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PREFACE

The work described in this report was accomplished as support effort for several projectile research and development programs being conducted at Chemical Systems Laboratory. The work was started in September 1976 and completed in September 1977. The computer program is general in nature and should be applicable to any study of a projectile's trajectory.

Work was authorized under Project 1L162622A554-1, Lethal Chemical Weapons Technology.

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SUMMARY

This report describes a computer program that predicts the flight trajectory, spin decay, and gyroscopic and dynamic stability factors for spin- or fin-stabilized cannon-launched projectiles with solid or liquid payloads. The program provides a fast, accurate, and efficient method of evaluating projectile trajectories. A short introduction provides the mechanics of trajectory theory. However, no effort is made to give a complete mathematical analysis of the theory. The theory may be found in the literature cited (given as footnotes in the report).

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A COMPUTER PROGRAM FOR ANALYZING PROJECTILE FLIGHT TRAJECTORY

I. INTRODUCTION.

The purpose of this report is to present a computer program that assists design personnel in analyzing projectile flight. After aerodynamic coefficients for a proposed munition shape are derived from wind tunnel tests, a prediction of projectile stability, range, and accuracy must be made. In addition, the effect on projectile flight of a liquid payload or shift in center-of-gravity location may be required. This program can be used as a design tool in analyzing projectile flight.

II. THEORY.

A. Simple Particle Trajectory.

As in any trajectory, simple particle trajectory is the curve traced by the center of gravity of a projectile with respect to a horizontal surface when fired at a particular charge/elevation combination. However, simple particle trajectory uses velocity and aerodynamic drag to calculate the horizontal and vertical velocity components.

The fundamental equations used in the computer program are:

$$\Delta V = \left(\frac{-\text{drag}}{\text{projectile mass}} - g \sin \theta \right) \Delta t \quad (1)$$

$$\Delta \theta = \left(\frac{-g \cos \theta}{V} \right) \Delta t \quad (2)$$

$$\Delta X = (V \cos \theta) \Delta t \quad (3)$$

$$\Delta Z = (V \sin \theta) \Delta t \quad (4)$$

where

V = projectile velocity

θ = acute angle between a horizontal plane and the tangent to the trajectory at the projectile center of mass

g = gravitational constant

t = time

X = horizontal distance

Z = height above horizontal plane

B. Spin Decay for Liquid-Filled Projectiles.

When a projectile is fired from a gun, the liquid, initially, is not rotating with the projectile. During the down-range flight, the liquid acquires angular momentum from the projectile and the liquid spin rate approaches that of the projectile. This process of the liquid acquiring angular momentum is referred to as the spinup process. This process, whereby the liquid acquires angular momentum from an initial condition of zero rotation, was explained by Wedemeyer.* Wedemeyer showed that for the case of a completely filled cylinder, viscous regions, known as Ekman layers, near the end walls act as centrifugal fans sucking non-rotating liquid from the inviscid core and throwing the liquid outwards.

To incorporate liquid effects (spinup process) on rigid body spin decay, the difference between rigid body rotation and zero liquid rotation at the muzzle is calculated. The theoretical spin decay assumes a percentage of liquid rotating with the projectile at muzzle exit. The particular decay curve (see the figure) for the percentage of liquid rotating with the projectile at muzzle exit is:

$$y = a^t \quad (5)$$

where

- a = percentage of liquid rotating with the projectile at muzzle exit.
- t = time after launch
- y = spin decay correction factor.

The decay curve asymptotically approaches the t-axis. The value of y (equation 5) is multiplied by the difference between rigid body payload rotation and zero payload rotation at muzzle exit to determine projectile spin decay due to liquid effects.

