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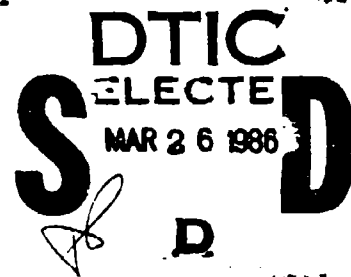
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TECHNICAL REPORT ARAED-TR-85010

COMPUTER SIMULATION OF ROCKET/MISSILE SAFING AND ARMING MECHANISM
(CONTAINING PIN PALLET RUNAWAY ESCAPEMENT, THREE-PASS INVOLUTE
GEAR TRAIN AND ACCELERATION DRIVEN ROTOR)

P. T. GORMAN
F. R. TEPPER



MARCH 1986

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A complete simulation of missile and rocket safing and arming (S&A) mechanisms containing an acceleration-driven rotor, a three-pass involute gear train, and a pin pallet runaway escapement was developed. In addition, a modification to this simulation was formulated for the special case of the PATRIOT M143 S&A mechanism which has a pair of driving gears in addition to the three-pass gear train. The three motion regimes involved in escapement operation--coupled motion, free motion, and impact--are considered in the computer simulation.		

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20. ABSTRACT (cont)

The simulation determines both the arming time of the device and the non-impact contact forces of all interacting components. The program permits parametric studies to be made, and is capable of analyzing pallets with arbitrarily located centers of mass. A sample simulation of the PATRIOT M143 S&A in an 11.9 g constant acceleration arming test was run. The results were in good agreement with laboratory test data.

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CONTENTS

	Page
Introduction	1
Description of Computer Program MISLSA	1
Three Regimes of Motion	3
Coupled Motion	3
Free Motion	7
Impact	8
Transfer Between Motion Regimes	9
Additional Program Features	13
Program Input/Output	14
Computer Simulation of an Example Mechanism	16
Escapement Parameters	17
Mass Properties of Components	17
General Parameters	18
Gear Parameters	19
Angle Indexing Parameters	22
Parameters Needed for M143 Two-Rotor System	22
Acceleration Defining Parameters	22
Results	23
Conclusions	23
Recommendations	23
References	25
Appendixes	
A Dynamics of Rotor Driven Missile or Rocket S&A Mechanism with a Three-Pass Involute Gear Train and a Pin Pallet Runaway Escapement	27
B Program MISLSA	59
C Conversion of Two Rotor System to an Equivalent Single Rotor	79
D Program M143SA	87
Distribution List	137

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Availability Codes	
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A-1	23

FIGURES

	Page
1 Rotor driven S&A device with three-pass involute gear train and pin pallet runaway escapement	2
2 Flow chart for simulation of pin pallet runaway escapement	4
3 Coupled motion	6
4 Free motion	10

INTRODUCTION

A computer simulation was developed for missile and rocket safing and arming (S&A) mechanisms which incorporate an acceleration-driven rotor, a three-pass involute gear train, and a pin pallet runaway escapement (fig. 1). A modification was also developed which simulates a system with a pair of meshed acceleration-driven rotors in addition to the three-pass gear train.

Several portions of the computer program for this simulation are taken directly from the program SANDA3 of reference 1.¹

The basis of the computer simulation is the development of mathematical equations to describe the three regimes of motion of the runaway escapement: coupled motion, free motion, and impact of the escape wheel and pallet. As in reference 1, the effect of a pallet with an arbitrarily located center of mass is considered, and all non-impact contact forces are determined for considerations of strength.

With this simulation, predictions of the S&A arming time can be made. The arming time can be computed either for a variable axial and normal acceleration field, as would be experienced in missile or rocket flight, or for a constant axial acceleration field, as occurs in centrifuge testing. The simulation can be used to determine the effect of design changes made to the escapement, gear train, and acceleration driven rotor. Conversely, design changes can be suggested to produce a desired alteration of the S&A arming time.

In this report, the PATRIOT M143 S&A is modeled as a sample mechanism. The results are in agreement with laboratory test data. Details of the input parameters needed in order to use the computer program are completely described in the M143 S&A sample.

DESCRIPTION OF COMPUTER PROGRAM MISLSA

The computer program MISLSA uses logic that is virtually identical to that used in the computer program SANDA3 of reference 1. A complete description of MISLSA is offered here for clarity. With little deviation, the description of SANDA3 offered in reference 1 applies to MISLSA as well, and should be referred to if an alternate description might improve the reader's understanding at any point in this report.

¹ This work draws to a considerable extent on work completed and published by Dr. F. R. Tepper and Dr. G. G. Lowen in references 1 through 4.

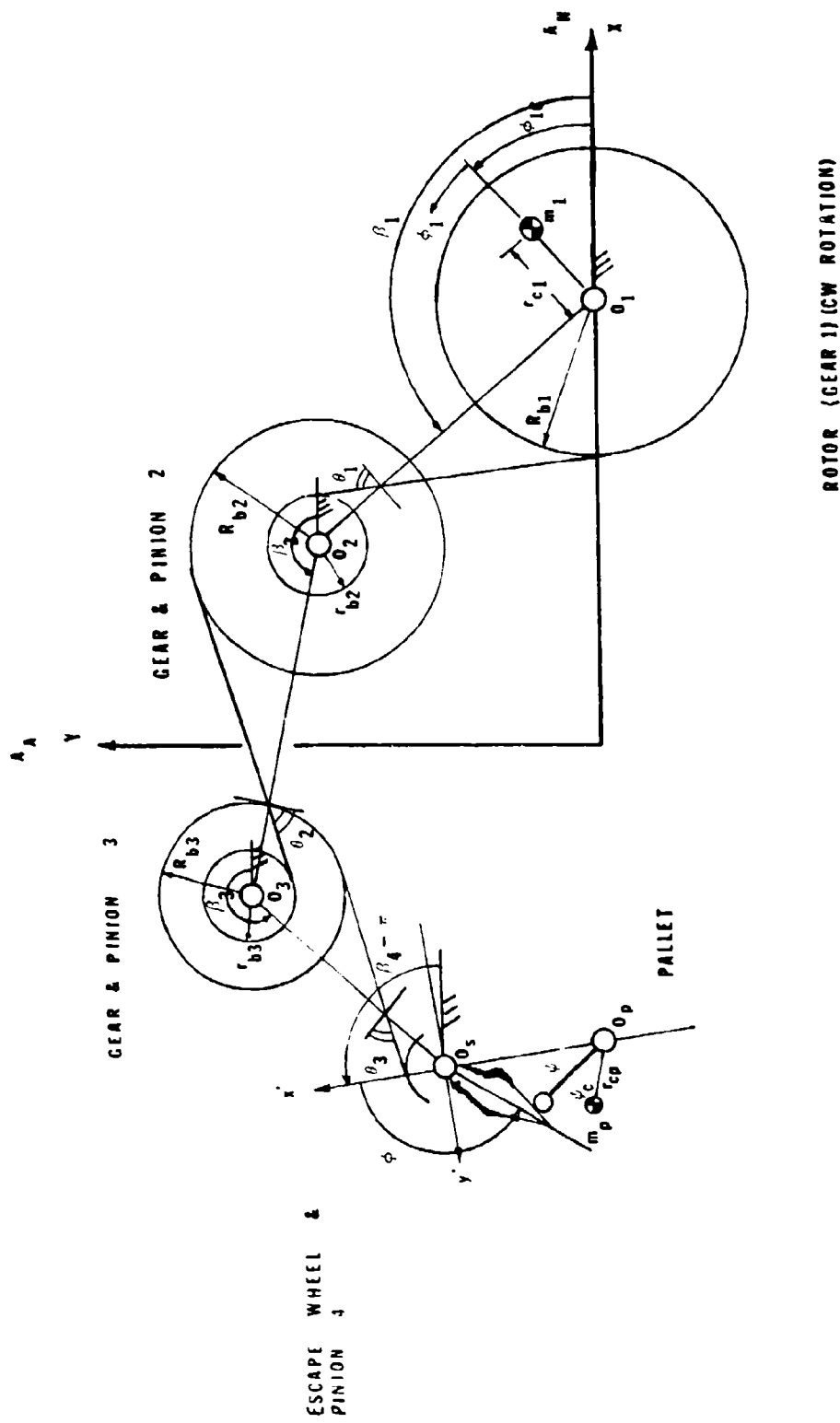


Figure 1. Rotor driven S&A device with three-pass involute gear train and pin pallet runaway escapement

Three Regimes of Motion

The computer model is based upon following the escape wheel continuously through the three regimes of motion it experiences. At first, the escape wheel and entrance pallet pin are in contact; thus, upon experiencing acceleration, the rotor drives the entire system in coupled motion. A differential equation is developed to describe this coupled motion. The pallet pin rides along the escape wheel tooth until the tip is reached or the contact force becomes zero, at which point the escape wheel system (escape wheel, gear train, and driving rotor) moves separately from the pallet. Here separate differential equations are needed to describe the free motion of both the pallet and escape wheel system independently. A new escape wheel tooth and the exit pallet pin approach each other through this free motion until impact occurs. According to the severity of the impact and the coefficient of restitution, either coupled or free motion will follow this impact. Eventually, the escape wheel tooth will reach the point where further contact with the exit pallet pin is not possible, and a new escape wheel tooth will approach the entrance pallet pin. This cycle repeats itself several hundred times within a matter of 3 to 4 seconds in the case of the PATRIOT M143 SSA.

As can be seen in the flow chart in figure 2 (reproduced with minor, but necessary, modification from reference 1, figure 5), the computer program must have the capability to test many situations and make several decisions in order to follow the escape wheel motion accurately.

Coupled Motion

Appendix A is devoted to developing the equations of motion, both free and coupled, for the escape wheel system and pallet, as well as contact force expressions between each gearing interface and at the escape wheel-pallet interface, when applicable. Equation A-146 is the differential equation of coupled motion for the entire system.

$$A_{58} \ddot{\phi} + A_{59} \dot{\phi}^2 = A_{60} A_A + A_{61} A_N \quad (1)$$

where ϕ represents the angular position of the escape wheel (thus $\dot{\phi}$ is the angular velocity and $\ddot{\phi}$ is the angular acceleration). A_A and A_N are the axial and normal or lateral accelerations, respectively. A_{58} through A_{61} are variables developed through a series of force and moment balances throughout the system, as described in appendix A. The solution of this differential equation is accomplished with a fourth order Runge-Kutta routine.² The associated computer program for its solution is given in Appendix B. Appropriate setup parameters are

² RKGS Routine, IBM System/360 Scientific Subroutine Package (360A-CM-0X3), Version III.

necessary in the main program to utilize this subroutine along with two additional subroutines FCT and OUTP. The subroutine FCT presents the second order differential equation as two first order equations to RKGS.

$$DPHI(1) = PHI(2) \quad (2)$$

$$DPHI(2) = (-AA59 * PHI(2) ** 2 + AA60 * AA + AA61 * AX)/AA58 \quad (3)$$

where

$$\dot{\phi} = PHI(1) \quad (4)$$

$$\ddot{\phi} = PHI(2) = DPHI(1) \quad (5)$$

$$\ddot{\phi} = DPHI(2) \quad (6)$$

The basic responsibilities of subroutine OUTP are to write the output of each increment of the solution of the differential equation, to calculate and write the contact forces, and to determine whether coupled motion is to be continued.

Aside from the main program and the subroutines mentioned, several other subroutines are called in the solution of the coupled motion differential equation (as well as the free motion differential equations).

Subroutine KINEM

This subroutine computes the values of the moment arms A_1 , B_1 , C_1 , and D_1 as well as values of g , $\dot{g}$, ψ , and $\dot{\psi}$. Details of the development of this subroutine are given in reference 2; a brief description of the parameters g and ψ are offered here. The parameter g represents the distance between the contact point of the pallet pin with the escape wheel, and the end of the escape wheel tooth (fig. 3). The parameter $\dot{g}$ is the rate of change of this distance, or the relative linear velocity at which the pallet pin is approaching the end of the escape wheel tooth. By monitoring this parameter, along with the calculated contact force between the components, P_n , the program is able to determine when coupled motion has ended. If the contact force is positive and the parameter g is negative (due to the direction of the unit vector in the coordinate system, appendix A, reference 2), then coupled motion continues. At the point where g becomes zero or the contact force becomes zero, the computer program returns control to the main program and eventually to the subroutines devoted to the analysis of free motion.

ψ and $\dot{\psi}$ are the angular position and angular velocity of the pallet, respectively.

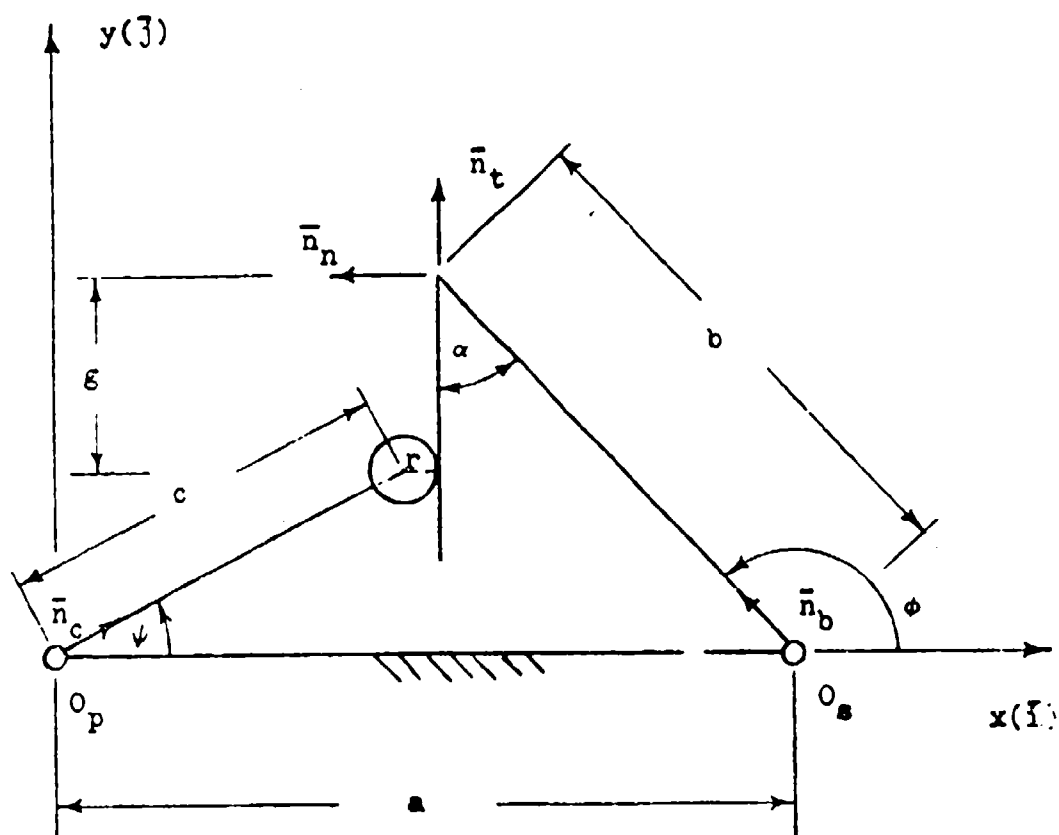


Figure 3. Coupled motion

Subroutines IN3 and IN3A

The main purpose of these subroutines is to determine values for the variables A1 through A57, needed in order to solve the differential equations. These variables are developed and described completely in appendix A. (Two subroutines are needed due to a limit on the number of arguments permitted in a single subroutine.) The variables are represented as AA1 through AA57 in the computer program to differentiate these variables from the fixed parameters a_1 through a_3 which are represented as A1 through A3 in the computer program. In addition to solving for the variables AA1 through AA54, subroutine IN3 first determines the appropriate signum functions S_1 through S_7 needed to determine AA1 through AA57. These signum functions are needed to assure that friction opposes the motion in all cases. Signum functions S_1 , S_2 , and S_3 are developed in a manner similar to that for the signum function S described in reference 3, appendix A. To determine signum function S_1 through S_3 , gear train angle data must be updated to ascertain whether approach or recess contact is present at each gear mesh. Signum functions S_4 and S_5 are described in reference 1, equations A-59 and A-60. Finally, signum functions S_6 and S_7 are discussed in appendix A, preceding equation A-29.

Subroutine GCURVE

This subroutine is called in order to obtain the current values for both the axial and normal accelerations. GCURVE accepts up to 100 points, defining an acceleration-time curve for both the axial and normal accelerations. The subroutine performs a linear interpolation to determine the acceleration values at each time increment; then converts the acceleration values from g's to in./sec² for use in the differential equation solution.

Free Motion

Several subroutines used in solving the free motion differential equations are the same as those needed to solve the coupled motion differential equation; namely, KINEM, IN3, IN3A, and GCURVE. Two very similar subroutines to FCT and OUTP--FCTF and OUTPF--are used to present the two free motion differential equations to RKGS and produce the continuous output. Two differential equations are needed, one for the pallet in free motion, and one for the escape wheel, gear train, and drive rotor system. These equations are developed in appendix A and are shown here:

$$A_{62} \ddot{\psi} + A_{14} \dot{\psi}^2 = A_{63} A_A + A_{64} A_N \quad (7)$$

$$A_{65} \ddot{\phi} + A_{66} \dot{\phi}^2 = A_{67} A_A + A_{68} A_N \quad (8)$$

where equation 7 is the expression for the free motion of the pallet and equation 8 is the expression for free motion of the escape wheel system. To solve both equations at the same time, the two second-order differential equations are presented in a single subroutine, FCTF, as four first-order equations. While the equations are really two pairs of coupled first-order equations, the routine treats the four equations as coupled, thus giving solutions for ϕ , ψ , and their derivatives, for identical time increments. The equations are presented in subroutine FCTF as follows:

$$DX(1) = X(2) (= \dot{\phi}) \quad (9)$$

$$DX(3) = X(4) (= \dot{\psi}) \quad (10)$$

$$(\ddot{\phi}) DX(2) = (AA67 * AA + AA68 * AN - AA66 * X(2) ** 2)/AA65 \quad (11)$$

$$(\ddot{\psi}) DX(4) = (AA63 * AA + AA64 * AN - AA14 * X(4) ** 2)/AA62 \quad (12)$$

Again, the basic responsibility of subroutine OUTPF is to compute the contact forces, write the output for each time increment, and determine whether free motion will continue at the next time increment.

Impact

Transformation from free motion to coupled motion usually involves an impact between the escape wheel and pallet pin. When the program has decided that an impact is to occur, subroutine IMPACT is called to determine from the current angular velocities $\dot{\phi}_i$ and $\dot{\psi}_i$ what the post impact angular velocities $\dot{\phi}_f$ and $\dot{\psi}_f$ will be by applying equations F-20 and F-21 of reference 2. (The moment of inertia is expressed according to equation A-169, appendix A, which refers the rotor and gear train inertia to the escape wheel shaft. As shown in reference 2, appendix F, tangential impact has been neglected and, therefore, $E_2 = D_1$ and $F_2 = A_1$.)

In certain cases the impact torque on the escape wheel can be great enough to reverse the motion of the entire gear train; i.e., the escape wheel velocity $\dot{\phi}$ becomes negative. This will result in a change in direction of the frictional forces which must be accounted for. This change in the friction forces must be expressed for both free and coupled motion. It is accomplished by allowing the coefficient of friction in all the gear train components to become negative (ref 1, app E). Subroutine IN3 is responsible for this sign change by using the following signum function $\dot{\phi}/|\dot{\phi}|$:

$$MU = ABS(MU) * \dot{\phi}/|\dot{\phi}| \quad (13)$$

The coefficient friction of μ_1 is used for the escapement interface and pallet pivot area. The signum functions S_4 and S_5 handle the motion reversals for these two surfaces.

Transfer Between Motion Regimes

The main program and subroutines OUTP and OUTPF are responsible for the decision process to determine which motion regime is appropriate. What follows is a description of how each decision is accomplished by the simulation.

Coupled Motion to Free Motion

With each increment of the numerical solution to the differential equation of coupled motion, subroutine OUTP checks to determine if coupled motion continues. Two parameters must be checked to make this determination, g and P_n . The parameter g is negative when the location of the pallet pin is along the escape wheel tooth, and is a measure of the distance along the plane of the tooth to its end. [Again, parameter g has a negative value due to the direction of the unit vector in the coordinate system (ref 2, app A.)] P_n is the contact force between the pallet pin and escape wheel tooth. The statement,

IF (.NOT.(G.LT.0..AND.PN.GT.0.)) PRMT(5) = 2. (14)

is used to make this test. $PRMT(5) = 2$. (or any non-zero $PRMT(5)$ value) is a signal to the subroutine RKGS that coupled motion has ended and to return control to the main program. At the point control is returned to the main program, the value of g is immediately checked. A negative value of g indicates that further contact between the pallet pin and the escape wheel tooth which had just left coupled motion, could still occur. This depends on the relative angular velocities of the pallet and escape wheel during free motion. The program then initializes parameters for the free motion subroutines and turns control over to RKGS to solve the free motion differential equations. If the value of g is greater than zero, however, no further contact is possible with that escape wheel tooth before a new escape wheel tooth experiences impact. Therefore, angle indexing (which varies according to whether entrance or exit action is expected, and is yet to be discussed) must take place before continuing to the free motion regime.

Free Motion to Impact, Coupled Motion, or Free Motion

Two parameters are continuously monitored in OUTPF in order to determine if the escape wheel system and pallet remain in free motion. These parameters are f and g' (fig. 4). (Reference 2, appendix C gives the details of how these parameters are evaluated.) The parameter f is a measure of the distance between the pallet pin and escape wheel tooth taken normal to the plane of the escape wheel tooth. The parameter g' is similar to the parameter g of coupled motion in that it measures the distance from the pallet pin center to the escape wheel tooth tip along the plane of the tooth. First the parameter f is monitored. If f is not positive, control is returned to the main program. With f less than or equal to zero, if g' is greater than or equal to zero, no contact with the escape wheel tooth being monitored is possible. Therefore, after the appropriate angle

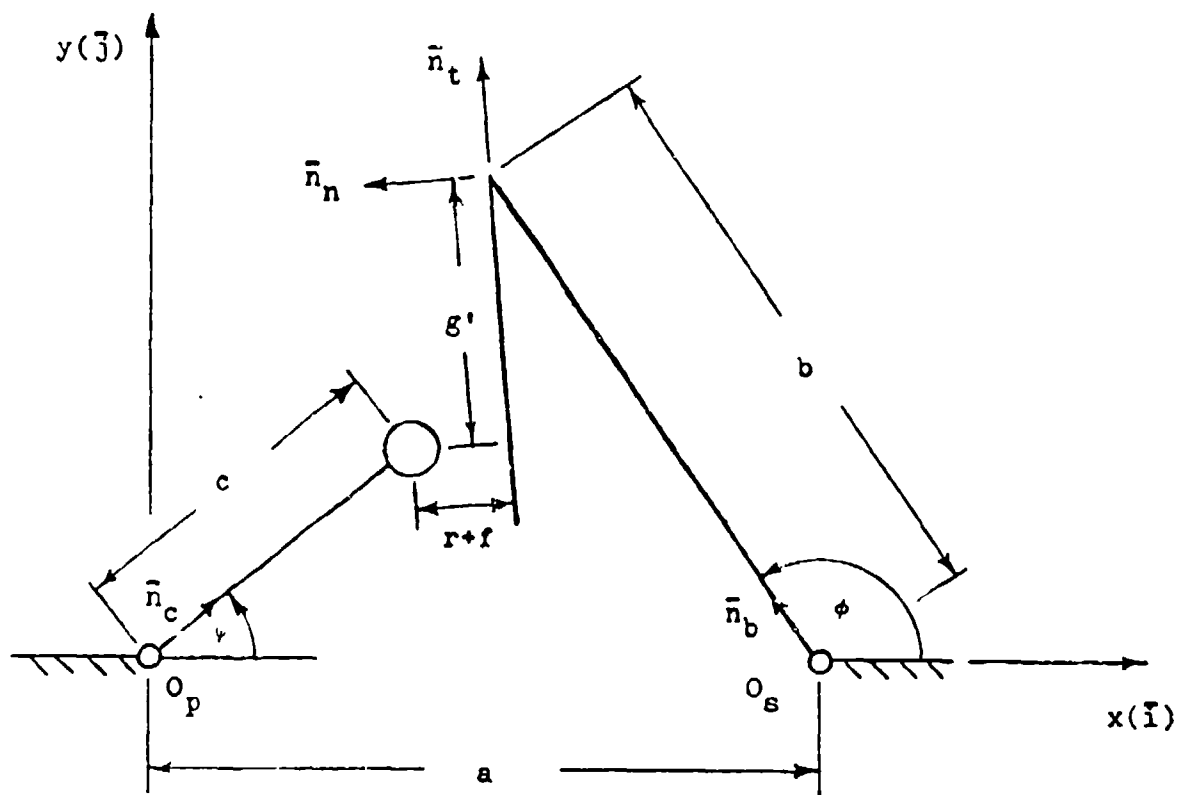


Figure 4. Free motion

indexing (according to whether in entrance or exit action), control is returned to solving the free motion differential equations. If g' is less than zero, however, sixteen possibilities must be considered to determine whether coupled motion, free motion, or impact will result. These sixteen possibilities are due to the different combinations of relative velocities of the escape wheel and pallet; absolute velocities of the contact points; and the type of action, entrance or exit. The sixteen possibilities are shown here, with the motion that will result from each combination.

Entrance action

$\dot{\phi} > 0$ and $\dot{\psi} > 0$ and $ v_p > v_s $	free motion
$\dot{\phi} > 0$ and $\dot{\psi} > 0$ and $ v_p = v_s $	coupled motion
$\dot{\phi} > 0$ and $\dot{\psi} > 0$ and $ v_p < v_s $	impact
$\dot{\phi} < 0$ and $\dot{\psi} > 0$	free motion
$\dot{\phi} > 0$ and $\dot{\psi} < 0$	impact
$\dot{\phi} < 0$ and $\dot{\psi} < 0$ and $ v_p > v_s $	free motion
$\dot{\phi} < 0$ and $\dot{\psi} < 0$ and $ v_p = v_s $	coupled motion
$\dot{\phi} < 0$ and $\dot{\psi} < 0$ and $ v_p < v_s $	impact

Exit action

$\dot{\phi} > 0$ and $\dot{\psi} < 0$ and $ v_p > v_s $	free motion
$\dot{\phi} > 0$ and $\dot{\psi} < 0$ and $ v_p = v_s $	coupled motion
$\dot{\phi} > 0$ and $\dot{\psi} < 0$ and $ v_p < v_s $	impact
$\dot{\phi} < 0$ and $\dot{\psi} > 0$ and $ v_p > v_s $	impact
$\dot{\phi} < 0$ and $\dot{\psi} > 0$ and $ v_p = v_s $	coupled motion
$\dot{\phi} < 0$ and $\dot{\psi} > 0$ and $ v_p < v_s $	free motion
$\dot{\phi} > 0$ and $\dot{\psi} > 0$	impact
$\dot{\phi} < 0$ and $\dot{\psi} < 0$	free motion

Returning to OUTPF, the possibility of g' being greater than zero when f is greater than zero must also be considered. If g' becomes greater than zero,

control is returned to the main program. In the main program, angle indexing is accomplished after determining whether entrance or exit action is present, and then control is returned to the numerical routine to solve the free motion differential equations.

Impact to Free or Coupled Motion

The subroutine IMPACT uses the input angular velocities of the escape wheel and pallet to determine the angular velocities after impact. (The equations are developed in reference 2, appendix F.) After the impact occurs, the subroutine returns control to the main program. The main program first tests for entrance or exit action; then computes the velocities of the contact points V_p and V_s from the new values $\dot{\phi}_f$ and $\dot{\psi}_f$. If the absolute value of the difference of the two post-impact velocities is less than 1 inch per second; i.e.,

$$|V_p - V_s| < 1.0 \quad (15)$$

then control is transferred to solving the coupled motion differential equation. If this is not the case, six possibilities exist for both entrance and exit action which lead to either free or coupled motion. They are as follows:

Entrance action

$\dot{\phi} > 0$ and $\dot{\psi} > 0$ and $ V_p > V_s $	free motion
$\dot{\phi} > 0$ and $\dot{\psi} > 0$ and $ V_p < V_s $	coupled motion
$\dot{\phi} > 0$ and $\dot{\psi} < 0$	coupled motion
$\dot{\phi} < 0$ and $\dot{\psi} > 0$	free motion
$\dot{\phi} < 0$ and $\dot{\psi} < 0$ and $ V_p > V_s $	coupled motion
$\dot{\phi} < 0$ and $\dot{\psi} < 0$ and $ V_p < V_s $	free motion

Exit action

$\dot{\phi} > 0$ and $\dot{\psi} < 0$ and $ V_p > V_s $	free motion
$\dot{\phi} > 0$ and $\dot{\psi} < 0$ and $ V_p < V_s $	coupled motion
$\dot{\phi} > 0$ and $\dot{\psi} > 0$	coupled motion
$\dot{\phi} < 0$ and $\dot{\psi} < 0$	free motion
$\dot{\phi} < 0$ and $\dot{\psi} > 0$ and $ V_p > V_s $	coupled motion
$\dot{\phi} < 0$ and $\dot{\psi} > 0$ and $ V_p < V_s $	free motion

Additional Program Features

Angle Indexing

In the description of the operation of the computer program, angle indexing was mentioned several times. Angle indexing is necessitated by the changing of the relative positions of the escape wheel and pallet pin. It involves going from entrance to exit motion or vice versa. As an example, when control is released to the main program from the routines to solve the coupled motion differential equation, and $g > 0$, the current escape wheel angle is measured against a test angle TANG. If the escape wheel angle is less than this test angle, it is known that the entrance action coupled motion has been completed, and the escape wheel angle ϕ is indexed forward NT teeth, and the pallet angle ψ is incremented by $2\pi - \lambda$ in preparation for analysis during exit action (λ is the angle between the pallet pins). Conversely, if the escape wheel angle is greater than the test angle, it is known that exit action coupled motion has terminated and entrance action is expected. To return to entrance action, the escape wheel angle is indexed back (NT + 1) teeth, and the pallet angle is decremented by $-2\pi + \lambda$.

In addition to indexing the angle of the escape wheel to accommodate changes from entrance to exit action, the same must be done for the pallet center of mass angle ψ_c . During entrance action, this angle is expressed as

$$\psi_c \text{ or PSICC}$$

while during exit action, the angle is expressed as

$$\psi_c + \lambda \text{ or PSICC} + \text{LAMBDA} * \text{ZZ}$$

The multiplication by ZZ is a conversion from degrees to radians.

Cumulative Escape Wheel Angle

To solve the differential equations as well as to determine when arming has occurred, the instantaneous rotor angle must be known. This angle is expressed in appendix A as $\phi_{lc} + N_{41} \phi_T$ where ϕ_{lc} is the initial rotor angle, ϕ_T is the cumulative angle of rotation of the escape wheel, and N_{41} is the gear ratio between the rotor and escape wheel. Since angle indexing is occurring with the angle ϕ , the Runge-Kutta variable PHI(1), ϕ_T can only be obtained by continuous addition of the increments due to each Runge-Kutta cycle. Therefore,

$$\phi_T = \phi_{TOT} + \Delta\phi \quad (16)$$

where

$$\phi_{TOT} = \text{total escape wheel angle up to a given Runge-Kutta cycle} \\ (\text{PHITOT in computer program})$$

$\Delta\phi$ = increment of escape wheel during a given Runge-Kutta cycle

The increment $\Delta\phi$ is calculated as the difference between the latest value of ϕ [PHI(1)] and the previous value of ϕ (PHIPR). With this, equation 16 becomes

$$\phi_T = \text{PHITOT} + \text{PHI}(1) - \text{PHIPR} \quad (17)$$

The program reads in the escape wheel angular displacement at which the mechanism arms (which for instance might be a 90 degree rotor displacement multiplied by the gear ratio between the rotor and escape wheel). After every increment, PHITOT is compared with this "cut-off" angle PHICUTD, and the simulation is terminated when PHITOT reaches PHICUTD. Additional information on the computation of ϕ_T can be obtained from the section on Fuze Body Configuration in reference 1.

Subroutine ALFA

This subroutine is needed in the solution of the differential equations of both coupled and free motion. Values for the initial (earliest possible) and final (latest possible) contact angles of the gear meshes are determined in this subroutine, which is called by the main program for each mesh. (Details of the development of this subroutine are available in reference 3, appendix A.) These initial and final gear mesh angles are needed in order to compute the instantaneous gear mesh angles in subroutine IN3. These, in turn, are needed in the solution of the differential equations.

Maximum Contact Forces

The subroutines OUTP and OUTPF use expressions developed in appendix A of this report to calculate the contact forces at each gear mesh. In addition, when the pallet pin and escape wheel are in coupled motion, a contact force exists between them and is calculated in OUTP. It is calculated with two expressions, one in terms of the escape wheel variable ϕ and one in terms of the pallet variable ψ . This serves as a check on the accuracy of the equations developed, since it is known that the contact force should be the same for both calculations.

Both subroutines keep track of the maximum contact force at each interface experienced through the arming cycle, and return this information to the main program.

Program Input/Output

The input parameters needed for the computer program are discussed in detail in the sample run for the PATRIOT M143 S&A.

The output of the program begins with a summary of all of the input parameters given. Following this, the program begins by solving the differential equation of coupled motion. For each time increment of the numerical solution to the differential equation, the following parameters are printed.

T	=	t	=	time (sec)
PHID	=	ϕ	=	instantaneous escape wheel angle (deg)
PHIDOT	=	$\dot{\phi}$	=	angular velocity of escape wheel (rad/sec)
G	=	g	=	distance from pallet pin to end of escape wheel tooth along the plane of the tooth (negative for coupled motion to exist) (in.)
GDOT	=	$\dot{g}$	=	time rate of change of the parameter g, or relative velocity of pallet pin along the escape wheel tooth (in./sec)
PSID	=	ψ	=	pallet angle (deg)
PSIDOT	=	$\dot{\psi}$	=	angular velocity of pallet (rad/sec)
PHITOT	=	ϕ_T	=	cumulative escape wheel angle (deg)
F34	=	F_{34}	=	normal contact force between gear no. 3 and pinion no. 4 (lbf)
F23	=	F_{23}	=	normal contact force between gear no. 2 and pinion no. 3 (lbf)
F12	=	F_{12}	=	normal contact force between gear no. 1 and pinion no. 2 (lbf)
PN	=	P_n	=	normal contact force between escape wheel and pallet (lbf) (calculated with equation in terms of the escape wheel variable ϕ)
PNPSI	=	$P_{n\psi}$	=	normal contact force between escape wheel and pallet (lbf) (calculated with equation in terms of the pallet variable ψ ; should be equal to PN)
DPHI2	=	$\ddot{\phi}$	=	angular acceleration of escape wheel (rad/sec ²)

The output continues in this manner until the free motion regime is reached. The output for free motion is as follows:

T	=	t	=	time (sec)
PHID	=	ϕ	=	instantaneous escape wheel angle (deg)
PHIDOT	=	$\dot{\phi}$	=	angular velocity of escape wheel (rad/sec)

$PSID = \psi =$ pallet angle (deg)
 $PSIDOT = \dot{\psi} =$ angular velocity of pallet (rad/sec)
 $PHITOT = \phi_T =$ cumulative escape wheel angle (deg)
 $FF12 = F_{F12} =$ normal contact force between gear no. 1 and pinion no. 2 (lbf)
 $FF23 = F_{F23} =$ normal contact force between gear no. 2 and pinion no. 3 (lbf)
 $FF34 = F_{F34} =$ normal contact force between gear no. 3 and pinion no. 4 (lbf)

When impact is sensed, the following parameters are written

$VP = V_p =$ velocity of the contact point of the pallet pin (in./sec) (first printed just prior to impact)
 $VS = V_s =$ velocity of the contact point of the escape wheel tooth (in./sec) (first printed just prior to impact)

Next, immediately after impact, the parameters PHID, PHIDOT, PSID, PSIDOT, and PHITOT are printed, as well as the post-impact values for VP and VS.

Upon the termination of the computer program, the final values printed are the maximum contact forces experienced at each interface during both free and coupled motion, and the arming time of the device.

Within the program, statements have been added in order to reduce the output. The time increment being used in the numerical analysis of the differential equations is 0.001 second, and in the case of the PATRIOT M143 S&A, an arming time of approximately 3 to 4 second is expected. This would result in approximately 30,000 to 40,000 lines of output. In order to limit this output, statements have been added to allow full print-out of only the first and last 30 degrees of escape wheel travel (in the case of the M143 S&A, the escape wheel travels over 13,000 degrees in the arming process). The output between the first and last 30 degrees is limited to every 1,000th line with further control statements. All output control statements can be easily removed or altered to suit the needs of the user.

COMPUTER SIMULATION OF AN EXAMPLE MECHANISM

Because the PATRIOT M143 S&A actually has a four-pass gear train due to the mesh between the two driving rotors, some minor modifications had to be made to the analysis and to the computer program. The revised analysis is given in appendix C and the associated computer program is shown in appendix D. This S&A will now be used as a sample mechanism. The balance rotor will be used as the

driving rotor. The input parameters³ needed to simulate the M143 S&A in an 11.9 g centrifuge arming test are described in detail below:

Escapement Parameters

A	=	a	=	0.1996 (in.) (5.0698 mm)	=	distance between the pallet and escape wheel pivot centers
B	=	b	=	0.1495 (in.) (3.7973 mm)	=	escape wheel radius
C	=	c	=	0.1188 (in.) (3.0175 mm)	=	distance from pivot center to pin center of pallet (identical for entrance and exit)
R	=	r	=	0.01575 (in.) (4.0005 mm)	=	pallet pin radius (identical for entrance and exit)
ALPHA	=	α	=	45.0 deg	=	escape wheel tooth half angle
EREST	=	ξ	=	0.0	=	coefficient of restitution (high speed motion pictures of runaway escapements indicate totally inelastic impacts)
LAMBDA	=	λ	=	108.42 deg	=	angle formed between pallet pins with radii taken to pivot center
DELTA	=	δ	=	30.0 deg	=	angle between individual escape wheel teeth

Reference 2 gives further details of these parameters, if needed.

