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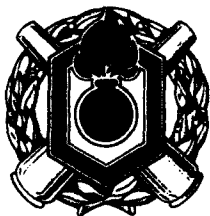
Technical Report ARAED-TR-92011

**WIND TUNNEL SPIN DATA REDUCTION TO OBTAIN
AERODYNAMIC SPIN DAMPING COEFFICIENTS BY USING
NONLINEAR EQUATION OF MOTION**

Chiu H. Ng
and
Seungeuk Han

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13. ABSTRACT (Maximum 200 words) A computer program, SPINFIT, is designed for extracting the linear and nonlinear spin damping coefficients by fitting calculated values to the observed wind tunnel spin data. The approach used in this program is the technique developed by Chapman and Kirk of Ames, NASA. The example given in this report showed significant improvement in fitting with the nonlinear spin damping term in the equation of motion when compared to this exponential fit.				
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SUMMARY

A computer program, SPINFIT, is designed for determining the linear and nonlinear spin damping coefficients by fitting calculated values to the observed wind tunnel spin data. The previous method of fitting a closed form (exponential form) of the differential equation for spin rate only considered linear spin damping coefficients. The results from this exponential fitting were found to be unsatisfactory for some cases of the wind tunnel test data. This result suggested that a nonlinear spin damping coefficient term should be included in the equation of motion.

The SPINFIT computer program uses an equation that has a second order term in spin rate to extract the nonlinearity in a spin damping coefficient. This was demonstrated by fitting the wind tunnel spin-up test data for the 81-mm M819 RP smoke projectile. The result shows that the SPINFIT more closely fits the data when compared to the exponential fitting. This indicates that the spin-up test data has considerable amount of nonlinearity in spin damping coefficient. Because of the additional second order term, the residuals and the probable errors are reduced, and the estimated values of initial spin rate and steady state spin rate are closer to the observed wind tunnel test data when compared to the results from the exponential fit.

The SPINFIT program is not limited to the reduction of wind tunnel test spin data. It can also be used for free flight test data when sufficient data points are available for the fitting process.

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INTRODUCTION

Exponential fitting is done by matching the solution of the linear equation of motion to the observed data points. This method assumes that there is no nonlinearity in the spin damping coefficient. Therefore, this method may be used successfully only if the spin data contains negligible nonlinearities in spin damping coefficient. However, in many cases, the large nonlinearity does exist and the second order term in spin damping coefficient must be added to the equation of motion.

A computer program called SPINFIT has been developed to extract the nonlinear spin damping coefficient by adding a second order spin damping term in the differential equation of motion. Because of this additional coefficient, it's able to match the observed data curve more closely. Even though the first order differential equation with nonlinear spin damping term can be integrated to obtain a closed form solution, the approach used in this program can handle any additional higher order spin damping terms in the differential equation with simple modification.

Chapman and Kirk of Ames, National Aeronautics and Space Administration, developed a technique which is used to extract aerodynamic coefficients from projectile angular motion by numerically integrating the second order differential equations of motion and fitting the results to the observed data (ref 1). This report employed this technique to determine the linear and nonlinear spin damping coefficients from the wind tunnel experimental spin data.

ANALYSIS

The equation of motion for the spin of a test model is assumed to be in the form of

$$\dot{P} = \frac{qsd}{I_x} \left\{ C_{l_1} \delta + C_{l_1} \left(\frac{Pd}{2V} \right) + C_{l_2} \left(\frac{Pd}{2V} \right)^2 \right\} + \frac{L_f}{I_x} \quad (1)$$

$$q = \frac{1}{2} \rho V^2$$

$$S = \pi R^2 = \frac{1}{4} \pi d^2$$

where $\frac{L_f}{I_x}$ is bearing friction term in wind tunnel test.

And

$$\dot{P} = \left(\frac{qsd}{I_x} \right) C_{l, \delta} + \frac{L_f}{I_x} + \left(\frac{qsd}{I_x} \right) \left(\frac{d}{2V} \right) C_{l, P} + \left(\frac{qsd}{I_x} \right) \left(\frac{d}{2V} \right)^2 C_{l, P^2}$$

Let's define

$$C_2 = \left(\frac{qsd}{I_x} \right) C_{l, \delta} + \frac{L_f}{I_x}$$

$$C_3 = \left(\frac{qsd}{I_x} \right) \left(\frac{d}{2V} \right) C_{l, P}$$

$$C_4 = \left(\frac{qsd}{I_x} \right) \left(\frac{d}{2V} \right)^2 C_{l, P^2}$$

and

$$C_1 = P_0 \quad @ \quad t = 0.0 \quad \text{Initial condition}$$

So rewrite the equation in terms of C's

$$\dot{P} = C_2 + C_3 P + C_4 P^2 \quad (2)$$

The constant C_2 , C_3 , and C_4 can be determined by fitting the solution of the assumed differential equation of motion directly to the observed wind tunnel spin data (P_o).

During the fitting process, the initial spin C_1 and the spin parameters C_2 , C_3 , and C_4 will be adjusted until the best fit is obtained. The best fit is defined as when the sum of the squares of the residuals (R_e) defined below is a minimum.

$$R_e = \frac{1}{2} \sum_{i=1}^N [P_c(t_i) - P_o(t_i)]^2 \quad (3)$$

Where N is the total number of data points and t_i is the time at the i^{th} data point. The necessary conditions for residual to be minimum with respect to the initial spin C_1 and the spin parameters C_2 , C_3 , and C_4 are

$$\frac{\partial R_e}{\partial C_k} = - \sum_{i=1}^N [P_c(t_i) - P_o(t_i)] \frac{\partial P_c(t_i)}{\partial C_k} = 0.0 \quad k=1,2,3,4 \quad (4)$$