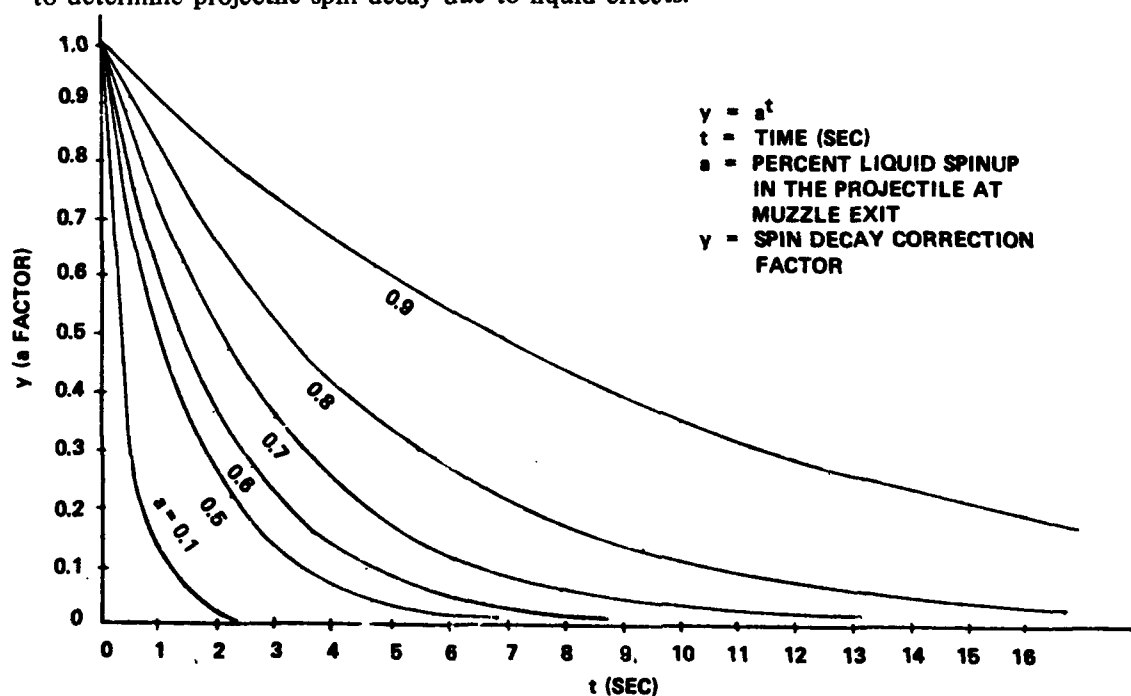


Figure. Spin Decay Curves for Liquid-Filled Spin-Stabilized Projectiles

* Wedemeyer, F. H. BRL Report 1252. The Unsteady Flow Within a Spinning Cylinder. Aberdeen Proving Ground, MD 21005. 1963.

C. Roll Rate For Fin-Stabilized Munitions.*

Unlike spin-stabilized projectiles whose spin is generated by the gun tube rifling, fin-stabilized munitions generate spin by the air flowing over the canted fin blades. The spin equilibrium roll rate, p_e , for fin munitions is:

$$p_e = \frac{-C_{ls} V S_{fc}}{C_{lp} d} \quad (6)$$

where

C_{ls} = roll moment coefficient due to fin cant (at zero spin)

C_{lp} = roll damping-moment coefficient

S_{fc} = fin cant angle, radians

V = velocity, ft/sec

d = maximum projectile body diameter, ft

Theoretically, resonance instabilities can occur in spin-stabilized projectiles due to the coincidence of spin and yaw frequencies, however, this phenomenon is more likely to occur with fin-stabilized projectiles. The spin is most likely to coincide with nutational frequency $\dot{\phi}_1$, given by:

$$\dot{\phi}_1 = \frac{P}{2} + \left(\frac{P^2}{4} - M \right)^{0.5} = \frac{P}{2} (1 + (1 - S_g)^{0.5}) \quad (7)$$

where

S_g = gyroscopic stability factor

$$M = \frac{\rho S d^3}{2 I_y} C_{Ma}$$

C_{Ma} = static moment coefficient, per radian

d = maximum body diameter, ft

ρ = air density, slug/ft³

S = projectile cross-sectional area, ft²

*Engineering Design Handbook AMCP 706-242. Design for Control of Projectile Flight Characteristics. Headquarters, US Army Materiel Command, Washington, D.C. 1966.

$$P = \frac{I_x}{I_y} \text{ and } \dot{\phi}_1 = \frac{pd}{V}$$

u = static moment factor (per radian)

p = spin in radian per caliber of travel

I_x = axial moment of inertia, slugs - ft²

I_y = transverse moment of inertia, slugs - ft²

This reduces to a resonance roll rate, p_r , represented as:

$$p_r = \left(\frac{-u}{I_y - I_x} \right)^{0.5}$$

It has been suggested that the roll rate at exit for a fin munition fired from a rifled tube should be three times resonance roll rate. A fin munition fired from a smooth-bore tube exits with zero spin. Theory states that munition roll rate will pass through resonance roll rate prior to equilibrium roll rate. The greater the equilibrium roll rate/resonance roll rate ratio the shorter time the projectile is in the vicinity of resonance roll rate, thus temporary growth in yaw due to resonance will be insignificant.

III. THE PROGRAM.

The program given in Fortran symbols on pages 13 through 20 calculates the flight trajectories of spin- and fin-stabilized projectiles with liquid or solid payloads. The input parameters (i.e., launch conditions, aerodynamic coefficients, projectile physical characteristics) required are listed at the beginning of the program. The program consists of three parts (1) the main program calculates trajectory and stability, (2) a subroutine calculates the liquid effects on projectile spin, and (3) a subroutine calculates equilibrium and resonance roll rates for a fin-stabilized munition. Sample outputs for solid and liquid spin-stabilized projectiles are shown in tables 1 and 2. Table 3 shows an output for fin-stabilized projectiles.