Mass Properties of Components

M1	=	m_1	=	$2.6775 \times 10^{-4} \text{ lb-sec}^2/\text{in.}$ ($4.6963 \times 10^{-2} \text{ kg}$)	=	mass of rotor assembly
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³ All rotor input parameters subscripted with a 1 are those of the balance rotor.

M2	=	m_2	=	$1.9324 \times 10^{-6} \text{ lb-sec}^2/\text{in.}$ ($3.3894 \times 10^{-4} \text{ kg}$)	=	mass of no. 2 gear and pinion assembly
M3	=	m_3	=	$1.2185 \times 10^{-6} \text{ lb-sec}^2/\text{in.}$ ($2.1372 \times 10^{-4} \text{ kg}$)	=	mass of no. 3 gear and pinion assembly
M4	=	m_4	=	$1.0570 \times 10^{-6} \text{ lb-sec}^2/\text{in.}$ ($1.8540 \times 10^{-4} \text{ kg}$)	=	mass of escape wheel and pinion no. 4 assembly
MP	=	m_p	=	$5.3540 \times 10^{-6} \text{ lb-sec}^2/\text{in.}$ ($9.3909 \times 10^{-4} \text{ kg}$)	=	mass of pallet assembly
I1	=	I_1	=	$8.2140 \times 10^{-5} \text{ in.-lb-sec}^2$ $9.2952 \times 10^{-6} \text{ kg-m}$	=	moment of inertia of rotor assembly
I2	=	I_2	=	$1.3692 \times 10^{-9} \text{ in.-lb-sec}^2$ ($1.5494 \times 10^{-10} \text{ kg-m}$)	=	moment of inertia of no. 2 gear and pinion assembly
I3	=	I_3	=	$8.5991 \times 10^{-9} \text{ in.-lb-sec}^2$ ($9.7317 \times 10^{-10} \text{ kg-m}$)	=	moment of inertia of no. 3 gear and pinion assembly
I4	=	I_4	=	$6.8996 \times 10^{-9} \text{ in.-lb-sec}^2$ ($7.8078 \times 10^{-10} \text{ kg-m}$)	=	moment of inertia of escape wheel and no. 4 pinion assembly
IP	=	I_p	=	$6.8390 \times 10^{-8} \text{ in.-lb-sec}^2$ ($7.739 \times 10^{-9} \text{ kg-m}$)	=	moment of inertia of pallet assembly

General Parameters

RC1	=	r_{c1}	=	0.2656 in. (6.7462 mm)	=	distance from rotor pivot center to center of mass
RCP	=	r_{cp}	=	0.0 in. (0.0 mm)	=	pallet eccentricity or distance from pivot center to center of mass
RHOP	=	ρ_p	=	0.0152 in. (0.3861 mm)	=	pallet pivot radius
PHI1CD	=	ϕ_{1c}	=	45.0 deg	=	rotor angle in starting position (fig. 1)
PSICD	=	ψ_c	=	0 deg	=	eccentricity angle of pallet (fig. 1)
PHI0	=		=	133.45 deg	=	escape wheel starting angle of initial coupled motion simulation (for choice of this angle, see ref 2)

PHICUTD	=	13,268	deg	= cumulative escape wheel angle at which arming occurs, obtained from product of gear ratio and known rotor displacement necessary for arming
MU	=	μ	= 0.10	= coefficient of friction of gear train (pivots, tooth-to-tooth contacts, and escape wheel pivot)
MU1	=	μ_1	= 0.10	= coefficient of friction of pallet-escape wheel interface and pallet pivot
BETA1D	=	β_1	= 90.0 deg	= angle between lateral axis (x-axis) and line from rotor pivot to no. 2 gear-and-pinion assembly pivot (fig. 1)
BETA2D	=	β_2	= 90.0 deg	= angle between lateral axis and line from no. 2 gear and pinion assembly pivot to no. 3 gear and pinion assembly pivot (fig. 1)
BETA3D	=	β_3	= 180.0 deg	= angle between lateral axis and line from no. 3 gear and pinion assembly pivot to escape wheel and pinion assembly pivot (fig. 1)
BETA4D	=	β_4	= 180.0 deg	= angle between lateral axis and line from escape wheel and pinion assembly pivot to pallet assembly pivot (fig. 1)

Gear Parameters

PSUBD1	=	P_{d1}	= 75.4	= diametral pitch of mesh no. 1 (rotor and pinion no. 2)
PSUBD2	=	P_{d2}	= 96.5	= diametral pitch of mesh no. 2 (gear no. 2 and pinion no. 3)

PSUBD3	=	P_{d3}	=	102.9	=	diametral pitch of mesh no. 3 (gear no. 3 and escape wheel pinion)
NG1	=	N_{G1}	=	111	=	number of teeth of rotor (full gear no. 1)
NG2	=	N_{G2}	=	30	=	number of teeth of gear no. 2
NG3	=	N_{G3}	=	30	=	number of teeth of gear no. 3
NP2	=	N_{P2}	=	10	=	number of teeth of pinion no. 2
NP3	=	N_{P3}	=	8	=	number of teeth of pinion no. 3
NP4	=	N_{P4}	=	8	=	number of teeth of pinion no. 4 (escape wheel pinion)
CAPRP1	=	R_{p1}	=	0.73410 in. (18.64614 mm)	=	pitch radius of gear no. 1 (rotor)
CAPRP2	=	R_{p2}	=	0.15545 in. (3.94843 mm)	=	pitch radius of gear no. 2
CAPRP3	=	R_{p3}	=	0.14575 in. (3.70205 mm)	=	pitch radius of gear no. 3
RP2	=	r_{p2}	=	0.06635 in. (1.68529 mm)	=	pitch radius of pinion no. 2
RP3	=	r_{p3}	=	0.04145 in. (1.05283 mm)	=	pitch radius of pinion no. 3
RP4	=	r_{p4}	=	0.03885 in. (0.98679 mm)	=	pitch radius of pinion no. 4 (escape wheel pinion)
THETA1	=	θ_1	=	20.0 deg	=	pressure angle of mesh no. 1
THETA2	=	θ_2	=	20.0 deg	=	pressure angle of mesh no. 2
THETA3	=	θ_3	=	20.0 deg	=	pressure angle of mesh no. 3
RHO1	=	ρ_1	=	0.0770 in. (1.9558 mm)	=	pivot radius of rotor
RHO2	=	ρ_2	=	0.0190 in. (0.4826 mm)	=	pivot radius of no. 2 gear and pinion assembly

RH03	=	ρ_3	=	0.0154 in. (0.3912 mm)	=	pivot radius of no. 3 gear and pinion assembly
RH04	=	ρ_4	=	0.0154 in. (0.3912 mm)	=	pivot radius of escape wheel and pinion no. 4 assembly
CAPRB1	=	R_{b1}	=	0.7115 in. (18.0721 mm)	=	base radius of gear no. 1 (rotor)
CAPRB2	=	R_{b2}	=	0.1425 in. (3.6195 mm)	=	base radius of gear no. 2
CAPRB3	=	R_{b3}	=	0.1340 in. (3.4036 mm)	=	base radius of gear no. 3
RB2	=	r_{b2}	=	0.04375 in. (1.11125 mm)	=	base radius of pinion no. 2
RB3	=	r_{b3}	=	0.02700 in. (0.68580 mm)	=	base radius of pinion no. 3
RB4	=	r_{b4}	=	0.02450 in. (0.62230 mm)	=	base radius of pinion no. 4
CAPRO1	=	R_{o1}	=	0.75250 in. (19.1135 mm)	=	outside radius of gear no. 1
CAPRO2	=	R_{o2}	=	0.16630 in. (4.22402 mm)	=	outside radius of gear no. 2
CAPRO3	=	R_{o3}	=	0.15615 in. (3.96621 mm)	=	outside radius of gear no. 3
R02	=	r_{o2}	=	0.07585 in. (1.92659)	=	outside radius of pinion no. 2
R03	=	r_{o3}	=	0.04915 in. (1.24841 mm)	=	outside radius of pinion no. 3
R04	=	r_{o4}	=	0.04660 in. (1.18364 mm)	=	outside radius of pinion no. 4
J1	=	J_1	=	0	=	initialization parameter for mesh no. 1 (zero corresponds to the earliest possible contact of mesh, reference 3)
J2	=	J_2	=	0	=	initialization parameter for mesh no. 2
J3	=	J_3	=	0	=	initialization parameter for mesh no. 3

Angle Indexing Parameters

TANG	=	160 deg	= escape wheel angle at which coupled motion is no longer possible (see reference 2 to choose this angle)
NT	=	2	= number of escape wheel teeth spanned by the pallet pins when in entrance coupled motion

Parameters Needed for M143 Two-Rotor System

BD	=	β_D	=	97.3 deg	= detonator rotor angle in starting position (app B)
RD	=	r_D	=	0.17349 in. (4.40665 mm)	= distance from detonator rotor pivot center to center of mass
ID	=	I_D	=	$6.9974 \times 10^{-5} \text{ in.-lb-sec}^2$ ($7.9185 \times 10^{-6} \text{ kg-m}^2$)	= moment of inertia of detonator rotor
MD	=	m_D	=	$2.679 \times 10^{-4} \text{ in.-sec}^2/\text{lb}$ ($4.699 \times 10^{-2} \text{ kg}$)	= mass of detonator rotor

Acceleration Defining Parameters

N	=	2	= number of points used to define the acceleration profile
TIM(J), where J = 1 to N	=		= time data points for acceleration profile (sec)
GA(J)	=		= axial acceleration data points corresponding to TIM(J) data points (g's)
GL(J)	=		= lateral (normal) acceleration data points corresponding to TIM(J) data points (g's)

RESULTS

The program M143SA and the computer output for the run which simulates the M143 S&A in an 11.9 g centrifuge arming test are listed in appendix D. The results predict S&A arming in 3.57 seconds. This falls well within the arming specification of 3.1 to 4.2 seconds. The maximum non-impact contact forces calculated in the program are as follows:

$$F_{34} = 0.04 \text{ lbf} \\ (0.018 \text{ kg})$$

$$F_{F34} = 0.03 \text{ lbf} \\ (0.014 \text{ kg})$$

$$F_{23} = 0.20 \text{ lbf} \\ (0.091 \text{ kg})$$

$$F_{r34} = 0.18 \text{ lbf} \\ (0.082 \text{ kg})$$

$$F_{12} = 0.75 \text{ lbf} \\ (0.340 \text{ kg})$$

$$F_{F12} = 0.66 \text{ lbf} \\ (0.299 \text{ kg})$$

$$P_n = 0.01 \text{ lbf} \\ (0.005 \text{ kg})$$

CONCLUSIONS

With this simulation, an increased capability to analyze various safing and arming (S&A) mechanisms has been achieved. This capability to date includes artillery S&A mechanisms (spin driven) with involute two- and three-pass gear trains and pin pallet runaway escapements (ref 1), artillery S&A mechanisms in an aeroballistic environment with two-pass involute gear trains and straight-sided verge runaway escapements (ref 4), and now missile and rocket S&A mechanisms with involute three-pass gear trains and pin pallet runaway escapements.

The computer simulation developed in this report has been shown to be applicable to the PATRIOT M143 S&A after some slight modifications. The results were in good agreement with the specification requirement for this mechanism.

RECOMMENDATIONS

The M143 safing and arming (S&A) mechanism is currently the subject of a study to improve the producibility of the device. Changes generated through this study may affect the timing function of the device. The computer simulation developed here should be used in conjunction with laboratory testing to recommend adjustments to the escapement assembly so that the S&A can continue to meet its arming time specification.

REFERENCES

1. G. G. Lowen and F. R. Tepper, "Computer Simulation of Artillery S&A Mechanisms (Involute Gear Train and Pin Pallet Runaway Escapement)," Technical Report ARLCD-TR-81039, ARRADCOM, Dover, NJ, July 1982.
2. G. G. Lowen and F. R. Tepper, "Dynamics of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.
3. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.
4. F. R. Tepper and G. G. Lowen, "Computer Simulation of Artillery Safing and Arming Mechanism in Aeroballistic Environment (Involute Gear Train and Straight-Sided Verge Runaway Escapement)," Technical Report ARLCD-TR-83050, ARDC, Dover, NJ, July 1984.

APPENDIX A

DYNAMICS OF ROTOR DRIVEN MISSILE OR ROCKET S&A MECHANISM WITH
A THREE-PASS INVOLUTE GEAR TRAIN AND A PIN PALLET RUNAWAY ESCAPEMENT

This appendix gives derivations for a complete mathematical model of a missile or rocket S&A mechanism consisting of a rotor driven by axial acceleration, a three-pass involute step-up gear train, and a pin-pallet runaway escapement. The configuration of this model is shown in figure A-1.

This work was patterned to follow, to a considerable extent, work done by G. G. Lowen and F. R. Tepper in reference 1. That work, in turn, draws to a large degree on previous efforts by the above-mentioned authors; i.e., the dynamics of the pin-pallet runaway escapement (ref 2) and the analysis of fuze gear trains (ref 3). As in reference 1 and 2, the following three regimes of the mechanisms are considered:^{A-1}

1. Coupled Motion

The escape wheel is in contact with one of the pallet pins while it is driven by the rotor (gear no. 1) through the gear and pinion sets nos 2 and 3. The coupled motion differential equation is written in terms of the escape wheel variable and is obtained by combining the solutions to the Newtonian force and moment expressions for the individual mechanism components.

2. Free Motion

The pallet and the escape wheel, gear train, rotor system move independently of each other during this phase of motion. A differential equation is required to describe the motion of each. The differential equation of the pallet is expressed in terms of the pallet variable ψ , and that of the combined system in terms of the escape wheel variable ϕ .

3. Impact

The formulation of the impact regime is taken directly from reference 2, except now the moment of inertia of the escape wheel and pinion no. 4 also contains the referred mass properties of the rotor and gear pinion sets nos 2 and 3. This impact simulation is based on the classical angular impulse momentum model, where a coefficient of restitution is used to account for the energy losses. It is assumed that the effect of the impact force between the escape wheel and the pallet is significantly greater than the effect of the driving torque of the rotor and the various retarding torques caused by friction. Therefore, the driving torque of the rotor and the retarding torque are not considered in the model.

The influence of friction forces is considered both in the coupled and free motion regimes. There is friction at the escape wheel-pallet interface during coupled motion, and there is friction between the gear teeth and at all pivots during both of these regimes. As in references 1 and 3, the individual pivot friction torques are obtained by the algebraic addition of the two friction forces due to the x and y components of the normal bearing forces, rather than by direct use of the resulting normal forces. This conservative approach to friction is necessary in order to avoid difficulties which the presence of a square root introduces into the solutions of various differential equations.

^{A-1} For a more detailed description, consult figures in reference 2.

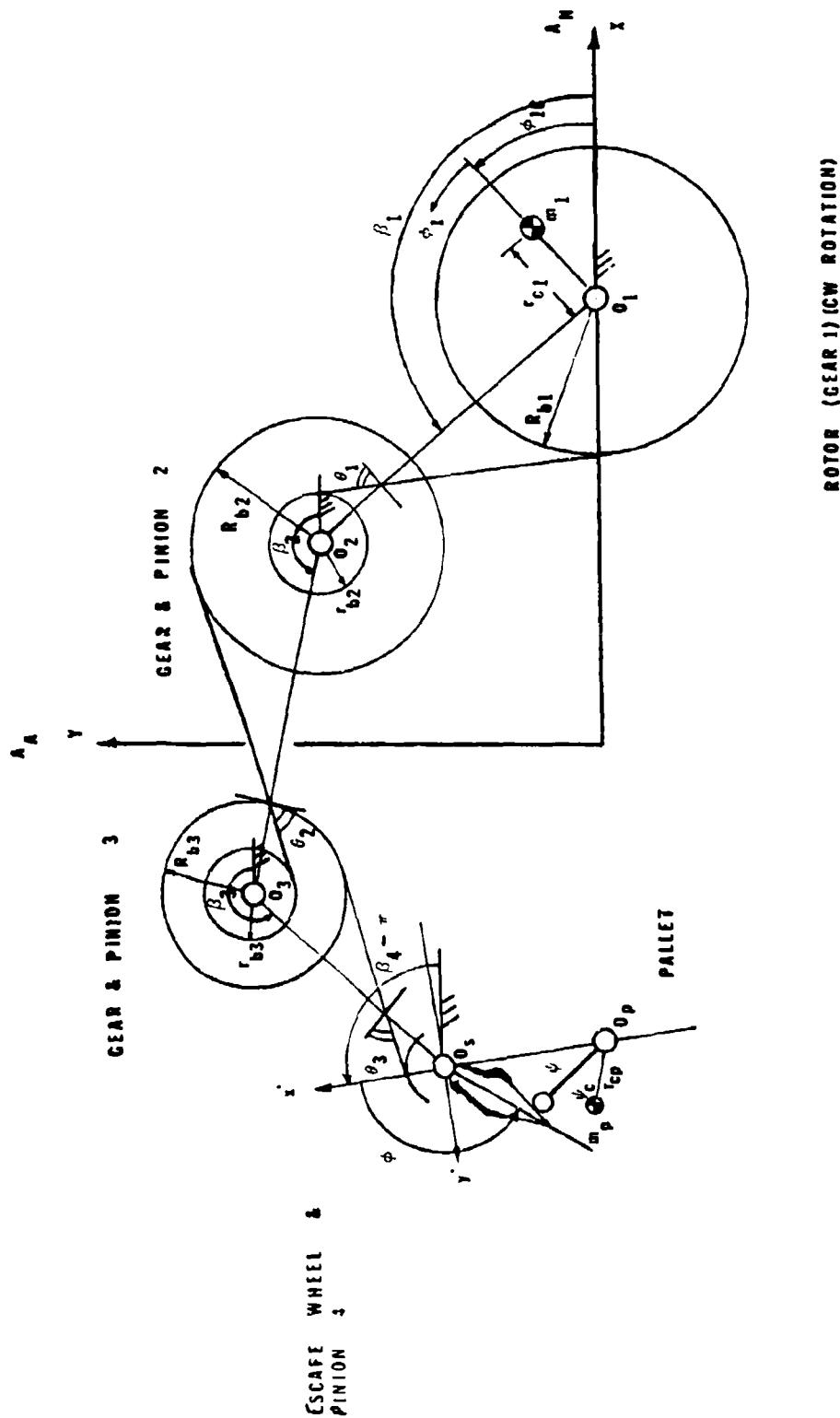


Figure A-1. Rotor driven S&A device with three pass involute gear train and pin pallet runaway escapement

The following outlines the derivations of the differential equations for both free and coupled motion as well as the development of contact force expressions.

Dynamics of the Pallet in Coupled Motion

The dynamic analysis of the pallet is most conveniently performed in the primed coordinate system (fig. A-1). The coefficient of friction at the pallet-escape wheel interface and at the pallet pivot has the designation μ_1 .

With $\bar{A}_A$ representing the axial acceleration of the missile and $\bar{A}_N$ representing the normal acceleration, the acceleration of the center of mass of the pallet can be expressed as follows (figs. A-1 and A-2):

$$\begin{aligned}\bar{A}_{cp} = & \bar{A}_A \bar{j} + \bar{A}_N \bar{i} - \dot{\psi}^2 r_{cp} [\cos(\psi + \psi_c) \bar{i}' + \sin(\psi + \psi_c) \bar{j}'] \\ & + \ddot{\psi} r_{cp} [-\sin(\psi + \psi_c) \bar{i}' + \cos(\psi + \psi_c) \bar{j}']\end{aligned}\quad (A-1)$$

A coordinate transformation is necessary to express $\bar{A}_A$ and $\bar{A}_N$ in the primed coordinate system

$$\bar{A}_A \bar{j} = -(A_A \sin \beta_4 \bar{i}' + A_A \cos \beta_4 \bar{j}')$$

(A-2)

$$\bar{A}_N \bar{i} = -A_N \cos \beta_4 \bar{i}' + A_N \sin \beta_4 \bar{j}'$$

(A-3)

With the above acceleration expression and the free body diagram of figure A-2, Newton's Law can be written as follows:

$$\begin{aligned}P_{nn} - \mu_1 s_4 P_{nt} + F'_{xp} \bar{i}' - \mu_1 s_5 F_{yp} \bar{j}' + \mu_1 s_5 F'_{xp} \bar{j}' \\ = m_p \{- (A_A \sin \beta_4 + A_N \cos \beta_4) \bar{i}' + (A_N \sin \beta_4 - A_A \cos \beta_4) \bar{j}' \\ - \dot{\psi}^2 r_{cp} [\cos(\psi + \psi_c) \bar{i}' + \sin(\psi + \psi_c) \bar{j}'] \\ + \ddot{\psi} r_{cp} [-\sin(\psi + \psi_c) \bar{i}' + \cos(\psi + \psi_c) \bar{j}']\end{aligned}\quad (A-4)$$

The signum functions introduced here, S_4 and S_5 , assure proper direction of the friction forces at the escape wheel-pallet interface as well as at the pallet shaft, regardless of the direction of pallet rotation. Thus,

$$S_4 = \frac{\dot{g}}{|\dot{g}|}\quad (A-5)$$

and

$$s_5 = \frac{\dot{\psi}}{|\dot{\psi}|} \quad (A-6)$$

(reference 2, eq B-1). The unit vectors $\bar{n}_t$ and $\bar{n}_n$ are adapted from equations A-1 and A-2 of reference 1.

The moment equation of the pallet must be written with respect to the accelerated pivot O_p , i.e.,

$$\bar{M}_{O_p} = - \ddot{\bar{r}}_{O_p} \times m_p \bar{r}_{cp} + \dot{\bar{H}}_{O_p} \quad (A-7)$$

where

$\bar{M}_{O_p}$ = sum of all external moments with respect to pivot O_p

$\ddot{\bar{r}}_{O_p}$ = absolute acceleration of point O_p

$\dot{\bar{H}}_{O_p}$ = time rate of change angular momentum of the pallet with respect to point O_p

With the acceleration of the missile or rocket expressed in terms of axial and normal acceleration, equation A-7 takes the form:

$$\begin{aligned} \bar{M}_{O_p} = & A_A (\sin \beta_4 \bar{i}' + \cos \beta_4 \bar{j}') + A_N (\cos \beta_4 \bar{i}' - \sin \beta_4 \bar{j}') \\ & \times m_p \bar{r}_{cp} (\cos (\psi + \psi_c) \bar{i}' + \sin (\psi + \psi_c) \bar{j}') + I_p \ddot{\psi} \bar{k} \end{aligned} \quad (A-8)$$

Appropriate computations and substitution of all moments, according to figure A-2, results in the final scalar moment equation (the moment arms A_1 , B_1 , C_1 , and D_1 of reference 2 are now primed):

$$\begin{aligned} & P_n (D_1' + C_1' u_1 s_4) - \rho_p u_1 s_5 (\tilde{F}_{xp} + \tilde{F}_{yp}) \\ & = I_p \ddot{\psi} + m_p \bar{r}_{cp} [A_A (\sin (\psi + \psi_c) \sin \beta_4 - \cos (\psi + \psi_c) \cos \beta_4) \\ & \quad + A_N (\sin (\psi + \psi_c) \cos \beta_4 + \cos (\psi + \psi_c) \sin \beta_4)] \end{aligned} \quad (A-9)$$

where

$$D_1' = C \cos (\phi - \alpha - \psi) \quad (A-10)$$

$$C'_1 = -[r + C \sin (\phi - \alpha - \psi)] \quad (A-11)$$

As in reference 3, $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$ represent conservatively evaluated pivot force components which assure that the pivot friction moments are opposed to the rotation at all times. The following illustrates how this goal may be accomplished.

The pivot force components F'_{xp} and F'_{yp} must first be obtained from component expressions of the equation developed using Newton's law (eq A-4). The component expressions are as follows:

$$\begin{aligned} & -P_n \sin (\phi - \alpha) - \mu_1 s_4 P_n \cos (\phi - \alpha) + F'_{xp} - \mu_1 s_5 F'_{yp} \\ & = m_p [-A_N \cos \beta_4 - A_A \sin \beta_4 - \dot{\psi}^2 r_{cp} \cos (\psi + \psi_c) \\ & + \ddot{\psi} r_{cp} \sin (\psi + \psi_c)] \end{aligned} \quad (A-12)$$

and

$$\begin{aligned} & P_n \cos (\phi - \alpha) - \mu_1 s_4 P_n \sin (\phi - \alpha) + F'_{yp} + \mu_1 s_5 F'_{xp} \\ & = m_p [A_N \sin \beta_4 - A_A \cos \beta_4 - \dot{\psi}^2 r_{cp} \sin (\psi + \psi_c) \\ & + \ddot{\psi} r_{cp} \cos (\psi + \psi_c)] \end{aligned} \quad (A-13)$$

The pivot force components F'_{xp} and F'_{yp} are found through simultaneous solution of the above component expressions. Subsequently, they are approximated as $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$, respectively. The resulting expressions for $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$ are given as:

$$\tilde{F}_{yp} = A_1 P_n \pm A_2 A_A \pm A_3 A_N \pm A_4 \dot{\psi}^2 \pm A_5 \ddot{\psi} \quad (A-14)$$

$$\tilde{F}_{xp} = A_6 P_n \pm A_7 A_A \pm A_8 A_N \pm A_9 \dot{\psi}^2 \pm A_{10} \ddot{\psi} \quad (A-15)$$

where

$$A_1 = \left| \frac{\mu_1 (s_4 - s_5) \sin (\phi - \alpha) - (1 + \mu_1^2 s_4 s_5) \cos (\phi - \alpha)}{1 + \mu_1^2} \right| \quad (A-16)$$

$$A_2 = \left| \frac{m_p (\cos \beta_4 - \mu_1 s_5 \sin \beta_4)}{1 + \mu_1^2} \right| \quad (A-17)$$

$$A_3 = \left| \frac{m_p (\sin \beta_4 - \mu_1 s_5 \cos \beta_4)}{1 + \mu_1^2} \right| \quad (A-18)$$

$$A_4 = \left| \frac{m_p r_{cp} [\mu_1 s_5 \cos (\psi + \psi_c) - \sin (\psi + \psi_c)]}{1 + \mu_1^2} \right| \quad (A-19)$$

$$A_5 = \left| \frac{m_p r_{cp} [\mu_1 s_5 \sin (\psi + \psi_c) + \cos (\psi + \psi_c)]}{1 + \mu_1^2} \right| \quad (A-20)$$

$$A_6 = \left| \frac{\mu_1 (s_4 - s_5) \cos (\phi - \alpha) + (1 + s_4 s_5 \mu_1^2) \sin (\phi - \alpha)}{1 + \mu_1^2} \right| \quad (A-21)$$

$$A_7 = \left| \frac{m_p \mu_1 s_5 \cos \beta_4 + m_p \sin \beta_4}{1 + \mu_1^2} \right| \quad (A-22)$$

$$A_8 = \left| \frac{m_p \mu_1 s_5 \sin \beta_4 + m_p \cos \beta_4}{1 + \mu_1^2} \right| \quad (A-23)$$

$$A_9 = \left| \frac{m_p r_{cp} [\cos (\psi + \psi_c) + \mu_1 s_5 \sin (\psi + \psi_c)]}{1 + \mu_1^2} \right| \quad (A-24)$$

$$A_{10} = \left| \frac{m_p r_{cp} [\sin (\psi + \psi_c) - \mu_1 s_5 \cos (\psi + \psi_c)]}{1 + \mu_1^2} \right| \quad (A-25)$$

To make the final decision concerning the signs of equations A-14 and A-15, these forces are substituted into the moment equation (A-9), and the influence of the direction of rotation on each of the resulting moment computations is explored:

$$\begin{aligned} & P_n [D_1' + C_1' \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_6)] \pm \rho_p \mu_1 s_5 A_A (A_2 + A_7) \\ & \pm \rho_p \mu_1 s_5 A_N (A_3 + A_8) \pm \rho_p \mu_1 s_5 \dot{\psi}^2 (A_4 + A_9) \pm \rho_p \mu_1 s_5 \ddot{\psi} (A_5 + A_{10}) \\ & = I_p \ddot{\psi} + m_p r_{cp} [A_A (\sin (\psi + \psi_c) \sin \beta_4 - \cos (\psi + \psi_c) \cos \beta_4) \\ & + A_N (\sin (\psi + \psi_c) \cos \beta_4 + \cos (\psi + \psi_c) \sin \beta_4)] \end{aligned} \quad (A-26)$$

In order for the friction moments to appropriately oppose the motion, the following signum assignments are made:

With s_5 positive for positive rotation (CCW) and vice versa, while all other parameters are positive at all times, the following moment components of equation A-26 must have negative signs during positive rotation:

$$- P_n \rho_p \mu_1 s_5 (A_1 + A_6) \quad (A-27)$$

$$- \rho_p \mu_1 s_5 \dot{\psi}^2 (A_4 + A_9) \quad (A-28)$$

The axial and normal acceleration terms A_A and A_N can be both positive and negative due to varying flight patterns and decay due to air resistance. This requires the introduction of signum functions s_6 and s_7 . These signum functions are assigned values in the following manner:

$$s_6 = -1 \text{ for } A_A \text{ positive}$$

$$s_6 = +1 \text{ for } A_A \text{ negative}$$

and

$$s_7 = -1 \text{ for } A_N \text{ positive}$$

$$s_7 = +1 \text{ for } A_N \text{ negative}$$

With the introduction of s_6 and s_7 , the following moment components of equation A-26 must have positive signs during positive rotation:

$$+ s_6 A_A \rho_p \mu_1 s_5 (A_2 + A_7) \quad (A-29)$$

$$+ s_7 A_N \rho_p \mu_1 s_5 (A_3 + A_8) \quad (A-30)$$

The choice of sign for the friction moment term in equation A-26, which is proportional to the pallet angular acceleration $\dot{\psi}$, is discussed in detail in reference 1, appendix F. That work results in the computational rules of equations A-36 and A-37, which deal with the sign of the effective moment of inertia I_{PR} of the pallet. (Note that the signum function s_5 has now been omitted.)

With these sign considerations, the moment equation A-26 becomes:

$$\begin{aligned} & A_{11} \ddot{\psi} + A_{12} A_A + A_{13} A_N - A_{14} \dot{\psi}^2 \\ & = I_{PR} \ddot{\psi} + m_p r_{cp} [A_A (\sin(\psi + \psi_c) \sin \beta_4 - \cos(\psi + \psi_c) \cos \beta_4) \\ & + A_N (\sin(\psi + \psi_c) \cos \beta_4 - \cos(\psi + \psi_c) \sin \beta_4)] \end{aligned} \quad (A-31)$$

where

$$A_{11} = D_1' + C_1' \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_6) \quad (A-32)$$

$$A_{12} = s_6 \rho_p \mu_1 s_5 (A_2 + A_7) \quad (A-33)$$

$$A_{13} = s_7 \rho_p \mu_1 s_5 (A_3 + A_8) \quad (A-34)$$

$$A_{14} = \rho_p \mu_1 s_5 (A_4 + A_9) \quad (A-35)$$

$$I_{PR} = I_p + A_{15} \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have the same signs} \quad (A-36)$$

$$I_{PR} = I_P - A_{15} \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have opposite signs}^{A-2} \quad (A-37)$$

$$A_{15} = \rho_p u_1 (A_5 + A_{10}) \quad (A-38)$$

Equation A-31 can now be rearranged in order to yield an expression for the contact force P_n . This contact force is to be the common force in the development of the dynamics of the escape wheel. This expression will later be used to establish a single differential equation for the escapement in coupled motion. Solving A-31 for P_n ,

$$\begin{aligned} P_n = \frac{1}{A_{11}} \{ & I_{PR} \ddot{\psi} + A_{14} \dot{\psi}^2 - A_{12} A_A - A_{13} A_N \\ & + m_p r_{cp} [A_A (\sin(\psi + \psi_c) \sin \beta_4 - \cos(\psi + \psi_c) \cos \beta_4) \\ & + A_N (\sin(\psi + \psi_c) \cos \beta_4 + \cos(\psi + \psi_c) \sin \beta_4)] \} \end{aligned} \quad (A-39)$$

The above equation can be rewritten in terms of escape wheel variables, $\dot{\phi}$ and ϕ . As in references 1 and 2,

$$\ddot{\psi} = U\ddot{\phi} + V\dot{\phi} \quad (A-40)$$

and

$$\dot{\psi} = U\dot{\phi} \quad (A-41)$$

Substituting in equation A-39, the expression for the contact force in terms of the escape wheel variables is:

$$\begin{aligned} P_n = \frac{1}{A_{11}} \{ & I_{PR} U\ddot{\phi} + (A_{14} U^2 + I_{PR} V) \dot{\phi}^2 - A_{12} A_A - A_{13} A_N \\ & + m_p r_{cp} [A_A (\sin(\psi + \psi_c) \sin \beta_4 - \cos(\psi + \psi_c) \cos \beta_4) \\ & + A_N (\sin(\psi + \psi_c) \cos \beta_4 + \cos(\psi + \psi_c) \sin \beta_4)] \} \end{aligned} \quad (A-42)$$

A-2 Care must be taken that $I_P - A_{15}$ does not become negative. If this occurs, I_{PR} must be set equal to zero. For free motion, I_{PR} cannot be zero since it would make the values of ψ indefinite in the Runge-Kutta solution.

Dynamics of the Escape Wheel in Coupled Motion (Escape Wheel Incorporates Pinion No. 4)

A free body diagram of the escape wheel and pinion no. 4 is shown in figure A-3. The pivot forces F_{x4} and F_{y4} as well as the forces F_{34} , $(m_4 \bar{A}_A)$, and $(m_4 \bar{A}_N)$ are now defined in the general (unprimed) x-y system. The unit vectors $\bar{n}_t$ and $\bar{n}_n$ must now be expressed in terms of the general coordinate system. From equations A-1 and A-2 of reference 2:

$$\bar{n}_t = \cos (\phi - \alpha) \bar{i}' + \sin (\phi - \alpha) \bar{j}' \quad (A-43)$$

$$\bar{n}_n = -\sin (\phi - \alpha) \bar{i}' + \cos (\phi - \alpha) \bar{j}' \quad (A-44)$$

Equations A-55 and A-56 of reference 1

$$\bar{i}' = -\cos \beta_4 \bar{i} - \sin \beta_4 \bar{j} \quad (A-45)$$

$$\bar{j}' = \sin \beta_4 \bar{i} - \cos \beta_4 \bar{j} \quad (A-46)$$

can be used to perform the transformation. The resulting equations are

$$\bar{n}_t = -\cos (\phi - \alpha + \beta_4) \bar{i} - \sin (\phi - \alpha + \beta_4) \bar{j} \quad (A-47)$$

and

$$\bar{n}_n = \sin (\phi - \alpha + \beta_4) \bar{i} - \cos (\phi - \alpha + \beta_4) \bar{j} \quad (A-48)$$

The expressions for the unit vectors $\bar{n}_{34}$ and $\bar{n}_{N34}$, as used in the analysis of pinion no. 4 in reference 3, section A-1a are of further interest,

$$\bar{n}_{34} = \sin (\beta_3 + \theta_3) \bar{i} - \cos (\beta_3 + \theta_3) \bar{j} \quad (A-49)$$

$$\bar{n}_{N34} = \cos (\beta_3 + \theta_3) \bar{i} + \sin (\beta_3 + \theta_3) \bar{j} \quad (A-50)$$

With the use of these unit vectors and the free body diagram (fig. A-3), the force equation for counterclockwise rotation of the escape wheel assembly as given by Newton's law is:^{A-3}

A-3 See reference 1, appendix F for description of motion reversal; i.e., clockwise escape wheel rotation. This may occur after severe impacts.

$$\begin{aligned}
& - P_n \bar{n}_n + \mu_1 s_4 \bar{n}_t + F_{34} \bar{n}_{34} + \mu s_3 F_{34} \bar{n}_{N34} + F_{x4} \bar{i} + \mu F_{y4} \bar{i} \\
& + \mu F_{x4} \bar{j} - F_{y4} \bar{j} = m_4 (A_A \bar{j} + A_N \bar{i})
\end{aligned} \tag{A-51}$$

Note that the coefficient of friction μ is now used for all pivots and gear tooth contacts of the remainder of the mechanism train.^{A-4}

Using figure A-3, the moment equation of the escape wheel for counterclockwise rotation can be written

$$\begin{aligned}
& - P_n (A_1' + B_1' \mu_1 s_4) - \mu p_4 (\tilde{F}_{x4} + \tilde{F}_{y4}) + r_{b4} F_{34} \\
& - \mu s_3 (d_3 - a_3) F_{34} = I_4 \ddot{\phi}
\end{aligned} \tag{A-52}$$

where

$$A_1' = b \cos \alpha + g \tag{A-53}$$

$$B_1' = b \sin \alpha \tag{A-54}$$

The escape wheel pivot forces $\tilde{F}_{x4}$ and $\tilde{F}_{y4}$ are derived in the same manner as the pallet pivot forces. They are obtained from the component expressions of equations A-51; i.e.,

$$\begin{aligned}
& - P_n \sin (\phi - \alpha + \beta_4) - s_4 \mu_1 P_n \cos (\phi - \alpha + \beta_4) \\
& + F_{34} \sin (\beta_3 + \theta_3) + \mu s_3 F_{34} \cos (\beta_3 + \theta_3) - m_4 A_N \\
& + F_{x4} + \mu F_{y4} = 0
\end{aligned} \tag{A-55}$$

$$\begin{aligned}
& P_n \cos (\phi - \alpha + \beta_4) - s_4 \mu_1 P_n \sin (\phi - \alpha + \beta_4) \\
& - F_{34} \cos (\beta_3 + \theta_3) + \mu s_3 F_{34} \sin (\beta_3 + \theta_3) - m_4 A_A \\
& - F_{y4} + \mu F_{x4} = 0
\end{aligned} \tag{A-56}$$

Simultaneous solution of equations A-55 and A-56 yields

$$\tilde{F}_{y4} = A_{16} P_n + A_{17} F_{34} \pm A_{18} A_A \pm A_{19} A_N \tag{A-57}$$

^{A-4} The signum functions s_1 , s_2 , and s_3 are defined in reference 3 in connection with the tooth contact friction of various meshes.