Since P is an implicit function of C_j 's, the equation has to be solved by iteration procedure. To obtain the corrections for the parameters from the j^{th} iteration to the

$j + 1^{st}$ iteration, P is expanded in a Taylor Series. Neglecting the second and higher order terms, then the result becomes

$$P_c(t_i)_{j+1} = P_c(t_i)_j + \frac{\partial P(t_i)}{\partial C_1} \big|_j \Delta C_1 + \frac{\partial P(t_i)}{\partial C_2} \big|_j \Delta C_2 + \frac{\partial P(t_i)}{\partial C_3} \big|_j \Delta C_3 + \frac{\partial P(t_i)}{\partial C_4} \big|_j \Delta C_4 \quad (5)$$

For $i=1,2,\dots,N$

The equation (5) is substituted into equation (4) for calculating the $j+1^{st}$ corrections. For simplicity, the subscripts j and $j + 1$ will be omitted in the following expressions without ambiguity.

$$\begin{aligned} \sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) - \frac{\partial P_c(t_i)}{\partial C_1} \Delta C_1 - \frac{\partial P_c(t_i)}{\partial C_2} \Delta C_2 - \frac{\partial P_c(t_i)}{\partial C_3} \Delta C_3 - \frac{\partial P_c(t_i)}{\partial C_4} \Delta C_4 \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_1} \right\} &= 0.0 \\ \sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) - \frac{\partial P_c(t_i)}{\partial C_1} \Delta C_1 - \frac{\partial P_c(t_i)}{\partial C_2} \Delta C_2 - \frac{\partial P_c(t_i)}{\partial C_3} \Delta C_3 - \frac{\partial P_c(t_i)}{\partial C_4} \Delta C_4 \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_2} \right\} &= 0.0 \\ \sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) - \frac{\partial P_c(t_i)}{\partial C_1} \Delta C_1 - \frac{\partial P_c(t_i)}{\partial C_2} \Delta C_2 - \frac{\partial P_c(t_i)}{\partial C_3} \Delta C_3 - \frac{\partial P_c(t_i)}{\partial C_4} \Delta C_4 \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_3} \right\} &= 0.0 \\ \sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) - \frac{\partial P_c(t_i)}{\partial C_1} \Delta C_1 - \frac{\partial P_c(t_i)}{\partial C_2} \Delta C_2 - \frac{\partial P_c(t_i)}{\partial C_3} \Delta C_3 - \frac{\partial P_c(t_i)}{\partial C_4} \Delta C_4 \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_4} \right\} &= 0.0 \end{aligned}$$

That is

$$\sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) - \sum_{l=1}^4 \frac{\partial P_c(t_i)}{\partial C_l} \Delta C_l \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_k} \right\} = 0.0 \quad \text{where } k=1,2,3,4$$

Since the summation operator is reversible, and after manipulation, the above equation yields

$$\sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_k} \right\} = \sum_{l=1}^4 \left\{ \sum_{i=1}^N \left\{ \frac{\partial P_c(t_i)}{\partial C_l} \frac{\partial P_c(t_i)}{\partial C_k} \right\} \Delta C_l \right\} \quad \text{where } k=1,2,3,4$$

Rewrite the equation in matrix notation

$$\begin{aligned}
 & [A][C] = [B] \\
 & A_{i,k} = \sum_{i=1}^N \left\{ \frac{\partial P_c(t_i)}{\partial C_l} \frac{\partial P_c(t_i)}{\partial C_k} \right\} \quad l,k=1,2,3,4 \\
 & B_k = \sum_{i=1}^N \left\{ P_e(t_i) - P_c(t_i) \right\} \left\{ \frac{\partial P_c(t_i)}{\partial C_k} \right\} \quad k=1,2,3,4 \\
 & C_k = \Delta C_k \quad \text{where } k=1,2,3,4
 \end{aligned}$$

Where the dimensions are (4 by 4), (4 by 1), and (4 by 1), respectively.

Then the correction of spin parameters ΔC_1 , ΔC_2 , ΔC_3 , and ΔC_4 , can be determined by $[C] = [A]^{-1} [B]$ if and only if the $[A]^{-1}$ exists.

The iteration process is employed to obtain corrections of the spin parameters from the equation by fitting the wind tunnel spin data. It will be terminated if any prescribed degree of convergence or number of iterations is reached. The method of obtaining the partial derivatives is to integrate the parametric spin function of the spin parameters with time.

If we assumed the order of differentiation can be reversed then that is

$$\begin{aligned}
 \frac{\partial}{\partial C_j} \dot{P}(t_i) &= \frac{\partial}{\partial C_j} \left\{ \frac{dP(t_i)}{dt} \right\} = \frac{d}{dt} \left\{ \frac{\partial P(t_i)}{\partial C_j} \right\} = \dot{Q}_j(t_i) \\
 \text{Where } Q_j(t_i) &= \frac{\partial P(t_i)}{\partial C_j} \quad J = 1,2,3,4
 \end{aligned}$$

Then

$$\begin{aligned}
 \dot{Q}_1 &= (C_3 + 2C_4 P) Q_1 \\
 \dot{Q}_2 &= (C_3 + 2C_4 P) Q_2 + 1 \\
 \dot{Q}_3 &= (C_3 + 2C_4 P) Q_3 + P \\
 \dot{Q}_4 &= (C_3 + 2C_4 P) Q_4 + P^2
 \end{aligned}$$

with (t_i) omitted for the P and Q's

In the program, equations for spin and Q_j calculations are integrated numerically with the initial conditions of

$$P(0) = C_1$$

$$Q_1(0) = 1.0$$

$$Q_2(0) = Q_3(0) = Q_4(0) = 0.0$$

At each iteration, the corrections for the spin parameters is added to values to get new spin parameters, and the new spin data is calculated and compares with the wind tunnel spin data. This process is repeated until the residual reaches its minimum value or reaches the iteration number limit.

