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**COMPUTER SIMULATIONS OF ARTILLERY S&A  
MECHANISMS (INVOLUTE GEAR TRAIN AND  
PIN PALLET RUNAWAY ESCAPEMENT)**

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DOVER, NEW JERSEY**

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>Computer simulations of complete safing and arming mechanisms containing pin pallet runaway escapements, two- or three-pass involute gear trains and spin driven rotors were developed. The three motion regimes of the runaway escapement, i.e., coupled motion, free motion and impact, were included. In addition, the ability to consider the effects of pallets with arbitrarily located centers of mass has been introduced. Further, the contact forces of the gear trains and the escapement may be obtained. Simulation runs of actually existing mechanisms were made and good agreement with experimental data was obtained. |                                            |                                                                |

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## INTRODUCTION

Computer simulations for complete safing and arming (S&A) mechanisms were developed. Figures 1 and 2 show the essentials of two different configurations of such mechanisms, consisting of spin driven rotors, three pass involute step-up gear trains, and pin pallet runaway escapements. Figures 3 and 4 illustrate two configurations of similar mechanisms which contain two pass involute step-up gear trains.

The present work draws on ideas developed previously by the authors. A dynamic model of a pin pallet runaway escapement driven by a constant torque was developed first (ref 1). The ideas of pivot and tooth-to-tooth friction and the resultant efficiencies of multi-mesh gear trains were then formulated (ref 2), and subsequently, the computational technique of describing mesh initialization at arbitrary points was derived (ref 3).

This report reflects many of the ideas originated in references 1 through 3,<sup>1</sup> in describing combined mechanism trains which are driven by the variable torques of centrifugal rotors. Again, the three motion regimes of the runaway escapement, i.e., coupled motion, free motion, and impact, are considered. In addition, the ability to include the effect of a pallet which has an arbitrarily located center of mass has been introduced. Further, all non-impact contact forces can now be determined for strength considerations.

The complete and detailed derivations of both mathematical models and their configuration variations are given. The associated computer programs are described in detail, with instructions for running them. These programs were extensively tested, both for the configuration no. 1 data (fig. 1) of the three pass M125A1 booster S&A as well as for the configuration no. 2 data (fig. 4) of the two pass M577 SSD mechanism. The M125A1 booster simulation armed in 45 turns for average friction conditions at various spin rates. Under similar conditions, the simulation of the M577 SSD required 31.7 turns for its arming cycle.

## DESCRIPTION OF COMPUTER PROGRAMS SANDA3 AND SANDA2

The essential steps of programs SANDA3 and SANDA2, which are listed in appendixes C and D, respectively, follow. This discussion is based on the computer program description in reference 1, which deals with a runaway escapement driven by a constant torque. For the sake of clarity the description in reference 1 is repeated and, whenever necessary, changes in the programs due to the presence of the gear trains and the rotors are identified.

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<sup>1</sup>These models can be adapted to spring driven mechanisms with only minor changes.

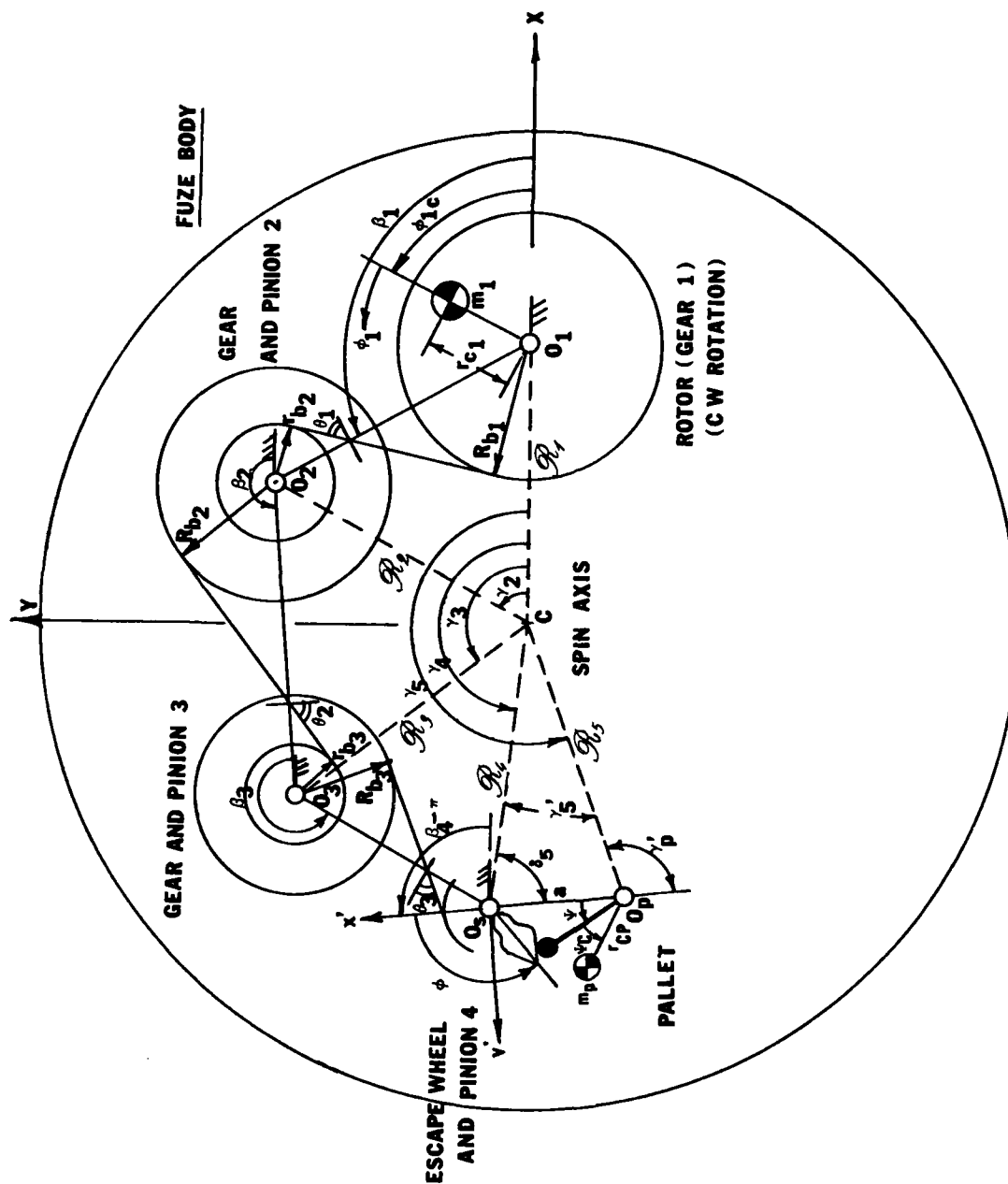


Figure 1. Rotor driven S&A device with three pass step-up gear train, configuration no. 1

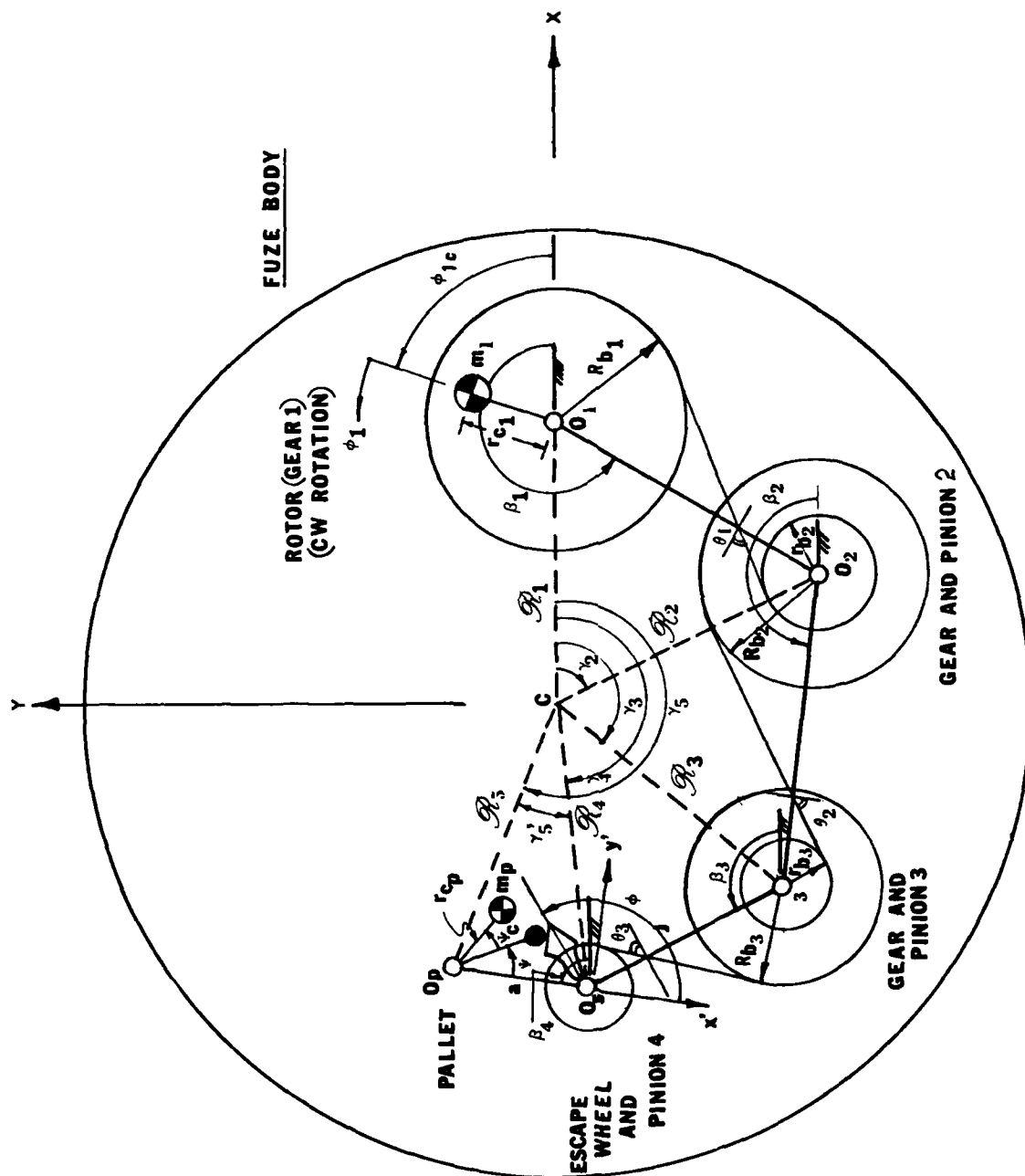


Figure 2. Rotor driven S&A device with three pass step-up gear train, configuration no. 2





Both programs may be used for each of the two possible mechanisms configurations. To differentiate between these configurations, a special input parameter CONFIG must be provided.

The flow chart of the pin pallet runaway escapement part of the programs, is shown in figure 5 which was taken from reference 1. The choice of variable designations was made so that they differ as little as possible from the nomenclature used in the various derivations given in the appendixes of the present report as well as in appendixes A through F and H of reference 1.

Both main programs start with the reading in and writing of the configuration type as well as of all relevant physical data. This is followed by the computation of gear ratios (app A and B), fuze body angles of the applicable configuration, with the help of signum function  $s_6$  (app A and B and ref 2), centrifugal forces (ref 2), earliest and latest possible values of the gear angles by way of subroutine ALFA (ref 2), and the initialization of the gear angles (ref 3). In each case, the simulation begins with entrance coupled motion at a starting angle PHID, which represents the angle  $\phi$  of the escape wheel which is associated with the approximate center of the escape wheel tooth. This angle corresponds to the cumulative escape wheel angle PHITOT of  $0^\circ$ .

#### Program SANDA3

##### Coupled Motion (Location 1)

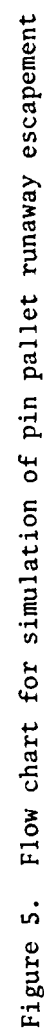
To solve the differential equation of coupled motion (eq A-185, app A), the main program calls on an available fourth order Runge-Kutta routine.<sup>2</sup> The main purpose of the subroutine FCT is to present the second order differential equation in terms of two first order equations to RKGS. PHI(1) and PHI(2) represent the angle  $\phi$  and the angular velocity  $\dot{\phi}$ , respectively. The computation of all parameters of the differential equation takes place in subroutine FCT as well as in subroutines IN3 and KINEM.

The subroutine KINEM computes current values of  $g$ ,  $\dot{g}$ ,  $\psi$  and  $\dot{\psi}$ , including the moment arms  $A'_1$ ,  $B'_1$ ,  $C'_1$ , and  $D'_1$  (which are primed in the present report). The associated expressions for the above values are cited in reference 1.

Subroutine IN3 computes various gear mesh parameters and instantaneous mesh contact angles, as well as the signum functions  $s_1$  to  $s_5$ . In addition, the parameters  $A_1$  to  $A_{53}$ , listed in appendix A, are obtained. (Note that the program uses the symbols AAl, etc., and that the parameters  $A_{54}$  to  $A_{59}$  are computed in subroutine FCT. This division is dictated by the limited number of arguments permitted in any one subroutine.) Finally, the gear indexing operation (ref 2) is performed with the help of the angle  $\phi$ .

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



The manner in which the instantaneous rotor angle,  $\phi_{1C} + N_{41}\phi_T$ , of the coupled motion differential equation (A-185) must be expressed in subroutine FCT will now be discussed. Recall that  $\phi_{1C}$  is the initial rotor angle,  $\phi_T$  is the total angle of rotation of the escape wheel, and  $N_{41}$  stands for the gear ratio between the rotor and the escape wheel. Since the angle  $\phi$ , and consequently the Runge-Kutta variable PHI(1), varies between  $140^\circ$  and  $155^\circ$  during entrance and between  $185^\circ$  to  $200^\circ$  during exit coupled motion, the total escape wheel angle  $\phi_T$  can only be obtained by continuously adding the increments due to each cycle of Runge-Kutta computations. Thus

$$\phi_T = \phi_{TOT} + \Delta\phi \quad (1)$$

where

$\phi_{TOT}$  = total escape wheel angle up to a given Runge-Kutta cycle. This is represented by PHITOT in the program.

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

This increment,  $\Delta\phi$ , is calculated as the difference between the latest value of PHI(1) and its previous value, which has been stored as PHIPR. In this manner, equation 1 becomes

$$\phi_T = PHITOT + PHI(1) - PHIPR \quad (2)$$

Subroutine FCT also decides on the values of  $I_{PR}$  and  $I_{1R}$  as required by equations A-88 and A-89 as well as equations A-155 and A-156, respectively. The associated conditional statements assign the larger values for these combined moments of inertia whenever the product of the angular velocity and the angular acceleration is positive, i.e., both quantities have the same sign (app F and paragraph preceding eq A-148).

The associated subroutine OUTP is responsible for printing out the results  $\phi$ ,  $\dot{\phi}$ , and  $\ddot{\phi}$  together with the current values of time,  $g$ ,  $\dot{g}$ ,  $\psi$ ,  $\dot{\psi}$ , and PHITOT. Further, all coupled motion contact forces are calculated according to equations A-192 to A-196, and the maximum values of these forces during one rotor cycle are determined. Finally, this subroutine decides, according to the following criteria, whether coupled motion is to be continued. These are:

1. The distance  $g < 0$  (ref 1, eq A-12) and because of the nature of the coordinate system  $g$  is always negative while the pallet pin makes contact with the escape wheel tooth, and

2. The contact force  $P_n > 0$  (eq A-196)

The introduction of the contact force between the escape wheel and the pallet allows the use of simpler controls than those given in reference 1.

Thus, when control is returned to the main program, it is either because the pallet pin has left the end of the tooth and there is no further possibility of coupled motion, or the pin has disengaged from the inside of the tooth. In either case, free motion results and control is eventually shifted to the subroutines FCTF and OUTPF through RKGS (location 5). This is done directly if  $g < 0$ . If  $g > 0$ , the main program must decide whether the preceding computations have been made for entrance or for exit action and whether the next contact will occur in entrance or in exit. In the sample mechanism,  $g = 0$  when  $\phi$  is approximately  $155^\circ$  for entrance action and approximately  $200^\circ$  for exit action. If  $g > 0$  and  $\phi < 160^\circ$ , all possibility for entrance contact is ended and  $\phi$  must be incremented by the tooth angle  $\delta$  (ref 1, figs. 2 and 5), while  $\psi$  must be incremented by the angle  $(2\pi - \lambda)$  in order to get the initial angles for exit motion. For  $g > 0$  and  $\phi > 160^\circ$ , entrance contact is expected and  $\phi$  must be decremented by the angle  $2\delta$  (ref 1, fig 4, where the new entrance tooth no. 3 comes into action). At the same time, the pallet angle  $\psi$  must be decremented by  $(-2\pi + \lambda)$  for the initial angle of entrance motion. This shift from one side of the pallet to the other must also be observed in connection with the pallet center of mass angle  $\psi_C$  (figs. 1 and 2). During entrance action,

$$\psi_C = \text{PSICC} \quad (3)$$

in the program, while during exit action

$$\psi_C = \lambda + \text{PSICC} \quad (4)$$

These indexing operations due to pallet position occur both in coupled and in free motion. They have no effect on the continuous computation of the cumulative escape wheel angle PHITOT.

#### Free Motion (Location 5)

The differential equations of free motion, as given by equation A-197 for the pallet and equation A-203 for the combined escape wheel, gear train and rotor, are again solved by the Runge-Kutta routine. In order to obtain the magnitudes of the variables  $\phi$  and  $\psi$  and their derivatives at identical times, the two independent second-order differential equations are transformed into four simultaneous first-order equations. (While only the two first-order equations associated with each of the two variables are actually coupled, the routine treats all four as if they were coupled and thus produces solutions for identical time increments.) These four expressions, which are presented in subroutine FCTF are given in the following form.

$$\text{DX}(1) = \text{X}(2) : (= \dot{\phi}) \quad (5)$$

$$DX(3) = X(4) : (= \dot{\psi}) \quad (6)$$

$$DX(2) = \frac{1}{A_{64}} [-A_{65}(X(2))^2 + A_{66}X(2) + A_{67} + A_{68}\sin(\phi_{1C} + N_{41}(\phi_T + X(1) - PHIPR))] : (= \ddot{\phi}) \quad (7)$$

$$DX(4) = \frac{1}{A_{60}} [-A_{21}(X(4))^2 - A_{61}X(4) - A_{62} + A_{63}\sin(\gamma_p - \psi - \psi_C)] : (= \ddot{\psi}) \quad (8)$$

Subroutine FCTF also computes the parameters  $A_{60}$  to  $A_{68}$  and calls on subroutine IN3 for the computation of all gear related parameters.<sup>3</sup>

The associated subroutine OUTPF computes the free motion contact forces according to equations A-209 through A-211, and finds their maxima, after determining the parameters  $A_{60}$  to  $A_{68}$ . The computation of these latter variables also requires a call on subroutine IN3. In addition to the above, a continuous count of PHITOT is provided in OUTPF. This angle, time,  $\phi$ ,  $\dot{\phi}$ ,  $\psi$ ,  $\dot{\psi}$ , and the contact forces are printed. This subroutine also makes the decision of whether or not to remain in free motion. The sensing variables,  $f$  and  $g' = GP$  (ref 1, eq D-7 and D-11), are used for this purpose.

If  $f > 0$  and  $g' < 0$ , free motion is continued without indexing. If  $f > 0$  and  $g' > 0$ , free motion is also continued, but since contact is no longer possible for the component pair for which the previous computations were made, indexing must take place. This is accomplished in the same manner as in coupled motion.

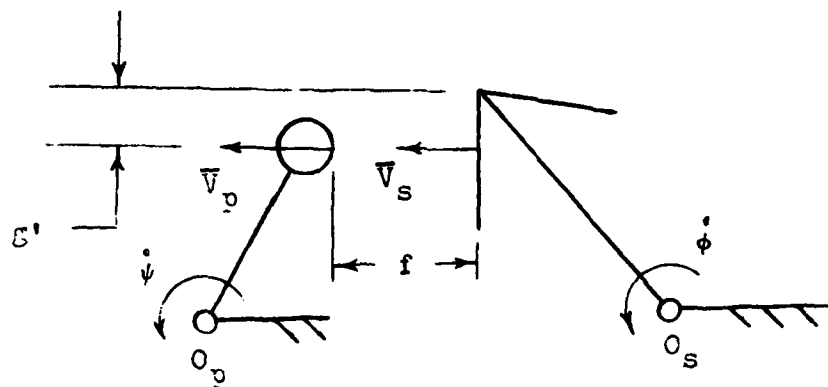
If  $f < 0$ , control is returned unconditionally to the main program. If it finds that  $g' > 0$ , indexing takes place and control is given back to the subroutine FCTF. If  $g' < 0$ , contact is about to take place or has just occurred. This program must decide whether this contact represents just a close approach which is followed by further free motion, an impending impact, or the beginning of coupled motion. To this end, the quantities  $V_p$  and  $V_s$  (ref 1, eq F-22 and F-23), are computed for the entrance and exit free motion tests.<sup>4</sup> The first three

<sup>3</sup> Whenever  $A_{60} = I_{PR} = 0$ , the simulation stops because of division by zero. Should this occur, FCTF prints "IPR EQUALS ZERO - SIMULATION TERMINATED."

<sup>4</sup> Under the present circumstances, if  $\phi < 160^\circ$ , only entrance contact can follow; if  $\phi > 160^\circ$ , exit contact will occur.

cases of the entrance free motion test of the main program are illustrated in figure 6. With both angular velocities ( $\dot{\phi} = \text{PHI}(2) = X(2)$  and  $\dot{\psi} = \text{DPSI} = X(4)$ ) positive, the following three possibilities exist:

1. If  $|V_p| > |V_s|$ , the contacting surfaces will separate again, free motion will result, and control must be transferred to subroutine RKGS (location 6), which calls free motion subroutine FCTF.
2. If  $|V_p| = |V_s|$ , the escape wheel will start driving the pallet in coupled motion, and control must be transferred to subroutine RKGS (location 1 initiates RKGS), which in this case, calls coupled motion subroutine FCT.
3. If  $|V_p| < |V_s|$ , impact will occur, and control must be given to subroutine IMPACT (location 15).



( $\dot{\phi}$  and  $\dot{\psi}$  are positive. Distance  $f$  is enlarged.)

Figure 6. Entrance free motion test

#### Impact (Location 15)

The subroutine IMPACT uses the current values of the angular velocities  $\dot{\phi}_1$  and  $\dot{\psi}_1$  and computes the post impact angular velocities  $\dot{\phi}_f$  and  $\dot{\psi}_f$ , applying equations F-20 and F-21, ref 1. (The moment of inertia of the escape wheel is now expressed according to equation A-212, appendix A of the present report, which refers the rotor, as well as the gear train inertias, to the escape wheel shaft. As shown in reference 1, the tangential impact has been neglected and, therefore,  $E_2 = D_1$  and  $F_2 = A_1$ .)

After control is returned to the main program, it is decided whether free or coupled motion follows the impact. This is accomplished by considering

the post-impact contact point velocities,  $V_p$  and  $V_g$ , in the impact tests, which are similar to the free motion tests.

If the contact velocities are vectorially equal to each other, or if the absolute value of the difference of their absolute magnitudes is less than 2.0 in./sec (5.08 cm/sec), control is transferred to coupled motion. If these velocities indicate a subsequent separation, which is more usual, computation is transferred to free motion.

#### Reversal of Gear Train Motion Due to Impact

If the impact torque on the escape wheel is sufficiently large, the motion of the gear train may be temporarily reversed (i.e., the escape wheel angular velocity  $\dot{\phi}$  becomes negative). This causes the friction forces between the gear teeth and at the various gear pivots to be reversed in direction. (The normal forces between the gear teeth remain unaffected, and the normal bearing forces are solved for in the usual manner.) This change in the direction of the friction forces is expressed both for coupled and free motion by letting the coefficient of friction  $\mu$  of all gear train components become negative (app E). This is accomplished in subroutines IN3 and IN2 by the following use of the signum function  $\phi / \dot{\phi}$  :

$$\mu = \text{ABS}(\mu) * \dot{\phi} / |\dot{\phi}| \quad (9)$$

[The coefficient of friction associated with the escapement interface and the pallet pivot is called  $\mu_1$  (read into the program as MU1).] Any motion reversal at these locations is accounted for by the signum functions  $s_4$  and  $s_5$ , respectively.

#### Termination of Computations

Computations are terminated whenever the geared motion of the rotor ends. This corresponds to  $\phi = \text{PHICUTD}$ . (See Program SANDA3, General Parameters, below.) The duration of the subsequent unretarded motion of the rotor is assumed to be negligible.

#### Program SANDA2

Program SANDA2 is very similar to program SANDA3, and where possible, the following description will refer to program SANDA3.

#### Coupled Motion (Location 1)

To solve the differential equation of coupled motion (app B, eq B-113), the main program calls on the fourth order Runge-Kutta routine. Subroutine FCT presents the second order differential equation in terms of two first order equations to RKGS, which computes PHI(1) and PHI(2) as in SANDA3. The computation of all necessary parameters takes place in FCT and KINEM. In addition, subroutine IN2 is used. This subroutine, which differs from IN3, computes various gear mesh

parameters and contact angles of the two pass train. It further computes the signum functions  $s_1$ ,  $s_2$ ,  $s_4$ , and  $s_5$  as well as the parameters  $A_1$  to  $A_{44}$ , listed in appendix B. The parameters  $A_{45}$  to  $A_{50}$  are computed in subroutine FCT. Finally, the gear indexing operation is performed with the help of the angle  $\phi$ .

The instantaneous rotor angle now becomes  $\phi_{1C} + N_{31}\phi_T$ , and is treated in FCT in the same manner as shown by equations 1 and 2. Subroutine FCT also decides on the values of  $I_{PR}$  and  $I_{1R}$  as required by equations A-88 and A-89 as well as equations B-87 and B-88. The associated conditional statements assign the larger values for these combined moments of inertia whenever the product of the angular velocity and the angular acceleration is positive, i.e., both quantities have the same sign. (See discussion following eq 2.)

The associated subroutine OUTP is responsible for printing out the results  $\phi$ ,  $\dot{\phi}$ , and  $\ddot{\phi}$ , together with the current values of time,  $g$ ,  $\dot{g}$ ,  $\psi$ ,  $\dot{\psi}$ , and PHITOT. Further, all coupled motion contact forces and their maxima are determined according to equations B-120 to B-123. The coupled motion control criteria given in this subroutine are identical to those described in connection with subroutine OUTP of SANDA3. This is also true of the indexing operations connected with the angles  $\phi$ ,  $\psi$ , and  $\psi_C$ .

#### Free Motion (Location 5)

The differential equations of free motion, as given in equation B-124 for the pallet and equation B-130 for the combined escape wheel, gear train and rotor, are also solved by the Runge-Kutta routine. The associated four simultaneous first order differential equations, which are given in subroutine FCTF, are similar to those used in SANDA3. (See paragraph before eq 5.).

$$DX(1) = X(2) : (= \dot{\phi}) \quad (10)$$

$$DX(3) = X(4) : (= \dot{\psi}) \quad (11)$$

$$DX(2) = \frac{1}{A_{55}} \left[ -A_{56}(X(2))^2 - A_{57}X(2) + A_{58} - A_{59}\sin(\phi_{1C} + N_{31}(\phi_T + X(1) - PHIPR)) \right] : (= \ddot{\phi}) \quad (12)$$

$$DX(4) = \frac{1}{A_{51}} \left[ -A_{21}(X(4))^2 - A_{52}X(4) - A_{53} + A_{54}\sin(\gamma_P' - \psi - \psi_C) \right] : (= \ddot{\psi}) \quad (13)$$

The subroutine FCTF also computes the parameters  $A_{51}$  to  $A_{59}$  and calls on subroutine IN2 for the computation of all gear related parameters.

The associated subroutine OUTPF computes the parameters  $A_{51}$  to  $A_{59}$  in order to obtain the free motion contact forces according to equations B-136 and B-137. In addition, it determines the maxima of these contact forces. These operations also require a call on subroutine IN2. Again, a continuous count of PHITOT is provided in OUTPF, and time,  $\phi$ ,  $\dot{\phi}$ ,  $\psi$ ,  $\dot{\psi}$  and the contact forces are caused to be printed together with PHITOT. Whether or not to remain in free motion is decided by the same free motion tests outlined in SANDA3.

#### Impact (Location 15)

The treatment of the impact phase of the motion is identical to that given in connection with SANDA3. (The moment of inertia of the escape wheel is now expressed according to equation B-138, app B, which refers the rotor as well as gear and pinion no. 2 to the escape wheel shaft.)

#### Reversal of Gear Train Motion Due to Impact

Any reversal of the gear train due to impact is treated in the same manner as that described in SANDA3 (eq 9). The control of the coefficient of friction,  $\mu$ , now takes place in subroutine IN2. The coefficient of friction associated with the escapement interface and the pallet pivot is again called  $\mu_1$  and is read into the program as MUL.

#### Termination of Computations

Computations are terminated whenever the geared motion of the rotor ends. This corresponds to  $\phi = \text{PHICUTD}$  (Program SANDA2, General Parameters, below). The duration of the subsequent unretarded motion of the rotor is assumed to be negligible.

### COMPUTER SIMULATIONS OF EXAMPLE MECHANISMS

Computer simulations of modified M125A1 and M577 spin driven S&A devices are discussed in this section. Both contain appropriately adapted involute gear trains rather than the actual clock gear trains used.<sup>5</sup> Program SANDA3 has been used for the M125A1 mechanism, which has configuration type no. 1. Both the program as well as the relevant output are given in appendix C. The simulation of the M577 mechanism, which has configuration no. 2, was accomplished with the help of SANDA2. This program, as well as associated output, is given in appendix D. Both simulations were run for 30,000 RPM in order to obtain maximum contact forces.

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<sup>5</sup> All gears and pinions have the original number of teeth and diametral pitches. The individual meshes, with unity contact ratio, are designed to operate at standard center distances and have unequal addenda (obtained with program INVOLL of ref 2).

The data requirements of both programs, an explanation of the various output data, and the manner in which the number of turns to arm results are obtained for a given spin velocity are presented below.

### Program SANDA3

#### Input Data

The required input data is the first portion of the output of Program SANDA3. They represent the mechanism parameters of the M125A1 booster and are listed below both as computer variables and as symbols.

#### Escapement Parameters.

|        |   |            |                         |                                                                                                                   |
|--------|---|------------|-------------------------|-------------------------------------------------------------------------------------------------------------------|
| A      | = | a          | = 0.2061 in. (5.234 mm) | = distance between pivots $O_p$ and $O_s$ (fig.1)                                                                 |
| B      | = | b          | = 0.192 in. (4.877 mm)  | = escape wheel radius                                                                                             |
| C      | = | c          | = 0.0788 in. (2.001 mm) | = pallet radius from pivot to center of pin (identical for entrance and exit)                                     |
| R      | = | r          | = 0.015 in. (0.381 mm)  | = pallet pin radius (identical for entrance and exit)                                                             |
| ALPHA  | = | $\alpha$   | = $51^\circ$            | = escape wheel tooth half angle                                                                                   |
| CONFIG | = | l          |                         | = configuration no. 1                                                                                             |
| EREST  | = | $\epsilon$ | = 0                     | = coefficient of restitution (high speed motion pictures of runaway escapement suggest totally inelastic impacts) |
| LAMBDA | = | $\lambda$  | = $152.144^\circ$       | = angle between entrance and exit pallet radii                                                                    |
| DELTA  | = | $\delta$   | = $30^\circ$            | = angle between individual escape wheel teeth                                                                     |

For details of the above nomenclature see reference 1.

#### Mass Properties of Components.

|    |   |       |                                                                                 |                                 |
|----|---|-------|---------------------------------------------------------------------------------|---------------------------------|
| M1 | = | $m_1$ | = $0.1155 \times 10^{-3}$ lb-sec <sup>2</sup> /in. ( $2.022 \times 10^{-2}$ kg) | = mass of rotor                 |
| M2 | = | $m_2$ | = $0.686 \times 10^{-5}$ lb-sec <sup>2</sup> /in. ( $1.201 \times 10^{-3}$ kg)  | = mass of gear and pinion no. 2 |
| M3 | = | $m_3$ | = $0.282 \times 10^{-5}$ lb-sec <sup>2</sup> /in. ( $4.938 \times 10^{-3}$ kg)  | = mass of gear and pinion no. 3 |

$M4 = m_4 = 0.252 \times 10^{-5} \text{ lb-sec}^2/\text{in.} \quad (4.412 \times 10^{-4} \text{ kg})$  = mass of escape wheel and pinion no. 4  
 $MP = m_p = 0.359 \times 10^{-5} \text{ lb-sec}^2/\text{in.} \quad (6.286 \times 10^{-4} \text{ kg})$  = mass of pallet  
 $I1 = I_1 = 0.1055 \times 10^{-4} \text{ in.-lb-sec}^2 \quad (0.1189 \times 10^{-5} \text{ kg-m}^2)$  = moment of inertia of rotor  
 $I2 = I_2 = 0.126 \times 10^{-6} \text{ in.-lb-sec}^2 \quad (0.142 \times 10^{-7} \text{ kg-m}^2)$  = moment of inertia of gear and pinion no. 2  
 $I3 = I_3 = 0.308 \times 10^{-7} \text{ in.-lb-sec}^2 \quad (0.348 \times 10^{-8} \text{ kg-m}^2)$  = moment of inertia of gear and pinion no. 3  
 $I4 = I_4 = 0.268 \times 10^{-7} \text{ in.-lb-sec}^2 \quad (0.303 \times 10^{-8} \text{ kg-m}^2)$  = moment of inertia of escape wheel and pinion no. 4  
 $IP = I_p = 0.245 \times 10^{-7} \text{ in.-lb-sec}^2 \quad (0.277 \times 10^{-8} \text{ kg-m}^2)$  = moment of inertia of pallet

General Parameters.

$RC1 = r_{C1} = 0.106 \text{ in.} \quad (2.692 \text{ mm})$  = distance from rotor pivot to center of mass  
 $RCP = r_{CP} = 0$  = pallet eccentricity  
 $RHOP = \rho_p = 0.016 \text{ in.} \quad (0.406 \text{ mm})$  = pallet pivot radius  
 $RPM = 30,000$  = spin rate  
 $PHI1CD = \phi_{1C} = 144^\circ$  = rotor angle in starting position (fig. 1)  
 $PSICCD = \psi_C = 0^\circ$  = eccentricity angle of pallet (fig. 1)  
 $PHID = 145^\circ$  = escape wheel starting angle of initial coupled motion simulation (for choice of this angle, see ref 1)

PHICUTD = 3600° = cumulative escape wheel angle, obtained from product of total rotor rotation and gear train ratio. The total rotor rotation for the M125A1 is 76° while the gear ratio is 47.25. Thus, PHICUTD = 76 x 47.25 ≈ 3600°.

MU =  $\mu$  = 0.15 = coefficient of friction of gear train (pivots and tooth-to-tooth contacts, includes escape wheel pivot)

MU1 =  $\mu_1$  = 0.15 = coefficient of friction on pallet-escape wheel interface and pallet pivot

Gear Parameter.

PSUBD1 =  $P_{d1}$  = 44 = diametral pitch of mesh no. 1 (rotor and pinion no. 2)

PSUBD2 =  $P_{d2}$  = 65 = diametral pitch of mesh no. 2 (gear no. 2 and pinion no. 3)

PSUBD3 =  $P_{d3}$  = 77 = diametral pitch of mesh no. 3 (gear no. 3 and escape wheel pinion)

NG1 =  $N_{G1}$  = 42 = number of teeth of rotor (full gear no. 1)

NG2 =  $N_{G2}$  = 27 = number of teeth of gear no. 2

NG3 =  $N_{G3}$  = 27 = number of teeth of gear no. 3

NP2 =  $N_{P2}$  = 8 = number of teeth of pinion no. 2

NP3 =  $N_{P3}$  = 9 = number of teeth of pinion no. 3

NP4 =  $N_{P4}$  = 9 = number of teeth of pinion no. 4 (escape wheel pinion)

CAPRP1 =  $R_{p1}$  = 0.47727 in. (12.1226 mm) = pitch radius of gear no. 1 (rotor)

CAPRP2 =  $R_{p2}$  = 0.20769 in. (5.2753 mm) = pitch radius of gear no. 2

CAPRP3 =  $R_{p3}$  = 0.17532 in. (4.4531 mm) = pitch radius of gear no. 3

|        |   |            |                            |                                                                    |
|--------|---|------------|----------------------------|--------------------------------------------------------------------|
| RP2    | = | $r_{p2}$   | = 0.09091 in. (2.3091 mm)  | = pitch radius of pinion no. 2                                     |
| RP3    | = | $r_{p3}$   | = 0.06923 in. (1.7584 mm)  | = pitch radius of pinion no. 3                                     |
| RP4    | = | $r_{p4}$   | = 0.05844 in. (1.4844 mm)  | = pitch radius of pinion no. 4<br>(escape wheel pinion)            |
| THETA1 | = | $\theta_1$ | = 20°                      | = pressure angle of mesh no. 1                                     |
| THETA2 | = | $\theta_2$ | = 20°                      | = pressure angle of mesh no. 2                                     |
| THETA3 | = | $\theta_3$ | = 20°                      | = pressure angle of mesh no. 3                                     |
| R1     | = | $\delta_1$ | = 0.225 in. (5.715 mm)     | = distance of rotor pivot from<br>spin axis                        |
| R2     | = | $\delta_2$ | = 0.436 in. (11.074 mm)    | = distance of pivot of gear and<br>pinion set no. 2 from spin axis |
| R3     | = | $\delta_3$ | = 0.504 in. (12.602 mm)    | = distance of pivot of gear and<br>pinion set no. 3 from spin axis |
| R4     | = | $\delta_4$ | = 0.520 in. (13.208 mm)    | = distance of pivot of escape<br>wheel from spin axis              |
| R5     | = | $\delta_5$ | = 0.433 in. (10.998 mm)    | = distance of pivot of pallet<br>from spin axis                    |
| RHO1   | = | $\rho_1$   | = 0.062 in. (1.575 mm)     | = pivot radius of rotor                                            |
| RHO2   | = | $\rho_2$   | = 0.025 in. (0.635 mm)     | = pivot radius of gear and pinion<br>no. 2                         |
| RHO3   | = | $\rho_3$   | = 0.018 in. (0.457 mm)     | = pivot radius of gear and pinion<br>no. 3                         |
| RHO4   | = | $\rho_4$   | = 0.016 in. (0.406 mm)     | = pivot radius of escape wheel                                     |
| CAPRB1 | = | $R_{b1}$   | = 0.44849 in. (11.3916 mm) | = base radius of gear no. 1                                        |
| CAPRB2 | = | $R_{b2}$   | = 0.19517 in. (4.9573 mm)  | = base radius of gear no. 2                                        |
| CAPRB3 | = | $R_{b3}$   | = 0.16475 in. (4.1847 mm)  | = base radius of gear no. 3                                        |
| RB2    | = | $r_{b2}$   | = 0.08543 in. (2.1699 mm)  | = base radius of pinion no. 2                                      |
| RB3    | = | $r_{b3}$   | = 0.06506 in. (1.6525 mm)  | = base radius of pinion no. 3                                      |
| RB4    | = | $r_{b4}$   | = 0.05492 in. (1.3950 mm)  | = base radius of escape wheel<br>pinion                            |
| CAPR01 | = | $R_{o1}$   | = 0.48791 in. (12.3929 mm) | = outside radius of gear no. 1                                     |

CAPRO2 =  $R_{o2}$  = 0.21579 in. (5.4811 mm) = outside radius of gear no. 2

CAPRO3 =  $R_{o3}$  = 0.18216 in. (4.6269 mm) = outside radius of gear no. 3

RO2 =  $r_{o2}$  = 0.110 in. (2.7940 mm) = outside radius of pinion no. 2

RO3 =  $r_{o3}$  = 0.08089 in. (2.0546 mm) = outside radius of pinion no. 3

RO4 =  $r_{o4}$  = 0.06828 in. (1.7343 mm) = outside radius of escape wheel pinion

J1 =  $J_1$  = 0 = initialization parameter for mesh no. 1. (The value of zero corresponds to earliest possible contact of mesh, ref 3.)

J2 =  $J_2$  = 0 = initialization parameter for mesh no. 2

J3 =  $J_3$  = 0 = initialization parameter for mesh no. 3

#### Output Data

Fuze Geometry. The angles BETA1D =  $\beta_1$  to BETA4D =  $\beta_4$  and GAMMA2D =  $\gamma_2$  to GAMMA5D =  $\gamma_5$  are printed for checking purposes.

Coupled motion. For each time increment T of the coupled motion, the following variables are evaluated:

PHI =  $\phi$  = instantaneous escape wheel angle (deg)

PHIDOT =  $\dot{\phi}$  = escape wheel angular velocity (rad/sec)

G =  $g$  = pallet - escape wheel contact position (in.), ref 1

GDOT =  $\dot{g}$  = time rate of change of g used to determine the direction of relative sliding (in./sec), ref 1

PSID =  $\psi$  = pallet angle (deg)

PSIDOT =  $\dot{\psi}$  = pallet angular velocity (rad/sec)

PHITOT =  $\phi_T$  = cumulative escape wheel angle (deg)

F34 =  $F_{34}$  = normal contact force of gear no. 3 on pinion no. 4 (lb)

F23 =  $F_{23}$  = normal contact force of gear no. 2 on pinion no. 3 (lb)

$F_{12}$       =       $F_{12}$       =      normal contact force of gear no. 1 on pinion no. 2 (lb)  
 $P_N$         =       $P_n$         =      normal contact force between escape wheel and pallet (lb), computed according to equation A-195  
 $P_{NPSI}$      =       $P_{n\psi}$      =      normal contact force between escape wheel and pallet (lb), computed according to equation A-196 (serves for checking)  
 $DPHI2$       =       $\ddot{\phi}$         =      escape wheel acceleration (rad/sec<sup>2</sup>), Runge-Kutta output

Free Motion. For each time increment T of the free motion, the following variables are evaluated:

$PHI$         =       $\phi$         =      instantaneous escape wheel angle (deg)  
 $PHIDOT$     =       $\dot{\phi}$         =      escape wheel angular velocity (rad/sec)  
 $PSI$         =       $\psi$         =      pallet angle (deg)  
 $PSIDOT$     =       $\dot{\psi}$         =      pallet angular velocity (rad/sec)  
 $PHITOT$     =       $\phi_T$        =      cumulative escape wheel angle (deg)  
 $FF12$        =       $F_{F12}$      =      normal contact force of gear no. 1 on pinion no. 2 for free motion (lb)  
 $FF23$        =       $F_{F23}$      =      normal contact force of gear no. 2 on pinion no. 3 for free motion (lb)  
 $FF34$        =       $F_{F34}$      =      normal contact force of gear no. 3 on escape wheel pinion for free motion (lb)

Impact. Just preceding the "IMPACT" label, the program prints the values VP and VS, which stand for the pre-impact velocity components, normal to the escape wheel tooth, of both the pallet and escape wheel contact points (ref 1). Subsequent to the "IMPACT" label, the following variables are evaluated:

$PHI$         =       $\phi$         =      instantaneous escape wheel angle (deg), same as before impact  
 $PHIDOT$     =       $\dot{\phi}$         =      post-impact escape wheel angular velocity (rad/sec)  
 $PSI$         =       $\psi$         =      pallet angle (deg), same as before impact  
 $PSIDOT$     =       $\dot{\psi}$         =      post-impact pallet angular velocity (rad/sec)  
 $PHITOT$     =       $\phi_T$        =      cumulative escape wheel angle (deg), same as before impact

VP =  $V_p$  = post-impact normal velocity component of pallet (pin) at contact point (ref 1)

VS =  $V_s$  = post-impact normal velocity component of escape wheel tooth at contact point (ref 1)

In the present program VP is equal to VS since the coefficient of restitution is zero.