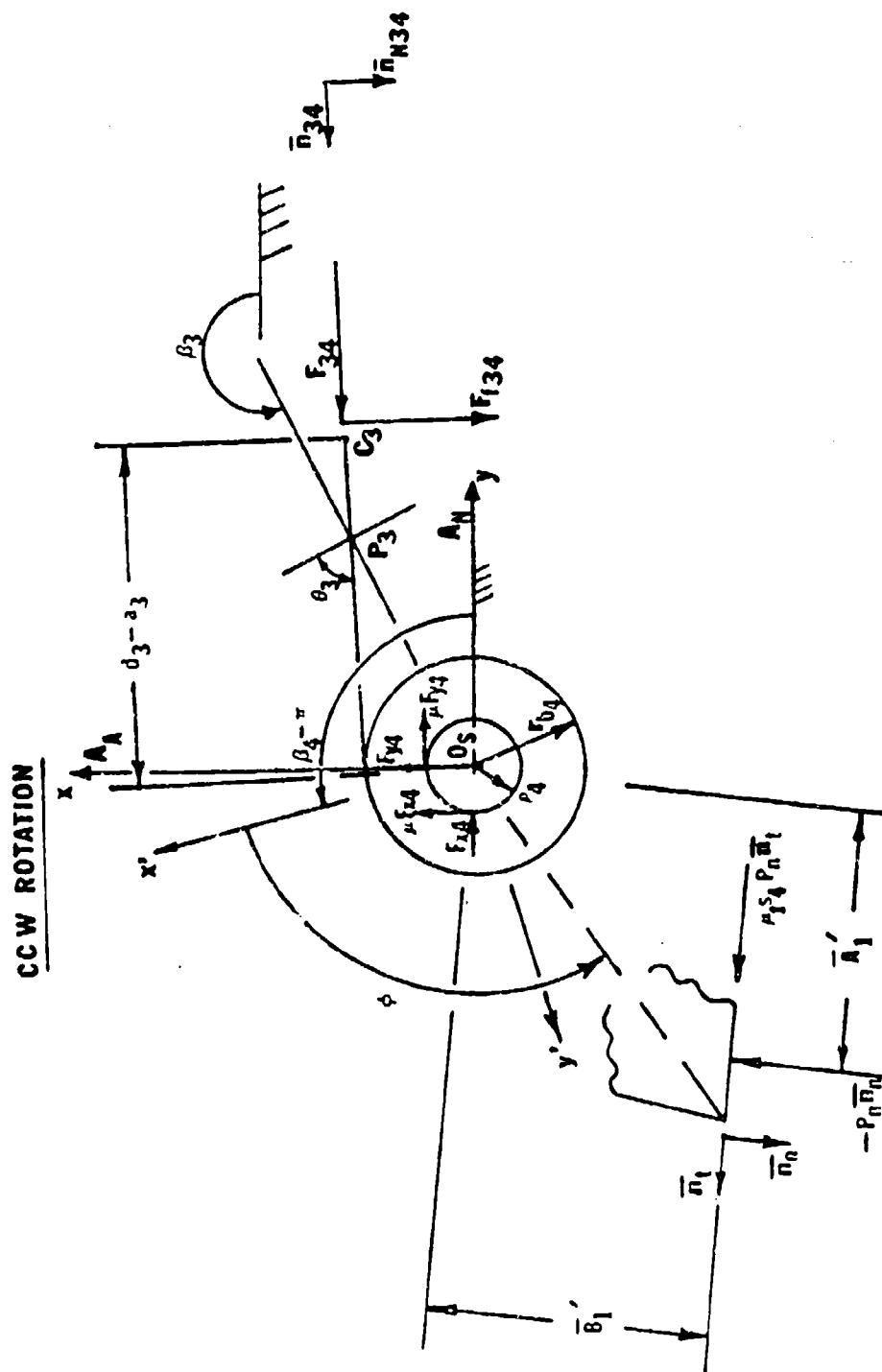


Figure A-3. Free body diagram of escape wheel and pinion 4

$$\tilde{F}_{x4} = A_{20} P_n + A_{21} F_{34} \pm A_{22} A_A \pm A_{23} A_N \quad (A-58)$$

where

$$A_{16} = \left| \frac{-(\mu_1 s_4 - \mu) \sin(\phi - \alpha + \beta_4) + (1 + \mu \mu_1 s_4) \cos(\phi - \alpha + \beta_4)}{1 + \mu^2} \right| \quad (A-59)$$

$$A_{17} = \left| \frac{-\mu(1 - s_3) \sin(\beta_3 + \theta_3) - (1 + \mu^2 s_3) \cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-60)$$

$$A_{18} = \left| \frac{m_4}{1 + \mu^2} \right| \quad (A-61)$$

$$A_{19} = \left| \frac{-\mu m_4}{1 + \mu^2} \right| \quad (A-62)$$

$$A_{20} = \left| \frac{1 + \mu_1 \mu s_4 \sin(\phi - \alpha + \beta_4) + (s_4 \mu_1 - \mu) \cos(\phi - \alpha + \beta_4)}{1 + \mu^2} \right| \quad (A-63)$$

$$A_{21} = \left| \frac{-(1 + \mu^2 s_3) \sin(\beta_3 + \theta_3) + \mu(1 - s_3) \cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-64)$$

$$A_{22} = \left| \frac{-m_4 \mu}{1 + \mu^2} \right| \quad (A-65)$$

$$A_{23} = \left| \frac{-m_4}{1 + \mu^2} \right| \quad (A-66)$$

Noting that $A_{18} = A_{23}$ and $A_{19} = A_{22}$, equations A-57 and A-58 are rewritten dropping the unnecessary variables A_{22} and A_{23} .

$$\tilde{F}_{y4} = A_{16} P_n + A_{17} F_{34} \pm A_{18} A_A \pm A_{19} A_N \quad (A-67)$$

$$\tilde{F}_{x4} = A_{20} P_n + A_{21} F_{34} \pm A_{19} A_A \pm A_{18} A_N \quad (A-68)$$

These pivot forces are now substituted into the moment equation A-58,

$$\begin{aligned} & -P_n (A'_1 + B'_1 \mu_1 s_4) - \mu \rho_4 [(A_{16} + A_{20}) P_n + (A_{17} + A_{21}) F_{34} \\ & \pm (A_{18} + A_{19}) A_A \pm (A_{18} + A_{19}) A_N] + r_{b4} F_{34} \\ & - \mu s_3 (d_3 - a_3) F_{34} = I_4 \ddot{\phi} \end{aligned} \quad (A-69)$$

Again, care must be taken to assure that the pivot friction moment opposes the motion. The terms

$$\pm \mu \rho_4 (A_{18} + A_{19}) A_A$$

and

$$\pm \mu \rho_4 (A_{18} + A_{19}) A_N$$

must be negative for counterclockwise rotation. This is again accomplished with the signum functions s_6 and s_7 . Thus, the two above terms become

$$+ s_6 \mu \rho_4 (A_{18} + A_{19}) A_A$$

and

$$+ s_7 \mu \rho_4 (A_{18} + A_{19}) A_N$$

Now equation A-69 can be solved for the contact force P_n ,

$$P_n = \frac{-I_4 \ddot{\phi} + A_{22} F_{34} + A_{23} A_A + A_{24} A_N}{A_{25}} \quad (A-70)$$

where

$$A_{22} = r_{b4} - \mu [s_3(d_3 - a_3) + \rho_4 (A_{17} + A_{21})] \quad (A-71)$$

$$A_{23} = s_6 \mu \rho_4 (A_{18} + A_{19}) \quad (A-72)$$

$$A_{24} = s_7 \mu \rho_4 (A_{18} + A_{19}) \quad (A-73)$$

$$A_{25} = A'_1 + B'_1 \mu s_4 + \mu \rho_4 (A_{16} + A_{20}) \quad (A-74)$$

Combined Coupled Motion Differential Equation for Escape Wheel and Pallet

Two expressions have now been developed for the contact force, P_n , between the pallet and escape wheel. By equating the two equations A-70 and A-42, a differential equation of the coupled motion in terms of the escape wheel angle ϕ is obtained,

$$\begin{aligned}
& (A_{25} I_{PR} U + A_{11} I_4) \ddot{\phi} + (A_{25} A_{14} U^2 + A_{25} I_{PR} V) \dot{\phi}^2 \\
& = A_{11} A_{22} F_{34} + (A_{11} A_{23} + A_{12} A_{25} - A_{25} m_p r_{cp} \sin(\psi + \psi_c) \sin \beta_4 \\
& + A_{25} m_p r_{cp} \cos(\psi + \psi_c) \cos \beta_4) A_A + (A_{11} A_{24} + A_{13} A_{25} \\
& - A_{25} m_p r_{cp} \sin(\psi + \psi_c) \cos \beta_4 - A_{25} m_p r_{cp} \cos(\psi + \psi_c) \sin \beta_4) A_N
\end{aligned}
\tag{A-75}$$

The system differential equation cannot be solved until the contact force F_{34} is known. An expression can be developed for F_{34} by combining the appropriate differential equations for gear and pinion numbers 2 and 3 and the rotor (gear no. 1).

Dynamics of Rotor (Gear No. 1)

A free body diagram of the rotor is shown in figure A-4. The acceleration of its center of mass is given by

$$\begin{aligned}
\bar{A}_{CR} &= A_A \bar{j} + A_N \bar{i} - \dot{\phi}_1^2 r_{cl} [\cos(\phi_{lc} + \phi_1) \bar{i} \\
&+ \sin(\phi_{lc} + \phi_1) \bar{j}] + \ddot{\phi}_1 r_{cl} [-\sin(\phi_{lc} + \phi_1) \bar{i} \\
&+ \cos(\phi_{lc} + \phi_1) \bar{j}]
\end{aligned}
\tag{A-76}$$

It is desired to continue to express motion in terms of escape wheel variables, ϕ , $\dot{\phi}$, and $\ddot{\phi}$. This is accomplished by introducing the gear ratio which relates the motion; i.e.,

$$\dot{\phi}_1 = N_{41} \dot{\phi} \tag{A-77}$$

$$\ddot{\phi}_1 = N_{41} \ddot{\phi} \tag{A-78}$$

where

$$N_{41} = \frac{-N_{P4} N_{P3} N_{P2}}{N_{G3} N_{G2} N_{G1}} \tag{A-79}$$

The rotor angle $\phi_{lc} + \phi_1$ is expressed as follows:

$$\phi_{lc} + \phi_1 = \phi_{lc} + N_{41} \phi_T \tag{A-80}$$

where ϕ_T represents the total rotation of the escape wheel from the inception of the motion. (The section on Additional Program Features describes the manner in which ϕ_T is obtained as a function of the instantaneous angle ϕ .)

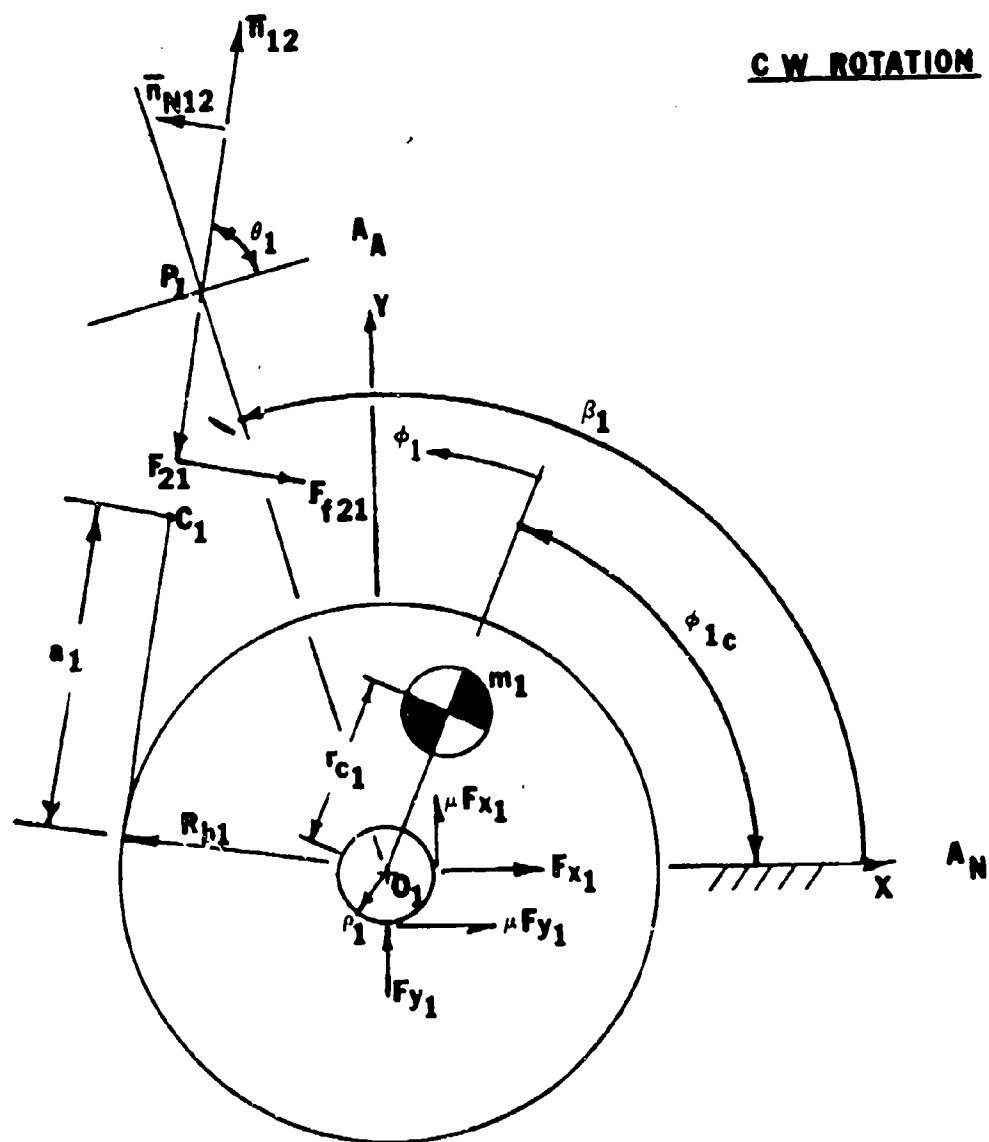


Figure A-4. Free body diagram of rotor (gear no. 1)

Equation A-76 can now be rewritten as,

$$\begin{aligned} \bar{A}_{CR} = & \bar{A}_A \bar{j} + \bar{A}_N \bar{i} - (N_{41} \ddot{\phi})^2 r_{c1} [\cos (\phi_{1c} + N_{41} \phi_T) \bar{i} \\ & + \sin (\phi_{1c} + N_{41} \phi_T) \bar{j}] + N_{41} \ddot{\phi} r_{c1} [-\sin (\phi_{1c} + N_{41} \phi_T) \bar{i} \\ & + \cos (\phi_{1c} + N_{41} \phi_T) \bar{j}] \end{aligned} \quad (A-81)$$

With figure A-4, Newton's force equation can now be written for clockwise rotation of the rotor.^{A-5}

$$-F_{12} \bar{n}_{12} - \mu s_1 F_{12} \bar{n}_{N12} - F_{x1} \bar{i} + \mu F_{y1} \bar{j} + \mu F_{x1} \bar{j} = m_1 \bar{A}_{CR} \quad (A-82)$$

where

$$\bar{n}_{12} = \sin (\beta_1 + \theta_1) \bar{i} - \cos (\beta_1 + \theta_1) \bar{j} \quad (A-83)$$

$$\bar{n}_{N12} = \cos (\beta_1 + \theta_1) \bar{i} + \sin (\beta_1 + \theta_1) \bar{j} \quad (A-84)$$

(ref 3, eqs A-78 and A-79).

Further, in figure A-4

$$\bar{F}_{21} = -F_{12} \bar{n}_{12} \quad (A-85)$$

and

$$\bar{F}_{f21} = -\mu s_1 F_{12} \bar{n}_{N12} \quad (A-86)$$

(ref 3, eqs A-103 and A-104).

The moment equation must be written in the manner of equation A-7 with respect to the accelerated point O_1 . The pivot friction reactions $\tilde{F}_{x1}$ and $\tilde{F}_{y1}$ are treated so that the associated friction moments retard the clockwise rotation of the rotor. This leads to

$$\begin{aligned} R_{b1} F_{12} \bar{k} - \mu s_1 a_1 F_{12} \bar{k} + \mu \rho_1 (\tilde{F}_{x1} + \tilde{F}_{y1}) \bar{k} \\ = -(\bar{A}_A \bar{j} + \bar{A}_N \bar{i}) \times m_1 r_{c1} [\cos (\phi_{1c} + N_{41} \phi_T) \bar{i} \\ + \sin (\phi_{1c} + N_{41} \phi_T) \bar{j}] + I_1 N_{41} \ddot{\phi} \bar{k} \end{aligned} \quad (A-87)$$

Performing the cross product, and then simplifying, the moment equation becomes:

^{A-5} Description of motion reversal, reference 1, appendix F.

$$\begin{aligned}
& R_{b1} F_{12} - \mu s_1 a_1 F_{12} + \mu p_1 (\tilde{F}_{x1} + \tilde{F}_{y1}) \\
& = m_1 r_{c1} \cos (\phi_{1c} + N_{41} \phi_T) A_A - m_1 r_{c1} \sin (\phi_{1c} + N_{41} \phi_T) A_N \\
& + I_1 N_{41} \ddot{\phi}
\end{aligned} \tag{A-88}$$

The force equation A-82 can be rewritten as two component expressions which, through simultaneous solution, give the forces $\tilde{F}_{x1}$ and $\tilde{F}_{y1}$.

$$\begin{aligned}
& - F_{12} \sin (\beta_1 + \theta_1) - \mu s_1 F_{12} \cos (\beta_1 + \theta_1) - F_{x1} + \mu F_{y1} \\
& = m_1 [A_N - (N_{41} \dot{\phi})^2 r_{c1} \cos (\phi_{1c} + N_{41} \phi_T) \\
& - N_{41} \ddot{\phi} r_{c1} \sin (\phi_{1c} + N_{41} \phi_T)]
\end{aligned} \tag{A-89}$$

and

$$\begin{aligned}
& F_{12} \cos (\beta_1 + \theta_1) - \mu s_1 F_{12} \sin (\beta_1 + \theta_1) + F_{y1} + \mu F_{x1} \\
& = m_1 [A_A - (N_{41} \dot{\phi})^2 r_{c1} \sin (\phi_{1c} + N_{41} \phi_T) \\
& + N_{41} \ddot{\phi} r_{c1} \cos (\phi_{1c} + N_{41} \phi_T)]
\end{aligned} \tag{A-90}$$

Simultaneous solution yields

$$\tilde{F}_{y1} = \pm A_{26} F_{12} \pm A_{27} A_A \pm A_{28} A_N \pm A_{29} (N_{41} \dot{\phi})^2 \pm A_{30} N_{41} \ddot{\phi} \tag{A-91}$$

$$\tilde{F}_{x1} = \pm A_{31} F_{12} \pm A_{28} A_A \pm A_{27} A_N \pm A_{32} (N_{41} \dot{\phi})^2 \pm A_{33} N_{41} \ddot{\phi} \tag{A-92}$$

where

$$A_{26} = \left| \frac{\mu (1 + s_1) \sin (\beta_1 + \theta_1) + (\mu^2 s_1 - 1) \cos (\beta_1 + \theta_1)}{(1 + \mu^2)} \right| \tag{A-93}$$

$$A_{27} = \left| \frac{m_1}{(1 + \mu^2)} \right| \tag{A-94}$$

$$A_{28} = \left| \frac{m_1 \mu}{(1 + \mu^2)} \right| \tag{A-95}$$

$$A_{29} = \left| \frac{m_1 r_{c1} [\mu \cos (\phi_{1c} + N_{41} \phi_T) + \sin (\phi_{1c} + N_{41} \phi_T)]}{(1 + \mu^2)} \right| \tag{A-96}$$

$$A_{30} = \left| \frac{m_1 r_{c1} [\cos (\phi_{1c} + N_{41} \phi_T) - \mu \sin (\phi_{1c} + N_{41} \phi_T)]}{(1 + \mu^2)} \right| \tag{A-97}$$

$$A_{31} = \left| \frac{(1 - \mu^2 s_1) \sin (\theta_1 + \theta_1) + \mu (1 + s_1) \cos (\theta_1 + \theta_1)}{(1 + \mu^2)} \right| \quad (A-98)$$

$$A_{32} = \left| \frac{m_1 r_{cl} [\cos (\phi_{lc} + N_{41} \phi_T) - \mu \sin (\phi_{lc} + N_{41} \phi_T)]}{(1 + \mu^2)} \right| \quad (A-99)$$

$$A_{33} = \left| \frac{m_1 r_{cl} [\mu \cos (\phi_{lc} + N_{41} \phi_T) + \sin (\phi_{lc} + N_{41} \phi_T)]}{(1 + \mu^2)} \right| \quad (A-100)$$

Equations A-91 and A-92 are now substituted into the moment equation A-88,

$$\begin{aligned} R_{b1} F_{12} - \mu s_1 a_1 F_{12} + \mu \rho_1 [\pm (A_{26} + A_{31}) F_{12} \\ \pm (A_{27} + A_{28}) A_A \pm (A_{27} + A_{28}) A_N \pm (A_{29} + A_{32}) (N_{41} \dot{\phi})^2 \\ \pm (A_{30} + A_{33}) N_{41} \ddot{\phi}] = m_1 r_{cl} \cos (\phi_{lc} + N_{41} \phi_T) A_A \\ - m_1 r_{cl} \sin (\phi_{lc} + N_{41} \phi_T) A_N + I_1 N_{41} \ddot{\phi} \end{aligned} \quad (A-101)$$

Again, care must be taken to assure that the friction moments oppose the motion; i.e., are positive for clockwise rotation. In order for this to be true, the following terms must be positive:

$$\mu \rho_1 F_{12} (A_{26} + A_{31})$$

$$\mu \rho_1 \dot{\phi}^2 (A_{29} + A_{32})$$

and the following must be negative:

$$- s_6 \mu \rho_1 A_A (A_{27} + A_{28})$$

$$- s_7 \mu \rho_1 A_N (A_{27} + A_{28})$$

remembering that the signum functions s_6 and s_7 are defined in such a way that the products $s_6 \times A_A$ and $s_7 \times A_N$ will yield a negative number.

To determine the sign of the pivot friction moment which is proportional to the angular acceleration $\ddot{\phi}$ of the escape wheel in equation A-101, the ideas presented in reference 1, appendix F are used. In order to accomplish this, let the coefficient of friction μ of this term become absolute so that it ceases to serve as a directional signum function in the sense of reference 1, appendix E. Further, let the expression be changed, for the time being, so that it becomes a function of the rotor angular acceleration $\ddot{\phi}_1$. With the above, and in the sense of equation F-2, reference 1, appendix F, the absolute value of the friction moment M_{AA} may be expressed as

$$M_{AA} = |\mu| \rho_1 (A_{30} + A_{33}) \ddot{\phi}_1$$

From this point on, one may use the reasoning of reference 1, appendix F directly, keeping in mind that $|\mu| \rho_1 (A_{30} + A_{33})$ and $\ddot{\phi}_1$, are now used instead of A_{22} and $\ddot{\psi}$, respectively.

As in the four cases of reference 1, appendix F, the effective moment of inertia I_{1R} takes two forms:

$$I_{1R} = I_1 + |\mu| \rho_1 (A_{30} + A_{33}), \text{ when } \dot{\phi}_1 \text{ and } \ddot{\phi}_1 \text{ have the same sign (A-102)}$$

$$I_{1R} = I_1 - |\mu| \rho_1 (A_{30} + A_{33}), \text{ when } \dot{\phi}_1 \text{ and } \ddot{\phi}_1 \text{ have opposite signs (A-103)}$$

The moment equation, A-101, gives all relevant expressions in terms of the escape wheel variables $\dot{\phi}$ and $\ddot{\phi}$. Since they are both proportional to $\dot{\phi}_1$ and $\ddot{\phi}_1$ by the identical gear ratio N_{41} , one may readily extend the above computational rule to the escape wheel variables.

The above considerations give the moment equation the following form:

$$\begin{aligned} F_{12} [R_{b1} - \mu s_1 a_1 + \mu \rho_1 (A_{26} + A_{31})] - s_6 \mu \rho_1 (A_{27} + A_{28}) A_A \\ - s_7 \mu \rho_1 (A_{27} + A_{28}) A_N + \mu \rho_1 (A_{29} + A_{32}) N_{41}^2 \dot{\phi}^2 \\ = m_1 r_{c1} \cos(\phi_{1c} + N_{41} \phi_T) A_A - m_1 r_{c1} \sin(\phi_{1c} + N_{41} \phi_T) A_N \\ + I_{1R} N_{41} \ddot{\phi} \end{aligned} \quad (\text{A-104})$$

Solving for F_{12}

$$F_{12} = \frac{A_{35} A_A + A_{36} A_N + A_{37} (N_{41} \dot{\phi})^2 + I_{1R} N_{41} \ddot{\phi}}{A_{34}} \quad (\text{A-105})$$

where:

$$A_{34} = R_{b1} - \mu s_1 a_1 + \mu \rho_1 (A_{26} + A_{31}) \quad (\text{A-106})$$

$$A_{35} = s_6 \mu \rho_1 (A_{27} + A_{28}) + m_1 r_{c1} \cos(\phi_{1c} + N_{41} \phi_T) \quad (\text{A-107})$$

$$A_{36} = s_7 \mu \rho_1 (A_{27} + A_{28}) - m_1 r_{c1} \sin(\phi_{1c} + N_{41} \phi_T) \quad (\text{A-108})$$

$$A_{37} = -\mu \rho_1 (A_{29} + A_{32}) \quad (\text{A-109})$$

Dynamics of Gear and Pinion Set No. 3

The equations for force and moment equilibrium on and about gear and pinion set no. 3 are developed similarly to the work shown in reference 3, pp A27 - A32. In this case, however, the inertia force T_3 is omitted and replaced with $m_3 (A_A \bar{j} + A_N \bar{i})$. Letting

$$\ddot{\phi}_3 = N_{43} \ddot{\phi}$$

with

$$N_{43} = \frac{-N_{P4}}{N_{G3}} \quad (A-110)$$

the force and moment equilibrium equations are as follows:

Force Equilibrium

$$\begin{aligned} F_{23} \bar{n}_{23} - \mu s_2 F_{23} \bar{n}_{N23} - F_{34} \bar{n}_{34} - \mu s_3 F_{34} \bar{n}_{n34} + F_{x3} \bar{i} \\ - \mu F_{y3} \bar{i} - F_{y3} \bar{j} - \mu F_{x3} \bar{j} = m_3 A_A \bar{j} + m_3 A_N \bar{i} \end{aligned} \quad (A-111a)$$

Moment Equilibrium

$$\begin{aligned} R_{b3} F_{34} - \mu s_3 a_3 F_{34} - r_{b3} F_{23} + \mu s_2 (d_2 - a_2) F_{23} \\ + \mu p_3 (\tilde{F}_{x3} + \tilde{F}_{y3}) = I_3 N_{43} \ddot{\phi} \end{aligned} \quad (A-111b)$$

The force equation can be rewritten in component form as:

$$\begin{aligned} - F_{23} \sin (\beta_2 - \theta_2) + \mu s_2 F_{23} \cos (\beta_2 - \theta_2) - F_{34} \sin (\beta_3 + \theta_3) \\ - \mu s_3 F_{34} \cos (\beta_3 + \theta_3) + F_{x3} - \mu F_{y3} - m_3 A_N = 0 \end{aligned} \quad (A-112)$$

and

$$\begin{aligned} F_{23} \cos (\beta_2 - \theta_2) + \mu s_2 F_{23} \sin (\beta_2 - \theta_2) + F_{34} \cos (\beta_3 + \theta_3) \\ - \mu s_3 F_{34} \sin (\beta_3 + \theta_3) - F_{y3} - \mu F_{x3} - m_3 A_A = 0 \end{aligned} \quad (A-113)$$

Simultaneous solution of equations A-112 and A-113 yields the following results:

$$\tilde{F}_{y3} = \pm A_{38} F_{23} \pm A_{39} A_A \pm A_{40} A_N \pm A_{41} F_{34} \quad (A-114)$$

$$\tilde{F}_{x3} = \pm A_{42} F_{23} \pm A_{40} A_A \pm A_{39} A_N \pm A_{43} F_{34} \quad (A-115)$$

where

$$A_{38} = \left| \frac{(1 + \mu^2 s_2) \cos(\beta_2 - \theta_2) + \mu(s_2 - 1) \sin(\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-116)$$

$$A_{39} = \left| \frac{-\mu m_3}{1 + \mu^2} \right| \quad (A-117)$$

$$A_{40} = \left| \frac{-m_3}{1 + \mu^2} \right| \quad (A-118)$$

$$A_{41} = \left| \frac{(1 - \mu^2 s_3) \cos(\beta_3 + \theta_3) - \mu(1 + s_3) \sin(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-119)$$

$$A_{42} = \left| \frac{(1 + \mu^2 s_2) \sin(\beta_2 - \theta_2) + \mu(1 - s_2) \cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-120)$$

$$A_{43} = \left| \frac{(1 - \mu^2 s_3) \sin(\beta_3 + \theta_3) + \mu(1 + s_3) \cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-121)$$

The moment equation, A-111b, can now be rewritten with the evaluated friction terms. Again, the signs are chosen so that the friction forces oppose the motion.

$$\begin{aligned} R_{b3} F_{34} - \mu s_3 a_3 F_{34} - r_{b3} F_{23} + \mu s_2 (d_2 - a_2) F_{23} \\ + \mu \rho_3 [(A_{38} + A_{42}) F_{23} - s_6 (A_{39} + A_{40}) A_A - s_7 (A_{39} + A_{40}) A_N \\ + F_{34} (A_{41} + A_{43})] = I_3 N_{43} \ddot{\phi} \end{aligned} \quad (A-122)$$

The moment equation can now be solved for the contact force F_{23} :

$$F_{23} = \frac{A_{44} F_{34} + A_{45} A_A + A_{46} A_N - I_3 N_{43} \ddot{\phi}}{A_{47}} \quad (A-123)$$

where

$$A_{44} = R_{b3} - \mu s_3 a_3 + \mu \rho_3 (A_{41} + A_{43}) \quad (A-124)$$

$$A_{45} = -\mu \rho_3 s_6 (A_{39} + A_{40}) \quad (A-125)$$

$$A_{46} = -\mu \rho_3 s_7 (A_{39} + A_{40}) \quad (A-126)$$

$$A_{47} = r_{b3} - \mu [s_2 (d_2 - a_2) + \rho_3 (A_{38} + A_{42})] \quad (A-127)$$

Dynamics of Gear and Pinion Set Number 2

The moment equation of gear and pinion set number 2 is developed and solved similarly to that for gear and pinion set number 3 by replacing T_2 with $m_2 (\bar{A}_N \bar{1} + \bar{A}_A \bar{j})$ in reference 3 and using the free body diagram in reference 3, page A-35.

The force equation is divided into its component parts and solved for $\tilde{F}_{x2}$ and $\tilde{F}_{y2}$ with the following results:

$$\tilde{F}_{y2} = \pm A_{48} F_{12} \pm A_{49} A_A \pm A_{50} A_N \pm A_{51} F_{23} \quad (A-128)$$

$$\tilde{F}_{x2} = \pm A_{52} F_{12} \pm A_{50} A_A \pm A_{49} A_N \pm A_{53} F_{23} \quad (A-129)$$

where

$$A_{48} = \left| \frac{\mu (s_1 - 1) \sin (\beta_1 + \theta_1) - (\mu^2 s_1 + 1) \cos (\beta_1 + \theta_1)}{1 + \mu^2} \right| \quad (A-130)$$

$$A_{49} = \left| \frac{m_2}{1 + \mu^2} \right| \quad (A-131)$$

$$A_{50} = \left| \frac{\mu m_2}{1 + \mu^2} \right| \quad (A-132)$$

$$A_{51} = \left| \frac{(\mu^2 s_2 - 1) \cos (\beta_2 - \theta_2) - \mu (s_2 + 1) \sin (\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-133)$$

$$A_{52} = \left| \frac{\mu (1 - s_1) \cos (\beta_1 + \theta_1) - (1 + \mu^2 s_1) \sin (\beta_1 + \theta_1)}{1 + \mu^2} \right| \quad (A-134)$$

$$A_{53} = \left| \frac{(1 - \mu^2 s_2) \sin (\beta_2 - \theta_2) - \mu (1 + s_2) \cos (\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-135)$$

Again, in writing the moment equation, signs are chosen and signum functions are employed to ensure that the frictional forces always oppose the motion.

$$\begin{aligned}
 & - R_{b2} F_{23} + \mu s_2 a_2 F_{23} + r_{b2} F_{12} - \mu s_1 (d_1 - a_1) F_{12} \\
 & - \mu \rho_2 [(A_{48} + A_{52}) F_{12} - s_6 (A_{49} + A_{50}) A_A - s_7 (A_{49} + A_{50}) A_N \\
 & + (A_{51} + A_{53}) F_{23}] = I_2 N_{42} \ddot{\phi}
 \end{aligned} \tag{A-136}$$

where

$$\ddot{\phi}_2 = N_{42} \ddot{\phi} \tag{A-137}$$

and

$$N_{42} = \frac{N_{P4} N_{P3}}{N_{G3} N_{G2}} \tag{A-138}$$

Finally, equation A-136 is solved for F_{12} yielding:

$$F_{12} = \frac{A_{54} F_{23} + A_{55} A_A + A_{56} A_N + I_2 N_{42} \ddot{\phi}}{A_{57}} \tag{A-139}$$

where

$$A_{54} = R_{b2} + \mu \rho_2 (A_{51} + A_{53}) - \mu s_2 a_2 \tag{A-140}$$

$$A_{55} = -\mu \rho_2 s_6 (A_{49} + A_{50}) \tag{A-141}$$

$$A_{56} = -\mu \rho_2 s_7 (A_{49} + A_{50}) \tag{A-142}$$

$$A_{57} = r_{b2} - \mu s_1 (d_1 - a_1) - \mu \rho_2 (A_{48} + A_{52}) \tag{A-143}$$

Dynamics of the Combined System in Coupled Motion

Equation A-75 is the differential equation of coupled motion of the entire system in terms of the escape wheel variable ϕ . In order to solve the equation, an expression must be developed for the contact force F_{34} . A combination of equations A-105 and A-139 (both expressions for the contact force F_{12}) will yield an expression for the contact force F_{23} . The resulting expression for F_{23} can be combined with equation A-123, also an expression for F_{23} . This will lead to an expression for the contact force F_{34} . Combining A-105 and A-139 yields:

$$\begin{aligned}
 F_{23} = \frac{1}{A_{34} A_{54}} & [(A_{35} A_{57} - A_{34} A_{55}) A_A + (A_{36} A_{57} - A_{34} A_{56}) A_N \\
 & + (A_{37} A_{57} N_{41}^2) \dot{\phi}^2 + (A_{57} N_{41} I_{1R} - A_{34} I_2 N_{42}) \ddot{\phi}]
 \end{aligned} \tag{A-144}$$

Now, combining this equation with equation A-123 results in an expression for F_{34} :

$$F_{34} = \frac{1}{A_{34} A_{44} A_{54}} [(A_{35} A_{47} A_{57} - A_{34} A_{47} A_{55} - A_{34} A_{45} A_{54}) A_A \\ + (A_{36} A_{47} A_{57} - A_{34} A_{47} A_{56} - A_{34} A_{46} A_{54}) A_N \\ + (A_{37} A_{47} A_{54} N_{41}^2) \ddot{\phi} + (A_{47} A_{57} N_{41} I_{1R} + A_{34} A_{54} I_3 N_{43} \\ - A_{34} A_{47} I_2 N_{42}) \ddot{\phi}] \quad (A-145)$$

Now this expression for the contact force F_{34} can be substituted into equation A-75 to give the differential equation of coupled motion of the system:

$$A_{58} \ddot{\phi} + A_{59} \dot{\phi}^2 = A_{60} A_A + A_{61} A_N \quad (A-146)$$

where

$$A_{58} = A_{25} I_{PR} U + A_{11} I_4 - \frac{A_{11} A_{22}}{A_{34} A_{44} A_{54}} (A_{47} A_{57} N_{41} I_{1R} \\ + A_{34} A_{54} I_3 N_{43} - A_{34} A_{47} I_2 N_{42}) \quad (A-147)$$

$$A_{59} = A_{14} A_{25} U^2 + A_{25} I_{PR} V - \frac{A_{11} A_{22} A_{37} A_{47} A_{57}}{A_{34} A_{44} A_{54}} N_{41}^2 \quad (A-148)$$

$$A_{60} = \frac{A_{11} A_{22}}{A_{34} A_{44} A_{54}} (A_{35} A_{47} A_{57} - A_{34} A_{47} A_{55} - A_{34} A_{45} A_{54}) \\ + A_{11} A_{23} + A_{12} A_{25} - A_{25} m_p r_{cp} \sin(\psi + \psi_c) \sin \beta_4 \\ + A_{25} m_p r_{cp} \cos(\psi + \psi_c) \cos \beta_4 \quad (A-149)$$

$$A_{61} = \frac{A_{11} A_{22}}{A_{34} A_{44} A_{54}} (A_{36} A_{47} A_{57} - A_{34} A_{47} A_{56} - A_{34} A_{46} A_{54}) \\ + A_{11} A_{24} + A_{13} A_{25} - A_{25} m_p r_{cp} \sin(\psi + \psi_c) \cos \beta_4 \\ - A_{25} m_p r_{cp} \cos(\psi + \psi_c) \sin \beta_4 \quad (A-150)$$

DIFFERENTIAL EQUATIONS FOR FREE MOTION REGIME

The differential equations of free motion of both the pallet and the escape wheel, gear and pinion no. 3, gear and pinion no. 2, and the rotor system can be developed from coupled motion expressions previously established.