1* C LINEAR INTERPOLATION INPUT
 2* C ENGINEERING DESIGN HANDBOOK AMC 706-242
 3* C CALC FLIGHT TRAJECTORY OF PROJECTILE
 4* C DATA CARD 1
 5* C IJ = NUMBER OF TIMES PROGRAM EXECUTES
 6* C K = NUMBER OF COEFFICIENT CARDS
 7* C INC = TIME INCREMENT FOR PRINT OUT INC = .02 SEC
 8* C JC = 0 - ALL AERO COEFFICIENTS, 1 - VELOCITY, DRAG ONLY
 9* C JA = 0 - SOLID PAYLOAD, 1 - LIQUID PAYLOAD
 10* C JB = 0 - STABILITY FACTOR CALC, 1 - NO STABILITY FACTOR CALC
 11* C JD = 0 - SPIN STAB MUN, 1 - FIN STAR MUN
 12* C DATA CARD 2 TO N
 13* C CDT = DRAG COEFFICIENT FOR VT
 14* C VT = VELOCITY
 15* C CMA COEFFICIENT
 16* C SAG = MAGNUS COEFFICIENT
 17* C CLAL = LIFT COEFFICIENT
 18* C DAM = DAMPING MOMENT COEFFICIENT
 19* C CLSR = ROLL MOMENT COEFFICIENT
 20* C CLPD = SPIN DECELERATION COEFFICIENT
 21* C DATA CARD
 22* C THETO = ANGLE OF FIRE, DEG
 23* C VO = INITIAL VELOCITY, FT/SEC
 24* C ZO = INITIAL HEIGHT, FT
 25* C WT = WEIGHT OF SHELL, LB
 26* C DEN = AIR DENSITY, LB/CUFT
 27* C S = AREA OF SHELL, SQFT
 28* C RANGE = INITIAL RANGE, FT
 29* C DATA CARD
 30* C AXMO = AXIAL MOMENT OF SHELL, LB-SQFT
 31* C TWIST = TWIST OF SHELL, CAL/TUM
 32* C DIA = DIAMETER OF SHELL, FT
 33* C ZMSL = HEIGHT ABOVE SEA LEVEL, FT
 34* C TRANA = TRANSVERSE MOMENT OF SHELL, LB-SQFT

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36* C DATA CARD
37* C AXM = AXIAL MOMENT OF SHELL RIGID PARTS, LB-SQFT
38* C WRR = WEIGHT OF SHELL RIGID PARTS, LB
39* C AL PERCENT SPINUP/100
40* C TMAX= TIME USING LIQUID SPIN CURVES
41* C DATA CARD
42* C SECF= FIN CANT ANGLE,RADIAN
43* C P1 INITIAL SPIN AT,MU7ZLF,REV/SEC
44* COMPLEX SPRCL
45* DIMENSION VT(50),COT(50),CMA(50),SAG(50),CLA(50),DAM(50)
46* DIMENSION CLS(50),CLPD(50)
47* COMMON/BLK1/CCL,SFC,CLCP,OPT,P,T
48* COMMON/BLK2/DEN,V,S,DIA,DELT
49* COMMON/BLK3/CM,SPIN,PRATIO,AXMS,TRAN
50* COMMON/BLK4/B,W,TT,TMAX
51* C READ COEFFICIENTS
52* READ(5,15) IJ,K,INC,JC,JA,JB,JD
53* 15 FORMAT(2I2,14,4I2)
54* READ(5,57) (VT(I),COT(I),CMA(I),SAG(I),CLA(I),DAM(I),
55* 1CLS(I),CLPD(I)),I=1,K)
56* 57 FORMAT(8F10,4)
57* WRITE(6,70)
58* 70 FORMAT(17,31X,25H AERODYNAMIC COEFFICIENTS)
59* WRITE(6,58)
60* 59 FORMAT(17,1X,9H VELOCITY,1X,10H DRAG COEF,3X,4H CMA,3X,
61* 112H MAGNUS COEF,1X,10H 1 IFT COEF,3X,12H DAMPING MOM,
62* 23X,9H ROLL MOM,3X,10HSPIN DECEL)
63* WRITE(6,59) (VT(I),COT(I),CMA(I),SAG(I),CLA(I),DAM(I),
64* 1CLS(I),CLPD(I)),I=1,K)
65* 59 FORMAT(4F10,4,3X,F10,4,3X,F10,4,3X,F10,4,3X,F10,4)
66* C READ DATA
67* DO 435 JKL=1,IJ
68* 100 READ(5,11) THETO,VO,ZO,WT,DEN,S,RANGE
69* READ(5,11) AXMC,TWIST,DIA,TMSL,TRANA
70* IF(JA,EQ,0) GO TO 87
71* READ(5,52)AXM,WRR,P,TMAX
72* 57 IF(JD,EQ,0) GO TO 25
73* READ(5,11) SFC,P
74* SPIN=P
75* 57 FORMAT(8F10,3)
76* 1 FORMAT(5F10,3)
77* 11 FORMAT(5F10,3)
78* 20 WRITE(6,13)
79* 13 FORMAT(17,7X,19H INITIAL CONDITIONS)
80* C WRITE DATA
81* 20 WRITE(6,400) THETO,VO,ZO,WT,DEN,S,RANGE,AXMC,TWIST,DIA,TMSL,
82* 1TRANA
83* 400 FORMAT(17,1X,22H THETO(DEG) =,F9,3/1X,
84* 122H VO(FT/SEC) =,F9,3/1X,22H ZO(FT) =,
85* 2F9,3/1X,22H WT(LB) =,F9,3/1X,
86* 322H DEN(LB/CM3) =,F9,3/1X,22H S(SQFT) =,
87* 4F9,7/1X,22H INITIAL RANGE =,F9,3/1X,
88* 522H SHELL AXMO(LB-SQFT) =,F9,3/1X,
89* 612H TWIST(CAL/TURN) =,F9,3/1X,22H SHELL DIA(FT) =,
90* 7F9,3/1X,22H HEIGHT ABOVE SEA(FT)=,F9,3/1X,
91* 822H SHELL TRMO(LB-SQFT) =,F9,3/1
92* IF(JA,EQ,0) GO TO 320