RESULTS AND DISCUSSION

The SPINFIT program gives improved fitting when compared to the exponential fit. The differential equation of motion for spin used in the program is as follows:

$$\dot{P} = \frac{qsd}{I_x} \left\{ C_{l_1} \delta + C_{l_p} \left\{ \frac{Pd}{2V} \right\} + C_{l_{p^2}} \left\{ \frac{Pd}{2V} \right\}^2 \right\} + \frac{L_f}{I_x}$$

Unlike the equation above, the exponential fit results from the solution of a differential equation which does not contain the second order term $C_{l_{p^2}}$. The exponential fit cannot take into account the nonlinearity in the observed data because the equation doesn't have higher order terms. As we all know, more higher order terms give better estimated results, but in most cases, terms higher than the second order, are not needed because the higher order terms are negligible in spin damping coefficient. The SPINFIT program contains a second order term to handle nonlinearity in the observed spin data for better fitting.

For the example of M819 RP smoke cartridge, configuration 119123 (round 137) wind tunnel spin-up test data, it shows larger residual from the exponential fit than from the SPINFIT program. According to the computer results, the spin-up test data has nonlinearity which the SPINFIT program is able to detect. The calculated

spin data curve from the SPINFIT follows the test data more closely than the exponential one.

The significant improvement of using nonlinear fit method to calculate initial spin rate and the steady state spin rate was observed from the example. From the computed result, SPINFIT gave 0.05 rev/s of probable error for the initial spin rate where the exponential fit gave 0.12 rev/s. Overall residual of SPINFIT result was 0.33 (rev/s)² when the exponential fit was 2.98 (rev/s)². The SPINFIT reduced the probable error of fitting process to 0.0098 rev/s from 0.085 rev/s of the exponential fit. The results of the fits are summarized in tables 1 and 2.

CONCLUSIONS

The nonlinear and exponential fits to the observed data for 81-mm M819 RP smoke cartridge spin-up wind tunnel test are shown in the figure. The fit obtained using the nonlinear spin damping term in the equation of motion is improved when compared to the exponential fit. That is because the wind tunnel data does contain nonlinearity and it is handled by the second order term of the differential equation of motion in the SPINFIT program. This program gives excellent estimations of an initial spin rate, a steady state spin rate, and spin damping coefficients

Table 1. Linear and nonlinear fitting comparisons

COMPARISON		
ITEMS	EXPONENTIAL FIT	SPINFIT
STEADY STATE SPIN RATE (rev/sec)	29.331	26.7534
SPIN DAMPIN MOMENT COEFF AT STEADY STATE	-0.01096	-0.00866
TOTAL RESIDUAL (rev/sec) ²	2.981	0.330
TOTAL PROBABLE ERROR (rev/sec)	0.2483	0.0846
P_0	1.34	1.89
PROBABLE ERROR OF P_0	0.12	0.05
$C_{l\delta}$	0.0008	0.0006
PROBABLE ERROR OF $C_{l\delta}$	0.000015	0.000013
C_{l_p}	-0.011	0.004
PROBABLE ERROR OF C_{l_p}	0.000	0.000801
$C_{l_{p^2}}$	N/A	-0.183
PROBABLE ERROR OF $C_{l_{p^2}}$	N/A	0.010131

Table 2. Observed and calculated data points

OBSERVED DATA POINTS AND FITTED RESULT POINTS				
NUM.	TIME	OBSERVED SPIN	EXPONENTIAL FIT	SPINFIT
	sec	rev/sec	rev/sec	rev/sec
1	1.94	1.82	1.3363	1.8898
2	2.41	2.55	2.3494	2.6902
3	2.76	3.24	3.0799	3.2881
4	3.05	3.87	3.6701	3.7842
5	3.29	4.44	4.1486	4.1949
6	3.51	4.62	4.5793	4.5711
7	3.72	5.0	4.9836	4.9299
8	3.92	5.0	5.3625	5.2711
9	4.19	5.85	5.8647	5.7307
10	4.51	6.49	6.4462	6.2734
11	4.82	6.67	6.9959	6.7965
12	5.10	7.27	7.4810	7.2664
13	5.43	7.83	8.0392	7.8163
14	5.80	8.37	8.6481	8.4274
15	6.15	9.00	9.2081	8.9993
16	6.48	9.47	9.7221	9.5324
17	6.78	10.00	10.1781	10.0114
18	7.08	10.59	10.6234	10.4846
19	7.40	10.91	11.0870	10.9827
20	7.76	11.43	11.5949	11.5343
21	15.0	20.25	19.2783	20.1429
22	21.5	23.90	23.2928	24.0043
23	25.5	25.25	24.9185	25.1993
24	30.5	26.10	26.3497	26.0038
25	32.5	26.10	26.7824	26.1951

