that the DRD files are a source of excellent data provided the following two conditions are met. First, more than just two continuous years of demand history is needed and second, that all weapons codes, as assigned in AR 725-50, be a required entry on all requisitions originating in CONUS and from OCONUS.

b. From the analysis above there appears to be (based on available data) no need to alter the current component buy policy. However, with at least four years of demand data, the above analyses may be able to adequately predict when changes may be needed before problems arise.

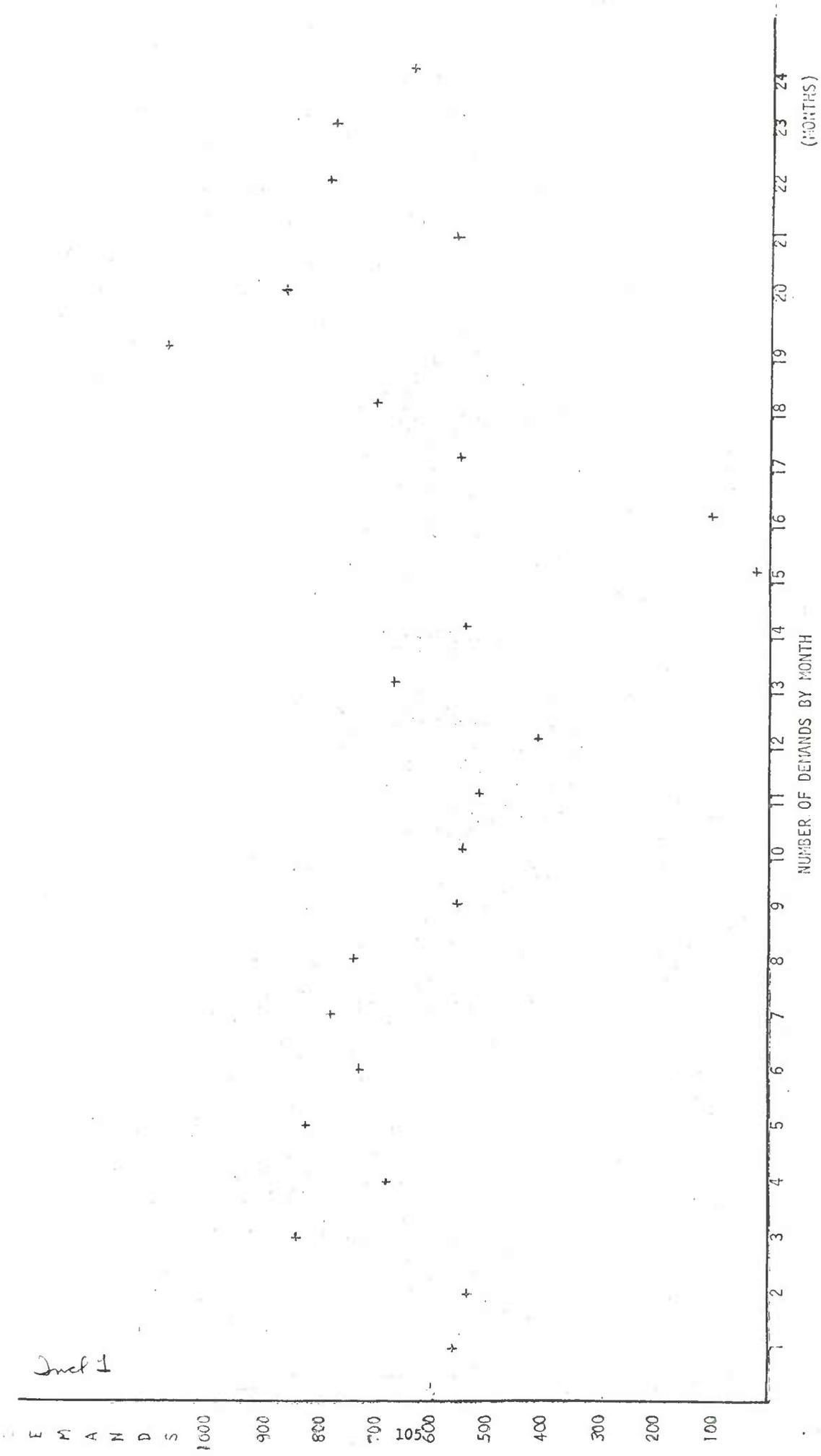


LARRY W. KRUEGER

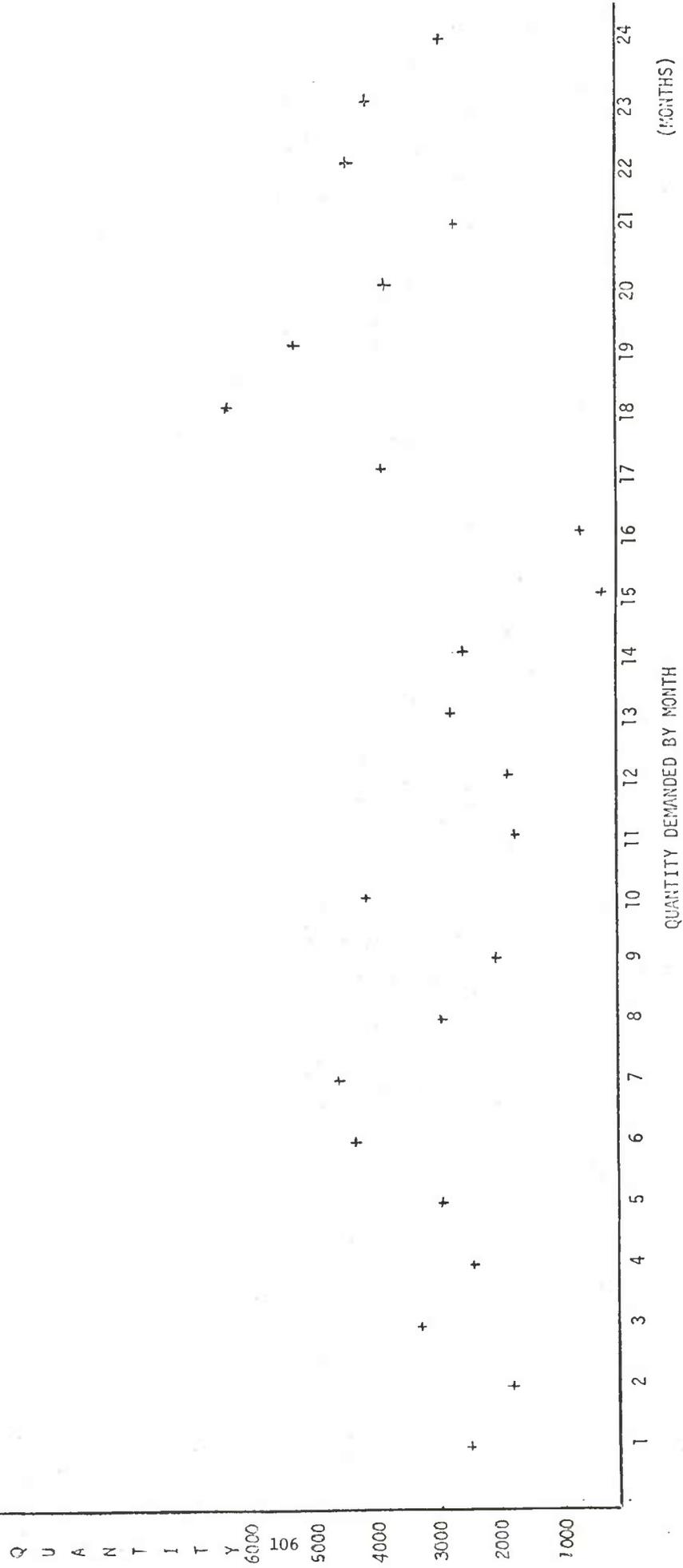
CPT, OrdC

Systems Assessment Division

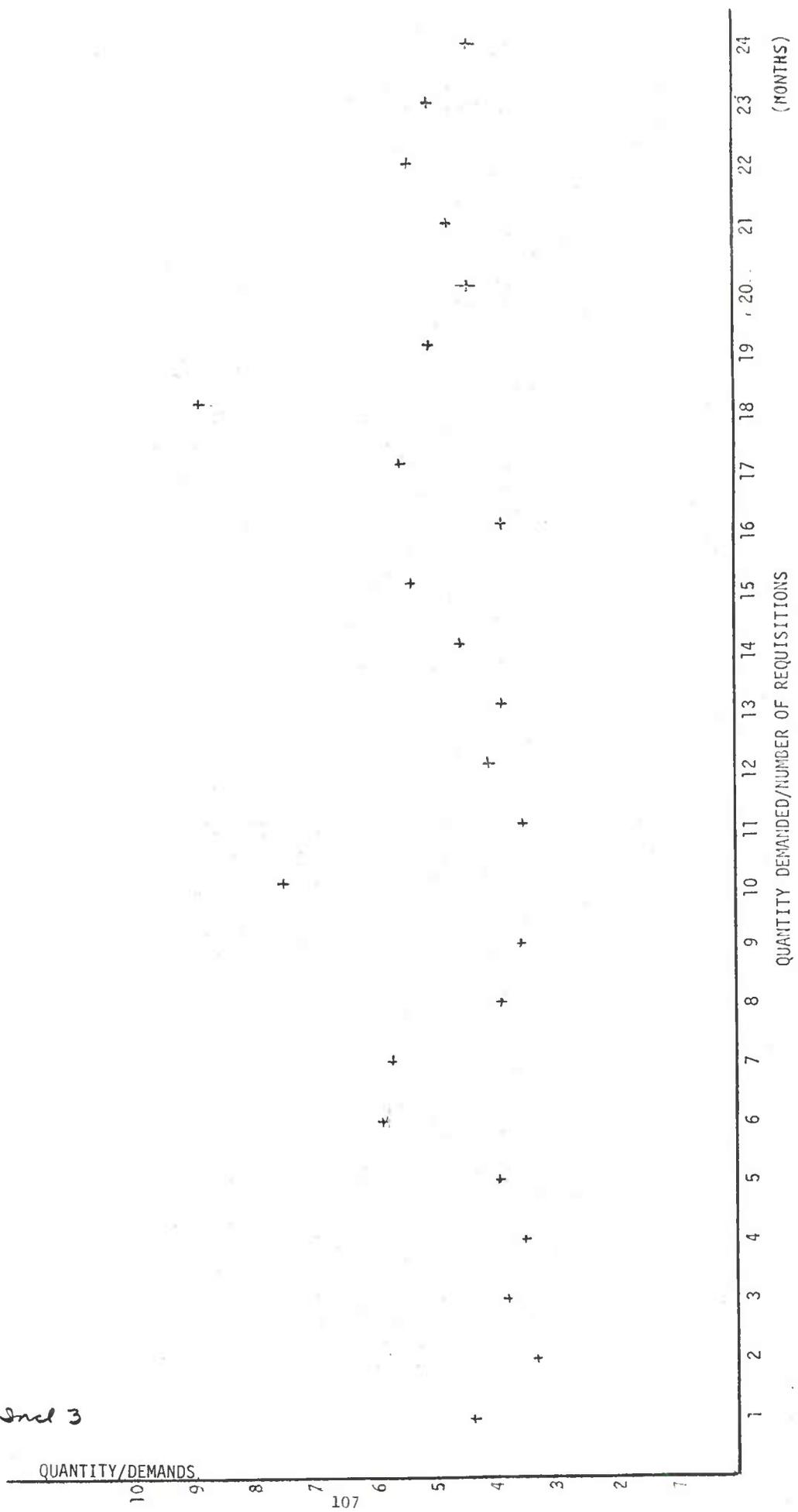
Incl 1



Incl 2



Incl 3



(MONTHS)

QUANTITY DEMANDED/NUMBER OF REQUISITIONS

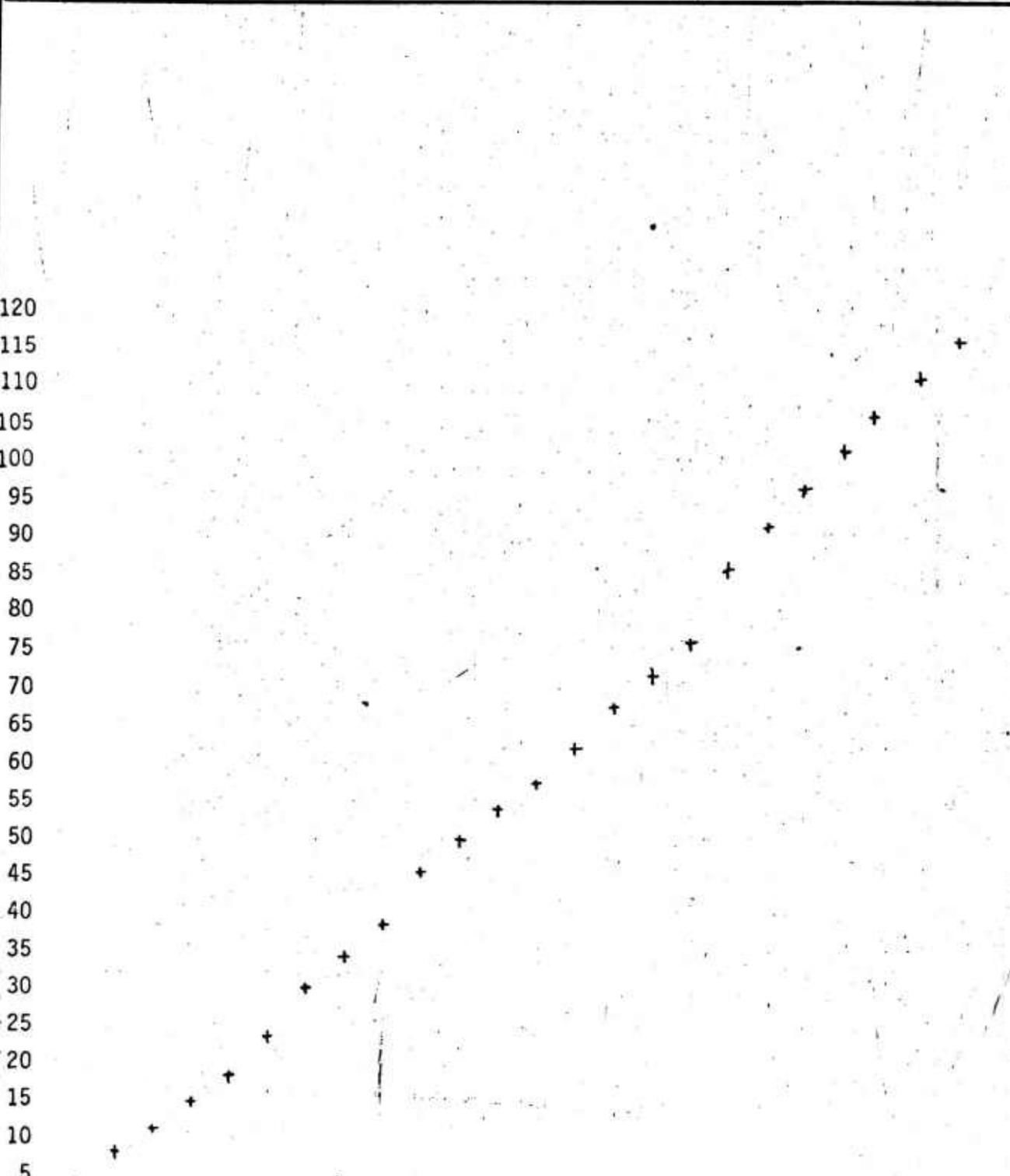
QUANTITY/DEMANDS

Cumulative Average Monthly
Quantity Requested

120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5

June 4

108



23 JUN 1977

MEMORANDUM FOR RECORD

SUBJECT: Statistical Methods Pertinent to a Potential Ignition Problem in the M188E1 Propelling Charge

1. References:

a. MFR, STEAP-MT-G, 11 Apr 77, subject: M188E1 Charge--Max Negative ΔP Results.

b. Letter, DRDAR-LCU-E-P, 24 May 77, subject: Test Program Request ADEP 2061 Charge Propelling 8-Inch M188E1.

2. Background

The author was asked by the PM-110E2 to review a potential safety problem in the M110A1 SP howitzer when using the M188E1 propelling charge. During development testing of this charge, pressure is measured simultaneously at two locations: near the breechface and at the forward end of the chamber (toward the muzzle). After proper ignition and throughout the interior ballistic cycle, the pressure is generally higher at the breech than at the base of projectile. However, during ignition reverse pressure gradients, i.e., a larger pressure forward, can occur. The magnitude of the negative pressure differential, measured in the manner indicated above, has been found to correlate positively with the peak chamber pressure subsequently experienced during the interior ballistic cycle. Thus, a large absolute pressure differential, Δp , is accompanied by a large value of p_{max} , the peak chamber pressure.