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92*      WRITE(6,25)AXM,WRR,B,TMAX
93*      25 FORMAT(1X,22H RIGID AXMO(LR-SOFT) =,F9.3/1X,
94*      122H RIGID WT(LB)      =,F9.3/1X,
95*      222H PERCENT SPINUP/100 =,F9.3/1X,
96*      322H LIQ SPINUP TIME(SEC)=,F9.3/)
97*      320 IF(JD.EQ.0) GO TO 321
98*      WRITE(6,28) SFC,P
99*      28 FORMAT(1X,22H FIN CANT ANG(RADIAN)=,F9.3,/1X,
100*      122H INITIALSPIN(REV/SEC)=,F9.3///)
101*      321 THETO=THETO+.14159/180.
102*      WRITE(6,7)
103*      7 FORMAT(60X,15HTRAJECTORY PLOT)
104*      IF(JA.EQ.0) GO TO 365
105*      WRITE(6,366)
106*      366 FORMAT(1/45X,42H THEORETICAL LIQUID FILLED PROJECTILE SPIN./)
107*      365 WRITE(6,8)
108*      8 FORMAT(8X,4HTIME,4X,4HTRAJ,5X,5HHORIZ,5X,4HVERT,6X,3HVEL,6X,
109*      13HACC,5X,3HACC,5X,4HDRAJ,6X,2HCD,7X,3HDEN,5X,4HSPIN,8X,3HYAL,/,
110*      116X,5HANGLE,4X,4HDIST,32X,5HANGLE,39X,4HREAL,4X,3HIMG,/,
111*      17X,5H(SEC),4X,5H(DEG),4X,3H(M),8X,5H(M),2X,4H(FT/SEC),
112*      13X,4H(FT/,6X,3HDEG,3X,5H(FT/LB-,14X,4H(LB/,
113*      15X,5H(REV/,7X,5H(DEG),/,51X,7HSEC 50),10X,7HSEC 50),
114*      112Y,6HFT CU),5X,3HSEC)
115*      C INITIALIZATION
116*      X1=PANGF/3.281
117*      X=PANGE
118*      TI=0.0
119*      IF (Z0.GT.0.0) GO TO 23
120*      Z0=.01
121*      23 Z=Z0
122*      Z1=Z/3.281
123*      T=0.0
124*      THETA=THETO
125*      DELT=0.02
126*      V=V0
127*      IF(TWIST.EQ.0) GO TO 435
128*      430 TWIST0=TWIST
129*      TWISTL=TWIST
130*      SRPC=6.28318/TWIST
131*      GO TO 43E
132*      43E SRPC=(6.28318+P+DIA)/V
133*      43A SRPC0=SRPC
134*      AXMS=AXMO/32.17
135*      AXMP=AXM/32.17
136*      W=WT/32.17
137*      WR=WR/32.17
138*      TRAN=TRANA/32.17
139*      OPT=0
140*      KOPT=0
141*      VDEN=DEN
142*      DENSL = (EXP(7MSL/22000.0)) * DEN
143*      C DETERMINE DRAG,CMA,MAGNUS
144*      16 IF(V.LT.VT(1)) GO TO 34
145*      GO TO 18
146*      34 V=VT(1)
147*      18 J=2
148*      20 IF (V-VT(J))112,111,110