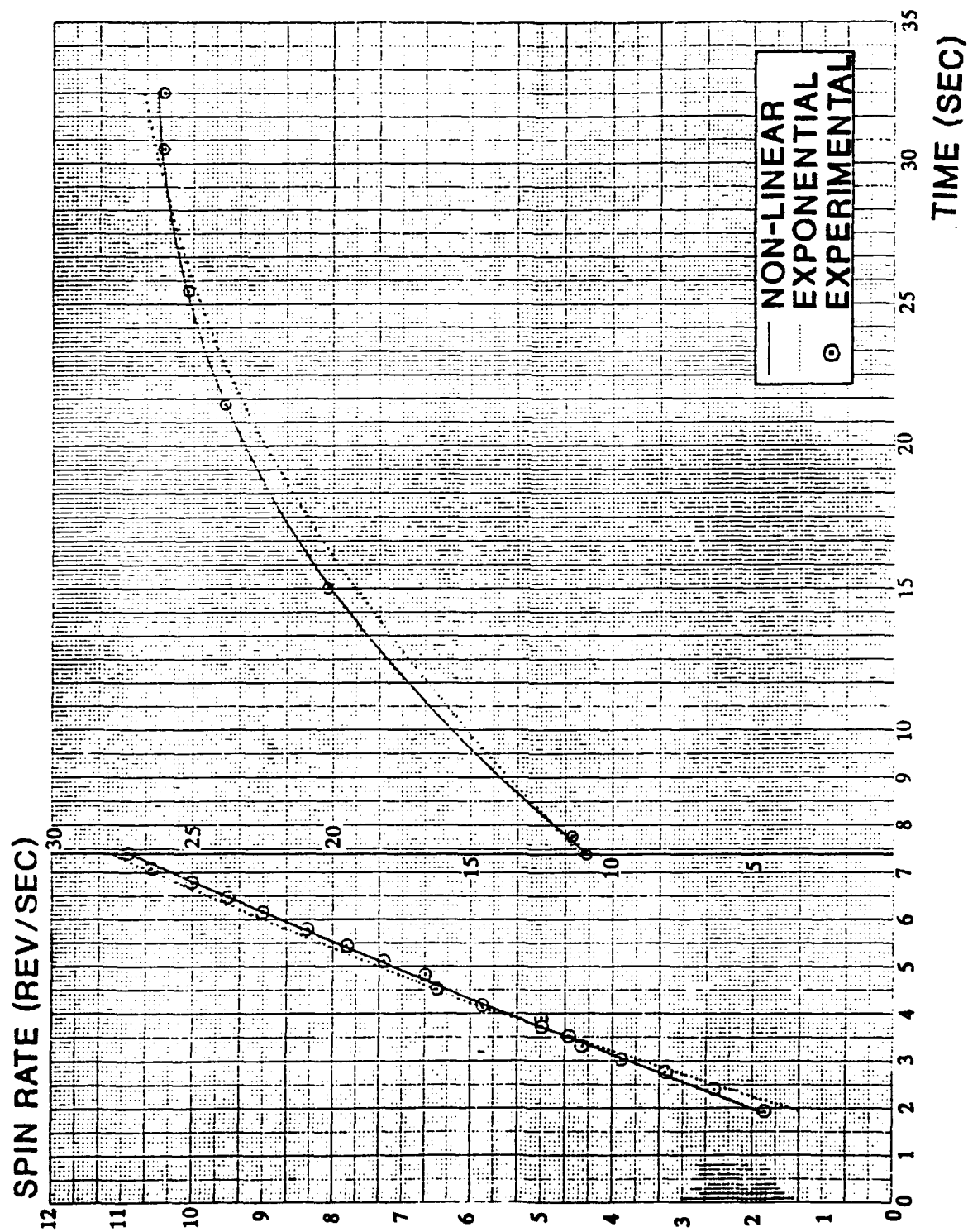


Figure. 81-mm, M819 RP smoke cartridge (mach = 0.3)

LIST OF SYMBOLS

C_{l_δ}	Roll moment coefficient due to fin cant (per rad)
C_{l_p}	Linear spin damping coefficient (per rad)
$C_{l_{p^2}}$	Nonlinear spin damping coefficient (per rad^2)
δ	Fin canted angle (rad)
d	Projectile reference diameter (ft)
L_f	Bearing frictional torque (lb-ft)
I_x	Projectile axial moment of inertia (lb _m -ft ²)
P_e	Experimental spin data (rev/s)
P_c	Calculated spin data (rev/s)
q	Dynamic pressure (lb/ft ²)
Q_i	Partial derivative of spin with respect to C_1 , C_2 , C_3 , and C_4
s	Reference area (ft ²)
C_1	(P_0) Initial spin
C_2	$\left(= \frac{qsdC_{l_\delta}\delta}{I_x} \right)$ Constant of linear spin moment term
C_3	$\left(= \frac{qsdC_{l_{p^2}}d^2}{4V^2I_x} \right)$ Constant of nonlinear spin damping moment term
C_4	$\left(= \frac{qsdC_{l_p}d}{2VI_x} \right)$ Constant of linear spin damping moment term

V	Velocity (ft/s)
ρ	Free stream air density (<i>slug/ft³</i>)
$(\cdot)$	Derivative () respect to time

REFERENCES

1. Chapman, G.T. and Kirk, D.B., "A New Method for Extracting Aerodynamic Coefficients From Free-Flight Data", AIAA Paper No. 69-134, AIAA 7th Aerospace Sciences Meeting, January 20-22, 1969.
2. Beers, Yardley, "Introduction to the Theory of Error" (Special Topics in the Adjustment of Data), Addison-Wesley Publishing Company, Inc., 1953, 1957.

APPENDIX A
PROGRAM SYMBOL CONVERSION TABLE

COMPUTER CODE	SYMBOL
DIA	d
AX	$I_x(lb_m - ft^2)$
AXX	$I_x(slug - ft^2)$
DEL	δ
FT	L_f
AC(1)	P_0
AC(2)	C_{l_1}
AC(3)	$C_{l_1'}$
AC(4)	$C_{l_1''}$
QQ	q
PI(i)	Wind Tunnel Spin Data
P(i)	Computed Spin Data
Q(N,M)	$Q_N(M)$
DT	Δt
TIME(i)	Time Table