Turns-to-Arm and Maximum Contact Forces. The number of turns-to-arm is obtained by the program for that time  $T_{3600}$  which corresponds to the escape wheel angle PHICUTD =  $3600^\circ$ . Therefore

$$\text{Number of turns-to-arm} = \frac{\text{RPM}}{60} \times T_{3600}$$

Thus, with  $T_{3600} = 0.09068$  second (the actual time corresponds to  $3600.04^\circ$ ) and 30,000 RPM

$$\begin{aligned} \text{Number of turns-to-arm} &= \frac{30,000}{60} \times 0.09068 \\ &= 45.34 \text{ turns} \end{aligned}$$

The maximum non-impact contact forces for the total cycle, both for coupled and for free motion, are listed at the end of the output.

## Program SANDA2

### Input Data

The required input data represent the first portion of the output of program SANDA2. They stand for the following mechanism parameters of the M577 SSD:

#### Escapement Parameters.

|       |   |          |                         |                                                                               |
|-------|---|----------|-------------------------|-------------------------------------------------------------------------------|
| A     | = | a        | = 0.2097 in. (5.326 mm) | = distance between pivots $O_p$ and $O_s$                                     |
| B     | = | b        | = 0.193 in. (4.902 mm)  | = escape wheel radius                                                         |
| C     | = | c        | = 0.0788 in. (2.001 mm) | = pallet radius from pivot to center of pin (identical for entrance and exit) |
| R     | = | r        | = 0.015 in. (0.381 mm)  | = pallet pin radius (identical for entrance and exit)                         |
| ALPHA | = | $\alpha$ | = $52^\circ$            | = escape wheel tooth half angle                                               |

|        |   |                           |                                                                                                                               |
|--------|---|---------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| CONFIG | = | 2                         | = configuration no. 2                                                                                                         |
| EREST  | = | $\epsilon = 0$            | = coefficient of restitution<br>(high speed motion pictures<br>of runaway escapement<br>suggest totally inelastic<br>impacts) |
| LAMBDA | = | $\lambda = 152.144^\circ$ | = angle between entrance and<br>exit pallet radii                                                                             |
| DELTA  | = | $\delta = 30^\circ$       | = angle between individual<br>escape wheel teeth                                                                              |

Details of the above nomenclature are given in reference 1.

#### Mass Properties of Components.

|            |   |                                                     |                                          |                                                            |
|------------|---|-----------------------------------------------------|------------------------------------------|------------------------------------------------------------|
| $M1 = m_1$ | = | $0.3531 \times 10^{-4} \text{ lb-sec}^2/\text{in.}$ | $(6.182 \times 10^{-3} \text{ kg})$      | = mass of rotor                                            |
| $M2 = m_2$ | = | $0.3226 \times 10^{-5} \text{ lb-sec}^2/\text{in.}$ | $(5.648 \times 10^{-4} \text{ kg})$      | = mass of gear and<br>pinion no. 2                         |
| $M3 = m_3$ | = | $0.2656 \times 10^{-5} \text{ lb-sec}^2/\text{in.}$ | $(4.650 \times 10^{-4} \text{ kg})$      | = mass of escape<br>wheel and pinion<br>no. 3              |
| $MP = m_p$ | = | $0.2451 \times 10^{-5} \text{ lb-sec}^2/\text{in.}$ | $(4.291 \times 10^{-4} \text{ kg})$      | = mass of pallet                                           |
| $I1 = I_1$ | = | $0.3350 \times 10^{-5} \text{ in.-lb-sec}^2$        | $(0.3788 \times 10^{-6} \text{ kg-m}^2)$ | = moment of inertia<br>of rotor                            |
| $I2 = I_2$ | = | $0.3750 \times 10^{-7} \text{ in.-lb-sec}^2$        | $(0.4240 \times 10^{-8} \text{ kg-m}^2)$ | = moment of inertia of<br>gear and pinion no. 2            |
| $I3 = I_3$ | = | $0.2490 \times 10^{-7} \text{ in.-lb-sec}^2$        | $(0.2815 \times 10^{-8} \text{ kg-m}^2)$ | = moment of inertia of<br>escape wheel and<br>pinion no. 3 |
| $IP = I_p$ | = | $0.6572 \times 10^{-7} \text{ in.-lb-sec}^2$        | $(0.7430 \times 10^{-8} \text{ kg-m}^2)$ | = moment of inertia of<br>pallet                           |

#### General Parameters.

|     |   |                              |                      |                                                  |
|-----|---|------------------------------|----------------------|--------------------------------------------------|
| RC1 | = | $r_{C1} = 0.115 \text{ in.}$ | $(2.921 \text{ mm})$ | = distance from rotor pivot to center<br>of mass |
| RCP | = | $r_{CP} = 0$                 |                      | = pallet eccentricity                            |

|         |   |             |                         |                                                                                                                                                                                                               |
|---------|---|-------------|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RHOP    | = | $\rho_p$    | = 0.0155 in. (0.394 mm) | = pallet pivot radius                                                                                                                                                                                         |
| RPM     | = | 30,000      |                         | = spin rate                                                                                                                                                                                                   |
| PHI1CD  | = | $\phi_{1C}$ | = -122.23°              | = eccentricity angle of rotor in starting position (fig. 4)                                                                                                                                                   |
| PSICCD  | = | $\psi_C$    | = 0°                    | = eccentricity angle of pallet (fig. 4)                                                                                                                                                                       |
| PHID    |   |             | = 150°                  | = escape wheel starting angle of initial coupled motion simulation (for choice of this angle, see pp 7 and 14, ref 1)                                                                                         |
| PHICUTD |   |             | = 1600°                 | = cumulative escape wheel angle, obtained from product of total rotor rotation and gear train ratio. The total rotor rotation for the M577 is 48.3° while the gear ratio is 33.02. Thus, 48.3 X 33.02 ≈ 1600. |
| MU      | = | $\mu$       | = 0.15                  | = coefficient of friction of gear train (pivots and tooth-to-tooth contacts, includes escape wheel pivot)                                                                                                     |
| MU1     | = | $\mu_1$     | = 0.15                  | = coefficient of friction on pallet - escape wheel interface and pallet pivot                                                                                                                                 |

#### Gear Parameters.

|        |   |          |                           |                                                                      |
|--------|---|----------|---------------------------|----------------------------------------------------------------------|
| PSUBD1 | = | $P_{d1}$ | = 44                      | = diametral pitch of mesh no. 1 (rotor and pinion no. 2)             |
| PSUBD2 | = | $P_{d2}$ | = 63.5                    | = diametral pitch of mesh no. 2 (gear no. 2 and escape wheel pinion) |
| NG1    | = | $N_{G1}$ | = 41                      | = number of teeth of rotor (full gear no. 1)                         |
| NG2    | = | $N_{G2}$ | = 29                      | = number of teeth of gear no. 2                                      |
| NP2    | = | $N_{P2}$ | = 6                       | = number of teeth of pinion no. 2                                    |
| NP3    | = | $N_{P3}$ | = 6                       | = number of teeth of pinion no. 3 (escape wheel pinion)              |
| CAPRP1 | = | $R_{p1}$ | = 0.46591 in. (11.834 mm) | = pitch radius of gear no. 1 (rotor)                                 |

|        |   |            |                           |                                                                                                                                   |
|--------|---|------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| CAPRP2 | = | $R_{p2}$   | = 0.22835 in. (5.800 mm)  | = pitch radius of gear no. 2                                                                                                      |
| RP2    | = | $r_{p2}$   | = 0.06818 in. (1.732 mm)  | = pitch radius of pinion no. 2                                                                                                    |
| RP3    | = | $r_{p3}$   | = 0.04724 in. (1.200 mm)  | = pitch radius of pinion no. 3<br>(escape wheel pinion)                                                                           |
| THETA1 | = | $\theta_1$ | = 20°                     | = pressure angle of mesh no. 1                                                                                                    |
| THETA2 | = | $\theta_2$ | = 20°                     | = pressure angle of mesh no. 2                                                                                                    |
| R1     | = | $d_1$      | = 0.225 in. (5.715 mm)    | = distance of rotor pivot from<br>spin axis                                                                                       |
| R2     | = | $d_2$      | = 0.408 in. (10.200 mm)   | = distance of pivot of gear and<br>pinion set no. 2 from spin axis                                                                |
| R3     | = | $d_3$      | = 0.368 in. (9.100 mm)    | = distance of pivot of escape wheel<br>from spin axis                                                                             |
| R4     | = | $d_4$      | = 0.361 in. (9.025 mm)    | = distance of pivot of pallet from<br>spin axis                                                                                   |
| RHO1   | = | $\rho_1$   | = 0.0465 in. (1.181 mm)   | = pivot radius of rotor                                                                                                           |
| RHO2   | = | $\rho_2$   | = 0.0155 in. (0.394 mm)   | = pivot radius of gear and pinion<br>no. 2                                                                                        |
| RHO3   | = | $\rho_3$   | = 0.0155 in. (0.394 mm)   | = pivot radius of escape wheel                                                                                                    |
| CAPRB1 | = | $R_{b1}$   | = 0.43781 in. (11.120 mm) | = base radius of gear no. 1                                                                                                       |
| CAPRB2 | = | $R_{b2}$   | = 0.21458 in. (5.450 mm)  | = base radius of gear no. 2                                                                                                       |
| RB2    | = | $r_{b2}$   | = 0.06407 in. (1.627 mm)  | = base radius of pinion no. 2                                                                                                     |
| RB3    | = | $r_{b3}$   | = 0.04439 in. (1.128 mm)  | = base radius of escape wheel pinion                                                                                              |
| CAPRO1 | = | $R_{o1}$   | = 0.47388 in. (12.037 mm) | = outside radius of gear no. 1                                                                                                    |
| CAPRO2 | = | $R_{o2}$   | = 0.23387 in. (5.940 mm)  | = outside radius of gear no. 2                                                                                                    |
| RO2    | = | $r_{o2}$   | = 0.09373 in. (2.381 mm)  | = outside radius of pinion no. 2                                                                                                  |
| RO3    | = | $r_{o3}$   | = 0.07321 in. (1.860 mm)  | = outside radius of escape wheel<br>pinion                                                                                        |
| J1     | = | $J_1$      | = 0                       | = initialization parameter for mesh<br>no. 1. (The value of zero<br>corresponds to earliest possible<br>contact of mesh (ref 3).) |

J2 = J<sub>2</sub> = 0

= initialization parameter for mesh  
no. 2

#### Output Data

Fuze Geometry. The angles BETA1D =  $\beta_1$  to BETA3D =  $\beta_3$  and GAMMA2D =  $\gamma_2$  to GAMMA4D =  $\gamma_4$  are printed for checking purposes.

Coupled Motion. For each time increment, T, of the coupled motion, the following variables are evaluated:

PHI =  $\phi$  = instantaneous escape wheel angle (deg)  
 PHIDOT =  $\dot{\phi}$  = escape wheel angular velocity (rad/sec)  
 G = g = pallet - escape wheel contact position (in.) (ref 1)  
 GDOT =  $\dot{g}$  = time rate of change of g used to determine the direction of relative sliding (in./sec) (ref 1)  
 PSID =  $\psi$  = pallet angle (deg)  
 PSIDOT =  $\dot{\psi}$  = pallet angular velocity (rad/sec)  
 PHITOT =  $\phi_T$  = cumulative escape wheel angle (deg)  
 F23 = F<sub>23</sub> = normal contact force of gear no. 2 on pinion no. 3 (lb)  
 F12 = F<sub>12</sub> = normal contact force of gear no. 1 on pinion no. 2 (lb)  
 PN = P<sub>n</sub> = normal contact force between escape wheel and pallet (lb), computed according to equation B-83  
 PNPSI = P<sub>n</sub> $\psi$  = normal contact force between escape wheel and pallet (lb), computed according to equation B-84, (serves for checking)  
 DPHI2 =  $\ddot{\phi}$  = escape wheel acceleration (rad/sec<sup>2</sup>), Runge-Kutta output

Free Motion. For each time increment, T, of the free motion, the following variables are evaluated:

PHI =  $\phi$  = instantaneous escape wheel angle (deg)  
 PHIDOT =  $\dot{\phi}$  = escape wheel angular velocity (rad/sec)  
 PSI =  $\psi$  = pallet angle (deg)

$PSIDOT = \dot{\psi} =$  pallet angular velocity (rad/sec)  
 $PHITOT = \phi_T =$  cumulative escape wheel angle (deg)  
 $FF12 = F_{F12} =$  normal contact force of gear no. 1 on pinion no. 2 for free motion (lb)  
 $FF23 = F_{F23} =$  normal contact force of gear no. 2 on escape wheel pinion for free motion (lb)

Impact. Just preceding the "IMPACT" label, the program prints the values VP and VS, which stand for the pre-impact velocity components, normal to the escape wheel tooth, of both the pallet and escape wheel contact points (ref 1). Subsequent to the "IMPACT" label, the following variables are evaluated:

$PHI = \phi =$  instantaneous escape wheel angle (deg), same as before impact  
 $PHIDOT = \dot{\phi} =$  post-impact escape wheel angular velocity (rad/sec)  
 $PSI = \psi =$  pallet angle (deg), same as before impact  
 $PSIDOT = \dot{\psi} =$  post-impact pallet angular velocity (rad/sec)  
 $PHITOT = \phi_T =$  cumulative escape wheel angle (deg), same as before impact  
 $VP = V_p =$  post-impact normal velocity component of pallet (pin) at contact point (ref 1)  
 $VS = V_s =$  post-impact normal velocity component of escape wheel tooth at contact point (ref 1)

Note that in the present program VP is equal to VS since the coefficient of restitution is zero.

Turns-to-Arm and Maximum Contact Forces. The result of 27.93 turns to arm at a spin velocity of 30,000 RPM is obtained by the program in a manner similar to that shown in Program SANDA3 under paragraph entitled Turns-to-Arm and Maximum Contact Forces for the M125A1 booster mechanism. (Now the escape wheel angle PHICUTD = 1600°.)

The maximum non-impact contact forces for the total cycle both for coupled and free motion, are listed at the end of the output.

## CONCLUSIONS

While it was not the purpose of the present investigation to undertake parametric studies of either of the two mechanisms for which the programs were written, both programs were sufficiently tested to confirm that such studies are possible. They may include variations in masses and moments of inertia of all components, variations of gear, escapement and fuze geometries, as well as various friction conditions.

Test runs for average friction conditions and standard geometries showed that the M577 SSD simulation required 27.9 turns to arm regardless of the assumed spin rate. Under similar conditions, the M125A1 booster model needed 45.3 turns to arm. Both of these values are well within the military specifications for these devices.

The ability to determine the contact forces during coupled and free motion furnishes the foundation for future work concerning the strength of fuze gear teeth. Such work will also have to include the determination of the appropriate dynamic factors due to the impact of the runaway escapement.

A most interesting phenomenon, which may also serve as the starting point of a future investigation, occurred following the first exit impact during the initial motion cycle of the M577 SSD simulation. The preceding coupled motion was initiated closer to the root of the escape wheel tooth than usual, i.e., the starting angle of the escape wheel was chosen to be  $\text{PHID} = 145^\circ$ , when a more usual value during stable operation is equal to, or larger than  $150^\circ$ . With this entrance starting condition and the resulting higher than usual pallet angular velocity, the exit impact was sufficiently large to reverse the motion of the escape wheel and the gear train. During this backward motion of the escape wheel, its deceleration (i.e., acceleration in the forward direction), due to the influence of the driving rotor, became approximately 20 times larger than usual and all contact forces increased substantially. This increase in forces subsided as soon as the forward motion of the escape wheel was restored. This phenomenon did not occur during normal operation, since once the escapement has become stable coupled motion starts much nearer to the tip of the escape wheel tooth. The resulting smaller free motion angular velocities of the pallet caused less severe impacts and, as a result, prevented motion reversals.

#### REFERENCES

1. G. G. Lowen and F. R. Tepper, "Dynamics of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.
2. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.
3. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Efficiency," Technical Report ARLCD-TR-80024, ARRADCOM, Dover, NJ, November 1981.

APPENDIX A

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

## DESCRIPTION OF SYSTEMS AND OUTLINE OF DERIVATIONS

The present appendix gives derivations for a complete mathematical model of an S&A mechanism, consisting of a spin driven rotor, a three pass involute step-up gear train, and a pin pallet runaway escapement. Figures A-1 and A-2 show the two types of configurations to which this model can be adapted.

This work draws to a considerable extent on previous efforts by the authors, i.e., the dynamics of the pin pallet runaway escapement (ref A-1) and the fuze gear train analysis (ref A-2). As in reference A-1 the following three regimes of the mechanism are considered:<sup>A-1</sup>

### 1. Coupled Motion

The escape wheel is in constant contact with one of the pallet pins while it is driven by the rotor (gear no. 1) through the gear and pinion sets no. 2 and 3. The coupled motion differential equation in the escape wheel variable  $\phi$  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 systems move independently of each other in this phase of motion. Thus, there results one differential equation for the pallet in the variable  $\psi$ , and another one for the combined system in the escape wheel variable  $\phi$ .

### 3. Impact

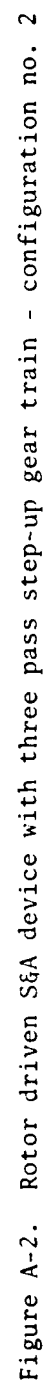
The formulation of the impact regime is taken directly from reference A-1, except that now the moment of inertia of the escape wheel and pinion no. 4 also contains the referred mass properties of the rotor and gear and pinion sets no. 2 and 3. This impact simulation is based on the classical angular impulse - momentum model, where a coefficient of restitution is used to account for the energy losses. Since it is assumed that the effect of the impact force between the escape wheel and the pallet is much greater than the effects due to the driving torque of the rotor and the various retarding torques due to friction, the latter are disregarded.

The influence of friction forces is considered both in the coupled and the 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 reference 2 the individual pivot friction

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A-1 For better understanding, consult figures in reference A-1.





torques are obtained by the algebraic addition of the two friction moments due to the x and y components of the normal bearing forces, rather than by the direct use of the resulting normal forces. This conservative approach to friction is necessary in order to avoid the difficulties which the presence of a square root introduces into the solutions of the various differential equations.

The following briefly outlines the course of the derivations in the individual sections. While the derivations are specifically for configuration no. 1 the results are always applicable to both configurations as long as the appropriate fuze body angles are used.

### GEOMETRY OF FUZE BODY CONFIGURATIONS

The following section contains derivations of expressions for the various fuze body angles associated with the pivot holes of both configurations of the three pass step-up gear mechanisms. They represent extensions of previous work pertaining to configuration no. 1 given in reference A-2, appendix A. In addition, relationships between the unit vectors of the body-fixed x-y and x'-y' systems (figures A-1 and A-2) are given in order to make it possible to derive the escapement relationships in the primed coordinate system, whose x'-axis is oriented along the escapement centerline  $O_p-O_s$  (ref A-1). Finally, a signum function is introduced so that common programming expressions can be devised for both configurations.

#### Fuze Body Configuration No. 1

Figure A-3 indicates the following relationships for the angles  $\gamma_1$ ,  $\delta_1$ , and  $\beta_1$  for fuze body configuration no. 1.

Angles  $\gamma_1$

From

$$(R_{p1} + r_{p2})^2 = R_1^2 + R_2^2 - 2R_1R_2\cos\gamma_2$$

the following expression is obtained for  $\gamma_2$

$$\gamma_2 = \cos^{-1} \left[ \frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2R_1R_2} \right] \quad (A-1)$$

Similarly, from

$$\gamma_3 = \cos^{-1} \left[ \frac{R_2^2 + R_3^2 - (R_{p2} + r_{p3})^2}{2R_2R_3} \right] \quad (A-2)$$

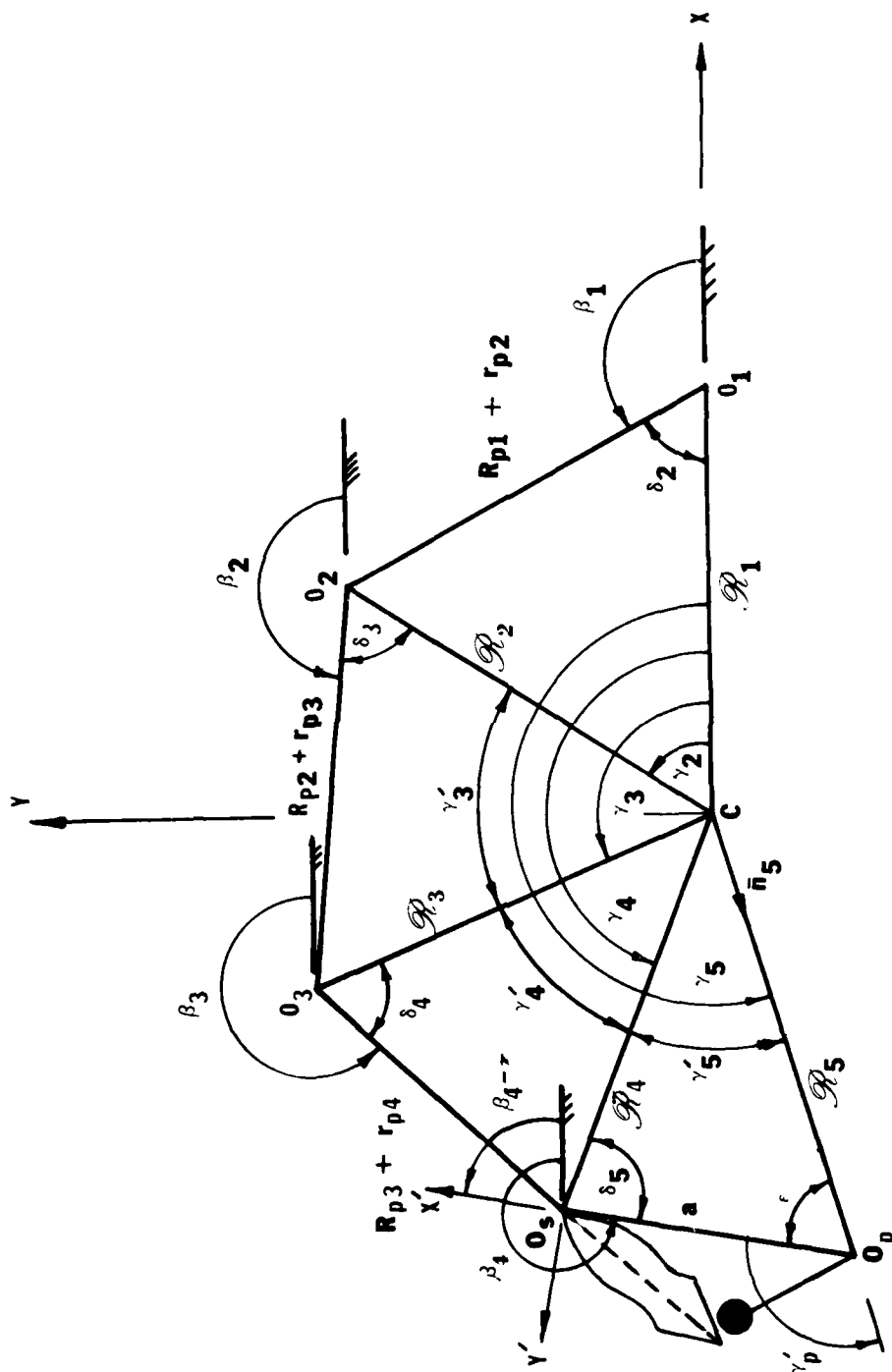


Figure A-3. Fuze body configuration no. 1 (three pass)

the following is obtained

$$\gamma_3 = \gamma_2 + \gamma'_3 \quad (A-3)$$

Also from

$$\gamma'_4 = \cos^{-1} \left[ \frac{R_3^2 + R_4^2 - (R_{p3} + r_{p4})^2}{2 R_3 R_4} \right] \quad (A-4)$$

the following is obtained

$$\gamma_4 = \gamma_3 + \gamma'_4 \quad (A-5)$$

With  $a$ , the distance between the pallet and the escape wheel pivots, the following is obtained

$$a^2 = R_4^2 + R_5^2 - 2 R_4 R_5 \cos \gamma'_5 \quad (A-6)$$

then,

$$\gamma'_5 = \cos^{-1} \left[ \frac{R_4^2 + R_5^2 - a^2}{2 R_4 R_5} \right] \quad (A-7)$$

and

$$\gamma_5 = \gamma_4 + \gamma'_5 \quad (A-8)$$

Angles  $\delta_i$

Since

$$R_2^2 = (R_{p1} + r_{p2})^2 + R_1^2 - 2(R_{p1} + r_{p2}) R_1 \cos \delta_2$$

$$\delta_2 = \cos^{-1} \left[ \frac{(R_{p1} + r_{p2})^2 + R_1^2 - R_2^2}{2 R_1 (R_{p1} + r_{p2})} \right] \quad (A-9)$$

Similarly,

$$\delta_3 = \cos^{-1} \left[ \frac{(R_{p2} + r_{p3})^2 + R_2^2 - R_3^2}{2 R_2 (R_{p2} + r_{p3})} \right] \quad (A-10)$$

and

$$\delta_4 = \cos^{-1} \left[ \frac{(R_{p3} + r_{p4})^2 + R_3^2 - R_4^2}{2 R_3 (R_{p3} + r_{p4})} \right] \quad (A-11)$$

Further, from

$$R_5^2 = a^2 + R_4^2 - 2a R_4 \cos \delta_5 \quad (A-12)$$

the following is obtained

$$\delta_5 = \cos^{-1} \left[ \frac{a^2 + R_4^2 - R_5^2}{2a R_4} \right] \quad (A-13)$$

Angles  $\beta_i$

With equation A-9

$$\beta_1 = \pi - \delta_2 \quad (A-14)$$

Further, with equations A-1 and A-10

$$\beta_2 = \gamma_2 + \pi - \delta_3 \quad (A-15)$$

With equations A-3 and A-11

$$\beta_3 = \gamma_3 + \pi - \delta_4 \quad (A-16)$$

Finally, this furnishes with equations A-5 and A-13:

$$\beta_4 = \gamma_4 + \pi - \delta_5 \quad (A-17)$$

Figure A-3 also shows that the angle  $\gamma'_p$  between the  $x'$ -axis and the unit vector  $\bar{n}_5$  is given by:

$$\gamma'_p = \pi - \varepsilon \quad (A-18)$$

where

$$\epsilon = \pi - \delta_5 - \gamma_5 \quad (\text{A-19})$$

and therefore

$$\gamma_p' = \delta_5 + \gamma_5 \quad (\text{A-20})$$

The unit vector  $\bar{n}_5$  may now be expressed in terms of the primed coordinate system as follows:

$$\bar{n}_5 = \cos \gamma_p' \bar{i}' + \sin \gamma_p' \bar{j}' \quad (\text{A-21})$$

Further, the unit vectors  $\bar{i}'$  and  $\bar{j}'$  are given in terms of the x-y system by:

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

$$\bar{i}' = -\cos \beta_4 \bar{i} - \sin \beta_4 \bar{j} \quad (\text{A-22})$$

$$\bar{j}' = \bar{k}' \times \bar{i}' = -\sin(\beta_4 - \pi) \bar{i} + \cos(\beta_4 - \pi) \bar{j}$$

$$\bar{j}' = \sin \beta_4 \bar{i} - \cos \beta_4 \bar{j} \quad (\text{A-23})$$

#### Fuze Body Configuration No. 2

Figure A-4 indicates the following relationships between the angles  $\gamma_1$ ,  $\delta_1$ , and  $\beta_1$  for fuze body configuration no. 2.

#### Angles $\gamma_1$

Since these angles are given in the clockwise direction with respect to the body-fixed x - axis, their values are negative. Thus, with the help of equation A-1:

$$\gamma_2 = -\cos^{-1} \left[ \frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2 R_1 R_2} \right] \quad (\text{A-24})$$

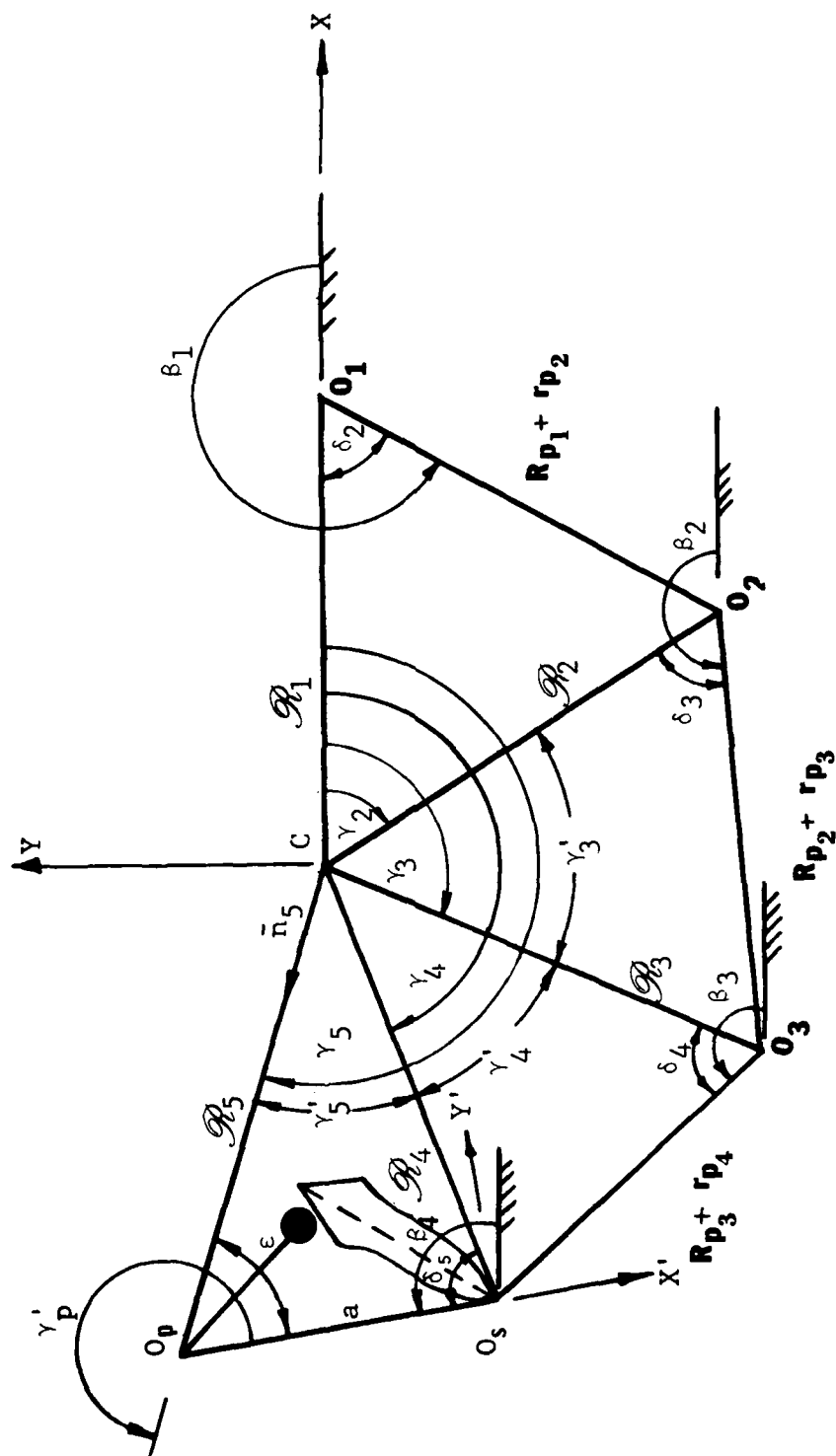


Figure A-4. Fuze body configuration no. 2 (three pass)

$\gamma_3'$  is given by equation A-2, and with that  $\gamma_3$  becomes

$$\gamma_3 = \gamma_2 - \gamma_3' \quad (\text{A-25})$$

The negative sign for  $\gamma_3'$  is necessary in order to make  $\gamma_3$  negative.

$\gamma_4$  is given by equation A-4. This leads to the following expression for  $\gamma_4$  :

$$\gamma_4 = \gamma_3 - \gamma_4' \quad (\text{A-26})$$

The angle  $\gamma_5'$  is again taken directly from equation A-7, and with that  $\gamma_5$  becomes

$$\gamma_5 = \gamma_4 - \gamma_5' \quad (\text{A-27})$$

Angles  $\delta_1$

The angles  $\delta_2$ ,  $\delta_3$ ,  $\delta_4$ , and  $\delta_5$  may be taken directly from equations A-9, A-10, A-11, and A-13, respectively.

Angles  $\beta_1$

With equation A-9

$$\beta_1 = \pi + \delta_2 \quad (\text{A-28})$$

With equations A-10 and A-24

$$\beta_2 = \gamma_2 + \pi + \delta_3 \quad (\text{A-29})$$

where the negative sign of equation A-24 for  $\gamma_2$  is accounted for.

Similarly, with a negative sign of  $\gamma_3$ , one obtains with the help of equations A-11 and A-25:

$$\beta_3 = \gamma_3 + \pi + \delta_4 \quad (\text{A-30})$$

Finally, with equations A-13 and A-24

$$\beta_4 = \gamma_4 + \pi + \delta_5 \quad (A-31)$$

According to figure A-4, the angle  $\gamma'_p$  between the positive  $x'$ -axis and the direction of unit vector  $\bar{n}_5$  is now given by <sup>P</sup>

$$\gamma'_p = \pi + \epsilon \quad (A-32)$$

where

$$\epsilon = \pi - \delta_5 - \gamma'_5 \quad (A-33)$$

so that

$$\gamma'_p = 2\pi - \delta_5 - \gamma'_5 \quad (A-34)$$

The unit vector  $\bar{n}_5$ , when expressed in the primed coordinate system, is again given by equation A-21, i.e.,

$$\bar{n}_5 = \cos \gamma'_p \bar{i}' + \sin \gamma'_p \bar{j}' \quad (A-35)$$

Further, the unit vectors  $\bar{i}'$  and  $\bar{j}'$  are given in terms of the  $x$ - $y$  system by

$$\bar{i}' = \cos(\beta_4 + \pi) \bar{i} + \sin(\beta_4 + \pi) \bar{j}$$

$$\bar{i}' = -\cos \beta_4 \bar{i} - \sin \beta_4 \bar{j} \quad (A-36)$$

$$\bar{j}' = \bar{k}' \times \bar{i}' = -\sin(\beta_4 + \pi) \bar{i} + \cos(\beta_4 + \pi) \bar{j}$$

$$\bar{j}' = \sin \beta_4 \bar{i} - \cos \beta_4 \bar{j} \quad (A-37)$$

# Common Computational Expressions for Both Configurations

In order to find common programming expressions for the angles of both configurations (with the exception of the angles  $\gamma'_p$  of equations A-20 and A-34), the following signum function  $s_6$  is introduced, where

$$s_6 = +1 \text{ for configuration no. 1} \quad (\text{A-38})$$

$$s_6 = -1 \text{ for configuration no. 2} \quad (\text{A-39})$$

This leads to the following expressions:

according to equations A-1 and A-24

$$\gamma_2 = s_6 \cos^{-1} \left[ \frac{\alpha_1^2 + \alpha_2^2 - (R_{p1} + r_{p2})^2}{2 \alpha_1 \alpha_2} \right] \quad (\text{A-40})$$

according to equation A-2

$$\gamma'_3 = \cos^{-1} \left[ \frac{\alpha_2^2 + \alpha_3^2 - (R_{p2} + r_{p3})^2}{2 \alpha_2 \alpha_3} \right] \quad (\text{A-41})$$

according to equations A-3 and A-25

$$\gamma_3 = \gamma_2 + s_6 \gamma'_3 \quad (\text{A-42})$$

according to equation A-4

$$\gamma'_4 = \cos^{-1} \left[ \frac{\alpha_3^2 + \alpha_4^2 - (R_{p3} + r_{p4})^2}{2 \alpha_3 \alpha_4} \right] \quad (\text{A-43})$$

according to equations A-5 and A-26

$$\gamma_4 = \gamma_3 + s_6 \gamma'_4 \quad (\text{A-44})$$

according to equation A-7

$$\gamma'_5 = \cos^{-1} \left[ \frac{\alpha_4^2 + \alpha_5^2 - a^2}{2 \alpha_4 \alpha_5} \right] \quad (\text{A-45})$$

according to equations A-8 and A-27

$$\gamma_5 = \gamma_4 + s_6 \gamma_5' \quad (A-46)$$

according to equations A-9, A-10, A-11, and A-13

$$\delta_2 = \cos^{-1} \left[ \frac{(R_{p1} + r_{p2})^2 + R_1^2 - R_2^2}{2 R_1 (R_{p1} + r_{p2})} \right] \quad (A-47)$$

$$\delta_3 = \cos^{-1} \left[ \frac{(R_{p2} + r_{p3})^2 + R_2^2 - R_3^2}{2 R_2 (R_{p2} + r_{p3})} \right] \quad (A-48)$$

$$\delta_4 = \cos^{-1} \left[ \frac{(R_{p3} + r_{p4})^2 + R_3^2 - R_4^2}{2 R_3 (R_{p3} + r_{p4})} \right] \quad (A-49)$$

$$\delta_5 = \cos^{-1} \left[ \frac{a^2 + R_4^2 - R_5^2}{2a R_4} \right] \quad (A-50)$$

according to equations A-14 and A-28

$$\beta_1 = \pi - s_6 \delta_2 \quad (A-51)$$

according to equations A-15 and A-29

$$\beta_2 = \gamma_2 + \pi - s_6 \delta_3 \quad (A-52)$$

according to equations A-16 and A-30

$$\beta_3 = \gamma_3 + \pi - s_6 \delta_4 \quad (A-53)$$

according to equations A-17 and A-31

$$\beta_4 = \gamma_4 + \pi - s_6 \delta_5 \quad (A-54)$$

The signum function  $s_6$  will also be useful in conditional statements which distinguish between the  $\gamma'_p$ 's of configuration no. 1 and 2 as given by equations A-20 and A-34.

Finally, according to equations A-22, A-23, A-36, and A-37, identical expressions may be used for both configurations when expressing the unit vectors of the primed coordinate systems in terms of the unprimed ones, i.e.,

$$\bar{i}' = -\cos\beta_4\bar{i} - \sin\beta_4\bar{j} \quad (A-55)$$

$$\bar{j}' = \sin\beta_4\bar{i} - \cos\beta_4\bar{j} \quad (A-56)$$

#### DYNAMICS OF THE PALLET IN COUPLED MOTION

While the following derivation for the dynamics of the pallet in coupled motion is illustrated with figures relating to configuration no. 1, all expressions are also applicable to configuration no. 2 as long as the appropriate sign for the signum function  $s_6$  (eq A-38 and A-39), as well as the correct form of the angle  $\gamma'_p$  (eq A-20 and A-34) are used. <sup>A-2</sup>

As stated earlier, the dynamic analysis of the pallet is most conveniently performed in the primed coordinate system. The coefficient of friction at the pallet-escape wheel interface and at the pallet pivot has the designation  $\mu_1$ .

With the spin  $\omega$  of the fuze body constant, the acceleration of the center of mass of the pallet is given by figure A-5.

$$\begin{aligned} \bar{A}_{CP} = & -\omega^2 r_{5\bar{n}_5} - (\omega + \dot{\psi})^2 r_{CP} [\cos(\psi + \psi_C)\bar{i}' + \sin(\psi + \psi_C)\bar{j}'] \\ & + \ddot{\psi} r_{CP} [-\sin(\psi + \psi_C)\bar{i}' + \cos(\psi + \psi_C)\bar{j}'] \end{aligned} \quad (A-57)$$

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A-2 This simple change in angles is all that is required since the relative rotation directions of the components are identical for both configurations, and therefore, force and moment expressions retain the same general form.

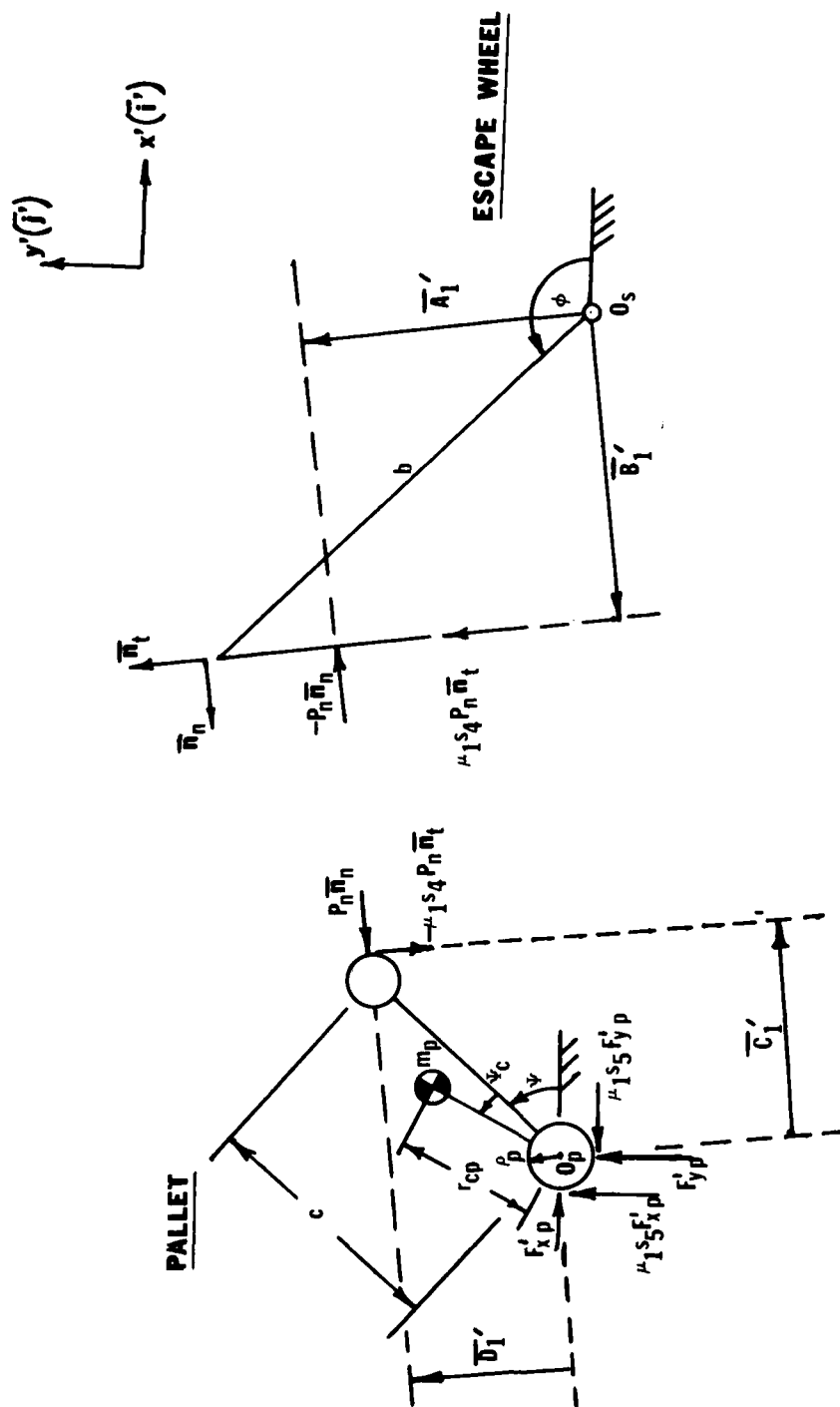


Figure A-5. Free body diagram of pallet with eccentric center of mass (given in  $x'-y'$  system, escape wheel shown for reference only)

With the above, and according to the free body diagram of figure A-5, substitution into Newton's law gives

$$\begin{aligned}
 P_n \bar{n}_n &= \mu_1 s_4 P_n \bar{n}_t + F'_{xp} \bar{i}' - \mu_1 s_5 F'_{yp} \bar{i}' + F'_{yp} \bar{j}' + \mu_1 s_5 F'_{xp} \bar{j}' \\
 &= m_p \left[ -\omega^2 R_5 \bar{n}_5 - (\omega + \dot{\psi})^2 r_{CP} (\cos(\psi + \psi_C) \bar{i}' + \sin(\psi + \psi_C) \bar{j}') \right. \\
 &\quad \left. + \ddot{\psi} r_{CP} (-\sin(\psi + \psi_C) \bar{i}' + \cos(\psi + \psi_C) \bar{j}') \right] \quad (A-58)
 \end{aligned}$$

The signum functions  $s_4$  and  $s_5$  assure the proper directions of the friction forces on the escape wheel - pallet interface as well as on the pallet shaft, regardless of the direction of pallet rotation. Thus,

$$s_4 = \frac{\dot{g}}{|\dot{g}|} \quad (A-59)$$

(ref A-1, eq B-1) and

$$s_5 = \frac{\dot{\psi}}{|\dot{\psi}|} \quad (A-60)$$

The unit vectors  $\bar{n}_t$  and  $\bar{n}_n$  are adapted from equations A-1 and A-2 (ref 1).