Free Motion of the Pallet

Equation A-39 is an expression for the contact force P_n between the pallet and escape wheel. By setting P_n equal to zero, the differential equation of free motion of the pallet is obtained.

$$A_{62} \ddot{\psi} + A_{14} \dot{\psi}^2 = A_{63} A_A + A_{64} A_N \quad (A-151)$$

where

$$A_{62} = I_{PR}^{A-6} \quad (A-152)$$

$$A_{63} = A_{12} - m_p r_{cp} (\sin(\psi + \psi_c) \sin \beta_4 - \cos(\psi + \psi_c) \cos \beta_4) \quad (A-153)$$

$$A_{64} = A_{13} - m_p r_{cp} (\sin(\psi + \psi_c) \cos \beta_4 - \cos(\psi + \psi_c) \sin \beta_4) \quad (A-154)$$

Free Motion of the Escape Wheel, Gear Train, and Rotor System

The differential equation can again be developed in this case by first allowing the contact force P_n to equal zero. This is done in the escape wheel expression (eq A-70) yielding:

$$I_4 \ddot{\phi} = A_{22} F_{34} + A_{23} A_A + A_{24} A_N \quad (A-155)$$

Now equation A-145, an expression for the contact force F_{34} , is substituted into equation A-155, resulting in the desired free motion differential equation:

$$A_{65} \ddot{\phi} + A_{66} \dot{\phi}^2 = A_{67} A_A + A_{68} A_N \quad (A-156)$$

where

$$A_{65} = I_4 - \frac{A_{22}}{A_{34} A_{44} A_{54}} (A_{47} A_{57} N_{41} I_{1R} + A_{34} A_{54} I_3 N_{43} - A_{34} A_{47} I_2 N_{42}) \quad (A-157)$$

A-6 For free motion, I_{PR} cannot be zero since it would make the value of $\ddot{\psi}$ indefinite in the Runge-Kutta solution (footnote A-2).

$$A_{66} = \frac{-A_{22} A_{37} A_{47} A_{57} N_{41}^2}{A_{34} A_{44} A_{54}} \quad (A-158)$$

$$A_{67} = \frac{A_{22}}{A_{34} A_{44} A_{54}} (A_{35} A_{47} A_{57} - A_{34} A_{47} A_{55} - A_{34} A_{45} A_{54}) + A_{23} \quad (A-159)$$

$$A_{68} = \frac{A_{22}}{A_{34} A_{44} A_{54}} (A_{36} A_{47} A_{57} - A_{34} A_{47} A_{56} - A_{34} A_{46} A_{54}) + A_{24} \quad (A-160)$$

Contact Force Expressions for Coupled and Free Motions

In developing differential equations to model the system, various contact force expressions have resulted. These contact force expressions can be useful in component strength calculations. The contact forces will vary according to whether the escape wheel and pallet are in free or coupled motion; thus, two sets of contact force expressions are shown here.

Coupled Motion

According to equation A-145

$$\begin{aligned} F_{34} = & \frac{1}{A_{34} A_{44} A_{54}} [(A_{35} A_{47} A_{57} - A_{34} A_{47} A_{55} - A_{34} A_{45} A_{54}) A_A \\ & + (A_{36} A_{47} A_{57} - A_{34} A_{47} A_{56} - A_{34} A_{46} A_{54}) A_N \\ & + (A_{37} A_{47} A_{57} N_{41}^2) \ddot{\phi} + (A_{47} A_{57} N_{41} I_{1R} \\ & + A_{34} A_{54} I_3 N_{43} - A_{34} A_{47} I_2 N_{42}) \ddot{\phi}] \end{aligned} \quad (A-161)$$

According to equation A-123

$$F_{23} = \frac{A_{44} F_{34} + A_{45} A_A + A_{46} A_N - I_3 N_{43} \ddot{\phi}}{A_{47}} \quad (A-162)$$

According to equation A-139

$$F_{12} = \frac{A_{54} F_{23} + A_{55} A_A + A_{56} A_N + I_2 N_{42} \ddot{\phi}}{A_{57}} \quad (A-163)$$

The contact force P_n between the escape wheel and pallet may be expressed in terms of either the escape wheel variable ϕ or the pallet variable ψ . Therefore, according to equation A-70,

$$P_n = \frac{-I_4 \ddot{\phi} + A_{22} F_{34} + A_{23} A_A + A_{24} A_N}{A_{25}} \quad (A-164)$$

or according to equation A-39

$$\begin{aligned} P_{n\psi} = & \frac{1}{A_{11}} \{ I_{PR} \ddot{\psi} + A_{14} \dot{\psi}^2 - A_{12} A_A - A_{13} A_N \\ & + m_p r_{cp} [A_A (\sin(\psi + \psi_c) \sin \beta_4 - \cos(\psi + \psi_c) \cos \beta_4) \\ & + A_N (\sin(\psi + \psi_c) \cos \beta_4 + \cos(\psi + \psi_c) \sin \beta_4)] \} \end{aligned} \quad (A-165)$$

Free Motion

Here, by definition, $P_n = 0$. The contact force F_{F34} can be obtained by taking the contact force expression A-70 and setting $P_n = 0$. This results in the following equation:

$$F_{F34} = \frac{I_4 \ddot{\phi} - A_{23} A_A + A_{24} A_N}{A_{22}} \quad (A-166)$$

The expressions for F_{F23} and F_{F12} can now be developed by replacing F_{34} with F_{F34} and F_{23} with F_{F23} in equations A-162 and A-163, respectively.

$$F_{F23} = \frac{A_{44} F_{F34} + A_{45} A_A + A_{46} A_N - I_3 N_{43} \ddot{\phi}}{A_{47}} \quad (A-167)$$

$$F_{F12} = \frac{A_{54} F_{F23} + A_{55} A_A + A_{56} A_N + I_2 N_{42} \ddot{\phi}}{A_{57}} \quad (A-168)$$

Changes in Impact Expressions

The impact description of reference 2 basically remains unchanged; however, as in reference 1, pp 72-73, the total moment of inertia I_{STOT} of the escape wheel is increased by the inclusion of the rotor and gear train. Therefore,

$$I_{STOT} = I_4 + I_3 N_{43}^2 + I_2 N_{42}^2 + I_1 N_{41}^2 \quad (A-169)$$

where

I_4 = escape wheel - pinion no. 4 moment of inertia

I_3 = gear and pinion set no. 3 moment of inertia

I_2 = gear and pinion set no. 2 moment of inertia

I_1 = rotor moment of inertia

See equations A-79, A-110, and A-138, for the gear ratios.

APPENDIX B
PROGRAM MISLSA

```

170      PROGRAM MISLSA(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
180      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
190      1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
200      2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
210      3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
220      43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
230      6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
240      7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
250      8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
260      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
270      COMMON/GCU/ TIM(100),GA(100),GL(100),N
280      DIMENSION AUX(8,2),AUX2(8,4),PRMT(5),PHI(2),DPHI(2),X(4),DX(
290      14)
300      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,LAMBDA,K,N41,N42,N43,J1,J2,J3,N
310      1G1,NG2,NG3,NP2,NP3,NP4,MU,MU1
320      EXTERNAL FCT,OUTP,FCTF,OUTPF
330 C
340 C      READ IN AND WRITE DATA
350 C
360      WRITE(6,300)
370 300 FORMAT('ESCAPEMENT DATA'////)
380      READ(5,22)A,B,C,R,ALPHA
390      WRITE(6,23) A,B,C,R,ALPHA
400      READ(5,32) BETA1,BETA2,BETA3,BETA4
410      WRITE(6,41) BETA1,BETA2,BETA3,BETA4
420      READ(5,24) EREST,LAMBDA,DELTA
430      WRITE(6,25) EREST,LAMBDA,DELTA
440      WRITE(6,301)
450 301 FORMAT('MASS PROPERTIES'////)
460      READ(5,26) M1,M2,M3,M4,MP
470      WRITE(6,27) M1,M2,M3,M4,MP
480      READ(5,26) I1,I2,I3,I4,IP
490      WRITE(6,28) I1,I2,I3,I4,IP
500      WRITE(6,302)
510 302 FORMAT('MISCELLANEOUS PARAMETERS'////)
520      READ(5,29) RC1,RCP,RHOP,PHI1C,PSICCD,PHID,PHICUTD,MU,MU1
530      WRITE(6,30) RC1,RCP,RHOP,PHI1C,PSICCD,PHID,PHICUTD,MU,MU1
540      WRITE(6,303)
550 303 FORMAT('GEAR PARAMETERS'////)
560      READ(5,31) PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRP1,CA
570      1PRP2,CAPRP3,RP2,RP3,RP4,THETA1,THETA2,THETA3
580      WRITE(6,35) PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRP1,C
590      1APRP2,CAPRP3,RP2,RP3,RP4,THETA1,THETA2,THETA3
600      READ(5,32) RH01,RH02,RH03,RH04
610      WRITE(6,37) RH01,RH02,RH03,RH04
620      READ(5,33) CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4
630      WRITE(6,38) CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4
640      READ(5,33) CAPRO1,CAPRO2,CAPRO3,RO2,RO3,RO4
650      WRITE(6,39) CAPRO1,CAPRO2,CAPRO3,RO2,RO3,RO4
660      READ(5,34) J1,J2,J3
670      WRITE(6,40) J1,J2,J3
680      WRITE(6,304)
690 304 FORMAT('ANGLE INDEXING PARAMETERS'////)
700      READ(5,89) TANG,NT
710      WRITE(6,90) TANG,NT
720      WRITE(6,305)

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730 305 FORMAT(///'ACCELERATION PROFILE DATA'///)
740 89 FORMAT (F10.3,I3)
750 90 FORMAT (3X,'TANG = ',F10.3,3X,'NT = ',I3/)
760 READ (5,91) N
770 91 FORMAT(I3)
780 READ (5,92)(TIM(J),GA(J),GL(J),J=1,N)
790 92 FORMAT (3F10.3)
800 WRITE (6,93) (TIM(J),GA(J),GL(J),J=1,N)
810 93 FORMAT (F10.2,4X,F10.2,4X,F10.2/)
820 WRITE (6,94)
830 94 FORMAT(////////)
840 C
850 C
860 C      INITIALIZATION OF PARAMETERS AND CONVERSION TO RADIANS
870 C
880 C
890 J=0
900 TIME=0.
910 PHITOT=0.
920 PHIPR=PHID
930 DPHI2=0.
940 DPSI2=0.
950 F34MAX=0.
960 F23MAX=0.
970 F12MAX=0.
980 FF34MAX=0.
990 FF23MAX=0.
1000 FF12MAX=0.
1010 PNMAX=0.
1020 PI=3.14159
1030 ZZ=PI/180.
1040 PHI1C=PHI1C*ZZ
1050 PSICC=PSICCD*ZZ
1060 PSIC=PSICC
1070 ALPHR=ALPHA*ZZ
1080 C
1090 C      COMPUTATION OF GEAR RATIOS
1100 C
1110 N41=-NP2*NP3*NP4/(NG1*NG2*NG3)
1120 N42=NP3*NP4/(NG2*NG3)
1130 N43=-NP4/NG3
1140 C
1150 C      CONVERSION OF PRESSURE ANGLES TO RADIANS
1160 C
1170 THETA1=THETA1*ZZ
1180 THETA2=THETA2*ZZ
1190 THETA3=THETA3*ZZ
1200 C
1210 C      DETERMINATION OF GEAR TRAIN CONSTANTS
1220 C
1230 TEST1=TAN(THETA1)
1240 TEST2=TAN(THETA2)
1250 TEST3=TAN(THETA3)
1260 D1=(CAPRB1+RB2)*TAN(THETA1)

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1270 D2=((CAPRB2+RB3)*TAN(THETA2)
1280 D3=((CAPRB3+RB4)*TAN(THETA3)
1290 C
1300 C DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS
1310 C
1320 CALL ALFA (CAPRB1, RB2, THETA1, CAPR01, R02, AL1IN, AL1FIN)
1330 CALL ALFA (CAPRB2, RB3, THETA2, CAPR02, R03, AL2IN, AL2FIN)
1340 CALL ALFA (CAPRB3, RB4, THETA3, CAPR03, R04, AL3IN, AL3FIN)
1350 C
1360 C INITIALIZATION OF ALPHAS
1370 C
1380 ALPHA1=AL1IN+(AL1FIN-AL1IN)*J1
1390 ALPHA2=AL2IN+(AL2FIN-AL2IN)*J2
1400 ALPHA3=AL3IN+(AL3FIN-AL3IN)*J3
1410 C
1420 C DATA FOR RUNGE KUTTA
1430 C
1440 PRMT(2)=10.
1450 PRMT(4)=.01
1460 NDIM=2
1470 NDIM2=4
1480 PHI(1)=PHID*ZZ
1490 PHI(2)=0.
1500 C
1510 C COUPLED MOTION
1520 C
1530 1 PRMT(1)=TIME
1540 PRMT(3)=.0001
1550 DPHI(1)=.5
1560 DPHI(2)=.5
1570 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 2
1580 WRITE (6,42)
1590 2 CALL RKGS (PRMT, PHI, DPHI, NDIM, IMLF, FCT, OUTP, AUX)
1600 IF (PRMT(5).EQ. 1.) GO TO 21
1610 IF (PHITOT.GE.PHICUTD) GO TO 21
1620 C
1630 C TEST FOR ENTRANCE OR EXIT ACTION
1640 C
1650 IF (G.LE.0.) GO TO 5
1660 PHID=PHI(1)/ZZ
1670 IF (PHID.LE.TANG) GO TO 3
1680 GO TO 4
1690 3 PHI(1)=PHI(1)+DELTA*ZZ*NT
1700 PHIPR=PHI(1)/ZZ
1710 PSI=PSI+2.*PI-LAMBDA*ZZ
1720 PSIC=PSICC+LAMBDA*ZZ
1730 GO TO 5
1740 4 PHI(1)=PHI(1)-DELTA*ZZ*(NT+1.)
1750 PHIPR=PHI(1)/ZZ
1760 PSI=PSI-2.*PI+LAMBDA*ZZ
1770 PSIC=PSICC
1780 C
1790 C FREE MOTION
1800 C

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1810      5 PRMT(1)=TIME
1820      X(1)=PHI(1)
1830      X(2)=PHI(2)
1840      X(3)=PSI
1850      X(4)=DPSI
1860      DX(1)=.25
1870      DX(2)=.25
1880      DX(3)=.25
1890      DX(4)=.25
1900      PRMT(3)=.0001
1910      IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 6
1920      WRITE (6,43)
1930      6 CALL RKGS (PRMT,X,DX,NDIM2,IMLF,FCTF,OUTPF,AUX2)
1940      IF (PHITOT.GE.PHICUTD) GO TO 21
1950      PHI(1)=X(1)
1960      PHI(2)=X(2)
1970      H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
1980      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*R*SIN(
1990      PHI(1)-ALPHR)
2000      GONE=(-H+SORT(H*H-4.*K))/2.
2010      GTWO=(-H-SORT(H*H-4.*K))/2.
2020      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 7
2030      G=GTWO
2040      GO TO 8
2050      7 G=GONE
2060      8 PHID=PHI(1)/ZZ
2070      IF (GP.LT.0.) GO TO 11
2080      IF (PHID.LE.TANG) GO TO 9
2090      GO TO 10
2100      9 PHI(1)=PHI(1)+DELTA*ZZ*NT
2110      PHIPR=PHI(1)/ZZ
2120      PSI=PSI+2.*PI-LAMBDA*ZZ
2130      PSIC=PSICC+LAMBDA*ZZ
2140      GO TO 5
2150      10 PHI(1)=PHI(1)-DELTA*ZZ*(NT+1.)
2160      PHIPR=PHI(1)/ZZ
2170      PSI=PSI-2.*PI+LAMBDA*ZZ
2180      PSIC=PSICC
2190      GO TO 5
2200      11 IF (PHID.LE.TANG) GO TO 13
2210 C
2220 C      EXIT ACTION
2230 C
2240 C      COMPUTATION OF VELOCITIES UP AND US FOR EXIT ACTION
2250 C
2260 C      AONE=B*COS(ALPHR)+G
2270 C      DONE=C*COS(PHI(1)-ALPHR-PSI)
2280 C      UP=DONE*DPSI
2290 C      US=AONE*PHI(2)
2300 C      IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 12
2310 C      WRITE (6,44) UP,US
2320 C
2330 C      EXIT ACTION TEST
2340 C
2350      12 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 15

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2360 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
2370 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 15
2380 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2390 IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(UP).GT.ABS(US)) GO TO 15
2400 IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2410 IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
2420 IF (PHI(2).LE.0..AND.DPSI.LE.0..) GO TO 5
2430 C
2440 C
2450 C
2460 13 AONE=B*COS(ALPHR)+G
2470 DONE=C*COS(PHI(1)-ALPHR-PSI)
2480 UP=DONE*DPSI
2490 US=AONE*PHI(2)
2500 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 14
2510 WRITE (6,44) UP,US
2520 C
2530 C
2540 C
2550 14 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
2560 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2570 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).LT.ABS(US)) GO TO 15
2580 IF (PHI(2).LE.0..AND.DPSI.LE.0..) GO TO 5
2590 IF (PHI(2).LE.0..AND.DPSI.LE.0..) GO TO 15
2600 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
2610 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 15
2620 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2630 C
2640 C
2650 C
2660 15 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)
2670 H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
2680 K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*
2690 1SIN(PHI(1)-ALPHR)
2700 GONE=(-H+SQRT(H**2-4.*K))/2.
2710 GTWO=(-H-SQRT(H**2-4.*K))/2.
2720 IF (ABS(GONE).LT.ABS(GTWO)) GO TO 16
2730 G=GTWO
2740 GO TO 17
2750 16 G=GONE
2760 17 CONTINUE
2770 C
2780 C
2790 C
2800 C
2810 PHID=PHI(1)/ZZ
2820 IF (PHID.LE.TANG) GO TO 19
2830 C
2840 C
2850 C
2860 C
2870 19 COMPUTATION OF VELOCITIES UP AND US FOR BOTTOM ACTION
2880 AONE=B*COS(ALPHR)+G
2890 DONE=C*COS(PHI(1)-ALPHR-PSI)
2900 UP=DONE*DPSI
2910 US=AONE*PHI(2)
2920 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 18

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2920      WRITE (6,44) UP,US
2930      18 IF (ABS(UP-US).LT.1.0) GO TO 1
2940 C
2950 C      EXIT ACTION TESTS
2960 C
2970      IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1
2980      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
2990      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 1
3000      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
3010      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(UP).GT.ABS(US)) GO TO 1
3020      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
3030 C
3040 C      COMPUTATION OF VELOCITIES UP AND US FOR ENTRANCE ACTION
3050 C
3060      19 AONE=R*COS(ALPHR)+G
3070      DONE=C*COS(PHI(1)-ALPHR-PSI)
3080      UP=DONE*DPSI
3090      US=AONE*PHI(2)
3100      IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 20
3110      WRITE (6,44) UP,US
3120      20 IF (ABS(UP-US).LT.1.0) GO TO 1
3130 C
3140 C      ENTRANCE ACTION TESTS
3150 C
3160      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
3170      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).LT.ABS(US)) GO TO 1
3180      IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
3190      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 1
3200      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 1
3210      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
3220      21 WRITE(6,45)F34MAX,F23MAX,F12MAX,FF34MAX,FF23MAX,FF12MAX,PNMAX
3230      ATM=TIME
3240      WRITE(6,75) ATM
3250      75 FORMAT(' THE S&A ARMS IN',2X,F6.3,2X,'SECONDS.')
3260      STOP
3270 C
3280 C
3290 C
3300      22 FORMAT (5F10.5)
3310      23 FORMAT (1H1,5X,2HA*,F13.5,5X,2HB*,F13.5,5X,2HC*,F13.5,5X,2HR*,F13.
3320      15,5X,6HALPHA*,F9.4/)
3330      24 FORMAT (3F10.5)
3340      25 FORMAT (1H 5X,6HEREST*,F5.2,3X,7HLAMBDA*,F8.3,3X,6HDELTA*,F8.3/)
3350      26 FORMAT (5E12.5)
3360      27 FORMAT (1H 5X,4HM1 *,E15.5,3X,4HM2 *,E15.5,3X,4HM3 *,E15.5,3X,4HM
3370      14 *,E15.5,3X,4HMP *,E15.5/)
3380      28 FORMAT (1H 5X,4HI1 *,E15.5,3X,4HI2 *,E15.5,3X,4HI3 *,E15.5,3X,4HI
3390      14 *,E15.5,3X,4HIP *,E15.5/)
3400      29 FORMAT (6F10.4/3F10.4)
3410      30 FORMAT (6X,SHRC1 *,F7.4,3X,SHRCP *,F7.4,3X,6HHRHOP *,F7.4,3X,
3420      13X,7HPH11C *,F9.4,3X,8HPSICCD *,F9.4,3X,6HPHID *,F9.4/6X,
3430      29HPHICUTD *,F6.0/6X,4HMMU *,F5.3,3X,5HMMU1 *,F5.3/)
3440      31 FORMAT (3F10.4/6F10.0/6F10.5/3F10.4)
3450      32 FORMAT (4F10.4)
3460      33 FORMAT (6F10.5)
3470      34 FORMAT (3F10.2)

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3480 35 FORMAT (1H,5X,8HPSUBD1 *,F5.1,3X,8HPSUBD2 *,F5.1,3X,8HPSUBD3 *,F5
3490 1.1//6X,5HNC1 *,F4.0,3X,5HNC2 *,F4.0,3X,5HNC3 *,F4.0,3X,5HNP2 *,F4.
3500 20,3X,5HNP3 *,F4.0,3X,5HNP4 *,F4.0//6X,8HCAPRP1 *,F8.5,3X,8HCAPRP2
3510 3*,F8.5,3X,8HCAPRP3 *,F8.5//6X,5HNP2 *,F8.5,3X,5HNP3 *,F8.5,3X,5HNP
3520 44 *,F8.5//6X,8HTheta1 *,F8.3,3X,8HTheta2 *,F8.3,3X,8HTheta3 *,F8.3
3530 5/)
3540 37 FORMAT (6X,6HRH01 *,F7.5,3X,6HRH02 *,F7.5,3X,6HRH03 *,F7.5,3X,6HRH
3550 104 *,F7.5/)
3560 38 FORMAT (6X,8HCAPRB1 *,F7.5,3X,8HCAPRB2 *,F7.5,3X,8HCAPRB3 *,F7.5,3
3570 1X,5HRB2 *,F7.5,3X,5HRB3 *,F7.5,3X,5HRB4 *,F7.5/)
3580 39 FORMAT (6X,8HCAPRO1 *,F7.5,3X,8HCAPRO2 *,F7.5,3X,8HCAPRO3 *,F7.5,3
3590 1X,5HRO2 *,F7.5,3X,5HRO3 *,F7.5,3X,5HRO4 *,F7.5/)
3600 40 FORMAT (1H0,5X,4HJ1 *,F4.2,3X,4HJ2 *,F4.2,3X,4HJ3 *,F4.2/)
3610 41 FORMAT (6X,8HBETA1D *,F7.2,3X,8HBETA2D *,F7.2,3X,8HBETA3D *,F7.2,3
3620 1X,8HBETA4D *,F7.2/)
3630 42 FORMAT (1H0,5X,14HCOUPLED MOTION)
3640 43 FORMAT (1H0,5X,11HFREE MOTION//)
3650 44 FORMAT (4H0UP*,F8.3,3X,3HVS*,F8.3)
3660 45 FORMAT (1H0,6X,1F34MAX *,F6.2/1H0,6X,1F23MAX *,F6.2/1H0,6X,1F12
3670 1MAX *,F6.2/1H0,6X,1FF34MAX *,F6.2/1H0,6X,1FF23MAX *,F6.2/1H0,6X
3680 1,1FF12MAX *,F6.2/1H0,6X,1PNMAX *,F6.2/)
3690 END
3700 SUBROUTINE IMPACT (PHI,DPHI,PSI,I )
3710 COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2, M4,MP,I1,I2,I3,I4,IP,EREST,LAM
3720 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PMI1C,TEST1,TEST2
3730 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
3740 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
3750 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
3760 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
3770 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPSI2,F34MAX,F23MAX,F12MAX,
3780 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
3790 REAL I1,I2,I3,I4,IP,LAMBDA,N41,N42,N43,ISTOT,K
3800 ISTOT=I4+I1*N41+N41+I2*N42+N42+I3*N43+N43
3810 M=2.1*(B1COS(ALPHR)+A1COS(PHI-ALPHR))
3820 K=A1*12+B1*12+R1*12-C1*12+2.15*R1SIN(ALPHR)+2.1A1B1COS(PHI)-2.1A1R1SIN
3830 1(PHI-ALPHR)
3840 GONE=(-H+SQRT(H*12-4.1K))/2.
3850 GTUO=(-H-SQRT(H*12-4.1K))/2.
3860 IF (ABS(GONE).LT.ABS(GTUO)) GO TO 1
3870 G=GTUO
3880 GO TO 2
3890 1 G=GONE
3900 2 AONE=B1COS(ALPHR)+G
3910 DONE=C1COS(PHI-ALPHR-PSI)
3920 DPHIIN=DPHI
3930 DPHI=(IP*AONE*DPSI+ISTOT*DONE*DPHI+IP*AONE*EREST/DONE*(DPSI*DONE-D
3940 1PHI*AONE))/(IP*AONE*12/DONE+ISTOT*DONE)
3950 DPSI=(DPHI*AONE-EREST*(DPSI*DONE-DPHIIN*AONE))/DONE
3960 PHID=PHI/ZZ
3970 PSID=PSI/ZZ
3980 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 3
3990 WRITE (6,4)
4000 WRITE (6,5) PHID,DPHI,PSID,DPSI,PHITOT
4010 3 RETURN
4020 C
4030 C

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4040 C
4050 4 FORMAT (1H0,5X,6HIMPACT)
4060 5 FORMAT (1H0,15X,4HPHI*,F8.3,3X,7HPHIDOT*,F8.3,3X,4HPSI*,F8.3,3X,7H
4070 1PSIDOT*,F8.3,3X,8HPHITOT*,F9.2)
4080 END
4090 SUBROUTINE FCT (T,PHI,DPHI)
4100 COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
4110 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
4120 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH
4130 3BETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
4140 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
4150 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
4160 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
4170 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
4180 DIMENSION PHI(2),DPHI(2)
4190 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
4200 PHID=PHI(1)/ZZ
4210 DELPHI=PHID-PHIPR
4220 PHIT=(PHITOT+DELPHI)*ZZ
4230 IN=1
4240 CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
4250 1,DONE,U,U,2)
4260 CALL GCURVE(T,AA,AN)
4270 CALL IN3 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
4280 12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
4290 2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
4300 33,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
4310 43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
4320 C
4330 CALL IN3A(AA54,AA55,AA56,AA57,CAPR82,MU,RH02,AA51,AA53,
4340 +S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
4350 IF (DPSI*DP512.GE.0.) IPR=IP+AA15
4360 IF (DPSI*DP512.LT.0.) IPR=IP-AA15
4370 IF (PHI(2)*DPH12.GE.0.) I1R=I1+ABS(MU)*RH01*(AA30+AA33)
4380 IF (PHI(2)*DPH12.LT.0.) I1R=I1-ABS(MU)*RH01*(AA30+AA33)
4390 IF (I1R.LT.0.) I1R=0.
4400 IF (IPR.LT.0.) IPR=0.
4410 AA58=AA25*IPR+AA11*I1-AA11*AA22/(AA34*AA44*AA54)*(AA47*AA57*AA1
4420 1*I1R+AA34*AA54*I13*AA43-AA34*AA47*I12*AA42)
4430 AA59=AA14*AA25*U*I2+AA25*IPR+AA11*AA22*AA37*AA47*AA57*AA1*I2
4440 +/(AA34*AA44*AA54)
4450 AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
4460 1AA34*AA45*AA54)+AA11*AA23*AA12*AA25-AA25*MP*RCP*PSIN(PSI+PSIC)*
4470 2SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
4480 AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
4490 1AA34*AA46*AA54)+AA11*AA24*AA13*AA25-AA25*MP*RCP*PSIN(PSI+PSIC)*
4500 2COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
4510 DPHI(1)=PHI(2)
4520 DPHI(2)=(-AA59*PHI(2)*I2+AA60*AA+AA61*AN)/AA58
4530 RETURN
4540 END
4550 SUBROUTINE OUTP (T,PHI,DPHI,IHLF,NDIM,PRNT)
4560 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
4570 DIMENSION PHI(2),DPHI(2),PRNT(5)

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4580 COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
4590 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHIC,TEST1,TEST2
4600 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
4610 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
4620 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
4630 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
4640 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F23MAX,F12MAX,
4650 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
4660 COMMON /ZETA/ PSI,TIME,G,DPSI,GP
4670 PHID=PHI(1)/ZZ
4680 DELPHI=PHID-PHIPR
4690 PHIPR=PHID
4700 PHITOT=PHITOT+DELPHI
4710 PHIT=PHITOT*ZZ
4720 IN=0
4730 CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
4740 1,DONE,U,U,Z)
4750 CALL GCURVE(T,AA,AN)
4760 CALL INJ (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
4770 12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
4780 2A17,AA18,AA19,AA23,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
4790 330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
4800 43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
4810 C
4820 CALL INJA(AA54,AA55,AA56,AA57,CAPRB2,MU,RH02,AA51,AA53,
4830 +S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
4840 C
4850 IF (DPSI*DPS12.GE.0.) IPR=IP+AA15
4860 IF (DPSI*DPS12.LT.0.) IPR=IP-AA15
4870 IF (PHI(2)*DPH12.GE.0.) I1R=I1+ABS(MU)*RH01*(AA30+AA33)
4880 IF (PHI(2)*DPH12.LT.0.) I1R=I1-ABS(MU)*RH01*(AA30+AA33)
4890 IF (I1R.LT.0.) I1R=0.
4900 IF (IPR.LT.0.) IPR=0.
4910 AA58=AA25*(IPR+AA11*(1-4-4*AA11*AA22/(AA34*AA44*AA54))*(AA47*AA57*AA1
4920 1*I1R+AA34*AA54*I3*AA43-AA34*AA47*I2*AA42)
4930 AA59=AA14*AA25*(U+AA25*(IPR+AA11*AA22*AA37*AA47*AA57*AA41*AA2
4940 +/(AA34*AA44*AA54)
4950 AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55
4960 1AA34*AA45*AA54)+AA11*AA23*AA12*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
4970 2SIN(BETA4)+AA25*MP*RCP*ICOS(PSI+PSIC)*ICOS(BETA4)
4980 AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
4990 1AA34*AA46*AA54)+AA11*AA24*AA13*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
5000 2COS(BETA4)-AA25*MP*RCP*ICOS(PSI+PSIC)*SIN(BETA4)
5010 DPH12=(-AA59*PHI(2)*AA60*AA*AA61*AN)/AA58
5020 DPS12=U*DPH12+V*PHI(2)*PHI(2)
5030 C
5040 C
5050 C
5060 C
5070 F34=1/(AA34*AA44*AA54)*((AA35*AA47*AA57-AA34*AA47*AA55-AA34*AA45*
5080 1AA54)*AA*(AA36*AA47*AA57-AA34*AA47*AA56-AA34*AA46*AA54)*AN+AA37*
5090 2AA47*AA57*AA41*AA2*PHI(2)*PHI(2)+(AA47*AA57*AA41*I1R+AA34*AA54*I3*AA43
5100 3-AA34*AA47*I2*AA42)*DPH12)
5110 F23=(AA44*F34+AA45*AA*AA46*AN-I3*AA43*DPH12)/AA47
5120 F12=(AA54*F23+AA55*AA*AA56*AN-I2*AA42*DPH12)/AA57
5130 IF (F34.GT.F34MAX) F34MAX=F34

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5130 IF (F23.GT.F23MAX) F23MAX=F23
5140 IF (F12.GT.F12MAX) F12MAX=F12
5150 PN=(-I4*DPH12+AA22*F34+AA23*AA+AA24*AN)/AA25
5160 PNPSI=(IPR*DP512+AA14*DP51*DP51-AA12*AA-AA13*AN+NP*RCP*(AA*(SIN(
5170 1PSI+PSIC)*SIN(BETA4)-COS(PSI+PSIC)*COS(BETA4))+AN*(SIN(PSI+PSIC)*
5180 2COS(BETA4)+COS(PSI+PSIC)*SIN(BETA4))))/AA11
5190 IF (PN.GT.PNMAX) PNMAX=PN
5200 C
5210 C TEST FOR CONTINUATION OF COUPLED MOTION
5220 C
5230 C IF (.NOT.(G.LT.0..AND.PN.GT.0.)) PRMT(5)=2.
5240 C
5250 C WRITE OUTPUT
5260 C
5270 C PSID=PSI/ZZ
5280 IF (J.EQ.J/1000*1000) GO TO 50
5290 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 1
5300 50 WRITE (6,2) T,PHID,PHI(2),G,GDOT,PSID,DPSI,PHITOT,F34,F23,F12,PN,P
5310 1NPSI,DPH12
5320 1 TIME=T
5330 J=J+1
5340 IF (PHITOT.GE.PHICUTD) PRMT(5)=1.
5350 RETURN
5360 C
5370 C
5380 2 FORMAT (6X,3HT *,F8.5,3X,5HPHI *,F7.2,3X,8HPHIDOT *,F7.2,3X,3HG *,
5390 1F6.4,3X,6HGDOT *,F6.2,3X,6HPSID *,F7.2,3X,8HPSIDOT *,F8.2,3X,8HPHI
5400 2TOT *,F9.2/20X,5HF34 *,F9.4,3X,5HF23 *,F9.4,3X,5HF12 *,F9.4,3X,4HP
5410 3N *,F10.4,3X,7HPNPSI *,F10.4,3X,7HDPH12 *,E12.4)
5420 END
5430 SUBROUTINE FCTF (T,X,DX)
5440 COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
5450 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
5460 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,R82,R83,R84,TH
5470 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
5480 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
5490 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
5500 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPSI2,F34MAX,F23MAX,F12MAX,
5510 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
5520 DIMENSION X(4),DX(4)
5530 COMMON /ZETA/ PSI,TIME,G,DPSI,GP
5540 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IPR,I1R,MU,MU1,N41,N42,N43,
5550 *IP
5560 PHID=X(1)/ZZ
5570 DELPHI=PHID-PHIPR
5580 PHIT=(PHITOT+DELPHI)*ZZ
5590 IN=1
5600 CALL GCURVE(T,AA,AN)
5610 CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
5620 1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
5630 219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
5640 32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
5650 4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
5660 C
5670 CALL IN3A (AA54,AA55,AA56,AA57,CAPR82,MU,RH02,AA51,AA53,

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5680      +S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
5690 C
5700      IF (X(4)*DPSI2.GE.0.) IPR=IP+AA15
5710      IF (X(4)*DPSI2.LT.0.) IPR=IP-AA15
5720      IF (X(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RH01*(AA30+AA33)
5730      IF (X(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RH01*(AA30+AA33)
5740      IF (I1R.LT.0.) I1R=0.
5750      IF (IPR.LT.0.) IPR=0.
5760      IF (IPR.EQ.0.) WRITE (6,1)
5770      AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
5780      +AA34*AA45*AA54)+AA11*AA23+AA12*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
5790      +SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
5800      AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
5810      +AA34*AA46*AA54)+AA11*AA24+AA13*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
5820      +COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
5830      AA62=IPR
5840      AA63=AA12-MP*RCP*(SIN(PSI+PSIC)*SIN(BETA4)-COS(PSI+PSIC)*COS(
5850      BETA4))
5860      AA64=AA13-MP*RCP*(SIN(PSI+PSIC)*COS(BETA4)-COS(PSI+PSIC)*SIN(
5870      BETA4))
5880      AA65=I4-AA22/(AA34*AA44*AA54)*(AA47*AA57*N41*I1R+AA34*AA54*I3*N43
5890      I-AA34*AA47*I2*N42)
5900      AA66=-AA22*AA37*AA47*AA57*N41*I2/(AA34*AA44*AA54)
5910      AA67=AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-AA34*
5920      I*AA45*AA54)+AA23
5930      AA68=AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-AA34*
5940      I*AA46*AA54)+AA24
5950      DX(1)=X(2)
5960      DX(3)=X(4)
5970      DX(2)=(AA67*AA+AA68*AN-AA66*X(2)*I2)/AA65
5980      DX(4)=(AA63*AA+AA64*AN-AA14*X(4)*I2)/AA62
5990      RETURN
6000 C
6010 C
6020      1 FORMAT ('40H0IPR EQUALS ZERO - SIMULATION TERMINATED')
6030      END
6040      SUBROUTINE OUTPF (T,X,DX,INLF,NDIM,PRMT)
6050      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
6060      I8DA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
6070      2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
6080      3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
6090      43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
6100      6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
6110      7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
6120      8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
6130      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
6140      DIMENSION X(4),DX(4),PRMT(5)
6150      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
6160      PHID=X(1)/ZZ
6170      PSID=X(3)/ZZ
6180      DELPHI=PHID-PHIPR
6190      PHITOT=PHITOT+DELPHI
6200      PHIT=PHITOT*ZZ
6210      PHIPR=PHID
6220      IN=0
6230      CALL GCURVE(T,AA,AN)

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6240 CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
6250 1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
6260 219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
6270 32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
6280 4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
6290 C
6300 CALL IN3A (AA54,AA55,AA56,AA57,CAPR82,MU,RHO2,AA51,AA53,
6310 +S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
6320 C
6330 IF (X(4)*DPS12.GE.0.) IPR=IP+AA15
6340 IF (X(4)*DPS12.LT.0.) IPR=IP-AA15
6350 IF (X(2)*DPH12.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA30+AA33)
6360 IF (X(2)*DPH12.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA30+AA33)
6370 IF (I1R.LT.0.) I1R=0.
6380 IF (IPR.LT.0.) IPR=0.
6390 AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
6400 +AA34*AA45*AA54)+AA11*AA23+AA12*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
6410 +SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
6420 AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
6430 +AA34*AA46*AA54)+AA11*AA24+AA13*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
6440 +COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
6450 AA62=IPR
6460 AA63=AA12-MP*RCP*(SIN(PSI+PSIC)*SIN(BETA4)-COS(PSI+PSIC)*COS(BETA4
6470 1))
6480 AA64=AA13-MP*RCP*(SIN(PSI+PSIC)*COS(BETA4)-COS(PSI+PSIC)*SIN(BETA4
6490 1))
6500 AA65=14-AA22/(AA34*AA44*AA54)*(AA47*AA57*IN41*I1R+AA34*AA54*I3*IN43
6510 1-AA34*AA47*I2*IN42)
6520 AA66=-AA22*AA37*AA47*AA57*IN41*I2/(AA34*AA44*AA54)
6530 AA67=AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-AA34*
6540 1AA45*AA54)+AA23
6550 AA68=AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-AA34*
6560 1AA46*AA54)+AA24
6570 PSI=X(3)
6580 DPS1=X(4)
6590 DPH12=(-AA66*X(2)*X(2)+AA67*AA+AA68*AN)/AA65
6600 DPS12=(-AA14*X(4)*X(4)+AA63*AA+AA64*AN)/AA62
6610 C
6620 C
6630 C
6640 FF34=(I4*DPH12-AA23*AA+AA24*AN)/AA22
6650 FF23=(AA44*FF34+AA45*AA+AA46*AN-I3*IN43*DPH12)/AA47
6660 FF12=(AA54*FF23+AA55*AA+AA56*AN+I2*IN42*DPH12)/AA57
6670 IF (FF34.GT.FF34MAX) FF34MAX=FF34
6680 IF (FF23.GT.FF23MAX) FF23MAX=FF23
6690 IF (FF12.GT.FF12MAX) FF12MAX=FF12
6700 IF (J.EQ.J/1000*1000) GO TO 50
6710 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 1
6720 50 WRITE (6,4) T,PHID,X(2),PSID,X(4),PHITOT,FF12,FF23,FF34
6730 1 IF (T.EQ.TIME) GO TO 3
6740 C
6750 J=J+1
6760 C CHECK FOR CONTINUED FREE MOTION

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6770 C      F=A*SIN(X(1)-ALPHR)-B*SIN(ALPHR)-C*SIN(X(1)-ALPHR-PSI)-R
6780      GP=C*COS(X(1)-ALPHR-PSI)-B*COS(ALPHR)-A*COS(X(1)-ALPHR)
6790      IF (F.GT.0.) GO TO 2
6800      PRMT(5)=2.
6810      GO TO 3
6820      2 IF (GP.GT.0.) PRMT(5)=2.
6830      3 TIME=T
6840      IF (PHITOT.GE.PHICUTD) PRMT(5)=1.
6850      RET,RN
6860
6870 C
6880 C
6890 C
6900      4 FORMAT (6X,3HT =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI
6910      1 =,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F9.2/20X,6HFF12 =,F7.3,3X,
6920      26HFF23 =,F7.3,3X,6HFF34 =,F7.3)
6930      END
6940      SUBROUTINE KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BON
6950      1E,CONE,DONE,U,V,Z)
6960      DIMENSION PHI(2)
6970      REAL K
6980      PI=3.14159
6990      H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
7000      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
7010      1PHI(1)-ALPHR)
7020      GONE=(-H+SQRT(H*H-4.*K))/2.
7030      GTUO=(-H-SQRT(H*H-4.*K))/2.
7040      IF (ABS(GONE).LT.ABS(GTUO)) GO TO 1
7050      G=GTUO
7060      GO TO 2
7070      1 G=CONE
7080      2 P=B*SIN(PHI(1))+G*SIN(PHI(1)-ALPHR)+R*COS(PHI(1)-ALPHR)
7090      Q=B*COS(PHI(1))+G*COS(PHI(1)-ALPHR)-R*SIN(PHI(1)-ALPHR)
7100      S=G+B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)
7110      GDOT=PHI(2)*A*P/S
7120      PSI=ASIN(P/C)
7130      IF (PSI.LT.0.) GO TO 3
7140      GO TO 4
7150      3 PSI=2.*PI-ABS(PSI)
7160      4 DPSI=(Q*PHI(2)+GDOT*SIN(PHI(1)-ALPHR))/(C*COS(PSI))
7170      AONE=B*COS(ALPHR)+G
7180      BONE=B*SIN(ALPHR)
7190      CONE=-(R+C*SIN(PHI(1)-ALPHR-PSI))
7200      DONE=C*COS(PHI(1)-ALPHR-PSI)
7210      Z=(Q+A*P/S*SIN(PHI(1)-ALPHR))/(C*COS(PSI))
7220      U=(Q+SIN(PHI(1)-ALPHR)*P*A/S)/(C*COS(PSI))
7230      V=(Q+A*P*SIN(PHI(1)-ALPHR)/S)*S*TAN(PSI)/(C*SIN(COS(PSI))*S2)+(1.
7240      1/(C*COS(PSI))*S2)*A*P*COS(PHI(1)-ALPHR)/S-P+2.*A*S2*P*(SIN(PHI(1)
7250      2-ALPHR))*S2/S*S2+A*Q*SIN(PHI(1)-ALPHR)/S-A*S2*P*S2*SIN(PHI(1)-ALPH
7260      3R)/S*S2)
7270      RETURN
7280      END