APPENDIX B
COMPUTER INPUT FORMAT

CARD

NUMBER	COLUMN	NAME	FORMAT	DESCRIPTIONS	UNITS
1	1~ 72	DIDENT	18A4	Identification card	-
2	1~ 5	NT	I5	Number of data point	-
	6~ 10	DT	F5.0	Time increment of data	sec
3	1~ 10	V	F10.0	Velocity	ft/sec
	11~ 20	DIA	F10.0	Diameter	in
	21~ 30	AX	F10.0	Axial moment	$lb_m - in^2$
	31~ 40	RHO	F10.0	Density	$slug/ft^3$
	41~ 50	DEL	F10.0	Canted angle	deg
4	1~ 70	TIME	9F8.3	Time table for spin.	
				(Only when DT= 0)	sec
				The number of entry must equal to NT.	
5	1~ 72	PI	9F8.3	Spin table. The number of spin entry must equal to NT.	rev/sec
6	1~ 10	AC(1)	F10.0	Guessed initial spin	
	11~ 20	AC(2)	F10.0	Guessed C_{l_1}	
	21~ 30	AC(3)	F10.0	Guessed C_{l_p}	
	31~ 40	AC(4)	F10.0	Guessed $C_{l_{p2}}$	

< NOTE> Card number 4 is only required when the time increment (DT) is zero,
otherwise do not input the card.

Card number 6 is only an optional. If you don't have guessed value, put 0.0 for
each entry.

APPENDIX C
PROGRAM LISTING AND INPUT EXAMPLE

```

      PROGRAM SPINFIT(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,
+    PUNCH,TAPE7=PUNCH,TAPE1,TAPE2,TAPE3,TAPE4 )
C    EQUATION SOLVED IS PDOT= CN2 + CN3*P + CN4*P*P
C    FT1=CONSTANT TERM OF BEARING FRICTION (FT-LB) (NEGATIVE)
C    FT2=LINEAR TERM OF BEARING FRICTION (FT-LB/RPS) (NEGATIVE)
C    CLPZ =(PD/2V) CLP FOR BARE BODY WITHOUT FINS (NEGATIVE)
C    DEL = FIN CANT ANGLE IN RADIANS
C    NT = NUMBER OF POINTS
C    DT = TIME INCREMENT FOR SPIN VALUES INPUTTED
C    AC(1) = INITIAL SPIN VALUE
C    AC(2) = ESTIMATED CLD
C    AC(3) = ESTIMATED CLP. MAY BE LEFT BLANK
C    AC(4) = ESTIMATED CLP2. MAY BE LEFT BLANK
C    P=SPIN RATE (INPUT IN RPM)
C    FTR = FACTOR TO CORRECT CN(J)
C    VMACH = MACH NO
C    DIA = DIAMETER IN INCHES
C    AX = AXIAL INERTIA -LBF-INSQ
C    TO = TEMPERATURE - DEG F
C    PO = BAROMETRIC PRESSURE - PSI
      COMMON CN(5),P(200),Q(5,200),TIME(200)
      COMMON NT,DTI
      DIMENSION PI(200),R(200),WXX(5),C(5,6),AC(5)
      DIMENSION DIDENT(8)
1000 FORMAT(8A10)
1001 FORMAT(I5,F5.0)
1002 FORMAT(5F10.3)
1003 FORMAT(9F8.3)
1004 FORMAT(/25X, 34HCLP TOTAL = CLPZERO + CLP2*(PD/2V)/)
1005 FORMAT(/20X, 26HCALCULATED INITIAL SPIN = ,F7.2, 19H REV/SEC ERR
COR = ,F4.2)
1006 FORMAT(/36X, 10HCLPZERO = ,F8.3,10X, 8HERROR = ,F8.6)
1007 FORMAT(/30X, 16HCLDELTA*DELTA = ,F9.4, 9X, 8HERROR = ,F8.6)
1008 FORMAT(/39X, 7HCLP2 = ,F8.3, 10X, 8HERROR = , F8.6)
1009 FORMAT(/21X,25HSTEADY STATE SPIN RATE = , F9.4)
1011 FORMAT(4F10.3)
2000 FORMAT(1H1)
2001 FORMAT(/20X,I5,2F12.2)
2002 FORMAT(/10X,8F12.4/)
2003 FORMAT(/10X,10F10.3)
2004 FORMAT(/10X,I2,2F20.8)
2005 FORMAT(/10X,5E18.6)
2006 FORMAT(/10X,2F15.4)
2007 FORMAT(/10X,7F15.4)
2010 FORMAT(/20X,4HTIME,8X,8HOBSERVED,7X,10HCALCULATED,6X,8HOBS-CALC,
C5X,9HCLP TOTAL)
2011 FORMAT(20X, 5H(SEC),8X,36H(ROLL RATE - REVOLUTIONS PER SECOND))
2012 FORMAT(/15X,12HTOTAL POINTS,3X,10HDELTA TIME)
2013 FORMAT(/15X,8HDIAMETER,6X,4HAREA,5X,10HAX. MOMENT,2X,8HVELOCITY,
C 2X,12HDYN.PRESSURE,3X,8HFIN CANT/
C 17X,4H(FT),6X,7H(SQ-FT),4X,10H(LB-SQ-FT),2X,8H(FT/SEC),3X,
C 10H(LB/SQ-FT),3X,9H(RADIANS))
2014 FORMAT(/10X,39HSPIN INPUT DATA - REVOLUTION PER SECOND/)
2015 FORMAT(1H1/4X,13HITERATION NO.,6X,9HRESIDUALS,7X,14HPROBABLE ERROR
C /20X,12H(REV/SEC)**2,11X,9H(REV/SEC)
C //10X,42HCORRECTION OF CONSTANTS FOR EACH ITERATION/)
2016 FORMAT(/10X,17HINITIAL GUESSES--/18X,2HP0,9X,3HCLD,9X,3HCLP,
C 9X,4HCLP2)
2017 FORMAT(/10X,25HTIME INPUT DATA - SECONDS/)
2100 FORMAT(1H0/10X,8A10)
10 READ (5,1000) DIDENT
IF (EOF(5) .NE. 0.0) GO TO 300
READ(5,1001) NT,DTI
DT=DTI
DO 40 I=1,4
CN(I)=0.0