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

$$\bar{M}_{Op} = -\ddot{r}_{Op} \times m_p \bar{r}_{CP} + \dot{\bar{H}}_{Op} \quad (A-61)$$

where

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

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

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

Since the angular velocity  $\bar{\omega}$  of the fuze body is constant equation A-61 takes the following form:

$$\bar{M}_{Op} = -(-\omega^2 r_{5n}) \times m_p r_{CP} (\cos(\psi + \psi_C) \bar{i}' + \sin(\psi + \psi_C) \bar{j}') + I_p \ddot{\psi} \quad (A-62)$$

Appropriate computations and substitution of all moments, according to figure A-5, furnish the final moment equation (the moment arms  $A_1$ ,  $B_1$ ,  $C_1$ , and  $D_1$  of reference A-1 are now primed)

$$P_n (D_1' + C_1' \mu_1 s_4) - \rho_p \mu_1 s_5 (\tilde{F}_{xp} + \tilde{F}_{yp}) = I_p \ddot{\psi} - m_p r_{CP} r_{5\omega}^2 \sin(\gamma_p' - \psi - \psi_C) \quad (A-63)$$

where

$$D_1' = c \cos(\phi - \alpha - \psi) \quad (A-64)$$

$$C_1' = -[r + c \sin(\phi - \alpha - \psi)] \quad (A-65)$$

As originally discussed in reference A-2,  $\tilde{F}_{xp}$  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 friction components  $F_{xp}'$  and  $F_{yp}'$  are first obtained from the following component expressions of equation A-58. Subsequently, they are transformed to become  $\tilde{F}_{xp}$  and  $\tilde{F}_{yp}$ , respectively.

$$\begin{aligned} -P_n \sin(\phi - \alpha) - \mu_1 s_4 P_n \cos(\phi - \alpha) + F_{xp}' - \mu_1 s_5 F_{yp}' \\ = m_p [-\omega^2 r_{5\omega} \cos \gamma_p' - (\omega + \dot{\psi})^2 r_{CP} \cos(\psi + \psi_C) - \ddot{\psi} r_{CP} \sin(\psi + \psi_C)] \end{aligned} \quad (A-66)$$

and

$$\begin{aligned} P_n \cos(\phi - \alpha) - \mu_1 s_4 P_n \sin(\phi - \alpha) + F_{yp}' + \mu_1 s_5 F_{xp}' \\ = m_p [-\omega^2 r_{5\omega} \sin \gamma_p' - (\omega + \dot{\psi})^2 r_{CP} \sin(\psi + \psi_C) + \ddot{\psi} r_{CP} \cos(\psi + \psi_C)] \end{aligned} \quad (A-67)$$

Simultaneous solution of equations A-66 and A-67 furnishes

$$\tilde{F}_{yp} = P_n A_1 + \omega^2 A_2 \pm 2 \frac{\omega^2}{|\omega|} \dot{\psi} A_3 \pm \dot{\psi}^2 A_4 \pm \ddot{\psi} A_4 \quad (A-68)$$

$$\tilde{F}_{xp} = P_n A_5 + \omega^2 A_6 \pm 2 \frac{\omega^2}{|\omega|} \dot{\psi} A_7 \pm \dot{\psi}^2 A_7 \pm \ddot{\psi} A_8 \quad (A-69)$$

where

$$A_1 = \left| \frac{\mu_1 (s_4 - s_5) \sin(\phi - \alpha) - (1 + s_4 s_5 \mu_1^2) \cos(\phi - \alpha)}{1 + \mu_1^2} \right| \quad (A-70)$$

$$A_2 = \left| \frac{m_p [R_5 (\sin \gamma'_p - \mu_1 s_5 \cos \gamma'_p) + r_{CP} (\sin(\psi + \psi_C) - \mu_1 s_5 \cos(\psi + \psi_C))] }{1 + \mu_1^2} \right| \quad (A-71)$$

$$A_3 = \left| \frac{m_p r_{CP} [\sin(\psi + \psi_C) - \mu_1 s_5 \cos(\psi + \psi_C)] }{1 + \mu_1^2} \right| \quad (A-72)$$

$$A_4 = \left| \frac{m_p r_{CP} [\cos(\psi + \psi_C) + \mu_1 s_5 \sin(\psi + \psi_C)] }{1 + \mu_1^2} \right| \quad (A-73)$$

$$A_5 = \left| \frac{\mu_1 (s_4 - s_5) \cos(\phi - \alpha) + (1 + s_4 s_5 \mu_1^2) \sin(\phi - \alpha)}{1 + \mu_1^2} \right| \quad (A-74)$$

$$A_6 = \left| \frac{m_p [-R_5 (\cos \gamma'_p + \mu_1 s_5 \sin \gamma'_p) - r_{CP} (\cos(\psi + \psi_C) + \mu_1 s_5 \sin(\psi + \psi_C))] }{1 + \mu_1^2} \right| \quad (A-75)$$

$$A_7 = \left| \frac{m_p r_{CP} [\cos(\psi + \psi_C) + \mu_1 s_5 \sin(\psi + \psi_C)] }{1 + \mu_1^2} \right| \quad (A-76)$$

$$A_8 = \left| \frac{m_p r_{CP} [\sin(\psi + \psi_C) - \mu_1 s_5 \cos(\psi + \psi_C)] }{1 + \mu_1^2} \right| \quad (A-77)$$

The factor  $\omega^2/|\omega|$  is introduced in place of  $\omega$  in order to make sure that the quantity is positive regardless of direction of spin. (This too, assures that the friction moments oppose rotation. The driving moment is proportional to  $\omega^2$ , and therefore independent of spin direction.) To make the final decision concerning the signs of equations A-68 and A-69, these forces are substituted into moment equation A-63, and the influence of the direction of rotation on each of the resulting moment computations is explored:

$$\begin{aligned}
 & P_n [D_1' + C_1 \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_5)] \pm \rho_p \mu_1 s_5 \omega^2 (A_2 + A_6) \\
 & \pm 2 \rho_p \mu_1 s_5 \frac{\omega^2}{|\omega|} \dot{\psi} (A_3 + A_7) \pm \rho_p \mu_1 s_5 \dot{\psi}^2 (A_3 + A_7) \pm \rho_p \mu_1 s_5 \ddot{\psi} (A_4 + A_8) \\
 & = I_P \ddot{\psi} - m_P r_{CP}^2 \delta_5 \omega^2 \sin(\gamma_P' - \psi - \psi_C) \quad (A-78)
 \end{aligned}$$

With  $s_5$  positive for positive rotation, and vice versa, while all other parameters are positive at all times, the following moment components of equation A-78 must have negative signs during positive rotation:

$$-P_n \rho_p \mu_1 s_5 (A_1 + A_5) \quad (A-79)$$

$$-\rho_p \mu_1 s_5 \omega^2 (A_2 + A_6) \quad (A-80)$$

$$-\rho_p \mu_1 s_5 \dot{\psi}^2 (A_3 + A_7) \quad (A-81)$$

The sign of the term containing  $\dot{\psi}$  is negative and is controlled by the sign of  $\dot{\psi}$ . Therefore, the signum operator  $s_5$  is omitted and the term becomes

$$-2 \rho_p \mu_1 \frac{\omega^2}{|\omega|} \dot{\psi} (A_3 + A_7) \quad (A-82)$$

The choice of sign for the friction moment term in equation A-78, which is proportional to the angular acceleration  $\ddot{\psi}$ , is discussed in detail in appendix F. This work results in the computational rules of equations A-88 and A-89, which deal with the sign in the effective moment of inertia  $I_{PR}$ . (Note that the signum function  $s_5$  function has now been omitted.)

With these considerations equation A-78 then becomes

$$\begin{aligned}
 P_n A_{18} - \omega^2 A_{19} - 2 \frac{\omega^2}{|\omega|} \dot{\psi} A_{20} - \dot{\psi}^2 A_{21} \\
 = I_{PR} \ddot{\psi} - m_p r_{CP}^2 \omega_5^2 [\sin(\gamma_p' - \psi - \psi_C)]
 \end{aligned}
 \quad (A-83)$$

where A-3

$$A_{18} = D_1 + C_1 \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_5) \quad (A-84)$$

$$A_{19} = \rho_p \mu_1 s_5 (A_2 + A_6) \quad (A-85)$$

$$A_{20} = \rho_p \mu_1 (A_3 + A_7) \quad (A-86)$$

$$A_{21} = \rho_p \mu_1 s_5 (A_3 + A_7) \quad (A-87)$$

$$I_{PR} = I_p + A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have identical signs} \quad (A-88)$$

$$I_{PR} = I_p - A_{22},^{A-4} \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have opposite signs} \quad (A-89)$$

$$A_{22} = \rho_p \mu_1 (A_4 + A_8) \quad (A-90)$$

Equation A-83 is now used to find an expression for the contact force  $P_n$ . This expression will later make it possible to establish a single differential equation for the escapement in coupled motion. Thus,

$$= \frac{I_{PR} \ddot{\psi} + A_{21} \dot{\psi}^2 + 2 \frac{\omega^2}{|\omega|} A_{20} \dot{\psi} + \omega^2 A_{19} - m_p r_{CP}^2 \omega_5^2 \sin(\gamma_p' - \psi - \psi_C)}{A_{18}}
 \quad (A-91)$$

<sup>3</sup> The parameters  $A_n$  are not sequential at this point.  $A_9$  to  $A_{17}$  may be found in equations A-111 through A-116 and equations A-118 through A-120.

<sup>4</sup> Care must be taken that  $I_p - A_{22}$  does not become negative. If this occurs,  $I_{PR}$  must be set equal to zero. See footnote A-8 where the possible value of  $I_{PR}$  in the free motion equation of the pallet is discussed.

As in reference A-1 the variables  $\dot{\psi}$  and  $\ddot{\psi}$  are now expressed in terms of  $\dot{\phi}$  and  $\ddot{\phi}$  the escape wheel variables (ref A-1, eq A-15 through A-18 and B-6)

$$\ddot{\psi} = U \ddot{\phi} + V \dot{\phi}^2 \quad (\text{A-92})$$

and

$$\dot{\psi} = Z \dot{\phi} \quad (Z \text{ is not defined in ref A-1}) \quad (\text{A-93})$$

where

$$Z = \frac{1}{c \cos \psi} \left[ Q + \frac{aP}{S} \sin(\phi - \alpha) \right] \quad (\text{A-94})$$

Equation A-91 then becomes

$$\begin{aligned} P_n = \frac{1}{A_{18}} \left[ I_{PR} U \ddot{\phi} + (A_{21} Z^2 + I_{PR} V) \dot{\phi}^2 + 2 \frac{\omega}{|\omega|} A_{20} Z \dot{\phi} \right. \\ \left. + \omega^2 A_{19} - m_p r_{CP}^2 \omega^2 \sin(\gamma_p' - \psi - \psi_C) \right] \quad (\text{A-95}) \end{aligned}$$

#### DYNAMICS OF ESCAPE WHEEL IN COUPLED MOTION (ESCAPE WHEEL INCORPORATES PINION NO. 4)

While figure A-6 shows a free body diagram of the escape wheel and pinion no. 4 of configuration no. 1, the following derivations hold for both configurations as long as the appropriate signum function  $s_6$  is chosen. The pivot forces  $F_{x4}$  and  $F_{y4}$  as well as forces  $F_{34}$  and  $T_4$  are now defined in the general x-y system. This makes it necessary to give the unit vectors  $\bar{n}_t$  and  $\bar{n}_n$  in terms of the x-y system.

From equations A-1 and A-2, reference A-1 (and using x'-y' coordinates)

$$\bar{n}_t = \cos(\phi - \alpha) \bar{i}' + \sin(\phi - \alpha) \bar{j}' \quad (\text{A-96})$$

$$\bar{n}_n = -\sin(\phi - \alpha) \bar{i}' + \cos(\phi - \alpha) \bar{j}' \quad (\text{A-97})$$

CCW ROTATION

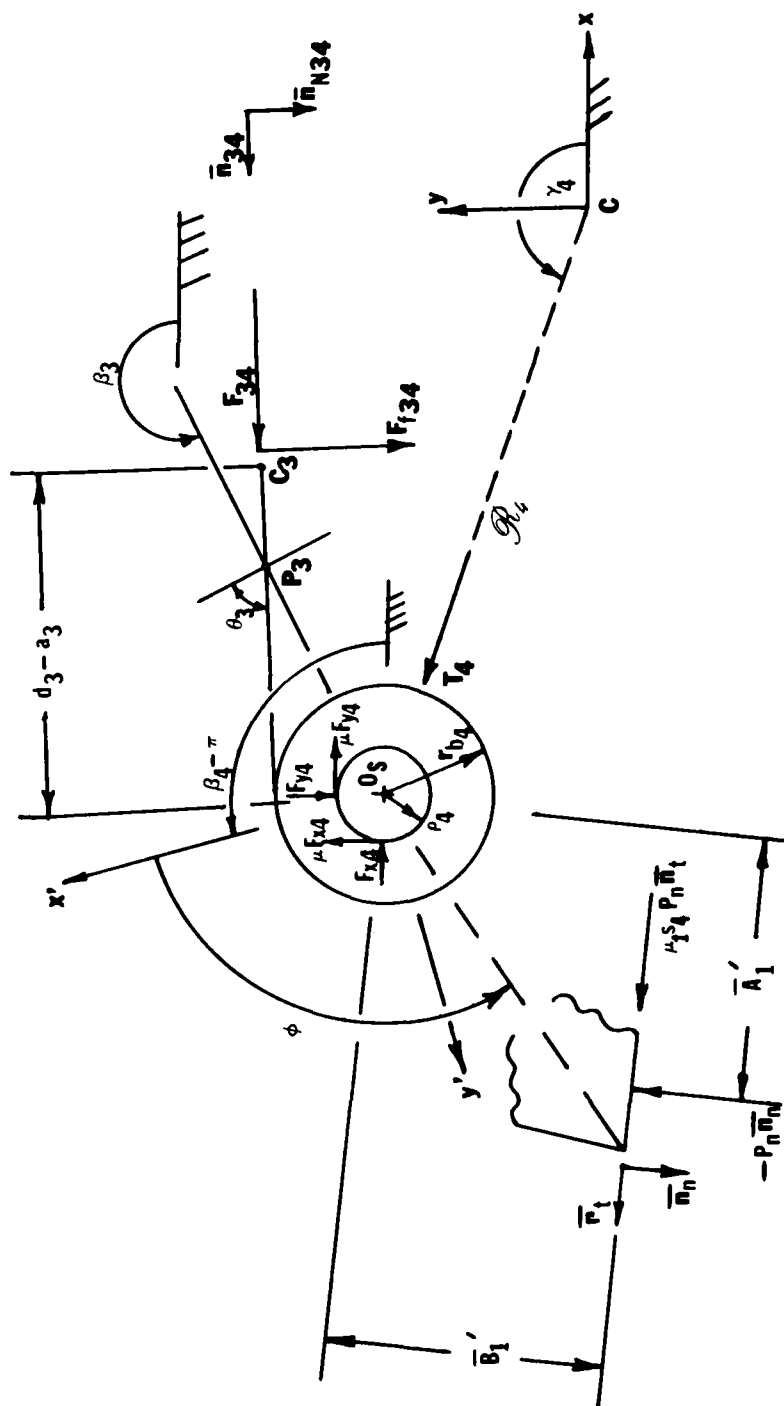


Figure A-6. Free body diagram of escape wheel and pinion 4

Equations A-55 and A-56, which hold regardless of configurations, are used for the following transformed expressions:

$$\bar{n}_t = -\cos(\phi - \alpha + \beta_4) \bar{i} - \sin(\phi - \alpha + \beta_4) \bar{j} \quad (A-98)$$

and

$$\bar{n}_n = \sin(\phi - \alpha + \beta_4) \bar{i} - \cos(\phi - \alpha + \beta_4) \bar{j} \quad (A-99)$$

The expressions for the unit vectors  $\bar{n}_{34}$  and  $\bar{n}_{N34}$ , as used in the analysis of pinion no. 4 in reference A-2, section A-1a, are of further interest

$$\bar{n}_{34} = \sin(\beta_3 + \theta_3) \bar{i} - \cos(\beta_3 + \theta_3) \bar{j} \quad (A-100)$$

and

$$\bar{n}_{N34} = \cos(\beta_3 + \theta_3) \bar{i} + \sin(\beta_3 + \theta_3) \bar{j} \quad (A-101)$$

Using the concept of the D'Alembert force

$$\bar{T}_4 = m_4 R_4 \omega^2 (\cos \gamma_4 \bar{i} + \sin \gamma_4 \bar{j}), \quad (A-102)$$

the force equation of the escape wheel assembly becomes for counterclockwise rotation<sup>A-5</sup> (ref A-2, eq A-35)

$$\begin{aligned} -P_n \bar{n}_n + \mu_1 s \mu_n^P \bar{n}_t + F_{34} \bar{n}_{34} + \mu_3 s F_{34} \bar{n}_{N34} + \bar{T}_4 + F_{x4} \bar{i} + \mu F_{y4} \bar{i} \\ + \mu F_{x4} \bar{j} - F_{y4} \bar{j} = 0 \end{aligned} \quad (A-103)$$

Note that the coefficient of friction  $\mu$  is now used for all pivots and gear tooth contacts<sup>A-6</sup> of the remainder of the mechanism train.

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A-5 See appendix F for description of motion reversal, i.e., clockwise escape wheel rotation. This may occur after severe impacts.

A-6 The signum functions  $s_1$ ,  $s_2$ , and  $s_3$  are defined in reference A-2 in connection with the tooth contact friction of the various meshes.

The moment equation of the escape wheel for counterclockwise rotation is written with the help of figure A-6

$$-P_n(A_1' + B_1'\mu_1s_4) - \mu\rho_4(\tilde{F}_{x4} + \tilde{F}_{y4}) + r_{b4}F_{34} - \mu s_3(d_3 - a_3)F_{34} = I_4\ddot{\phi} \quad (A-104)$$

where

$$A_1' = b \cos \alpha + g \quad (A-105)$$

$$B_1' = b \sin \alpha \quad (A-106)$$

The pivot forces  $\tilde{F}_{x4}$  and  $\tilde{F}_{y4}$  are treated again in the manner discussed earlier. They are obtained from the component expressions of equation A-103, i.e.,

$$\begin{aligned} & -P_n \sin(\phi - \alpha + \beta_4) - s_4\mu_1P_n \cos(\phi - \alpha + \beta_4) + F_{34}\sin(\beta_3 + \theta_3) \\ & + \mu s_3F_{34}\cos(\beta_3 + \theta_3) + T_4\cos\gamma_4 + F_{x4} + \mu F_{y4} = 0 \end{aligned} \quad (A-107)$$

and

$$\begin{aligned} & P_n \cos(\phi - \alpha + \beta_4) - s_4\mu_1P_n \sin(\phi - \alpha + \beta_4) - F_{34}\cos(\beta_3 + \theta_3) \\ & + \mu s_3F_{34}\sin(\beta_3 + \theta_3) + T_4\sin\gamma_4 - F_{y4} + \mu F_{x4} = 0 \end{aligned} \quad (A-108)$$

Simultaneous solution of equations A-107 and A-108 gives

$$\tilde{F}_{y4} = P_n A_9 + F_{34} A_{10} + T_4 A_{11} \quad (A-109)$$

$$\tilde{F}_{x4} = P_n A_{12} + F_{34} A_{13} + T_4 A_{14} \quad (A-110)$$

where

$$A_9 = \left| \frac{-(\mu_1 s_4 - \mu) \sin(\phi - \alpha + \beta_4) + (1 + \mu \mu_1 s_4) \cos(\phi - \alpha + \beta_4)}{1 + \mu^2} \right| \quad (A-111)$$

$$A_{10} = \left| \frac{-\mu(1 - s_3) \sin(\beta_3 + \theta_3) - (1 + \mu^2 s_3) \cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-112)$$

$$A_{11} = \left| \frac{\sin \gamma_4 - \mu \cos \gamma_4}{1 + \mu^2} \right| \quad (A-113)$$

$$A_{12} = \left| \frac{(1 + \mu_1 s_4) \sin(\phi - \alpha + \beta_4) + (s_4 \mu_1 - \mu) \cos(\phi - \alpha + \beta_4)}{1 + \mu^2} \right| \quad (A-114)$$

$$A_{13} = \left| \frac{-(1 + \mu^2 s_3) \sin(\beta_3 + \theta_3) + \mu(1 - s_3) \cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-115)$$

$$A_{14} = \left| \frac{-\cos \gamma_4 - \mu \sin \gamma_4}{1 + \mu^2} \right| \quad (A-116)$$

Substitution of the pivot force component expressions, with the indicated signs, into the moment equation A-104 will furnish the correct pivot friction moments. The resulting expression is then solved for the contact force  $P_n$

$$P_n = \frac{-I_4 \ddot{\phi} + F_{34} A_{15} - T_4 A_{16}}{A_{17}} \quad (A-117)$$

where

$$A_{15} = r_{b4} - \mu [s_3(d_3 - a_3) + \rho_4(A_{10} + A_{13})] \quad (A-118)$$

$$A_{16} = \mu \rho_4(A_{11} + A_{14}) \quad (A-119)$$

$$A_{17} = A_1' + \mu_1 s_4 B_1' + \mu \rho_4(A_9 + A_{12}) \quad (A-120)$$

COMBINED COUPLED MOTION DIFFERENTIAL EQUATION  
FOR ESCAPE WHEEL AND PALLET  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

To obtain a combined coupled motion differential equation for the pallet and escape wheel in terms of the escape wheel angle  $\phi$ , equations A-95 and A-117, both for the contact force  $P_n$  are set equal to each other. This furnishes

$$\begin{aligned} & \left[ I_4 A_{18} + I_{PR} A_{17} U \right] \ddot{\phi} + \left[ I_{PR} A_{17} V + A_{17} A_{21} Z^2 \right] \dot{\phi}^2 + 2 \frac{\omega}{|\omega|} A_{17} A_{20} Z \dot{\phi} \\ & = A_{15} A_{18} F_{34} - A_{16} A_{18} T_4 - A_{17} \omega^2 \left[ A_{19} - m_p r_{CP} R_5 \sin(\gamma_p' - \psi - \psi_C) \right] \end{aligned} \quad (A-121)$$

To complete the system differential equation, it is necessary to find an expression for the contact force  $F_{34}$  in the above. This will be accomplished by combining the appropriate differential equations for gear and pinion no. 2 and 3 and for the rotor.

DYNAMICS OF ROTOR (GEAR NO. 1)  
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER  $s_6$ )

A free body diagram of the rotor for configuration no. 1 is shown in figure A-7. The acceleration  $\bar{A}_{CR}$  of its center of mass, with constant spin velocity  $\omega$ , is given by

$$\begin{aligned} \bar{A}_{CR} = & -\omega^2 R_1 \bar{i} - (\omega + \dot{\phi}_1)^2 r_{C1} \left[ \cos(\phi_{1C} + \phi_1) \bar{i} + \sin(\phi_{1C} + \phi_1) \bar{j} \right] \\ & + \ddot{\phi}_1 r_{C1} \left[ -\sin(\phi_{1C} + \phi_1) \bar{i} + \cos(\phi_{1C} + \phi_1) \bar{j} \right] \end{aligned} \quad (A-122)$$

Since the motion of the rotor must be expressed in terms of the escape wheel variables, the following transformations are now introduced:

$$\dot{\phi}_1 = N_{41} \dot{\phi} \quad (A-123)$$

$$\ddot{\phi}_1 = N_{41} \ddot{\phi} \quad (A-124)$$

where

$$N_{41} = - \frac{N_{P4} N_{P3} N_{P2}}{N_{G3} N_{G2} N_{G1}} \quad (A-125)$$

Figure A-7. Free body diagram of rotor (gear no. 1)

The rotor angle  $\phi_{1C} + \phi_1$ , is expressed as follows:

$$\phi_{1C} + \phi_1 = \phi_{1C} + N_{41} \phi_T \quad (A-126)$$

where  $\phi_T$  represents the total rotation of the escape wheel from the inception of motion. (The section on Geometry of Fuze Body Configuration describes the manner in which  $\phi_T$  is obtained as a function of the instantaneous angle  $\phi$ .)

Equation A-122 then becomes

$$\begin{aligned} \bar{A}_{CR} = & -\omega^2 R_1 \bar{i} - (\omega + N_{41} \dot{\phi})^2 r_{C1} [\cos(\phi_{1C} + N_{41} \phi_T) \bar{i} + \sin(\phi_{1C} + N_{41} \phi_T) \bar{j}] \\ & + N_{41} \ddot{\phi} r_{C1} [-\sin(\phi_{1C} + N_{41} \phi_T) \bar{i} + \cos(\phi_{1C} + N_{41} \phi_T) \bar{j}] \end{aligned} \quad (A-127)$$

Newton's force equation is now written for clockwise rotation of the rotor with the help of equation A-127 and the free body diagram of figure A-7:<sup>A-7</sup>

$$-F_{12} \bar{n}_{12} - \mu s_1 F_{12} \bar{n}_{N12} - F_{x1} \bar{i} + \mu F_{y1} \bar{i} + F_{y1} \bar{j} + \mu F_{x1} \bar{j} = m_1 \bar{A}_{CR} \quad (A-128)$$

where

$$\bar{n}_{12} = \sin(\beta_1 + \theta_1) \bar{i} - \cos(\beta_1 + \theta_1) \bar{j} \quad (A-129)$$

$$\bar{n}_{N12} = \cos(\beta_1 + \theta_1) \bar{i} + \sin(\beta_1 + \theta_1) \bar{j} \quad (A-130)$$

(ref A-2, eq A-78 and A-79)

Further, in figure A-7

$$\bar{F}_{21} = -F_{12} \bar{n}_{12} \quad (A-131)$$

and

$$\bar{F}_{f21} = -\mu s_1 F_{12} \bar{n}_{N12} \quad (A-132)$$

(ref A-2, eq A-103 and A-104)

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A-7 Description of motion reversal, appendix F.

The moment equation must be written in the manner of equation A-61, with respect to the accelerated point  $O_1$ . The pivot 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

$$\begin{aligned} R_{b1} F_{12} \bar{k} - \mu s_1 a_1 F_{12} \bar{k} + \mu \rho_1 (\tilde{F}_{x1} + F_{y1}) \bar{k} \\ = -(-\omega^2 R_1 \bar{i}) \times m_1 r_{C1} [\cos(\phi_{1C} + N_{41} \phi_T) \bar{i} + \sin(\phi_{1C} + N_{41} \phi_T) \bar{j}] \\ + I_1 N_{41} \ddot{\phi} \bar{k} \end{aligned} \quad (A-133)$$

This becomes

$$\begin{aligned} R_{b1} F_{12} - \mu s_1 a_1 F_{12} + \mu \rho_1 (\tilde{F}_{x1} + \tilde{F}_{y1}) \\ = m_1 \omega^2 R_1 r_{C1} \sin(\phi_{1C} + N_{41} \phi_T) + I_1 N_{41} \ddot{\phi} \end{aligned} \quad (A-134)$$

The forces  $\tilde{F}_{x1}$  and  $\tilde{F}_{y1}$  are obtained from the simultaneous solution of the following component expressions of equation A-128:

$$\begin{aligned} -F_{12} \sin(\beta_1 + \theta_1) - \mu s_1 F_{12} \cos(\beta_1 + \theta_1) - F_{x1} + \mu F_{y1} \\ = m_1 [-\omega^2 R_1 - (\omega + N_{41} \dot{\phi})^2 r_{C1} \cos(\phi_{1C} + N_{41} \phi_T) - N_{41} \ddot{\phi} r_{C1} \sin(\phi_{1C} + N_{41} \phi_T)] \end{aligned} \quad (A-135)$$

$$\begin{aligned} F_{12} \cos(\beta_1 + \theta_1) - \mu s_1 F_{12} \sin(\beta_1 + \theta_1) + F_{y1} + \mu F_{x1} \\ = m_1 [-(\omega + N_{41} \dot{\phi})^2 r_{C1} \sin(\phi_{1C} + N_{41} \phi_T) + N_{41} \ddot{\phi} r_{C1} \cos(\phi_{1C} + N_{41} \phi_T)] \end{aligned} \quad (A-136)$$

Simultaneous solution of the above gives

$$\tilde{F}_{y1} = F_{12} A_{23} \pm \omega^2 A_{24} \pm \frac{2\omega}{|\omega|} N_{41} \dot{\phi} A_{25} \pm (N_{41} \dot{\phi})^2 A_{25} \pm N_{41} \ddot{\phi} A_{26} \quad (A-137)$$

and

$$\tilde{F}_{x1} = F_{12} A_{27} \pm \omega^2 A_{28} \pm 2 \frac{\omega}{|\omega|} N_{41} \dot{\phi} A_{29} \pm (N_{41} \dot{\phi})^2 A_{29} \pm N_{41} \ddot{\phi} A_{30} \quad (A-138)$$

where

$$A_{23} = \left| \frac{\mu(1+s_1)\sin(\beta_1+\theta_1) - (1-\mu^2 s_1)\cos(\beta_1+\theta_1)}{1 + \mu^2} \right| \quad (A-139)$$

$$A_{24} = \left| \frac{m_1 [\mu R_1 + r_{C1} (\mu \cos(\phi_{1C} + N_{41} \phi_T) + \sin(\phi_{1C} + N_{41} \phi_T))] }{1 + \mu^2} \right| \quad (A-140)$$

$$A_{25} = \left| \frac{m_1 r_{C1} [\mu \cos(\phi_{1C} + N_{41} \phi_T) + \sin(\phi_{1C} + N_{41} \phi_T)] }{1 + \mu^2} \right| \quad (A-141)$$

$$A_{26} = \left| \frac{m_1 r_{C1} [\cos(\phi_{1C} + N_{41} \phi_T) - \mu \sin(\phi_{1C} + N_{41} \phi_T)] }{1 + \mu^2} \right| \quad (A-142)$$

and

$$A_{27} = \left| \frac{(1-\mu^2 s_1)\sin(\beta_1+\theta_1) + \mu(1+s_1)\cos(\beta_1+\theta_1)}{1 + \mu^2} \right| \quad (A-143)$$

$$A_{28} = \left| \frac{m_1 [\mu R_1 + r_{C1} (\cos(\phi_{1C} + N_{41} \phi_T) - \mu \sin(\phi_{1C} + N_{41} \phi_T))] }{1 + \mu^2} \right| \quad (A-144)$$

$$A_{29} = \left| \frac{m_1 r_{C1} [\cos(\phi_{1C} + N_{41} \phi_T) - \mu \sin(\phi_{1C} + N_{41} \phi_T)] }{1 + \mu^2} \right| \quad (A-145)$$

$$A_{30} = \left| \frac{m_1 r_{C1} [\sin(\phi_{1C} + N_{41} \phi_T) + \mu \cos(\phi_{1C} + N_{41} \phi_T)] }{1 + \mu^2} \right| \quad (A-146)$$

Equations A-137 and A-138 are now substituted into the moment equation A-134 as follows:

$$\begin{aligned}
 R_{b1} F_{12} - \mu s_1 a_1 F_{12} + \mu \rho_1 [F_{12}(A_{23} + A_{27}) \pm \omega^2 (A_{24} + A_{28}) \\
 \pm 2 \frac{\omega}{|\omega|} N_{41} \dot{\phi} (A_{25} + A_{29}) \pm (N_{41} \dot{\phi})^2 (A_{25} + A_{29}) \pm N_{41} \ddot{\phi} (A_{26} + A_{30})] \\
 = m_1 \omega^2 r_{c1}^2 \sin(\phi_{1C} + N_{41} \phi_T) + I_1 N_{41} \ddot{\phi}
 \end{aligned} \tag{A-147}$$

In order to have the pivot friction moments positive for clockwise rotation, the following terms must be positive:

$$\mu \rho_1 F_{12} (A_{23} + A_{27})$$

$$\mu \rho_1 \omega^2 (A_{24} + A_{28})$$

$$\mu \rho_1 (N_{41} \dot{\phi})^2 (A_{25} + A_{29})$$

The term

$$2 \mu \rho_1 \frac{\omega}{|\omega|} N_{41} \dot{\phi} (A_{25} + A_{29})$$

must also be positive for clockwise rotation of the rotor. This can only be accomplished by making the term negative since  $N_{41}$  is negative. To avoid the use of  $\mu$  as a signum function, as required for motion reversal according to appendix E, its value is made absolute. Possible motion reversal is then only affected by the sign of  $\dot{\phi}$ , the angular velocity of the escape wheel, which is normally positive. Then the resulting term has the following form:

$$-2 |\mu| \rho_1 \frac{\omega}{|\omega|} N_{41} \dot{\phi} (A_{25} + A_{29})$$

In order 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-147, the ideas presented in appendix F are used. To be able to do this let the value of the

coefficient of friction of this term become absolute, so that it ceases to serve as a directional signum function in the sense of appendix E. Further let the expression be changed, for the time being, so that it becomes a function of the rotor acceleration  $\ddot{\phi}_1$ . With the above and in the sense of equation F-2, appendix F, the absolute value of this friction moment  $M_{AA}$  may be expressed as

$$M_{AA} = |\mu|\rho_1 (A_{26} + A_{30}) \ddot{\phi}_1$$

From this point on one may use the reasoning of appendix F directly, keeping in mind that  $|\mu|\rho_1(A_{26} + A_{30})$  and  $\ddot{\phi}_1$  are now used instead of  $A_{22}$  and  $\psi$ , respectively.

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

$$I_{1R} = I_1 + |\mu|\rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi}_1 \text{ and } \ddot{\phi}_1 \text{ have the same sign,}$$

and

$$I_{1R} = I_1 - |\mu|\rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi}_1 \text{ and } \ddot{\phi}_1 \text{ have opposite signs}$$

Equation A-147 gives all relevant expressions in terms of the escape wheel variables  $\dot{\phi}$  and  $\ddot{\phi}$ . Since they both are proportional to  $\dot{\phi}_1$  and  $\ddot{\phi}_1$  by the identical gear ratio  $N_{41}$  (or in the case of the two pass train by way of  $N_{31}$ ), one may readily extend the above computational rule to the escape wheel variables. This is reflected by equations A-155 and A-156.

The above considerations give the moment equation A-147 the following form:

$$\begin{aligned} F_{12} [R_{b1} - \mu_1 a_1 + \mu \rho_1 (A_{23} + A_{27})] + \omega^2 \rho_1 \mu (A_{24} + A_{28}) \\ - 2 |\mu| \rho_1 \frac{\omega}{|\omega|} N_{41} \dot{\phi} (A_{25} + A_{29}) + \mu \rho_1 (N_{41} \dot{\phi})^2 (A_{25} + A_{29}) \\ = m_1 r_{C1} \ell_{1\omega}^2 \sin(\phi_{1C} + N_{41} \phi_T) + (I_1 + \mu \rho_1 (A_{26} + A_{30})) N_{41} \ddot{\phi} \end{aligned} \quad (A-148)$$

Finally the above expression is solved for  $F_{12}$

$$F_{12} = \frac{-A_{32} + N_{41} A_{33} \dot{\phi} - A_{34} (N_{41} \dot{\phi})^2 + A_{35} \sin(\phi_{1C} + N_{41} \phi_T) + I_{1R} N_{41} \ddot{\phi}}{A_{31}} \quad (A-149)$$

where

$$A_{31} = R_{b1} - \mu s_1 a_1 + \mu \rho_1 (A_{23} + A_{27}) \quad (A-150)$$

$$A_{32} = \omega^2 \rho_1 \mu (A_{24} + A_{28}) \quad (A-151)$$

$$A_{33} = 2 \frac{\omega}{|\omega|} |\mu| \rho_1 (A_{25} + A_{29}) \quad (A-152)$$

$$A_{34} = \mu \rho_1 (A_{25} + A_{29}) \quad (A-153)$$

$$A_{35} = m_1 R_{1C}^2 \omega^2 \quad (A-154)$$

$$I_{1R} = I_1 + |\mu| \rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have the same signs} \quad (A-155)$$

$$I_{1R} = I_1 - |\mu| \rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have opposite signs} \quad (A-156)$$

#### DYNAMICS OF GEAR AND PINION SET NO. 3 (APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER $s_6$ )

The moment equation of gear and pinion no. 3 may be taken from reference A-2 if its right hand side is set equal to  $I_3 \ddot{\phi}_3$  rather than to zero. (The dynamic force equation was already satisfied by the inclusion of the inertia force  $T_3$ .) Thus, with the help of equation A-65, reference A-2, and letting

$$\ddot{\phi}_3 = N_{43} \ddot{\phi} \quad (A-157)$$

1

$$N_{43} = - \frac{N_{P4}}{N_{G3}} \quad (A-158)$$

following expression is obtained

$$\begin{aligned} &_3 F_{34} - \mu s_3 a_3 F_{34} - r_{b3} F_{23} + \mu s_2 (d_2 - a_2) F_{23} \\ &+ \mu \rho_3 [F_{23}(A_{36} + A_{39}) + T_3(A_{37} + A_{40}) + F_{34}(A_{38} + A_{41})] \\ &= I_3 N_{43} \phi \end{aligned} \quad (A-159)$$

re

$$6 = \left| \frac{(1 + \mu^2 s_2) \cos(\beta_2 - \theta_2) + \mu(s_2 - 1) \sin(\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-160)$$

$$7 = \left| \frac{\sin \gamma_3 + \mu \cos \gamma_3}{1 + \mu^2} \right| \quad (A-161)$$

$$8 = \left| \frac{(1 - \mu^2 s_3) \cos(\beta_3 + \theta_3) - \mu(1 + s_3) \sin(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-162)$$

$$9 = \left| \frac{(1 + \mu^2 s_2) \sin(\beta_2 - \theta_2) + \mu(1 - s_2) \cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-163)$$

$$0 = \left| \frac{\mu \sin \gamma_3 - \cos \gamma_3}{1 + \mu^2} \right| \quad (A-164)$$

$$1 = \left| \frac{(1 - \mu^2 s_3) \sin(\beta_3 + \theta_3) + \mu(1 + s_3) \cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \quad (A-165)$$

If equation A-159 is solved for  $F_{23}$ , the following is obtained:

$$F_{23} = \frac{F_{34} A_{42} + T_3 A_{43} - I_3 N_{43} \ddot{\phi}}{A_{44}} \quad (A-166)$$

where

$$A_{42} = R_{b3} - \mu [s_3 a_3 - \rho_3 (A_{38} + A_{41})] \quad (A-167)$$

$$A_{43} = \mu \rho_3 (A_{37} + A_{40}) \quad (A-168)$$

$$A_{44} = r_{b3} - \mu [s_2 (d_2 - a_2) + \rho_3 (A_{36} + A_{39})] \quad (A-169)$$

#### DYNAMICS OF GEAR AND PINION SET NO. 2 (APPLICATION TO BOTH CONFIGURATIONS WITH PROPER $s_6$ )

The moment equation of gear and pinion set no. 2 may also be taken from reference A-2 with the provision that its right hand side is set equal to  $I_2 \ddot{\phi}$ , rather than equal to zero. (Again, the force equation was already satisfied by the inertia force  $T_2$ .)