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149*      110 J=J+1
150*      500 IF (J.LT.K1) GO TO 69
151*      WRITE(6,55)
152*      55 FORMAT(1X,20H ERROR STATEMENT 500)
153*      STOP
154*      111 CD=CDT(J)
155*      CM=CMA(J)
156*      SA=SAG(J)
157*      DA=DAM(J)
158*      CSL=CLS(J)
159*      CLDP=CLPD(J)
160*      CL=CLA(J)
161*      IF (OPT.GT.0) GO TO 40
162*      GO TO 81
163*      112 CD=CDT(J-1)+(CDT(J)-CDT(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
164*      CM=CMA(J-1)+(CMA(J)-CMA(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
165*      SA=SAG(J-1)+(SAG(J)-SAG(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
166*      DA=DAM(J-1)+(DAM(J)-DAM(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
167*      CSL=CLS(J-1)+(CLS(J)-CLS(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
168*      CLDP=CLPD(J-1)+(CLPD(J)-CLPD(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
169*      CL=CLA(J-1)+(CLA(J)-CLA(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
170*      IF (OPT.GT.0) GO TO 40
171*      31 NCNT1=0
172*      NCNT2=0
173*      C VELOCITY COMPONENTS
174*      VX=V*COS(THETA)
175*      VZ=V*SIN(THETA)
176*      FACTOR = .5*DEN*CD*S
177*      GO TO 169
178*      40 FACTOR = .5*VDEN*CD*S
179*      C DRAG COMPONENTS
180*      159 DRAG=FACTOR*V*V
181*      DX=DRAG*COS(THETA)
182*      DZ=DRAG*SIN(THETA)
183*      C ACCELERATION
184*      AX=-DRAG/WT*COS(THETA)
185*      AZ=-DRAG/WT*SIN(THETA)-32.17
186*      THEACC=ATAN2(AZ,AX)
187*      A=SQRT(AX*AX+AZ*AZ)
188*      IF (Z) 50,50,45
189*      45 THEACC=THEACC+180./3.14159
190*      THETA=THETA+180./3.14159
191*      C PRINT OUT INTERVAL
192*      IF (NCNT1.NE.NCNT2) GO TO 21
193*      IF (JD.EQ.1) GO TO 360
194*      705 FORMAT(4F15.4)
195*      SPR=VO/(DIA*TWIST0)
196*      SPIN=SPR
197*      IF (JA.EQ.0) GO TO 360
198*      SPINL=VO/(DIA*TWISTL)
199*      SPIN=SPINL
200*      360 IF (JC.GT.0) GO TO 300
201*      WRITE(6,2) T,THETA,X1,Z1,V,A,THEACC,DRAG,CD,VDEN,
202*      1SPIN,SPRCL
203*      2 FORMAT(1H,2X,6F3.2,2F3.5,1F4.2,2F7.3)
204*      GO TO 310
205*      310 WRITE(6,4) T,THETA,X1,Z1,V,A,THEACC,DRAG,CD,VDEN,SPIN

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206*      4  FORMAT(3X,8F9.2,2F9.5,1F9.2)
207*      310 NCNT1=NCNT1+INC
208*      21  NCNT2=NCNT2+1
209*      VXSAVE=VX
210*      VZSAVE=VZ
211*      VSAVE=SQRT(VXSAVE*VXSAVE+VZSAVE*VZSAVE)
212*      THETAS=ATAN2(VZSAVE,VXSAVE)
213*      TSAVE=T
214*      XSAVE=X
215*      ZSAVE=Z
216*      DXSAVE=DX
217*      DZSAVE=DZ
218*      AXSAVE=AX
219*      AZSAVE=AZ
220*      C INCREMENTING TRAJECTORY
221*      DELVX=AX*DELT
222*      DELVZ=AZ*DELT
223*      DELX=DELT*(VX+.5*DELVX)
224*      DELZ=DELT*(VZ+.5*DELVZ)
225*      VX=VX+DELVX
226*      VZ=VZ+DELVZ
227*      T=T+DELT
228*      THETA=ATAN2(VZ,VX)
229*      V=SQRT(VX*VX+VZ*VZ)
230*      X=X+DELX
231*      XOIST=X-XSAVE
232*      X1=X/3.281
233*      Z=Z+DELZ
234*      ZOIST=Z-ZSAVE
235*      VDFN = (EXP((-ZMSL-Z1/22000*.01))*DENS1
236*      IF (VDEN.LE.DEN) GO TO 43
237*      VDFN = DEN
238*      43  Z1=Z/3.281
239*      C SPIN CALCULATION
240*      FAC=VDEN*.785*DIA*DIA/(2.0*WT)
241*      IF (JD.EQ.0) GO TO 214
242*      CALL FTN
243*      214 DIST=SQRT(XOIST*ZOIST+ZOIST*ZOIST)
244*      RGA=W*W*DIA*.2./AXM0
245*      RGT=W*W*DIA*.2./TRAN
246*      ARATIO=COS(THETA)/(COS(THETAS))
247*      CLP=-CD/(3.0*RGAT)
248*      COF=RGAT*CLP+CD
249*      SRPC=SRPC0+ARATIO*(EXP(FAC*DIST*COF))
250*      TWISTO=(6.28318*V0)/(SRPC*V)
251*      SRPC0=SRPC
252*      IF (JA.EQ.0) GO TO 370
253*      IF (TI.GE.TMAX) GO TO 370
254*      DSRPC=SRPC*(AXM/AXM0)
255*      SP1=SRPC-DSRPC
256*      CALL DECAY
257*      SP2=W*SP1
258*      SPL=SP2+DSRPC
259*      TWISTL=(6.28318*V0)/(SPL*V)
260*      IF (TI.GE.TMAX) GO TO 371
261*      GO TO 370
262*      371 IF (KOPT.EQ.2) GO TO 370