```

```

      AC(I)=0.0
      WXX(I)=0.0
      DO 20 J=1,NT
      Q(I,J)=0.0
20  CONTINUE
40  CONTINUE
      DO 50 I=1,NT
      P(I)=0.0
      PI(I)=0.0
      R(I)=0.0
50  CONTINUE
      READ(5,1002) V,DIA,AX,RHO,DEL
      IF(DTI .NE. 0.0) GO TO 60
      READ(5,1003) (TIME(I),I=1,NT)
60  READ(5,1003) (PI(I),I=1,NT)
      READ(5,1011) (AC(I),I=1,4)
      QQ=0.5*RHO*V**2
      A1=6.2831852
      DEL=DEL*(A1/360.0)
      AIX=AX/144.0
      D=DIA/12.0
      S=3.14159*D*D/4.0
      WRITE(6,2000)
      WRITE(6,2100) DIDENT
      WRITE(6,2012)
      WRITE(6,2001) NT,DT
      WRITE(6,2013)
      WRITE(6,2002) D,S,AIX,V,QQ,DEL
      IF(DTI .NE. 0.0) GO TO 70
      WRITE(6,2017)
      WRITE(6,2003) (TIME(I),I=1,NT)
70  WRITE(6,2014)
      WRITE(6,2003) (PI(I),I=1,NT)
      WRITE(6,2016)
      WRITE(6,2002) (AC(I),I=1,4)
      WRITE(6,2015)
      AXX=AIX/32.174
      CD=QQ*S*D/AXX
      DV=D/(2*V)
      CV=CD*DV
      DO 90 K=1,NT
      PI(K)=PI(K)*A1
90  CONTINUE
      IF(AC(2) .NE. 0.0) AC(2)=AC(2)*DEL
      IF(AC(1) .EQ. 0.0) AC(1)=PI(1)
      IF(PI(NT-3) .LT. PI(1)) GO TO 119
      IF(AC(2) .NE. 0.0) GO TO 113
      IF(DT .NE. 0.0) GO TO 112
      DO 91 I=1,4
      AA=(PI(I+1)-PI(1))/(TIME(I+1)-TIME(1))
      CN(2)=CN(2)+AA
91  CONTINUE
      AC(2)=(1.0/(4.0*CD))*CN(2)
      GO TO 113
112 DO 92 I=1,4
      AA=(PI(I+1)-PI(1))/(FLOAT(I)*DT)
      CN(2)=CN(2)+AA
92  CONTINUE
      AC(2)=(1.0/(4.0*CD))*CN(2)
113 CONTINUE
      IF(AC(3) .NE. 0.0) GO TO 114
      ICHECK=NT-5
      PRATIO=PI(NT)/PI(6)
      XXX=ALOG(PRATIO)
      TT=ICHECK*DT
      IF(DT .EQ. 0.0) TT=TIME(NT)-TIME(6)

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```

      AC(3)=XXX/(CV*TT)
      GO TO 114
119  CONTINUE
      IF(AC(3) .NE. 0.0) GO TO 114
      ICHECK=NT-3
      PRATIO=PI(ICHECK)/PI(1)
      XXX=ALOG(PRATIO)
      TT=ICHECK*DT
      IF(DT .EQ. 0.0) TT=TIME(ICHECK)-TIME(1)
      AC(3)=XXX/(CV*TT)
114  CONTINUE
      CN(1)=AC(1)
      CN(2)=AC(2)*CD
      CN(3)=AC(3)*CV
      CN(4)=AC(4)*CV*DV
      NR=0
      E=0.0
100  SR=0.0
      CALL INT
      DO 110 K=1,NT
      R(K)=PI(K)-P(K)
      SR=SR+R(K)**2
110  CONTINUE
      NR=NR+1
      E1=E
      E=0.6745*SQRT(SR/(NT-4))
      SRR=SR/A1**2
      EE=E/A1
      WRITE(6,2004) NR,SRR,EE
      IF(ABS(E1-E)-1E-04) 200,200,120
120  IF(NR-15) 130,130,200
130  DO 140 I=1,4
      DO 140 J=1,5
      C(I,J)=0.0
140  CONTINUE
      DO 150 I=1,4
      DO 150 J=1,4
      DO 150 K=1,NT
      C(I,J)=C(I,J)+Q(I,K)*Q(J,K)
150  CONTINUE
      DO 160 I=1,4
      DO 160 K=1,NT
      C(I,5)=C(I,5)+R(K)*Q(I,K)
160  CONTINUE
      CALL INV(C,4,5,WXX)
      DO 170 M=1,4
      CN(M)=CN(M)+C(M,5)
170  CONTINUE
      WRITE(6,2005) (C(I,5),I=1,4)
      GO TO 100
200  CONTINUE
      AC(1)=CN(1)/A1
      AC(2)=CN(2)/CD
      AC(3)=CN(3)/CV
      AC(4)=CN(4)/(CV*DV)
      DO 210 I=1,4
210  WXX(I)=SQRT(ABS(C(I,I)))*E
      WXX(1)=WXX(1)/A1
      WXX(2)=WXX(2)/CD
      WXX(3)=WXX(3)/CV
      WXX(4)=WXX(4)/(CV*DV)
      C4C=SQRT(ABS(CN(3)**2-4*CN(2)*CN(4)))