3. Statement of the Problem

Because p_{max} must be limited to a value consistent with projectile and cannon allowable stresses, it follows that the associated value of Δp must be limited by some safe value. The Δp limit is determined in part by the relationship between p_{max} and Δp . Presently this relationship is poorly defined and may, in fact, depend upon other variables such as propellant temperature. Even if the safe limit of Δp were well defined, the risk of exceeding this limit depends upon the probability distribution function of the random variable Δp , which itself may depend upon propellant temperature, among other variables. Data analyzed in Ref a. indicate that the probability distribution of Δp is affected by large changes in propellant temperature.

SUBJECT: Statistical Methods Pertinent to a Potential Ignition Problem in the M188E1 Propelling Charge

During safety tests of the M110 system, the M188E1 propelling charge had been subjected to a sequence of rough handling operations and subsequently temperature conditioned to -50 degrees F. Several of the rounds fired with this treatment experienced Δp values in excess of 2 ksi and displayed values of p_{\max} which generally increased with Δp . Furthermore, tests of M188E1 charges with intentionally malconstructed igniters when subjected to -50 degree F conditioning have displayed extremely large (>5 ksi) values of Δp and anomalously large values of p_{\max} .

5. In the light of these results STEAP-MT has begun a series of tests (Ref. b) whose general purpose is to better quantify the factors to be considered in estimating the risk of a catastrophic malfunction of the M188E1 propelling charge. Since the anomalously large chamber pressures accompany improper ignition at low temperature, it is important to define the effect of temperature on the probability distribution of Δp in unmodified charges following anticipated operational rough handling.

6. A Particular Issue

In this connection an immediate question is whether the probability distribution of Δp has a temperature dependence for temperatures below zero degrees F. To answer the question of temperature dependence as efficiently as possible, one requires powerful statistical tests and should, of course, make use of all applicable existing data. With these things in mind, I have prepared some statistical methods which may be helpful in:

- a. selecting a statistical sample to provide an adequate degree of discrimination between propelling charge treatments.
- b. estimating the value of Δp which would be exceeded at a given risk (a percentile of the distribution of Δp) and an associated confidence interval for this estimate.

7. The derivation of some pertinent statistical tests and the presentation of their operating characteristics for several sample sizes are given in Attachment 1 (Incl 1). The treatment is not intended to be exhaustive but rather to define the power of some parametric and non-parametric tests for this particular application. Computer programs are presented in Attachment 2 (Incl 2).



GEORGE SCHLENKER
Operations Research Analyst
Methodology Division
Systems Analysis Directorate

2 Incl
as

ATTACHMENT 1

SOME STATISTICAL METHODS PERTAINING TO THE IGNITION PROBLEM IN THE M188E1 PROPELLING CHARGE

Background

At low temperatures following sequential rough handling tests of the XM188 propelling charge, some unusually large maximum absolute values of negative pressure differential have been experienced within the combustion chamber of the eight-inch M201 cannon. Typically, a large value of the maximum absolute pressure differential, Δp , accompanies a large peak chamber pressure during the interior ballistic period. Several tests have been proposed to investigate this problem, which is regarded as potentially serious because of possibly unsafe peak chamber pressures.

In one series of tests it is proposed to fire sets of these charges conditioned at several temperatures, in order to determine the effect of temperature on the probability distribution of Δp produced during ignition of the charge.

Parametric Methods

Available data on the XM188 charge indicate that at both low (-50°F) temperatures and high temperatures (145°F) a two-parameter Weibull distribution is a reasonable statistical model for Δp^* . These data suggest that the shape parameter, β , is nearly unity--the high-temperature distribution having a value of β only slightly in excess of 1, and the low-temperature distribution having a β slightly less than 1. However, due to the limited sample these distributions are not statistically distinguishable from the (negative) exponential distribution which corresponds to a Weibull with $\beta = 1$. Therefore, in the following analysis the exponential model is assumed. Because of its relationship to risk, the first topic addressed is percentile estimation.

Variance of Percentile Estimates for Exponential Random Variables

The 100p th percentile, x_p , of an exponential distribution with parameter θ is given by

*MFR, STEAP-MT-G, 11 Apr 77, subject: M188E1 Charge--Max Neg ΔP Results.

$$p = 1 - \exp - x_p/\theta \quad (1.1)$$

or

$$x_p = -\theta \ln(1 - p) \quad (1.2)$$

Thus with p chosen, x_p is proportional to the parameter θ .

The maximum likelihood estimate of θ , $\hat{\theta}$, obtained from a sample of n : $\{X_i, i = 1, n\}$ is, simply,

$$\hat{\theta} = \sum_{i=1}^n X_i/n \quad (1.3)$$

To obtain an estimate of the variance of x_p , one notes that, from (1.2),

$$\text{Var}(x_p) = \text{Var}(\hat{\theta}) \ln^2(1 - p) \quad (1.4)$$

Now, a well known result for the exponential distribution is that the parameter $2n\hat{\theta}/\theta$ has a chi-squared (χ^2) distribution with $2n$ degrees of freedom. Further,

$$\text{Var}(\chi_{2n}^2) = 4n \quad (1.5)$$

so that

$$\text{Var}(\hat{\theta}) = \theta^2/n \quad (1.6)$$

Thus, from (1.4) and (1.6),

$$\text{Var}(x_p) = \theta^2 \ln^2(1 - p)/n \quad (1.7)$$

or, with (1.2),

$$\text{Var}(x_p) = x_p^2/n \quad (1.8)$$

Note that the distribution of $2nx_p/x_p$ is also χ^2 with $2n$ degrees of freedom since x_p and θ are proportional.

Detecting a Difference Between Two Samples

Suppose that two samples of n each are used to estimate the x_p th percentile (and parameter θ), producing $\hat{\theta}$ and $\hat{\theta}_0$. Making use of the Central Limit Theorem, for n greater than about 10 the following statistic is approximately standard normal:

$$\zeta = \frac{\hat{\theta} - \hat{\theta}_0 - (\theta - \theta_0)}{[\text{Var}(\hat{\theta}) + \text{Var}(\hat{\theta}_0)]^{1/2}} \quad (1.9)$$

Alternatively, with

$$f = \theta/\theta_0, \quad (1.10)$$

$$\zeta = \frac{(\hat{\theta} - \hat{\theta}_0)\sqrt{n}}{[\hat{\theta}^2 + \hat{\theta}_0^2]^{1/2}} - \frac{(f - 1)\sqrt{n}}{(f^2 + 1)^{1/2}}. \quad (1.11)$$

One hypothesizes that $H_0: \theta = \theta_0$, with the alternative $H_1: \theta > \theta_0$. With the gaussian assumption,

$$P\{\zeta < 1.65\} = 0.95. \quad (1.12)$$

Consequently, at a risk of only 5% of the declaring H_0 false if true, one can accept H_1 if

$$\frac{(\hat{\theta} - \hat{\theta}_0)\sqrt{n}}{\sqrt{\hat{\theta}^2 + \hat{\theta}_0^2}} > 1.65. \quad (1.13)$$

Notationally, let $\beta = P\{\text{accept } H_1\}$ (1.14)

Then,

$$\beta = P\left\{\frac{(\hat{\theta} - \hat{\theta}_0)\sqrt{n}}{\sqrt{\hat{\theta}^2 + \hat{\theta}_0^2}} - 1.65 > 0\right\} \quad (1.15)$$

Using the expected value of the denominator in (1.15), approximately,

$$\beta = P\left\{\zeta + \frac{(f - 1)\sqrt{n}}{(f^2 + 1)^{1/2}} - 1.65 > 0\right\}$$

or

$$\beta = \Phi(\sqrt{n}(f - 1)(f^2 + 1)^{-1/2} - 1.65), \quad (1.16a)$$

with

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^z e^{-x^2/2} dx. \quad (1.16b)$$

Plots of $\beta(f)$ for various values of n , calculated from (1.16), are displayed in Figure 1.