```

```

7290 SUBROUTINE IN3 (ZZZ,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,
7300 1AA1,AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,
7310 2AA16,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,A
7320 3AA29,AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA
7330 442,AA43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
7340 DIMENSION ZZZ(4)
7350 COMMON A,B,C,R,ALPHR,P1,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
7360 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
7370 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
7380 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
7390 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
7400 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
7410 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
7420 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7
7430 REAL M1,M2,M3,M4,MP,MU,MU1,N41,N42,N43,I1,IIR
7440 PHI=ZZZ(1)
7450 DPHI=ZZZ(2)
7460 IF (DPHI.EQ.0.) GO TO 1
7470 MU=ABS(MU)*DPHI/ABS(DPHI)
7480 1 IF (IN.EQ.0) GO TO 2
7490 C
7500 C UPDATE VALUES OF ALPHAS
7510 C
7520 DELAL3=DELPHI*ZZ
7530 DELAL2=DELAL3*RB3/CAPRB2
7540 DELAL1=DELAL2*RB2/CAPRB1
7550 ALPHA1=ALPHA1+DELAL1
7560 ALPHA2=ALPHA2+DELAL2
7570 ALPHA3=ALPHA3+DELAL3
7580 IF (ALPHA1.GT.AL1FIN) ALPHA1=AL1IN
7590 IF (ALPHA2.GT.AL2FIN) ALPHA2=AL2IN
7600 IF (ALPHA3.GT.AL3FIN) ALPHA3=AL3IN
7610 C
7620 C DETERMINATION OF SIGNUMS
7630 C
7640 2 IF (ALPHA1.LT.TEST1) S1=1.
7650 IF (ALPHA2.LT.TEST2) S2=1.
7660 IF (ALPHA3.LT.TEST3) S3=1.
7670 IF (ALPHA1.GT.TEST1) S1=-1.
7680 IF (ALPHA2.GT.TEST2) S2=-1.
7690 IF (ALPHA3.GT.TEST3) S3=-1.
7700 IF (ALPHA1.EQ.TEST1) S1=0.
7710 IF (ALPHA2.EQ.TEST2) S2=0.
7720 IF (ALPHA3.EQ.TEST3) S3=0.
7730 IF (GDOT.NE.0.) GO TO 3
7740 S4=1.
7750 GO TO 4
7760 3 S4=GDOT/ABS(GDOT)
7770 4 IF (DPSI.NE.0.) GO TO 5
7780 S5=1.
7790 GO TO 6
7800 5 S5=DPSI/ABS(DPSI)

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```

7810 6 IF (AA.NE.0.) GO TO 7
7820 S6=1.
7830 GO TO 8
7840 7 S6=-(AA/ABS(AA))
7850 8 IF (AN.NE.0.) GO TO 9
7860 S7=1.
7870 GO TO 10
7880 9 S7=-(AN/ABS(AN))
7890 10 CONTINUE
7900 C
7910 C
7920 C COMPUTATION OF A1,A2 AND A3
7930 C
7940 C
7950 A1=ALPHA1*CAPR81
7960 A2=ALPHA2*CAPR82
7970 A3=ALPHA3*CAPR83
7980 DENOM=1.+MU*MU
7990 DENOM1=1.+MU1*MU1
8000 PI=3.14159
8010 C
8020 C COMPUTATION OF AA1 TO AA57
8030 C
8040 AA1=ABS((MU1*(S4-S5)*SIN(PHI-ALPHR)-(1.+S4*S5*MU1*MU1)*COS(PHI-ALP
8050 1HR))/DENOM1)
8060 AA2=ABS(MP*(COS(BETA4)-MU1*S5*SIN(BETA4)))/DENOM1
8070 AA3=ABS(MP*(SIN(BETA4)-MU1*S5*COS(BETA4)))/DENOM1
8080 AA4=ABS((MP*RCPI*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
8090 AA5=ABS((MP*RCPI*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
8100 AA6=ABS((MU1*(S4-S5)*COS(PHI-ALPHR)+(1.+S4*S5*MU1*MU1)*SIN(PHI-ALP
8110 1HR))/DENOM1)
8120 AA7=ABS(MP*(MU1*S5*COS(BETA4)+SIN(BETA4)))/DENOM1
8130 AA8=ABS(MP*(MU1*S5*SIN(BETA4)+COS(BETA4)))/DENOM1
8140 AA9=ABS((MP*RCPI*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
8150 AA10=ABS((MP*RCPI*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
8160 AA11=DONE+CONE*MU1*S4-RHOP*MU1*S5*(AA1+AA6)
8170 AA12=S6*RHOP*MU1*S5*(AA2+AA7)
8180 AA13=S7*RHOP*MU1*S5*(AA3+AA8)
8190 AA14=RHOP*MU1*S5*(AA4+AA9)
8200 AA15=RHOP*MU1*(AA5+AA10)
8210 AA16=ABS((- (MU1*S4-MU)*SIN(PHI-ALPHR+BETA4)+(1.+MU*MU*S4)*COS(PHI
8220 1-ALPHR+BETA4))/DENOM)
8230 AA17=ABS((MU*(1.-S3)*SIN(BETA3+THETA3)+(1.+MU*MU*S3)*COS(BETA3+THE
8240 1TA3))/DENOM)
8250 AA18=ABS(M4/DENOM)
8260 AA19=ABS(MU*M4/DENOM)
8270 AA20=ABS(((1.+MU*MU*S4)*SIN(PHI-ALPHR+BETA4)+(S4*MU1-MU)*COS(PHI-
8280 1ALPHR+BETA4))/DENOM)
8290 AA21=ABS((- (1.+MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.-S3)*COS(BETA3+TH
8300 1ETA3))/DENOM)
8310 AA22=RD4-MU*(S3*(D3-A3)*RH04*(AA17+AA21))
8320 AA23=MU*RH04*S6*(AA18+AA19)
8330 AA24=MU*RH04*S7*(AA18+AA19)
8340 AA25=ADONE+ADONE*MU1*S4+MU*RH04*(AA16+AA20)
8350 AA26=ABS((MU*(1.+S1)*SIN(BETA1+THETA1)-(1.-MU*MU*S1)*COS(BETA1+THE

```

```

8360      1TA1))/DENOM)
8370      AA27=ABS(M1/DENOM)
8380      AA28=ABS(M1*MU/DENOM)
8390      AA29=ABS((M1*RC1*(MU*COS(PHI1C+N41*PHIT))+SIN(PHI1C+N41*PHIT)))/DEN
8400      1OM)
8410      AA30=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))/DEN
8420      1OM)
8430      AA31=ABS(((1.-MU*MU*S1)*SIN(BETA1+THETA1)+MU*(1.+S1)*COS(BETA1+THE
8440      1TA1))/DENOM)
8450      AA32=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))/DEN
8460      1OM)
8470      AA33=ABS((M1*RC1*(SIN(PHI1C+N41*PHIT)+MU*COS(PHI1C+N41*PHIT)))/DEN
8480      1OM)
8490      AA34=CAPRB1-MU*S1*A1+MU*RH01*(AA26+AA31)
8500      AA35=S6*MU*RH01*(AA27+AA28)+M1*RC1*COS(PHI1C+N41*PHIT)
8510      AA36=S7*MU*RH01*(AA27+AA28)-M1*RC1*SIN(PHI1C+N41*PHIT)
8520      AA37=-MU*RH01*(AA29+AA32)
8530      AA38=ABS(((1.+MU*MU*S2)*COS(BETA2-THETA2)+MU*(S2-1.)*SIN(BETA2-THE
8540      1TA2))/DENOM)
8550      AA39=ABS(MU*M3/DENOM)
8560      AA40=ABS(M3/DENOM)
8570      AA41=ABS(((1.-MU*MU*S3)*COS(BETA3+THETA3)-MU*(1.+S3)*SIN(BETA3+THE
8580      1TA3))/DENOM)
8590      AA42=ABS(((1.+MU*MU*S2)*SIN(BETA2-THETA2)+MU*(1.-S2)*COS(BETA2-THE
8600      1TA2))/DENOM)
8610      AA43=ABS(((1.-MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.+S3)*COS(BETA3+THE
8620      1TA3))/DENOM)
8630      AA44=CAPRB3-MU*S3*A3+MU*RH03*(AA41+AA43)
8640      AA45=-MU*RH03*S6*(AA39+AA40)
8650      AA46=-MU*RH03*S7*(AA39+AA40)
8660      AA47=RB3-MU*(S2*(D2-A2)+RH03*(AA38+AA42))
8670      AA48=ABS((MU*(1.-S1)*SIN(BETA1+THETA1)+(1.+MU*MU*S1)*COS(BETA1+THE
8680      1TA1))/DENOM)
8690      AA49=ABS(M2/DENOM)
8700      AA50=ABS(MU*M2/DENOM)
8710      AA51=ABS((MU*(1.+S2)*SIN(BETA2-THETA2)+(1.-MU*MU*S2)*COS(BETA2-THE
8720      1TA2))/DENOM)
8730      AA52=ABS((MU*(1.-S1)*COS(BETA1+THETA1)-(1.+MU*MU*S1)*SIN(BETA1+THE
8740      1TA1))/DENOM)
8750      AA53=ABS(((1.-MU*MU*S2)*SIN(BETA2-THETA2)-MU*(1.+S2)*COS(BETA2-THE
8760      1TA2))/DENOM)
8770      RETURN
8780      END
8790      SUBROUTINE IN3A (AA54,AA55,AA56,AA57,CAPRB2,MU,RH02,AA51,AA53,
8800      +S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
8810      REAL MU
8820      C THIS SUBROUTINE COMPUTES AA54-AA57
8830      AA54=CAPRB2+MU*RH02*(AA51+AA53)-MU*S2*A2
8840      AA55=-MU*RH02*S6*(AA49+AA50)
8850      AA56=-MU*RH02*S7*(AA48+AA50)
8860      AA57=RB2-MU*S1*(D1-A1)-MU*RH02*(AA48+AA52)
8870      RETURN
8880      END
8890      SUBROUTINE ALFA(CAPRB, RB, THETA, CAPRO, RO, ALIN, ALFIN)
8900      ALIN=((CAPRB+RB)*TAN(THETA)-SQRT(RO*RO-RB*RB))/CAPRB
8910      ALFIN=SQRT(CAPRO*CAPRO-CAPRB*CAPRB)/CAPRB
8920      RETURN

```

```

8930      END
8940      SUBROUTINE GCURVE(T,AA,AN)
8950      COMMON/CCV/ TIM(100),G(100),GL(100),N
8960      AA=0.
8970      AN=0.
8980      GO TO 50
8990      5 J=J-1
9000      50 IF(T.EQ.TIM(1)) J=1
9010      IF(J.GE.N) GO TO 30
9020      IF(T.EQ.TIM(J)) GO TO 10
9030      IF(T.GT.TIM(J+1)) J=J+1
9040      IF(J.GE.N) GO TO 30
9050      IF(T.EQ.TIM(J+1)) GO TO 40
9060      IF(T.GT.TIM(J).AND.T.LT.TIM(J+1)) GO TO 20
9070      IF(T.LT.TIM(J)) GO TO 5
9080      GO TO 20
9090      10 AA=G(J)
9100      AN=GL(J)
9110      GO TO 1000
9120      20 AA=(G(J)+(G(J+1)-G(J))*(T-TIM(J))/(TIM(J+1)-TIM(J)))
9130      AN=(GL(J)+(GL(J+1)-GL(J))*(T-TIM(J))/(TIM(J+1)-TIM(J)))
9140      GO TO 1000
9150      30 AA=G(N)
9160      AN=GL(N)
9170      GO TO 1000
9180      40 AA=G(J+1)
9190      AN=GL(J+1)
9200      J=J+1
9210      1000 AA=12.132.2*AA
9220      AN=12.132.2*AN
9230      RETURN
9240      END

```

APPENDIX C

CONVERSION OF TWO ROTOR SYSTEM TO AN EQUIVALENT SINGLE ROTOR

The computer simulation has been written to model a pin-pallet runaway escapement with a three-pass involute gear train driven by a single rotor. The PATRIOT M143 safety and arming (S&A) device is an example of a mechanism which could be modeled by this computer program with the exception of the single-rotor requirement. The PATRIOT S&A incorporates a detonator rotor and a balance rotor. This two-rotor system is used to reduce the effect of lateral acceleration on the timing function of the device. For example, suppose a lateral acceleration A_N results from a missile maneuver in the positive X direction (fig. C-1). From the position of the rotors shown, this acceleration would result in a counterclockwise moment on the balance rotor, as well as a counterclockwise moment on the detonator rotor. Since the rotors are of equal size and number of teeth, and have similar mass properties, the resulting reactions are virtually equal and opposite, greatly reducing the effect of the acceleration in comparison with the effect the same acceleration would have on a single-rotor system.

To use the computer program to model the PATRIOT S&A, the two-rotor system must be modeled as a single equivalent rotor.

Detonator Rotor

Using figure C-1, the moment balance written about the pivot of the detonator rotor can be expressed as

$$-FR - f_D = A_A m_D r_D \cos(\beta_D + 45^\circ + \alpha) - A_N m_D r_D \sin(\beta_D + 45^\circ + \alpha) + I_D \ddot{\alpha}_1 \quad (C-1)$$

where

F = contact force between balance and detonator rotors

R = base circle radius of balance and detonator rotor gears

f_D = detonator rotor pivot friction torque

m_D = mass of detonator rotor

r_D = distance from pivot center to c.g. of detonator rotor

A_A = axial acceleration of missile

A_N = lateral or normal acceleration of missile

α = angular position of detonator rotor

β_D = angle used to locate c.g. of detonator rotor

I_D = mass moment of inertia of detonator rotor

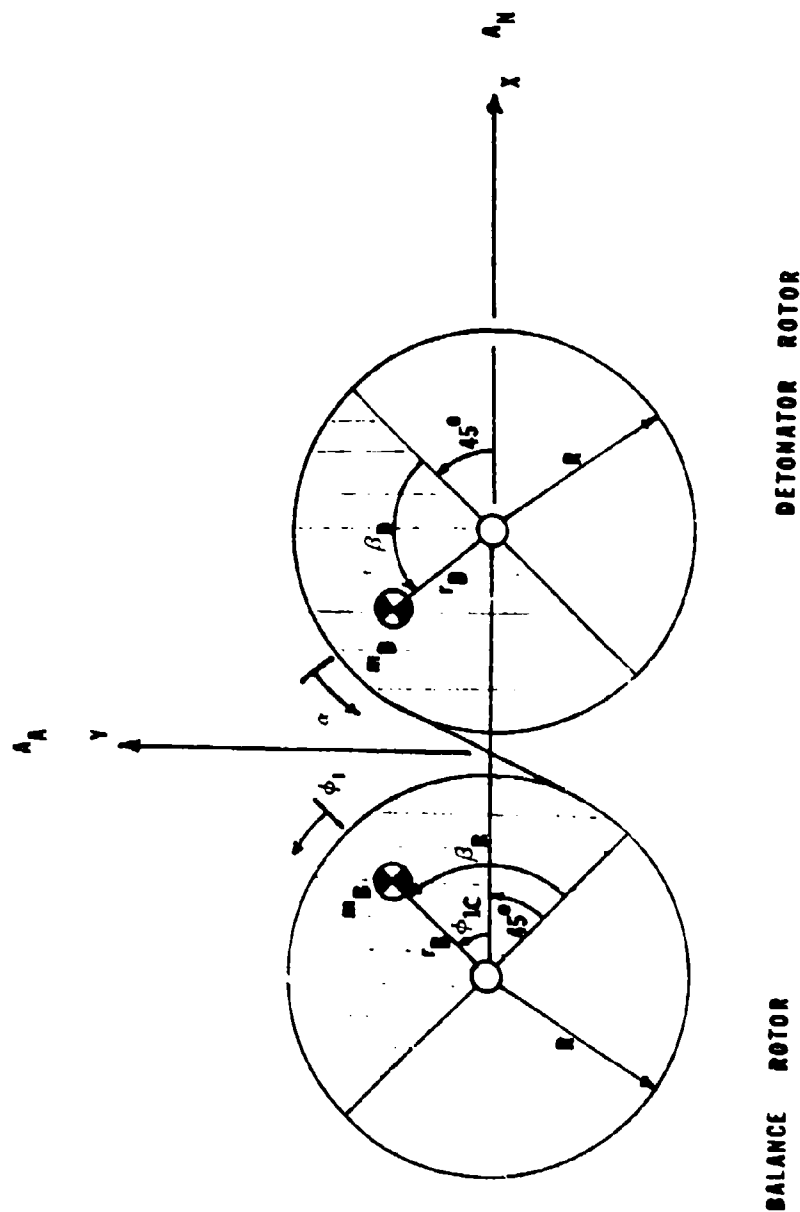


Figure C-1. PATRIOT M143 S&A two rotor system

Balance Rotor

Similarly, the moment balance can be performed on the balance rotor. At present, the resistive moment contributed by the delay escapement assembly is not included. The resulting equation is as follows:

$$\begin{aligned}
 -FR - f_B &= A_A m_B r_B \cos(\beta_B - 45^\circ + \phi_1) \\
 &\quad - A_N m_B r_B \sin(\beta_B - 45^\circ + \phi_1) + I_B \ddot{\phi}_1
 \end{aligned}
 \tag{C-2}$$

where

m_B = mass of balance rotor

β_B = angle locating c.g. of balance rotor

r_B = distance from pivot center to c.g. of balance rotor

ϕ_1 = angular position of balance rotor

f_B = balance rotor pivot friction torque

Equations C-1 and C-2 can now be combined to form a single equation eliminating the dependence on the contact force F .

$$\begin{aligned}
 -f_B + f_D &= -A_A m_D r_D \cos(\beta_D + 45^\circ + \alpha) \\
 &\quad + A_A m_B r_B \cos(\beta_B - 45^\circ + \phi_1) \\
 &\quad + A_N m_D r_D \sin(\beta_D + 45^\circ + \alpha) \\
 &\quad - A_N m_B r_B \sin(\beta_B - 45^\circ + \phi_1) + I_B \ddot{\phi}_1 - I_D \ddot{\alpha}_1
 \end{aligned}
 \tag{C-3}$$

Recognizing that since the two rotors are of equal size and number of teeth,

$$\alpha = -\phi_1 \tag{C-4}$$

$$\dot{\alpha} = -\dot{\phi}_1 \tag{C-5}$$

$$\ddot{\alpha} = -\ddot{\phi}_1 \tag{C-6}$$

From figure C-1 it can be seen that

$$\phi_{1c} = \beta_B - 45^\circ \tag{C-7}$$

Using the gear ratio N_{41} (equation A-79), the balance rotor angle and its derivatives can be expressed in terms of the escape wheel angle ϕ and its derivatives as:

$$\phi_1 = N_{41} \phi \quad (C-8)$$

$$\dot{\phi}_1 = N_{41} \dot{\phi} \quad (C-9)$$

$$\ddot{\phi}_1 = N_{41} \ddot{\phi} \quad (C-10)$$

Again using appendix A, equation A-80, the balance rotor angle can be expressed as

$$\phi_{1c} + \phi_1 = \phi_{1c} + N_{41} \phi_T \quad (C-11)$$

Finally, rewriting equation C-5 with this information

$$\begin{aligned} -f_B + f_D &= \Lambda_A [m_B r_B \cos(\phi_{1c} + N_{41} \phi_T) - m_D r_D \cos(\beta_D + 45^\circ - N_{41} \phi_T)] \\ &\quad - \Lambda_N [m_B r_B \sin(\phi_{1c} + N_{41} \phi_T) - m_D r_D \sin(\beta_D + 45^\circ - N_{41} \phi_T)] \\ &\quad + (I_D + I_B) N_{41} \ddot{\phi} \end{aligned} \quad (C-12)$$

At this point, equation C-12 can be compared to the moment equation for the rotor (equation A-101 in appendix A). It can be seen that the effective moment of inertia I_1 can be expressed as

$$I_1 = I_D + I_B \quad (C-13)$$

Further, it can be seen that additional "driving torque" terms (in the coefficients of Λ_A and Λ_N on the right hand side of the equation) have arisen. Tracing the original driving torque expression back in appendix A, it is found that equations A-107 and A-108 must be modified to account for the additional contribution of the detent force:

$$\begin{aligned} \Lambda_{25} &= s_{10} s_{11} [\Lambda_{27} + \Lambda_{28} + (m_1 r_{c1} \cos(\phi_{1c} + N_{41} \phi_T) \\ &\quad + m_1 r_{10} \cos(\beta_D + 45^\circ - N_{41} \phi_T))] \end{aligned} \quad (C-14)$$

$$\begin{aligned} \Lambda_{26} &= s_{12} s_{11} [\Lambda_{27} + \Lambda_{28} + (m_1 r_{c1} \sin(\phi_{1c} + N_{41} \phi_T) \\ &\quad + m_1 r_{10} \sin(\beta_D + 45^\circ - N_{41} \phi_T))] \end{aligned} \quad (C-15)$$

where

$$s_{10} = \frac{r_{10}}{r_{c1}} \quad (C-16)$$

To avoid significant mathematical complexity, this modification does not account for the pivot friction of the detonator rotor. In appendix D, a revised version of the computer simulation is presented for the M143 S&A. All revisions of the program to make it suitable for simulation of the M143 S&A are clearly identified.