With the help of equation A-92, reference A-2, and letting

$$\ddot{\phi}_2 = N_{42} \ddot{\phi} \quad (A-170)$$

where

$$N_{42} = - \frac{N_{P4} N_{P3}}{N_{G3} N_{G2}} \quad (A-171)$$

the following is obtained:

$$\begin{aligned} & -R_{b2} F_{23} + \mu s_2 a_2 F_{23} + r_{b2} F_{12} - \mu s_1 (d_1 - a_1) F_{12} \\ & - \mu \rho_2 [F_{12} (A_{45} + A_{48}) + T_2 (A_{46} + A_{49}) + F_{23} (A_{47} + A_{50})] = I_2 N_{42} \ddot{\phi} \end{aligned} \quad (A-172)$$

where

$$A_{45} = \left| \frac{\mu(1 - s_1)\sin(\beta_1 + \theta_1) + (1 + \mu^2 s_1)\cos(\beta_1 + \theta_1)}{1 + \mu^2} \right| \quad (A-173)$$

$$A_{46} = \left| \frac{\sin\gamma_2 - \mu\cos\gamma_2}{1 + \mu^2} \right| \quad (A-174)$$

$$A_{47} = \left| \frac{\mu(1 + s_2)\sin(\beta_2 - \theta_2) + (1 - \mu^2 s_2)\cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-175)$$

$$A_{48} = \left| \frac{\mu(1 - s_1)\cos(\beta_1 + \theta_1) - (1 + \mu^2 s_1)\sin(\beta_1 + \theta_1)}{1 + \mu^2} \right| \quad (A-176)$$

$$A_{49} = \left| \frac{\mu\sin\gamma_2 + \cos\gamma_2}{1 + \mu^2} \right| \quad (A-177)$$

$$A_{50} = \left| \frac{(1 - \mu^2 s_2)\sin(\beta_2 - \theta_2) - \mu(1 + s_2)\cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \quad (A-178)$$

The following is found if equation A-172 is solved for  $F_{12}$ :

$$F_{12} = \frac{F_{23} A_{51} + T_2 A_{52} + I_2 N_{42} \ddot{\phi}}{A_{53}} \quad (A-179)$$

where

$$A_{51} = R_{b2} - \mu [s_2 a_2 - \rho_2 (A_{47} + A_{50})] \quad (A-180)$$

$$A_{52} = \mu \rho_2 (A_{46} + A_{49}) \quad (A-181)$$

$$A_{53} = r_{b2} - \mu [s_1 (d_1 - a_1) + \rho_2 (A_{45} + A_{48})] \quad (A-182)$$

DYNAMICS OF COMBINED SYSTEM IN COUPLED MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER  $s_6$ )

In order to obtain a single differential equation for the total system in coupled motion, in terms of the escape wheel variable  $\phi$ , an appropriate expression for the contact force  $F_{34}$  must be substituted into equation A-121. To this end, equations A-149 and A-179, both expressions for the force  $F_{12}$  and originating from the expressions for the rotor and gear and pinion set no. 2, are first set equal to each other and then are solved for the force  $F_{23}$ :

$$F_{23} = \frac{1}{A_{31}A_{51}} \left[ -A_{32}A_{53} - A_{31}A_{52}T_2 + A_{35}A_{53}\sin(\phi_{1C} + N_{41}\phi_T) \right. \\ \left. + A_{33}A_{53}N_{41}\dot{\phi} - A_{34}A_{53}N_{41}^2\dot{\phi}^2 \right. \\ \left. + (A_{53}I_{1R}N_{41} - A_{31}I_{2N}N_{42})\ddot{\phi} \right] \quad (A-183)$$

The just determined expression for  $F_{23}$  is set equal to equation A-166 for  $F_{23}$ , which originates from the dynamics of gear and pinion set no. 3. This results in:

$$F_{34} = \frac{1}{A_{31}A_{42}A_{51}} \left[ -A_{32}A_{44}A_{53} - A_{31}A_{44}A_{52}T_2 - A_{31}A_{43}A_{51}T_3 \right. \\ \left. + A_{35}A_{44}A_{53}\sin(\phi_{1C} + N_{41}\phi_T) + A_{33}A_{44}A_{53}N_{41}\dot{\phi} \right. \\ \left. - A_{34}A_{44}A_{53}(N_{41}\dot{\phi})^2 \right. \\ \left. + (A_{44}A_{53}I_{1R}N_{41} - A_{31}A_{44}I_{2N}N_{42} + A_{31}A_{51}I_{3N}N_{43})\ddot{\phi} \right] \quad (A-184)$$

Finally, the above is substituted into equation A-121. The following system differential equation for coupled motion is obtained:

$$A_{54}\ddot{\phi} + A_{55}\dot{\phi}^2 + A_{56}\dot{\phi} = A_{57} + A_{58}\sin(\gamma_p - \psi - \psi_c) + A_{59}\sin(\phi_{1c} + N_{41}\phi_T) \quad (A-185)$$

where

$$A_{54} = I_{4A}A_{18} + I_{PR}A_{17}U - \frac{A_{15}A_{18}A_{44}A_{53}}{A_{31}A_{42}A_{51}}N_{41}I_{1R} \\ + \frac{A_{15}A_{18}A_{44}}{A_{42}A_{51}}N_{42}I_2 - \frac{A_{15}A_{18}}{A_{42}}N_{43}I_3 \quad (A-186)$$

$$A_{55} = I_{PR}A_{17}V + A_{17}A_{21}Z^2 + \frac{A_{15}A_{18}A_{34}A_{44}A_{53}}{A_{31}A_{42}A_{51}}N_{41}^2 \quad (A-187)$$

$$A_{56} = 2\frac{\omega}{|\omega|}A_{17}A_{20}Z - \frac{A_{15}A_{18}A_{34}A_{44}A_{53}}{A_{31}A_{42}A_{51}}N_{41} \quad (A-188)$$

$$A_{57} = -A_{16}A_{18}T_4 - \frac{A_{15}A_{18}A_{43}}{A_{42}}T_3 - \frac{A_{15}A_{18}A_{44}A_{52}}{A_{42}A_{51}}T_2 \\ - \frac{A_{15}A_{18}A_{32}A_{44}A_{53}}{A_{31}A_{42}A_{51}} - A_{17}A_{19}\omega^2 \quad (A-189)$$

$$A_{58} = A_{17}\omega^2 m_p r_{CP} R_5 \quad (A-190)$$

$$A_{59} = \frac{A_{15}A_{18}A_{35}A_{44}A_{53}}{A_{31}A_{42}A_{51}} \quad (A-191)$$

CONTACT FORCE EXPRESSIONS FOR COUPLED MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER  $s_6$ )

The following force expressions for various contact forces are useful for strength calculations, and are applicable to both configurations.

According to equation A-184

$$F_{34} = \frac{1}{A_{31}A_{42}A_{51}} \left[ -A_{32}A_{44}A_{53} - A_{31}A_{44}A_{52}T_2 - A_{31}A_{43}A_{51}T_3 \right. \\ \left. + A_{35}A_{44}A_{53}\sin(\phi_{1C} + N_{41}\phi_T) + A_{33}A_{44}A_{53}N_{41}\dot{\phi} \right. \\ \left. - A_{34}A_{44}A_{53}(N_{41}\dot{\phi})^2 + (A_{44}A_{53}I_{1R}N_{41} \right. \\ \left. - A_{31}A_{44}I_2N_{42} + A_{31}A_{51}I_3N_{43})\ddot{\phi} \right] \quad (A-192)$$

According to equation A-166

$$F_{23} = \frac{F_{34}A_{42} + T_3A_{43} - I_3N_{43}\ddot{\phi}}{A_{44}} \quad (A-193)$$

According to equation A-123

$$F_{12} = \frac{F_{23}A_{51} + T_2A_{52} + I_2N_{42}\ddot{\phi}}{A_{53}} \quad (A-194)$$

The contact force  $P_0$ , between escape wheel and pallet, may either be expressed in terms of the escape wheel variable  $\phi$  according to equation A-117, or in terms of the pallet variable  $\psi$  according to equation A-91. Thus,

$$P_n = \frac{-I_4 \ddot{\phi} + F_{34} A_{15} - T_4 A_{16}}{A_{17}} \quad (A-195)$$

or

$$P_{n\psi} = \frac{1}{A_{18}} \left[ I_{PR} \ddot{\psi} + A_{21} \dot{\psi}^2 + 2 \frac{\omega}{|\omega|} A_{20} \dot{\psi} + \omega^2 A_{19} - m_p r_{CP} R_5 \omega^2 \sin(\gamma_p' - \psi - \psi_C) \right] \quad (A-196)$$

DIFFERENTIAL EQUATIONS FOR FREE MOTION REGIME  
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER  $s_6$ )

Both the differential equations for the free motion of the pallet and the system composed of the escape wheel, gear and pinion no. 3, gear and pinion no. 2, and the rotor may be obtained from certain coupled motion expressions.

Free Motion of Pallet

Let  $P_n = 0$  in equation A-91. After some rearrangement, the following differential equation results:

$$A_{60} \ddot{\psi} + A_{21} \dot{\psi}^2 + A_{61} \dot{\psi} = -A_{62} + A_{63} \sin(\gamma_p' - \psi - \psi_C) \quad (A-197)$$

where

$$A_{60} = I_{PR}^{A-8} \quad (A-198)$$

---

A-8 For free motion,  $I_{PR}$  cannot be zero since it would make the value of  $\ddot{\psi}$  in the Runge-Kutta solution indefinite (footnote A-4).

$$\Lambda_{61} = 2 \frac{\omega^2}{|\omega|} \Lambda_{20} \quad (\text{A-199})$$

$$\Lambda_{62} = \omega^2 \Lambda_{19} \quad (\text{A-200})$$

$$\Lambda_{63} = \omega^2 m_p r_{CP} \phi_5 \quad (\text{A-201})$$

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

For the present case start by letting  $P_n = 0$  in the escape wheel expression A-117, i.e.,

$$I_4 \ddot{\phi} = \Lambda_{15} F_{34} - T_4 \Lambda_{16} \quad (\text{A-202})$$

Equation A-184, which furnishes an expression for force  $F_{34}$ , is then substituted into equation A-202. This provides the desired second free motion differential equation

$$\Lambda_{64} \ddot{\phi} + \Lambda_{65} \dot{\phi}^2 - \Lambda_{66} \dot{\phi} = \Lambda_{67} + \Lambda_{68} \sin(\phi_{1C} + N_{41} \phi_T) \quad (\text{A-203})$$

where

$$\Lambda_{64} = I_4 - \frac{A_{15} A_{44} A_{53}}{A_{31} A_{42} A_{51}} N_{41} I_{1R} + \frac{A_{15} A_{44}}{A_{42} A_{51}} N_{42} I_2 - \frac{A_{15}}{A_{42}} N_{43} I_3 \quad (\text{A-204})$$

$$\Lambda_{65} = \frac{A_{15} A_{34} A_{44} A_{53}}{A_{31} A_{42} A_{51}} N_{41}^2 \quad (\text{A-205})$$

$$\Lambda_{66} = \frac{A_{15} A_{33} A_{44} A_{53}}{A_{31} A_{42} A_{51}} N_{41} \quad (\text{A-206})$$

$$A_{67} = -A_{16}T_4 - \frac{A_{15}A_{43}}{A_{42}} T_3 - \frac{A_{15}A_{44}A_{52}}{A_{42}A_{51}} T_2 - \frac{A_{15}A_{32}A_{44}A_{53}}{A_{31}A_{42}A_{51}} \quad (A-207)$$

$$A_{68} = \frac{A_{15}A_{35}A_{44}A_{53}}{A_{31}A_{42}A_{51}} \quad (A-208)$$

CONTACT FORCE EXPRESSIONS FOR FREE MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER  $s_6$ )

The contact force  $F_{F34}$  may be obtained from equation A-117 by setting  $P_n$  equal to zero, so that

$$F_{F34} = \frac{I_4 \ddot{\phi} + T_4 A_{16}}{A_{15}} \quad (A-209)$$

The expression for the contact force  $F_{F23}$  has the same form as equation A-193 since it originates from the dynamics of gear and pinion set no. 3

$$F_{F23} = \frac{F_{F34} A_{42} + T_3 A_{43} - I_3 N_{43} \ddot{\phi}}{A_{44}} \quad (A-210)$$

Similarly, the form of  $F_{F12}$  is like that of equation A-194

$$F_{F12} = \frac{F_{F23} A_{51} + T_2 A_{52} + I_2 N_{42} \ddot{\phi}}{A_{53}} \quad (A-211)$$

CHANGES IN IMPACT EXPRESSIONS  
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER  $s_6$ )

While generally the impact description of reference A-1 remains unchanged, the total moment of inertia  $I_{STOT}$  of the escape wheel is now increased, since it must also account for the presence of the gear train and the rotor. Therefore,

$$I_{STOT} = I_4 + I_3 N_{43}^2 + I_2 N_{42}^2 + I_1 N_{41}^2 \quad (A-212)$$

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-125, A-158, and A-171 for the transmission ratios.

#### REFERENCES

- A-1. G. G. Lowen and F. R. Tepper, "Dynamics of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.
- A-2. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX B

DYNAMICS OF ROTOR DRIVEN S&A DEVICE WITH A TWO-PASS  
INVOLUTE GEAR TRAIN AND A PIN PALLET RUNAWAY ESCAPEMENT

## DESCRIPTION OF SYSTEMS AND OUTLINE OF DERIVATIONS

Figures B-1 and B-2 show the two configurations of the S&A mechanism discussed in this appendix. These devices differ from those described in appendix A because they contain only two step-up gear meshes. Since the escape wheel still is assumed to have counterclockwise rotation, the motion of the rotor must also be counterclockwise, and the gear and pinion set no. 2 must turn in a clockwise direction. This requires certain changes in the rotor geometry as well as in the direction of the lines of action of the gear contact forces  $F_{12}$  and  $F_{23}$ . Naturally, all quantities previously associated with gear and pinion set no. 3 are now absent.

The general approach to the modeling of these devices is the same as that used in appendix A. While the derivations are specifically for configuration no. 1, the results are applicable to both configurations as long as the appropriate fuze body angles are used.

### GEOMETRY OF FUZE BODY CONFIGURATIONS

#### Fuze Body Configuration No. 1

Figure B-3 indicates the following relationships for the angles  $\gamma_1$ ,  $\delta_1$  and  $\beta_1$  for configuration no. 1:

According to equation A-1 (app A)

$$\gamma_2 = \cos^{-1} \left[ \frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2 R_1 R_2} \right] \quad (B-1)$$

Further, according to equation A-2 (app A)

$$\gamma_3' = \cos^{-1} \left[ \frac{R_2^2 + R_3^2 - (R_{p2} + r_{p3})^2}{2 R_2 R_3} \right] \quad (B-2)$$

Finally, from equation A-3 (app A)

$$\gamma_3 = \gamma_2 + \gamma_3' \quad (B-3)$$

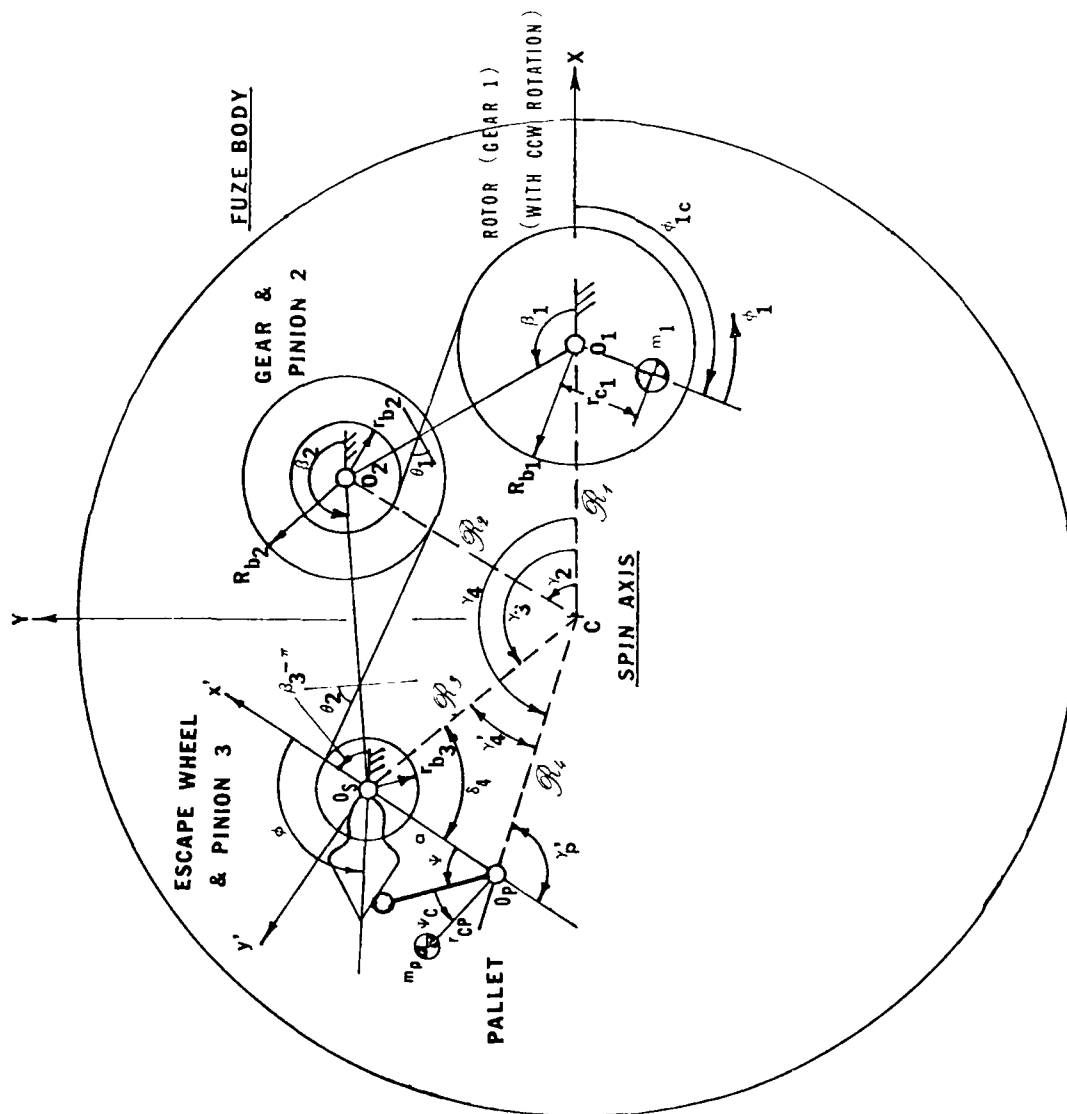


Figure B-1. Rotor driven S&A device with two pass step-up gear train - configuration no. 1

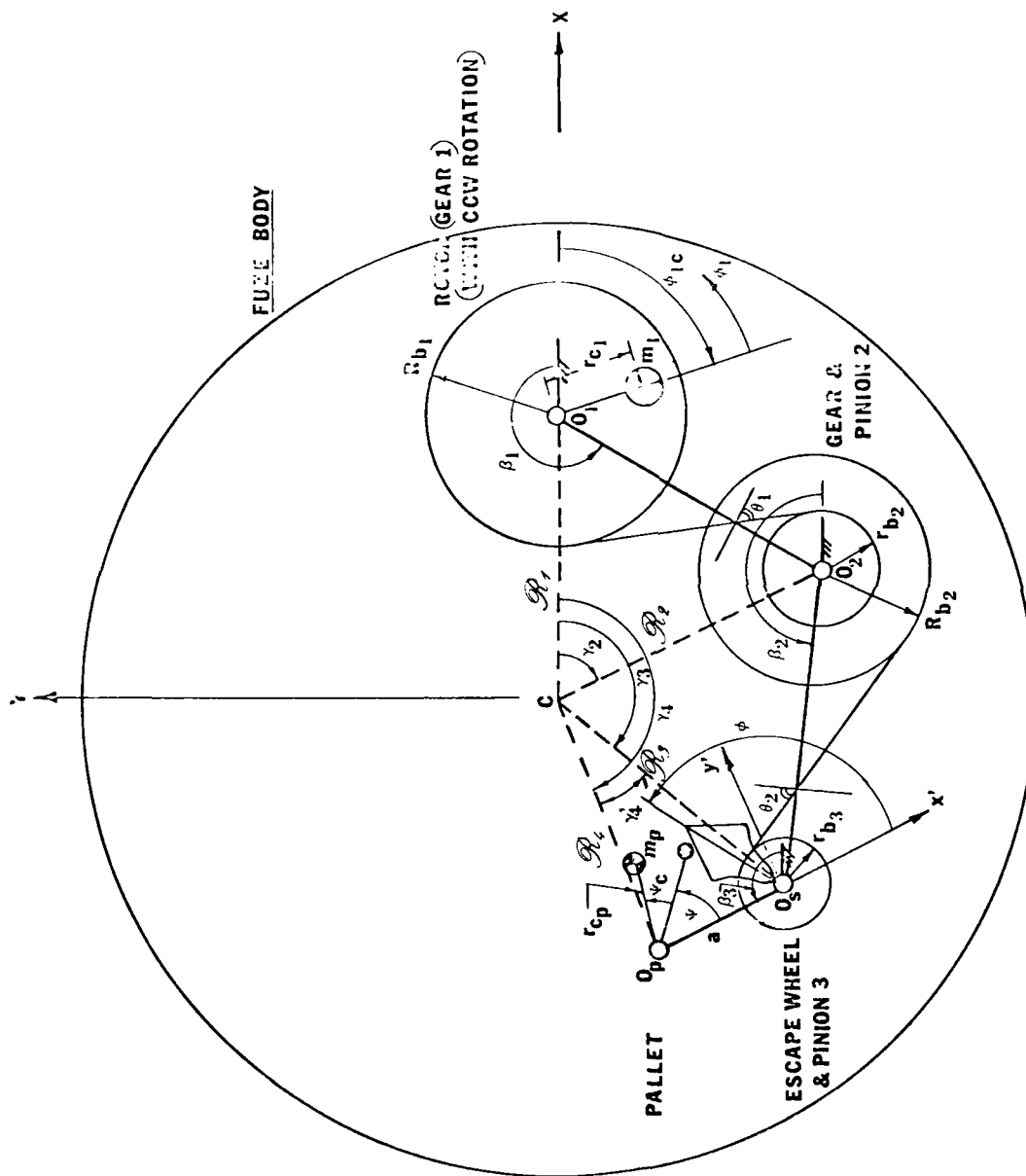


Figure B-2. Rotor driven S&A device with two pass step-up gear train configuration no. 2

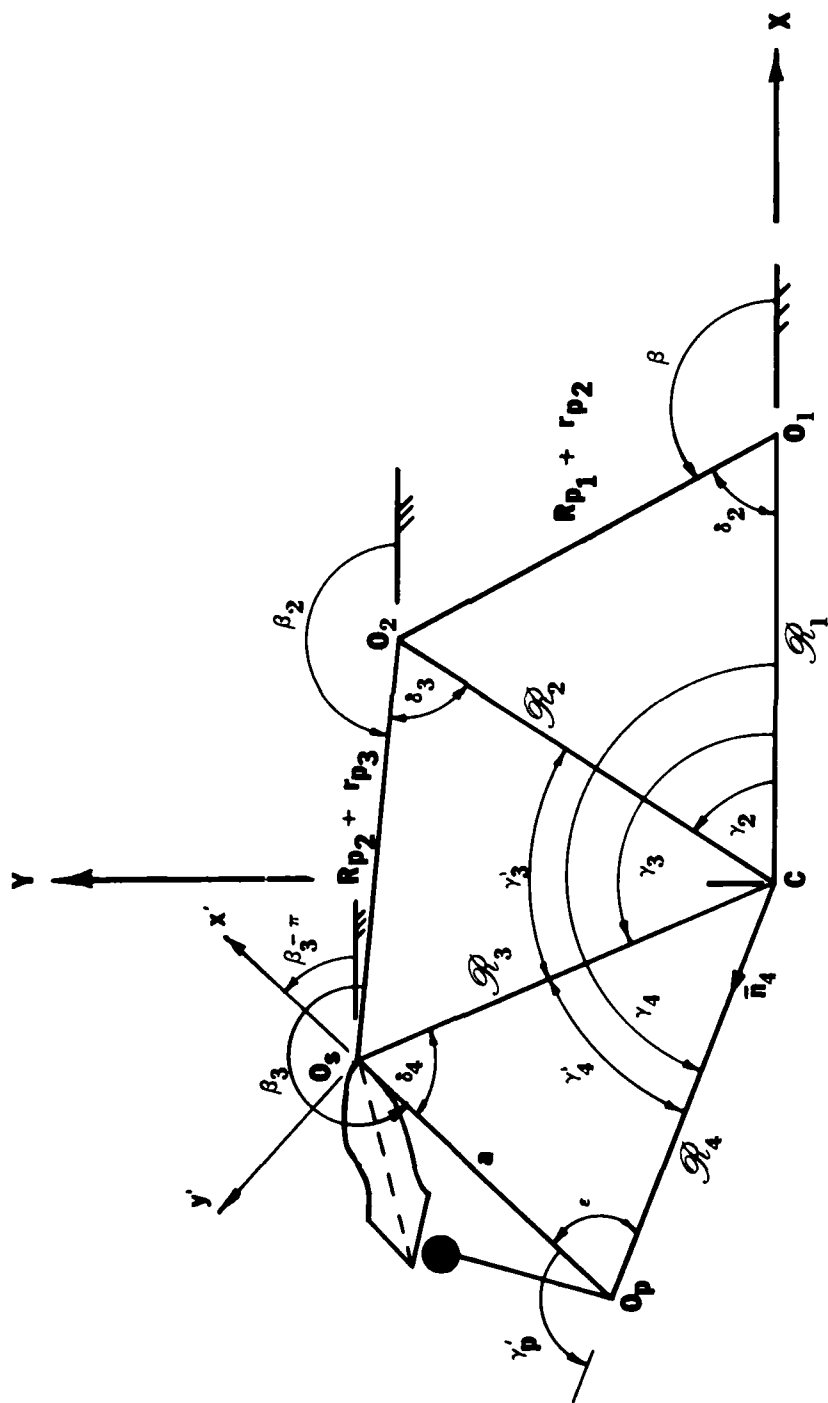


Figure B-3. Fuze body configuration no. 1 (two pass)

The angle  $\gamma_4'$  must be newly derived. Thus,

$$\gamma_4' = \cos^{-1} \left[ \frac{\delta_3^2 + \delta_4^2 - a^2}{2 \delta_3 \delta_4} \right] \quad (B-4)$$

Then, as in equation A-5 (app A)

$$\gamma_4 = \gamma_3 + \gamma_4' \quad (B-5)$$

Angles  $\delta_i$

The angles  $\delta_2$  and  $\delta_3$  can be taken directly from equations A-9 and A-10 (app A), respectively, i.e.,

$$\delta_2 = \cos^{-1} \left[ \frac{(R_{p1} + r_{p2})^2 + \delta_1^2 - \delta_2^2}{2 \delta_1 (R_{p1} + r_{p2})} \right] \quad (B-6)$$

and

$$\delta_3 = \cos^{-1} \left[ \frac{(R_{p2} + r_{p3})^2 + \delta_2^2 - \delta_3^2}{2 \delta_2 (R_{p2} + r_{p3})} \right] \quad (B-7)$$

The angle  $\delta_4$  must take the pivot-to-pivot distance  $a$  of the escapement into account. Therefore,

$$\delta_4 = \cos^{-1} \left[ \frac{a^2 + \delta_3^2 - \delta_4^2}{2a \delta_3} \right] \quad (B-8)$$

Angles  $\beta_i$

The angles  $\beta_1$  and  $\beta_2$  may also be taken directly from equations A-14 and A-15 (app A), respectively, i.e.,

$$\beta_1 = \pi - \delta_2 \quad (B-9)$$

and

$$\beta_2 = \gamma_2 + \pi - \delta_3 \quad (B-10)$$

The angle  $\beta_3$  is found with the help of angle  $\delta_4$  of equation B-8. Then, similar to equation A-16 (app A)

$$\beta_3 = \gamma_3 + \pi - \delta_4 \quad (B-11)$$

Figure B-3 shows the angle  $\gamma'_p$  between the positive X- axis and the unit vector  $\bar{n}_4$ . It is given by

$$\gamma'_p = \pi - \epsilon \quad (B-12)$$

where  $\epsilon$  is obtained with the help of equations B-4 and B-8

$$\epsilon = \pi - \delta_4 - \gamma'_4, \quad (B-13)$$

and therefore

$$\gamma'_p = \delta_4 + \gamma'_4 \quad (B-14)$$

The unit vector  $\bar{n}_4$  is expressed in terms of the primed coordinate system as follows:

$$\bar{n}_4 = \cos \gamma'_p \bar{i}' + \sin \gamma'_p \bar{j}' \quad (B-15)$$

Further, the unit vectors  $\bar{i}'$  and  $\bar{j}'$ , when expressed in the x-y system, become

$$\bar{i}' = \cos(\beta_3 - \pi) \bar{i} + \sin(\beta_3 - \pi) \bar{j}$$

or

$$\bar{i}' = -\cos \beta_3 \bar{i} - \sin \beta_3 \bar{j} \quad (B-16)$$

and

$$\bar{j}' = \bar{k}' \times \bar{i}' = \sin \beta_3 \bar{i} - \cos \beta_3 \bar{j} \quad (B-17)$$

## Fuze Body Configuration No. 2

Figure B-4 is used to define the angles  $\gamma_1$ ,  $\delta_1$ , and  $\beta_1$  of configuration no. 2.

Angles  $\gamma_1$

Since these angles are defined in the clockwise direction with respect to the body fixed X- axis, their value must be negative, as is the case for the three pass configuration no. 2 of appendix A.

According to equation A-24 (app A)

$$\gamma_2 = -\cos^{-1} \left[ \frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2 R_1 R_2} \right] \quad (B-18)$$

Angle  $\gamma_3$  is given by equation B-2, and with that  $\gamma_3$  becomes

$$\gamma_3 = \gamma_2 - \gamma_3' \quad (B-19)$$

The negative sign for  $\gamma_3'$  is necessary in order to make  $\gamma_3$  negative.

The angle  $\gamma_4$  is given by equation B-4. It allows the following expression for angle  $\gamma_4$

$$\gamma_4 = \gamma_3 - \gamma_4' \quad (B-20)$$

Again,  $\gamma_4'$  must have a negative sign to make  $\gamma_4$  negative.

Angles  $\delta_1$

The angles  $\delta_2$ ,  $\delta_3$ , and  $\delta_4$  can be taken directly from equations B-6, B-7, and B-8, respectively.

Angles  $\beta_1$

As in equation A-28 (app A)

$$\beta_1 = \pi + \delta_2 \quad (B-21)$$

Further, according to equation A-29 (app A)

$$\beta_2 = \gamma_2 + \pi + \delta_3 \quad (B-22)$$

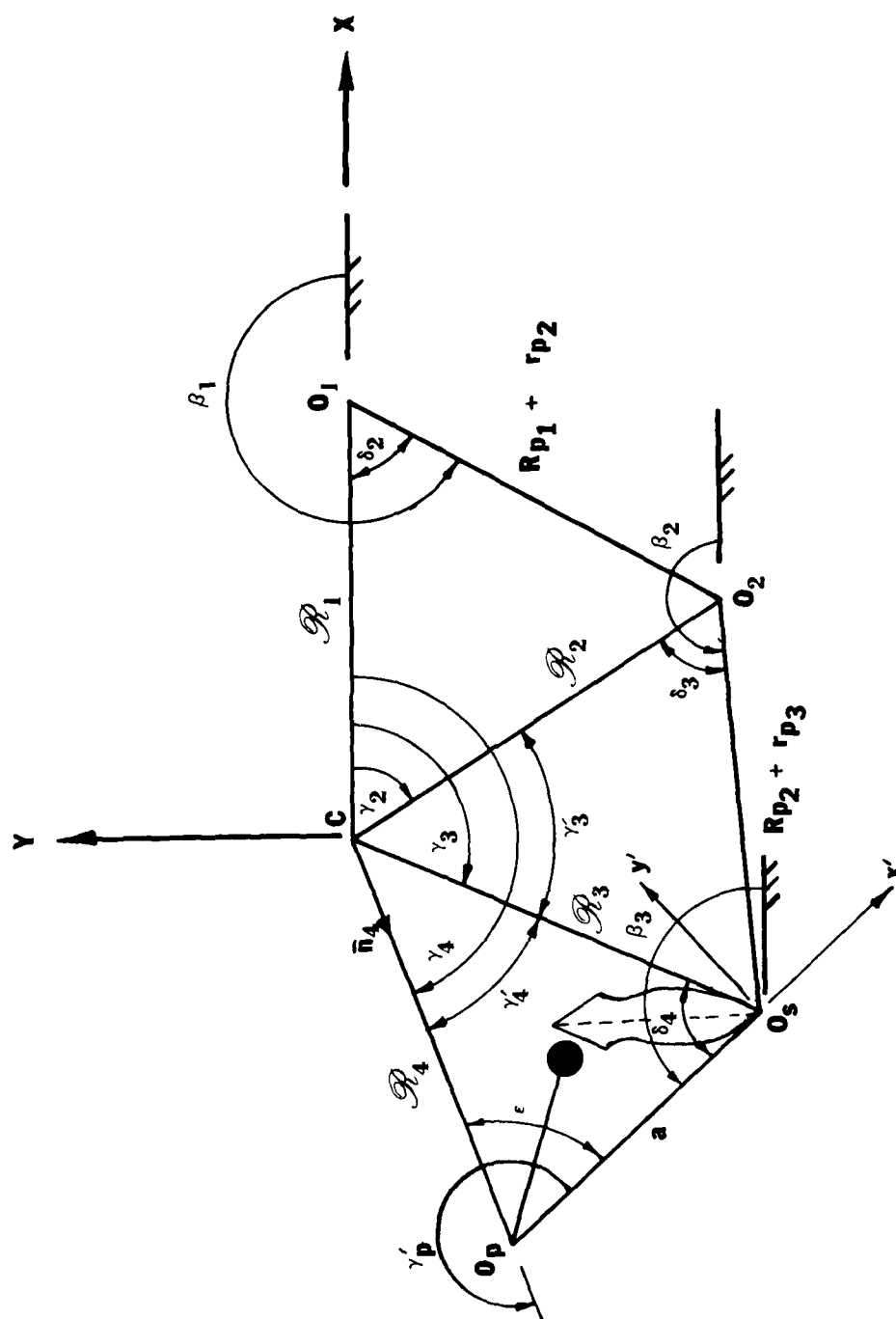


Figure B-4. Fuze body configuration no. 2 (two pass)

Finally, according to equation A-30 (app A)

$$\beta_3 = \gamma_3 + \pi + \delta_4 \quad (B-23)$$

Figure B-4 shows the angle  $\gamma'_p$  between the positive  $x'$ -axis and the unit vector  $\bar{n}_4$ . This angle is given by

$$\gamma'_p = \pi + \epsilon \quad (B-24)$$

where

$$\epsilon = \pi - \delta_4 - \gamma'_4 \quad (B-25)$$

Therefore,

$$\gamma'_p = 2\pi - \delta_4 - \gamma'_4 \quad (B-26)$$

The unit vector  $\bar{n}_4$  can again be expressed in terms of the primed coordinate system as

$$\bar{n}_4 = \cos \gamma'_p \bar{i}' + \sin \gamma'_p \bar{j}' \quad (B-27)$$

In a manner parallel to that used for equations A-36 and A-37 (app A), the unit vectors  $\bar{i}'$  and  $\bar{j}'$  in the X-Y system are expressed as follows:

$$\bar{i}' = -\cos \beta_3 \bar{i} - \sin \beta_3 \bar{j} \quad (B-28)$$

and

$$\bar{j}' = \sin \beta_3 \bar{i} - \cos \beta_3 \bar{j} \quad (B-29)$$

#### Common Computational Expressions for Both Configurations

In order to find common programming expressions for all angles of both configurations, with the exception of the angles  $\gamma'_p$  of equations B-14 and B-26, the following signum function  $s_6$  is again introduced<sup>p</sup>

$$s_6 = +1 \text{ for configuration no. 1} \quad (B-30)$$

$s_6 = -1$  for configuration no. 2

(B-31)

This leads to the following expressions:

according to equations B-1 and B-18

$$\gamma_2 = s_6 \cos^{-1} \left[ \frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2 R_1 R_2} \right] \quad (B-32)$$

according to equation B-2

$$\gamma_3 = \cos^{-1} \left[ \frac{R_2^2 + R_3^2 - (R_{p2} + r_{p3})^2}{2 R_2 R_3} \right] \quad (B-33)$$

according to equations B-3 and B-19

$$\gamma_3 = \gamma_2 + s_6 \gamma_3' \quad (B-34)$$

according to equation B-4

$$\gamma_4 = \cos^{-1} \left[ \frac{R_3^2 + R_4^2 - a^2}{2 R_3 R_4} \right] \quad (B-35)$$

according to equations B-5 and B-20

$$\gamma_4 = \gamma_3 + s_6 \gamma_4' \quad (B-36)$$

according to equations B-6 through B-8, respectively

$$\delta_2 = \cos^{-1} \left[ \frac{(R_{p1} + r_{p2})^2 + R_1^2 - R_2^2}{2 R_1 (R_{p1} + r_{p2})} \right] \quad (B-37)$$

$$\delta_3 = \cos^{-1} \left[ \frac{(R_{p2} + r_{p3})^2 + R_2^2 - R_3^2}{2 R_2 (R_{p2} + r_{p3})} \right] \quad (B-38)$$

$$\delta_4 = \cos^{-1} \left[ \frac{a^2 + R_3^2 - R_4^2}{2a R_3} \right] \quad (B-39)$$

according to equations B-9 and B-21

$$\beta_1 = \pi - s_6 \delta_2 \quad (B-40)$$

according to equations B-10 and B-22

$$\beta_2 = \gamma_2 + \pi - s_6 \delta_3 \quad (B-41)$$

according to equations B-11 and B-23

$$\beta_3 = \gamma_2 + \pi - s_6 \delta_4 \quad (B-42)$$

The signum function  $s_6$  will also be useful in conditional statements which distinguish between the  $\gamma_p$ 's of configuration no. 1 and 2, as given by equations B-14 and B-26, respectively.

The expressions for the unit vectors  $\bar{i}'$  and  $\bar{j}'$  are identical for both configurations according to equations B-16 and B-17 as well as equations B-28 and B-29. Thus,

$$\bar{i}' = -\cos \beta_3 \bar{i} - \sin \beta_3 \bar{j} \quad (B-43)$$

and

$$\bar{j}' = \sin \beta_3 \bar{i} - \cos \beta_3 \bar{j} \quad (B-44)$$

DYNAMICS OF PALLET IN COUPLED MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

Equation A-95, appendix A, which gives the contact force  $P_n$  between pallet and escape wheel, may be readily adapted to the present two pass mechanism. It is only required that, depending on configuration, the angle  $\gamma'$  is computed according to either equation B-14 or equation B-26. Further, the distance from the spin axis to the pallet pivot is now given by  $R_4$  rather than by  $R_5$ . Thus equation A-95 becomes

$$P_n = \frac{1}{A_{18}} \left[ I_{PR} \ddot{\phi} + (A_{21} Z^2 + I_{PR} V) \dot{\phi}^2 + 2 \frac{\omega}{|\omega|} A_{20} Z \dot{\phi} + \omega^2 A_{19} - m_p r_{CP} R_4 \omega^2 \sin(\gamma_p' - \psi - \psi_C) \right] \quad (B-45)$$

The parameters  $A_1$  to  $A_8$ ,  $A_{18}$  to  $A_{21}$  and  $I_{PR}$  may essentially be taken directly from equations A-70 through A-77 and equations A-84 through A-90, appendix A. In equations A-71 and A-75 it is necessary to substitute  $R_4$  for  $R_5$ .

DYNAMICS OF ESCAPE WHEEL IN COUPLED MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH THE APPROPRIATE  $s_6$ )

The analysis of the escape wheel can be taken over from appendix A, once the appropriate signum function  $s_6$  has been chosen for the given configuration and the following changes in nomenclature have been made:

|            |         |            |
|------------|---------|------------|
| $\beta_4$  | becomes | $\beta_3$  |
| $\theta_3$ | becomes | $\theta_2$ |
| $m_4$      | becomes | $m_3$      |
| $R_4$      | becomes | $R_3$      |
| $I_4$      | becomes | $I_3$      |
| $\gamma_4$ | becomes | $\gamma_3$ |
| $s_3$      | becomes | $s_2$      |

|                 |         |                 |
|-----------------|---------|-----------------|
| $d_3$           | becomes | $d_2$           |
| $a_3$           | becomes | $a_2$           |
| $\bar{n}_{34}$  | becomes | $\bar{n}_{23}$  |
| $\bar{n}_{N34}$ | becomes | $\bar{n}_{N23}$ |
| $F_{34}$        | becomes | $F_{23}$        |
| $F_{x4}$        | becomes | $F_{x3}$        |
| $\rho_4$        | becomes | $\rho_3$        |
| $F_{y4}$        | becomes | $F_{y3}$        |
| $r_{b4}$        | becomes | $r_{b3}$        |
| $T_4$           | becomes | $T_3$           |

Note that the meanings of  $s_4$  and  $s_5$  remain unchanged (eq A-59 and A-60).

Similar to equation A-117, the contact force equation, as derived for the escape wheel, then has the following form:

$$P_n = \frac{-I_3 \ddot{\phi} + F_{23} A_{15} - T_3 A_{16}}{A_{17}} \quad (B-46)$$

where now

$$A_{15} = r_{b3} - \mu [s_2(d_2 - a_2) + \rho_3(A_{10} + A_{13})] \quad (B-47)$$

$$A_{16} = \mu \rho_3(A_{11} + A_{14}) \quad (B-48)$$

$$A_{17} = A_1' + \mu_1 s_4 B_1' + \mu \rho_3 (A_9 + A_{12}) \quad (B-49)$$

and similarly

$$A_9 = \left| \frac{-(\mu_1 s_4 - \mu) \sin(\phi - \alpha + \beta_3) + (1 + \mu \mu_1 s_4) \cos(\phi - \alpha + \beta_3)}{1 + \mu^2} \right| \quad (B-50)$$

$$A_{10} = \left| \frac{-\mu(1 - s_2) \sin(\beta_2 + \theta_2) - (1 + \mu^2 s_2) \cos(\beta_2 + \theta_2)}{1 + \mu^2} \right| \quad (B-51)$$

$$A_{11} = \left| \frac{\sin \gamma_3 - \mu \cos \gamma_3}{1 + \mu^2} \right| \quad (B-52)$$

$$A_{12} = \left| \frac{(1 + \mu_1 \mu s_4) \sin(\phi - \alpha + \beta_3) + (s_4 \mu_1 - \mu) \cos(\phi - \alpha + \beta_3)}{1 + \mu^2} \right| \quad (B-53)$$

$$A_{13} = \left| \frac{-(1 + \mu^2 s_2) \sin(\beta_2 + \theta_2) + \mu(1 - s_2) \cos(\beta_2 + \theta_2)}{1 + \mu^2} \right| \quad (B-54)$$

$$A_{14} = \left| \frac{-\cos \gamma_3 - \mu \sin \gamma_3}{1 + \mu^2} \right| \quad (B-55)$$

COMBINED COUPLED MOTION DIFFERENTIAL EQUATION FOR ESCAPE WHEEL AND PALLET  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

Equations B-45 and B-46, are now set equal to each other in order to obtain a combined differential equation for the escapement. This leads to

$$\begin{aligned} & \left[ I_3 A_{18} + I_{PR} A_{17} U \right] \ddot{\phi} + \left[ I_{PR} A_{17} V + A_{17} A_{21} Z^2 \right] \dot{\phi}^2 \\ & + 2 \frac{\omega}{|\omega|} A_{17} A_{20} Z \dot{\phi} \\ & = A_{15} A_{18} F_{23} - A_{16} A_{18} T_3 - A_{17} \omega^2 \left[ A_{19} - m_p r_{CP}^2 \sin(\gamma_p - \psi - \psi_C) \right] \end{aligned} \quad (B-56)$$

Again, it is necessary now to determine an expression for the contact force  $F_{23}$ .

DYNAMICS OF ROTOR (Gear No. 1)  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

Figure B-5 shows a free body diagram of the rotor of configuration no. 1, which moves in a counterclockwise direction. The acceleration of its center of mass is given by equation A-122, appendix A.

Since the motion of the rotor must be expressed again in terms of the escape wheel variables, use must be made of

$$\dot{\phi}_1 = N_{31} \dot{\phi} \quad (B-57)$$

and

$$\ddot{\phi}_1 = N_{31} \ddot{\phi} \quad (B-58)$$

where

$$N_{31} = \frac{N_{P3} \times N_{P2}}{N_{G2} \times N_{G1}} \quad (B-59)$$

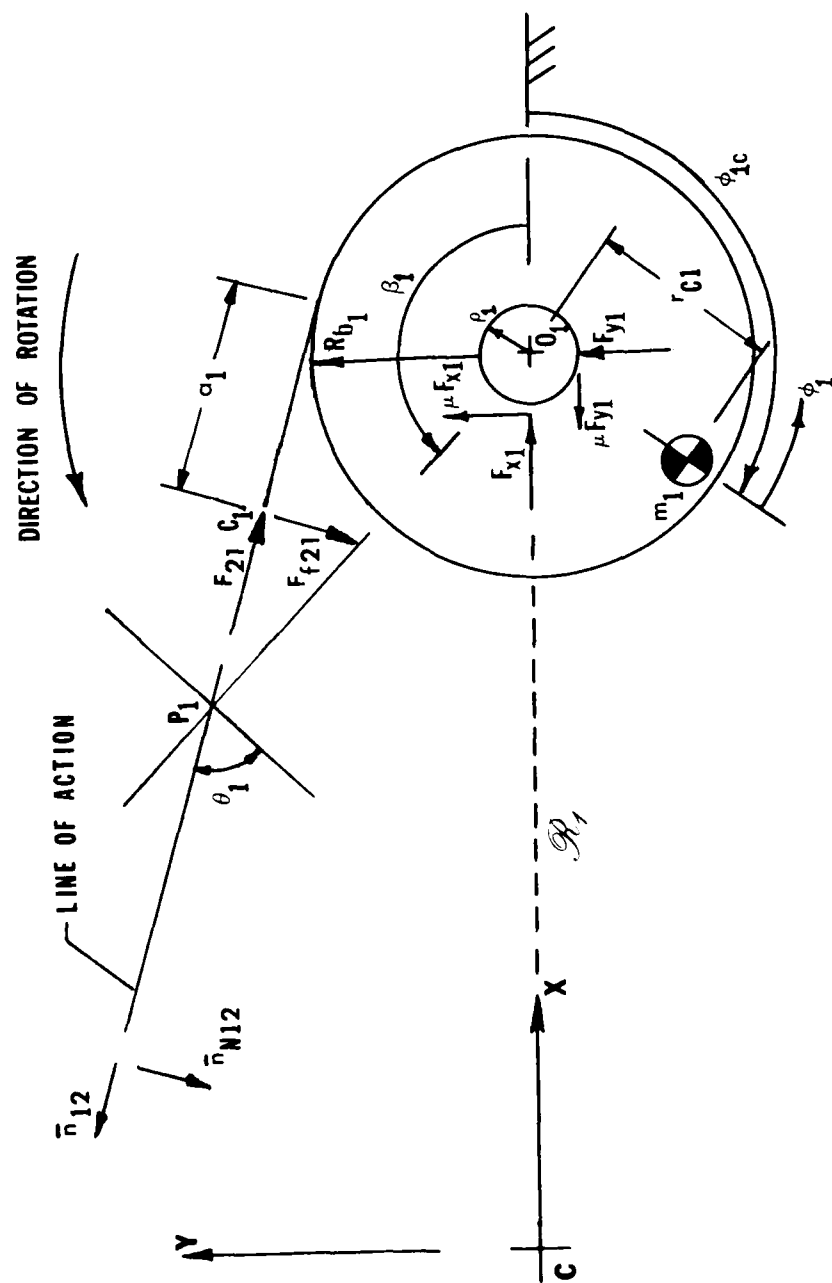


Figure B-5. Free body diagram of rotor

The rotor angle  $\phi_{1C} + \phi_1$  is expressed in terms of the total escape wheel rotation  $\phi_T$

$$\phi_{1C} + \phi_1 = \phi_{1C} + N_{31} \phi_T \quad (B-60)$$

(For details, see program description.)