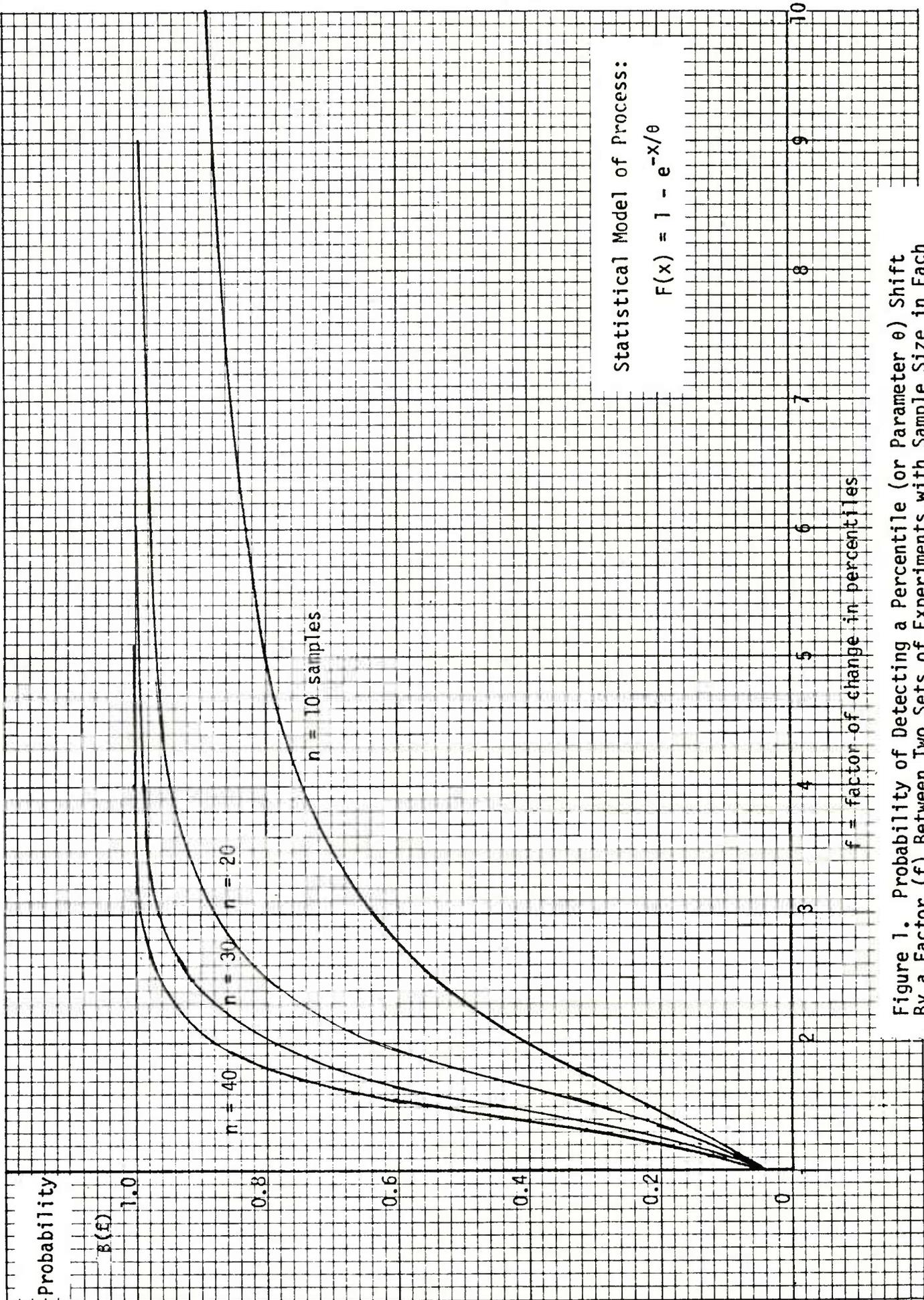


Figure 1. Probability of Detecting a Percentile (or Parameter θ) Shift By a Factor (f) Between Two Sets of Experiments with Sample Size in Each

These operating characteristics or OC curves indicate the value of the fractional shift f which must occur to detect a shift in the parameter θ between samples. The rule used to detect a shift is given by (1.13) with $\hat{\theta}$ and $\hat{\theta}_0$ calculated using equation (1.3). The results of several experiments can be compared by applying the above test to all possible pairs, where the basic parameter θ_0 is estimated from the sample whose population parameter θ is expected to be minimal on physical grounds. However, if the number of sets of samples at, say, different temperatures is large, pairwise comparison is not the most powerful statistical method to detect a temperature effect. If the number of experiments is greater than about 3, regression of $\hat{\theta}$ on temperature appears preferable.

The use of parametric methods to discriminate between treatments requires an assumption concerning the form of the distribution function. If the nature of the distribution function is seriously in doubt, particularly for large values of the argument Δp , as is the case here, it is preferable to use non-parametric methods. In the next section a specific non-parametric statistic is suggested for detecting the effect of treatment when three treatments are applied to three samples. To facilitate comparisons between the operating characteristics of the above parametric test and the non-parametric tests, we display in Figure 2 the relationship between f --as defined in (1.10)-- and a probability used in the non-parametric tests, namely, the proportion of the population of Δp lying above 2000 psi.

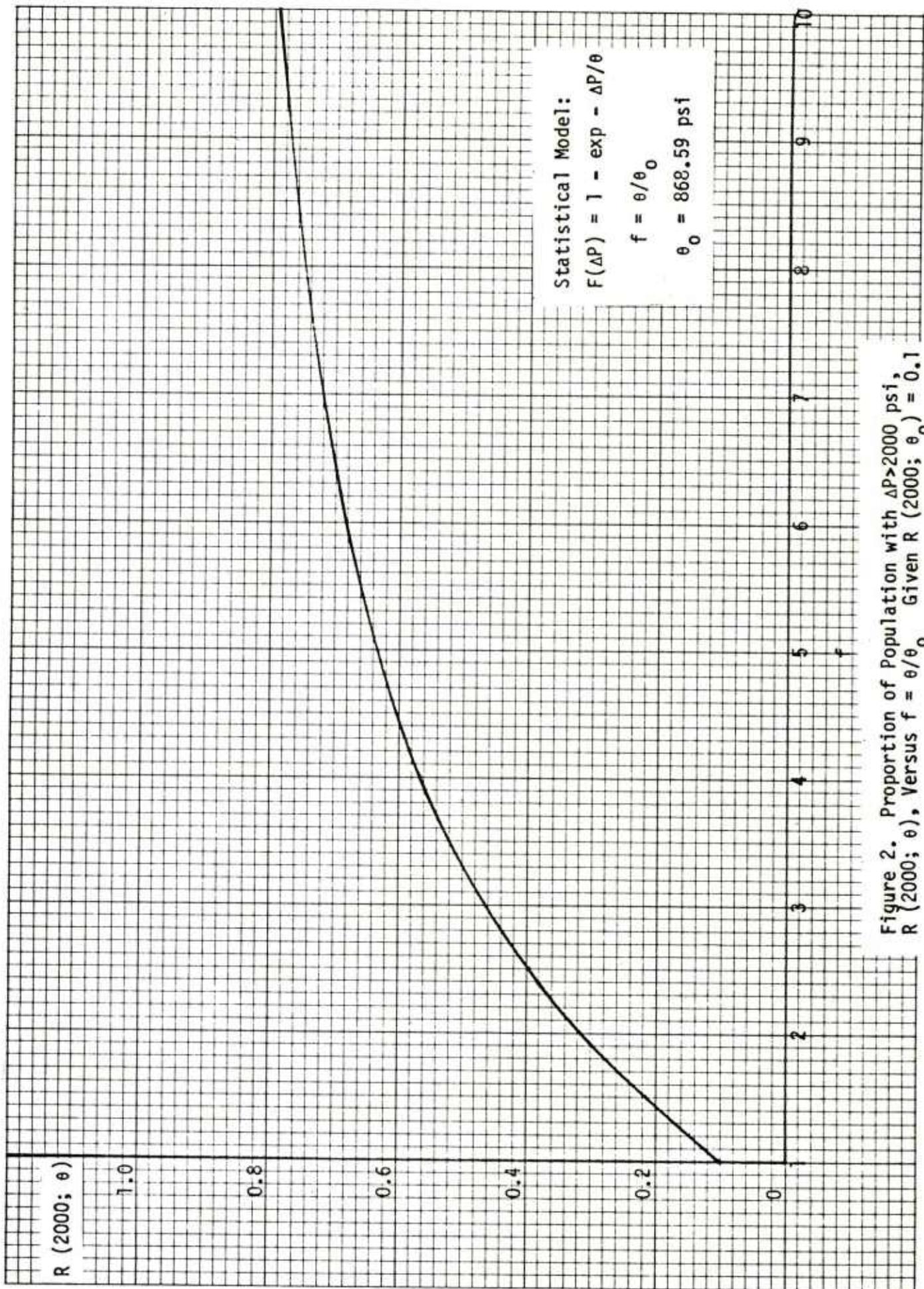


Figure 2. Proportion of Population with $\Delta P > 2000 \text{ psi}$, $R(2000; \theta)$, Versus $f = \theta/\theta_0$ Given $R(2000; \theta_0) = 0.1$

Non-Parametric Methods

To detect whether the experimental treatment affects the distribution of Δp (the variable of interest), one can examine some non-parametric measure such as the number of occasions in a sample of n in which Δp exceeds a specified value. This reduces the analysis of each experiment to counting the number of such "successes" over Bernoulli trials. The discrimination between treatments is based upon a comparison of the number of successes. If one is merely interested in whether any sort of change occurs in the probability of success over the three sets of Bernoulli trials, one possible test statistic is the (discrete) binomial range or extreme spread* in the number of successes. This statistic has the virtue that it combines the results of all experiments into one index value. In the following derivations the distribution function for the binomial range is developed and used to formulate a test to detect departures from constancy in the probability of success over the three sets of Bernoulli trials, i.e., to detect $\pi_1 \neq \pi_2 \neq \pi_3$. The operating characteristic of this test is calculated. In this context the operating characteristic is the probability of detecting a departure from constancy as a function of the magnitude of the departure.