APPENDIX D
PROGRAM M143SA

```

170      PROGRAM M143SA(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT)
180
190
200      NOTE THE INCLUSION OF M143 S&A PARAMETERS IN COMMON
210      AND REAL STATEMENTS WHERE APPLICABLE IN PROGRAM
220
230      COMMON A,B,C,R,ALPHA,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
240      18DA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
250      2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
260      BETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
270      43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
280      6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
290      TRCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
300      SFF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7,BD,RD,ID,MD
310      COMMON ZETA,PSI,TIME,G,DPSI,GP
320      COMMON GCU,TIM(100),GA(100),GL(100),N
330      DIMENSION AUX(8,2),AUX2(8,4),PRMT(5),PHI(2),DFHI(2),X(4),DX(
340      14)
350      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,LAMBDA,K,N41,N42,N43,J1,J2,J3,N
360      IG1,NG2,NG3,NP2,NP3,NP4,MU,MU1,ID,MD
370      EXTERNAL FCT,OUTP,FCTF,OUTPF
380
390      C
400      C      READ IN AND WRITE DATA
410      C      WRITE(6,300)
420      300 FORMAT('ESCAPEMENT DATA'////)
430      C
440      READ(5,22)A,B,C,R,ALPHA
450      WRITE(6,23) A,B,C,R,ALPHA
460      READ(5,32) BETA1,BETA2,BETA3,BETA4
470      WRITE(6,41) BETA1,BETA2,BETA3,BETA4
480      READ(5,24) EREST,LAMBDA,DELTA
490      WRITE(6,25) EREST,LAMBDA,DELTA
500      WRITE(6,301)
510      301 FORMAT('///MASS PROPERTIES'////)
520      READ(5,26) M1,M2,M3,M4,MP
530      WRITE(6,27) M1,M2,M3,M4,MP
540      READ(5,26) I1,I2,I3,I4,IP
550      WRITE(6,28) I1,I2,I3,I4,IP
560      WRITE(6,302)
570      302 FORMAT('///MISCELLANEOUS PARAMETERS'////)
580      READ(5,29) RC1,RCP,RHOP,PHI1C,PSICCD,PHID,PHICUTD,MU,MU1
590      WRITE(6,30) RC1,RCP,RHOP,PHI1C,PSICCD,PHID,PHICUTD,MU,MU1
600      READ(5,31) PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRP1,CA
610      1PRP2,CAPRP3,RP2,RP3,RP4,THETA1,THETA2,THETA3
620      WRITE(6,303)
630      303 FORMAT('///GEAR PARAMETERS'////)
640      WRITE(6,35) PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRP1,C
650      1APRP2,CAPRP3,RP2,RP3,RP4,THETA1,THETA2,THETA3
660      READ(5,32) RH01,RH02,RH03,RH04
670      WRITE(6,37) RH01,RH02,RH03,RH04
680      READ(5,33) CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4
690      WRITE(6,38) CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4

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600      READ (5,33) CAPR01,CAPR02,CAPR03,R02,R03,R04
610      WRITE (6,39) CAPR01,CAPR02,CAPR03,R02,R03,R04
620      READ (5,34) J1,J2,J3
630      WRITE (6,40) J1,J2,J3
632      WRITE(6,304)
634      304 FORMAT(///'ANGLE INDEXING PARAMETERS'////)
660      READ(5,59) TANG,NT
670      WRITE(6,90) TANG,NT
680      59 FORMAT (F10.3,13)
690      90 FORMAT (2X,'TANG = ',F10.3,3X,'NT = ',13/)
700 C
710 C
720 C READ & WRITE SPECIAL DATA FOR M143 S&A
730 C
740 C
750      READ(5,200) BD,RD,ID,MD
760      WRITE (6,201)
770      WRITE (6,202) BD,RD,ID,MD
780      200 FORMAT(2F10.6/2E12.6)
790      201 FORMAT(///'SPECIAL DATA FOR M143 DETONATOR ROTR'////)
800      202 FORMAT(3X,'BD = ',F10.6,3X,'RD = ',F10.6,3X,'ID = ',E12.6,3X,
810      + 'MD = ',E12.6////////)
820 C
830 C
840 C READ & WRITE ACCELERATION DATA
850 C
860 C
862      WRITE(6,305)
864      305 FORMAT(///'ACCELERATION PROFILE DATA'////)
870      READ(5,91) N
880      91 FORMAT(I3)
890      READ (5,92)(TIM(J),GA(J),GL(J),J=1,N)
900      92 FORMAT (3F10.3)
910      WRITE (6,93) (TIM(J),GA(J),GL(J),J=1,N)
920      93 FORMAT (F10.2,4X,F10.2,4X,F10.2/)
930      WRITE (6,94)
940      94 FORMAT(////////)
950 C
960 C
970 C INITIALIZATION OF PARAMETERS AND CONVERSION TO RADIANs
980 C
990 C
1000      J=0
1010      TIME=0.
1020      PHITOT=0.
1030      PHIRX=PHID
1040      DPHI2=0.
1050      DPHI2=0.
1060      F34MAX=0.
1070      F23MAX=0.
1080      F12MAX=0.
1090      FF34MAX=0.
1100      FF23MAX=0.

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1110 FF12MAX=0.
1120 PNMAX=0.
1130 PI=3.14159
1140 ZZ=PI/180.
1150 PHI1C=PHI1C*ZZ
1160 PSICC=PSICCD*ZZ
1170 PSIC=PSICC
1180 ALPHR=ALPHA*ZZ
1190 C
1200 C
1210 C NOTE M143 PARAMETER BD TO RADIANS
1220 C
1230 C
1240 BD=BD*ZZ
1250 C
1260 C
1270 C CONVERSION TO EFFECTIVE MOMENT OF INERTIA FOR M143 ROTOR SYSTEM
1280 C
1290 C
1300 I1=I1*ID
1310 C
1320 C COMPUTATION OF GEAR RATIOS
1330 C
1340 N41=-NP2*NP3*NP4/(NG1*NG2*NG3)
1350 N42=NP3*NP4/(NG2*NG3)
1360 N43=-NP4/NG3
1370 C
1380 C CONVERSION OF PRESSURE ANGLES TO RADIANS
1390 C
1400 THETA1=THETA1*ZZ
1410 THETA2=THETA2*ZZ
1420 THETA3=THETA3*ZZ
1430 C
1440 C DETERMINATION OF GEAR TRAIN CONSTANTS
1450 C
1460 TEST1=TAN(THETA1)
1470 TEST2=TAN(THETA2)
1480 TEST3=TAN(THETA3)
1490 D1=(CAPRB1*RB2)*TAN(THETA1)
1500 D2=(CAPRB2*RB3)*TAN(THETA2)
1510 D3=(CAPRB3*RB4)*TAN(THETA3)
1520 C
1530 C DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS
1540 C
1550 CALL ALFA (CAPRB1, RB2, THETA1, CAPR01, R02, AL1IN, AL1FIN)
1560 CALL ALFA (CAPRB2, RB3, THETA2, CAPR02, R03, AL2IN, AL2FIN)
1570 CALL ALFA (CAPRB3, RB4, THETA3, CAPR03, R04, AL3IN, AL3FIN)
1580 C
1590 C INITIALIZATION OF ALPHAS
1600 C
1610 ALPHA1=AL1IN+(AL1FIN-AL1IN)*J1
1620 ALPHA2=AL2IN+(AL2FIN-AL2IN)*J2
1630 ALPHA3=AL3IN+(AL3FIN-AL3IN)*J3
1640 C

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1650 C      DATA FOR RUNGE KUTTA
1660 C
1670      PRMT(2)=10.
1680      PRMT(4)=.01
1690      NDIM=2
1700      NDIM2=4
1710      PHI(1)=PHID*ZZ
1720      PHI(2)=0.
1730 C
1740 C      COUPLED MOTION
1750 C
1760      1 PRMT(1)=TIME
1770      PRMT(3)=.0001
1780      DPHI(1)=.5
1790      DPHI(2)=.5
1800      IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 2
1810      WRITE (6,42)
1820      2 CALL RKGS (PRMT,PHI,DPHI,NDIM,IHLF,FCT,OUTP,AUX)
1830      IF (PRMT(5).EQ. 1.) GO TO 21
1840      IF (PHITOT.GE.PHICUTD) GO TO 21
1850 C
1860 C      TEST FOR ENTRANCE OR EXIT ACTION
1870 C
1880      IF (.S.(F.0.)) GO TO 5
1890      PHID=PHI(1)/ZZ
1900      IF (PHID.LE.TANG) GO TO 3
1910      GO TO 4
1920      3 PHI(1)=PHI(1)+DELTA*ZZ*NT
1930      PHIPR=PHI(1)/ZZ
1940      PSI=PSI+2.*PI-LAMBDA*ZZ
1950      PSIC=PSICC+LAMBDA*ZZ
1960      GO TO 5
1970      4 PHI(1)=PHI(1)-DELTA*ZZ*(NT+1.)
1980      PHIPR=PHI(1)/ZZ
1990      PSI=PSI-2.*PI+LAMBDA*ZZ
2000      PSIC=PSICC
2010 C
2020 C      FREE MOTION
2030 C
2040      5 PRMT(1)=TIME
2050      X(1)=PHI(1)
2060      X(2)=PHI(2)
2070      X(3)=PSI
2080      X(4)=DPHI
2090      DX(1)=.25
2100      DX(2)=.25
2110      DX(3)=.25
2120      DX(4)=.25
2130      PRMT(3)=.0001
2140      IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 6
2150      WRITE (6,43)
2160      6 CALL RKGS (PRMT,X,DX,NDIM2,IHLF,FCTF,OUTPF,AUX2)
2170      IF (PHITOT.GE.PHICUTD) GO TO 21
2180      PHI(1)=X(1)
2190      PHI(2)=X(2)

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2200      H=2.*B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)
2210      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
2220      1PHI(1)-ALPHR)
2230      GONE=(-H+SQRT(H*H-4.*K))/2.
2240      GTUO=(-H-SQRT(H*H-4.*K))/2.
2250      IF (ABS(GONE).LT.ABS(GTUO)) GO TO 7
2260      G=GTUO
2270      GO TO 8
2280      7 G=GONE
2290      8 PHIC=PHI(1)/ZZ
2300      IF (GP.LT.0.) GO TO 11
2310      IF (PHID.LE.TANG) GO TO 9
2320      GO TO 10
2330      9 PHI(1)=PHI(1)+DELTA*ZZ*NT
2340      PHIPR=PHI(1)/ZZ
2350      PSI=PSI+2.*PI-LAMBDA*ZZ
2360      PSIC=PSIC+LAMBDA*ZZ
2370      GO TO 5
2380      10 PHI(1)=PHI(1)-DELTA*ZZ*(NT+1.)
2390      PHIPR=PHI(1)/ZZ
2400      PSI=PSI-2.*PI+LAMBDA*ZZ
2410      PSIC=PSIC
2420      GO TO 5
2430      11 IF (PHID.LE.TANG) GO TO 13
2440      C
2450      C EXIT ACTION
2460      C
2470      C COMPUTATION OF VELOCITIES UP AND US FOR EXIT ACTION
2480      C
2490      ACNE=B*COS(ALPHR)*G
2500      DONE=C*COS(PHI(1)-ALPHR-PSI)
2510      UP=DONE*DPSI
2520      US=ACNE*PHI(2)
2530      IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 12
2540      WRITE (6,44) UP,US
2550      C
2560      C EXIT ACTION TEST
2570      C
2580      12 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 15
2590      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
2600      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 15
2610      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2620      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(UP).GT.ABS(US)) GO TO 15
2630      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2640      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
2650      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
2660      C
2670      C COMPUTATION OF VELOCITIES UP AND US FOR ENTRANCE ACTION
2680      C
2690      13 ACNE=B*COS(ALPHR)+G
2700      DONE=C*COS(PHI(1)-ALPHR-PSI)
2710      UP=DONE*DPSI
2720      US=ACNE*PHI(2)

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2730 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 14
2740 WRITE (6,44) UP,US
2750 C
2760 C ENTRANCE ACTION
2770 C
2780 14 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
2790 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2800 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).LT.ABS(US)) GO TO 15
2810 IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
2820 IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 15
2830 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
2840 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 15
2850 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).EQ.ABS(US)) GO TO 1
2860 C
2870 C IMPACT
2880 C
2890 15 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)
2900 H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
2910 K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*
2920 1 SIN(PHI(1)-ALPHR)
2930 GONE=(H+SQRT(H**2-4.*K))/2.
2940 GTWO=(H-SQRT(H**2-4.*K))/2.
2950 IF (ABS(GONE).LT.ABS(GTWO)) GO TO 16
2960 G=GTWO
2970 GO TO 17
2980 16 G=GONE
2990 17 CONTINUE
3000 C
3010 C
3020 C TEST FOR EXIT ACTION
3030 C
3040 PHID=PHI(1)/22
3050 IF (PHID.LE.TANG) GO TO 19
3060 C
3070 C EXIT ACTION
3080 C
3090 C COMPUTATION OF VELOCITIES UP AND US FOR BOTTOM ACTION
3100 AONE=B*COS(ALPHR)+G
3110 DONE=C*COS(PHI(1)-ALPHR-PSI)
3120 UP=DONE*DPSI
3130 US=AONE*PHI(2)
3140 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 18
3150 WRITE (6,44) UP,US
3160 18 IF (ABS(UP-US).LT.1.0) GO TO 1
3170 C
3180 C EXIT ACTION TESTS
3190 C
3200 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1
3210 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
3220 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 1
3240 IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
3250 IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(UP).GT.ABS(US)) GO TO 1
3270 IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
3280 C

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3290 C      COMPUTATION OF VELOCITIES UP AND US FOR ENTRANCE ACTION
3300 C
3310 19 AONE=B*COS(ALPHR)+G
3320     DONE=C*COS(PHI(1)-ALPHR-PSI)
3330     UP=DONE+DPSI
3340     US=AONE+PHI(2)
3350     IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 20
3360     URITE (6,4) UP,US
3370 20 IF(ABS(UP-US).LT.1.0) GO TO 1
3380 C
3390 C      ENTRANCE ACTION TESTS
3400 C
3410     IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).GT.ABS(US)) GO TO 5
3420     IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(UP).LT.ABS(US)) GO TO 1
3430     IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
3440     IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 1
3450     IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).GT.ABS(US)) GO TO 1
3460     IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(UP).LT.ABS(US)) GO TO 5
3470 21 URITE(6,45)F34MAX,F23MAX,F12MAX,FF34MAX,FF23MAX,FF12MAX,PNMAX
3480     ATM=TIME
3490     URITE(6,75) ATM
3500 75 FORMAT(' THE S&A ARMS IN',2X,F6.3,2X,'SECONDS.')
3510     STOP
3520 C
3530 C
3540 C
3550 C
3560 C
3570 22 FORMAT (5F10.5)
3580 23 FORMAT (1H,5X,2HA=,F13.5,5X,2HB=,F13.5,5X,2HC=,F13.5,5X,2HR=,F13.
3590     5,5X,6HALPHA=,F9.4/)
3600 24 FORMAT (3F10.5)
3610 25 FORMAT (1H,5X,6HEREST=,F5.2,3X,7HLAMBDA=,F8.3,3X,6HDELTA=,F8.3/)
3620 26 FORMAT (5E12.5)
3630 27 FORMAT (1H,5X,4HM1 =,E15.5,3X,4HM2 =,E15.5,3X,4HM3 =,E15.5,3X,4HM
3640     14 =,E15.5,3X,4HMP =,E15.5/)
3650 28 FORMAT (1H,5X,4HI1 =,E15.5,3X,4HI2 =,E15.5,3X,4HI3 =,E15.5,3X,4HI
3660     14 =,E15.5,3X,4HIP =,E15.5/)
3670 29 FORMAT (6F10.4/3F10.4)
3680 30 FORMAT (6X,5HRC1 =,F7.4,3X,5HRC2 =,F7.4,3X,6HRHOP =,F7.4,3X,
3690     13X,7HPHI1C =,F9.4,3X,8HPSICCD =,F9.4,3X,6HPHID =,F9.4//6X,
3700     29HPHICUTD =,F6.0//6X,4HMMU =,F5.3,3X,5HMMU1 =,F5.3/)
3710 31 FORMAT (3F10.4/6F10.0/6F10.5/3F10.4)
3720 32 FORMAT (4F10.4)
3730 33 FORMAT (6F10.5)
3740 34 FORMAT (3F10.2)
3750 35 FORMAT (1H,5X,3HPSUBD1 =,F5.1,3X,8HPSUBD2 =,F5.1,3X,8HPSUBD3 =,F5
3760     1.1//6X,5HNG1 =,F4.0,3X,5HNG2 =,F4.0,3X,5HNG3 =,F4.0,3X,5HNP2 =,F4.
3770     20,3X,5HNP3 =,F4.0,3X,5HNP4 =,F4.0//6X,8HCAPRP1 =,F8.5,3X,8HCAPRP2
3780     3=,F8.5,3X,8HCAPRP3 =,F8.5//6X,5HRP2 =,F8.5,3X,5HRP3 =,F8.5,3X,5HRP
3790     44 =,F8.5//6X,8HTHETA1 =,F8.3,3X,8HTHETA2 =,F8.3,3X,8HTHETA3 =,F8.3
3800     5/)
3810 37 FORMAT (6X,6HRH01 =,F7.5,3X,6HRH02 =,F7.5,3X,6HRH03 =,F7.5,3X,6HRH
3820     104 =,F7.5/)
3830 38 FORMAT (6X,8HCAPRB1 =,F7.5,3X,8HCAPRB2 =,F7.5,3X,8HCAPRB3 =,F7.5,3
3840     1X,5HRB2 =,F7.5,3X,5HRB3 =,F7.5,3X,5HRB4 =,F7.5/)

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3550 39 FORMAT (6X,8HCAPR01 =,F7.5,3X,8HCAPR02 =,F7.5,3X,8HCAPR03 =,F7.5,3
3560 1X,SHR02 =,F7.5,3X,SHR03 =,F7.5,3X,SHR04 =,F7.5/)
3570 40 FORMAT (1H0,5X,4HJ1 =,F4.2,3X,4HJ2 =,F4.2,3X,4HJ3 =,F4.2/)
3580 41 FORMAT (6X,8HBETA1D =,F7.2,3X,8HBETA2D =,F7.2,3X,8HBETA3D =,F7.2,3
3590 1X,8HBETA4D =,F7.2/)
3600 42 FORMAT (5X,14HCOUPLED MOTION)
3610 43 FORMAT (5X,11HFREE MOTION//)
3620 44 FORMAT (3HUP =,F8.3,3X,3HVS =,F8.3)
3630 45 FORMAT (1H0,6X,*F34MAX =*,F6.2/1H0,6X,*F23MAX =*,F6.2/1H0,6X,*F12
3640 1MAX =*,F6.2/1H0,6X,*FF34MAX =*,F6.2/1H0,6X,*FF23MAX =*,F6.2/1H0,5X
3650 2*FF12MAX =*,F6.2/1H0,6X,*PNMAX =*,F6.2/)
3660 END
3670 SUBROUTINE IMPACT (PHI,DPHI,PSI,DPSI)
3680 COMMON A,B,C,R,ALPHR,P1,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
3690 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
3700 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH
3710 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RH0P,J1,J2,J
3720 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
3730 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
3740 TRCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPSI2,F34MAX,F23MAX,F12MAX,
3750 SFF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7,BD,RD,ID,MD
3760 REAL I1,I2,I3,I4,IP,LAMBDA,N41,N42,N43,ISTOT,K
3770 1STOT=I4+I1*N41+N41+I2*N42+N42+I3*N43+N43
3780 M=2.1*(B*COS(ALPHR)+A*COS(PHI-ALPHR))
3790 K=A*I2*B*I2+R*I2-C*I2+2.1*B*R*SIN(ALPHR)+2.1*A*B*COS(PHI)-2.1*A*R*SIN
3800 1(PHI-ALPHR)
3810 GONE=(-H+SORT(H*I2-4.*K))/2.
3820 GTWO=(-H-SORT(H*I2-4.*K))/2.
3830 IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1
3840 G=GTWO
3850 GO TO 2
3860 1 G=GONE
3870 2 AONE=B*COS(ALPHR)+G
3880 DONE=C*COS(PHI-ALPHR-PSI)
3890 DPHI1=DPHI
3900 DPHI=(IP*AONE*DPSI+ISTOT*DONE*DPHI+IP*AONE*EREST/DONE*(DPSI*DONE-D
3910 1PHI*AONE))/(IP*AONE*I2/DONE+ISTOT*DONE)
3920 DPSI=(DPHI*AONE-EREST*(DPSI*DONE-DPHI1*AONE))/DONE
3930 PHID=PHI/ZZ
3940 PSID=PSI/ZZ
3950 IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 3
3960 WRITE (6,4)
3970 WRITE (6,5) PHID,DPHI,PSID,DPSI,PHITOT
3980 3 RETURN
3990 C
4000 C
4010 C
4020 4 FORMAT (1H0,5X,6HIMPACT)
4030 5 FORMAT (1H0,18X,4HPHI =,F8.3,3X,7HPHIDOT =,F8.3,3X,4HPSI =,F8.3,3X,7H
4040 1PSIDOT =,F8.3,3X,8HPHITOT =,F9.2)
4050 END
4060 SUBROUTINE FCT (T,PHI,DPHI)
4070 COMMON A,B,C,R,ALPHR,P1,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
4080 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2

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4390 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
4400 3ETA1,THETA2,THETA3,R1,R2,R3,R4,P5,RH01,RH02,RH03,RH04,RH0P,J1,J2,J
4410 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
4420 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
4430 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F23MAX,F12MAX,
4440 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7,B0,RO,IO,MD
4450 DIMENSION PHI(2),DPHI(2)
4460 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR,MD
4470 PHID=PHI(1)*ZZ
4480 DELPHI=PHID-PHIPR
4490 PHIT=(PHITOT+DELPHI)*ZZ
4500 IN=1
4510 CALL KINEM(A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
4520 1,DONE,U,V,Z)
4530 CALL GCURVE(T,AA,AN)
4540 CALL IN3(PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
4550 12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
4560 2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
4570 330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
4580 43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
4590 C
4600 CALL IN3A(AA54,AA55,AA56,AA57,CAPRB2,MU,RH02,AA51,AA53,
4610 *S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
4620 IF(DPSI*DPSI2.GE.0.) IPR=IP+AA15
4630 IF(DPSI*DPSI2.LT.0.) IPR=IP-AA15
4640 IF(PHI(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RH01*(AA30+AA33)
4650 IF(PHI(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RH01*(AA30+AA33)
4660 IF(I1R.LT.0.) I1R=0.
4670 IF(IPR.LT.0.) IPR=0.
4680 AA58=AA25*IPR*U+AA11*I4-AA11*AA22/(AA34*AA44*AA54)*(AA47*AA57*N41
4690 1*I1R+AA34*AA54*I3*N43-AA34*AA47*I2*N42)
4700 AA59=AA14*AA25*U*I2+AA25*IPR*U-AA11*AA22*AA37*AA47*AA57*N41*I2
4710 +/(AA34*AA44*AA54)
4720 AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
4730 1AA34*AA45*AA54)+AA11*AA23+AA12*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
4740 2SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
4750 AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
4760 1AA34*AA46*AA54)+AA11*AA24+AA13*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
4770 2COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
4780 DPHI(1)=PHI(2)
4790 DPHI(2)=(-AA59*PHI(2)*I2+AA60*AA+AA61*AN)/AA58
4800 RETURN
4810 END
4820 SUBROUTINE OUTP(T,PHI,DPHI,IHLF,NDIM,PRMT)
4830 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR,MD
4840 DIMENSION PHI(2),DPHI(2),PRMT(5)
4850 COMMON A,B,C,R,ALPHR,P1,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
4860 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
4870 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
4880 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RH0P,J1,J2,J
4890 43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
4900 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
4910 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F23MAX,F12MAX,

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4920 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7,BD,RD,ID,MD
4930 COMMON /ZETA/ PSI,TIME,G,DPSI,GP
4940 PHID=PHI(1)/22
4950 DELPHI=PHID-PHIPR
4960 PHIPR=PHID
4970 PHITOT=PHITOT+DELPHI
4980 PHIT=PHITOT*22
4990 IN=0
5000 CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,O,S,GDOT,PSI,DPSI,AONE,BONE,CONE
5010 1,DONE,U,U,2)
5020 CALL GCURVE(T,AA,AN)
5030 CALL IN3 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
5040 12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
5050 2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
5060 30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
5070 43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
5080 C
5090 CALL IN3A(AA54,AA55,AA56,AA57,CAPR82,MU,RH02,AA51,AA53,
5100 +S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
5110 C
5120 IF (DPSI>DPSI2.GE.0.) IPR=IP+AA15
5130 IF (DPSI<DPSI2.LT.0.) IPR=IP-AA15
5140 IF (PHI(2)>DPHI2.GE.0.) I1R=I1+ABS(MU)*RH01*(AA30+AA33)
5150 IF (PHI(2)<DPHI2.LT.0.) I1R=I1-ABS(MU)*RH01*(AA30+AA33)
5160 IF (I1R.LT.0.) I1R=0.
5170 IF (IPR.LT.0.) IPR=0.
5180 AA54=AA25*(IPR+U+AA11*(14-AA11*AA22/(AA34*AA44*AA54)))*(AA47*AA57*AA41
5190 1*I1R+AA34*AA54*(13*AA43-AA34*AA47*(12*AA42)
5200 AA59=AA14*AA25*(12+AA25*(IPR+U-AA11*AA22*AA37*AA47*AA57*AA41*AA2
5210 +/(AA34*AA44*AA54))
5220 AA60=AA11*AA22*(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
5230 1AA34*AA45*AA54)+AA11*AA23*AA12*AA25-AA25*MP*RCP*PSI*(PSI+PSIC)*
5240 2SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
5250 AA61=AA11*AA22*(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
5260 1AA34*AA46*AA54)+AA11*AA24*AA13*AA25-AA25*MP*RCP*PSI*(PSI+PSIC)*
5270 2COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
5280 DPHI2=(-AA59*PHI(2)*12+AA60*AA+AA61*AN)/AA58
5290 DPSI2=U*DPHI2+U*PHI(2)*PHI(2)
5300 C
5310 C
5320 C
5330 COMPUTATION OF CONTACT FORCES
5340 F34=1/(AA34*AA44*AA54)*((AA35*AA47*AA57-AA34*AA47*AA55-AA34*AA45*
5350 1AA54)*AA+(AA36*AA47*AA57-AA34*AA47*AA56-AA34*AA46*AA54)*AN+AA37*
5360 2AA47*AA57*AA41*12*PHI(2)*PHI(2)+(AA47*AA57*AA41*I1R+AA34*AA54*(13*AA43
5370 3-AA34*AA47*(12*AA42)*DPHI2)
5380 F23=(AA44*(F34+AA45*AA+AA46*AN-13*AA43*DPHI2)/AA47
5390 F12=(AA54*(F23+AA55*AA+AA56*AN-12*AA42*DPHI2)/AA57
5400 IF (F34.GT.F34MAX) F34MAX=F34
5410 IF (F23.GT.F23MAX) F23MAX=F23
5420 IF (F12.GT.F12MAX) F12MAX=F12
5430 PN=(-14*DPHI2+AA22*F34+AA23*AA+AA24*AN)/AA25
5440 PNF51=(IPR*DPSI2+AA14*DP51*DP51-AA12*AA-AA13*AN+MP*RCP*(AA*(SIN(
5450 1PSI+PSIC)*SIN(BETA4)-COS(PSI+PSIC)*COS(BETA4))+AN*(SIN(PSI+PSIC)*
5460 2COS(BETA4)+COS(PSI+PSIC)*SIN(BETA4))))/AA11
5470 IF (PN.GT.PNMAX) PNMAX=PN

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```

5470 C
5480 C
5490 C
5500 C
5510 C
5520 C
5530 C
5540 C
5550 C
5560 C
5570 C
5580 C
5590 C
5600 C
5610 C
5620 C
5630 C
5640 C
5650 C
5660 C
5670 C
5680 C
5690 C
5700 C
5710 C
5720 C
5730 C
5740 C
5750 C
5760 C
5770 C
5780 C
5790 C
5800 C
5810 C
5820 C
5830 C
5840 C
5850 C
5860 C
5870 C
5880 C
5890 C
5900 C
5910 C
5920 C
5930 C
5940 C
5950 C
5960 C
5970 C
5980 C
5990 C
6000 C
6010 C
6020 C

TEST FOR CONTINUATION OF COUPLED MOTION

IF (.NOT.(G.LT.0..AND.PH.GT.0.)) PRMT(5)=2.

WRITE OUTPUT

PSID=PSI/ZZ
IF (J.EQ.1000*1000) GO TO 50
IF (PHITOT.GT.30..AND.PHITOT.LT.(PHICUTD-30.)) GO TO 1
50 WRITE (6,2) T,PHID,PHI(2),G,GDOT,PSID,DPSI,PHITOT,F34,F23,F12,PN,P
1NPSI,DPHI2
1 TIME=T
J=J+1
IF (PHITOT.GE.PHICUTD) PRMT(5)=1.
RETURN

2 FORMAT (6X,3HT *,F8.5,1X,5HPHI *,F6.2,1X,2HPHIDOT *,F6.2,1X,3HG *,
1F6.4,1X,6HGDOT *,F4.2,1X,6HPSID *,F7.2,1X,8HPSIDOT *,F8.2,1X,8HPI
2TOT *,F9.1,20X,5HF34 *,F6.4,3X,5HF23 *,F6.4,3X,5HF12 *,F6.4,3X,4HP
3N *,F6.4,3X,7HHPH1 *,F6.4,3X,7HDPH12 *,E12.4//)
END
SUBROUTINE FCTF (T,X,DX)
COMMON A,B,C,R,ALPHA,PI,ZZ,M1,M2,M3,M4,MP,11,12,13,14,IP,EREST,LAM
18DA,ELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,R82,R83,R84,TH
3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
6AL2IN,ALFIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
7ACP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F23MAX,F12MAX,
8FF34MAX,FF23MAX,FF12MAX,FNMAX,PHICUTD,AA,AN,S6,S7,BD,RD,ID,MD
DIMENSION X(4),DX(4)
COMMON /ZETA/ PSI,TIME,G,DPSI,GP
REAL M1,M2,M3,M4,MP,11,12,13,14,IPR,I1R,MU,MU1,N41,N42,N43,IP,MD
PHID=X(1)/ZZ
DELPHI=PHID-PHIPR
PHIT=(PHITOT+DELPHI)/ZZ
IN=1
CALL GCURVE(T,AA,AN)
CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,A
219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
CALL IN3A (AA54,AA55,AA56,AA57,CAPR82,MU,RH02,AA51,AA53,
+S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,R82)
IF (X(4)*DPS12.GE.0.) IPR=IP+AA15
IF (X(4)*DPS12.LT.0.) IPR=IP-AA15
IF (X(2)*DPH12.GE.0.) I1R=I1+ABS(MU)*RH01*(AA30+AA33)
IF (X(2)*DPH12.LT.0.) I1R=I1-ABS(MU)*RH01*(AA30+AA33)
IF (I1R.LT.0.) I1R=0.
IF (IPR.LT.0.) IPR=0.
IF (IPR.EQ.0.) WRITE (6,1)

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6030      AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
6040      +AA34*AA45*AA54)+AA11*AA23+AA12*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
6050      +SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
6060      AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
6070      +AA34*AA46*AA54)+AA11*AA24+AA13*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
6080      +COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
6090      AA62=IPR
6100      AA63=AA12-MP*RCP*(SIN(PSI+PSIC)*SIN(BETA4)-COS(PSI+PSIC)*COS(
6110      1BETA4))
6120      AA64=AA13-MP*RCP*(SIN(PSI+PSIC)*COS(BETA4)-COS(PSI+PSIC)*SIN(
6130      1BETA4))
6140      AA65=14-AA22/(AA34*AA44*AA54)*(AA47*AA57*N41*I1R+AA34*AA54*I3*N43
6150      1-AA34*AA47*I2*N42)
6160      AA66=-AA22*AA37*AA47*AA57*N41*I2/(AA34*AA44*AA54)
6170      AA67=AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-AA34*
6180      1AA45*AA54)+AA23
6190      AA68=AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-AA34*
6200      1AA46*AA54)+AA24
6210      DX(1)=X(2)
6220      DX(3)=X(4)
6230      DX(2)=(AA67*AA+AA68*AN-AA66*X(2)*I2)/AA65
6240      DX(4)=(AA63*AA+AA64*AN-AA14*X(4)*I2)/AA62
6250      RETURN
6260
6270
6280 1 FORMAT (40H0IPR EQUALS ZERO - SIMULATION TERMINATED)
6290
6300      END
6310      SUBROUTINE OUTPF (T,X,DX,IHLF,NDIM,PRMT)
6320      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
6330      1BD9,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
6340      2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH
6350      3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RHOP,J1,J2,J
6360      4,AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
6370      7RCR,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
6380      8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7,BD,RD,ID,MD
6390      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR,MD
6400      DIMENSION X(4),DX(4),PRMT(5)
6410      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
6420      PHID=X(1)/ZZ
6430      PSID=X(3)/ZZ
6440      DELPHI=PHID-PHIPR
6450      PHITOT=PHITOT+DELPHI
6460      PHIT=PHITOT*ZZ
6470      PHIPR=PHID
6480      IN=0
6490      CALL GCLRUE(T,AA,AN)
6500      CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
6510      1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
6520      219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
6530      32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
6540      4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
6550

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6560 CALL IN3A (AA54,AA55,AA56,AA57,CAPR82,MU,RH02,AA51,AA53,
6570 *S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
6580 C
6590 IF (X(4)*DPH12.GE.0.) IPR=IP+AA15
6600 IF (X(4)*DPH12.LT.0.) IPR=IP-AA15
6610 IF (X(2)*DPH12.GE.0.) IIR=I1+ABS(MU)*RH01*(AA30+AA33)
6620 IF (X(2)*DPH12.LT.0.) IIR=I1-ABS(MU)*RH01*(AA30+AA33)
6630 IF (IIR.LT.0.) IIR=0.
6640 IF (IPR.LT.0.) IPR=0.
6650 AA60=AA11*AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-
6660 +AA34*AA45*AA54)+AA11*AA23+AA12*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
6670 *SIN(BETA4)+AA25*MP*RCP*COS(PSI+PSIC)*COS(BETA4)
6680 AA61=AA11*AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-
6690 +AA34*AA46*AA54)+AA11*AA24+AA13*AA25-AA25*MP*RCP*SIN(PSI+PSIC)*
6700 *COS(BETA4)-AA25*MP*RCP*COS(PSI+PSIC)*SIN(BETA4)
6710 AA62=IPR
6720 AA63=AA12-MP*RCP*(SIN(PSI+PSIC)*SIN(BETA4)-COS(PSI+PSIC)*COS(BETA4
6730 I)
6740 AA64=AA13-MP*RCP*(SIN(PSI+PSIC)*COS(BETA4)-COS(PSI+PSIC)*SIN(BETA4
6750 I)
6760 AA65=14-AA22/(AA34*AA44*AA54)*(AA47*AA57*AA41*IIR+AA34*AA54*I3*AA43
6770 I-AA34*AA47*I2*AA42)
6780 AA66=-AA22*AA37*AA47*AA57*AA41*I2/(AA34*AA44*AA54)
6790 AA67=AA22/(AA34*AA44*AA54)*(AA35*AA47*AA57-AA34*AA47*AA55-AA34*
6800 *AA45*AA54)+AA23
6810 AA68=AA22/(AA34*AA44*AA54)*(AA36*AA47*AA57-AA34*AA47*AA56-AA34*
6820 *AA46*AA54)+AA24
6830 PSI=X(3)
6840 DPH1=X(4)
6850 DPH12=1-AA66*X(2)*X(2)+AA67*AA+AA68*AA)/AA65
6860 DPH12=-AA14*X(4)*X(4)+AA63*AA+AA64*AA)/AA62
6870 C
6880 C COMPUTATION OF CONTACT FORCES
6890 C
6900 FF34=(14*DPH12-AA23*AA+AA24*AA)/AA22
6910 FF23=(AA44*FF34+AA45*AA+AA46*AA-13*AA43*DPH12)/AA47
6920 FF12=(AA54*FF23+AA55*AA+AA56*AA-12*AA42*DPH12)/AA57
6930 IF (FF34.GT.FF34MAX) FF34MAX=FF34
6940 IF (FF23.GT.FF23MAX) FF23MAX=FF23
6950 IF (FF12.GT.FF12MAX) FF12MAX=FF12
6960 IF (J.EQ.J/1000*1000) GO TO 50
6970 IF (PHITOT.GT.30..AND,PHITOT.LT.(PHICUTD-30.)) GO TO 1
6980 50 WRITE (6,4) T,PHID,X(2),PSID,X(4),PHITOT,FF12,FF23,FF34