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263*      TWISTO=TWISTL
264*      SRPCO=SPL
265*      JA=0
266*      KOPT=2
267*      C YAW CALCULATION
268*      370 ADEN=VDEN/32.17
269*      SPRC=SRPC*(1./DIA)*V
270*      YAW1=AXMS*SPRC*32.17*COS(THETA)
271*      YAW2=.5*ADEN*S*DIA*CM*V**3.
272*      YAW3=(YAW1/YAW2)*180./3.14159
273*      YAW4=(SA*SPRC*DIA)/(CM*V)
274*      YAW5=(YAW3*YAW4)*180./3.14159
275*      SPRC1=CMPLX(YAW3,YAW5)
276*      IF(OPT.GT.0) GO TO 35
277*      C U= STATIC MOMENT FACTOR, LB-FT/RADIAN
278*      U=.39269*ADEN*DIA**3.*V**2.*CM
279*      IF(JB.GT.0) GO TO 35
280*      IF(JA.GT.0) GO TO 36
281*      C SOLID FILLED PROJECTILE
282*      C GYROSCOPIC STABILITY FACTOR
283*      SG=(AXMS**2.*SPRC**2.)/(4.*TRAN*U)
284*      C DYNAMIC STABILITY ESTIMATE
285*      SD1=2.*(CL+RGA*SA)
286*      SD2=CL-CD*(1-RGT*DA)
287*      GO TO 37
288*      C LIQUID FILLED PROJECTILE
289*      36 SG1=(AXMS**2.*SPRC**2.)/(4.*TRAN*U)
290*      SG2=AXMR/AXMS
291*      SG=SG1*SG2**2.
292*      RGAR=(WR*DIA**2.)/AXMR
293*      RGTR=(WW*DIA**2.)/TRAN
294*      SD1=2.*(CL+RGAR*SA)
295*      SD2=CL-CD*(RGTR*DA)
296*      37 SD0=SD1/SD2
297*      SG1=1./SG
298*      SD=SD0*(2.-SD0)
299*      35 OPT=1
300*      GO TO 16
301*      C DETERMINE POINT OF IMPACT
302*      50 RATIO=-ZSAVE/DELZ
303*      XFNL=RATIO*DELX+XSAVE
304*      XMFINL=XFNL/3.281
305*      ZFNL=RATIO*DELZ+ZSAVE
306*      ZMFINL=ZFNL/3.281
307*      TFNL=RATIO*(T-TSAVE)+TSAVE
308*      VXFNL=RATIO*DELVX+VXSAVE
309*      VZFNL=RATIO*DELVZ+VZSAVE
310*      VFNL=SQRT(VXFNL*VXFNL+VZFNL*VZFNL)
311*      THFNL=ATAN2(VZFNL,VXFNL)
312*      AXFNL=RATIO*(AX-AXSAVE)+AXSAVE
313*      AZFNL=RATIO*(AZ-AZSAVE)+AZSAVE
314*      AFNL=SQRT(AXFNL*AXFNL+AZFNL*AZFNL)
315*      THACFL=ATAN2(AZFNL,AXFNL)
316*      DXFNL=RATIO*(DX-DXSAVE)+DXSAVE
317*      DZFNL=RATIO*(DZ-DZSAVE)+DZSAVE
318*      DFNL=SQRT(DXFNL*DXFNL+DZFNL*DZFNL)
319*      THACFL=THACFL*180./3.14159