The Distribution for the Discrete Range of Successes in Three Sets of Bernoulli Trials

Given the event $E_r(i)$: during the i th experiment, there are r rounds which have a Δp in excess of, say, 2 ksi, given n rounds per experiment are fired with the probability equal to π_i that for any round of the i th set Δp will exceed 2 ksi. Then,

$$P\{E_r(i)\} = \lambda_r(i) = \binom{n}{r} \pi_i^r (1 - \pi_i)^{n-r}, \quad (2.1)$$

$$0 \leq r \leq n.$$

The expected number of rounds in the i th experiment with "success," i.e., having a Δp in excess of 2 ksi, is $n \pi_i$.

* The extreme spread of a random variable is defined as the difference between the largest and smallest values of a sample.

The range or maximum spread (s) of the observed successes from all of the three experiments has a probability density (p.d.f.) dependent upon n : $p_s(n)$, with s a member of the discrete set S ,
 $S = \{0, 1, \dots, n\}$. (2.2)

The p.d.f. for the range is derived as follows. Let r be a dummy variable for the number of successes in the first experiment. Then,

$$P\{\text{spread is exactly } s\} = p_s.$$

The expression for p_s is developed by exhaustively enumerating the events which produce a maximum spread s and then writing the probabilities of these events and taking their sum.

$$p_s = \sum_{r=0}^n P\{E_r(1)\} [P\{E_{r-s}(2) \text{ or } E_{r+s}(2), \text{ given } r \pm s \in S\} \cdot \\ \sum_q P\{E_q(3)\} + P\{E_{r-s}(3) \text{ or } E_{r+s}(3), \text{ given } r \pm s \in S\} \sum_q P\{E_q(2)\} \\ - P\{E_{r-s}(2) \text{ or } E_{r+s}(2), \text{ given } r \pm s \in S\} \cdot \\ P\{E_{r-s}(3) \text{ or } E_{r+s}(3), \text{ given } r \pm s \in S\}], \quad (2.3)$$

where the limits of q are

$$q_{\min} = \max(0, r - s)$$

$$q_{\max} = \min(n, r + s).$$

In evaluating the second factor within the sum on the r.h.s. of (2.3) only events for which the indices are in the set S are evaluated.

Example: $n = 3$

$$p_0 = \lambda_0(1)\lambda_0(2)\lambda_0(3) + \lambda_1(1)\lambda_1(2)\lambda_1(3) + \lambda_2(1)\lambda_2(2)\lambda_2(3) + \\ \lambda_3(1)\lambda_3(2)\lambda_3(3) \quad (2.4)$$

$$p_1 = \lambda_0(1)\lambda_1(2)\lambda_0(3) + \lambda_0(1)\lambda_1(3)(\lambda_0(2)+\lambda_1(2)) + \\ \lambda_1(1)(\lambda_0(2)+\lambda_2(2))\lambda_1(3) + \lambda_1(1)(\lambda_0(3)+\lambda_2(3))(\lambda_0(2)+\lambda_1(2)+\lambda_2(2)) + \\ \lambda_2(1)(\lambda_1(2)+\lambda_3(2))\lambda_2(3) + \lambda_2(1)(\lambda_1(3)+\lambda_3(3))(\lambda_1(2)+\lambda_2(2)+\lambda_3(2)) + \\ \lambda_3(1)\lambda_2(2)\lambda_3(3) + \lambda_3(1)\lambda_2(3)(\lambda_2(2)+\lambda_3(2)) \quad (2.5)$$

$$\begin{aligned}
p_2 = & \lambda_0(1)\lambda_2(2)(\lambda_0(3)+\lambda_1(3)) + \lambda_0(1)\lambda_2(3)(\lambda_0(2)+\lambda_1(2)+\lambda_2(2)) + \\
& \lambda_1(1)\lambda_3(2)(\lambda_1(3)+\lambda_2(3)) + \lambda_1(1)\lambda_3(3) + \\
& \lambda_2(1)\lambda_0(2)(\lambda_1(3)+\lambda_2(3)+\lambda_3(3)) + \lambda_2(1)\lambda_0(3) + \\
& \lambda_3(1)\lambda_1(2)(\lambda_2(3)+\lambda_3(3)) + \lambda_3(1)\lambda_1(3)(\lambda_1(2)+\lambda_2(2)+\lambda_3(2)) \quad (2.6)
\end{aligned}$$

$$\begin{aligned}
p_3 = & \lambda_0(1)\lambda_3(2) + \lambda_0(1)\lambda_3(3)(\lambda_0(2)+\lambda_1(2)+\lambda_2(2)) + \\
& \lambda_3(1)\lambda_0(2) + \lambda_3(1)\lambda_0(3)(\lambda_1(2)+\lambda_2(2)+\lambda_3(2)) \quad (2.7)
\end{aligned}$$

A numerical evaluation of (2.4) thru (2.7) with $\pi_1 = \pi_2 = \pi_3 = 0.1$ produces the following distribution of binomial range:

s	p_s	$\sum_{i=1}^s p_i$
0	0.4018	0.4018
1	0.5315	0.9332
2	0.0644	0.9976
3	0.0024	1.0000

Summary statistics are:

$$\text{mean} = \sum_{i=1}^n i p_i = 0.66735$$

$$\text{std. dev.} = [\sum_{i=1}^n i^2 p_i - \text{mean}^2]^{1/2} = 0.60418$$

$$\begin{aligned}
\text{coefficient of variation} &= \text{std. dev.}/\text{mean} \\
&= 0.90535
\end{aligned}$$

Test for Constancy of π_j

The distribution for the discrete binomial range was evaluated, using (2.3), for several sets of values of the parameters n , π_1 , π_2 , π_3 . These results are shown in Table 1. One notes that a progressive departure from constancy of the π 's in the manner indicated in Table 1 is accompanied by a shift in the distribution of the binomial range to the right, i.e., in the direction of larger values. Further, even though the standard deviation also increases with increasing π_2 or π_3 (π_1 being fixed), the coefficient of variation decreases. Thus, the distribution becomes relatively less disperse.

These characteristics of the distribution of binomial range, s , suggest a simple test of constancy of the π 's. Specifically, for a given sample size (n), select a value of s for which the π 's would be declared identical. Call this the acceptance number a . For values of s greater than a , one would accept the alternative hypothesis, viz., the π 's are not all identical. That is, if $s > a$, the treatment is declared to affect the value of π , the probability that Δp exceeds 2 ksi.

In selecting the acceptance number a for a given n , one must decide what risk will be accepted in declaring the π 's different if they are in fact not. For example for $n = 10$ and $a = 2$, from Table 1, the risk is about 10%. Similarly, for $n = 20$ and $a = 3$ this risk is about 11%, and for $n = 30$ and $a = 4$ the risk is approximately 9%.

If a sample (n) of 30 and an acceptance number (a) of 4 were chosen, the probability of detecting a shift of π_3 and π_4 from 0.1 to 0.4 would exceed 98% (from Table 1). It is of interest to compare the power of this test to that of the previous parametric test on the difference $\hat{\theta} - \hat{\theta}_0$. To facilitate the comparison, note from Figure 2 that the value of f corresponding to an ordinate of 0.4 ($= \pi$) is 2.513. Then, using this value of f and assigning the same risk of mistaking a shift of π as in the

non-parametric test, viz. 0.0927, the parametric test would yield a 96% probability of detecting this shift. In this case the non-parametric test is actually more discriminating. The reason for the better discrimination of the non-parametric test is that it takes information from all three experiments rather than from simply a pair as does the parametric test.