      PST=(-CN(3)-C4C)/(2*CN(4))/A1
      PSS=(-CN(3)+C4C)/(2*CN(4))/A1
      PINT=PI(NT)/A1
      PST1=ABS(PST-PINT)

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PST2=ABS(PSS-PINT)
IF(PST1 .GT. PST2) PST=PSS
WRITE(6,2000)
WRITE(6,2100) DIDENT
WRITE(6,1004)
WRITE(6,1005) AC(1),WXX(1)
WRITE(6,1006) AC(3),WXX(3)
WRITE(6,1008) AC(4),WXX(4)
WRITE(6,1007) AC(2),WXX(2)
WRITE(6,1009) PST
C
CLPP2=-(AC(2)/(DV*PST*A1))
WRITE(6,767) CLPP2
767 FORMAT(/20X,30HTHE TOTAL SPIN DAMPING MOMENT ,
C 38HCOEFFICIENT AT STEADY STATE SPIN IS = ,F10.5)
C
WRITE(6,2000)
WRITE(6,2100) DIDENT
WRITE(6,2010)
WRITE(6,2011)
DO 220 I=1,NT
T=DT*(I-1)
IF(DTI.EQ.0.0) T=TIME(I)
DPA=DV*P(I)
PI(I)=PI(I)/A1
P(I)=P(I)/A1
R(I)=R(I)/A1
CLP=AC(3)+AC(4)*DPA
TCLP=CLP*QQ*S*D*DPA
WRITE(6,2007) T,PI(I),P(I),R(I),CLP
220 CONTINUE
GO TO 10
300 STOP
END
SUBROUTINE INT
COMMON CN(5),P(200),Q(5,200),TIME(200)
COMMON NT,DTI
DT=DTI/5
N=1
I=6
Q(1,1)=1.0
P(1)=CN(1)
100 IF(DTI .EQ. 0.0) DT=(TIME(N+1)-TIME(N))/5
101 AK1=DT*(CN(2)+CN(3)*P(N)+CN(4)*P(N)**2)
PM1=P(N)+AK1/2
AK2=DT*(CN(2)+CN(3)*PM1+CN(4)*PM1**2)
PM2=P(N)+AK2/2
AK3=DT*(CN(2)+CN(3)*PM2+CN(4)*PM2**2)
PM3=P(N)+AK3
AK4=DT*(CN(2)+CN(3)*PM3+CN(4)*PM3**2)
P(N+1)=P(N)+(AK1+2*(AK2+AK3)+AK4)/6
CP1=CN(3)+2*CN(4)*P(N)
CP2=CN(3)+2*CN(4)*PM1
CP3=CN(3)+2*CN(4)*PM2
CP4=CN(3)+2*CN(4)*PM3
BK1=DT*CP1*Q(1,N)
BK2=DT*CP2*(Q(1,N)+BK1/2)
BK3=DT*CP3*(Q(1,N)+BK2/2)
BK4=DT*CP4*(Q(1,N)+BK3)
Q(1,N+1)=Q(1,N)+(BK1+2*(BK2+BK3)+BK4)/6
BK1=DT*(CP1*Q(2,N)+1.0)
BK2=DT*(CP2*(Q(2,N)+BK1/2)+1.0)
BK3=DT*(CP3*(Q(2,N)+BK2/2)+1.0)
BK4=DT*(CP4*(Q(2,N)+BK3)+1.0)
Q(2,N+1)=Q(2,N)+(BK1+2*(BK2+BK3)+BK4)/6
BK1=DT*(CP1*Q(3,N)+P(N))

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```

BK2=DT*(CP2*(Q(3,N)+BK1/2)+PM1)
BK3=DT*(CP3*(Q(3,N)+BK2/2)+PM2)
BK4=DT*(CP4*(Q(3,N)+BK3)+PM3)
Q(3,N+1)=Q(3,N)+(BK1+2*(BK2+BK3)+BK4)/6
BK1=DT*(CP1*Q(4,N)+P(N)**2)
BK2=DT*(CP2*(Q(4,N)+BK1/2)+PM1**2)
BK3=DT*(CP3*(Q(4,N)+BK2/2)+PM2**2)
BK4=DT*(CP4*(Q(4,N)+BK3)+PM3**2)
Q(4,N+1)=Q(4,N)+(BK1+2*(BK2+BK3)+BK4)/6
N=N+1
IF(N .LT. I ) GO TO 101
I=I+1
N=N-4
P(N)=P(N+4)
Q(1,N)=Q(1,N+4)
Q(2,N)=Q(2,N+4)
Q(3,N)=Q(3,N+4)
Q(4,N)=Q(4,N+4)
IF(N .LT. NT) GO TO 100
200 RETURN
END
SUBROUTINE INV(C,NC,NCS1,WXX)
DIMENSION C(5,6),WXX(5),PIVOT(2),CC(5,10)
3000 FORMAT(/10X, 20HDET IS EQUAL TO ZERO)
NCT=NC*2
NCP1=NC+1
DO 10 I=1,NC
DO 10 J=1,NC
10 CC(I,J)=C(I,J)
DO 20 I=1,NC
DO 20 J=NCP1,NCT
20 CC(I,J)=0.
DO 30 I=1,NC
30 CC(I,NC+I)=1.
DO 205 I=1,NC
PIVOT(1)=CC(I,I)
DO 200 K=1,NC
PIVOT(2)=CC(K,I)
126 IF(K-I) 135,130,140
130 DO 150 J=1,NCT
IF(PIVOT(1)) 134,210,134
134 CC(K,J)=CC(I,J)/PIVOT(1)
150 CONTINUE
GO TO 200
IF(PIVOT(1)) 136,160,136
136 CC(K,J)=CC(K,J)-CC(I,J)*PIVOT(2)/PIVOT(1)
160 CONTINUE
GO TO 200
140 DO 170 J=1,NCT
IF(PIVOT(2)) 145,170,145
145 CC(K,J)=CC(K,J)/PIVOT(2)-CC(I,J)
170 CONTINUE
200 CONTINUE
205 CONTINUE
GO TO 250
210 WRITE (6,3000)
250 DO 300 I=1,NC
DO 300 J=1,NC
300 C(I,J)=CC(I,J+NC)
NCS=NCS1
350 IF(NCS-NC)500,500,400
400 DO 420 I=1,NC
WXX(I)=C(I,NCS)
420 C(I,NCS)=0.
DO 450 J=1,NC
450 C(I,NCS)=C(I,NCS)+C(I,J)*WXX(J)