6990 1 IF (T.EQ.TIME) GO TO 3
7000 C
7010 J=J+1
7020 C CHECK FOR CONTINUED FREE MOTION
7030 C
7040 F=A*SIN(X(1)-ALPHR)-B*SIN(ALPHR)-C*SIN(X(1)-ALPHR-PSI)-R
7050 GP=C*COS(X(1)-ALPHR-PSI)-B*COS(ALPHR)-A*COS(X(1)-ALPHR)
7060 IF (F.GT.0.) GO TO 2
7070 PRMT(5)=2.
7080 GO TO 3
7090 2 IF (GP.GT.0.) PRMT(5)=2.

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7100 3 TIME=T
7110 IF(PHITOT.GE.PHICUTD) PRMT(5)=1.
7120 RETURN
7130
7140
7150
7160 4 FORMAT (EX,3HT =,F8.5,3X,SHPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI
7170 1=,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F9.2/20X,6HFF12 =,F7.3,3X,
7180 +6HFF23 =,F7.3,3X,6HFF34 =,F7.3//)
7190 END
7200 SUBROUTINE KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BON
7210 1E,CONE,DONE,U,U,Z)
7220 DIMENSION PHI(2)
7230 REAL K
7240 PI=3.14159
7250 H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
7260 K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
7270 1PHI(1)-ALPHR)
7280 GONE=(-H+SQRT(H*H-4.*K))/2.
7290 GTWO=(-H-SQRT(H*H-4.*K))/2.
7300 IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1
7310 G=GTWO
7320 GO TO 2
7330 1 G=GONE
7340 2 P=B*SIN(PHI(1))+G*SIN(PHI(1)-ALPHR)+R*COS(PHI(1)-ALPHR)
7350 Q=B*COS(PHI(1))+G*COS(PHI(1)-ALPHR)-R*SIN(PHI(1)-ALPHR)
7360 S=G*B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)
7370 GDOT=PHI(2)*A/P/S
7380 PSI=ASIN(P/C)
7390 IF (PSI.LT.0.) GO TO 3
7400 GO TO 4
7410 3 PSI=2.*PI-ABS(PSI)
7420 4 DPSI=(Q*PHI(2)+GDOT*SIN(PHI(1)-ALPHR))/(C*COS(PSI))
7430 AONE=B*COS(ALPHR)+G
7440 DONE=B*SIN(ALPHR)
7450 CONE=-(R+C*SIN(PHI(1)-ALPHR-PSI))
7460 DONE=C*COS(PHI(1)-ALPHR-PSI)
7470 Z=(G+A/P/S*SIN(PHI(1)-ALPHR))/(C*COS(PSI))
7480 U=(G+SIN(PHI(1)-ALPHR)*P*A/S)/(C*COS(PSI))
7490 V=(Q+A*P*SIN(PHI(1)-ALPHR)/S)**2*TAN(PSI)/(C**2*(COS(PSI))**2)+(1.
7500 1/(C*COS(PSI)))*(2.*A*P*COS(PHI(1)-ALPHR)/S-P+2.*A**2*P*(SIN(PHI(1)
7510 2-ALPHR))**2/S**2+A*Q*SIN(PHI(1)-ALPHR)/S-A**2*P**2*SIN(PHI(1)-ALPH
7520 3R)/S**3)
7530 RETURN
7540 END
7550 SUBROUTINE IN3 (ZZZ,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,
7560 1AA1,AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,
7570 2AA16,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,A
7580 3A29,AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA
7590 442,AA43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
7600 DIMENSION ZZZ(4)
7610 COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
7620 1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
7630 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,R82,R83,R84,TH
7640 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RH01,RH02,RH03,RH04,RH0P,J1,J2,J

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7650      43,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,J,TANG,NT,
7660      6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
7670      7RCP,FSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F23MAX,F12MAX,
7680      8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD,AA,AN,S6,S7,BD,RD,ID,MD
7690      REAL M1,M2,M3,M4,MP,MU,MU1,N41,N42,N43,I1,I1R,MD
7700      PHI=222(1)
7710      DPHI=222(2)
7720      IF (DPHI.EQ.0.) GO TO 1
7730      MU=ABS(MU)*DPHI/ABS(DPHI)
7740      1 IF (IN.EQ.0) GO TO 2
7750 C
7760 C      UPDATE VALUES OF ALPHAS
7770 C
7780      DELAL3=DELPHI*22
7790      DELAL2=DELAL3*RB3/CAPRB2
7800      DELAL1=DELAL2*RB2/CAPRB1
7810      ALPHA1=ALPHA1+DELAL1
7820      ALPHA2=ALPHA2+DELAL2
7830      ALPHA3=ALPHA3+DELAL3
7840      IF (ALPHA1.GT.AL1FIN) ALPHA1=AL1IN
7850      IF (ALPHA2.GT.AL2FIN) ALPHA2=AL2IN
7860      IF (ALPHA3.GT.AL3FIN) ALPHA3=AL3IN
7870 C
7880 C      DETERMINATION OF SIGNUMS
7890 C
7900      2 IF (ALPHA1.LT.TEST1) S1=1.
7910      IF (ALPHA2.LT.TEST2) S2=1.
7920      IF (ALPHA3.LT.TEST3) S3=1.
7930      IF (ALPHA1.GT.TEST1) S1=-1.
7940      IF (ALPHA2.GT.TEST2) S2=-1.
7950      IF (ALPHA3.GT.TEST3) S3=-1.
7960      IF (ALPHA1.EQ.TEST1) S1=0.
7970      IF (ALPHA2.EQ.TEST2) S2=0.
7980      IF (ALPHA3.EQ.TEST3) S3=0.
7990      IF (GDOT.NE.0.) GO TO 3
8000      S4=1.
8010      GO TO 4
8020      3 S4=GDOT/ABS(GDOT)
8030      4 IF (DPS1.NE.0.) GO TO 5
8040      S5=1.
8050      GO TO 6
8060      5 S5=DPS1/ABS(DPS1)
8070      6 IF (AA.NE.0.) GO TO 7
8080      S6=1.
8090      GO TO 8
8100      7 S6=-(AA/ABS(AA))
8110      8 IF (AN.NE.0.) GO TO 9
8120      S7=1.
8130      GO TO 10
8140      9 S7=-(AN/ABS(AN))
8150      10 CONTINUE
8160 C
8170 C
8180 C      COMPUTATION OF A1,A2 AND A3

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8190 C
8200 C
8210 A1=ALPHA1*CAPR81
8220 A2=ALPHA2*CAPR82
8230 A3=ALPHA3*CAPR83
8240 DENOM=1.+MU*MU
8250 DENOM1=1.+MU1*MU1
8260 FI=3.14159
8270 C
8280 C
8290 C
8300 COMPUTATION OF AA1 TO AA57
8310 AA1=ABS((MU1*(S4-S5)*SIN(PHI-ALPHR)-(1.+S4*S5*MU1*MU1)*COS(PHI-ALP
1HR))/DENOM1)
8320 AA2=ABS(MP*(COS(BETA4)-MU1*S5*SIN(BETA4)))/DENOM1
8330 AA3=ABS(MP*(SIN(BETA4)-MU1*S5*COS(BETA4)))/DENOM1
8340 AA4=ABS(MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
8350 AA5=ABS(MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
8360 AA6=ABS((MU1*(S4-S5)*COS(PHI-ALPHR)+(1.+S4*S5*MU1*MU1)*SIN(PHI-ALP
1HR))/DENOM1)
8370 AA7=ABS(MP*(MU1*S5*COS(BETA4)+SIN(BETA4)))/DENOM1
8380 AA8=ABS(MP*(MU1*S5*SIN(BETA4)+COS(BETA4)))/DENOM1
8390 AA9=ABS(MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
8400 AA10=ABS(MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
8410 AA11=DONE+ONE*MU1*S4-RHOP*MU1*S5*(AA1+AA6)
8420 AA12=S6*RHOP*MU1*S5*(AA2+AA7)
8430 AA13=S7*RHOP*MU1*S5*(AA3+AA8)
8440 AA14=RHOP*MU1*S5*(AA4+AA9)
8450 AA15=RHOP*MU1*(AA5+AA10)
8460 AA16=ABS((-MU1*S4-MU)*SIN(PHI-ALPHR+BETA4)+(1.+MU*MU1*S4)*COS(PHI
1-ALPHR+BETA4))/DENOM)
8470 AA17=ABS((MU*(1.-S3)*SIN(BETA3+THETA3)+(1.+MU*MU*S3)*COS(BETA3+THE
1TA3))/DENOM)
8480 AA18=ABS(M4/DENOM)
8490 AA19=ABS(MU*M4/DENOM)
8500 AA20=ABS(((1.+MU*MU1*S4)*SIN(PHI-ALPHR+BETA4)+(S4*MU1-MU)*COS(PHI-
1ALPHR+BETA4))/DENOM)
8510 AA21=ABS((-1.+MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.-S3)*COS(BETA3+TH
1ETA3))/DENOM)
8520 AA22=RB4-MU*(S3*(D3-A3)+RH04*(AA17+AA21))
8530 AA23=MU*RH04*S6*(AA18+AA19)
8540 AA24=MU*RH04*S7*(AA18+AA19)
8550 AA25=ACONE+BONE*MU1*S4+MU*RH04*(AA16+AA20)
8560 AA26=ABS((MU*(1.+S1)*SIN(BETA1+THETA1)-(1.-MU*MU*S1)*COS(BETA1+THE
1TA1))/DENOM)
8570 AA27=ABS(M1/DENOM)
8580 AA28=ABS(M1*MU/DENOM)
8590 AA29=ABS((M1*RC1*(MU*COS(PHI1C+PHIT*N41)+SIN(PHI1C+N41*PHIT)))/DEN
1OM)
8600 AA30=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))/DEN
1OM)
8610 AA31=ABS(((1.-MU*MU*S1)*SIN(BETA1+THETA1)+MU*(1.+S1)*COS(BETA1+THE
1TA1))/DENOM)
8620 AA32=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))/DEN
1OM)
8630 AA33=ABS((M1*RC1*(SIN(PHI1C+N41*PHIT)+MU*COS(PHI1C+N41*PHIT)))/DEN
1OM)
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S740      IOM)
S750      AA34=CAPRB1-MU*S1*A1+MU*RH01*(AA26+AA31)
S760 C
S770 C
S780 C AA35 AND AA36 REVISED FOR PATRIOT M143 S&A
S790 C
S800 C
S810      AA35=S6*MU*RH01*(AA27+AA28)+M1*RC1*COS(PHI1C+N41*PHIT)-MD*RD*COS(
S820      *ED+PI/4.-N41*PHIT)
S830      AA36=S7*MU*RH01*(AA27+AA28)-M1*RC1*SIN(PHI1C+N41*PHIT)+MD*RD*SIN(
S840      *ED+PI/4.-N41*PHIT)
S850      AA37=-MU*RH01*(AA29+AA32)
S860      AA38=ABS((1.+MU*MU*S2)*COS(BETA2-THETA2)+MU*(S2-1.)*SIN(BETA2-THE
S870      TTA2))/DENOM)
S880      AA39=ABS(MU*M3/DENOM)
S890      AA40=ABS(M3/DENOM)
S900      AA41=ABS((1.-MU*MU*S3)*COS(BETA3+THETA3)-MU*(1.+S3)*SIN(BETA3+THE
S910      TTA3))/DENOM)
S920      AA42=ABS((1.+MU*MU*S2)*SIN(BETA2-THETA2)+MU*(1.-S2)*COS(BETA2-THE
S930      TTA2))/DENOM)
S940      AA43=ABS((1.-MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.+S3)*COS(BETA3+THE
S950      TTA3))/DENOM)
S960      AA44=CAPRB3-MU*S3*A3+MU*RH03*(AA41+AA43)
S970      AA45=-MU*RH03*S6*(AA39+AA40)
S980      AA46=-MU*RH03*S7*(AA39+AA40)
S990      AA47=RB3-MU*(S2*(D2-A2)+RH03*(AA38+AA42))
9000      AA48=ABS((MU*(1.-S1)*SIN(BETA1+THETA1)+(1.+MU*MU*S1)*COS(BETA1+THE
9010      TTA1))/DENOM)
9020      AA49=ABS(M2/DENOM)
9030      AA50=ABS(MU*M2/DENOM)
9040      AA51=ABS((MU*(1.+S2)*SIN(BETA2-THETA2)+(1.-MU*MU*S2)*COS(BETA2-THE
9050      TTA2))/DENOM)
9060      AA52=ABS((MU*(1.-S1)*COS(BETA1+THETA1)-(1.+MU*MU*S1)*SIN(BETA1+THE
9070      TTA1))/DENOM)
9080      AA53=ABS((1.-MU*MU*S2)*SIN(BETA2-THETA2)-MU*(1.+S2)*COS(BETA2-THE
9090      TTA2))/DENOM)
9100      RETURN
9110      END
9120      SUBROUTINE IN3A (AA54,AA55,AA56,AA57,CAPRB2,MU,RH02,AA51,AA53,
9130      *S1,S2,A1,A2,S6,S7,AA49,AA50,AA48,AA52,D1,RB2)
9140      REAL MU
9150 C THIS SUBROUTINE COMPUTES AA54-AA57
9160      AA54=CAPRB2+MU*RH02*(AA51+AA53)-MU*S2*A2
9170      AA55=-MU*RH02*S6*(AA49+AA50)
9180      AA56=-MU*RH02*S7*(AA49+AA50)
9190      AA57=RB2-MU*S1*(D1-A1)-MU*RH02*(AA48+AA52)
9200      RETURN
9210      END
9220      SUBROUTINE ALFA(CAPRB,RB,THETA,CAPRO,RO,ALIN,ALFIN)
9230      ALIN=((CAPRB+RB)*TAN(THETA)-SQRT(RO*RO-RB*RB))/CAPRB
9240      ALFIN=SQRT(CAPRO*CAPRO-CAPRB*CAPRB)/CAPRB
9250      RETURN
9260      END

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9270 SUBROUTINE GOURVE (T,PHITOT,AA,AN)
9280 COMMON/CCU/ TIM(100),GL(100),M
9290 AA=0.
9300 AN=0.
9310 GO TO 50
9320 5 J=J+1
9330 50 IF (T.EQ. TIME(J)) GO TO 30
9340 IF (J.GE. N) GO TO 32
9350 IF (T.EQ. TIME(J)) GO TO 30
9360 IF (T.GT. TIME(J+1)) J=J+1
9370 IF (J.GE. N) GO TO 30
9380 IF (T.EQ. TIME(J+1)) GO TO 42
9390 IF (T.GT. TIME(J) AND T.LT. TIME(J+1)) GO TO 20
9400 IF (T.LT. TIME(J)) GO TO 5
9410 GO TO 20
9420 10 AA=GL(J)
9430 AN=GL(J)
9440 GO TO 1000
9450 20 AA=(GL(J)+GL(J+1)-GL(J))*(T-TIME(J))/(TIME(J+1)-TIME(J))
9460 AN=(GL(J)+GL(J+1)-GL(J))*(T-TIME(J))/(TIME(J+1)-TIME(J))
9470 GO TO 1000
9480 30 AA=GL(J)
9490 AN=GL(J)
9500 GO TO 1000
9510 40 AA=GL(J+1)
9520 AN=GL(J+1)
9530 J=J+1
9540 1000 AA=12.832.2*AA
9550 AN=12.832.2*AN
9560 IF (PHITOT.GT.10615.) AN=-AN
9570 RETURN
9580 END
9590 *EOP
9600 .14950 .1188 .01575 45.000
9610 90. 90. 180. 180.
9620 0. 108.42 30.
9630 2.6775E-4 1.9324E-6 1.2185E-8 1.0570E-6 5.3540E-8
9640 8.21395E-5 1.3692E-9 8.5991E-8 6.8996E-9 6.8390E-8
9650 .26561 0.0 .0152 45. 0. 133.45
9660 13268. .100 .100
9670 75.368 96.496 102.925
9680 111. 30. 30. 10. 8. 8.
9690 .7341 .15545 .14575 .06635 .04146 .03885
9700 20. 20. 20.
9710 .077 .019 .0154 .0154
9720 .7115 .1425 .1340 .04375 .027 .0245
9730 .7525 .1663 .15615 .07585 .04015 .0466
9740 0. 0. 0.
9750 160.0 2
9760 57.39 .17349
9770 6.99739E-5 2.6790E-4
9780 2
9790 0. 11.9 0.
9800 9. 11.9 0.

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10140 ESCAPEMENT DATA

10150	A	.19960	B	.14950	C	.11880	R	.01575	ALPHA	45.0000
10160										
10170	1									
10180										
10190										
10200										
10210										
10220										
10230										
10240										
10250										
10260										
10270										
10280										
10290										
10300										
10310										
10320	M1	.26775E-03	M2	.19324E-05	M3	.12185E-05	M4	.10570E-05	MP	.53540E-05
10330	I1	.82140E-04	I2	.13692E-08	I3	.85991E-08	I4	.68996E-08	IP	.68390E-07
10340										
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10660										

RETAID = 90.00 BETA20 = 90.00 BETA3D = 180.00 BETA4D = 180.00
 EREST = 0.00 LAMBDA = 108.420 DELTA = 30.000

MASS PROPERTIES

MISCELLANEOUS PARAMETERS

PC1 = .2656 PCP = 0.0000 RHOP = .0152 PHITC = 45.0000 PSICCD = 0.0000 PHID = 133.4500
 PHICUTD = 13268.
 MU = .100 MU1 = .100

GEAR PARAMETERS

PSUBD1 = 75.4 PSUBD2 = 96.5 PSUBD3 = 102.9
 NG1 = 111. NG2 = 30. NG3 = 30. NP2 = 10. NP3 = 8. NP4 = 8.
 CAPRP1 = .73410 CAPRP2 = .15545 CAPRP3 = .14575
 RP2 = .06635 RP3 = .04145 RP4 = .03885
 THETA1 = 20.000 THETA2 = 20.000 THETA3 = 20.000
 RH01 = 0.7700 RH02 = .01900 RH03 = .01540 RH04 = .01540

10670 CAPR81 = .71150 CAPR82 = .14250 CAPR83 = .13400 RB2 = .04375 RB3 = .02700 RB4 = .02450
 10680 CAPR01 = .75250 CAPR02 = .15630 CAPR03 = .15615 R02 = .07585 R03 = .04915 R04 = .04660
 10690
 10700 J1 = 0.00 J2 = 0.00 J3 = 0.00

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 10990
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 11120
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 11140
 11150

ANGLE INDEXING PARAMETERS

TANG = 160.000 NT = 2

SPECIAL DATA FOR M143 DETONATOR ROTR

PD = 97.300000 RD = .173490 ID = .699739E-04 MD = .267900E-03

ACCELERATION PROFILE DATA

0.00 11.90 0.00
 9.00 11.90 0.00

COUPLED MOTION
 T = 0.00000 PHI = 133.45 PHIDOT = 0.00 G --.0216 CDDT = 0.00 PSID = 47.37 PSIDOT = 0.00 PHITOT = -.0
 F34 = .0212 F23 = .1348 F12 = .5512 PH = .0037 PMP51 = .0037 DPM12 = .3756E+04

11160
 11170
 11180

11150	T	.00010	PHI	-.133.45	PH100T	.38	G	-.0216	GD0T	.07	PS10	47.37	PS100T	.35	PH10T	.0
11200		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3757E+04			
11210	T	.00020	PHI	-.133.45	PH100T	.75	G	-.0215	GD0T	.15	PS10	47.37	PS100T	.71	PH10T	.0
11220		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3755E+04			
11230	T	.00030	PHI	-.133.45	PH100T	1.13	G	-.0215	GD0T	.22	PS10	47.38	PS100T	1.05	PH10T	.0
11240		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3758E+04			
11250	T	.00040	PHI	-.133.47	PH100T	1.50	G	-.0215	GD0T	.29	PS10	47.40	PS100T	1.41	PH10T	.0
11260		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3754E+04			
11270	T	.00050	PHI	-.133.48	PH100T	1.89	G	-.0215	GD0T	.37	PS10	47.41	PS100T	1.77	PH10T	.0
11280		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3759E+04			
11290	T	.00060	PHI	-.133.49	PH100T	2.25	G	-.0214	GD0T	.44	PS10	47.42	PS100T	2.12	PH10T	.0
11300		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3753E+04			
11310	T	.00070	PHI	-.133.50	PH100T	2.63	G	-.0214	GD0T	.51	PS10	47.42	PS100T	2.42	PH10T	.0
11320		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3751E+04			
11330	T	.00080	PHI	-.133.51	PH100T	3.00	G	-.0213	GD0T	.59	PS10	47.43	PS100T	2.73	PH10T	.1
11340		F34	.0212	F23	.1348	F12	.5512	PH	.0037	PNPS1	.0037	DPH12	.3751E+04			
11350	T	.00090	PHI	-.133.54	PH100T	3.38	G	-.0213	GD0T	.66	PS10	47.45	PS100T	3.19	PH10T	.1
11360		F34	.0212	F23	.1348	F12	.5512	PH	.0038	PNPS1	.0038	DPH12	.3762E+04			
11370	T	.00100	PHI	-.133.56	PH100T	3.75	G	-.0212	GD0T	.73	PS10	47.47	PS100T	3.54	PH10T	.1
11380		F34	.0212	F23	.1348	F12	.5512	PH	.0038	PNPS1	.0038	DPH12	.3759E+04			
11390	T	.00110	PHI	-.133.58	PH100T	4.13	G	-.0211	GD0T	.81	PS10	47.49	PS100T	3.93	PH10T	.1
11400		F34	.0212	F23	.1349	F12	.5512	PH	.0038	PNPS1	.0038	DPH12	.3762E+04			

11500	T	.00160	PHI	133.60	PHIDOT	4.50	G	-.0210	GDCT	.88	PSID	47.52	PSIDCT	4.25	PHITOT	.2
11540		F34	.0213	F23	.1349	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3748E+04			
11580	T	.00160	PHI	133.60	PHIDOT	4.82	G	-.0203	GDCT	.95	PSID	47.54	PSIDCT	4.82	PHITOT	.2
11620		F34	.0213	F23	.1349	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3763E+04			
11660	T	.00160	PHI	133.66	PHIDOT	5.25	G	-.0208	GDCT	1.03	PSID	47.57	PSIDCT	4.58	PHITOT	.2
11700		F34	.0213	F23	.1349	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3746E+04			
11740	T	.00160	PHI	133.63	PHIDOT	5.63	G	-.0207	GDCT	1.10	PSID	47.60	PSIDCT	5.34	PHITOT	.2
11780		F34	.0214	F23	.1350	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3763E+04			
11820	T	.00160	PHI	133.73	PHIDOT	6.00	G	-.0206	GDCT	1.17	PSID	47.63	PSIDCT	5.70	PHITOT	.2
11860		F34	.0214	F23	.1350	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3744E+04			
11900	T	.00170	PHI	133.76	PHIDOT	6.38	G	-.0205	GDCT	1.25	PSID	47.66	PSIDCT	6.07	PHITOT	.2
11940		F34	.0214	F23	.1350	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3763E+04			
11980	T	.00180	PHI	133.80	PHIDOT	6.75	G	-.0204	GDCT	1.32	PSID	47.70	PSIDCT	6.43	PHITOT	.2
12020		F34	.0214	F23	.1350	F12	.5513	PH	.0038	PHPSI	.0038	DPH12	.3742E+04			
12060	T	.00190	PHI	133.84	PHIDOT	7.13	G	-.0202	GDCT	1.40	PSID	47.74	PSIDCT	6.80	PHITOT	.4
12100		F34	.0215	F23	.1351	F12	.5513	PH	.0039	PHPSI	.0039	DPH12	.3763E+04			
12140	T	.00200	PHI	133.88	PHIDOT	7.50	G	-.0201	GDCT	1.47	PSID	47.78	PSIDCT	7.17	PHITOT	.4
12180		F34	.0215	F23	.1351	F12	.5513	PH	.0039	PHPSI	.0039	DPH12	.3748E+04			
12220	T	.00210	PHI	133.92	PHIDOT	7.87	G	-.0199	GDCT	1.55	PSID	47.82	PSIDCT	7.54	PHITOT	.5
12260		F34	.0216	F23	.1351	F12	.5513	PH	.0039	PHPSI	.0039	DPH12	.3763E+04			
12300	T	.00220	PHI	133.97	PHIDOT	8.25	G	-.0198	GDCT	1.62	PSID	47.86	PSIDCT	7.92	PHITOT	.5
12340		F34	.0216	F23	.1351	F12	.5513	PH	.0039	PHPSI	.0039	DPH12	.3737E+04			

12050	T	.00230	PHI	-134.02	PHIDOT	8.62	G	--	.0196	GDOT	-1.69	PSID	47.91	PSIDOT	8.29	PHITOT	.6
12060		F34	.0216	F23	.1352	F12	.5513	PN	.0039	PNPSI	.0039	DPH12	.3763E+04				
12070																	
12080	T	.00240	PHI	-134.07	PHIDOT	8.99	G	--	.0194	GDOT	-1.77	PSID	47.96	PSIDOT	8.67	PHITOT	.6
12090		F34	.0216	F23	.1352	F12	.5514	PN	.0039	PNPSI	.0039	DPH12	.3735E+04				
12100																	
12110	T	.00250	PHI	-134.12	PHIDOT	9.37	G	--	.0193	GDOT	-1.84	PSID	48.01	PSIDOT	9.05	PHITOT	.7
12120		F34	.0217	F23	.1353	F12	.5513	PN	.0040	PNPSI	.0040	DPH12	.3763E+04				
12130																	
12140	T	.00260	PHI	-134.18	PHIDOT	9.74	G	--	.0191	GDOT	-1.92	PSID	48.06	PSIDOT	9.43	PHITOT	.7
12150		F34	.0217	F23	.1353	F12	.5514	PN	.0040	PNPSI	.0040	DPH12	.3732E+04				
12160																	
12170	T	.00270	PHI	-134.23	PHIDOT	10.11	G	--	.0189	GDOT	-2.00	PSID	48.12	PSIDOT	9.81	PHITOT	.8
12180		F34	.0218	F23	.1354	F12	.5513	PN	.0040	PNPSI	.0040	DPH12	.3762E+04				
12190																	
12200	T	.00280	PHI	-134.29	PHIDOT	10.49	G	--	.0187	GDOT	-2.07	PSID	48.18	PSIDOT	10.20	PHITOT	.8
12210		F34	.0218	F23	.1354	F12	.5514	PN	.0040	PNPSI	.0040	DPH12	.3729E+04				
12220																	
12230	T	.00290	PHI	-134.35	PHIDOT	10.86	G	--	.0185	GDOT	-2.15	PSID	48.23	PSIDOT	10.59	PHITOT	.8
12240		F34	.0219	F23	.1355	F12	.5514	PN	.0041	PNPSI	.0041	DPH12	.3762E+04				
12250																	
12260	T	.00300	PHI	-134.42	PHIDOT	11.23	G	--	.0182	GDOT	-2.22	PSID	48.30	PSIDOT	10.98	PHITOT	1.0
12270		F34	.0219	F23	.1355	F12	.5514	PN	.0041	PNPSI	.0041	DPH12	.3727E+04				
12280																	
12290	T	.00310	PHI	-134.43	PHIDOT	11.61	G	--	.0180	GDOT	-2.30	PSID	48.36	PSIDOT	11.37	PHITOT	1.0
12300		F34	.0220	F23	.1356	F12	.5514	PN	.0041	PNPSI	.0041	DPH12	.3761E+04				
12310																	
12320	T	.00320	PHI	-134.55	PHIDOT	11.98	G	--	.0178	GDOT	-2.37	PSID	48.43	PSIDOT	11.77	PHITOT	1.1
12330		F34	.0220	F23	.1356	F12	.5514	PN	.0041	PNPSI	.0041	DPH12	.3724E+04				
12340																	
12350	T	.00330	PHI	-134.62	PHIDOT	12.35	G	--	.0175	GDOT	-2.45	PSID	48.50	PSIDOT	12.17	PHITOT	1.2
12360		F34	.0221	F23	.1357	F12	.5514	PN	.0042	PNPSI	.0042	DPH12	.3761E+04				
12370																	
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T . .00340 PHI .134.69 PHIDOT . 12.72 G --.0173 GDOT -2.53 PSID . 48.57 PSIDOT . 12.57 PHITOT . 1.2
F34 . .0221 F23 . .1357 F12 . .5515 PN . .0042 PNPSI . .0042 DPH12 . .3721E+04

12520
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T . .00350 PHI .134.77 PHIDOT . 13.09 G --.0170 GDOT -2.60 PSID . 48.64 PSIDOT . 12.97 PHITOT . 1.3
F34 . .0222 F23 . .1358 F12 . .5514 PN . .0042 PNPSI . .0042 DPH12 . .3760E+04

12560
12570
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12590

T . .00360 PHI .134.84 PHIDOT . 13.47 G --.0168 GDOT -2.68 PSID . 48.72 PSIDOT . 13.38 PHITOT . 1.4
F34 . .0222 F23 . .1358 F12 . .5515 PN . .0042 PNPSI . .0042 DPH12 . .3718E+04

12600
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T . .00370 PHI .134.92 PHIDOT . 13.84 G --.0165 GDOT -2.76 PSID . 48.79 PSIDOT . 13.79 PHITOT . 1.5
F34 . .0223 F23 . .1359 F12 . .5514 PN . .0043 PNPSI . .0043 DPH12 . .3760E+04

12640
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12670

T . .00380 PHI .135.00 PHIDOT . 14.21 G --.0162 GDOT -2.84 PSID . 48.87 PSIDOT . 14.21 PHITOT . 1.5
F34 . .0223 F23 . .1359 F12 . .5515 PN . .0043 PNPSI . .0043 DPH12 . .3716E+04

12680
12690
12700
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T . .00390 PHI .135.08 PHIDOT . 14.58 G --.0159 GDOT -2.91 PSID . 48.96 PSIDOT . 14.63 PHITOT . 1.6
F34 . .0224 F23 . .1360 F12 . .5515 PN . .0043 PNPSI . .0043 DPH12 . .3759E+04

12720
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T . .00400 PHI .135.17 PHIDOT . 14.95 G --.0156 GDOT -2.99 PSID . 49.04 PSIDOT . 15.05 PHITOT . 1.7
F34 . .0224 F23 . .1360 F12 . .5515 PN . .0043 PNPSI . .0043 DPH12 . .3713E+04

12760
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T . .00410 PHI .135.25 PHIDOT . 15.32 G --.0153 GDOT -3.07 PSID . 49.13 PSIDOT . 15.48 PHITOT . 1.8
F34 . .0226 F23 . .1361 F12 . .5515 PN . .0044 PNPSI . .0044 DPH12 . .3758E+04

12800
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T . .00420 PHI .135.34 PHIDOT . 15.69 G --.0150 GDOT -3.15 PSID . 49.22 PSIDOT . 15.90 PHITOT . 1.9
F34 . .0226 F23 . .1362 F12 . .5516 PN . .0044 PNPSI . .0044 DPH12 . .3710E+04

12840
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T . .00430 PHI .135.43 PHIDOT . 16.06 G --.0147 GDOT -3.23 PSID . 49.31 PSIDOT . 16.33 PHITOT . 2.0
F34 . .0210 F23 . .1363 F12 . .5517 PN . .0043 PNPSI . .0043 DPH12 . .3607E+04

12880
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T . .00440 PHI .135.53 PHIDOT . 16.42 G --.0144 GDOT -3.30 PSID . 49.41 PSIDOT . 16.76 PHITOT . 2.1
F34 . .0210 F23 . .1363 F12 . .5518 PN . .0043 PNPSI . .0043 DPH12 . .3607E+04

12920

12930	T	.00450	PHI	-135.62	PHIDOT	16.77	G	--	.0140	GDOT	3.38	PSID	49.50	PSIDOT	17.12	PHITOT	2.2
12940																	
12950																	
12960																	
12970																	
12980	T	.00460	PHI	-135.72	PHIDOT	17.12	G	--	.0137	GDOT	3.45	PSID	49.60	PSIDOT	17.60	PHITOT	2.3
12990																	
13000																	
13010																	
13020																	
13030																	
13040	T	.00470	PHI	-135.82	PHIDOT	17.45	G	--	.0134	GDOT	3.53	PSID	49.70	PSIDOT	18.01	PHITOT	2.4
13050																	
13060																	
13070																	
13080	T	.00480	PHI	-135.92	PHIDOT	17.78	G	--	.0130	GDOT	3.60	PSID	49.81	PSIDOT	18.42	PHITOT	2.5
13090																	
13100																	
13110																	
13120	T	.00490	PHI	-136.02	PHIDOT	18.10	G	--	.0126	GDOT	3.67	PSID	49.92	PSIDOT	18.82	PHITOT	2.6
13130																	
13140																	
13150																	
13160	T	.00500	PHI	-136.13	PHIDOT	18.42	G	--	.0123	GDOT	3.74	PSID	50.02	PSIDOT	19.22	PHITOT	2.7
13170																	
13180																	
13190																	
13200	T	.00510	PHI	-136.23	PHIDOT	18.72	G	--	.0119	GDOT	3.81	PSID	50.14	PSIDOT	19.62	PHITOT	2.8
13210																	
13220																	
13230																	
13240	T	.00520	PHI	-136.34	PHIDOT	19.02	G	--	.0115	GDOT	3.87	PSID	50.25	PSIDOT	20.01	PHITOT	2.9
13250																	
13260																	
13270																	
13280	T	.00530	PHI	-136.45	PHIDOT	19.31	G	--	.0111	GDOT	3.94	PSID	50.36	PSIDOT	20.40	PHITOT	3.0
13290																	
13300																	
13310																	
13320	T	.00540	PHI	-136.56	PHIDOT	19.59	G	--	.0107	GDOT	4.00	PSID	50.48	PSIDOT	20.78	PHITOT	3.1
13330																	
13340																	
13350	T	.00550	PHI	-136.67	PHIDOT	19.86	G	--	.0103	GDOT	4.06	PSID	50.60	PSIDOT	21.16	PHITOT	3.2
13360																	

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T . .00560 PH1 .136.79 PH1DOT . 20.13 G --.0059 GDOT .4.13 PSID . 50.73 PSIDOT . 21.53 PHITOT . 3.3
F34 . .0213 F23 . .1276 F12 . .5537 PN . .0039 PNPSI . .0039 DPH12 . .2625E+04
T . .00560 PH1 .136.91 PH1DOT . 20.33 G --.0055 GDOT .4.13 PSID . 50.85 PSIDOT . 21.50 PHITOT . 3.5
F34 . .0214 F23 . .1278 F12 . .5535 PN . .0038 PNPSI . .0038 DPH12 . .2515E+04
T . .00560 PH1 .137.02 PH1DOT . 20.64 G --.0091 GDOT .4.24 PSID . 50.98 PSIDOT . 22.26 PHITOT . 3.6
F34 . .0214 F23 . .1378 F12 . .5535 PN . .0038 PNPSI . .0038 DPH12 . .2472E+04
T . .00560 PH1 .137.14 PH1DOT . 20.88 G --.0086 GDOT .4.30 PSID . 51.10 PSIDOT . 22.62 PHITOT . 3.7
F34 . .0214 F23 . .1381 F12 . .5537 PN . .0037 PNPSI . .0037 DPH12 . .2363E+04
T . .00560 PH1 .137.26 PH1DOT . 21.12 G --.0082 GDOT .4.36 PSID . 51.24 PSIDOT . 22.58 PHITOT . 3.8
F34 . .0214 F23 . .1381 F12 . .5538 PN . .0037 PNPSI . .0037 DPH12 . .2322E+04
T . .00560 PH1 .137.38 PH1DOT . 21.35 G --.0078 GDOT .4.41 PSID . 51.37 PSIDOT . 23.33 PHITOT . 3.9
F34 . .0232 F23 . .1382 F12 . .5538 PN . .0038 PNPSI . .0038 DPH12 . .2345E+04
T . .00560 PH1 .137.51 PH1DOT . 21.58 G --.0073 GDOT .4.47 PSID . 51.50 PSIDOT . 23.68 PHITOT . 4.1
F34 . .0232 F23 . .1383 F12 . .5538 PN . .0037 PNPSI . .0037 DPH12 . .2304E+04
T . .00560 PH1 .137.63 PH1DOT . 21.81 G --.0069 GDOT .4.52 PSID . 51.64 PSIDOT . 24.04 PHITOT . 4.2
F34 . .0234 F23 . .1384 F12 . .5538 PN . .0038 PNPSI . .0038 DPH12 . .2376E+04
T . .00540 PH1 .137.76 PH1DOT . 22.04 G --.0064 GDOT .4.58 PSID . 51.78 PSIDOT . 24.40 PHITOT . 4.3
F34 . .0234 F23 . .1384 F12 . .5538 PN . .0038 PNPSI . .0038 DPH12 . .2334E+04
T . .00650 PH1 .137.88 PH1DOT . 22.28 G --.0060 GDOT .4.63 PSID . 51.92 PSIDOT . 24.77 PHITOT . 4.4
F34 . .0236 F23 . .1386 F12 . .5537 PN . .0039 PNPSI . .0039 DPH12 . .2408E+04
T . .00650 PH1 .138.01 PH1DOT . 22.51 G --.0055 GDOT .4.69 PSID . 52.06 PSIDOT . 25.14 PHITOT . 4.6
F34 . .0236 F23 . .1386 F12 . .5538 PN . .0039 PNPSI . .0039 DPH12 . .2366E+04

13820	T	.00670	PHI	-138.14	PHIDOT	22.75	G	-.0050	GDOT	4.75	PSID	52.21	PSIDOT	25.52	PHITOT	4.7
13830		F34		.0238	F23	.1388	F12	.5537	PN	.0040	PNPSI	.0040	DPHI2	.2440E+04		
13840	T	.00680	PHI	-138.27	PHIDOT	22.99	G	-.0045	GDOT	4.81	PSID	52.35	PSIDOT	25.91	PHITOT	4.8
13850		F34		.0238	F23	.1388	F12	.5538	PN	.0042	PNPSI	.0040	DPHI2	.2396E+04		
13860	T	.00690	PHI	-138.41	PHIDOT	23.23	G	-.0041	GDOT	4.87	PSID	52.50	PSIDOT	26.30	PHITOT	5.0
13870		F34		.0240	F23	.1390	F12	.5537	PN	.0041	PNPSI	.0041	DPHI2	.2472E+04		
13880	T	.00700	PHI	-138.54	PHIDOT	23.47	G	-.0036	GDOT	4.93	PSID	52.66	PSIDOT	26.63	PHITOT	5.1
13890		F34		.0240	F23	.1390	F12	.5538	PN	.0041	PNPSI	.0041	DPHI2	.2427E+04		
13900	T	.00710	PHI	-138.67	PHIDOT	23.71	G	-.0031	GDOT	4.99	PSID	52.81	PSIDOT	27.09	PHITOT	5.2
13910		F34		.0242	F23	.1392	F12	.5537	PN	.0042	PNPSI	.0042	DPHI2	.2505E+04		
14000	T	.00720	PHI	-138.81	PHIDOT	23.96	G	-.0026	GDOT	5.05	PSID	52.97	PSIDOT	27.49	PHITOT	5.4
14010		F34		.0242	F23	.1392	F12	.5538	PN	.0042	PNPSI	.0042	DPHI2	.2459E+04		
14020	T	.00730	PHI	-138.95	PHIDOT	24.21	G	-.0021	GDOT	5.11	PSID	53.12	PSIDOT	27.91	PHITOT	5.5
14030		F34		.0244	F23	.1394	F12	.5537	PN	.0043	PNPSI	.0043	DPHI2	.2538E+04		
14040	T	.00740	PHI	-139.09	PHIDOT	24.45	G	-.0016	GDOT	5.17	PSID	53.29	PSIDOT	28.32	PHITOT	5.6
14050		F34		.0244	F23	.1394	F12	.5538	PN	.0043	PNPSI	.0043	DPHI2	.2491E+04		
14060	T	.00750	PHI	-139.23	PHIDOT	24.70	G	-.0010	GDOT	5.23	PSID	53.45	PSIDOT	28.74	PHITOT	5.8
14070		F34		.0228	F23	.1396	F12	.5539	PN	.0042	PNPSI	.0042	DPHI2	.2428E+04		
14080	T	.00760	PHI	-139.37	PHIDOT	24.95	G	-.0005	GDOT	5.29	PSID	53.62	PSIDOT	29.16	PHITOT	5.9
14090		F34		.0228	F23	.1396	F12	.5540	PN	.0042	PNPSI	.0042	DPHI2	.2382E+04		
14100	T	.00770	PHI	-139.51	PHIDOT	25.18	G	-.0000	GDOT	5.35	PSID	53.78	PSIDOT	29.57	PHITOT	6.1
14110		F34		.0228	F23	.1390	F12	.5542	PN	.0041	PNPSI	.0041	DPHI2	.2263E+04		
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FREE MOTION

T • .00770	PHI • 159.51 FF12 • .474	PHIDOT • FF23 •	PSI • 305.36 FF34 • .019	PSIDOT •	PHITOT •	6.06
T • .00780	PHI • 159.68 FF12 • .476	PHIDOT • FF23 •	PSI • 305.53 FF34 • .019	PSIDOT •	PHITOT •	6.23
T • .00790	PHI • 159.87 FF12 • .476	PHIDOT • FF23 •	PSI • 305.70 FF34 • .019	PSIDOT •	PHITOT •	6.42
T • .00800	PHI • 200.10 FF12 • .478	PHIDOT • FF23 •	PSI • 305.87 FF34 • .019	PSIDOT •	PHITOT •	6.65
T • .00810	PHI • 200.36 FF12 • .478	PHIDOT • FF23 •	PSI • 306.04 FF34 • .019	PSIDOT •	PHITOT •	6.91
T • .00820	PHI • 200.66 FF12 • .481	PHIDOT • FF23 •	PSI • 306.21 FF34 • .019	PSIDOT •	PHITOT •	7.21
T • .00830	PHI • 200.98 FF12 • .481	PHIDOT • FF23 •	PSI • 306.37 FF34 • .019	PSIDOT •	PHITOT •	7.53
T • .00840	PHI • 201.34 FF12 • .476	PHIDOT • FF23 •	PSI • 306.54 FF34 • .021	PSIDOT •	PHITOT •	7.89
T • .00850	PHI • 201.73 FF12 • .476	PHIDOT • FF23 •	PSI • 306.71 FF34 • .021	PSIDOT •	PHITOT •	8.28
T • .00860	PHI • 202.15 FF12 • .469	PHIDOT • FF23 •	PSI • 306.87 FF34 • .021	PSIDOT •	PHITOT •	8.70
T • .00870	PHI • 202.61 FF12 • .469	PHIDOT • FF23 •	PSI • 307.04 FF34 • .021	PSIDOT •	PHITOT •	9.16
T • .00880	PHI • 203.11 FF12 • .472	PHIDOT • FF23 •	PSI • 307.20 FF34 • .019	PSIDOT •	PHITOT •	9.66
T • .00890	PHI • 203.64 FF12 • .472	PHIDOT • FF23 •	PSI • 307.37 FF34 • .019	PSIDOT •	PHITOT •	10.19