Operating Characteristic of the Non-Parametric Test

Using the results in Table 1 (with equal values of π_2 and π_3), one can develop the operating characteristics of three non-parametric tests using the binomial range with values of $n = 10, 20, 30$ and corresponding values of $a = 2, 3, 4$. The probability of accepting the alternate hypothesis (H_1) that the π 's are different is shown in Figure 3 as a function of π_2 and π_3 . In constructing Figure 3, it is assumed that the values of π_2 and π_3 are the same. In this case the probability of accepting H_1 has only a single argument. However, this assumption is somewhat restrictive. In general, $P\{\text{accept } H_1\}$ depends upon two arguments-- π_2 and π_3 , which may be different. The latter relation is shown in Figure 4, an isometric graph. It is noted that the region in the domain of π_2 and π_3 for which the probability of accepting H_1 is less than 0.5 is approximately bounded by the circular arc:

$$(\pi_2 - 0.1)^2 + (\pi_3 - 0.1)^2 = (0.25 - 0.1)^2 ,$$

for the case in which $n = 30$ and $a = 4$.

TABLE 1. SUMMARY STATISTICS FROM THE DISTRIBUTION OF THE DISCRETE RANGE FROM THREE SETS OF BERNOULLI TRIALS

Description of Stat. Populations: (π_1, π_2, π_3)	Sample Size	Statistics						
		Mean	Standard Deviation	Coef. of Variation	P{range > 2}	P{range > 3}	P{range > 4}	P{range > 5}
0.1, 0.1, 0.1	10	1.408	0.867	0.615	0.1028	0.0181	0.0023	0.0002
	20	2.031	1.183	0.582	0.3007	0.1113	0.0329	0.0079
	30	2.503	1.432	0.572	0.4426	0.2202	0.0927	0.0334
0.1, 0.15, 0.15	10	1.682	0.997	0.592	0.1866	0.0474	0.0086	0.0011
	20	2.516	1.433	0.570	0.4484	0.2260	0.0948	0.0330
	30	3.222	1.803	0.560	0.6055	0.3912	0.2244	0.1137
0.1, 0.2, 0.2	10	2.038	1.158	0.568	0.3096	0.1101	0.0282	0.0052
	20	3.274	1.743	0.532	0.6308	0.4138	0.2330	0.1107
	30	4.437	2.233	0.503	0.7876	0.6289	0.4609	0.3054
0.1, 0.3, 0.3	10	2.913	1.429	0.490	0.5881	0.3295	0.1371	0.0410
	20	5.186	2.142	0.413	0.8916	0.7764	0.6175	0.4362
	30	7.422	2.669	0.360	0.9685	0.9286	0.8618	0.7624
0.1, 0.4, 0.4	10	3.891	1.570	0.404	0.8066	0.5956	0.3491	0.1525
	20	7.231	2.274	0.314	0.9810	0.9493	0.8858	0.7787
	30	10.507	2.788	0.265	0.9979	0.9939	0.9843	0.9640
0.1, 0.6, 0.6	10	5.863	1.567	0.267	0.9804	0.9310	0.8127	0.6061
	20	4.468	2.098	0.470	0.8140	0.6535	0.4724	0.3018
	30	6.388	2.697	0.422	0.9287	0.8525	0.7459	0.6141
0.1, 0.2, 0.3	20	6.461	2.316	0.358	0.9578	0.8994	0.8000	0.6580
	30	9.429	2.893	0.307	0.9929	0.9812	0.9576	0.9148

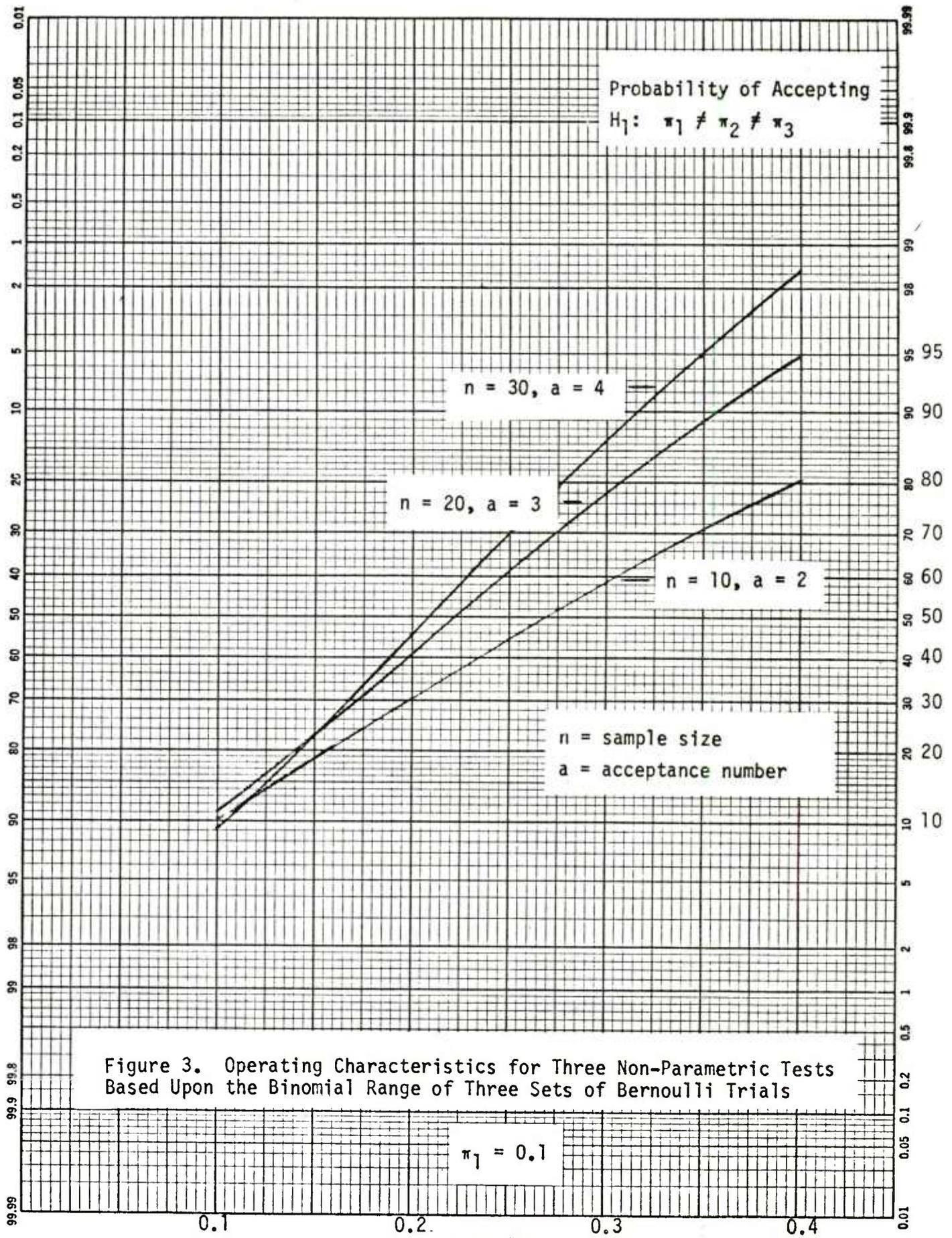


Figure 3. Operating Characteristics for Three Non-Parametric Tests Based Upon the Binomial Range of Three Sets of Bernoulli Trials

$\triangle P \left\{ \text{accept } H_1, \text{ given } \pi_1 = 0.1, n = 30, a = 4 \right\}$