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320*      THEFNL=THEFNL*.180./3.14159
321*      WRITE(6,3) TFINAL,THEFNL,XMFINL,ZMFINL,VFINAL,AFINAL,
322*      1THACFL,DFINAL
323*      3 FORMAT(1X,15HPOINT OF IMPACT,/,3X,8F9.2)
324*      C COMPARE SG TO SDO
325*      IF(JD.EQ.0) GO TO 379
326*      WRITE(6,381)PRATIO
327*      361 FORMAT(/,1X,42H RATIO OF EQUILIBRIUM ROLL/RESONANCE ROLL =,F10.4)
328*      379 IF(KOPT.NE.2) GO TO 471
329*      JA=1
330*      471 IF(JB.GT.0) GO TO 495
331*      IF(JA.EQ.1) GO TO 106
332*      WRITE(6,121)
333*      121 FORMAT(/,1X,23HSOLID FILLED PROJECTILE)
334*      GO TO 122
335*      106 WRITE(6,113)
336*      113 FORMAT(/,1X,24H LIQUID FILLED PROJECTILE)
337*      122 WRITE(6,101) SG
338*      101 FORMAT(/,1X,30HGYROSCOPIC STABILITY FACTOR =,F10.4)
339*      WRITE(6,102) SDO
340*      102 FORMAT(/,1X,27HDYNAMIC STABILITY FACTOR =,F13.4)
341*      IF(SG1.GE.SD) GO TO 210
342*      WRITE(6,205) SG1,SD
343*      205 FORMAT(/,1X,49H PROJECTILE IS STABLE SINCE : 1./SG < SDO(2.0-SDO),
344*      1.F10.4,3H < ,F7.4)
345*      GO TO 495
346*      210 WRITE(6,220) SG1,SD
347*      220 FORMAT(/,1X,51H PROJECTILE IS UNSTABLE SINCE : 1./SG > SDO(2.0-SDO),
348*      1.F10.4,3H > ,F7.4)
349*      495 CONTINUE
350*      550 END

```

```

1*      C THIS SUBROUTINE CALCULATES THE PROJECTILE SPIN
2*      C DECAY ASSUMING VARIOUS LIO SPINUP IN THE TUBE,B.
3*      C W IS THE PERCENT DECAY AT TIME,TI, FOR A GIVEN R
4*      SUBROUTINE DECAY
5*      COMMON/BLK4/B,W,TT,TMAX
6*      IF(B.GT.0.0.AND.B.LT.1.0) GO TO 10
7*      WRITE(6,5)
8*      5 FORMAT(1X,21H ERROR PERCENT SPINUP)
9*      STOP
10*      10 W=R**TI
11*      TI=TI+.02
12*      IF(TI.LT.TMAX) GO TO 20
13*      TMAX=TI
14*      GO TO 70
15*      20 IF(W.GT.0.001) GO TO 70
16*      TMAX=TI
17*      70 RETURN
18*      END

```

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1* C SUBROUTINE CALCULATES SPIN FOR A FIN MUNITION
2* C PE IS THE EQUILIBRIUM ROLL RATE.
3* C PR IS THE RESONANCE ROLL RATE
4* SUBROUTINE FIN
5* COMMON/BLK1/CSL,SFC,CLOP,OPT,P,T,
6* COMMON/BLK2/DEN,V,S,DIA,DELT
7* COMMON/BLK3/CM,SPIN,PRATIO,AXMS,TRAN
8* REAL MU
9* DOUBLE PRECISION SPI,E
10* E=2.71828**T
11* D1=-CSL/CLOP
12* D2=(V*SFC)/DIA
13* SPIN=D1*D2
14* IF(T.EQ.5.) GO TO 50
15* IF(P.EQ.SPIN) GO TO 50
16* IF(P.LT.SPIN) GO TO 40
17* SPI=SPIN+(P-SPIN)*(1./E)
18* GO TO 45
19* 40 SPI=P+(1.-(1./E))*(SPIN-P)
20* 45 SPIN=SPI
21* 50 MU=.5*DEN*V**2.*S*DIA*CM
22* IF(OPT.GT.0.) GO TO 30
23* IF(CM.LE.0.0) GO TO 10
24* WRITE(6,20)
25* 20 FORMAT(/,1X,45H SUBROUTINE REQUIRES NEGATIVE STATIC MOM COEF)
26* STOP
27* 10 PR=(SQRT(-MU/(TRAN-AXMS)))/(2.*3.1416)
28* PRATIO=SPIN/PR
29* 30 RETURN
30* END

```

Table 1. Output for Spin-Stabilized Solid-Filled Projectile

TIME (SEC)	TRAJ ANGLE (DEG)	HORIZ DIST (M)	VERT (M)	VEL (FT/SEC)	ACC (FT/ SEC SQ)	TRAJECTORY PLOT		CD	DEN (LB/ FT CU)	SPIN (REV/ SEC)	REAL (DEG)	IMG
						ACC ANGLE DEG	DRAG (FTLB- SEC SQ)					
.00	16.18	.00	6.10	1266.14	61.62	-133.72	4567.97	.36939	.07600	124.50	.000	.000
4.00	10.04	1389.18	334.03	1089.39	45.77	-126.17	2825.64	.32442	.07231	119.39	.220	.932
8.00	3.00	2648.27	480.31	1003.45	35.05	-110.56	1269.76	.17561	.07075	115.71	.271	1.082
12.00	-4.51	3843.55	465.66	963.33	32.86	-107.07	396.58	.14921	.07090	115.07	.310	1.207
16.00	-12.16	4991.30	297.78	943.95	31.56	-107.04	974.53	.14823	.07270	113.54	.314	1.206
POINT OF IMPACT												
19.82	-19.36	6045.17	.00	940.70	30.36	-107.75	1010.73					