Newton's force equation may now be written in the form of equation A-128. The tooth forces

$$\bar{F}_{21} = -F_{12} \bar{n}_{12} \quad (B-61)$$

and

$$\bar{F}_{f21} = \mu s_1 F_{12} \bar{n}_{N12} \quad (B-62)$$

have the appropriate directions to account for friction.

Thus

$$\begin{aligned} & -F_{12} \bar{n}_{12} + \mu s_1 F_{12} \bar{n}_{N12} + F_{x1} \bar{i} - \mu F_{y1} \bar{i} + F_{y1} \bar{j} + \mu F_{x1} \bar{j} \\ & = m_1 \{ -\omega^2 R_{11} \bar{i} - (\omega + N_{31} \dot{\phi})^2 r_{C1} [\cos(\phi_{1C} + N_{31} \phi_T) \bar{i} + \sin(\phi_{1C} + N_{31} \phi_T) \bar{j}] \\ & \quad + N_{31} \ddot{\phi} r_{C1} [-\sin(\phi_{1C} + N_{31} \phi_T) \bar{i} + \cos(\phi_{1C} + N_{31} \phi_T) \bar{j}] \} \end{aligned} \quad (B-63)$$

where

$$\bar{n}_{12} = -\sin(\beta_1 - \theta_1) \bar{i} + \cos(\beta_1 - \theta_1) \bar{j} \quad (B-64)$$

$$\bar{n}_{N12} = -\cos(\beta_1 - \theta_1) \bar{i} - \sin(\beta_1 - \theta_1) \bar{j} \quad (B-65)$$

The moment equation must be written in the manner of equation A-61 with respect to the accelerated point  $O_1$ . The pivot reactions  $\tilde{F}_{x1}$  and  $\tilde{F}_{y1}$  are written such that the associated friction moments retard the counterclockwise rotation of the rotor. This leads to

$$\begin{aligned} & -F_{12}R_{b1} + \mu s_1 a_1 F_{12} - \mu p_1 (\tilde{F}_{x1} + \tilde{F}_{y1}) \\ & = m_1 \omega^2 R_1 r_{C1} \sin(\phi_{1C} + N_{31}\phi_T) + I_1 N_{31} \ddot{\phi} \end{aligned} \quad (B-66)$$

The forces  $\tilde{F}_{x1}$  and  $\tilde{F}_{y1}$  are obtained after the simultaneous solution of the following component expressions of equation B-63 for  $F_{x1}$  and  $F_{y1}$ :

$$\begin{aligned} & F_{12} \sin(\beta_1 - \theta_1) + \mu s_1 F_{12} \cos(\beta_1 - \theta_1) + F_{x1} - \mu F_{y1} \\ & = m_1 \left[ -\omega^2 R_1 - (\omega + N_{31}\dot{\phi})^2 r_{C1} \cos(\phi_{1C} + N_{31}\phi_T) - N_{31} \ddot{\phi} r_{C1} \sin(\phi_{1C} + N_{31}\phi_T) \right] \end{aligned} \quad (B-67)$$

and

$$\begin{aligned} & -F_{12} \cos(\beta_1 - \theta_1) - \mu s_1 F_{12} \sin(\beta_1 - \theta_1) + F_{y1} + \mu F_{x1} \\ & = m_1 \left[ -(\omega + N_{31}\dot{\phi})^2 r_{C1} \sin(\phi_{1C} + N_{31}\phi_T) + N_{31} \ddot{\phi} r_{C1} \cos(\phi_{1C} + N_{31}\phi_T) \right] \end{aligned} \quad (B-68)$$

Simultaneous solution of the above furnishes

$$\tilde{F}_{x1} = F_{12} A_{23} \pm \omega^2 A_{24} \pm 2 \frac{\omega}{|\omega|} N_{31} \dot{\phi} A_{25} \pm (N_{31} \dot{\phi})^2 A_{25} \pm N_{31} \ddot{\phi} A_{26} \quad (B-69)$$

$$\tilde{F}_{y1} = F_{12} A_{27} \pm \omega^2 A_{28} \pm 2 \frac{\omega}{|\omega|} N_{31} \dot{\phi} A_{29} \pm (N_{31} \dot{\phi})^2 A_{29} \pm N_{31} \ddot{\phi} A_{30} \quad (B-70)$$

where

$$A_{23} = \left| \frac{(1-\mu^2 s_1) \sin(\beta_1 - \theta_1) - \mu(1+s_1) \cos(\beta_1 - \theta_1)}{1 + \mu^2} \right| \quad (B-71)$$

$$A_{24} = \left| \frac{m_1 \left[ R_1 + r_{C1} (\cos(\phi_{1C} + N_{31} \phi_T) + \mu \sin(\phi_{1C} + N_{31} \phi_T)) \right]}{1 + \mu^2} \right| \quad (B-72)$$

$$A_{25} = \left| \frac{m_1 r_{C1} \left[ \cos(\phi_{1C} + N_{31} \phi_T) + \mu \sin(\phi_{1C} + N_{31} \phi_T) \right]}{1 + \mu^2} \right| \quad (B-73)$$

$$A_{26} = \left| \frac{m_1 r_{C1} \left[ \sin(\phi_{1C} + N_{31} \phi_T) - \mu \cos(\phi_{1C} + N_{31} \phi_T) \right]}{1 + \mu^2} \right| \quad (B-74)$$

$$A_{27} = \left| \frac{\mu(1+s_1) \sin(\beta_1 - \theta_1) + (1-\mu^2 s_1) \cos(\beta_1 - \theta_1)}{1 + \mu^2} \right| \quad (B-75)$$

$$A_{28} = \left| \frac{m_1 R_1 + m_1 r_{C1} \left[ \mu \cos(\phi_{1C} + N_{31} \phi_T) - \sin(\phi_{1C} + N_{31} \phi_T) \right]}{1 + \mu^2} \right| \quad (B-76)$$

$$A_{29} = \left| \frac{m_1 r_{C1} \left[ \mu \cos(\phi_{1C} + N_{31} \phi_T) - \sin(\phi_{1C} + N_{31} \phi_T) \right]}{1 + \mu^2} \right| \quad (B-77)$$

$$A_{30} = \left| \frac{m_1 r_{C1} \left[ \mu \sin(\phi_{1C} + N_{31} \phi_T) + \cos(\phi_{1C} + N_{31} \phi_T) \right]}{1 + \mu^2} \right| \quad (B-78)$$

Equations B-69 and B-70 are now substituted into the moment equation B-66

$$\begin{aligned}
 & -F_{12}R_{b1} + \mu \rho_1 a_1 F_{12} - \mu \rho_1 [F_{12}(A_{23} + A_{27}) \pm \omega^2 (A_{24} + A_{28}) \\
 & \pm 2 \frac{\omega}{|\omega|} N_{31} \dot{\phi} (A_{25} + A_{29}) \pm (N_{31} \dot{\phi})^2 (A_{25} + A_{29}) \pm N_{31} \ddot{\phi} (A_{26} + A_{30})] \\
 & = m_1 \omega^2 R_1 r_{C1} \sin(\phi_{1C} + N_{31} \phi_T) + I_1 N_{31} \ddot{\phi}
 \end{aligned} \tag{B-79}$$

In order to have the pivot friction moment negative, the following terms on the left hand side of equation B-79 must be negative:

$$\mu \rho_1 F_{12} (A_{23} + A_{27})$$

$$\mu \rho_1 \omega^2 (A_{24} + A_{28})$$

$$\mu \rho_1 (N_{31} \dot{\phi})^2 (A_{25} + A_{29})$$

$$2 |\mu| \rho_1 \frac{\omega}{|\omega|} N_{31} \dot{\phi} (A_{25} + A_{29})$$

(With  $N_{31} \dot{\phi}$  positive,  $\mu$  must be absolute. See discussion following equation A-147.) The term  $\mu \rho_1 N_{31} \ddot{\phi} (A_{26} + A_{30})$  is treated in the same manner as was shown in connection with equation A-149, appendix A. (See the discussion in appendix F.)

The above considerations give the moment equation the following form:

$$\begin{aligned}
 & -F_{12} [R_{b1} - \mu_B a_1 + \mu \rho_1 (A_{23} + A_{27})] - \omega^2 \mu \rho_1 (A_{24} + A_{28}) \\
 & - \frac{2 \mu \rho_1 \omega^2 N_{31} \dot{\phi}}{|\omega|} (A_{25} + A_{29}) - \mu \rho_1 (N_{31} \dot{\phi})^2 (A_{25} + A_{29}) \\
 & = m_1 \omega^2 R_{1C1} \sin(\phi_{1C} + N_{31} \phi_T) + (I_{1R} \pm \mu \rho_1 (A_{26} + A_{30})) N_{31} \ddot{\phi}
 \end{aligned} \tag{B-80}$$

Finally, the above expression is solved for  $F_{12}$ , i.e.,

$$F_{12} = \frac{-A_{32} - A_{33} N_{31} \dot{\phi} - A_{34} (N_{31} \dot{\phi})^2 - A_{35} \sin(\phi_{1C} + N_{31} \phi_T) - I_{1R} N_{31} \ddot{\phi}}{A_{31}} \tag{B-81}$$

where

$$A_{31} = R_{b1} - \mu_B a_1 + \mu \rho_1 (A_{23} + A_{27}) \tag{B-82}$$

$$A_{32} = \mu \rho_1 \omega^2 (A_{24} + A_{28}) \tag{B-83}$$

$$A_{33} = 2 |\mu| \rho_1 \frac{\omega^2}{|\omega|} (A_{25} + A_{29}) \tag{B-84}$$

$$A_{34} = \mu \rho_1 (A_{25} + A_{29}) \tag{B-85}$$

$$A_{35} = m_1 R_{1C1} \omega^2 \tag{B-86}$$

$$I_{1R} = I_1 + |\mu|\rho_1(A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have the same signs} \quad (B-87)$$

$$I_{1R} = I_1 - |\mu|\rho_1(A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have opposite signs} \quad (B-88)$$

DYNAMICS OF GEAR AND PINION SET NO. 2  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

The free body diagram of gear and pinion set no. 2 of configuration no. 1 is shown in figure B-6. Its force equation is written as follows with the D'Alembert force

$$T_2 = m_2 R_2 \omega^2 \quad (B-89)$$

Thus

$$\begin{aligned} & -F_2 \bar{n}_{23} - s_2 \mu F_2 \bar{n}_{N23} + F_{12} \bar{n}_{12} - s_1 \mu F_{12} \bar{n}_{N12} + F_{x2} \bar{i} + \mu F_{y2} \bar{i} \\ & + F_{y2} \bar{j} - \mu F_{x2} \bar{j} + T_2 (\cos \gamma_2 \bar{i} + \sin \gamma_2 \bar{j}) = 0 \end{aligned} \quad (B-90)$$

where

$$\bar{n}_{23} = \sin(\beta_2 + \theta_2) \bar{i} - \cos(\beta_2 + \theta_2) \bar{j} \quad (B-91)$$

$$\bar{n}_{N23} = \cos(\beta_2 + \theta_2) \bar{i} + \sin(\beta_2 + \theta_2) \bar{j} \quad (B-92)$$

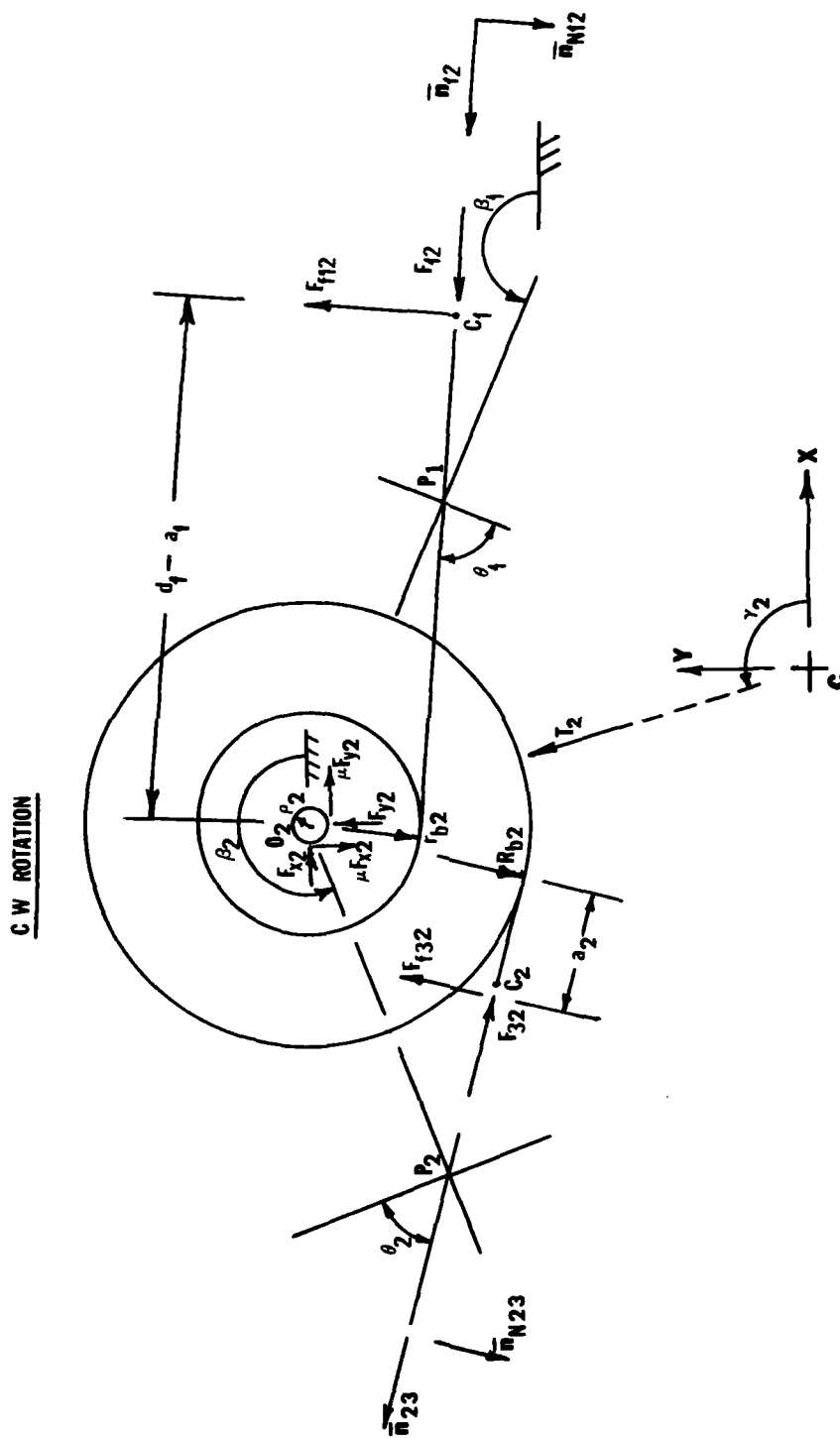


Figure B-6. Free body diagram of gear and pinion set no. 2

The unit vectors  $\bar{n}_{12}$  and  $\bar{n}_{N12}$  were given by equations B-64 and B-65. Hence

$$\bar{F}_{32} = -F_{23} \bar{n}_{23} \quad (B-93)$$

$$\bar{F}_{f32} = -s_2 \mu F_{23} \bar{n}_{N23} \quad (B-94)$$

To write the moment equation, let

$$\ddot{\phi}_2 = N_{32} \ddot{\phi} \quad (B-95)$$

where

$$N_{32} = -\frac{N_{P3}}{N_{G2}} \quad (B-96)$$

Then

$$\begin{aligned} F_{23} R_{b2} - \mu s_2 F_{23} a_2 - F_{12} r_{b2} + \mu s_1 F_{12} (d_1 - a_1) + \mu \rho_2 (\tilde{F}_{x2} + \tilde{F}_{y2}) \\ = I_2 N_{32} \ddot{\phi} \end{aligned} \quad (B-97)$$

The bearing forces  $\tilde{F}_{x2}$  and  $\tilde{F}_{y2}$  are obtained from the simultaneous solution of the following component equations of the force expression B-90:

$$\begin{aligned} -F_{23} \sin(\beta_2 + \theta_2) - F_{23} \mu s_2 \cos(\beta_2 + \theta_2) - F_{12} \sin(\beta_1 - \theta_1) \\ + \mu s_1 F_{12} \cos(\beta_1 - \theta_1) + F_{x2} + \mu F_{y2} + T_2 \cos \gamma_2 = 0 \end{aligned} \quad (B-98)$$

and

$$F_{23}\cos(\beta_2+\theta_2) - \mu s_2 F_{23}\sin(\beta_2+\theta_2) + F_{12}\cos(\beta_1-\theta_1)$$

$$+ \mu s_1 F_{12}\sin(\beta_1-\theta_1) + F_{y2} - \mu F_{x2} + T_2\sin\gamma_2 = 0 \quad (B-99)$$

This leads to

$$\tilde{F}_{x2} = F_{23} A_{36} + F_{12} A_{37} + T_2 A_{38} \quad (B-100)$$

$$\tilde{F}_{y2} = F_{23} A_{39} + F_{12} A_{40} + T_2 A_{41} \quad (B-101)$$

(all signs are left positive in order to furnish positive friction moments in equation B-97) where

$$A_{36} = \left| \frac{(1-\mu^2 s_2)\sin(\beta_2+\theta_2) + \mu(1+s_2)\cos(\beta_2+\theta_2)}{1 + \mu^2} \right| \quad (B-102)$$

$$A_{37} = \left| \frac{(1+\mu^2 s_1)\sin(\beta_1-\theta_1) + \mu(1-s_1)\cos(\beta_1-\theta_1)}{1 + \mu^2} \right| \quad (B-103)$$

$$A_{38} = \left| \frac{\cos\gamma_2 - \mu\sin\gamma_2}{1 + \mu^2} \right| \quad (B-104)$$

$$A_{39} = \left| \frac{\mu(1+s_2)\sin(\beta_2+\theta_2) - (1-\mu^2 s_2)\cos(\beta_2+\theta_2)}{1 + \mu^2} \right| \quad (B-105)$$

$$A_{40} = \left| \frac{\mu(1-s_1)\sin(\beta_1-\theta_1) - (1+\mu^2 s_1)\cos(\beta_1-\theta_1)}{1 + \mu^2} \right| \quad (B-106)$$

$$A_{41} = \left| \frac{\mu\cos\gamma_2 + \sin\gamma_2}{1 + \mu^2} \right| \quad (B-107)$$

Substitution of equations B-100 and B-101 into the moment equation B-97 and subsequent solution for the contact force  $F_{23}$  gives

$$F_{23} = \frac{F_{12} A_{42} - T_2 A_{43} + I_2 N_{32} \ddot{\phi}}{A_{44}} \quad (B-108)$$

where

$$A_{42} = r_{b2} - \mu [s_1(d_1 - a_1) + \rho_2(A_{37} + A_{40})] \quad (B-109)$$

$$A_{43} = \mu \rho_2(A_{38} + A_{41}) \quad (B-110)$$

$$A_{44} = R_{b2} - \mu [s_2 a_2 - \rho_2(A_{36} + A_{39})] \quad (B-111)$$

#### DYNAMICS OF COMBINED SYSTEM IN COUPLED MOTION (APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE $s_6$ )

In order to obtain a single differential equation for the total system in coupled motion, in terms of the escape wheel angle  $\phi$ , an appropriate expression for the contact force  $F_{23}$ , which also contains the contribution of the rotor, must be substituted into equation B-56.

Thus, first substitute equation B-81 for  $F_{12}$  into equation B-108, which is the above expression for  $F_{23}$ :

$$F_{23} = \frac{1}{A_{44}} \left[ \frac{-A_{42} A_{32}}{A_{31}} - T_2 A_{43} - \frac{A_{42} A_{33}}{A_{31}} N_{31} \dot{\phi} - \frac{A_{42} A_{34}}{A_{31}} N_{31}^2 \dot{\phi}^2 - \frac{A_{42} A_{35}}{A_{31}} \sin(\phi_{1C} + N_{31} \phi_T) + (I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}) \ddot{\phi} \right] \quad (B-112)$$

Now equation B-112 is substituted into equation B-56, and the final differential equation of coupled motion results

$$A_{45}\ddot{\phi} + A_{46}\dot{\phi}^2 + A_{47}\dot{\phi} = A_{48} - A_{49}\sin(\phi_{1C} + N_{31}\phi_T) + A_{50}\sin(\gamma_P' - \psi - \psi_C) \quad (B-113)$$

where

$$A_{45} = I_3 A_{18} + I_{PR} A_{17} U - \frac{A_{15} A_{18}}{A_{44}} (I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}) \quad (B-114)$$

$$A_{46} = I_{PR} A_{17} V + A_{17} A_{21} U^2 + \frac{A_{15} A_{18} A_{34} A_{42}}{A_{31} A_{44}} N_{31}^2 \quad (B-115)$$

$$A_{47} = 2 \frac{\omega}{|\omega|} A_{17} A_{20} U + \frac{A_{15} A_{18} A_{33} A_{42}}{A_{31} A_{44}} N_{31} \quad (B-116)$$

$$A_{48} = - \frac{A_{15} A_{18} A_{32} A_{42}}{A_{31} A_{44}} - \frac{A_{15} A_{18} A_{43}}{A_{44}} T_2 - A_{16} A_{18} T_3 - \omega^2 A_{17} A_{19} \quad (B-117)$$

$$A_{49} = \frac{A_{15} A_{18} A_{35} A_{42}}{A_{31} A_{44}} \quad (B-118)$$

$$A_{50} = m_P r_{CP}^2 \omega^2 A_{17} \quad (B-119)$$

CONTACT FORCE EQUATIONS FOR COUPLED MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

The contact force  $F_{23}$  is given by equation B-112

$$F_{23} = \frac{1}{A_{31}} \left[ \frac{-A_{32}A_{42}}{A_{31}} - T_2 A_{43} - \frac{A_{33}A_{42}}{A_{31}} N_{31} \dot{\phi} - \frac{A_{42}A_{34}}{A_{31}} N_{31} \dot{\phi}^2 \right. \\ \left. - \frac{A_{35}A_{42}}{A_{31}} \sin(\phi_{1C} + N_{31}\phi_T) + (I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}) \ddot{\phi} \right] \quad (B-120)$$

The contact force  $F_{12}$  is found with the help of equation B-108

$$F_{12} = \frac{F_{23} A_{44} + T_2 A_{43} - I_2 N_{32} \ddot{\phi}}{A_{42}} \quad (B-121)$$

The contact force  $P_n$  is given by equation B-46

$$P_n = \frac{-I_3 \ddot{\phi} + F_{23} A_{15} - T_3 A_{16}}{A_{17}} \quad (B-122)$$

If this force is desired in terms of the pallet variable  $\psi$ , equation A-91 must be used with the understanding that it now has the following form:

$$P_n = \frac{I_{PR} \ddot{\psi} + A_{21} \dot{\psi}^2 + 2 \frac{\omega}{|\omega|} A_{20} \dot{\psi} + \omega^2 A_{19} - m_P r_{CP}^2 R_4 \omega^2 \sin(\gamma_P' - \psi - \psi_C)}{A_{18}} \quad (B-123)$$

where  $R_4$  is used, together with  $\gamma_P'$  as defined earlier in this appendix. As stated previously, all other parameters may be taken from appendix A.

DIFFERENTIAL EQUATIONS FOR FREE MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

Free Motion of Pallet

Let  $P_n = 0$  in equation B-123. After some rearrangement, the free motion differential equation for the pallet becomes

$$A_{51}\ddot{\psi} + A_{52}\dot{\psi}^2 + A_{53}\dot{\psi} = -A_{53} + A_{54}\sin(\gamma_p' - \psi - \psi_C) \quad (B-124)$$

where

$$A_{51} = I_{PR} \quad (B-125)$$

$$A_{52} = 2 \frac{\omega^2}{|\omega|} A_{20} \quad (B-126)$$

$$A_{53} = \omega^2 A_{19} \quad (B-127)$$

$$A_{54} = \omega^2 m_p r_{CP}^2 \theta_k \quad (B-128)$$

(Again, the angle  $\gamma_p'$  is defined for both configurations by eq B-14 and B-26.)

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

By setting  $P_n = 0$  in equation B-46, the differential equation of the system without the pallet is obtained. This leads to

$$I_3 \ddot{\phi} = A_{15} F_{23} - T_3 A_{16} \quad (B-129)$$

Equation B-112 is then substituted into the above for  $F_{23}$ . The resulting differential equation is given by

$$A_{55}\ddot{\phi} + A_{56}\dot{\phi}^2 + A_{57}\dot{\phi} = A_{58} - A_{59}\sin(\phi_{IC} + N_{31}\phi_T) \quad (B-130)$$

where

$$A_{55} = I_3 - \frac{A_{15}}{A_{44}} N_{32} I_2 + \frac{A_{15} A_{42}}{A_{31} A_{44}} N_{31} I_{1R} \quad (B-131)$$

$$A_{56} = \frac{A_{15} A_{34} A_{42}}{A_{31} A_{44}} N_{31}^2 \quad (B-132)$$

$$A_{57} = \frac{A_{15} A_{33} A_{42}}{A_{31} A_{44}} N_{31} \quad (B-133)$$

$$A_{58} = -A_{16} T_3 - \frac{A_{15} A_{43}}{A_{44}} T_2 - \frac{A_{15} A_{32} A_{42}}{A_{31} A_{44}} \quad (B-134)$$

$$A_{59} = \frac{A_{15} A_{35} A_{42}}{A_{31} A_{44}} \quad (B-135)$$

CONTACT FORCE EQUATIONS FOR FREE MOTION  
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE  $s_6$ )

Equation B-129 may be solved for the free motion contact force  $F_{F23}$ , once  $\ddot{\phi}$  is known

$$F_{F23} = \frac{I_3 \ddot{\phi} + T_3 A_{16}}{A_{15}} \quad (B-136)$$

Equation B-108, which was derived from the force and moment equations of gear and pinion set no. 2, may be modified to obtain the free motion contact force  $F_{F12}$

$$F_{F12} = \frac{F_{F23} A_{44} + T_2 A_{43} - I_2 N_{32} \ddot{\phi}}{A_{42}} \quad (B-137)$$

It must be understood that, both in equations B-136 and B-137, the angular acceleration of free motion  $\ddot{\phi}$ , as obtained from the solution of equation B-130, is used.

CHANGES IN IMPACT EXPRESSIONS  
(APPLICABLE TO BOTH CONFIGURATIONS)

Both the rotor and gear and pinion set no. 2 must be referred to the escape wheel shaft. Thus, similar to equation A-212, appendix A

$$I_{STOT} = I_3 + I_2 N_{32}^2 + I_1 N_{31}^2 \quad (B-138)$$

See equations B-59 and B-96 for the above transmission ratios.

APPENDIX C  
COMPUTER PROGRAM SANDA3

Computer program SANDA3

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08/07/81

FIN 4.8-508

OPT=1

74/74

PROGRAM SANDA3

```

1  PROGRAM SANDA3(INPUT,OUTPUT,TAPES=INPUT,TAPES=OUTPUT)
   COMMON A,B,C,R,ALPHA,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
   1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHIC,TEST1,TEST2
   2 TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH
   3 ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
   4 3,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,GAMMA9,GAMMA10
   5 SELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,B1,B2,B3,B4,B5,B6,B7
   6 GAL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
   7 RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F12MAX,
   8 BFF34MAX,FF23MAX,FF12MAX,PHMAX,PHICUTD
   9 COMMON /ZETA/ PSI,TIME,G,DPS1,GP
   10 DIMENSION AUX(6,2),AUX2(8,4),PRMT(5),PHI(2),DPHI(2),X(4),DX(
   11 14)
   12 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,LAMBDA,K,N41,N42,N43,J1,J2,J3,N
   13 I,G1,NG2,NG3,NP2,NP3,NP4,MU,MU1
   14 EXTERNAL FCT,OUTP,FCTF,OUTPF
   15
   16 READ IN AND WRITE DATA
   17
   18 READ (5,22) A,B,C,R,ALPHA,CONFIG
   19 WRITE (6,23) A,B,C,R,ALPHA,CONFIG
   20 READ (5,24) EREST,LAMBDA,DELTA
   21 WRITE (6,25) EREST,LAMBDA,DELTA
   22 READ (5,26) M1,M2,M3,M4,MP
   23 WRITE (6,27) M1,M2,M3,M4,MP
   24 READ (5,28) I1,I2,I3,I4,IP
   25 WRITE (6,29) I1,I2,I3,I4,IP
   26 READ (5,30) RC1,RCP,RHOP,RPM,PHI1CD,PHICD,PHID,PHICUTD,MU,MU1
   27 WRITE (6,31) PSI,PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,CA
   28 PR82,CAPR83,RP2,RP3,RP4,THETA1,THETA2,THETA3
   29 WRITE (6,35) PSI,PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPR81,C
   30 PR82,CAPR83,RP2,RP3,RP4,THETA1,THETA2,THETA3
   31 READ (5,32) R1,R2,R3,R4,R5
   32 WRITE (6,33) R1,R2,R3,R4,R5
   33 READ (5,34) RHO1,RHO2,RHO3,RHO4
   34 WRITE (6,35) RHO1,RHO2,RHO3,RHO4
   35 READ (5,36) CAPR81,CAPR82,CAPR83,RB2,RB3,RB4
   36 WRITE (6,37) CAPR81,CAPR82,CAPR83,RB2,RB3,RB4
   37 READ (5,38) CAPR81,CAPR82,CAPR83,RB2,RB3,RB4
   38 WRITE (6,39) CAPR81,CAPR82,CAPR83,RB2,RB3,RB4
   39 READ (5,40) J1,J2,J3
   40 WRITE (6,41) J1,J2,J3
   41 READ (5,42) J1,J2,J3
   42 WRITE (6,43) J1,J2,J3
   43
   44 INITIALIZATION OF PARAMETERS AND CONVERSION TO RADIAN
   45
   46 TIME=0.
   47 PHITOT=0.
   48 PHIPR=PHID
   49 DPH12=0.
   50 DPS12=0.
   51 F34MAX=0.
   52 F12MAX=0.
   53 FF23MAX=0.
   54 FF34MAX=0.
   55 FF12MAX=0.
   56

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## Computer program SANDA3 (cont)

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PROGRAM SANDA3 74/74 OPT=1

```

60      PNMAR=0.
        PI=3.14159
        Z2=PI/180.
        OMEGA=RP1*2.*PI/60.
        PHI1C=PHI1CD*ZZ
        PSICC=PSICCD*ZZ
        PSICC=PSICC
        ALPHR=ALPHA*ZZ
        C
70      DETERMINATION OF SIGNUM FUNCTION S0
        IF (CONFIG.EQ.1.) S0=1.
        IF (CONFIG.EQ.2.) S0=-1.
        C
75      COMPUTATION OF GEAR RATIOS
        N41=-NP2*NP3*NP4/(NG1*NG2*NG3)
        N42=NP3*NP4/(NG2*NG3)
        N43=-NP4/NG3
        C
80      COMPUTATION OF GAMMAS AND BETAS
        GAMMA2=S6*ACOS((R1*R1+R2*R2-(CAPRP1+RP2)**2)/(2.*R1*R2))
        GAMMA3=ACOS((R2*R2+R3*R3-(CAPRP2+RP3)**2)/(2.*R2*R3))
        GAMMA4=ACOS((R3*R3+R4*R4-(CAPRP3+RP4)**2)/(2.*R3*R4))
        GAMMA5=ACOS((R4*R4+R5*R5-A*A)/(2.*R4*R5))
        GAMMA2D=GAMMA2/ZZ
        GAMMA3D=GAMMA3/ZZ
        GAMMA4D=GAMMA4/ZZ
        GAMMA5D=GAMMA5/ZZ
        DELTA2=ACOS(((CAPRP1+RP2)**2+R1*R1-R2*R2)/(2.*R1*(CAPRP1+RP2)))
        DELTA3=ACOS(((CAPRP2+RP3)**2+R2*R2-R3*R3)/(2.*R2*(CAPRP2+RP3)))
        DELTA4=ACOS(((CAPRP3+RP4)**2+R3*R3-R4*R4)/(2.*R3*(CAPRP3+RP4)))
        DELTA5=ACOS((A*A+R4*R4-R5*R5)/(2.*A*R4))
        BETA1=PI-S6*DELTA2
        BETA2=GAMMA2+PI-S6*DELTA3
        BETA3=GAMMA3+PI-S6*DELTA4
        BETA4=GAMMA4+PI-S6*DELTA5
        BETA1D=BETA1/ZZ
        BETA2D=BETA2/ZZ
        BETA3D=BETA3/ZZ
        BETA4D=BETA4/ZZ
        IF (CONFIG.EQ.1.) GAMAPP=DELTA5+GAMMA5P
        IF (CONFIG.EQ.2.) GAMAPP=2.*PI-DELTA5-GAMMA5P
        WRITE (6,41) BETA1D,BETA2D,BETA3D,BETA4D,GAMMA2D,GAMMA3D,GAMMA4D,G
        1AMMA5D
        C
100     CONVERSION OF PRESSURE ANGLES TO RADIAN
        C
110     THETA1=THETA1*ZZ
        THETA2=THETA2*ZZ
        THETA3=THETA3*ZZ
        C

```

Computer program SANDA3 (cont)

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PROGRAM SANDA3 74/74 OPT=1

```

115 C COMPUTATION OF CENTRIFUGAL FORCES
C
T2=N2+R2*CM2
T3=N3+R3*CM2
T4=N4+R4*CM2

120 C DETERMINATION OF GEAR TRAIN CONSTANTS
C
TEST1=TAN(THETA1)
TEST2=TAN(THETA2)
TEST3=TAN(THETA3)
D1=(CAPR81+RB2)*TAN(THETA1)
D2=(CAPR82+RB3)*TAN(THETA2)
D3=(CAPR83+RB4)*TAN(THETA3)

130 C DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS
C
CALL ALFA (CAPR81, RB2, THETA1, CAPR01, R02, AL1IN, AL1FIN)
CALL ALFA (CAPR82, RB3, THETA2, CAPR02, R03, AL2IN, AL2FIN)
CALL ALFA (CAPR83, RB4, THETA3, CAPR03, R04, AL3IN, AL3FIN)

135 C INITIALIZATION OF ALPHAS
C
ALPHA1=AL1IN+(AL1FIN-AL1IN)*J1
ALPHA2=AL2IN+(AL2FIN-AL2IN)*J2
ALPHA3=AL3IN+(AL3FIN-AL3IN)*J3

140 C DATA FOR RUNGE KUTTA
C
PRMT(2)=3.
PRMT(4)=.01
NDIN=2
NDIN2=4
PHI(1)=PHID*ZZ
PHI(2)=0.

145 C COUPLED MOTION
C
1 PRMT(1)=TIME
PRMT(3)=.00001
DPHI(1)=.5
DPHI(2)=.5
IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 2
WRITE (6,42)
2 CALL RKGS (PRMT, PHI, DPHI, NDIM, IHLF, FCT, OUTP, AUX)
IF (PHITOT.GE.PHICUTD) GO TO 21

150 C TEST FOR ENTRANCE OR EXIT ACTION
C
IF (G.LE.0.) GO TO 5
PHID=PHI(1)/ZZ
IF (PHID.GE.135.00..AND.PHID.LE.160.) GO TO 3
GO TO 4
3 PHI(1)=PHI(1)+DELTA*ZZ.
PHIDR=PHI(1)/ZZ
PSI=PSI+2.*PI-LAMBDA*ZZ
PSIC=PSIC+LAMBDA*ZZ

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Computer program SANDA3 (cont)

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175      GO TO 5
      4 PHI(1)=PHI(1)-DELTA*ZZ*2.
      PHIPR=PHI(1)/ZZ
      PSI=PSI-2.*PI*LAMBDA*ZZ
      PSIC=PSIC
      C
      C
      C
180      FREE MOTION
      5 PRMT(1)=TIME
      X(1)=PHI(1)
      X(2)=PHI(2)
      X(3)=PSI
      X(4)=DPSI
      DX(1)=.25
      DX(2)=.25
      DX(3)=.25
      DX(4)=.25
      PRMT(3)=.00001
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 6
      WRITE (6,43)
185      6 CALL RKGS (PRMT,X,DX,NDIM2,IMLF,FCTF,OUTPF,AUX2)
      IF (PHITOT.GE.PHICUTD) GO TO 21
      PHI(1)=X(1)
      PHI(2)=X(2)
      H=2.*(B*COB(ALPHR)+A*COB(PHI(1)-ALPHR))
      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COB(PHI(1))-2.*A*R*SIN(
190      1*PHI(1)-ALPHR)
      GONE=(-H+SQRT(H*H-4.*K))/2.
      GTWO=(-H-SQRT(H*H-4.*K))/2.
      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 7
      G=GTWO
      GO TO 8
      7 G=GONE
      8 PHID=PHI(1)/ZZ
      IF (GP.LT.0.) GO TO 11
      IF (PHID.GE.135.0.AND.PHID.LE.160.) GO TO 9
      GO TO 10
      9 PHI(1)=PHI(1)+DELTA*ZZ
      PHIPR=PHI(1)/ZZ
      PSI=PSI+2.*PI-LAMBDA*ZZ
      PSIC=PSIC+LAMBDA*ZZ
      GO TO 5
      10 PHI(1)=PHI(1)-DELTA*ZZ*2.
      PHIPR=PHI(1)/ZZ
      PSI=PSI-2.*PI+LAMBDA*ZZ
      PSIC=PSIC
      GO TO 5
      11 IF (PHID.LE.160.0) GO TO 13
      EXIT ACTION
      C
      C
      C
      C
200      COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION
      AONE=B*COB(ALPHR)+Q
      DONE=C*COB(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
      A 172
      A 173
      A 174
      A 175
      A 176
      A 177
      A 178
      A 179
      A 180
      A 181
      A 182
      A 183
      A 184
      A 185
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      A 224
      A 225
      A 226
      A 227
      A 228

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Computer program SANDA3 (cont.)