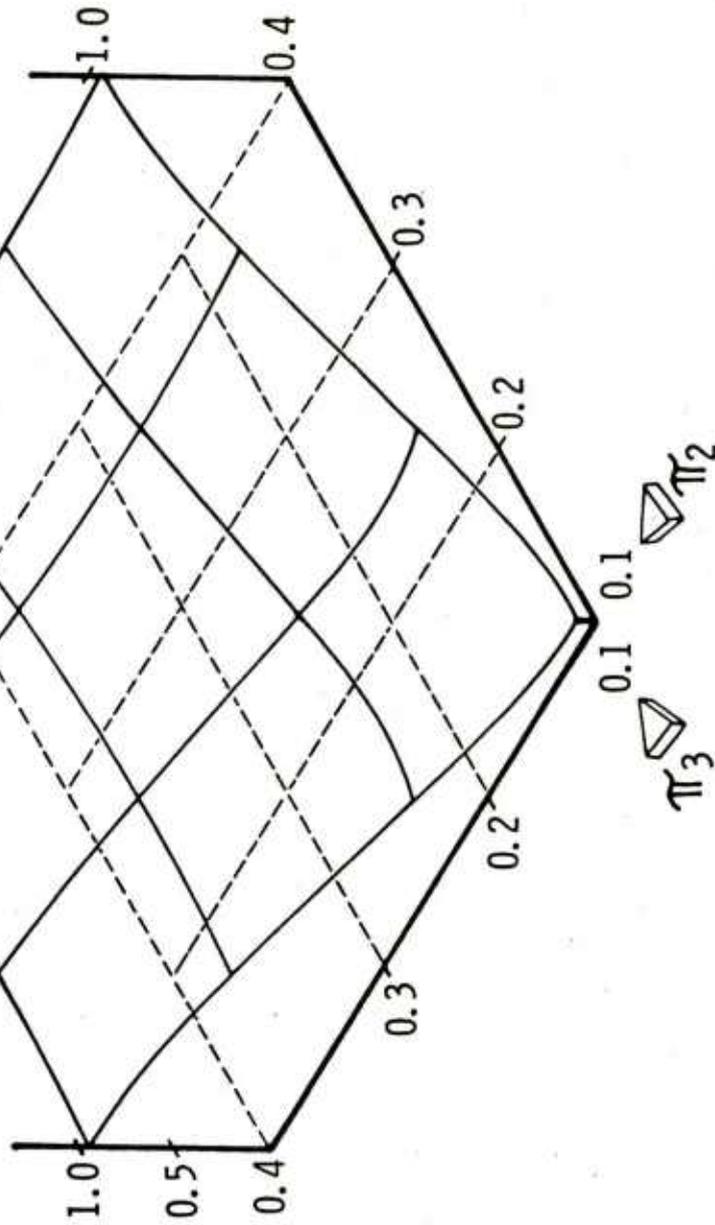


Figure 4. Two-Dimensional Operating Characteristic for a Non-Parametric Test Using the Binomial Range from Three Sets of Bernoulli Trials (Sample Size 30)

ATTACHMENT 2

COMPUTER SOURCE PROGRAMS FOR OBTAINING THE PROBABILITY DISTRIBUTION FUNCTION OF THE DISCRETE BINOMIAL RANGE FOR THREE SETS OF BERNOULLI TRIALS

Three source programs are given: an executive program for I/O and subprogram calls, MAIN; a subroutine for computing the distribution of binomial range, BINRNG; and a function for calculating the binomial probability, PBERN. All programs are written in FORTRAN 4 for the IBM 360 computer.

Input requirements are: (1) an alphameric title card and (2) a card specifying the sample size and binomial probability parameters for each of the three experiments. Output echoes input and lists the p.d.f., c.d.f., and upper tail probabilities for the discrete range. An example is provided.

```

C*****EXECUTIVE FOR PBERN*****
C
C   MAIN PROGRAM TO DEVELOP A SET OF DISTRIBUTION FUNCTIONS
C   FOR THE RANGE OF OUTCOMES FROM THREE EXPERIMENTS, EACH
C   CONSISTING OF N BERNOULLI TRIALS
C*****
  IMPLICIT REAL*8 (A-H,O-Z)
  DIMENSION TITLE(20),PS(100),CDF(100),PMEAN(3),NSAMP(3)
  1 CONTINUE
  READ (5,100,END=30) TITLE,NSAMP(1),NSAMP(2),NSAMP(3),
  1  PMEAN(1),PMEAN(2),PMEAN(3)
100 FORMAT(20A4/3I3,1X,3F10.0)
  WRITE (6,200) TITLE,NSAMP(1),NSAMP(2),NSAMP(3),
  1  PMEAN(1),PMEAN(2),PMEAN(3)
200 FORMAT(1H1,20A4/1H0,'SAMPLE SIZES ARE:',3(3X,I3),
  1  ', WITH TRIAL PROBS.:',3(2X,F10.4))
  N=MAX0(NSAMP(1),NSAMP(2),NSAMP(3))
  NP1=N+1

C
C   WRITE HEADINGS
C
  WRITE (6,300)
300 FORMAT(1H0,7X,3HNO.,3X,7HDFNSITY,11H CUMUL. PR.,9H REM. PR.)
  CALL BINRNG(NSAMP,PMEAN,PS,CDF,100)
  DO 7 I=1,NP1
  IM1=I-1
  RDF=1.000-CDF(I)
  WRITE (6,400) IM1,PS(I),CDF(I),RDF
400 FORMAT(7X,I3,3F10.4)
  7 CONTINUE
  SUM1=0.000
  SUM2=0.000
  DO 5 I=1,NP1
  FI=DFLOAT(I-1)
  SUM1=SUM1+FI*PS(I)
  SUM2=SUM2+FI*FI*PS(I)
  5 CONTINUE
  VARS=SUM2-SUM1**2
  STDDV=DSQRT(VARS)
  COFVA=STDDV/SUM1
  WRITE (6,10) SUM1,STDDV,COFVN
10 FORMAT(1H0,9X,6HMEAN,R,10X,5HSTDDV,8X,7HCOF VAR/3F15.5)
  GO TO 1
30 CONTINUE
  CALL EXIT
  STOP
  END

```

```
SUBROUTINE BINRNG(NSAMP,PMEAN,PS,CDF,NDIM)
```

```
*****  
SUBROUTINE TO OBTAIN THE DISTRIBUTION FUNCTION OF THE RANGE OF A  
BINOMIAL VARIABLE FROM THREE INDEPENDENT EXPERIMENTS, EACH  
OF WHICH CONSISTS OF N BERNOULLI TRIALS WITH PROB. PMEAN.  
*****
```

```
IMPLICIT REAL*8 (A-H,O-Z)  
INTEGER R,S  
DIMENSION PS(NDIM),CDF(NDIM),PMEAN(3),NSAMP(3)
```

```
NSAMP SAMPLE SIZE OF THE I TH EXPERIMENTAL SET  
N MAX SAMPLE SIZE OF BERNOULLI EXPERIMENTS  
PS(NS) PROBABILITY DENSITY FUNCTION OF THE RANGE FROM THREE EXP'MTS  
CDF(NS) THE CUMULATIVE DISTRIBUTION FUNCTION OF THE ABOVE RANGE  
PBERN(K,N,PMEAN) IS A FUNCTION WHICH CALCULATES THE BINOMIAL  
P.O.F. FOR ARGUMENT K WITH PARAMETERS N--THE SAMPLE SIZE--  
AND PMEAN--THE PROBABILITY OF THE EVENT (SUCCESS) ON A SINGLE TRIAL.  
K IS A MEMBER OF THE SET (0,N).
```

```
ORDER SAMPLE SIZE FROM LARGEST TO SMALLEST
```

```
DO 20 I=1,2
```

```
IP1=I+1
```

```
DO 30 II=IP1,3
```

```
IF(NSAMP(I).GE.NSAMP(II)) GO TO 31
```

```
NH=NSAMP(I)
```

```
NSAMP(I)=NSAMP(II)
```

```
NSAMP(II)=NH
```

```
HOLD=PMEAN(I)
```

```
PMEAN(I)=PMEAN(II)
```

```
PMEAN(II)=HOLD
```

```
31 CONTINUE
```

```
30 CONTINUE
```

```
20 CONTINUE
```

```
N=NSAMP(1)
```

```
INITIALIZE THE RANGE-ARGUMENT (NS) LOOP
```

```
TOTAL=0.000
```

```
NP1=N+1
```

```
START NS LOOP
```

```
DO 1 NS=1,NP1
```

```
S=NS-1
```

```
PSUM=0.000
```

```
START SUMMATION LOOP
```

```
DO 2 NR=1,NP1
```

```
R=NR-1
```

```
CALCULATE THE FIRST FACTOR
```

```
F1=PBERN(R,N,PMEAN(1))
```

C
C
SELECT THE TERMS OF THE SECOND FACTOR

```
K1=R-S  
K2=P+S  
IF(K1.LT.0) GO TO 3  
T1=PBERN(K1,NSAMP(2),PMEAN(2))  
TT1=PBERN(K1,NSAMP(3),PMEAN(3))  
GO TO 4  
3 T1=0.00  
TT1=0.000  
4 IF(K2.GT.N.OR.S.EQ.0) GO TO 5  
T2=PBERN(K2,NSAMP(2),PMEAN(2))  
TT2=PBERN(K2,NSAMP(3),PMEAN(3))  
GO TO 6  
5 T2=0.00  
TT2=0.000  
6 CONTINUE  
F2=T1+T2  
FF2=TT1+TT2
```