```

```

      NCS=NCS-1
      GO TO 350
500  CONTINUE
      RETURN
      END
*EOR
      81MM, M819 RP SMOKE CARTRIDGE ( MACH = 0.3 )
      25 0.0 0.0
335.55 3.189 0.504 0.002377 0.057
1.94 2.41 2.76 3.05 3.29 3.51 3.72 3.92 4.19
4.51 4.82 5.10 5.43 5.80 6.15 6.48 6.78 7.08
7.40 7.76 15.0 21.5 25.5 30.5 32.5
1.82 2.55 3.24 3.87 4.44 4.62 5.00 5.00 5.85
6.49 6.67 7.27 7.83 8.37 9.00 9.47 10.00 10.59
10.91 11.43 20.25 23.90 25.25 26.10 26.10
0.0 0.0 0.0 0.0

```

APPENDIX D
PROGRAM OUTPUT EXAMPLES

81MM, M819 RP SMOKE CARTRIDGE (MACH = 0.3)

TOTAL POINTS DELTA TIME

25 0.00

DIAMETER (FT)	AREA (SQ-FT)	AX. MOMENT (LB-SQ-FT)	VELOCITY (FT/SEC)	DYN.PRESSURE (LB/SQ-FT)	FIN CANT (RADIAN)
.2658	.0555	.0035	335.5500	133.8177	.0010

TIME INPUT DATA - SECONDS

1.940	2.410	2.760	3.050	3.290	3.510	3.720	3.920	4.190	4.510
4.820	5.100	5.430	5.800	6.150	6.480	6.780	7.080	7.400	7.760
15.000	21.500	25.500	30.500	32.500					

SPIN INPUT DATA - REVOLUTION PER SECOND

1.820	2.550	3.240	3.870	4.440	4.620	5.000	5.000	5.850	6.490
6.670	7.270	7.830	8.370	9.000	9.470	10.000	10.590	10.910	11.430
20.250	23.900	25.250	26.100	26.100					

INITIAL GUESSES--
P0

CLD	CLP	CLP2
0.0000	0.0000	0.0000

ITERATION NO. RESIDUALS
 (REV/SEC)**2 PROBABLE ERROR
 (REV/SEC)
 CORRECTION OF CONSTANTS FOR EACH ITERATION

1	41219.66284045	29.88302266	
.183458E+01	-.966689E+00	-.581463E-01	.428149E-04
2	2858.58084748	7.86950737	
-.314311E+01	.328480E+01	-.733116E-01	.102561E-03
3	174.12605513	1.94224578	
.325840E+00	-.592481E+00	.215574E-01	-.209033E-03
4	14.68677214	.56407322	
.105435E+01	-.171272E+01	.537446E-01	-.328188E-03
5	.85974779	.13647649	
.341713E+00	-.631507E+00	.201828E-01	-.119405E-03
6	.33173285	.08477476	
.246289E-01	-.438376E-01	.138279E-02	-.801743E-05
7	.33021108	.08458009	
.391805E-03	-.346121E-03	.746384E-05	-.353107E-07
8	.33021106	.08458008	

81MM, M819 RP SMOKE CARTRIDGE (MACH = 0.3)

$$\text{CLP TOTAL} = \text{CLPZERO} + \text{CLP2} * (\text{PD} / 2V)$$

CALCULATED INITIAL SPIN =	1.89 REV/SEC	ERROR =	.05
CLPZERO =	.004	ERROR =	.000801
CLP2 =	-.183	ERROR =	.010131
CLDELTA*DELTA =	.0006	ERROR =	.000013
STEADY STATE SPIN RATE =	26.7534		

THE TOTAL SPIN DAMPING MOMENT COEFFICIENT AT STEADY STATE SPIN IS = -.00866

81MM, M819 RP SMOKE CARTRIDGE (MACH = 0.3)

TIME (SEC)	OBSERVED (ROLL RATE - REVOLUTIONS PER SECOND)	CALCULATED (ROLL RATE - REVOLUTIONS PER SECOND)	OBS-CALC	CLP TOTAL
1.9400	1.8200	1.8898	-.0698	.0026
2.4100	2.5500	2.6902	-.1402	.0023
2.7600	3.2400	3.2881	-.0481	.0020
3.0500	3.8700	3.7842	.0858	.0018
3.2900	4.4400	4.1949	.2451	.0016
3.5100	4.6200	4.5711	.0489	.0014
3.7200	5.0000	4.9299	.0701	.0013
3.9200	5.0000	5.2711	-.2711	.0011
4.1900	5.8500	5.7307	.1193	.0009
4.5100	6.4900	6.2734	.2166	.0007
4.8200	6.6700	6.7965	-.1265	.0004
5.1000	7.2700	7.2664	.0036	.0002
5.4300	7.8300	7.8163	.0137	-.0000
5.8000	8.3700	8.4274	-.0574	-.0003
6.1500	9.0000	8.9993	.0007	-.0006
6.4800	9.4700	9.5324	-.0624	-.0008
6.7800	10.0000	10.0114	-.0114	-.0010
7.0800	10.5900	10.4846	.1054	-.0013
7.4000	10.9100	10.9827	-.0727	-.0015
7.7600	11.4300	11.5343	-.1043	-.0017
15.0000	20.2500	20.1429	.1071	-.0057
21.5000	23.9000	24.0043	-.1043	-.0074
25.5000	25.2500	25.1993	.0507	-.0079
30.5000	26.1000	26.0038	.0962	-.0083
32.5000	26.1000	26.1951	-.0951	-.0084

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