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OPT=1

PROGRAM SANDA3

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```

230 IF (PHITOT.GT.55..AND.PHITOT.LT.3500..) GO TO 12
    WRITE (6,44) VP,VS
    C
    C EXIT ACTION TEST
    C
235 12 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 15
    IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
    IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15
    IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
    IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
    IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
    IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
    IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
    C
    C COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
    C
245 13 AONE=B*COS(ALPHR)+G
    DONE=C*COS(PHI(1)-ALPHR-PSI)
    VP=DONE*DPSI
    VS=AONE*PHI(2)
    IF (PHITOT.GT.55..AND.PHITOT.LT.3500..) GO TO 14
    WRITE (6,44) VP,VS
    C
    C ENTRANCE ACTION
    C
255 14 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
    IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
    IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 15
    IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
    IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 15
    IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
    IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
    IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
    C
    C IMPACT
    C
265 15 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)
    H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
    K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)*2.*A*B*COS(PHI(1))-2.*A*R*
    1SIN(PHI(1)-ALPHR)
    GONE=(-H+SQRT(H**2-4.*K))/2.
    GTWO=(-H-SQRT(H**2-4.*K))/2.
    IF (ABS(GONE).LT.ABS(GTWO)) GO TO 16
    G=GTWO
    GO TO 17
    C
    C
    C
275 16 G=GONE
    17 IF (TIME.GT.5.0) GO TO 21
    C
    C TEST FOR EXIT ACTION
    C
    C
280 PHID=PHI(1)/ZZ
    IF (PHID.LE.160.0) GO TO 19
    C
    C EXIT ACTION
    C
285 19 COMPUTATION OF VELOCITIES VP AND VS FOR BOTTOM ACTION
    C

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      ADNE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1))-ALPHR-PSI
      VP=DONE*DPSI
      VS=ADNE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 18
      WRITE (6,44) VP,VS
18  IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C  EXIT ACTION TESTS
C
      IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
C
C  COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
C
19  ADNE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1))-ALPHR-PSI
      VP=DONE*DPSI
      VS=ADNE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 20
      WRITE (6,44) VP,VS
20  IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C  ENTRANCE ACTION TESTS
C
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
21  TURNS=TIME-RPM/60.
      WRITE (6,45) F34MAX,F23MAX,F12MAX,FF34MAX,FF23MAX,FF12MAX,PNMAX,
1TURNS
      STOP
C
C
C
22  FORMAT (6F10.5)
23  FORMAT (1H1.5X,2H2=F13.5,5X,2H2=F13.5,5X,2H2=F13.5,5X,2H2=F13.5,
15.5X,6HALPHA=F9.4,5X,14HCONFIGURATION=F3.0/)
24  FORMAT (3F10.5)
25  FORMAT (1H1.5X,6H6REST=F5.2,3X,7H1AMBDA=F8.3,3X,6HDELTA=F8.3/)
26  FORMAT (5E12.5)
27  FORMAT (1H1.5X,4H11=E15.5,3X,4H12=E15.5,3X,4H13=E15.5,3X,4H14=
14=E15.5,3X,4H15=E15.5/)
28  FORMAT (1H1.5X,4H11=E15.5,3X,4H12=E15.5,3X,4H13=E15.5,3X,4H14=
14=E15.5,3X,4H15=E15.5/)
29  FORMAT (7F10.4/3F10.4)

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Computer program SANDA3 (cont)

| PROGRAM SANDA3 | 74/74 | OPT=1                                                                                                                                                                                                                                                                                                                                                                 | FIN 4.8+508 | 08/07/81 | 13.32.47 | PAGE   | 7 |
|----------------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|----------|----------|--------|---|
| 345            | 30    | FORMAT (6X,SHRC1 =,F7.4,3X,SHRCP =,F7.4,3X,6HRHOP =,F7.4,3X,SHRPM<br>1 =,F6.0,3X,8HHPH1CD =,F9.4,3X,8HPSICCD =,F9.4,3X,6HHPHID =,F9.4//6X,<br>29HHPHICUD =,F6.0//6X,4HMU =,F4.2,3X,5HMU1 =,F4.2//)                                                                                                                                                                    |             |          |          | A 343  |   |
|                | 31    | FORMAT (3F10.4/6F10.0/6F10.5/3F10.4)                                                                                                                                                                                                                                                                                                                                  |             |          |          | A 344  |   |
|                | 32    | FORMAT (5F10.4)                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 345  |   |
|                | 33    | FORMAT (6F10.5)                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 346  |   |
|                | 34    | FORMAT (3F10.2)                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 347  |   |
|                | 35    | FORMAT (1H,5X,8HPSUBD1 =,F5.1,3X,8HPSUBD2 =,F5.1,3X,8HPSUBD3 =,F5<br>1.1//6X,SHNG1 =,F4.0,3X,SHNG2 =,F4.0,3X,SHNG3 =,F4.0,3X,SHNP2 =,F4.<br>20,3X,SHNP3 =,F4.0,3X,SHNP4 =,F4.0//6X,8HCAPRP1 =,F8.5,3X,8HCAPRP2<br>3 =,F8.5,3X,8HCAPRP3 =,F8.5//6X,SHRP2 =,F8.5,3X,SHRP3 =,F8.5,3X,SHRP<br>44 =,F8.5//6X,8HMTETA1 =,F8.3,3X,8HMTETA2 =,F8.3,3X,8HMTETA3 =,F8.3<br>5//) |             |          |          | A 348  |   |
| 350            | 36    | FORMAT (6X,4HR1 =,F7.5,3X,4HR2 =,F7.5,3X,4HR3 =,F7.5,3X,4HR4 =,F7.<br>15,3X,4HR5 =,F7.5//)                                                                                                                                                                                                                                                                            |             |          |          | A 349  |   |
|                | 37    | FORMAT (6X,6HRH01 =,F7.5,3X,6HRH02 =,F7.5,3X,6HRH03 =,F7.5,3X,6HRH<br>104 =,F7.5//)                                                                                                                                                                                                                                                                                   |             |          |          | A 350  |   |
|                | 38    | FORMAT (6X,8HCAPRB1 =,F7.5,3X,8HCAPRB2 =,F7.5,3X,8HCAPRB3 =,F7.5,3<br>1X,SHRB2 =,F7.5,3X,SHRB3 =,F7.5,3X,SHRB4 =,F7.5//)                                                                                                                                                                                                                                              |             |          |          | A 351  |   |
|                | 39    | FORMAT (6X,8HCAPRO1 =,F7.5,3X,8HCAPRO2 =,F7.5,3X,8HCAPRO3 =,F7.5,3<br>1X,SHPO2 =,F7.5,3X,SHPO3 =,F7.5,3X,SHPO4 =,F7.5//)                                                                                                                                                                                                                                              |             |          |          | A 352  |   |
|                | 40    | FORMAT (1H0.5X,4HJ1 =,F4.2,3X,4HJ2 =,F4.2,3X,4HJ3 =,F4.2//)                                                                                                                                                                                                                                                                                                           |             |          |          | A 353  |   |
|                | 41    | FORMAT (8X,8HBETA1D =,F7.2,3X,8HBETA2D =,F7.2,3X,8HBETA3D =,F7.2,3<br>1X,8HBETA4D =,F7.2//6X,9HGAMMA2D =,F7.2,3X,9HGAMMA3D =,F7.2,3X,9HGA<br>2HMA4D =,F7.2,3X,9HGAMMA5D =,F7.2//)                                                                                                                                                                                     |             |          |          | A 354  |   |
| 355            | 42    | FORMAT (1H0.5X,14HCOUPLED MOTION)                                                                                                                                                                                                                                                                                                                                     |             |          |          | A 355  |   |
|                | 43    | FORMAT (1H0.5X,11HFREE MOTION//)                                                                                                                                                                                                                                                                                                                                      |             |          |          | A 356  |   |
|                | 44    | FORMAT (4H0VP =,F8.3,3X,3HVS =,F8.3)                                                                                                                                                                                                                                                                                                                                  |             |          |          | A 357  |   |
|                | 45    | FORMAT (1H0.6X,*F34MAX =,F6.2/1H0.6X,*F23MAX =,F6.2/1H0.6X,*F12<br>1MAX =,F6.2/1H0.6X,*FF34MAX =,F6.2/1H0.6X,*FF23MAX =,F6.2/1H0.6X<br>2*FF12MAX =,F6.2/1H0.6X,*PNMAX =,F6.2/1H0.6X,*TURNS =,F6.2)                                                                                                                                                                    |             |          |          | A 358  |   |
|                |       | END                                                                                                                                                                                                                                                                                                                                                                   |             |          |          | A 359  |   |
| 360            |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 360  |   |
| 365            |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 361  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 362  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 363  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 364  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 365  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 366  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 367  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 368  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 369  |   |
| 370            |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 370  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 371  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 372  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 373  |   |
|                |       |                                                                                                                                                                                                                                                                                                                                                                       |             |          |          | A 374- |   |

| SUBROUTINE IMPACT | 74/74                                                                | OPT-1 | FTN 4.8+50R | 08/07/81 | 13.32.47 | PAGE | 1    |
|-------------------|----------------------------------------------------------------------|-------|-------------|----------|----------|------|------|
| 1                 | SUBROUTINE IMPACT (PHI,DPSI,PSI,DPSI)                                |       |             |          |          |      | B 1  |
|                   | COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,N4,NP,J1,I2,I3,I4,IP,EREST,LAM   |       |             |          |          |      | B 2  |
|                   | 1BOA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,ON2,RC1,PHITC,TEST1,TEST2  |       |             |          |          |      | B 3  |
| 5                 | 2,TEST3,NG1,NG2,NG3,NG4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH          |       |             |          |          |      | B 4  |
|                   | 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J  |       |             |          |          |      | B 5  |
|                   | 43,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,GAMMA9           |       |             |          |          |      | B 6  |
|                   | 5ETA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,   |       |             |          |          |      | B 7  |
|                   | 6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,I2,I3,I4,MU,MU1,  |       |             |          |          |      | B 8  |
| 10                | 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPSI2,F34MAX,F23MAX,F12MAX,        |       |             |          |          |      | B 9  |
|                   | 8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTO                               |       |             |          |          |      | B 10 |
|                   | REAL I1,I2,I3,I4,IP,LAMBDA,N41,N42,N43,ISTOT,K                       |       |             |          |          |      | B 11 |
|                   | 1ISTOT=I4+I1+N41+I2+N42+I3+N43*N43                                   |       |             |          |          |      | B 12 |
|                   | H=2.*(B+COS(ALPHR)+A+COS(PHI-ALPHR))                                 |       |             |          |          |      | B 13 |
| 15                | K=A**2+B**2+C**2+2.*B*R*SIN(ALPHR)*2.*A*B*COS(PHI)-2.*A*R*SIN        |       |             |          |          |      | B 14 |
|                   | 1(PHI-ALPHR)                                                         |       |             |          |          |      | B 15 |
|                   | GONE=(-H+SQRT(H**2-4.*K))/2.                                         |       |             |          |          |      | B 16 |
|                   | GTWO=(-H-SQRT(H**2-4.*K))/2.                                         |       |             |          |          |      | B 17 |
|                   | IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1                                  |       |             |          |          |      | B 18 |
|                   | G=GTWO                                                               |       |             |          |          |      | B 19 |
| 20                | GO TO 2                                                              |       |             |          |          |      | B 20 |
|                   | 1 G=GONE                                                             |       |             |          |          |      | B 21 |
|                   | 2 AONE=B*COS(ALPHR)+G                                                |       |             |          |          |      | B 22 |
|                   | DONE=C+COS(PHI-ALPHR-PSI)                                            |       |             |          |          |      | B 23 |
|                   | DPSIIN=DPSI                                                          |       |             |          |          |      | B 24 |
| 25                | DPSI=((IP+AONE*DPSI+1ISTOT*DONE+DPSI*IP+AONE*EREST/DONE*(DPSI+DONE-D |       |             |          |          |      | B 25 |
|                   | 1PHI+AONE))/((IP+AONE**2/DONE+1ISTOT*DONE)                           |       |             |          |          |      | B 26 |
|                   | DPSI=((DPSI+AONE-EREST*(DPSI+DONE-DPSIIN+AONE))/DONE                 |       |             |          |          |      | B 27 |
|                   | PHID=DPSI/ZZ                                                         |       |             |          |          |      | B 28 |
|                   | PSID=PSI/ZZ                                                          |       |             |          |          |      | B 29 |
| 30                | IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 3                       |       |             |          |          |      | B 30 |
|                   | WRITE (6,4)                                                          |       |             |          |          |      | B 31 |
|                   | WRITE (6,5) PHID,DPSI,PSID,DPSI,PHITOT                               |       |             |          |          |      | B 32 |
|                   | 3 RETURN                                                             |       |             |          |          |      | B 33 |
|                   | C                                                                    |       |             |          |          |      | B 34 |
| 35                | C                                                                    |       |             |          |          |      | B 35 |
|                   | C                                                                    |       |             |          |          |      | B 36 |
|                   | 4 FORMAT (1M0,5X,6HIMPACT)                                           |       |             |          |          |      | B 37 |
|                   | 5 FORMAT (1M0,18X,4HPHI=,F8.3,3X,7HPHIDOT=,F8.3,3X,4HPSI=,F8.3,3X,7H |       |             |          |          |      | B 38 |
| 40                | 1PSIDOT=,F8.3,3X,8HPHITOT =,F8.3)                                    |       |             |          |          |      | B 39 |
|                   | END                                                                  |       |             |          |          |      | B 40 |

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1  SUBROUTINE FCT (T,PHI,DPHI)
COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
18DA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
5  2,TEST3,NG1,NG2,NG3,NG2,NP3,NP4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH
3ET1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
43,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,GAMMA9,GAMMA10
5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPSI2,DPSI2,F34MAX,F23MAX,F12MAX,
10 BFF34MAX,FF12MAX,FF12MAX,PNMAX,PHICUTD
DIMENSION PHI(2),DPHI(2)
REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
PHID=PHI(1)/ZZ
DELPHI=PHID-PHIPR
15 PHIT=(PHITOT+DELPHI)*ZZ
IN=1
CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AGNE,BONE,CONE
1,DONE,U,V,Z)
CALL IN3 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AGNE,BONE,CONE,DONE,AA1,AA
20 12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA
2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
IF (DPSI-DPSI2.GE.O.) IPR=IP+AA22
IF (DPSI-DPSI2.LT.O.) IPR=IP-AA22
25 IF (PHI(2)*DPHI2.GE.O.) I1R=1+ABS(MU)*RHO1*(AA26+AA30)
IF (PHI(2)*DPHI2.LT.O.) I1R=1-ABS(MU)*RHO1*(AA26+AA30)
IF (I1R.LT.O.) I1R=0.
IF (IPR.LT.O.) IPR=0.
IF (IPR.LT.O.) IPR=0.
30 AA54=14*AA18+IPR*AA17+U-N41*I1R*AA15+AA18*AA44*AA53/(AA31*AA42*AA5
11)*N42*12*AA15+AA18*AA44/(AA42*AA51)-N43*13*AA15+AA18/AA42
AA55=IPR*AA17+V+AA17*AA21*Z+N41*N41*AA15+AA18*AA34*AA44*AA53/(AA
131*AA42*AA51)
AA56=2.*OM2/ABS(OMEGA)*AA17*AA20*Z-N41*AA15+AA18*AA33*AA44*AA53/(A
35 1A31*AA42*AA51)
AA57=-AA16*AA18-T4-T3*AA15+AA18*AA43/AA42-T2*AA15+AA18*AA44*AA52/(
1AA42*AA51)-AA15*AA18*AA32*AA44*AA53/(AA31*AA42*AA51)-AA17*OM2*AA19
AA58=AA17*MP*RCP*RS*OM2
AA59=AA15*AA18*AA35*AA44*AA53/(AA31*AA42*AA51)
40 DPHI(1)=PHI(2)
DPHI(2)=(-AA55*PHI(2)*PHI(2)-AA56*PHI(2)*AA57+AA58*PHI(2)*PHI(2)-
1PSIC)+AA59*SIN(PHI1C+N41*(PHITOT*ZZ+PHI(1)-PHIPR*ZZ))/AA54
RETURN
END

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1 SUBROUTINE OUTP (T,PHI,DPHI,IMLF,NOIM,PRMT)
2 REAL M1,M2,M3,M4,MP,11,12,13,14,IP,11R,N41,N42,N43,MU,MU1,IPR
3 DIMENSION PHI(2),DPHI(2),PRMT(5)
4 COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,11,12,13,14,IP,EREST,LAM
5 18DA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
6 2,TEST3,NG1,NG2,NG3,NP3,NP4,CAPR81,CAPR82,CAPR83,RB2,RB3,RB4,TH
7 3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
8 43,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,GAMMA9,GAMMA10
9 5,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,01,02,03,AL1IN,AL1FIN,
10 GAL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
11 7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPH12,DPS12,F34MAX,F23MAX,F12MAX,
12 8FF34MAX,FF23MAX,FF12MAX,PMAX,PHICUTD
13 COMMON /ZETA/ PSI,TIME,G,DP31,GP
14 PHID=PHI(1)/ZZ
15 DELPHI=PHID-PHIPR
16 PHIPR=PHID
17 PHITOT=PHITOT+DELPHI
18 PHIT=PHITOT+ZZ
19 IN=0
20 CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DP31,AONE,BONE,CONE)
21 1,DONE,U,V,Z)
22 CALL IN3 (PHI,PHIT,DELPHI,GDOT,PSI,DP31,AONE,BONE,CONE,DONE,AA1,AA
23 12,AA3,AA4,AA5,APG,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA
24 2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
25 330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
26 43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
27 IF (DPS1-DPS12-GE.O.) IPR=IP+AA22
28 IF (DPS1-DPS12-LT.O.) IPR=IP-AA22
29 IF (PHI(2)*DPH12-GE.O.) 11R=11+ABS(MU)*RHO1*(AA26+AA30)
30 IF (PHI(2)*DPH12-LT.O.) 11R=11-ABS(MU)*RHO1*(AA26+AA30)
31 IF (11R-LT.O.) 11R=0.
32 IF (IPR-LT.O.) IPR=0.
33 AA54=14*AA18+IPR*AA17-U*N41*11R*AA15*AA18*AA44*AA53/(AA31*AA2*AA5
34 11)*N42*12*AA15*AA18*AA44/(AA42*AA51)-N43*13*AA15*AA18*AA44
35 AA55=IPR*AA17+V*AA17*AA21*Z+2*N41*N41*AA15*AA10*AA34*AA44*AA53/(AA
36 131*AA42*AA51)
37 AA56=2.*OM2/ABS(OMEGA)*AA17*AA20*Z-N41*AA15*AA18*AA33*AA44*AA53/(A
38 1A31*AA42*AA51)
39 AA57=-AA16*AA18*74-T3*AA15*AA18*AA43/AA42-12*AA15*AA18*AA44*AA52/(
40 1AA42*AA51)-AA15*AA18*AA32*AA44*AA53/(AA31*AA42*AA51)-AA17*OM2*AA19
41 AA58=AA17*MP/RCP/R5*OM2
42 AA59=AA15*AA18*AA35*AA44*AA53/(AA31*AA42*AA51)
43 DPH12=(-AA55*PHI(2)*PHI(2)-AA56*PHI(2)*AA57*AA58*SIN(GAMAPP-PSI-PS
44 11C)+AA59*SIN(PHI1C+N41*PHI1))/AA54
45 DPS12=U*DPH12+V*PHI(2)*PHI(2)
46
47 COMPUTATION OF CONTACT FORCES
48
49 F34=(-AA32*AA40*AA53-AA31*AA44*AA52*T2-AA31*AA43*AA51*T3+AA35*AA44
50 1*AA53*SIN(PHI1C+N41*PHI1)+AA33*AA44*AA53*N41*PHI(2)-AA34*AA44*AA53
51 2*N41*PHI(2)*PHI(2))+((AA44*AA53*11R-N41-AA31-AA44*12*N42+AA31*AA
52 351*13*N43)*DPH12)/(AA31*AA42*AA51)
53 F23=(F34*AA42+T3*AA43-13*N43*DPH12)/AA44
54 F12=(F23*AA51+T2*AA52+12*N42*DPH12)/AA53
55 IF (F34*GT.F34MAX) F34MAX=F34
56 IF (F23*GT.F23MAX) F23MAX=F23
57 IF (F12*GT.F12MAX) F12MAX=F12

```

## Computer program SANDA3 (cont)

| SUBROUTINE | OUTP | 74/74 | OPT=1 | FTN 4.8+50B | 08/07/81 | 13.32.47 | PAGE |
|------------|------|-------|-------|-------------|----------|----------|------|
| 60         | C    |       |       |             | D 58     |          |      |
|            | C    |       |       |             | D 59     |          |      |
|            | C    |       |       |             | D 60     |          |      |
|            | C    |       |       |             | D 61     |          |      |
|            | C    |       |       |             | D 62     |          |      |
|            | C    |       |       |             | D 63     |          |      |
|            | C    |       |       |             | D 64     |          |      |
|            | C    |       |       |             | D 65     |          |      |
|            | C    |       |       |             | D 66     |          |      |
|            | C    |       |       |             | D 67     |          |      |
|            | C    |       |       |             | D 68     |          |      |
|            | C    |       |       |             | D 69     |          |      |
| 70         |      |       |       |             | D 70     |          |      |
|            |      |       |       |             | D 71     |          |      |
|            |      |       |       |             | D 72     |          |      |
|            |      |       |       |             | D 73     |          |      |
|            |      |       |       |             | D 74     |          |      |
|            |      |       |       |             | D 75     |          |      |
| 75         | C    |       |       |             | D 76     |          |      |
|            | C    |       |       |             | D 77     |          |      |
|            |      |       |       |             | D 79     |          |      |
| 80         |      |       |       |             | D 80     |          |      |
|            |      |       |       |             | D 81     |          |      |
|            |      |       |       |             | D 82     |          |      |
|            |      |       |       |             | D 83-    |          |      |

SUBROUTINE FCTF

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1 SUBROUTINE FCTF (T,X,DX)
2 COMMON A,B,C,R,ALPHR,FI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
3 180A,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
4 2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
5 3ET1,THETA2,THETA3,R1,R2,R3,R4,RS,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
6 3, GAMMA2, GAMMA3, GAMMA4, GAMMA5, GAMMA6, GAMMA7, GAMMA8, GAMMA9,
7 5ELTA3, DELTA4, DELTA5, BETA1, BETA2, BETA3, BETA4, D1, D2, D3, AL1IN, AL1FIN,
8 7AL2IN, AL2FIN, AL3IN, AL3FIN, ALPA1, ALPHA2, ALPHA3, IN, T2, T3, T4, MU, MU1,
9 9RC1P, PSIC, S1, S2, S3, S4, S5, A1, A2, A3, DPHI2, DPS12, F34MAX, F23MAX, F12MAX,
10 10BFF34MAX, F23MAX, F12MAX, PNMAX, PHICUTD
11 DIMENSION X(4), DX(4)
12 REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,MU,MU1,N41,N42,N43,I4R
13 PHID=X(1)/ZZ
14 DELPHI=PHID-I*H1PR
15 PHIT=(PHITOT+DELPHI)*ZZ
16 IN=1
17 CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
18 1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
19 219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
20 32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
21 4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
22 IF (X(4)*DPS12*GE.0.) IPR=IP+AA22
23 IF (X(4)*DPS12*LT.0.) IPR=IP-AA22
24 IF (X(2)*DPHI2*GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
25 IF (X(2)*DPHI2*LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
26 IF (I1R*LT.0.) I1R=0.
27 IF (IPR*LT.0.) IPR=0.
28 IF (IPR*EQ.0.) WRITE (6,1)
29 AA60=IPR
30 AA61=2.*OM2+AA20/ABS(OMEGA)
31 AA62=AA19*OM2
32 AA63=OM2*NP+RCP*R5
33 AA64=I4-AA15*AA44+AA53*N41+I1R/(AA31*AA42+AA51)+AA15*AA44*AA42*I2/(
34 1AA42+AA15)-AA15*N43*I3/AA42
35 AA65=AA15*AA34+AA44*AA53*N41+I1R/(AA31*AA42+AA51)
36 AA66=AA15*AA33+AA44*AA53*N41/(AA31*AA42+AA51)
37 AA67=-AA16*T4-AA15*AA43*T3-AA42-AA15*AA44+AA52*T2/(AA42+AA51)-AA15
38 1*AA32+AA44*AA53/(AA31*AA42+AA51)
39 AA68=AA15*AA35+AA44*AA53/(AA31*AA42+AA51)
40 DX(1)=X(2)
41 DX(3)=X(4)
42 DX(2)=(-AA65*X(2)+X(2)+AA66*X(2)+AA67+AA68*SIN(PHITC+N41*(PHITOT+Z
43 1Z+X(1)-PHIPR*ZZ)))/AA64
44 DX(4)=(-AA21*X(4)+X(4)-AA61*X(4)-AA62+AA63*SIN(GAMAPP-X(3)-PSIC))/
45 1AA60
46 RETURN
47
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Computer program SANDA3 (cont)

| SUBROUTINE | OUTPF | 74/74 | OPT=1 | FTN 4.8+508 | 08/07/81 | 13.32.47 | PAGE | 1 |
|------------|-------|-------|-------|-------------|----------|----------|------|---|
| 1          |       |       |       |             |          |          |      |   |
| 5          |       |       |       |             |          |          |      |   |
| 10         |       |       |       |             |          |          |      |   |
| 15         |       |       |       |             |          |          |      |   |
| 20         |       |       |       |             |          |          |      |   |
| 25         |       |       |       |             |          |          |      |   |
| 30         |       |       |       |             |          |          |      |   |
| 35         |       |       |       |             |          |          |      |   |
| 40         |       |       |       |             |          |          |      |   |
| 45         |       |       |       |             |          |          |      |   |
| 50         |       |       |       |             |          |          |      |   |
| 55         |       |       |       |             |          |          |      |   |

Computer program SANDA3 (cont)

PAGE 2

13.32.47

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FTN 4.8+508

74/74 OPT=1

SUBROUTINE OUTPF

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      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 1
      WRITE (6,4) T,PHID,X(2),PSID,X(4),PHITOT,FF12,FF23,FF34
      1 IF (T.EQ.TIME) GO TO 3
      C
      C CHECK FOR CONTINUED FREE MOTION
      C
      F=A*SIN(X(1)-ALPHR)-B*SIN(ALPHR)-C*SIN(X(1)-ALPHR-PSI)-R
      GP=C*COS(X(1)-ALPHR-PSI)-B*COS(ALPHR)-A*COS(X(1)-ALPHR)
      IF (F.GT.0.) GO TO 2
      PRNT(5)=1.
      GO TO 3
      2 IF (GP.GT.0.) PRNT(5)=1.
      3 TIME=T
      IF (PHITOT.GE.PHICUTD) PRMT(5)=1.
      RETURN
      C
      C
      4 FORMAT (6X,3HT =,F8.5,3X,5PHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI
      1=,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F7.2/20X,6HFF12 =,F7.3,3X,
      26HFF23 =,F7.3,3X,6HFF34 =,F7.3)
      END

```

Computer program SANDA3 (cont)

| SUBROUTINE KINEM | 74/74                                                               | OPT=1 | FTN 4.8+508 | 08/07/81 | 13.32.47 | PAGE | 1   |
|------------------|---------------------------------------------------------------------|-------|-------------|----------|----------|------|-----|
| 1                | SUBROUTINE KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BON  |       |             |          |          |      | 1   |
|                  | 1E,CONE,DONE,U,V,Z)                                                 |       |             |          |          |      | 2   |
|                  | DIMENSION PHI(2)                                                    |       |             |          |          |      | 3   |
|                  | REAL K                                                              |       |             |          |          |      | 4   |
| 5                | PI=3.14159                                                          |       |             |          |          |      | 5   |
|                  | H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))                             |       |             |          |          |      | 6   |
|                  | K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN   |       |             |          |          |      | 7   |
|                  | PHI(1)-ALPHR)                                                       |       |             |          |          |      | 8   |
|                  | GONE=(-H+SQRT(H*H-4.*K))/2.                                         |       |             |          |          |      | 9   |
| 10               | GTWO=(-H-SQRT(H*H-4.*K))/2.                                         |       |             |          |          |      | 10  |
|                  | IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1                                 |       |             |          |          |      | 11  |
|                  | G=GTWO                                                              |       |             |          |          |      | 12  |
|                  | GO TO 2                                                             |       |             |          |          |      | 13  |
|                  | 1 G=GONE                                                            |       |             |          |          |      | 14  |
| 15               | 2 P=B*SIN(PHI(1))*G*SIN(PHI(1)-ALPHR)+R*COS(PHI(1)-ALPHR)           |       |             |          |          |      | 15  |
|                  | Q=B*COS(PHI(1))*G*COS(PHI(1)-ALPHR)-R*SIN(PHI(1)-ALPHR)             |       |             |          |          |      | 16  |
|                  | S=G*B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)                                |       |             |          |          |      | 17  |
|                  | GDOT=PHI(2)*A*P/S                                                   |       |             |          |          |      | 18  |
|                  | PSI=ASIN(P/C)                                                       |       |             |          |          |      | 19  |
| 20               | IF (PSI.LT.0.) GO TO 3                                              |       |             |          |          |      | 20  |
|                  | GO TO 4                                                             |       |             |          |          |      | 21  |
|                  | 3 PSI=2.*PI-ABS(PSI)                                                |       |             |          |          |      | 22  |
|                  | 4 DPSI=(Q*PHI(2)+GDOT*SIN(PHI(1)-ALPHR))/(C*COS(PSI))               |       |             |          |          |      | 23  |
|                  | AONE=B*COS(ALPHR)+G                                                 |       |             |          |          |      | 24  |
| 25               | BONE=B*SIN(ALPHR)                                                   |       |             |          |          |      | 25  |
|                  | CDNE=(R+C*SIN(PHI(1)-ALPHR-PSI))                                    |       |             |          |          |      | 26  |
|                  | DDNE=C*COS(PHI(1)-ALPHR-PSI)                                        |       |             |          |          |      | 27  |
|                  | Z=(Q*A*P/S*SIN(PHI(1)-ALPHR))/(C*COS(PSI))                          |       |             |          |          |      | 28  |
|                  | U=(Q*SIN(PHI(1)-ALPHR)*P*A/S)/(C*COS(PSI))                          |       |             |          |          |      | 29  |
| 30               | V=(Q*A*P*SIN(PHI(1)-ALPHR)/S)**2*TAN(PSI)/(C**2*(COS(PSI))**2)+(1.  |       |             |          |          |      | 30  |
|                  | 1/(C*COS(PSI)))*(2.*A*B*COS(PHI(1)-ALPHR)/S-P*2.*A**2*P*(SIN(PHI(1) |       |             |          |          |      | 31  |
|                  | 2-ALPHR))**2/S**2+A*Q*SIN(PHI(1)-ALPHR)/S-A**2*P**2*SIN(PHI(1)-ALPH |       |             |          |          |      | 32  |
|                  | 3R)/S**3)                                                           |       |             |          |          |      | 33  |
|                  | RETURN                                                              |       |             |          |          |      | 34  |
| 35               | END                                                                 |       |             |          |          |      | 35- |

| SUBROUTINE IN3 | 74/74 | OPT=1 | FTN 4.81500 | 08/07/81 | 13.32.47 | PAGE | 1  |
|----------------|-------|-------|-------------|----------|----------|------|----|
| 1              |       |       |             |          |          |      | 1  |
|                |       |       |             |          |          |      | 2  |
|                |       |       |             |          |          |      | 3  |
|                |       |       |             |          |          |      | 4  |
|                |       |       |             |          |          |      | 5  |
| 5              |       |       |             |          |          |      | 6  |
|                |       |       |             |          |          |      | 7  |
|                |       |       |             |          |          |      | 8  |
|                |       |       |             |          |          |      | 9  |
| 10             |       |       |             |          |          |      | 10 |
|                |       |       |             |          |          |      | 11 |
|                |       |       |             |          |          |      | 12 |
|                |       |       |             |          |          |      | 13 |
| 15             |       |       |             |          |          |      | 14 |
|                |       |       |             |          |          |      | 15 |
|                |       |       |             |          |          |      | 16 |
|                |       |       |             |          |          |      | 17 |
|                |       |       |             |          |          |      | 18 |
| 20             |       |       |             |          |          |      | 19 |
|                |       |       |             |          |          |      | 20 |
|                |       |       |             |          |          |      | 21 |
|                |       |       |             |          |          |      | 22 |
|                |       |       |             |          |          |      | 23 |
|                |       |       |             |          |          |      | 24 |
|                |       |       |             |          |          |      | 25 |
| 25             |       |       |             |          |          |      | 26 |
|                |       |       |             |          |          |      | 27 |
|                |       |       |             |          |          |      | 28 |
| 30             |       |       |             |          |          |      | 29 |
|                |       |       |             |          |          |      | 30 |
|                |       |       |             |          |          |      | 31 |
|                |       |       |             |          |          |      | 32 |
|                |       |       |             |          |          |      | 33 |
|                |       |       |             |          |          |      | 34 |
| 35             |       |       |             |          |          |      | 35 |
|                |       |       |             |          |          |      | 36 |
|                |       |       |             |          |          |      | 37 |
|                |       |       |             |          |          |      | 38 |
|                |       |       |             |          |          |      | 39 |
| 40             |       |       |             |          |          |      | 40 |
|                |       |       |             |          |          |      | 41 |
|                |       |       |             |          |          |      | 42 |
|                |       |       |             |          |          |      | 43 |
| 45             |       |       |             |          |          |      | 44 |
|                |       |       |             |          |          |      | 45 |
|                |       |       |             |          |          |      | 46 |
|                |       |       |             |          |          |      | 47 |
|                |       |       |             |          |          |      | 48 |
| 50             |       |       |             |          |          |      | 49 |
|                |       |       |             |          |          |      | 50 |
|                |       |       |             |          |          |      | 51 |
|                |       |       |             |          |          |      | 52 |
|                |       |       |             |          |          |      | 53 |
| 55             |       |       |             |          |          |      | 54 |
|                |       |       |             |          |          |      | 55 |
|                |       |       |             |          |          |      | 56 |
|                |       |       |             |          |          |      | 57 |

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60      A2=ALPHA3*CAPR82
        A3=ALPHA3*CAPR83
        DENOM=1.+MU*MU
        DENOM1=1.+MU1*MU1
        C
        C
        C      COMPUTATION OF AA1 TO AA53
        AA1=ABS((MU1*(S4-S5)*SIN(PHI-ALPHR))-(1.+S4*S5*MU1*MU1)*COS(PHI-ALP
1HR))/DENOM1)
        AA2=ABS((MP*(R5*(SIN(GAMAPP)-MU1*S5*COS(GAMAPP))+RCP*(SIN(PSI+PSIC
1)*MU1*S5-COS(PSI+PSIC)))/DENOM1)
        AA3=ABS((MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
        AA4=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
        AA5=ABS((MU1*(S4-S5)*COS(PHI-ALPHR))*(1.+S4*S5*MU1*MU1)*SIN(PHI-ALP
1HR))/DENOM1)
        AA6=ABS((MP*(R5*(COS(GAMAPP)+MU1*S5*SIN(GAMAPP))-RCP*(COS(PSI+PSI
1C)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
        AA7=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
        AA8=ABS((MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
        AA9=ABS((R5*(MU1*S4-MU)*SIN(PHI-ALPHR+BETA4)+(1.+MU*MU1*S4)*COS(PHI-
1ALPHR+BETA4))/DENOM)
        AA10=ABS((MU*(1.-S3)*SIN(BETA3+THETA3)+(1.+MU*MU*S3)*COS(BETA3+TH
1TA3))/DENOM)
        AA11=ABS((SIN(GAMMA4)-MU*COS(GAMMA4))/DENOM)
        AA12=ABS(((1.+MU*MU1*S4)*SIN(PHI-ALPHR+BETA4)+(S4*MU1-MU)*COS(PHI-
1ALPHR+BETA4))/DENOM)
        AA13=ABS(((1.+MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.-S3)*COS(BETA3+TH
1ETA3))/DENOM)
        AA14=ABS((COS(GAMMA4)+MU*SIN(GAMMA4))/DENOM)
        AA15=RB4-MU*(S3*(D3-A3)+RHO4*(AA10+AA13))
        AA16=MU*RHO4*(AA11+AA14)
        AA17=ADNE*MU1*S4*BONE+MU*RHO4*(AA9+AA12)
        AA18=DONE+CONC*MU1*S4-RHOP*MU1*S5*(AA1+AA5)
        AA19=RHOP*MU1*S5*(AA2+AA6)
        AA20=RHOP*MU1*(AA3+AA7)
        AA21=S5*AA20
        AA22=RHOP*MU1*(AA4+AA8)
        AA23=ABS((MU*(1.+S1)*SIN(BETA1+THETA1)-(1.-MU*MU*S1)*COS(BETA1+TH
1TA1))/DENOM)
        AA24=ABS((M1*(MU*R1+RC1*(MU*COS(PHI1C+N41*PHIT)+SIN(PHI1C+N41*PHIT
1))/DENOM)
        AA25=ABS((M1*RC1*(MU*COS(PHI1C+PHIT+N41)+SIN(PHI1C+N41*PHIT))/DEN
1DM)
        AA26=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT))/DEN
1DM)
        AA27=ABS(((1.-MU*MU*S1)*SIN(BETA1+THETA1)+MU*(1.+S1)*COS(BETA1+TH
1TA1))/DENOM)
        AA28=ABS((M1*(R1+RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))
1)/DENOM)
        AA29=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT))/DEN
1DM)
        AA30=ABS((M1*RC1*(SIN(PHI1C+N41*PHIT)+MU*COS(PHI1C+N41*PHIT))/DEN
1DM)
        AA31=CAPR81-MU*S1*A1+MU*RHO1*(AA23+AA27)
        AA32=OM2+RHO1*MU*(AA24+AA28)
        AA33=OM2/ABS(OMEGA)*2.*ABS(MU)*RHO1*(AA25+AA29)
        AA34=MU*RHO1*(AA25+AA29)

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Computer program SANDA3 (cont)

PAGE 3

13.32.47

FTN 4.8+508

74/74 OPT=1

SUBROUTINE IN3

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115      AA35=M1*R1*RC1*OM2
      AA36=ABS(((1.+MU*MU*S2)*COS(BETA2-THETA2)+MU*(S2-1.)*SIN(BETA2-THE
1TA2))/DENOM)
      AA37=ABS((SIN(GAMMA3)+MU*COS(GAMMA3))/DENOM)
      AA38=ABS(((1.-MU*MU*S3)*COS(BETA3+THETA3)-MU*(1.+S3)*SIN(BETA3+THE
1TA3))/DENOM)
      AA39=ABS(((1.+MU*MU*S2)*SIN(BETA2-THETA2)+MU*(1.-S2)*COS(BETA2-THE
1TA2))/DENOM)
      AA40=ABS((MU*SIN(GAMMA3)-COS(GAMMA3))/DENOM)
      AA41=ABS(((1.-MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.+S3)*COS(BETA3+THE
1TA3))/DENOM)
      AA42=CAPR83-MU*(S3*A3-RHO3*(AA38+AA41))
      AA43=MU*RHO3*(AA37+AA40)
      AA44=RB3-MU*(S2*(D2-A2)+RHO3*(AA36+AA39))
      AA45=ABS((MU*(1.-S1)*SIN(BETA1+THETA1)+(1.+MU*MU*S1)*COS(BETA1+THE
1TA1))/DENOM)
      AA46=ABS((SIN(GAMMA2)-MU*COS(GAMMA2))/DENOM)
      AA47=ABS((MU*(1.+S2)*SIN(BETA2-THETA2)+(1.-MU*MU*S2)*COS(BETA2-THE
1TA2))/DENOM)
      AA48=ABS((MU*(1.-S1)*COS(BETA1+THETA1)-(1.+MU*MU*S1)*SIN(BETA1+THE
1TA1))/DENOM)
      AA49=ABS((MU*SIN(GAMMA2)+COS(GAMMA2))/DENOM)
      AA50=ABS(((1.-MU*MU*S2)*SIN(BETA2-THETA2)-MU*(1.+S2)*COS(BETA2-THE
1TA2))/DENOM)
      AA51=CAPR82-MU*(S2*A2-RHO2*(AA47+AA50))
      AA52=MU*RHO2*(AA46+AA49)
      AA53=RB2-MU*(S1*(D1-A1)+RHO2*(AA45+AA48))
      RETURN
      END
H 115
H 116
H 117
H 118
H 119
H 120
H 121
H 122
H 123
H 124
H 125
H 126
H 127
H 128
H 129
H 130
H 131
H 132
H 133
H 134
H 135
H 136
H 137
H 138
H 139
H 140
H 141
H 142
H 143-

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Computer program SANDA3 (cont)

A = .20810 B = .19200 C = .07880 R = .01500 ALPHA = 51.0000 CONFIGURATION = 1.  
 EREST = 0.00 LAMBDA = 152.144 DELTA = 30.000  
 N1 = .11550E-03 M2 = .68600E-05 M3 = .28200E-05 M4 = .25200E-05 MP = .35900E-05  
 I1 = .10550E-04 I2 = .12600E-06 I3 = .30800E-07 I4 = .26800E-07 IP = .24500E-07  
 RC1 = .1080 RCP = 0.0000 RHOP = .0160 RPM = 30000. PHICD = 144.0000 PSICD = 0.0000 PHID = 145.0000  
 PHICUTO = 3600.  
 MU = .15 MU1 = .15  
 PSUBD1 = 44.0 PSUBD2 = 65.0 PSUBD3 = 77.0  
 NG1 = 42. NG2 = 27. NG3 = 27. NP2 = 8. NP3 = 9. NP4 = 9.  
 CAPRP1 = .47727 CAPRP2 = .20769 CAPRP3 = .17532  
 RP2 = .09091 RP3 = .06923 RP4 = .05844  
 THETA1 = 20.000 THETA2 = 20.000 THETA3 = 20.000  
 R1 = .22500 R2 = .43600 R3 = .50400 R4 = .52000 R5 = .43300  
 RHO1 = .06200 RHO2 = .02500 RHO3 = .01800 RHO4 = .01600  
 CAPRB1 = .44849 CAPRB2 = .19517 CAPRB3 = .18475 RB2 = .08543 RB3 = .08506 RB4 = .05492  
 CAPRO1 = .48791 CAPRO2 = .21579 CAPRO3 = .18216 RO2 = .11000 RO3 = .08089 RO4 = .06828  
 J1 = 0.00 J2 = 0.00 J3 = 0.00  
 BETA1D = 135.82 BETA2D = 207.77 BETA3D = 247.36 BETA4D = 300.15  
 GAMMA2D = 114.74 GAMMA3D = 148.02 GAMMA4D = 174.35 GAMMA5D = 197.06  
  