SOLID FILLED PROJECTILE

GYROSCOPIC STABILITY FACTOR = 1.8597

DYNAMIC STABILITY FACTOR = .3809

PROJECTILE IS STABLE SINCE : $L/S6 < SDO12.0-SDO1$.5377 < .6167

Table 2. Output for Spin-Stabilized Liquid-Filled Projectile

TRAJECTORY PLOT													
THEORETICAL LIQUID FILLED PROJECTILE SPIN													
TIME (SEC)	TRAJ ANGLE (DEG)	HORIZ DIST (M)	VERT (M)	VEL (FT/SEC)	ACC (FT/SEC ²)	ACC ANGLE DEG	DRAG (FT/SEC ²)	CD	DEN (LB/FT CU)	SPIN (REV/SEC)	REAL (DEG)	YAW ING	
0.00	22.94	0.00	6.10	1266.14	64.14	-129.55	4567.97	-36.939	-0.7600	124.50	-0.00	-0.00	
4.00	16.98	1333.26	495.05	1078.99	45.76	-120.77	2521.64	-30.230	-0.7059	115.60	-2.13	-0.71	
8.00	10.00	2549.95	789.65	987.40	35.37	-106.39	1041.63	-15.611	-0.6756	113.32	-2.91	1.113	
12.00	2.37	3712.91	917.32	937.12	33.61	-104.01	673.73	-14.788	-0.6628	111.90	-3.56	1.347	
16.00	-5.62	4834.31	886.30	908.11	32.37	-104.10	816.12	-14.642	-0.6659	110.59	-3.90	1.453	
20.00	-13.68	5917.08	702.16	898.14	31.26	-104.29	817.69	-14.592	-0.6844	109.31	-3.80	1.400	
24.00	-21.48	6962.09	370.33	904.39	30.12	-105.18	871.07	-14.623	-0.7192	107.99	-3.34	1.216	
POINT OF IMPACT													
27.22	-27.41	7775.33	0.00	918.78	29.09	-106.47	956.97						
LIQUID FILLED PROJECTILE													
GYROSCOPIC STABILITY FACTOR =				1.7077									
DYNAMIC STABILITY FACTOR =				1.3250									
PROJECTILE IS STABLE SINCE :				1./56 < 500(2.0-SDC)									
				.5856 < .8944									

Table 3. Output for Fin-Stabilized Solid-Filled Projectile

TIME (SEC)	TRAJ ANGLE (DEG)	HORIZ DIST (M)	VERT (M)	VEL (FT/SEC)	ACC (FT/ SEC SQ)	TRAJECTORY PLOT ANGLE DEG	CD	DEFN (LB/ FT CU)	SPIN (REV/ SEC)	YAW REAL (DEG)	IMG (DEG)
-00	51.00	-00	6.10	3850.00	143.04	-120.86	-14.501	-07600	385.00	-000	-000
20.00	42.86	12822.97	13995.62	2684.74	37.76	-94.49	-15.700	-00943	378.09	-3.68	-000
40.00	30.76	24605.85	22987.34	2224.89	32.97	-92.26	-17.387	-00247	377.16	-2.152	-000
60.00	14.41	36201.17	27933.13	1956.39	32.33	-91.05	-18.911	-00118	376.87	-5.689	-000
80.00	-4.78	47719.00	28934.91	1891.10	32.13	-90.89	-19.356	-00102	376.69	-7.068	-000
100.00	-23.07	59172.41	26020.91	2035.35	31.85	-91.41	-16.373	-00157	376.48	-3.904	-000
120.00	-37.65	70520.00	19234.89	2331.75	30.52	-94.21	-16.901	-00432	376.03	-1.101	-000
140.00	-48.44	81535.56	8409.56	2625.37	22.83	-117.62	-15.878	-02043	374.22	-0.160	-000
POINT OF IMPACT											
154.10	-54.60	88529.32	-00	2522.15	35.00	157.56	5530.97				

RATIO OF EQUILIBRIUM ROLL/RESONANCE ROLL = -.0154

IV. CONCLUSIONS.

The program analyzes projectile flight as shown by the sample outputs. These predictions for spin- and fin-stabilized projectiles will assist design personnel in evaluating a projectile flight. However, it should be noted that since the program does not take into account meteorological conditions, other than air density, and that it adapts simple particle trajectory theory, the output provides a good trajectory estimate for a projectile fired under normal conditions.

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