14810	T	.00900	PHI - 204.20 FF12 . .480	PHIDOT - 101.84 FF23 . .115	PSI - 307.53 FF34 . .019	PSIDOT - 28.60	PHITOT - 10.75
14820							
14830							
14840							
14850	T	.00310	PHI - 204.80 FF12 . .480	PHIDOT - 107.59 FF23 . .115	PSI - 307.69 FF34 . .019	PSIDOT - 28.53	PHITOT - 11.35
14860							
14870							
14880							
14890	T	.00320	PHI - 205.44 FF12 . .475	PHIDOT - 113.20 FF23 . .114	PSI - 307.86 FF34 . .020	PSIDOT - 28.45	PHITOT - 11.99
14900							
14910							
14920							
14930	T	.00330	PHI - 206.10 FF12 . .475	PHIDOT - 118.97 FF23 . .114	PSI - 308.02 FF34 . .020	PSIDOT - 28.38	PHITOT - 12.65
14940							
14950							
14960							
14970	T	.00340	PHI - 206.80 FF12 . .476	PHIDOT - 125.07 FF23 . .114	PSI - 308.18 FF34 . .019	PSIDOT - 28.30	PHITOT - 13.35
14980							
14990							
15000							
15010	T	.00350	PHI - 207.54 FF12 . .476	PHIDOT - 131.18 FF23 . .114	PSI - 308.34 FF34 . .019	PSIDOT - 28.23	PHITOT - 14.09
15020							
15030							
15040							
15050	T	.00360	PHI - 208.30 FF12 . .484	PHIDOT - 136.87 FF23 . .116	PSI - 308.51 FF34 . .020	PSIDOT - 28.15	PHITOT - 14.85
15060							
15070							
15080							
15090	T	.00370	PHI - 209.10 FF12 . .484	PHIDOT - 142.27 FF23 . .116	PSI - 308.67 FF34 . .020	PSIDOT - 28.08	PHITOT - 15.65
15100							
15110							
15120							
15130	T	.00380	PHI - 209.93 FF12 . .475	PHIDOT - 147.82 FF23 . .114	PSI - 308.83 FF34 . .018	PSIDOT - 28.00	PHITOT - 16.48
15140							
15150							
15160							
15170	T	.00390	PHI - 210.80 FF12 . .476	PHIDOT - 153.61 FF23 . .114	PSI - 308.99 FF34 . .018	PSIDOT - 27.93	PHITOT - 17.35
15180							
15190							
15200							
15210							
15220	UP.	-2.657	US.	15.265			
15230	INFAC						
15240			PHI - 210.798	PHIDOT - 1.335	PSI - 308.988	PSIDOT - -1.394	PHITOT - 17.35
15250			.133				
15260	UP.						
15270							
15280							
15290							
15300							
15310							
15320							
15330							
15340							

COUPLED MOTION

T. .00990 PHI -210.80 PHIDOT - 1.33 G --.0063 GDOT - .26 PSID - 308.19 PSIDOT - -1.41 PHITOT - 17.3

F34 - .0220 F23 - .1327 F12 - .5528 PM - .0042 PNPFI - .0042 DPHI2 - .4346E+04

T. .01000 PHI -210.81 PHIDOT - 1.77 G --.0063 GDOT - .35 PSID - 308.18 PSIDOT - -1.87 PHITOT - 17.4

F34 - .0220 F23 - .1327 F12 - .5528 PM - .0042 PNPFI - .0042 DPHI2 - .4320E+04

15550	T	.01010	PHI	-210.82	PHIDOT	2.20	G	--.0053	GDOT	.44	PSID	303.17	PSIDOT	-2.33	PHITOT	17.4
15550		F34	.0220	F23	.1327	F12	.5529	PN	.0042	PNPSI	.0042	DPH12	.4316E+04			
15560	T	.01020	PHI	-210.83	PHIDOT	2.53	G	--.0062	GDOT	.52	PSID	303.16	PSIDOT	-2.78	PHITOT	17.4
15560		F34	.0220	F23	.1327	F12	.5529	PN	.0042	PNPSI	.0042	DPH12	.4288E+04			
15570	T	.01030	PHI	-210.85	PHIDOT	3.06	G	--.0062	GDOT	.61	PSID	303.14	PSIDOT	-3.24	PHITOT	17.4
15570		F34	.0220	F23	.1328	F12	.5529	PN	.0042	PNPSI	.0042	DPH12	.4271E+04			
15580	T	.01040	PHI	-210.87	PHIDOT	3.49	G	--.0051	GDOT	.69	PSID	303.12	PSIDOT	-3.70	PHITOT	17.4
15580		F34	.0220	F23	.1328	F12	.5530	PN	.0042	PNPSI	.0042	DPH12	.4233E+04			
15590	T	.01050	PHI	-210.89	PHIDOT	3.91	G	--.0050	GDOT	.78	PSID	303.10	PSIDOT	-4.15	PHITOT	17.4
15590		F34	.0220	F23	.1328	F12	.5530	PN	.0042	PNPSI	.0042	DPH12	.4211E+04			
15600	T	.01060	PHI	-210.91	PHIDOT	4.33	G	--.0059	GDOT	.86	PSID	303.07	PSIDOT	-4.60	PHITOT	17.5
15600		F34	.0219	F23	.1328	F12	.5531	PN	.0042	PNPSI	.0042	DPH12	.4164E+04			
15610	T	.01070	PHI	-210.94	PHIDOT	4.74	G	--.0058	GDOT	.94	PSID	303.05	PSIDOT	-5.05	PHITOT	17.5
15610		F34	.0219	F23	.1328	F12	.5531	PN	.0042	PNPSI	.0042	DPH12	.4132E+04			
15620	T	.01080	PHI	-210.97	PHIDOT	5.15	G	--.0057	GDOT	1.03	PSID	303.02	PSIDOT	-5.50	PHITOT	17.5
15620		F34	.0219	F23	.1328	F12	.5532	PN	.0041	PNPSI	.0041	DPH12	.4082E+04			
15630	T	.01090	PHI	-211.00	PHIDOT	5.56	G	--.0056	GDOT	1.11	PSID	307.98	PSIDOT	-5.95	PHITOT	17.5
15630		F34	.0219	F23	.1328	F12	.5532	PN	.0041	PNPSI	.0041	DPH12	.4051E+04			
15640	T	.01100	PHI	-211.03	PHIDOT	5.96	G	--.0055	GDOT	1.19	PSID	307.95	PSIDOT	-6.39	PHITOT	17.6
15640		F34	.0219	F23	.1329	F12	.5533	PN	.0041	PNPSI	.0041	DPH12	.3987E+04			
15650	T	.01110	PHI	-211.07	PHIDOT	6.36	G	--.0054	GDOT	1.27	PSID	307.91	PSIDOT	-6.83	PHITOT	17.6
15650		F34	.0219	F23	.1329	F12	.5534	PN	.0041	PNPSI	.0041	DPH12	.3952E+04			

15730 T . 01120 PHI 211.10 PHIDOT 6.76 G --.0053 GDOT 1.36 PSID 307.87 PSIDOT -7.27 PHITOT - 17.7
 15730 F34 . 0218 F23 . 1329 F12 . 5535 PN . 0041 PNPSI . 0041 LPHI2 . 3880E+04
 15800 T . 01130 PHI 211.14 PHIDOT 7.14 G --.0051 GDOT 1.44 PSID 307.83 PSIDOT -7.71 PHITOT - 17.7
 15800 F34 . 0218 F23 . 1329 F12 . 5536 PN . 0041 PNPSI . 0041 DPHI2 . 3841E+04
 15850 T . 01140 PHI 211.18 PHIDOT 7.52 G --.0050 GDOT 1.51 PSID 307.78 PSIDOT -8.14 PHITOT - 17.7
 15850 F34 . 0212 F23 . 1330 F12 . 5537 PN . 0040 PNPSI . 0040 DPHI2 . 3761E+04
 15900 T . 01150 PHI 211.23 PHIDOT 7.90 G --.0048 GDOT 1.53 PSID 307.73 PSIDOT -8.57 PHITOT - 17.8
 15900 F34 . 0218 F23 . 1330 F12 . 5537 PN . 0040 PNPSI . 0040 LPHI2 . 373E+04
 15950 T . 01160 PHI 211.28 PHIDOT 8.27 G --.0047 GDOT 1.67 PSID 307.68 PSIDOT -9.00 PHITOT - 17.8
 15950 F34 . 0218 F23 . 1330 F12 . 5539 PN . 0040 PNPSI . 0040 DPHI2 . 3633E+04
 16000 T . 01170 PHI 211.32 PHIDOT 8.63 G --.0045 GDOT 1.75 PSID 307.63 PSIDOT -9.42 PHITOT - 17.9
 16000 F34 . 0218 F23 . 1330 F12 . 5539 PN . 0040 PNPSI . 0040 LPHI2 . 3587E+04
 16050 T . 01180 PHI 211.37 PHIDOT 8.98 G --.0043 GDOT 1.82 PSID 307.57 PSIDOT -9.84 PHITOT - 17.9
 16050 F34 . 0217 F23 . 1331 F12 . 5541 PN . 0040 PNPSI . 0040 DPHI2 . 3494E+04
 16100 T . 01190 PHI 211.43 PHIDOT 9.33 G --.0041 GDOT 1.90 PSID 307.52 PSIDOT -10.25 PHITOT - 18.0
 16100 F34 . 0217 F23 . 1331 F12 . 5541 PN . 0040 PNPSI . 0040 DPHI2 . 3445E+04
 16150 T . 01200 PHI 211.48 PHIDOT 9.67 G --.0039 GDOT 1.97 PSID 307.46 PSIDOT -10.67 PHITOT - 18.0
 16150 F34 . 0217 F23 . 1331 F12 . 5543 PN . 0039 PNPSI . 0039 DPHI2 . 3348E+04
 16200 T . 01210 PHI 211.54 PHIDOT 10.01 G --.0037 GDOT 2.05 PSID 307.39 PSIDOT -11.08 PHITOT - 18.1
 16200 F34 . 0217 F23 . 1332 F12 . 5544 PN . 0039 PNPSI . 0039 DPHI2 . 3297E+04
 16250 T . 01220 PHI 211.60 PHIDOT 10.33 G --.0035 GDOT 2.12 PSID 307.33 PSIDOT -11.48 PHITOT - 18.1
 16250 F34 . 0216 F23 . 1332 F12 . 5545 PN . 0039 PNPSI . 0039 DPHI2 . 3195E+04

16110	- .01250 PHI -211.65 PHIDOT - 10.55 G --.0033 GDOT -2.13 PSID - 307.26 PSIDOT -	-11.88 PHITOT -	18.2
16120	F34 - .0216 F23 - .1332 F12 - .5546 PN - .0036 PNPSI - .0039	DPHI2 -	.3141E+04
16130			
16140	T - .01240 PHI -211.72 PHIDOT - 10.96 G --.0031 GDOT -2.25 PSID - 307.13 PSIDOT -	-12.27 PHITOT -	18.3
16150	F34 - .0216 F23 - .1333 F12 - .5548 PN - .0038 PNPSI - .0032	DPHI2 -	.5035E+04
16160			
16170	T - .01250 PHI -211.78 PHIDOT - 11.26 G --.0029 GDOT -2.33 PSID - 307.12 PSIDOT -	-12.67 PHITOT -	18.3
16180	F34 - .0216 F23 - .1333 F12 - .5548 PN - .0038 PNPSI - .0038	DPHI2 -	.2980E+04
16190			
16200	T - .01250 PHI -211.65 PHIDOT - 11.56 G --.0026 GDOT -2.43 PSID - 307.05 PSIDOT -	-13.05 PHITOT -	18.4
16210	F34 - .0215 F23 - .1333 F12 - .5550 PN - .0037 PNPSI - .0037	DPHI2 -	.2870E+04
16220			
16230	T - .01250 PHI -211.61 PHIDOT - 11.84 G --.0024 GDOT -2.46 PSID - 306.97 PSIDOT -	-13.43 PHITOT -	18.5
16240	F34 - .0215 F23 - .1334 F12 - .5551 PN - .0037 PNPSI - .0037	DPHI2 -	.2814E+04
16250			
16260	T - .01250 PHI -211.53 PHIDOT - 12.12 G --.0021 GDOT -2.53 PSID - 306.89 PSIDOT -	-13.81 PHITOT -	18.5
16270	F34 - .0214 F23 - .1334 F12 - .5553 PN - .0037 PNPSI - .0037	DPHI2 -	.2702E+04
16280			
16290	T - .01250 PHI -212.05 PHIDOT - 12.39 G --.0019 GDOT -2.59 PSID - 306.81 PSIDOT -	-14.18 PHITOT -	18.6
16300	F34 - .0214 F23 - .1334 F12 - .5554 PN - .0037 PNPSI - .0037	DPHI2 -	.2644E+04
16310			
16320	T - .01250 PHI -212.12 PHIDOT - 12.65 G --.0016 GDOT -2.66 PSID - 306.73 PSIDOT -	-14.55 PHITOT -	18.7
16330	F34 - .0214 F23 - .1335 F12 - .5555 PN - .0036 PNPSI - .0036	DPHI2 -	.2530E+04
16340			
16350	T - .01210 PHI -212.20 PHIDOT - 12.90 G --.0013 GDOT -2.72 PSID - 306.65 PSIDOT -	-14.91 PHITOT -	18.7
16360	F34 - .0214 F23 - .1335 F12 - .5556 PN - .0036 PNPSI - .0036	DPHI2 -	.2472E+04
16370			
16380	T - .01220 PHI -212.27 PHIDOT - 13.14 G --.0011 GDOT -2.78 PSID - 306.56 PSIDOT -	-15.27 PHITOT -	18.8
16390	F34 - .0213 F23 - .1336 F12 - .5558 PN - .0036 PNPSI - .0036	DPHI2 -	.2357E+04
16400			
16410	T - .01330 PHI -212.35 PHIDOT - 13.38 G --.0008 GDOT -2.84 PSID - 306.47 PSIDOT -	-15.62 PHITOT -	18.9
16420	F34 - .0213 F23 - .1336 F12 - .5559 PN - .0036 PNPSI - .0036	DPHI2 -	.2290E+04
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T • .01340 PHI • 212.43 PHIDOT • 13.60 C • -.0005 GDOT • 2.90 PSID • 306.38 PSIDOT • -15.97 PHITOT • 19.0
 F34 • .0212 F23 • .1336 F12 • .5561 PM • .0035 PNP51 • .0035 DPH12 • .2183E+04
 T • .01350 PHI • 212.50 PHIDOT • 13.82 C • -.0002 GDOT • 2.96 PSID • 306.29 PSIDOT • -16.31 PHITOT • 19.1
 F34 • .0212 F23 • .1337 F12 • .5561 PM • .0035 PNP51 • .0035 DPH12 • .2124E+04
 T • .01360 PHI • 212.58 PHIDOT • 14.03 C • .0001 GDOT • 3.01 PSID • 306.20 PSIDOT • -16.65 PHITOT • 19.1
 F34 • .0212 F23 • .1337 F12 • .5563 PM • .0034 PNP51 • .0034 DPH12 • .2008E+04

FREE MOTION

T • .01360 PHI • 122.58 PHIDOT • 14.03 PSI • 54.62 PSIDOT • -16.65 PHITOT • 19.13
 FF12 • .488 FF23 • .117 FF34 • .018
 T • .01370 PHI • 122.63 PHIDOT • 19.08 PSI • 54.52 PSIDOT • -16.57 PHITOT • 19.23
 FF12 • .488 FF23 • .117 FF34 • .019
 T • .01380 PHI • 122.80 PHIDOT • 24.14 PSI • 54.43 PSIDOT • -16.50 PHITOT • 19.35
 FF12 • .488 FF23 • .117 FF34 • .019
 T • .01390 PHI • 122.95 PHIDOT • 29.27 PSI • 54.33 PSIDOT • -16.42 PHITOT • 19.51
 FF12 • .486 FF23 • .117 FF34 • .019
 T • .01400 PHI • 123.14 PHIDOT • 34.44 PSI • 54.24 PSIDOT • -16.34 PHITOT • 19.69
 FF12 • .486 FF23 • .117 FF34 • .019
 T • .01410 PHI • 123.35 PHIDOT • 39.71 PSI • 54.14 PSIDOT • -16.27 PHITOT • 19.90
 FF12 • .483 FF23 • .125 FF34 • .019
 T • .01420 PHI • 123.59 PHIDOT • 45.08 PSI • 54.05 PSIDOT • -16.19 PHITOT • 20.14
 FF12 • .483 FF23 • .125 FF34 • .019
 T • .01430 PHI • 123.87 PHIDOT • 50.60 PSI • 53.96 PSIDOT • -16.11 PHITOT • 20.42
 FF12 • .479 FF23 • .124 FF34 • .019
 T • .01440 PHI • 124.17 PHIDOT • 56.24 PSI • 53.87 PSIDOT • -16.04 PHITOT • 20.78
 FF12 • .479 FF23 • .124 FF34 • .019
 T • .01450 PHI • 124.51 PHIDOT • 62.09 PSI • 53.77 PSIDOT • -15.96 PHITOT • 21.06

[illegible]

17750	FF12	•	.469	FF23	•	.118	FF34	•	.021			
17760	PHI	•	131.94	PHIDOT	•	139.33	PSI	•	52.62	PSIDOT	•	-14.56 PHITOT • 28.49
17770	FF12	•	.469	FF23	•	.118	FF34	•	.021			
17780	PHI	•	132.35	PHIDOT	•	142.51	PSI	•	52.58	PSIDOT	•	-14.92 PHITOT • 28.90
17790	FF12	•	.475	FF23	•	.120	FF34	•	.021			
17800	PHI	•	132.76	PHIDOT	•	145.61	PSI	•	52.54	PSIDOT	•	-14.88 PHITOT • 29.31
17810	FF12	•	.475	FF23	•	.120	FF34	•	.021			
17820	PHI	•	133.18	PHIDOT	•	148.59	PSI	•	52.50	PSIDOT	•	-14.84 PHITOT • 29.73
17830	FF12	•	.476	FF23	•	.120	FF34	•	.022			
17840	PHI	•	201.08	PHIDOT	•	56.65	PSI	•	306.26	PSIDOT	•	19.73 PHITOT • 307.63
17850	FF12	•	.498	FF23	•	.123	FF34	•	.018			
17860	PHI	•	203.98	PHIDOT	•	97.47	PSI	•	307.10	PSIDOT	•	21.31 PHITOT • 643.53
17870	FF12	•	.515	FF23	•	.120	FF34	•	.019			
17880	PHI	•	123.84	PHIDOT	•	55.78	PSI	•	53.96	PSIDOT	•	-18.24 PHITOT • 950.39
17890	FF12	•	.522	FF23	•	.127	FF34	•	.021			
17900	PHI	•	132.72	PHIDOT	•	14.63	G	•	-.0029	GDOT	•	3.08 PSID • 52.86 PSIDOT • 16.74 PHITOT • 1265.3
17910	F34	•	.0248	F23	•	.1463	F12	•	.6194	PN	•	.0047 PNP51 • .0047 LPH12 • .3638E+04
17920	PHI	•	207.56	PHIDOT	•	139.81	PSI	•	307.56	PSIDOT	•	20.58 PHITOT • 1574.11
17930	FF12	•	.546	FF23	•	.136	FF34	•	.024			
17940	PHI	•	211.21	PHIDOT	•	8.87	G	•	-.0049	GDOT	•	-1.79 PSID • 307.75 PSIDOT • -9.62 PHITOT • 1877.8
17950	F34	•	.0273	F23	•	.1620	F12	•	.6464	PN	•	.0044 PNP51 • .0044 DPH12 • .4089E+04
17960	PHI	•	128.13	PHIDOT	•	12.94	G	•	-.0051	GDOT	•	-2.70 PSID • 52.19 PSIDOT • 14.51 PHITOT • 2194.7
17970	F34	•	.0297	F23	•	.1778	F12	•	.6608	PN	•	.0056 PNP51 • .0056 DPH12 • .4776E+04
17980	PHI	•	212.43	PHIDOT	•	16.66	G	•	-.0005	GDOT	•	-3.55 PSID • 306.38 PSIDOT • -19.57 PHITOT • 2479.0
17990	F34	•	.0300	F23	•	.1613	F12	•	.6728	PN	•	.0049 PNP51 • .0049 DPH12 • .3253E+04
18000	PHI	•	136.81	PHIDOT	•	109.92	PSI	•	51.82	PSIDOT	•	-19.04 PHITOT • 2703.36

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FF12 • .593 FF23 • .137 FF34 • .024
T • .55330 PH1 • 137.58 PHIDOT • 196.53 PSI • 51.90 PHITOT • 3094.53
FF12 • .603 FF23 • .154 FF34 • .025
T • .53827 PH1 • 130.08 PHIDOT • 135.87 PSI • 52.69 PHITOT • 3326.63
FF12 • .605 FF23 • .157 FF34 • .026
T • 1.01955 PH1 • 200.12 PHIDOT • 43.08 PSI • 105.84 PHITOT • 3696.67
FF12 • .615 FF23 • .166 FF34 • .025
T • 1.00952 PH1 • 201.79 PHIDOT • 77.51 PSI • 306.44 PHITOT • 3938.34
FF12 • .622 FF23 • .147 FF34 • .026
T • 1.17227 PH1 • 207.26 PHIDOT • 147.33 PSI • 307.46 PHITOT • 4303.81
FF12 • .625 FF23 • .155 FF34 • .028
T • 1.25417 PH1 • 139.04 PHIDOT • 18.90 G • -.0017 CDOT • 3.99 PSID • 53.23 PSIDOT • 21.85 PHITOT • 4595.6
FF34 • .0332 FF23 • .1948 FF12 • .7323 PN • .0061 PNPST • .0061 DPH12 • .4720E+04
T • 1.13012 PH1 • 123.33 PHIDOT • 46.53 PSI • 54.13 PHITOT • 4879.88
FF12 • .642 FF23 • .163 FF34 • .023
T • 1.40527 PH1 • 205.35 PHIDOT • 123.62 PSI • 307.29 PHITOT • 5171.98
FF12 • .640 FF23 • .163 FF34 • .024
T • 1.48312 PH1 • 199.54 PHIDOT • 18.16 PSI • 305.40 PHITOT • 5466.09
FF12 • .643 FF23 • .165 FF34 • .026
T • 1.48322 PH1 • 199.67 PHIDOT • 25.90 PSI • 305.52 PHITOT • 5466.22
FF12 • .641 FF23 • .164 FF34 • .027
T • 1.55642 PH1 • 212.56 PHIDOT • 18.32 G • -.0000 CDOT • 3.93 PSID • 306.23 PSIDOT • -21.70 PHITOT • 5749.1
FF34 • .0340 FF23 • .1736 FF12 • .7469 PN • .0057 PNPST • .0057 DPH12 • .3715E+04
T • 1.63220 PH1 • 209.37 PHIDOT • 166.35 PSI • 307.92 PHITOT • 6045.92
FF12 • .647 FF23 • .151 FF34 • .024
T • 1.70667 PH1 • 138.66 PHIDOT • 18.73 G • -.0031 CDOT • 3.94 PSID • 52.79 PSIDOT • 21.30 PHITOT • 6305.2

18790	F34 - .0305	F23 - .1739	F12 - .7491	PH - .0057	PNPSI - .0057	DPH12 - .4389E+04
18800						
18810	PHI - 124.25	PHIDOT - 68.54	PSI - 53.85	PSIDOT - -19.50	PHITOT - 6650.80	
18820	FF12 - .641	FF23 - .171	FF34 - .027			
18830						
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18880						
18890						
18900	PHI - 121.47	PHIDOT - 158.23	PSI - 52.62	PSIDOT - -18.84	PHITOT - 7228.02	
18910	FF12 - .643	FF23 - .157	FF34 - .028			
18920						
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19320	T	2.71505	PHI	158.15	PHIDOT	12.62	G	--.0050	GDOT	2.63	PSID	52.21	PSIDOT	14.16	PHITOT	10174.7
19320			FF34	.0257	F23	.1606	F12	.6625	PM	.0049	PNPSI	.0049	DPH12	.4048E+04		
19330	T	2.73327	PHI	159.53	PHIDOT	17.30	G	.0001	GDOT	3.68	PSID	53.80	PSIDOT	20.33	PHITOT	10476.1
19330			FF34	.0251	F23	.1742	F12	.6202	PM	.0044	PNPSI	.0044	DPH12	.3100E+04		
19340	T	2.73717	PHI	162.52	PHIDOT	17.43	G	--.0002	GDOT	3.73	PSID	306.28	PSIDOT	20.59	PHITOT	10759.1
19340			FF34	.0269	F23	.1553	F12	.6688	PM	.0047	PNPSI	.0047	DPH12	.2880E+04		
19350	T	2.95470	PHI	210.19	PHIDOT	159.83	PSI	308.05	PSIDOT	21.16	PHITOT	11025.74				
19350			FF12	.572	FF23	.141	FF34	.023								
19360	T	3.02332	PHI	206.84	PHIDOT	135.38	PSI	307.20	PSIDOT	18.13	PHITOT	11413.39				
19360			FF12	.546	FF23	.136	FF34	.023								
19370	T	3.14027	PHI	135.47	PHIDOT	16.90	G	--.0002	GDOT	3.59	PSID	53.73	PSIDOT	19.82	PHITOT	11736.0
19370			FF34	.0269	F23	.1652	F12	.6284	PM	.0044	PNPSI	.0044	DPH12	.3196E+04		
19380	T	3.23352	PHI	125.05	PHIDOT	73.90	PSI	53.86	PSIDOT	13.17	PHITOT	12051.60				
19380			FF12	.533	FF23	.137	FF34	.022								
19390	T	3.31332	PHI	137.11	PHIDOT	179.79	PSI	52.06	PSIDOT	15.51	PHITOT	12363.66				
19390			FF12	.523	FF23	.129	FF34	.021								
19400	T	3.40202	PHI	207.72	PHIDOT	129.79	PSI	307.42	PSIDOT	16.71	PHITOT	12674.27				
19400			FF12	.503	FF23	.128	FF34	.022								
19410	T	3.42347	PHI	193.53	PHIDOT	17.26	PSI	305.38	PSIDOT	20.28	PHITOT	12996.08				
19410			FF12	.473	FF23	.128	FF34	.021								
19420	T	3.48357	PHI	199.65	PHIDOT	23.97	PSI	305.50	PSIDOT	20.21	PHITOT	12996.20				
19420			FF12	.474	FF23	.128	FF34	.021								
19430	T	3.56032	PHI	201.56	PHIDOT	68.29	PSI	306.39	PSIDOT	20.15	PHITOT	13238.11				
19430			FF12	.463	FF23	.109	FF34	.019								
19440	T	3.56042	PHI	201.97	PHIDOT	74.04	PSI	306.50	PSIDOT	20.08	PHITOT	13238.52				
19440			FF12	.475	FF23	.111	FF34	.019								

19300	T	3.56052	PHI	202.41	PHIDOT	79.65	PSI	306.62	PSIDOT	20.00	PHITOT	13238.96
19310		FF12		.475	FF23	.111	FF34	.019				
19320												
19330												
19340												
19350	T	3.56062	PHI	202.88	PHIDOT	85.02	PSI	306.73	PSIDOT	19.93	PHITOT	13239.43
19360		FF12		.473	FF23	.110	FF34	.020				
19370												
19380												
19390	T	3.56072	PHI	203.38	PHIDOT	90.48	PSI	306.85	PSIDOT	19.85	PHITOT	13239.93
19400		FF12		.473	FF23	.110	FF34	.020				
19410												
19420												
19430	T	3.56082	PHI	203.92	PHIDOT	96.19	PSI	306.96	PSIDOT	19.78	PHITOT	13240.47
19440		FF12		.468	FF23	.109	FF34	.020				
19450												
19460	T	3.56092	PHI	204.49	PHIDOT	102.06	PSI	307.07	PSIDOT	19.71	PHITOT	13241.04
19470		FF12		.468	FF23	.109	FF34	.020				
19480												
19490	T	3.56102	PHI	205.09	PHIDOT	107.94	PSI	307.19	PSIDOT	19.63	PHITOT	13241.64
19500		FF12		.474	FF23	.111	FF34	.018				
19510												
19520	T	3.56112	PHI	205.72	PHIDOT	113.63	PSI	307.30	PSIDOT	19.56	PHITOT	13242.27
19530		FF12		.474	FF23	.111	FF34	.018				
19540												
19550	T	3.56122	PHI	206.39	PHIDOT	118.94	PSI	307.41	PSIDOT	19.48	PHITOT	13242.94
19560		FF12		.477	FF23	.111	FF34	.019				
19570												
19580	T	3.56132	PHI	207.09	PHIDOT	124.11	PSI	307.52	PSIDOT	19.41	PHITOT	13243.64
19590		FF12		.477	FF23	.111	FF34	.019				
19600												
19610	T	3.56142	PHI	207.81	PHIDOT	129.57	PSI	307.63	PSIDOT	19.33	PHITOT	13244.36
19620		FF12		.472	FF23	.110	FF34	.017				
19630												
19640	T	3.56152	PHI	208.57	PHIDOT	135.23	PSI	307.74	PSIDOT	19.26	PHITOT	13245.12
19650		FF12		.472	FF23	.110	FF34	.017				
19660												
19670	T	3.56162	PHI	209.36	PHIDOT	140.73	PSI	307.85	PSIDOT	19.18	PHITOT	13245.91
19680		FF12		.482	FF23	.113	FF34	.017				
19690												
19700	T	3.56172	PHI	210.18	PHIDOT	145.95	PSI	307.96	PSIDOT	19.11	PHITOT	13246.73
19710		FF12		.482	FF23	.113	FF34	.017				
19720												
19730	T	3.56182	PHI	211.03	PHIDOT	150.95	PSI	308.07	PSIDOT	19.03	PHITOT	13247.58
19740		FF12		.475	FF23	.120	FF34	.018				
19750												
19760												

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T • 3.56282 PHI • 211.56 PHIDOT • 10.94 G • -.0036 GDOT • 2.24 PSID • 307.37 PSIDOT • -12.12 PHITOT • 13248.1
 F34 • .0210 F23 • .1385 F12 • .5470 PN • .0040 PNPSI • .0040 DPHI2 • .3283E+04
 T • 3.56292 PHI • 211.63 PHIDOT • 11.26 G • -.0034 GDOT • 2.31 PSID • 307.30 PSIDOT • -12.53 PHITOT • 13248.2
 F34 • .0211 F23 • .1386 F12 • .5471 PN • .0039 PNPSI • .0039 DPHI2 • .3191E+04
 T • 3.56302 PHI • 211.69 PHIDOT • 11.58 G • -.0032 GDOT • 2.38 PSID • 307.22 PSIDOT • -12.94 PHITOT • 13248.2
 F34 • .0211 F23 • .1387 F12 • .5472 PN • .0039 PNPSI • .0039 DPHI2 • .3132E+04
 T • 3.56312 PHI • 211.76 PHIDOT • 11.89 G • -.0029 GDOT • 2.45 PSID • 307.15 PSIDOT • -13.35 PHITOT • 13248.3
 F34 • .0211 F23 • .1388 F12 • .5474 PN • .0039 PNPSI • .0039 DPHI2 • .3036E+04
 T • 3.56322 PHI • 211.83 PHIDOT • 12.19 G • -.0027 GDOT • 2.52 PSID • 307.07 PSIDOT • -13.75 PHITOT • 13248.4
 F34 • .0211 F23 • .1388 F12 • .5474 PN • .0039 PNPSI • .0039 DPHI2 • .2975E+04
 T • 3.56332 PHI • 211.90 PHIDOT • 12.48 G • -.0024 GDOT • 2.59 PSID • 306.99 PSIDOT • -14.14 PHITOT • 13248.4
 F34 • .0211 F23 • .1390 F12 • .5476 PN • .0038 PNPSI • .0038 DPHI2 • .2876E+04
 T • 3.56342 PHI • 211.97 PHIDOT • 12.77 G • -.0022 GDOT • 2.66 PSID • 306.91 PSIDOT • -14.54 PHITOT • 13248.5
 F34 • .0211 F23 • .1390 F12 • .5477 PN • .0038 PNPSI • .0038 DPHI2 • .2814E+04
 T • 3.56352 PHI • 212.04 PHIDOT • 13.04 G • -.0019 GDOT • 2.73 PSID • 306.82 PSIDOT • -14.93 PHITOT • 13248.6
 F34 • .0212 F23 • .1391 F12 • .5478 PN • .0038 PNPSI • .0038 DPHI2 • .2713E+04
 T • 3.56362 PHI • 212.12 PHIDOT • 13.31 G • -.0016 GDOT • 2.80 PSID • 306.74 PSIDOT • -15.31 PHITOT • 13248.7
 F34 • .0212 F23 • .1391 F12 • .5479 PN • .0038 PNPSI • .0038 DPHI2 • .2649E+04
 T • 3.56372 PHI • 212.20 PHIDOT • 13.57 G • -.0013 GDOT • 2.86 PSID • 306.65 PSIDOT • -15.69 PHITOT • 13248.7
 F34 • .0212 F23 • .1393 F12 • .5481 PN • .0038 PNPSI • .0038 DPHI2 • .2546E+04
 T • 3.56382 PHI • 212.27 PHIDOT • 13.83 G • -.0011 GDOT • 2.92 PSID • 306.56 PSIDOT • -16.07 PHITOT • 13248.8
 F34 • .0212 F23 • .1393 F12 • .5481 PN • .0038 PNPSI • .0038 DPHI2 • .2482E+04

21760	T	3.56502	PHI	124.25	PHIDOT	56.95	PSI	53.80	PSIDOT	-16.92	PHITOT	13250.80
21770			FF12	.474	FF23	.122	FF34	.020				
21780	T	3.56512	PHI	124.59	PHIDOT	62.58	PSI	53.71	PSIDOT	-16.84	PHITOT	13251.14
21790			FF12	.469	FF23	.121	FF34	.020				
21800	T	3.56522	PHI	124.96	PHIDOT	68.36	PSI	53.61	PSIDOT	-16.76	PHITOT	13251.51
21810			FF12	.469	FF23	.121	FF34	.020				
21820	T	3.56532	PHI	125.37	PHIDOT	74.39	PSI	53.51	PSIDOT	-16.69	PHITOT	13251.92
21830			FF12	.468	FF23	.121	FF34	.019				
21840	T	3.56542	PHI	125.82	PHIDOT	80.41	PSI	53.42	PSIDOT	-16.61	PHITOT	13252.37
21850			FF12	.468	FF23	.121	FF34	.019				
21860	T	3.56552	PHI	126.29	PHIDOT	86.27	PSI	53.32	PSIDOT	-16.53	PHITOT	13252.84
21870			FF12	.473	FF23	.123	FF34	.019				
21880	T	3.56562	PHI	126.80	PHIDOT	92.00	PSI	53.23	PSIDOT	-16.46	PHITOT	13253.35
21890			FF12	.473	FF23	.123	FF34	.019				
21900	T	3.56572	PHI	127.35	PHIDOT	97.54	PSI	53.14	PSIDOT	-16.38	PHITOT	13253.90
21910			FF12	.471	FF23	.123	FF34	.021				
21920	T	3.56582	PHI	127.92	PHIDOT	103.10	PSI	53.04	PSIDOT	-16.30	PHITOT	13254.47
21930			FF12	.471	FF23	.123	FF34	.021				
21940	T	3.56592	PHI	128.53	PHIDOT	109.06	PSI	52.95	PSIDOT	-16.23	PHITOT	13255.08
21950			FF12	.462	FF23	.121	FF34	.021				
21960	T	3.56602	PHI	129.17	PHIDOT	115.29	PSI	52.86	PSIDOT	-16.15	PHITOT	13255.72
21970			FF12	.461	FF23	.121	FF34	.021				
21980	T	3.56612	PHI	129.85	PHIDOT	121.66	PSI	52.76	PSIDOT	-16.07	PHITOT	13256.40
21990			FF12	.468	FF23	.115	FF34	.020				
22000	T	3.56622	PHI	130.57	PHIDOT	127.85	PSI	52.67	PSIDOT	-16.00	PHITOT	13257.12
22010			FF12	.468	FF23	.115	FF34	.020				
22020												
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22250	T • 3.56632	PHI • 131.31 FF12 • .468	PHIDOT • 133.60 FF23 • .115	PSI • 52.58 FF34 • .021	PSIDOT • -15.92	PHITOT • 13257.86
22300	T • 3.56642	PHI • 132.10 FF12 • .468	PHIDOT • 139.40 FF23 • .115	PSI • 52.49 FF34 • .021	PSIDOT • -15.84	PHITOT • 13258.65
22350	T • 3.56652	PHI • 132.91 FF12 • .467	PHIDOT • 145.58 FF23 • .115	PSI • 52.40 FF34 • .019	PSIDOT • -15.76	PHITOT • 13259.46
22400	T • 3.56662	PHI • 133.77 FF12 • .467	PHIDOT • 151.85 FF23 • .115	PSI • 52.31 FF34 • .019	PSIDOT • -15.69	PHITOT • 13260.32
22450	T • 3.56667	PHI • 134.20 FF12 • .473	PHIDOT • 154.62 FF23 • .117	PSI • 52.26 FF34 • .020	PSIDOT • -15.65	PHITOT • 13260.75
22500	T • 3.56672	PHI • 134.65 FF12 • .473	PHIDOT • 157.38 FF23 • .117	PSI • 52.22 FF34 • .020	PSIDOT • -15.61	PHITOT • 13261.20
22550	T • 3.56677	PHI • 135.11 FF12 • .468	PHIDOT • 160.25 FF23 • .116	PSI • 52.17 FF34 • .020	PSIDOT • -15.57	PHITOT • 13261.66
22600	T • 3.56682	PHI • 135.57 FF12 • .468	PHIDOT • 163.19 FF23 • .116	PSI • 52.13 FF34 • .020	PSIDOT • -15.53	PHITOT • 13262.12
22650	T • 3.56687	PHI • 136.04 FF12 • .471	PHIDOT • 166.22 FF23 • .116	PSI • 52.09 FF34 • .018	PSIDOT • -15.50	PHITOT • 13262.59
22700	T • 3.56692	PHI • 136.52 FF12 • .471	PHIDOT • 169.19 FF23 • .116	PSI • 52.04 FF34 • .018	PSIDOT • -15.46	PHITOT • 13263.07
22750	T • 3.56697	PHI • 137.01 FF12 • .477	PHIDOT • 172.01 FF23 • .118	PSI • 52.00 FF34 • .018	PSIDOT • -15.42	PHITOT • 13263.56
22800	T • 3.56702	PHI • 137.51 FF12 • .477	PHIDOT • 174.75 FF23 • .118	PSI • 51.95 FF34 • .018	PSIDOT • -15.38	PHITOT • 13264.06
22850	T • 3.56707	PHI • 138.01 FF12 • .476	PHIDOT • 177.35 FF23 • .118	PSI • 51.91 FF34 • .019	PSIDOT • -15.34	PHITOT • 13264.56
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COUPLED MOTION
T • 3.56707 PHI • 138.01 PHIDOT • 12.73 G • -.0055 GDOT • 2.65 PSID • 52.06 PSIDOT • 14.21 PHITOT • 13264.6
F34 • .0233 F23 • .1355 F12 • .5479 PN • .0038 PNPSI • .0038 DPHI2 • .2943E+04

T • 3.56717 PHI • 138.09 PHIDOT • 13.02 G • -.0052 GDOT • 2.72 PSID • 52.14 PSIDOT • 14.58 PHITOT • 13264.6
F34 • .0232 F23 • .1355 F12 • .5479 PN • .0039 PNPSI • .0039 DPHI2 • .2961E+04

T • 3.56727 PHI • 138.16 PHIDOT • 13.32 G • -.0050 GDOT • 2.78 PSID • 52.23 PSIDOT • 14.95 PHITOT • 13264.7
F34 • .0232 F23 • .1355 F12 • .5480 PN • .0038 PNPSI • .0038 DPHI2 • .2932E+04

T • 3.56737 PHI • 138.24 PHIDOT • 13.61 G • -.0047 GDOT • 2.84 PSID • 52.31 PSIDOT • 15.32 PHITOT • 13264.8
F34 • .0232 F23 • .1355 F12 • .5479 PN • .0039 PNPSI • .0039 DPHI2 • .2950E+04

T • 3.56747 PHI • 138.32 PHIDOT • 13.90 G • -.0044 GDOT • 2.91 PSID • 52.40 PSIDOT • 15.69 PHITOT • 13264.9
F34 • .0232 F23 • .1355 F12 • .5480 PN • .0039 PNPSI • .0039 DPHI2 • .2920E+04

T • 3.56757 PHI • 138.40 PHIDOT • 14.19 G • -.0041 GDOT • 2.97 PSID • 52.49 PSIDOT • 16.06 PHITOT • 13264.9
F34 • .0232 F23 • .1355 F12 • .5480 PN • .0039 PNPSI • .0039 DPHI2 • .2939E+04

T • 3.56767 PHI • 138.48 PHIDOT • 14.48 G • -.0038 GDOT • 3.04 PSID • 52.59 PSIDOT • 16.44 PHITOT • 13265.0
F34 • .0232 F23 • .1355 F12 • .5480 PN • .0039 PNPSI • .0039 DPHI2 • .2907E+04

T • 3.56777 PHI • 138.56 PHIDOT • 14.77 G • -.0035 GDOT • 3.10 PSID • 52.68 PSIDOT • 16.81 PHITOT • 13265.1
F34 • .0232 F23 • .1356 F12 • .5480 PN • .0040 PNPSI • .0040 DPHI2 • .2927E+04

T • 3.56787 PHI • 138.65 PHIDOT • 15.06 G • -.0032 GDOT • 3.17 PSID • 52.78 PSIDOT • 17.19 PHITOT • 13265.2
F34 • .0232 F23 • .1356 F12 • .5480 PN • .0039 PNPSI • .0039 DPHI2 • .2894E+04

T • 3.56797 PHI • 138.74 PHIDOT • 15.35 G • -.0029 GDOT • 3.23 PSID • 52.88 PSIDOT • 17.57 PHITOT • 13265.3
F34 • .0234 F23 • .1458 F12 • .5480 PN • .0040 PNPSI • .0040 DPHI2 • .2944E+04

T • 3.56807 PHI • 138.82 PHIDOT • 15.64 G • -.0025 GDOT • 3.30 PSID • 52.98 PSIDOT • 17.96 PHITOT • 13265.4

23260 F34 • .0234 F23 • .1458 F12 • .5480 PN • .0040 PNPSI • .0040 DPHI2 • .2910E+04
 23290
 23300 T • 3.56817 PHI • 138.91 PHIDOT • 15.93 G • -.0022 GDOT • 3.36 PSID • 53.09 PSIDOT • 18.35 PHITOT • 13265.5
 23310 F34 • .0235 F23 • .1459 F12 • .5479 PN • .0041 PNPSI • .0041 DPHI2 • .2956E+04
 23320
 23330 T • 3.56827 PHI • 139.01 PHIDOT • 16.23 G • -.0019 GDOT • 3.43 PSID • 53.19 PSIDOT • 18.74 PHITOT • 13265.6
 23340 F34 • .0235 F23 • .1459 F12 • .5480 PN • .0041 PNPSI • .0041 DPHI2 • .2921E+04
 23350
 23360 T • 3.56837 PHI • 139.10 PHIDOT • 16.52 G • -.0015 GDOT • 3.49 PSID • 53.30 PSIDOT • 19.14 PHITOT • 13265.7
 23370 F34 • .0237 F23 • .1460 F12 • .5479 PN • .0041 PNPSI • .0041 DPHI2 • .2969E+04
 23380
 23390 T • 3.56847 PHI • 139.20 PHIDOT • 16.81 G • -.0012 GDOT • 3.56 PSID • 53.41 PSIDOT • 19.54 PHITOT • 13265.7
 23400 F34 • .0237 F23 • .1460 F12 • .5480 PN • .0041 PNPSI • .0041 DPHI2 • .2933E+04
 23410
 23420 T • 3.56857 PHI • 139.29 PHIDOT • 17.10 G • -.0008 GDOT • 3.62 PSID • 53.52 PSIDOT • 19.94 PHITOT • 13265.8
 23430 F34 • .0221 F23 • .1462 F12 • .5481 PN • .0041 PNPSI • .0041 DPHI2 • .2850E+04
 23440
 23450 T • 3.56867 PHI • 139.39 PHIDOT • 17.39 G • -.0004 GDOT • 3.69 PSID • 53.64 PSIDOT • 20.34 PHITOT • 13265.9
 23460 F34 • .0221 F23 • .1462 F12 • .5481 PN • .0041 PNPSI • .0041 DPHI2 • .2814E+04
 23470
 23480 T • 3.56877 PHI • 139.49 PHIDOT • 17.66 G • -.0001 GDOT • 3.75 PSID • 53.76 PSIDOT • 20.73 PHITOT • 13266.0
 23490 F34 • .0221 F23 • .1464 F12 • .5483 PN • .0040 PNPSI • .0040 DPHI2 • .2729E+04
 23500
 23510 T • 3.56887 PHI • 139.59 PHIDOT • 17.94 G • .0003 GDOT • 3.82 PSID • 53.88 PSIDOT • 21.12 PHITOT • 13266.1
 23520 F34 • .0221 F23 • .1464 F12 • .5483 PN • .0040 PNPSI • .0040 DPHI2 • .2694E+04
 23530
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FREE MOTION

T • 3.56887 PHI • 199.59 PHIDOT • 17.94 PSI • 305.46 PSIDOT • 21.12 PHITOT • 13266.14
 FF12 • .471 FF23 • .126 FF34 • .018
 T • 3.56897 PHI • 199.71 PHIDOT • 23.73 PSI • 305.58 PSIDOT • 21.05 PHITOT • 13266.26
 FF12 • .472 FF23 • .126 FF34 • .018
 T • 3.56907 PHI • 199.87 PHIDOT • 29.49 PSI • 305.70 PSIDOT • 20.97 PHITOT • 13266.42
 FF12 • .472 FF23 • .126 FF34 • .018

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