 COUPLED MOTION  
 T = 0.00000 PHI = 145.00 PHIDOT = 0.00 G = -.0394 GDOT = 0.00 PSID = 62.32 PSIDOT = 0.00 PHITOT = -.00  
 F34 = 3.2663 F23 = 10.6137 F12 = 31.1443 PN = .9936 PNPSI = .9936 DPHI2 = .2826E+06 PHITOT = .00  
 T = .00001 PHI = 145.00 PHIDOT = 2.83 G = -.0394 GDOT = .61 PSID = 62.32 PSIDOT = .2830E+06 PHITOT = .00  
 F34 = 3.2667 F23 = 10.6140 F12 = 31.1441 PN = .9938 PNPSI = .9938 DPHI2 = 6.87 .TOT = .00  
 T = .00002 PHI = 145.00 PHIDOT = 5.65 G = -.0391 GDOT = 1.21 PSID = 62.32 PSIDOT = .2830E+06 PHITOT = .00  
 F34 = 3.2667 F23 = 10.6140 F12 = 31.1441 PN = .9938 PNPSI = .9938 DPHI2 = 10.11 .TOT = .00  
 T = .00003 PHI = 145.01 PHIDOT = 8.49 G = -.0394 GDOT = 1.82 PSID = 62.32 PSIDOT = .2844E+06 PHITOT = .01  
 F34 = 3.2692 F23 = 10.6150 F12 = 31.1435 PN = .9947 PNPSI = .9947 DPHI2 = 13.76 PHITOT = .01  
 T = .00004 PHI = 145.01 PHIDOT = 11.32 G = -.0393 GDOT = 2.43 PSID = 62.32 PSIDOT = .2841E+06 PHITOT = .02  
 F34 = 3.2682 F23 = 10.6150 F12 = 31.1437 PN = .9946 PNPSI = .9946 DPHI2 = 17.23 PHITOT = .02  
 T = .00005 PHI = 145.02 PHIDOT = 14.17 G = -.0393 GDOT = 3.04 PSID = 62.32 PSIDOT = .2841E+06 PHITOT = .03  
 F34 = 3.2708 F23 = 10.6168 F12 = 31.1428 PN = .9962 PNPSI = .9962 DPHI2 = 20.11 PHITOT = .03  
 T = .00006 PHI = 145.03 PHIDOT = 17.03 G = -.0393 GDOT = 3.65 PSID = 62.32 PSIDOT = .2841E+06 PHITOT = .04  
 F34 = 3.2708 F23 = 10.6170 F12 = 31.1431 PN = .9960 PNPSI = .9960 DPHI2 = 24.21 PHITOT = .04  
 T = .00007 PHI = 145.04 PHIDOT = 19.90 G = -.0392 GDOT = 4.27 PSID = 62.32 PSIDOT = .2841E+06 PHITOT = .05  
 F34 = 3.2745 F23 = 10.6198 F12 = 31.1420 PN = .9983 PNPSI = .9983 DPHI2 = 27.73 PHITOT = .05  
 T = .00008 PHI = 145.05 PHIDOT = 22.78 G = -.0392 GDOT = 4.89 PSID = 62.32 PSIDOT = .2841E+06 PHITOT = .07  
 F34 = 3.2746 F23 = 10.6198 F12 = 31.1424 PN = .9981 PNPSI = .9981 DPHI2 = 31.29 PHITOT = .07  
 T = .00009 PHI = 145.07 PHIDOT = 25.69 G = -.0391 GDOT = 5.51 PSID = 62.40 PSIDOT = .2841E+06 PHITOT = .07  
 F34 = 3.2794 F23 = 10.6232 F12 = 31.1410 PN = 1.0010 PNPSI = 1.0010 DPHI2 = .2945E+06

|            |              |                 |            |             |               |              |                 |               |
|------------|--------------|-----------------|------------|-------------|---------------|--------------|-----------------|---------------|
| T = .00010 | PHI = 145.08 | PHIDOT = 28.61  | G = -.0391 | PN = 1.0008 | PNPSI = 6.14  | PSID = 62.42 | PSIDOT = 34.87  | PHITOT = .08  |
| T = .00011 | PHI = 145.10 | PHIDOT = 31.57  | G = -.0390 | PN = 1.0008 | PNPSI = 6.78  | PSID = 62.44 | PSIDOT = 38.50  | PHITOT = .10  |
| T = .00012 | PHI = 145.12 | PHIDOT = 34.54  | G = -.0390 | PN = 1.0045 | PNPSI = 7.41  | PSID = 62.46 | PSIDOT = 42.15  | PHITOT = .12  |
| T = .00013 | PHI = 145.14 | PHIDOT = 37.54  | G = -.0384 | PN = 1.0042 | PNPSI = 8.06  | PSID = 62.48 | PSIDOT = 45.87  | PHITOT = .14  |
| T = .00014 | PHI = 145.16 | PHIDOT = 40.57  | G = -.0388 | PN = 1.0085 | PNPSI = 8.71  | PSID = 62.51 | PSIDOT = 49.61  | PHITOT = .16  |
| T = .00015 | PHI = 145.18 | PHIDOT = 43.64  | G = -.0387 | PN = 1.0082 | PNPSI = 9.37  | PSID = 62.54 | PSIDOT = 53.42  | PHITOT = .18  |
| T = .00016 | PHI = 145.21 | PHIDOT = 46.73  | G = -.0386 | PN = 1.0133 | PNPSI = 10.04 | PSID = 62.58 | PSIDOT = 57.28  | PHITOT = .21  |
| T = .00017 | PHI = 145.24 | PHIDOT = 49.88  | G = -.0385 | PN = 1.0129 | PNPSI = 10.72 | PSID = 62.61 | PSIDOT = 61.20  | PHITOT = .24  |
| T = .00018 | PHI = 145.27 | PHIDOT = 53.05  | G = -.0384 | PN = 1.0188 | PNPSI = 11.40 | PSID = 62.65 | PSIDOT = 65.18  | PHITOT = .27  |
| T = .00019 | PHI = 145.30 | PHIDOT = 56.28  | G = -.0383 | PN = 1.0184 | PNPSI = 12.10 | PSID = 62.68 | PSIDOT = 69.24  | PHITOT = .30  |
| T = .00020 | PHI = 145.33 | PHIDOT = 59.54  | G = -.0382 | PN = 1.0250 | PNPSI = 12.81 | PSID = 62.72 | PSIDOT = 73.36  | PHITOT = .33  |
| T = .00021 | PHI = 145.37 | PHIDOT = 62.87  | G = -.0380 | PN = 1.0245 | PNPSI = 13.53 | PSID = 62.77 | PSIDOT = 77.57  | PHITOT = .37  |
| T = .00022 | PHI = 145.40 | PHIDOT = 66.23  | G = -.0379 | PN = 1.0320 | PNPSI = 14.25 | PSID = 62.81 | PSIDOT = 81.84  | PHITOT = .40  |
| T = .00023 | PHI = 145.44 | PHIDOT = 69.66  | G = -.0377 | PN = 1.0315 | PNPSI = 15.00 | PSID = 62.86 | PSIDOT = 86.23  | PHITOT = .44  |
| T = .00024 | PHI = 145.48 | PHIDOT = 73.13  | G = -.0376 | PN = 1.0399 | PNPSI = 15.75 | PSID = 62.91 | PSIDOT = 90.68  | PHITOT = .48  |
| T = .00025 | PHI = 145.53 | PHIDOT = 76.68  | G = -.0374 | PN = 1.0393 | PNPSI = 16.52 | PSID = 62.97 | PSIDOT = 95.25  | PHITOT = .53  |
| T = .00026 | PHI = 145.57 | PHIDOT = 80.27  | G = -.0372 | PN = 1.0485 | PNPSI = 17.30 | PSID = 63.02 | PSIDOT = 99.90  | PHITOT = .57  |
| T = .00027 | PHI = 145.62 | PHIDOT = 83.94  | G = -.0371 | PN = 1.0479 | PNPSI = 18.10 | PSID = 63.08 | PSIDOT = 104.69 | PHITOT = .62  |
| T = .00028 | PHI = 145.67 | PHIDOT = 87.66  | G = -.0369 | PN = 1.0581 | PNPSI = 18.91 | PSID = 63.14 | PSIDOT = 109.56 | PHITOT = .67  |
| T = .00029 | PHI = 145.72 | PHIDOT = 91.48  | G = -.0367 | PN = 1.0574 | PNPSI = 19.74 | PSID = 63.21 | PSIDOT = 114.57 | PHITOT = .72  |
| T = .00030 | PHI = 145.77 | PHIDOT = 95.35  | G = -.0365 | PN = 1.0666 | PNPSI = 20.58 | PSID = 63.27 | PSIDOT = 119.68 | PHITOT = .77  |
| T = .00031 | PHI = 145.83 | PHIDOT = 99.32  | G = -.0363 | PN = 1.0679 | PNPSI = 21.45 | PSID = 63.34 | PSIDOT = 124.96 | PHITOT = .83  |
| T = .00032 | PHI = 145.89 | PHIDOT = 103.34 | G = -.0361 | PN = 1.0802 | PNPSI = 22.33 | PSID = 63.42 | PSIDOT = 130.33 | PHITOT = .89  |
| T = .00033 | PHI = 145.95 | PHIDOT = 107.47 | G = -.0358 | PN = 1.0793 | PNPSI = 23.24 | PSID = 63.49 | PSIDOT = 135.89 | PHITOT = .95  |
| T = .00034 | PHI = 146.01 | PHIDOT = 111.66 | G = -.0355 | PN = 1.0928 | PNPSI = 24.15 | PSID = 63.57 | PSIDOT = 141.55 | PHITOT = 1.01 |
| T = .00035 | PHI = 146.08 | PHIDOT = 115.93 | G = -.0354 | PN = 1.0919 | PNPSI = 25.09 | PSID = 63.65 | PSIDOT = 147.36 | PHITOT = 1.08 |
| T = .00036 | PHI = 146.14 | PHIDOT = 120.14 | G = -.0351 | PN = 1.0914 | PNPSI = 26.02 | PSID = 63.74 | PSIDOT = 153.14 | PHITOT = 1.14 |
| T = .00037 | PHI = 146.21 | PHIDOT = 124.25 | G = -.0348 | PN = 1.0904 | PNPSI = 26.92 | PSID = 63.83 | PSIDOT = 158.84 | PHITOT = 1.21 |
| T = .00038 | PHI = 146.29 | PHIDOT = 128.28 | G = -.0346 | PN = 1.0849 | PNPSI = 27.81 | PSID = 63.92 | PSIDOT = 164.48 | PHITOT = 1.29 |
| T = .00039 | PHI = 146.36 | PHIDOT = 132.21 | G = -.0343 | PN = 1.0838 | PNPSI = 28.68 | PSID = 64.02 | PSIDOT = 170.04 | PHITOT = 1.36 |
| T = .00040 | PHI = 146.44 | PHIDOT = 136.06 | G = -.0340 | PN = 1.0779 | PNPSI = 29.53 | PSID = 64.12 | PSIDOT = 175.53 | PHITOT = 1.44 |

## Computer program SANDA3 (cont)

|            |                 |                 |               |              |                |          |           |          |      |
|------------|-----------------|-----------------|---------------|--------------|----------------|----------|-----------|----------|------|
| T = .00041 | F34 = 3.1427    | F23 = 10.8285   | F12 = 31.1651 | PN = 1.0767  | PNPSI = 1.0767 | DPH12 =  | .3735E+06 | PHITOT = | 1.52 |
|            | PHITOT = 146.52 | PHIDOT = 139.80 | G = -.0337    | GOOT = 30.36 | PSID = 64.22   | PSIDOT = | 180.94    | PHITOT = | 1.52 |
| T = .00042 | F34 = 3.1503    | F23 = 10.8593   | F12 = 31.1796 | PN = 1.0703  | PNPSI = 1.0703 | DPH12 =  | .3652E+06 | PHITOT = | 1.60 |
|            | PHITOT = 146.60 | PHIDOT = 143.46 | G = -.0334    | GOOT = 31.18 | PSID = 64.32   | PSIDOT = | 188.27    | PHITOT = | 1.60 |
| T = .00043 | F34 = 3.1572    | F23 = 10.8611   | F12 = 31.1835 | PN = 1.0690  | PNPSI = 1.0690 | DPH12 =  | .3601E+06 | PHITOT = | 1.68 |
|            | PHITOT = 146.68 | PHIDOT = 147.00 | G = -.0331    | GOOT = 31.97 | PSID = 64.43   | PSIDOT = | 191.52    | PHITOT = | 1.68 |
| T = .00044 | F34 = 3.1716    | F23 = 10.8936   | F12 = 31.1987 | PN = 1.0622  | PNPSI = 1.0622 | DPH12 =  | .3451E+06 | PHITOT = | 1.77 |
|            | PHITOT = 146.77 | PHIDOT = 150.46 | G = -.0327    | GOOT = 32.74 | PSID = 64.54   | PSIDOT = | 196.69    | PHITOT = | 1.77 |
| T = .00045 | F34 = 3.1725    | F23 = 10.8954   | F12 = 31.2027 | PN = 1.0608  | PNPSI = 1.0608 | DPH12 =  | .3399E+06 | PHITOT = | 1.85 |
|            | PHITOT = 146.85 | PHIDOT = 153.80 | G = -.0324    | GOOT = 33.49 | PSID = 64.66   | PSIDOT = | 201.75    | PHITOT = | 1.85 |
| T = .00046 | F34 = 3.5290    | F23 = 10.9375   | F12 = 31.2340 | PN = 1.0364  | PNPSI = 1.0364 | DPH12 =  | .2944E+06 | PHITOT = | 1.94 |
|            | PHITOT = 146.94 | PHIDOT = 157.05 | G = -.0321    | GOOT = 34.22 | PSID = 64.78   | PSIDOT = | 206.74    | PHITOT = | 1.94 |
| T = .00047 | F34 = 3.5300    | F23 = 10.9393   | F12 = 31.2380 | PN = 1.0350  | PNPSI = 1.0350 | DPH12 =  | .2892E+06 | PHITOT = | 2.03 |
|            | PHITOT = 147.03 | PHIDOT = 160.03 | G = -.0317    | GOOT = 34.89 | PSID = 64.90   | PSIDOT = | 211.42    | PHITOT = | 2.03 |
| T = .00048 | F34 = 3.5528    | F23 = 10.9620   | F12 = 31.2237 | PN = 1.0547  | PNPSI = 1.0547 | DPH12 =  | .3212E+06 | PHITOT = | 2.13 |
|            | PHITOT = 147.13 | PHIDOT = 163.10 | G = -.0314    | GOOT = 35.59 | PSID = 65.02   | PSIDOT = | 216.26    | PHITOT = | 2.13 |
| T = .00049 | F34 = 3.5538    | F23 = 10.9640   | F12 = 31.2339 | PN = 1.0531  | PNPSI = 1.0531 | DPH12 =  | .3159E+06 | PHITOT = | 2.22 |
|            | PHITOT = 147.22 | PHIDOT = 166.35 | G = -.0310    | GOOT = 36.32 | PSID = 65.14   | PSIDOT = | 221.38    | PHITOT = | 2.22 |
| T = .00050 | F34 = 3.5982    | F23 = 10.9876   | F12 = 31.2253 | PN = 1.0739  | PNPSI = 1.0739 | DPH12 =  | .3491E+06 | PHITOT = | 2.32 |
|            | PHITOT = 147.32 | PHIDOT = 169.69 | G = -.0305    | GOOT = 37.08 | PSID = 65.27   | PSIDOT = | 226.68    | PHITOT = | 2.32 |
| T = .00051 | F34 = 3.5993    | F23 = 10.9897   | F12 = 31.2297 | PN = 1.0723  | PNPSI = 1.0723 | DPH12 =  | .3434E+06 | PHITOT = | 2.41 |
|            | PHITOT = 147.41 | PHIDOT = 173.22 | G = -.0303    | GOOT = 37.87 | PSID = 65.40   | PSIDOT = | 232.27    | PHITOT = | 2.41 |
| T = .00052 | F34 = 3.6355    | F23 = 11.0144   | F12 = 31.2207 | PN = 1.0942  | PNPSI = 1.0942 | DPH12 =  | .3781E+06 | PHITOT = | 2.51 |
|            | PHITOT = 147.51 | PHIDOT = 176.84 | G = -.0299    | GOOT = 38.69 | PSID = 65.54   | PSIDOT = | 238.05    | PHITOT = | 2.51 |
| T = .00053 | F34 = 3.6367    | F23 = 11.0166   | F12 = 31.2255 | PN = 1.0925  | PNPSI = 1.0925 | DPH12 =  | .3719E+06 | PHITOT = | 2.57 |
|            | PHITOT = 147.57 | PHIDOT = 178.86 | G = -.0297    | GOOT = 39.15 | PSID = 65.61   | PSIDOT = | 241.22    | PHITOT = | 2.57 |
| T = .00054 | F34 = 3.6319    | F23 = 11.0461   | F12 = 31.2105 | PN = 1.1218  | PNPSI = 1.1218 | DPH12 =  | .4204E+06 | PHITOT = | 2.62 |
|            | PHITOT = 147.62 | PHIDOT = 180.92 | G = -.0295    | GOOT = 39.61 | PSID = 65.68   | PSIDOT = | 244.48    | PHITOT = | 2.62 |
| T = .00055 | F34 = 3.6825    | F23 = 11.0473   | F12 = 31.2130 | PN = 1.1210  | PNPSI = 1.1210 | DPH12 =  | .4170E+06 | PHITOT = | 2.67 |
|            | PHITOT = 147.67 | PHIDOT = 183.03 | G = -.0293    | GOOT = 40.09 | PSID = 65.75   | PSIDOT = | 247.83    | PHITOT = | 2.67 |
| T = .00056 | F34 = 3.7021    | F23 = 11.0604   | F12 = 31.2082 | PN = 1.1329  | PNPSI = 1.1329 | DPH12 =  | .4355E+06 | PHITOT = | 2.72 |
|            | PHITOT = 147.72 | PHIDOT = 185.15 | G = -.0291    | GOOT = 40.57 | PSID = 65.82   | PSIDOT = | 251.22    | PHITOT = | 2.72 |
| T = .00057 | F34 = 3.7028    | F23 = 11.0617   | F12 = 31.2108 | PN = 1.1321  | PNPSI = 1.1321 | DPH12 =  | .4320E+05 | PHITOT = | 2.77 |
|            | PHITOT = 147.77 | PHIDOT = 187.35 | G = -.0289    | GOOT = 41.07 | PSID = 65.89   | PSIDOT = | 254.70    | PHITOT = | 2.77 |
| T = .00058 | F34 = 3.3528    | F23 = 11.0757   | F12 = 31.2070 | PN = 1.1431  | PNPSI = 1.1431 | DPH12 =  | .4466E+06 | PHITOT = | 2.83 |
|            | PHITOT = 147.83 | PHIDOT = 189.56 | G = -.0287    | GOOT = 41.57 | PSID = 65.96   | PSIDOT = | 258.23    | PHITOT = | 2.83 |
| T = .00059 | F34 = 3.3535    | F23 = 11.0770   | F12 = 31.2097 | PN = 1.1422  | PNPSI = 1.1422 | DPH12 =  | .4450E+06 | PHITOT = | 2.88 |
|            | PHITOT = 147.88 | PHIDOT = 191.76 | G = -.0285    | GOOT = 42.07 | PSID = 66.04   | PSIDOT = | 261.78    | PHITOT = | 2.88 |
| T = .00060 | F34 = 3.3631    | F23 = 11.0986   | F12 = 31.2198 | PN = 1.1376  | PNPSI = 1.1376 | DPH12 =  | .4349E+06 | PHITOT = | 2.94 |
|            | PHITOT = 147.94 | PHIDOT = 193.94 | G = -.0283    | GOOT = 42.56 | PSID = 66.11   | PSIDOT = | 265.30    | PHITOT = | 2.94 |
| T = .00061 | F34 = 3.3638    | F23 = 11.1000   | F12 = 31.2225 | PN = 1.1366  | PNPSI = 1.1366 | DPH12 =  | .4313E+06 | PHITOT = | 2.99 |
|            | PHITOT = 147.99 | PHIDOT = 196.06 | G = -.0280    | GOOT = 43.04 | PSID = 66.19   | PSIDOT = | 268.76    | PHITOT = | 2.99 |
| T = .00062 | F34 = 3.3561    | F23 = 9.9688    | F12 = 31.2373 | PN = 1.1260  | PNPSI = 1.1260 | DPH12 =  | .4113E+06 | PHITOT = | 3.05 |
|            | PHITOT = 148.05 | PHIDOT = 198.14 | G = -.0278    | GOOT = 43.51 | PSID = 66.27   | PSIDOT = | 272.18    | PHITOT = | 3.05 |
| T = .00063 | F34 = 3.3567    | F23 = 9.9900    | F12 = 31.2405 | PN = 1.1251  | PNPSI = 1.1251 | DPH12 =  | .4077E+06 | PHITOT = | 3.11 |
|            | PHITOT = 148.11 | PHIDOT = 200.14 | G = -.0276    | GOOT = 43.97 | PSID = 66.35   | PSIDOT = | 275.52    | PHITOT = | 3.11 |
| T = .00064 | F34 = 3.3471    | F23 = 9.9902    | F12 = 31.2567 | PN = 1.1137  | PNPSI = 1.1137 | DPH12 =  | .3865E+06 | PHITOT = | 3.17 |
|            | PHITOT = 148.17 | PHIDOT = 202.09 | G = -.0274    | GOOT = 44.42 | PSID = 66.43   | PSIDOT = | 278.80    | PHITOT = | 3.17 |
| T = .00065 | F34 = 3.3478    | F23 = 10.0004   | F12 = 31.2594 | PN = 1.1127  | PNPSI = 1.1127 | DPH12 =  | .3830E+06 | PHITOT = | 3.22 |
|            | PHITOT = 148.22 | PHIDOT = 203.97 | G = -.0272    | GOOT = 44.85 | PSID = 66.51   | PSIDOT = | 282.00    | PHITOT = | 3.22 |
| T = .00066 | F34 = 3.3380    | F23 = 10.0098   | F12 = 31.2755 | PN = 1.1011  | PNPSI = 1.1011 | DPH12 =  | .3618E+06 | PHITOT = | 3.28 |
|            | PHITOT = 148.28 | PHIDOT = 205.80 | G = -.0269    | GOOT = 45.26 | PSID = 66.59   | PSIDOT = | 285.14    | PHITOT = | 3.28 |
| T = .00067 | F34 = 3.3386    | F23 = 10.0109   | F12 = 31.2783 | PN = 1.1001  | PNPSI = 1.1001 | DPH12 =  | .3584E+06 | PHITOT = | 3.34 |
|            | PHITOT = 148.34 | PHIDOT = 207.55 | G = -.0267    | GOOT = 45.67 | PSID = 66.67   | PSIDOT = | 288.21    | PHITOT = | 3.34 |
| T = .00068 | F34 = 3.3286    | F23 = 10.0204   | F12 = 31.2947 | PN = 1.0863  | PNPSI = 1.0863 | DPH12 =  | .3371E+06 | PHITOT = | 3.40 |
|            | PHITOT = 148.40 | PHIDOT = 209.26 | G = -.0265    | GOOT = 46.06 | PSID = 66.75   | PSIDOT = | 291.21    | PHITOT = | 3.40 |
| T = .00069 | F34 = 3.3292    | F23 = 10.0215   | F12 = 31.2974 | PN = 1.0873  | PNPSI = 1.0873 | DPH12 =  | .3337E+06 | PHITOT = | 3.46 |
|            | PHITOT = 148.46 | PHIDOT = 210.89 | G = -.0263    | GOOT = 46.44 | PSID = 66.84   | PSIDOT = | 294.13    | PHITOT = | 3.46 |
| T = .00070 | F34 = 3.3190    | F23 = 10.0311   | F12 = 31.3138 | PN = 1.0754  | PNPSI = 1.0754 | DPH12 =  | .3125E+06 | PHITOT = | 3.52 |
|            | PHITOT = 148.52 | PHIDOT = 212.47 | G = -.0260    | GOOT = 46.80 | PSID = 66.92   | PSIDOT = | 296.99    | PHITOT = | 3.52 |
| T = .00071 | F34 = 3.3196    | F23 = 10.0322   | F12 = 31.3165 | PN = 1.0743  | PNPSI = 1.0743 | DPH12 =  | .3092E+06 | PHITOT = | 3.52 |

|              |               |                 |            |              |              |                 |               |
|--------------|---------------|-----------------|------------|--------------|--------------|-----------------|---------------|
| T = .00061   | PHI = 148.58  | PHIDOT = 213.98 | G = -.0258 | GDOT = 47.15 | PSID = 67.01 | PSIDOT = 299.77 | PHITOT = 3.58 |
| F34 = 3.3092 | F23 = 10.0418 | F12 = 31.3330   | G = -.0258 | GDOT = 47.15 | PSID = 67.01 | PSIDOT = 299.77 | PHITOT = 3.58 |
| T = .00062   | PHI = 148.54  | PHIDOT = 215.44 | G = -.0256 | GDOT = 47.49 | PSID = 67.09 | PSIDOT = 302.49 | PHITOT = 3.64 |
| F34 = 3.3098 | F23 = 10.0429 | F12 = 31.3355   | G = -.0256 | GDOT = 47.49 | PSID = 67.09 | PSIDOT = 302.49 | PHITOT = 3.64 |
| T = .00062   | PHI = 148.71  | PHIDOT = 216.83 | G = -.0253 | GDOT = 47.82 | PSID = 67.18 | PSIDOT = 305.12 | PHITOT = 3.71 |
| F34 = 3.6576 | F23 = 10.0560 | F12 = 31.3595   | G = -.0253 | GDOT = 47.82 | PSID = 67.18 | PSIDOT = 305.12 | PHITOT = 3.71 |
| T = .00063   | PHI = 148.77  | PHIDOT = 218.05 | G = -.0251 | GDOT = 48.11 | PSID = 67.27 | PSIDOT = 307.53 | PHITOT = 3.77 |
| F34 = 3.6582 | F23 = 10.0571 | F12 = 31.3621   | G = -.0251 | GDOT = 48.11 | PSID = 67.27 | PSIDOT = 307.53 | PHITOT = 3.77 |
| T = .00063   | PHI = 148.83  | PHIDOT = 219.30 | G = -.0248 | GDOT = 48.40 | PSID = 67.36 | PSIDOT = 309.98 | PHITOT = 3.83 |
| F34 = 3.6576 | F23 = 10.0591 | F12 = 31.3635   | G = -.0248 | GDOT = 48.40 | PSID = 67.36 | PSIDOT = 309.98 | PHITOT = 3.83 |
| T = .00064   | PHI = 148.89  | PHIDOT = 220.55 | G = -.0246 | GDOT = 48.70 | PSID = 67.44 | PSIDOT = 312.46 | PHITOT = 3.89 |
| F34 = 3.6576 | F23 = 10.0602 | F12 = 31.3650   | G = -.0246 | GDOT = 48.70 | PSID = 67.44 | PSIDOT = 312.46 | PHITOT = 3.89 |
| T = .00064   | PHI = 148.95  | PHIDOT = 221.83 | G = -.0243 | GDOT = 49.00 | PSID = 67.53 | PSIDOT = 314.99 | PHITOT = 3.96 |
| F34 = 3.6576 | F23 = 10.0623 | F12 = 31.3655   | G = -.0243 | GDOT = 49.00 | PSID = 67.53 | PSIDOT = 314.99 | PHITOT = 3.96 |
| T = .00065   | PHI = 149.02  | PHIDOT = 223.13 | G = -.0241 | GDOT = 49.30 | PSID = 67.63 | PSIDOT = 317.54 | PHITOT = 4.02 |
| F34 = 3.6583 | F23 = 10.0634 | F12 = 31.3681   | G = -.0241 | GDOT = 49.30 | PSID = 67.63 | PSIDOT = 317.54 | PHITOT = 4.02 |
| T = .00065   | PHI = 149.09  | PHIDOT = 224.44 | G = -.0239 | GDOT = 49.61 | PSID = 67.72 | PSIDOT = 320.15 | PHITOT = 4.09 |
| F34 = 3.6577 | F23 = 10.0655 | F12 = 31.3686   | G = -.0239 | GDOT = 49.61 | PSID = 67.72 | PSIDOT = 320.15 | PHITOT = 4.09 |
| T = .00066   | PHI = 149.15  | PHIDOT = 225.77 | G = -.0236 | GDOT = 49.92 | PSID = 67.81 | PSIDOT = 322.78 | PHITOT = 4.15 |
| F34 = 3.6584 | F23 = 10.0666 | F12 = 31.3712   | G = -.0236 | GDOT = 49.92 | PSID = 67.81 | PSIDOT = 322.78 | PHITOT = 4.15 |
| T = .00066   | PHI = 149.22  | PHIDOT = 227.13 | G = -.0234 | GDOT = 50.24 | PSID = 67.90 | PSIDOT = 325.46 | PHITOT = 4.22 |
| F34 = 3.6578 | F23 = 10.0688 | F12 = 31.3719   | G = -.0234 | GDOT = 50.24 | PSID = 67.90 | PSIDOT = 325.46 | PHITOT = 4.22 |
| T = .00067   | PHI = 149.28  | PHIDOT = 228.49 | G = -.0231 | GDOT = 50.56 | PSID = 68.00 | PSIDOT = 328.17 | PHITOT = 4.28 |
| F34 = 3.6595 | F23 = 10.0700 | F12 = 31.3745   | G = -.0231 | GDOT = 50.56 | PSID = 68.00 | PSIDOT = 328.17 | PHITOT = 4.28 |
| T = .00067   | PHI = 149.35  | PHIDOT = 229.88 | G = -.0228 | GDOT = 50.89 | PSID = 68.09 | PSIDOT = 330.92 | PHITOT = 4.35 |
| F34 = 3.6579 | F23 = 10.0722 | F12 = 31.3751   | G = -.0228 | GDOT = 50.89 | PSID = 68.09 | PSIDOT = 330.92 | PHITOT = 4.35 |
| T = .00068   | PHI = 149.41  | PHIDOT = 231.28 | G = -.0226 | GDOT = 51.22 | PSID = 68.18 | PSIDOT = 333.71 | PHITOT = 4.41 |
| F34 = 3.6585 | F23 = 10.0733 | F12 = 31.3778   | G = -.0226 | GDOT = 51.22 | PSID = 68.18 | PSIDOT = 333.71 | PHITOT = 4.41 |
| T = .00068   | PHI = 149.48  | PHIDOT = 232.71 | G = -.0223 | GDOT = 51.55 | PSID = 68.28 | PSIDOT = 336.54 | PHITOT = 4.48 |
| F34 = 3.6580 | F23 = 10.0756 | F12 = 31.3785   | G = -.0223 | GDOT = 51.55 | PSID = 68.28 | PSIDOT = 336.54 | PHITOT = 4.48 |
| T = .00069   | PHI = 149.55  | PHIDOT = 234.15 | G = -.0221 | GDOT = 51.89 | PSID = 68.38 | PSIDOT = 339.41 | PHITOT = 4.55 |
| F34 = 3.6586 | F23 = 10.0768 | F12 = 31.3813   | G = -.0221 | GDOT = 51.89 | PSID = 68.38 | PSIDOT = 339.41 | PHITOT = 4.55 |
| T = .00069   | PHI = 149.61  | PHIDOT = 235.61 | G = -.0218 | GDOT = 52.23 | PSID = 68.48 | PSIDOT = 342.32 | PHITOT = 4.61 |
| F34 = 3.6581 | F23 = 10.0791 | F12 = 31.3820   | G = -.0218 | GDOT = 52.23 | PSID = 68.48 | PSIDOT = 342.32 | PHITOT = 4.61 |
| T = .00070   | PHI = 149.68  | PHIDOT = 237.08 | G = -.0216 | GDOT = 52.58 | PSID = 68.57 | PSIDOT = 345.26 | PHITOT = 4.68 |
| F34 = 3.6587 | F23 = 10.0803 | F12 = 31.3848   | G = -.0216 | GDOT = 52.58 | PSID = 68.57 | PSIDOT = 345.26 | PHITOT = 4.68 |
| T = .00070   | PHI = 149.75  | PHIDOT = 238.58 | G = -.0213 | GDOT = 52.93 | PSID = 68.67 | PSIDOT = 348.26 | PHITOT = 4.75 |
| F34 = 3.6580 | F23 = 10.0828 | F12 = 31.3865   | G = -.0213 | GDOT = 52.93 | PSID = 68.67 | PSIDOT = 348.26 | PHITOT = 4.75 |
| T = .00071   | PHI = 149.82  | PHIDOT = 240.03 | G = -.0210 | GDOT = 53.27 | PSID = 68.77 | PSIDOT = 351.20 | PHITOT = 4.82 |
| F34 = 3.6586 | F23 = 10.0850 | F12 = 31.3894   | G = -.0210 | GDOT = 53.27 | PSID = 68.77 | PSIDOT = 351.20 | PHITOT = 4.82 |
| T = .00071   | PHI = 149.89  | PHIDOT = 241.41 | G = -.0208 | GDOT = 53.60 | PSID = 68.87 | PSIDOT = 354.05 | PHITOT = 4.89 |
| F34 = 3.6585 | F23 = 10.0895 | F12 = 31.4174   | G = -.0208 | GDOT = 53.60 | PSID = 68.87 | PSIDOT = 354.05 | PHITOT = 4.89 |
| T = .00072   | PHI = 149.96  | PHIDOT = 242.73 | G = -.0205 | GDOT = 53.91 | PSID = 68.98 | PSIDOT = 356.83 | PHITOT = 4.96 |
| F34 = 3.6587 | F23 = 10.0907 | F12 = 31.4202   | G = -.0205 | GDOT = 53.91 | PSID = 68.98 | PSIDOT = 356.83 | PHITOT = 4.96 |
| T = .00072   | PHI = 150.03  | PHIDOT = 243.98 | G = -.0202 | GDOT = 54.21 | PSID = 69.08 | PSIDOT = 359.51 | PHITOT = 5.03 |
| F34 = 3.6589 | F23 = 10.1112 | F12 = 31.4382   | G = -.0202 | GDOT = 54.21 | PSID = 69.08 | PSIDOT = 359.51 | PHITOT = 5.03 |
| T = .00073   | PHI = 150.10  | PHIDOT = 245.18 | G = -.0199 | GDOT = 54.49 | PSID = 69.18 | PSIDOT = 362.13 | PHITOT = 5.10 |
| F34 = 3.6584 | F23 = 10.1123 | F12 = 31.4409   | G = -.0199 | GDOT = 54.49 | PSID = 69.18 | PSIDOT = 362.13 | PHITOT = 5.10 |
| T = .00073   | PHI = 150.17  | PHIDOT = 246.30 | G = -.0197 | GDOT = 54.76 | PSID = 69.29 | PSIDOT = 364.65 | PHITOT = 5.17 |
| F34 = 3.6531 | F23 = 10.1228 | F12 = 31.4590   | G = -.0197 | GDOT = 54.76 | PSID = 69.29 | PSIDOT = 364.65 | PHITOT = 5.17 |
| T = .00074   | PHI = 150.24  | PHIDOT = 247.37 | G = -.0194 | GDOT = 55.02 | PSID = 69.39 | PSIDOT = 367.10 | PHITOT = 5.24 |
| F34 = 3.6536 | F23 = 10.1239 | F12 = 31.4616   | G = -.0194 | GDOT = 55.02 | PSID = 69.39 | PSIDOT = 367.10 | PHITOT = 5.24 |
| T = .00074   | PHI = 150.31  | PHIDOT = 248.37 | G = -.0191 | GDOT = 55.26 | PSID = 69.50 | PSIDOT = 369.45 | PHITOT = 5.31 |
| F34 = 3.6531 | F23 = 10.1344 | F12 = 31.4796   | G = -.0191 | GDOT = 55.26 | PSID = 69.50 | PSIDOT = 369.45 | PHITOT = 5.31 |
| T = .00075   | PHI = 150.38  | PHIDOT = 249.31 | G = -.0188 | GDOT = 55.49 | PSID = 69.60 | PSIDOT = 371.74 | PHITOT = 5.38 |
| F34 = 3.6536 | F23 = 10.1355 | F12 = 31.4821   | G = -.0188 | GDOT = 55.49 | PSID = 69.60 | PSIDOT = 371.74 | PHITOT = 5.38 |
| T = .00075   | PHI = 150.45  | PHIDOT = 250.18 | G = -.0185 | GDOT = 55.70 | PSID = 69.71 | PSIDOT = 373.92 | PHITOT = 5.45 |
| F34 = 3.6536 | F23 = 10.1460 | F12 = 31.5001   | G = -.0185 | GDOT = 55.70 | PSID = 69.71 | PSIDOT = 373.92 | PHITOT = 5.45 |
| T = .00076   | PHI = 150.52  | PHIDOT = 251.01 | G = -.0183 | GDOT = 55.90 | PSID = 69.82 | PSIDOT = 376.04 | PHITOT = 5.52 |
| F34 = 3.6536 | F23 = 10.1470 | F12 = 31.5026   | G = -.0183 | GDOT = 55.90 | PSID = 69.82 | PSIDOT = 376.04 | PHITOT = 5.52 |
| T = .00076   | PHI = 150.59  | PHIDOT = 251.76 | G = -.0180 | GDOT = 56.09 | PSID = 69.93 | PSIDOT = 378.06 | PHITOT = 5.59 |

|              |                 |               |               |                |                   |                   |               |
|--------------|-----------------|---------------|---------------|----------------|-------------------|-------------------|---------------|
| T = .00077   | F34 = 3.5075    | F23 = 11.2700 | F12 = 31.5416 | PN = .9574     | PNPSI = .9574     | DPH12 = .9488E+05 | PHITOT = 5.67 |
| F34 = 3.5079 | PHI00T = 252.25 | F12 = 31.5416 | GDOT = 56.22  | PSID = 70.03   | PSIDOT = 379.71   | PHITOT = 5.67     |               |
| F34 = 3.5079 | F23 = 11.2711   | F12 = 31.5439 | PN = .9559    | PNPSI = .9559  | DPH12 = .9277E+05 | PHITOT = 5.74     |               |
| F34 = 3.5079 | PHI00T = 252.75 | G = -.0174    | GDOT = 56.35  | PSID = 70.14   | PSIDOT = 391.35   | PHITOT = 5.74     |               |
| F34 = 3.5344 | F23 = 11.2899   | F12 = 31.5387 | PN = .9705    | PNPSI = .9705  | DPH12 = .1158E+06 | PHITOT = 5.81     |               |
| F34 = 3.5349 | PHI00T = 253.29 | G = -.0172    | GDOT = 56.48  | PSID = 70.25   | PSIDOT = 383.06   | PHITOT = 5.81     |               |
| F34 = 3.5349 | F23 = 11.2910   | F12 = 31.5410 | PN = .9690    | PNPSI = .9690  | DPH12 = .1136E+06 | PHITOT = 5.88     |               |
| F34 = 3.5617 | PHI00T = 253.89 | G = -.0169    | GDOT = 56.64  | PSID = 70.36   | PSIDOT = 384.88   | PHITOT = 5.88     |               |
| F34 = 3.5617 | F23 = 11.3099   | F12 = 31.5357 | PN = .9839    | PNPSI = .9839  | DPH12 = .1368E+06 | PHITOT = 5.96     |               |
| F34 = 3.5622 | PHI00T = 254.53 | G = -.0166    | GDOT = 56.80  | PSID = 70.47   | PSIDOT = 396.75   | PHITOT = 5.96     |               |
| F34 = 3.5622 | F23 = 11.3110   | F12 = 31.5381 | PN = .9824    | PNPSI = .9824  | DPH12 = .1345E+06 | PHITOT = 6.03     |               |
| F34 = 3.5894 | PHI00T = 255.23 | G = -.0163    | GDOT = 56.97  | PSID = 70.58   | PSIDOT = 388.74   | PHITOT = 6.03     |               |
| F34 = 3.5894 | F23 = 11.3301   | F12 = 31.5328 | PN = .9974    | PNPSI = .9974  | DPH12 = .1578E+06 | PHITOT = 6.10     |               |
| F34 = 3.5899 | PHI00T = 255.98 | G = -.0160    | GDOT = 57.15  | PSID = 70.70   | PSIDOT = 390.79   | PHITOT = 6.10     |               |
| F34 = 3.5899 | F23 = 11.3312   | F12 = 31.5353 | PN = .9960    | PNPSI = .9960  | DPH12 = .1534E+06 | PHITOT = 6.18     |               |
| F34 = 3.6174 | PHI00T = 256.79 | G = -.0157    | GDOT = 57.35  | PSID = 70.81   | PSIDOT = 392.95   | PHITOT = 6.18     |               |
| F34 = 3.6174 | F23 = 11.3504   | F12 = 31.5299 | PN = 1.0113   | PNPSI = 1.0113 | DPH12 = .1738E+06 | PHITOT = 6.25     |               |
| F34 = 3.6179 | PHI00T = 257.83 | G = -.0155    | GDOT = 57.58  | PSID = 70.92   | PSIDOT = 395.17   | PHITOT = 6.25     |               |
| F34 = 3.6179 | F23 = 11.3515   | F12 = 31.5324 | PN = 1.0098   | PNPSI = 1.0098 | DPH12 = .1763E+06 | PHITOT = 6.32     |               |
| F34 = 3.6458 | PHI00T = 258.55 | G = -.0152    | GDOT = 57.78  | PSID = 71.03   | PSIDOT = 397.50   | PHITOT = 6.32     |               |
| F34 = 3.6458 | F23 = 11.3709   | F12 = 31.5269 | PN = 1.0253   | PNPSI = 1.0253 | DPH12 = .2000E+06 | PHITOT = 6.40     |               |
| F34 = 3.6464 | PHI00T = 259.50 | G = -.0149    | GDOT = 58.01  | PSID = 71.15   | PSIDOT = 399.91   | PHITOT = 6.40     |               |
| F34 = 3.6464 | F23 = 11.3721   | F12 = 31.5296 | PN = 1.0238   | PNPSI = 1.0238 | DPH12 = .1974E+06 | PHITOT = 6.47     |               |
| F34 = 3.6747 | PHI00T = 260.52 | G = -.0146    | GDOT = 58.26  | PSID = 71.26   | PSIDOT = 402.42   | PHITOT = 6.47     |               |
| F34 = 3.6747 | F23 = 11.3916   | F12 = 31.5240 | PN = 1.0397   | PNPSI = 1.0397 | DPH12 = .2212E+06 | PHITOT = 6.55     |               |
| F34 = 3.6753 | PHI00T = 261.58 | G = -.0143    | GDOT = 58.51  | PSID = 71.38   | PSIDOT = 405.00   | PHITOT = 6.55     |               |
| F34 = 3.6753 | F23 = 11.3928   | F12 = 31.5267 | PN = 1.0382   | PNPSI = 1.0382 | DPH12 = .2185E+06 | PHITOT = 6.62     |               |
| F34 = 3.6753 | PHI00T = 262.71 | G = -.0140    | GDOT = 58.78  | PSID = 71.50   | PSIDOT = 407.70   | PHITOT = 6.62     |               |
| F34 = 3.6753 | F23 = 11.4156   | F12 = 31.5271 | PN = 1.0468   | PNPSI = 1.0468 | DPH12 = .2311E+06 | PHITOT = 6.70     |               |
| F34 = 3.6753 | PHI00T = 263.86 | G = -.0137    | GDOT = 59.05  | PSID = 71.61   | PSIDOT = 410.46   | PHITOT = 6.70     |               |
| F34 = 3.6753 | F23 = 11.4169   | F12 = 31.5298 | PN = 1.0453   | PNPSI = 1.0453 | DPH12 = .2283E+06 | PHITOT = 6.77     |               |
| F34 = 3.6753 | PHI00T = 264.98 | G = -.0134    | GDOT = 59.32  | PSID = 71.73   | PSIDOT = 413.17   | PHITOT = 6.77     |               |
| F34 = 3.6753 | F23 = 11.4463   | F12 = 31.5421 | PN = 1.0389   | PNPSI = 1.0389 | DPH12 = .2190E+06 | PHITOT = 6.95     |               |
| F34 = 3.6753 | PHI00T = 266.08 | G = -.0131    | GDOT = 59.58  | PSID = 71.85   | PSIDOT = 415.85   | PHITOT = 6.95     |               |
| F34 = 3.6753 | F23 = 11.4475   | F12 = 31.5448 | PN = 1.0373   | PNPSI = 1.0373 | DPH12 = .2152E+06 | PHITOT = 6.93     |               |
| F34 = 3.6753 | PHI00T = 267.14 | G = -.0128    | GDOT = 59.83  | PSID = 71.97   | PSIDOT = 418.49   | PHITOT = 6.93     |               |
| F34 = 3.6753 | F23 = 11.4772   | F12 = 31.5572 | PN = 1.0308   | PNPSI = 1.0308 | DPH12 = .2049E+06 | PHITOT = 7.00     |               |
| F34 = 3.6753 | PHI00T = 268.17 | G = -.0125    | GDOT = 60.08  | PSID = 72.09   | PSIDOT = 421.39   | PHITOT = 7.00     |               |
| F34 = 3.6753 | F23 = 11.4784   | F12 = 31.5599 | PN = 1.0292   | PNPSI = 1.0292 | DPH12 = .2022E+06 | PHITOT = 7.08     |               |
| F34 = 3.6753 | PHI00T = 269.16 | G = -.0122    | GDOT = 60.32  | PSID = 72.21   | PSIDOT = 423.65   | PHITOT = 7.08     |               |
| F34 = 3.6753 | F23 = 11.5084   | F12 = 31.5723 | PN = 1.0226   | PNPSI = 1.0226 | DPH12 = .1919E+06 | PHITOT = 7.16     |               |
| F34 = 3.6753 | PHI00T = 270.12 | G = -.0119    | GDOT = 60.55  | PSID = 72.33   | PSIDOT = 426.17   | PHITOT = 7.16     |               |
| F34 = 3.6753 | F23 = 11.5096   | F12 = 31.5750 | PN = 1.0210   | PNPSI = 1.0210 | DPH12 = .1893E+06 | PHITOT = 7.23     |               |
| F34 = 3.6753 | PHI00T = 271.05 | G = -.0116    | GDOT = 60.77  | PSID = 72.45   | PSIDOT = 428.64   | PHITOT = 7.23     |               |
| F34 = 3.6753 | F23 = 11.5398   | F12 = 31.5875 | PN = 1.0143   | PNPSI = 1.0143 | DPH12 = .1789E+06 | PHITOT = 7.31     |               |
| F34 = 3.6753 | PHI00T = 271.95 | G = -.0113    | GDOT = 60.99  | PSID = 72.58   | PSIDOT = 431.07   | PHITOT = 7.31     |               |
| F34 = 3.6753 | F23 = 11.5410   | F12 = 31.5901 | PN = 1.0127   | PNPSI = 1.0127 | DPH12 = .1764E+06 | PHITOT = 7.39     |               |
| F34 = 3.6753 | PHI00T = 272.81 | G = -.0110    | GDOT = 61.20  | PSID = 72.70   | PSIDOT = 433.46   | PHITOT = 7.39     |               |
| F34 = 3.6753 | F23 = 11.5715   | F12 = 31.6027 | PN = 1.0058   | PNPSI = 1.0058 | DPH12 = .1660E+06 | PHITOT = 7.47     |               |
| F34 = 3.6753 | PHI00T = 273.65 | G = -.0107    | GDOT = 61.40  | PSID = 72.83   | PSIDOT = 435.81   | PHITOT = 7.47     |               |
| F34 = 3.6753 | F23 = 11.5727   | F12 = 31.6053 | PN = 1.0043   | PNPSI = 1.0043 | DPH12 = .1636E+06 | PHITOT = 7.55     |               |
| F34 = 3.6753 | PHI00T = 274.43 | G = -.0104    | GDOT = 61.59  | PSID = 72.95   | PSIDOT = 438.07   | PHITOT = 7.55     |               |
| F34 = 3.6753 | F23 = 11.6051   | F12 = 31.6211 | PN = .9933    | PNPSI = .9933  | DPH12 = .1472E+06 | PHITOT = 7.63     |               |
| F34 = 3.6753 | PHI00T = 275.12 | G = -.0101    | GDOT = 61.76  | PSID = 73.08   | PSIDOT = 440.22   | PHITOT = 7.63     |               |
| F34 = 3.6753 | F23 = 11.6062   | F12 = 31.6235 | PN = .9917    | PNPSI = .9917  | DPH12 = .1450E+06 | PHITOT = 7.70     |               |
| F34 = 3.6753 | PHI00T = 275.88 | G = -.0098    | GDOT = 61.94  | PSID = 73.20   | PSIDOT = 442.45   | PHITOT = 7.70     |               |
| F34 = 3.6753 | F23 = 11.6275   | F12 = 31.6182 | PN = 1.0083   | PNPSI = 1.0083 | DPH12 = .1698E+06 | PHITOT = 7.78     |               |
| F34 = 3.6753 | PHI00T = 276.68 | G = -.0093    | GDOT = 62.13  | PSID = 73.33   | PSIDOT = 444.77   | PHITOT = 7.78     |               |
| F34 = 3.6753 | F23 = 11.6286   | F12 = 31.6206 | PN = 1.0067   | PNPSI = 1.0067 | DPH12 = .1675E+06 | PHITOT = 7.86     |               |
| F34 = 3.6753 | PHI00T = 277.55 | G = -.0091    | GDOT = 62.34  | PSID = 73.46   | PSIDOT = 447.22   | PHITOT = 7.86     |               |
| F34 = 3.6753 | F23 = 11.6500   | F12 = 31.6149 | PN = 1.0236   | PNPSI = 1.0236 | DPH12 = .1925E+06 | PHITOT = 7.86     |               |