C
C
C
DEFINE THE RANGE LIMITS OF THE THIRD FACTOR

```
LLOW=MAX(0,R-S)  
LUPR=MIN(N,R+S)  
IF(LLOW.EQ.0.AND.LUPR.EQ.N) GO TO 8  
F3=0.00  
FF3=0.000  
LLO=LLOW+1  
LUP=LUPR+1  
DO 7 K=LLO,LUP  
K3=K-1  
F3=F3+PBERN(K3,NSAMP(3),PMEAN(3))  
FF3=FF3+PBERN(K3,NSAMP(2),PMEAN(2))  
7 CONTINUE  
GO TO 9  
8 F3=1.000  
FF3=1.000  
9 CONTINUE  
F1=F1*1.020  
F2=F2*1.020  
F3=F3*1.020  
FF2=FF2*1.020  
FF3=FF3*1.020  
PSUM=PSUM+F1*(F2*F3+FF2*FF3-F2*FF2)  
2 CONTINUE
```

C
C
C
END OF SUMMATION LOOP; FILL THE PROBABILITY DENSITY VECTOR PS.

```
PS(NS)=PSUM*1.0-60  
TOTAL=TOTAL+PS(NS)  
IF(1.000-TOTAL.LE.1.00-5) GO TO 11  
1 CONTINUE  
11 CONTINUE
```

```
NSP1=NS+1
DO 10 I=NSP1,NP1
PS(I)=0.0F0
8 CONTINUE
```

END OF RANGE-ARGUMENT LOOP; DEVELOP THE CUMULATIVE DISTRIBUTION FUNCTION

```
CDF(1)=PS(1)
DO 10 I=2,NP1
CDF(I)=CDF(I-1)+PS(I)
0 CONTINUE
RETURN
END
```


DISTRIBUTION OF THE DISCRETE RANGE FROM THREE SETS OF BERNOULLI TRIALS

SAMPLE SIZES ARE: 40 30 30 WITH TRIAL PROBS.: 0.1000 0.1000 0.2500

NO.	DENSITY	CUMUL. PR.	REM. PR.
0	0.0065	0.0065	0.9935
1	0.0562	0.0626	0.9374
2	0.1233	0.1860	0.8140
3	0.1768	0.3627	0.6373
4	0.1865	0.5493	0.4507
5	0.1581	0.7073	0.2927
6	0.1163	0.8236	0.1764
7	0.0777	0.9013	0.0987
8	0.0477	0.9490	0.0510
9	0.0268	0.9758	0.0242
10	0.0137	0.9895	0.0105
11	0.0063	0.9959	0.0041
12	0.0027	0.9985	0.0015
13	0.0010	0.9995	0.0005
14	0.0003	0.9999	0.0001
15	0.0001	1.0000	0.0000
16	0.0000	1.0000	0.0000
17	0.0	1.0000	0.0000
18	0.0	1.0000	0.0000
19	0.0	1.0000	0.0000
20	0.0	1.0000	0.0000
21	0.0	1.0000	0.0000
22	0.0	1.0000	0.0000
23	0.0	1.0000	0.0000
24	0.0	1.0000	0.0000
25	0.0	1.0000	0.0000
26	0.0	1.0000	0.0000
27	0.0	1.0000	0.0000
28	0.0	1.0000	0.0000
29	0.0	1.0000	0.0000
30	0.0	1.0000	0.0000
31	0.0	1.0000	0.0000
32	0.0	1.0000	0.0000
33	0.0	1.0000	0.0000
34	0.0	1.0000	0.0000
35	0.0	1.0000	0.0000
36	0.0	1.0000	0.0000
37	0.0	1.0000	0.0000
38	0.0	1.0000	0.0000
39	0.0	1.0000	0.0000
40	0.0	1.0000	0.0000

MEAN:R 4.49238 STDEV 2.21294 COF VAR 0.49260

DISTRIBUTION LIST

Copy No.

1 Commander
US Army Materiel Development and Readiness Command
ATTN: DRCRE
1 DRCPA-S
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Commander
US Army Armament Materiel Readiness Command
ATTN: DRSAR-CG
1 DRSAR-DCG
1 DRSAR-LC
1 DRSAR-LE
1 DRSAR-CP
21 DRSAR-SA
1 DRSAR-PA
1 DRSAR-PC
1 DRSAR-PD
1 DRSAR-IM
1 DRSAR-OP
1 DRSAR-QA
1 DRSAR-IS
1 DRSAR-MM
1 DRSAR-MA
1 DRSAR-AS
1 DRSAR-SF
Rock Island, IL 61201

1 Commander
US Army Armament Research and Development Command
ATTN: DRDAR-SEA
Dover, NJ 07801

1 Commander
US Army Test and Evaluation Command
ATTN: DRSTE-SY
Aberdeen Proving Ground, MD 21005

1 Commander
US Army Electronics Command
ATTN: DRSEL-SA
Fort Monmouth, NJ 07703

1 Commander
US Army Missile Materiel Readiness Command
ATTN: DRSMI-D
Redstone Arsenal, AL 35809

DISTRIBUTION LIST (Cont)

Copy No.

- 1 Commander
US Army Missile Research and Development Command
ATTN: DRDMI-DS
Redstone Arsenal, AL 35809

- 1 Commander
US Army Tank-Automotive Materiel and Readiness Command
ATTN: DRSTA-S
Warren, MI 48090

- 1 Commander
US Army Tank-Automotive Research and Development Command
ATTN: DRDTA-V
Warren, MI 48090

- 1 Commander
HQ, US Army Aviation Systems Command
ATTN: DRSAV-D
P.O. Box #209, Main Office
St. Louis, MO 64502

- 1 Commander
US Army Troop Support Command
ATTN: DRSTS-G
St. Louis, MO 63120

- 1 Project Manager for Cannon Artillery Weapons Systems
ATTN: DRCPM-CAWS
Dover, NJ 07801

- 1 Commander
US Army Development and Readiness Command
Office of the Project Manager for Selected Ammunition
ATTN: DRCPM-SA
Dover, NJ 07801

- 1 Project Manager for M110E2
ATTN: DRCPM-M110E2
Rock Island, IL 61201

- 1 Project Manager for Air Defense Gun Systems
ATTN: DRCPM-ADG
Rock Island, IL 61201

- 1 Product Manager for Production Base Modification and Expansion
ATTN: DRCPM-PBM
Dover, NJ 07801

DISTRIBUTION LIST (Cont)

Copy No.

- 1 Product Manager for Advanced Attack Helicopter Systems
US Army Aviation Systems Command
St. Louis, MO 63166
- 1 Product Manager for AH-1 Cobra Series Aircraft
US Army Development and Readiness Command
P.O. Box #209
St. Louis, MO 63166
- 1 Commander
Rock Island Arsenal
ATTN: SARRI-CO
- 1 SARRI-ADL
Rock Island, IL 61201
- 1 Commander
Watervliet Arsenal
ATTN: SARWV-CO
Watervliet, NJ 12189
- 1 Commander
Picatinny Arsenal
ATTN: SARPA-PA-S
Dover, NJ 07801
- 1 Commander
Edgewood Arsenal
ATTN: SAREA-DE-N
Aberdeen Proving Ground, MD 21010
- 1 Commander
Human Engineering Laboratories
ATTN: DRXHE-D
Aberdeen Proving Ground, MD 21005
- 1 Commander
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-D
Aberdeen Proving Ground, MD 21005
- 1 Commandant
US Army Field Artillery Center
Fort Sill, OK 73503

DISTRIBUTION LIST (Cont)

Copy No.

1 Commandant
US Army Infantry School
Fort Benning, GA 31905

1 Commander
US Army Missile and Munitions Center and School
Redstone Arsenal, AL 35809

1 Commandant
US Army Air Defense School
Fort Bliss, TX 79916

1 Director
US Army Management Engineering Training Agency
ATTN: DRXOM-QA
Rock Island, IL 61201

1 Commander
US Army TRADOC Systems Analysis Activity
White Sands Missile Range
White Sands, NM 88002

1 Director
Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

1 Commander
Defense Logistics Studies Information Exchange
Fort Lee, VA 23801

1 Commander
US Army Logistics Management Center
ATTN: DRXMC-LS
Fort Lee, VA 23801

1 Commander
US Army Logistics Center
ATTN: ATCL-S
Fort Lee, VA 23801

12 Defense Documentation Center
Cameron Station
Alexandria, VA 22314