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T = .00092  PHI = 152.94  PHIDOT = 278.47  G = -.0088  GDOT = 62.50  PSID = 73.59  PSIDOT = 449.74  PHITOT = 7.94
F34 = 3.8518  F23 = 11.6512  F12 = 31.6175  PN = 1.0220  DPH12 = .1900E+06
T = .00092  PHI = 153.02  PHIDOT = 279.45  G = -.0085  GDOT = 62.79  PSID = 73.72  PSIDOT = 452.38  PHITOT = 8.02
F34 = 3.8934  F23 = 11.6727  F12 = 31.6117  PN = 1.0392  DPH12 = .2153E+06
T = .00093  PHI = 153.10  PHIDOT = 280.48  G = -.0082  GDOT = 63.04  PSID = 73.85  PSIDOT = 455.10  PHITOT = 8.10
F34 = 3.8840  F23 = 11.6740  F12 = 31.6145  PN = 1.0376  DPH12 = .2127E+06
T = .00093  PHI = 153.18  PHIDOT = 281.58  G = -.0079  GDOT = 63.30  PSID = 73.98  PSIDOT = 457.95  PHITOT = 8.18
F34 = 3.9161  F23 = 11.6957  F12 = 31.6093  PN = 1.0551  DPH12 = .2383E+06
T = .00094  PHI = 153.26  PHIDOT = 282.72  G = -.0076  GDOT = 63.56  PSID = 74.11  PSIDOT = 460.88  PHITOT = 8.26
F34 = 3.9167  F23 = 11.6970  F12 = 31.6114  PN = 1.0535  DPH12 = .2335E+06
T = .00094  PHI = 153.35  PHIDOT = 283.94  G = -.0073  GDOT = 63.85  PSID = 74.24  PSIDOT = 463.94  PHITOT = 8.35
F34 = 3.9433  F23 = 11.7189  F12 = 31.6055  PN = 1.0713  DPH12 = .2613E+06
T = .00095  PHI = 153.43  PHIDOT = 285.19  G = -.0069  GDOT = 64.14  PSID = 74.37  PSIDOT = 467.08  PHITOT = 8.43
F34 = 3.9500  F23 = 11.7202  F12 = 31.6093  PN = 1.0697  DPH12 = .2584E+06
T = .00095  PHI = 153.51  PHIDOT = 286.52  G = -.0065  GDOT = 64.45  PSID = 74.51  PSIDOT = 470.35  PHITOT = 8.51
F34 = 3.9849  F23 = 11.7445  F12 = 31.6062  PN = 1.0828  DPH12 = .2771E+06
T = .00096  PHI = 153.59  PHIDOT = 287.89  G = -.0063  GDOT = 64.77  PSID = 74.64  PSIDOT = 473.70  PHITOT = 8.59
F34 = 3.9855  F23 = 11.7458  F12 = 31.6091  PN = 1.0811  DPH12 = .2741E+06
T = .00096  PHI = 153.67  PHIDOT = 289.24  G = -.0060  GDOT = 65.08  PSID = 74.78  PSIDOT = 477.04  PHITOT = 8.67
F34 = 3.9853  F23 = 10.5805  F12 = 31.6261  PN = 1.0692  DPH12 = .2561E+06
T = .00097  PHI = 153.76  PHIDOT = 290.54  G = -.0056  GDOT = 65.39  PSID = 74.92  PSIDOT = 480.31  PHITOT = 8.76
F34 = 3.9450  F23 = 10.5817  F12 = 31.6290  PN = 1.0675  DPH12 = .2532E+06
T = .00097  PHI = 153.84  PHIDOT = 291.77  G = -.0053  GDOT = 65.67  PSID = 75.05  PSIDOT = 483.47  PHITOT = 8.84
F34 = 3.5697  F23 = 10.5937  F12 = 31.6496  PN = 1.0508  DPH12 = .2285E+06
T = .00098  PHI = 153.92  PHIDOT = 292.94  G = -.0050  GDOT = 65.94  PSID = 75.19  PSIDOT = 486.54  PHITOT = 8.92
F34 = 3.5703  F23 = 10.5949  F12 = 31.6524  PN = 1.0491  DPH12 = .2257E+06
T = .00098  PHI = 154.01  PHIDOT = 294.03  G = -.0047  GDOT = 66.20  PSID = 75.33  PSIDOT = 489.49  PHITOT = 9.01
F34 = 3.5639  F23 = 10.6070  F12 = 31.6730  PN = 1.0324  DPH12 = .2012E+06
T = .00099  PHI = 154.09  PHIDOT = 295.06  G = -.0043  GDOT = 66.44  PSID = 75.47  PSIDOT = 492.36  PHITOT = 9.09
F34 = 3.5545  F23 = 10.6081  F12 = 31.6757  PN = 1.0307  DPH12 = .1987E+06
T = .00099  PHI = 154.18  PHIDOT = 296.01  G = -.0040  GDOT = 66.66  PSID = 75.62  PSIDOT = 495.10  PHITOT = 9.18
F34 = 3.5380  F23 = 10.6201  F12 = 31.6961  PN = 1.0139  DPH12 = .1745E+06
T = .00100  PHI = 154.26  PHIDOT = 296.91  G = -.0037  GDOT = 66.87  PSID = 75.76  PSIDOT = 497.77  PHITOT = 9.26
F34 = 3.5366  F23 = 10.6212  F12 = 31.6938  PN = 1.0122  DPH12 = .1721E+06
T = .00100  PHI = 154.35  PHIDOT = 297.74  G = -.0033  GDOT = 67.06  PSID = 75.90  PSIDOT = 500.31  PHITOT = 9.35
F34 = 3.5220  F23 = 10.6332  F12 = 31.7191  PN = .9956  DPH12 = .1483E+06
T = .00101  PHI = 154.43  PHIDOT = 298.50  G = -.0030  GDOT = 67.24  PSID = 76.04  PSIDOT = 502.77  PHITOT = 9.43
F34 = 3.5225  F23 = 10.6342  F12 = 31.7217  PN = .9938  DPH12 = .1461E+06
T = .00101  PHI = 154.52  PHIDOT = 299.14  G = -.0026  GDOT = 67.39  PSID = 76.19  PSIDOT = 505.01  PHITOT = 9.52
F34 = 3.8962  F23 = 10.6439  F12 = 31.7373  PN = .9834  DPH12 = .1335E+06
T = .00102  PHI = 154.60  PHIDOT = 299.77  G = -.0023  GDOT = 67.54  PSID = 76.33  PSIDOT = 507.24  PHITOT = 9.60
F34 = 3.8968  F23 = 10.6449  F12 = 31.7399  PN = .9816  DPH12 = .1294E+06
T = .00102  PHI = 154.69  PHIDOT = 300.43  G = -.0020  GDOT = 67.69  PSID = 76.48  PSIDOT = 509.54  PHITOT = 9.69
F34 = 3.8960  F23 = 10.6476  F12 = 31.7409  PN = .9806  DPH12 = .1427E+06
T = .00103  PHI = 154.78  PHIDOT = 301.12  G = -.0016  GDOT = 67.85  PSID = 76.63  PSIDOT = 511.88  PHITOT = 9.78
F34 = 3.8965  F23 = 10.6487  F12 = 31.7435  PN = .9889  DPH12 = .1406E+06
T = .00103  PHI = 154.86  PHIDOT = 301.84  G = -.0013  GDOT = 68.02  PSID = 76.77  PSIDOT = 514.29  PHITOT = 9.86
F34 = 3.8958  F23 = 10.6514  F12 = 31.7447  PN = .9979  DPH12 = .1538E+06
T = .00104  PHI = 154.95  PHIDOT = 302.58  G = -.0010  GDOT = 68.19  PSID = 76.92  PSIDOT = 516.74  PHITOT = 9.95
F34 = 3.8963  F23 = 10.6524  F12 = 31.7473  PN = .9961  DPH12 = .1514E+06
T = .00104  PHI = 155.04  PHIDOT = 303.35  G = -.0006  GDOT = 68.37  PSID = 77.07  PSIDOT = 519.26  PHITOT = 10.04
F34 = 3.8956  F23 = 10.6552  F12 = 31.7485  PN = 1.0051  DPH12 = .1648E+06
T = .00105  PHI = 155.12  PHIDOT = 304.15  G = -.0003  GDOT = 68.55  PSID = 77.22  PSIDOT = 521.81  PHITOT = 10.12
F34 = 3.8961  F23 = 10.6563  F12 = 31.7511  PN = 1.0034  DPH12 = .1625E+06
T = .00105  PHI = 155.21  PHIDOT = 304.98  G = -.0001  GDOT = 68.74  PSID = 77.37  PSIDOT = 524.44  PHITOT = 10.21
F34 = 3.8954  F23 = 10.6591  F12 = 31.7525  PN = 1.0124  DPH12 = .1756E+06

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FREE MOTION

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T = .00105  PHI = 185.21  PHIDOT = 304.98  PSI = 285.22  PSIDOT = 524.44  PHITOT = 10.21

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## Computer program SAND3 (cont)

[illegible]

|            |                               |                                  |                              |                 |                |
|------------|-------------------------------|----------------------------------|------------------------------|-----------------|----------------|
| T = .00115 | PHI = 187.87<br>FF12 = 26.491 | PHIDOT = 648.58<br>FF23 = 10.611 | PSI = 287.53<br>FF34 = 3.204 | PSIDOT = 345.97 | PHITOT = 12.87 |
| T = .00115 | PHI = 187.97<br>FF12 = 26.492 | PHIDOT = 709.12<br>FF23 = 10.612 | PSI = 287.59<br>FF34 = 3.204 | PSIDOT = 341.15 | PHITOT = 12.97 |
| T = .00115 | PHI = 188.08<br>FF12 = 26.443 | PHIDOT = 719.81<br>FF23 = 10.582 | PSI = 287.63<br>FF34 = 3.216 | PSIDOT = 336.32 | PHITOT = 13.08 |
| T = .00115 | PHI = 188.18<br>FF12 = 26.444 | PHIDOT = 730.60<br>FF23 = 10.582 | PSI = 287.68<br>FF34 = 3.216 | PSIDOT = 331.50 | PHITOT = 13.18 |
| T = .00116 | PHI = 188.29<br>FF12 = 26.394 | PHIDOT = 741.53<br>FF23 = 10.551 | PSI = 287.72<br>FF34 = 3.228 | PSIDOT = 326.68 | PHITOT = 13.29 |
| T = .00116 | PHI = 188.39<br>FF12 = 26.395 | PHIDOT = 752.55<br>FF23 = 10.552 | PSI = 287.77<br>FF34 = 3.228 | PSIDOT = 321.85 | PHITOT = 13.39 |
| T = .00116 | PHI = 188.50<br>FF12 = 26.343 | PHIDOT = 763.73<br>FF23 = 10.520 | PSI = 287.82<br>FF34 = 3.241 | PSIDOT = 317.03 | PHITOT = 13.50 |
| T = .00116 | PHI = 188.61<br>FF12 = 26.344 | PHIDOT = 775.01<br>FF23 = 10.521 | PSI = 287.86<br>FF34 = 3.241 | PSIDOT = 312.21 | PHITOT = 13.61 |
| T = .00117 | PHI = 188.72<br>FF12 = 26.328 | PHIDOT = 786.45<br>FF23 = 9.447  | PSI = 287.90<br>FF34 = 2.929 | PSIDOT = 307.38 | PHITOT = 13.72 |
| T = .00117 | PHI = 188.84<br>FF12 = 26.329 | PHIDOT = 797.91<br>FF23 = 9.448  | PSI = 287.95<br>FF34 = 2.929 | PSIDOT = 302.56 | PHITOT = 13.84 |
| T = .00117 | PHI = 188.95<br>FF12 = 26.378 | PHIDOT = 809.24<br>FF23 = 9.447  | PSI = 287.99<br>FF34 = 2.909 | PSIDOT = 297.74 | PHITOT = 13.95 |
| T = .00117 | PHI = 189.07<br>FF12 = 26.379 | PHIDOT = 820.46<br>FF23 = 9.448  | PSI = 288.03<br>FF34 = 2.909 | PSIDOT = 292.91 | PHITOT = 14.07 |
| T = .00118 | PHI = 189.19<br>FF12 = 26.428 | PHIDOT = 831.49<br>FF23 = 9.447  | PSI = 288.08<br>FF34 = 2.889 | PSIDOT = 288.09 | PHITOT = 14.19 |
| T = .00118 | PHI = 189.31<br>FF12 = 26.430 | PHIDOT = 842.42<br>FF23 = 9.447  | PSI = 288.12<br>FF34 = 2.889 | PSIDOT = 283.27 | PHITOT = 14.31 |
| T = .00118 | PHI = 189.43<br>FF12 = 26.480 | PHIDOT = 853.18<br>FF23 = 9.446  | PSI = 288.16<br>FF34 = 2.868 | PSIDOT = 278.44 | PHITOT = 14.43 |
| T = .00118 | PHI = 189.55<br>FF12 = 26.481 | PHIDOT = 863.78<br>FF23 = 9.446  | PSI = 288.20<br>FF34 = 2.869 | PSIDOT = 273.62 | PHITOT = 14.55 |
| T = .00119 | PHI = 189.68<br>FF12 = 26.511 | PHIDOT = 874.09<br>FF23 = 9.434  | PSI = 288.23<br>FF34 = 3.161 | PSIDOT = 268.79 | PHITOT = 14.68 |
| T = .00119 | PHI = 189.80<br>FF12 = 26.513 | PHIDOT = 884.40<br>FF23 = 9.434  | PSI = 288.27<br>FF34 = 3.161 | PSIDOT = 263.97 | PHITOT = 14.80 |
| T = .00119 | PHI = 189.93<br>FF12 = 26.484 | PHIDOT = 894.78<br>FF23 = 9.389  | PSI = 288.31<br>FF34 = 3.138 | PSIDOT = 259.15 | PHITOT = 14.93 |
| T = .00119 | PHI = 190.06<br>FF12 = 26.486 | PHIDOT = 905.20<br>FF23 = 9.390  | PSI = 288.35<br>FF34 = 3.138 | PSIDOT = 254.32 | PHITOT = 15.06 |
| T = .00120 | PHI = 190.19<br>FF12 = 26.457 | PHIDOT = 915.71<br>FF23 = 9.345  | PSI = 288.38<br>FF34 = 3.114 | PSIDOT = 249.50 | PHITOT = 15.19 |
| T = .00120 | PHI = 190.32<br>FF12 = 26.458 | PHIDOT = 926.26<br>FF23 = 9.345  | PSI = 288.42<br>FF34 = 3.114 | PSIDOT = 244.68 | PHITOT = 15.32 |
| T = .00120 | PHI = 190.45<br>FF12 = 26.429 | PHIDOT = 936.89<br>FF23 = 9.289  | PSI = 288.45<br>FF34 = 3.090 | PSIDOT = 239.85 | PHITOT = 15.45 |
| T = .00120 | PHI = 190.59<br>FF12 = 26.431 | PHIDOT = 947.56<br>FF23 = 9.300  | PSI = 288.49<br>FF34 = 3.090 | PSIDOT = 235.03 | PHITOT = 15.59 |
| T = .00121 | PHI = 190.73<br>FF12 = 26.468 | PHIDOT = 958.26<br>FF23 = 9.288  | PSI = 288.52<br>FF34 = 2.761 | PSIDOT = 230.21 | PHITOT = 15.73 |
| T = .00121 | PHI = 190.86<br>FF12 = 26.470 | PHIDOT = 968.84<br>FF23 = 9.249  | PSI = 288.55<br>FF34 = 2.761 | PSIDOT = 225.38 | PHITOT = 15.86 |
| T = .00121 | PHI = 191.00<br>FF12 = 26.526 | PHIDOT = 979.22<br>FF23 = 9.266  | PSI = 288.59<br>FF34 = 2.737 | PSIDOT = 220.58 | PHITOT = 16.00 |
| T = .00121 | PHI = 191.14<br>FF12 = 26.527 | PHIDOT = 989.47<br>FF23 = 9.287  | PSI = 288.62<br>FF34 = 2.737 | PSIDOT = 215.74 | PHITOT = 16.14 |
| T = .00122 | PHI = 191.29<br>FF12 = 26.583 | PHIDOT = 999.52<br>FF23 = 9.284  | PSI = 288.65<br>FF34 = 2.713 | PSIDOT = 210.91 | PHITOT = 16.29 |
| T = .00122 | PHI = 191.43<br>FF12 = 26.585 | PHIDOT = 1009.43<br>FF23 = 9.285 | PSI = 288.68<br>FF34 = 2.714 | PSIDOT = 206.09 | PHITOT = 16.43 |
| T = .00122 | PHI = 191.50<br>FF12 = 26.585 | PHIDOT = 1014.19<br>FF23 = 9.285 | PSI = 288.69<br>FF34 = 2.714 | PSIDOT = 203.68 | PHITOT = 16.50 |

Computer program SANDA3 (cont)

|            |               |                  |              |                 |                |
|------------|---------------|------------------|--------------|-----------------|----------------|
| T = .00122 | FF12 = 26.622 | FF23 = 10.296    | FF34 = 2.969 | PS100T = 201.27 | PHITOT = 16.58 |
|            | PHI = 191.58  | PHIDOT = 1018.95 | PS1 = 288.71 |                 |                |
| T = .00122 | FF12 = 26.623 | FF23 = 10.297    | FF34 = 2.969 | PS100T = 198.88 | PHITOT = 16.65 |
|            | PHI = 191.65  | PHIDOT = 1023.75 | PS1 = 288.72 |                 |                |
| T = .00122 | FF12 = 26.590 | FF23 = 10.277    | FF34 = 2.977 | PS100T = 196.44 | PHITOT = 16.72 |
|            | PHI = 191.72  | PHIDOT = 1028.59 | PS1 = 288.73 |                 |                |
| T = .00123 | FF12 = 26.591 | FF23 = 10.277    | FF34 = 2.978 | PS100T = 194.03 | PHITOT = 16.80 |
|            | PHI = 191.80  | PHIDOT = 1033.48 | PS1 = 288.75 |                 |                |
| T = .00123 | FF12 = 26.558 | FF23 = 10.257    | FF34 = 2.986 | PS100T = 191.62 | PHITOT = 16.87 |
|            | PHI = 191.87  | PHIDOT = 1038.39 | PS1 = 288.76 |                 |                |
| T = .00123 | FF12 = 26.559 | FF23 = 10.257    | FF34 = 2.986 | PS100T = 189.21 | PHITOT = 16.95 |
|            | PHI = 191.95  | PHIDOT = 1043.36 | PS1 = 288.78 |                 |                |
| T = .00123 | FF12 = 26.525 | FF23 = 10.237    | FF34 = 2.995 | PS100T = 186.80 | PHITOT = 17.02 |
|            | PHI = 192.02  | PHIDOT = 1048.36 | PS1 = 288.79 |                 |                |
| T = .00123 | FF12 = 26.526 | FF23 = 10.237    | FF34 = 2.995 | PS100T = 184.38 | PHITOT = 17.10 |
|            | PHI = 192.10  | PHIDOT = 1053.41 | PS1 = 288.80 |                 |                |
| T = .00123 | FF12 = 26.492 | FF23 = 10.217    | FF34 = 3.003 | PS100T = 181.97 | PHITOT = 17.17 |
|            | PHI = 192.17  | PHIDOT = 1058.49 | PS1 = 288.82 |                 |                |
| T = .00123 | FF12 = 26.493 | FF23 = 10.217    | FF34 = 3.003 | PS100T = 179.56 | PHITOT = 17.25 |
|            | PHI = 192.25  | PHIDOT = 1063.62 | PS1 = 288.83 |                 |                |
| T = .00123 | FF12 = 26.458 | FF23 = 10.196    | FF34 = 3.012 | PS100T = 177.15 | PHITOT = 17.32 |
|            | PHI = 192.32  | PHIDOT = 1068.79 | PS1 = 288.84 |                 |                |
| T = .00124 | FF12 = 26.459 | FF23 = 10.197    | FF34 = 3.012 | PS100T = 174.74 | PHITOT = 17.40 |
|            | PHI = 192.40  | PHIDOT = 1073.99 | PS1 = 288.85 |                 |                |
| T = .00124 | FF12 = 26.463 | FF23 = 10.198    | FF34 = 2.721 | PS100T = 172.33 | PHITOT = 17.48 |
|            | PHI = 192.48  | PHIDOT = 1079.17 | PS1 = 288.87 |                 |                |
| T = .00124 | FF12 = 26.464 | FF23 = 10.198    | FF34 = 2.721 | PS100T = 169.91 | PHITOT = 17.55 |
|            | PHI = 192.55  | PHIDOT = 1084.33 | PS1 = 288.88 |                 |                |
| T = .00124 | FF12 = 26.475 | FF23 = 10.204    | FF34 = 2.728 | PS100T = 167.50 | PHITOT = 17.63 |
|            | PHI = 192.63  | PHIDOT = 1089.48 | PS1 = 288.89 |                 |                |
| T = .00124 | FF12 = 26.476 | FF23 = 10.205    | FF34 = 2.728 | PS100T = 165.09 | PHITOT = 17.71 |
|            | PHI = 192.71  | PHIDOT = 1094.60 | PS1 = 288.90 |                 |                |
| T = .00124 | FF12 = 26.488 | FF23 = 10.211    | FF34 = 2.735 | PS100T = 162.68 | PHITOT = 17.79 |
|            | PHI = 192.79  | PHIDOT = 1099.70 | PS1 = 288.91 |                 |                |
| T = .00124 | FF12 = 26.489 | FF23 = 10.211    | FF34 = 2.736 | PS100T = 160.27 | PHITOT = 17.87 |
|            | PHI = 192.87  | PHIDOT = 1104.78 | PS1 = 288.93 |                 |                |
| T = .00124 | FF12 = 26.502 | FF23 = 10.218    | FF34 = 2.743 | PS100T = 157.86 | PHITOT = 17.95 |
|            | PHI = 192.95  | PHIDOT = 1109.84 | PS1 = 288.94 |                 |                |
| T = .00125 | FF12 = 26.502 | FF23 = 10.218    | FF34 = 2.743 | PS100T = 155.44 | PHITOT = 18.03 |
|            | PHI = 193.03  | PHIDOT = 1114.88 | PS1 = 288.95 |                 |                |
| T = .00125 | FF12 = 26.515 | FF23 = 10.224    | FF34 = 2.751 | PS100T = 153.03 | PHITOT = 18.11 |
|            | PHI = 193.11  | PHIDOT = 1119.89 | PS1 = 288.96 |                 |                |
| T = .00125 | FF12 = 26.516 | FF23 = 10.225    | FF34 = 2.751 | PS100T = 150.62 | PHITOT = 18.19 |
|            | PHI = 193.19  | PHIDOT = 1124.89 | PS1 = 288.97 |                 |                |
| T = .00125 | FF12 = 26.556 | FF23 = 10.248    | FF34 = 3.062 | PS100T = 148.21 | PHITOT = 18.27 |
|            | PHI = 193.27  | PHIDOT = 1129.85 | PS1 = 288.98 |                 |                |
| T = .00125 | FF12 = 26.557 | FF23 = 10.248    | FF34 = 3.062 | PS100T = 145.80 | PHITOT = 18.35 |
|            | PHI = 193.35  | PHIDOT = 1134.76 | PS1 = 288.99 |                 |                |
| T = .00125 | FF12 = 26.590 | FF23 = 9.922     | FF34 = 2.974 | PS100T = 143.39 | PHITOT = 18.43 |
|            | PHI = 193.43  | PHIDOT = 1139.71 | PS1 = 289.00 |                 |                |
| T = .00125 | FF12 = 26.592 | FF23 = 9.922     | FF34 = 2.974 | PS100T = 140.97 | PHITOT = 18.51 |
|            | PHI = 193.51  | PHIDOT = 1144.51 | PS1 = 289.01 |                 |                |
| T = .00125 | FF12 = 26.555 | FF23 = 9.926     | FF34 = 2.991 | PS100T = 138.56 | PHITOT = 18.59 |
|            | PHI = 193.59  | PHIDOT = 1149.35 | PS1 = 289.02 |                 |                |
| T = .00126 | FF12 = 26.556 | FF23 = 9.926     | FF34 = 2.991 | PS100T = 136.15 | PHITOT = 18.68 |
|            | PHI = 193.68  | PHIDOT = 1154.25 | PS1 = 289.03 |                 |                |
| T = .00126 | FF12 = 26.510 | FF23 = 9.930     | FF34 = 3.008 | PS100T = 133.74 | PHITOT = 18.76 |
|            | PHI = 193.76  | PHIDOT = 1159.20 | PS1 = 289.04 |                 |                |
| T = .00126 | FF12 = 26.519 | FF23 = 9.930     | FF34 = 3.009 | PS100T = 131.33 | PHITOT = 18.84 |
|            | PHI = 193.84  | PHIDOT = 1164.21 | PS1 = 289.05 |                 |                |
| T = .00126 | FF12 = 26.481 | FF23 = 9.933     | FF34 = 3.026 |                 |                |

T = .00126 PHI = 193.93 PHIDOT = 1169.27 PSI = 289.06 PSIDOT = 128.92 PHITOT = 18.93  
 FF12 = 29.482 FF23 = 9.934 FF34 = 3.026  
 T = .00126 PHI = 194.01 PHIDOT = 1174.39 PSI = 289.07 PSIDOT = 126.50 PHITOT = 19.01  
 FF12 = 29.443 FF23 = 9.937 FF34 = 3.044  
 T = .00126 PHI = 194.10 PHIDOT = 1179.56 PSI = 289.08 PSIDOT = 124.09 PHITOT = 19.10  
 FF12 = 29.444 FF23 = 9.937 FF34 = 3.044  
 T = .00126 PHI = 194.18 PHIDOT = 1184.79 PSI = 289.09 PSIDOT = 121.68 PHITOT = 19.18  
 FF12 = 29.405 FF23 = 9.940 FF34 = 3.061  
 T = .00126 PHI = 194.26 PHIDOT = 1190.07 PSI = 289.10 PSIDOT = 119.27 PHITOT = 19.26  
 FF12 = 29.406 FF23 = 9.940 FF34 = 3.061  
 T = .00127 PHI = 194.35 PHIDOT = 1195.38 PSI = 289.10 PSIDOT = 116.86 PHITOT = 19.35  
 FF12 = 29.432 FF23 = 9.963 FF34 = 2.765  
 T = .00127 PHI = 194.44 PHIDOT = 1200.68 PSI = 289.11 PSIDOT = 114.44 PHITOT = 19.44  
 FF12 = 29.433 FF23 = 8.963 FF34 = 2.765  
 T = .00127 PHI = 194.52 PHIDOT = 1205.92 PSI = 289.12 PSIDOT = 112.03 PHITOT = 19.52  
 FF12 = 29.474 FF23 = 8.985 FF34 = 2.759  
 T = .00127 PHI = 194.61 PHIDOT = 1211.14 PSI = 289.13 PSIDOT = 109.62 PHITOT = 19.61  
 FF12 = 29.475 FF23 = 8.986 FF34 = 2.759  
 T = .00127 PHI = 194.70 PHIDOT = 1216.30 PSI = 289.14 PSIDOT = 107.21 PHITOT = 19.70  
 FF12 = 29.517 FF23 = 9.008 FF34 = 2.752  
 T = .00127 PHI = 194.78 PHIDOT = 1221.43 PSI = 289.14 PSIDOT = 104.80 PHITOT = 19.78  
 FF12 = 29.519 FF23 = 9.009 FF34 = 2.753  
 T = .00127 PHI = 194.87 PHIDOT = 1226.51 PSI = 289.15 PSIDOT = 102.39 PHITOT = 19.87  
 FF12 = 29.561 FF23 = 9.031 FF34 = 2.746  
 T = .00127 PHI = 194.96 PHIDOT = 1231.55 PSI = 289.16 PSIDOT = 99.97 PHITOT = 19.96  
 FF12 = 29.562 FF23 = 9.032 FF34 = 2.746  
 T = .00128 PHI = 195.05 PHIDOT = 1236.55 PSI = 289.17 PSIDOT = 97.58 PHITOT = 20.05  
 FF12 = 29.605 FF23 = 9.054 FF34 = 2.739  
 T = .00128 PHI = 195.14 PHIDOT = 1241.51 PSI = 289.17 PSIDOT = 95.15 PHITOT = 20.14  
 FF12 = 29.608 FF23 = 9.055 FF34 = 2.739  
 T = .00128 PHI = 195.23 PHIDOT = 1246.37 PSI = 289.18 PSIDOT = 92.74 PHITOT = 20.23  
 FF12 = 29.636 FF23 = 9.072 FF34 = 3.034  
 T = .00128 PHI = 195.31 PHIDOT = 1251.23 PSI = 289.19 PSIDOT = 90.33 PHITOT = 20.31  
 FF12 = 29.637 FF23 = 9.072 FF34 = 3.034  
 T = .00128 PHI = 195.49 PHIDOT = 1261.07 PSI = 289.20 PSIDOT = 85.50 PHITOT = 20.49  
 FF12 = 29.602 FF23 = 9.061 FF34 = 3.020  
 T = .00128 PHI = 195.68 PHIDOT = 1271.00 PSI = 289.21 PSIDOT = 80.68 PHITOT = 20.68  
 FF12 = 29.604 FF23 = 9.062 FF34 = 3.020  
 T = .00129 PHI = 195.86 PHIDOT = 1281.08 PSI = 289.22 PSIDOT = 75.86 PHITOT = 20.86  
 FF12 = 29.569 FF23 = 9.052 FF34 = 3.006  
 T = .00129 PHI = 196.04 PHIDOT = 1291.27 PSI = 289.23 PSIDOT = 71.03 PHITOT = 21.04  
 FF12 = 29.571 FF23 = 9.053 FF34 = 3.006  
 VP = -4.539 VS = 135.614

## IMPACT

PHI = 196.043 PHIDOT = 431.204 PSI = 289.233 PSIDOT = -708.674 PHITOT = 21.043  
 VS = 45.287  
 COUPLED MOTION  
 T = .00129 PHI = 196.04 PHIDOT = 431.20 G = -.0158 GDOT = 103.50 PSID = 289.22 PHITOT = 21.04  
 F34 = 3.6907 F23 = 10.0902 F12 = 31.8141 PN = 1.1379 PNPSI = 1.1379 DPHI2 = -1.1652E+06  
 T = .00130 PHI = 196.29 PHIDOT = 429.44 G = -.0148 GDOT = 104.20 PSID = 288.81 PHITOT = 21.29  
 F34 = 3.2957 F23 = 10.1231 F12 = 31.8675 PN = 1.1157 PNPSI = 1.1157 DPHI2 = -718.89  
 T = .00131 PHI = 196.53 PHIDOT = 427.15 G = -.0137 GDOT = 104.80 PSID = 288.39 PHITOT = 21.53  
 F34 = 3.3008 F23 = 10.1323 F12 = 31.8803 PN = 1.1157 PNPSI = 1.1157 DPHI2 = -230.106  
 T = .00131 PHI = 196.60 PHIDOT = 426.27 G = -.0135 GDOT = 104.87 PSID = 288.29 PHITOT = 21.60  
 F34 = 3.5554 F23 = 11.2943 F12 = 31.9644 PN = 1.0430 PNPSI = 1.0438 DPHI2 = -2633E+06  
 T = .00131 PHI = 196.66 PHIDOT = 425.33 G = -.0132 GDOT = 104.94 PSID = 289.18 PHITOT = 21.66  
 F34 = 3.5566 F23 = 11.4964 F12 = 31.9688 PN = 1.0435 PNPSI = 1.0435 DPHI2 = -3641E+06  
 T = .00132 PHI = 196.72 PHIDOT = 424.41 G = -.0129 GDOT = 105.01 PSID = 288.08 PHITOT = 21.72  
 F34 = 3.5566 F23 = 11.4964 F12 = 31.9688 PN = 1.0435 PNPSI = 1.0435 DPHI2 = -3706E+06

## Computer program SANDA3 (cont.)

|            |               |                  |              |                  |                  |
|------------|---------------|------------------|--------------|------------------|------------------|
| T = .09064 | PHI = 142.54  | PHIDOT = 932.47  | PSI = 70.69  | PSIDOT = -934.56 | PHITOT = 3597.54 |
|            | FF12 = 14.581 | FF23 = 15.148    | FF34 = 4.060 |                  |                  |
| T = .09064 | PHI = 142.62  | PHIDOT = 1000.95 | PSI = 70.62  | PSIDOT = -932.56 | PHITOT = 3597.62 |
|            | FF12 = 14.580 | FF23 = 15.147    | FF34 = 4.060 |                  |                  |
| T = .09064 | PHI = 142.69  | PHIDOT = 1009.41 | PSI = 70.56  | PSIDOT = -930.56 | PHITOT = 3597.69 |
|            | FF12 = 14.601 | FF23 = 15.188    | FF34 = 4.079 |                  |                  |
| T = .09064 | PHI = 142.76  | PHIDOT = 1017.86 | PSI = 70.49  | PSIDOT = -928.56 | PHITOT = 3597.76 |
|            | FF12 = 14.600 | FF23 = 15.188    | FF34 = 4.079 |                  |                  |
| T = .09065 | PHI = 142.83  | PHIDOT = 1026.29 | PSI = 70.42  | PSIDOT = -926.56 | PHITOT = 3597.83 |
|            | FF12 = 14.621 | FF23 = 15.230    | FF34 = 4.099 |                  |                  |
| T = .09065 | PHI = 142.91  | PHIDOT = 1034.70 | PSI = 70.36  | PSIDOT = -924.56 | PHITOT = 3597.91 |
|            | FF12 = 14.620 | FF23 = 15.229    | FF34 = 4.099 |                  |                  |
| T = .09065 | PHI = 142.98  | PHIDOT = 1043.09 | PSI = 70.29  | PSIDOT = -922.56 | PHITOT = 3597.98 |
|            | FF12 = 14.643 | FF23 = 15.272    | FF34 = 4.119 |                  |                  |
| T = .09065 | PHI = 143.06  | PHIDOT = 1051.46 | PSI = 70.23  | PSIDOT = -920.56 | PHITOT = 3598.06 |
|            | FF12 = 14.642 | FF23 = 15.272    | FF34 = 4.119 |                  |                  |
| T = .09065 | PHI = 143.13  | PHIDOT = 1059.81 | PSI = 70.16  | PSIDOT = -918.56 | PHITOT = 3598.13 |
|            | FF12 = 14.721 | FF23 = 15.344    | FF34 = 4.594 |                  |                  |
| T = .09065 | PHI = 143.21  | PHIDOT = 1068.15 | PSI = 70.09  | PSIDOT = -916.56 | PHITOT = 3598.21 |
|            | FF12 = 14.720 | FF23 = 15.344    | FF34 = 4.594 |                  |                  |
| T = .09065 | PHI = 143.29  | PHIDOT = 1076.38 | PSI = 70.03  | PSIDOT = -914.56 | PHITOT = 3598.29 |
|            | FF12 = 14.664 | FF23 = 15.348    | FF34 = 4.618 |                  |                  |
| T = .09065 | PHI = 143.36  | PHIDOT = 1084.68 | PSI = 69.96  | PSIDOT = -912.56 | PHITOT = 3598.36 |
|            | FF12 = 14.664 | FF23 = 15.348    | FF34 = 4.618 |                  |                  |
| T = .09066 | PHI = 143.44  | PHIDOT = 1093.06 | PSI = 69.90  | PSIDOT = -910.56 | PHITOT = 3598.44 |
|            | FF12 = 14.607 | FF23 = 15.351    | FF34 = 4.642 |                  |                  |
| T = .09066 | PHI = 143.52  | PHIDOT = 1101.51 | PSI = 69.83  | PSIDOT = -908.56 | PHITOT = 3598.52 |
|            | FF12 = 14.606 | FF23 = 15.351    | FF34 = 4.642 |                  |                  |
| T = .09066 | PHI = 143.60  | PHIDOT = 1110.05 | PSI = 69.77  | PSIDOT = -906.56 | PHITOT = 3598.60 |
|            | FF12 = 14.547 | FF23 = 15.355    | FF34 = 4.667 |                  |                  |
| T = .09066 | PHI = 143.68  | PHIDOT = 1118.66 | PSI = 69.70  | PSIDOT = -904.57 | PHITOT = 3598.68 |
|            | FF12 = 14.546 | FF23 = 15.354    | FF34 = 4.667 |                  |                  |
| T = .09066 | PHI = 143.76  | PHIDOT = 1127.30 | PSI = 69.64  | PSIDOT = -902.57 | PHITOT = 3598.76 |
|            | FF12 = 14.486 | FF23 = 15.357    | FF34 = 4.693 |                  |                  |
| T = .09066 | PHI = 143.84  | PHIDOT = 1136.13 | PSI = 69.57  | PSIDOT = -900.57 | PHITOT = 3598.84 |
|            | FF12 = 14.485 | FF23 = 15.357    | FF34 = 4.692 |                  |                  |
| T = .09066 | PHI = 143.92  | PHIDOT = 1144.99 | PSI = 69.51  | PSIDOT = -898.57 | PHITOT = 3598.92 |
|            | FF12 = 14.424 | FF23 = 15.360    | FF34 = 4.718 |                  |                  |
| T = .09066 | PHI = 144.00  | PHIDOT = 1153.92 | PSI = 69.45  | PSIDOT = -896.57 | PHITOT = 3599.00 |
|            | FF12 = 14.423 | FF23 = 15.360    | FF34 = 4.718 |                  |                  |
| T = .09067 | PHI = 144.09  | PHIDOT = 1162.96 | PSI = 69.38  | PSIDOT = -894.57 | PHITOT = 3599.09 |
|            | FF12 = 14.361 | FF23 = 15.363    | FF34 = 4.744 |                  |                  |
| T = .09067 | PHI = 144.17  | PHIDOT = 1172.06 | PSI = 69.32  | PSIDOT = -892.57 | PHITOT = 3599.17 |
|            | FF12 = 14.360 | FF23 = 15.362    | FF34 = 4.744 |                  |                  |
| T = .09067 | PHI = 144.26  | PHIDOT = 1181.26 | PSI = 69.25  | PSIDOT = -890.57 | PHITOT = 3599.26 |
|            | FF12 = 14.352 | FF23 = 15.394    | FF34 = 4.297 |                  |                  |
| T = .09067 | PHI = 144.34  | PHIDOT = 1190.47 | PSI = 69.19  | PSIDOT = -888.57 | PHITOT = 3599.34 |
|            | FF12 = 14.351 | FF23 = 15.394    | FF34 = 4.297 |                  |                  |
| T = .09067 | PHI = 144.43  | PHIDOT = 1199.64 | PSI = 69.13  | PSIDOT = -886.57 | PHITOT = 3599.43 |
|            | FF12 = 14.377 | FF23 = 15.444    | FF34 = 4.320 |                  |                  |
| T = .09067 | PHI = 144.51  | PHIDOT = 1208.80 | PSI = 69.06  | PSIDOT = -884.57 | PHITOT = 3599.51 |
|            | FF12 = 14.376 | FF23 = 15.443    | FF34 = 4.320 |                  |                  |
| T = .09067 | PHI = 144.60  | PHIDOT = 1217.93 | PSI = 69.00  | PSIDOT = -882.57 | PHITOT = 3599.60 |
|            | FF12 = 14.403 | FF23 = 15.495    | FF34 = 4.344 |                  |                  |
| T = .09067 | PHI = 144.69  | PHIDOT = 1227.04 | PSI = 68.94  | PSIDOT = -880.57 | PHITOT = 3599.69 |
|            | FF12 = 14.402 | FF23 = 15.494    | FF34 = 4.344 |                  |                  |
| T = .09068 | PHI = 144.77  | PHIDOT = 1236.13 | PSI = 68.87  | PSIDOT = -878.57 | PHITOT = 3599.77 |
|            | FF12 = 14.430 | FF23 = 15.546    | FF34 = 4.369 |                  |                  |
| T = .09068 | PHI = 144.86  | PHIDOT = 1245.19 | PSI = 68.81  | PSIDOT = -876.57 | PHITOT = 3599.86 |
|            | FF12 = 14.429 | FF23 = 15.546    | FF34 = 4.368 |                  |                  |
| T = .09068 | PHI = 144.95  | PHIDOT = 1254.23 | PSI = 68.75  | PSIDOT = -874.57 | PHITOT = 3599.95 |

Computer program SANDA3 (cont)

T = .09068    FF12 = 44.457    FF23 = 15.599    FF34 = 4.393    PSIDOT = -872.57    PHITOT = 3600.04  
              PHI = 145.04    PHIDOT = 1263.25    PSI = 68.69  
              FF12 = 44.456    FF23 = 15.599    FF34 = 4.393  
 F34MAX = 7.32  
 F23MAX = 20.98  
 F12 MAX = 54.41  
 FF34MAX = 5.84  
 FF23MAX = 18.58  
 FF12MAX = 49.97  
 PNMAX = 2.28  
 TURNS = 45.34

APPENDIX D  
COMPUTER PROGRAM SANDA2

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1  PROGRAM SANDA2(INPUT, OUTPUT, TAPES=INPUT, TAPE6=OUTPUT)
   COMMON A,B,C,R,ALPHA,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
   1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
   3P2,NP3,CAPR81,CAPR82,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
   3HO3,RHOP,J1,J2,GAMMA2,GAMMA3P,GAMMA3,GAMMA4P,GAMMA4,GAMAPP,DELTA2,DE
   4LTA3,DELTA4,BETA1,BETA2,BETA3,DI,D2,ALIN,AL1FIN,AL2FIN,ALPH
   5A1,ALPHA2,IN,I2,T3,MU,MUI,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
   623MAX,F12MAX,FF23MAX,FF12MAX,PNNAX,PHICUTD
   7  COM:ON //ZETA/ PSI, TIME,G,DPSI,GP
   8  DIMENSION AUX(8,2), AUX2(8,4), PRMT(5), PHI(2), DPHI(2), X(4), DX(
   9  14)
  10  REAL M1,M2,M3,MP,I1,I2,I3,IP,LAMBDA,K,N31,N32,J1,J2,NG1,NG2,NP2,NP
  11  3,MU,MUI
  12  EXTERNAL FCT,OUTP,FCTF,OUTPF
  13  MU,MUI
  14  READ IN AND WRITE DATA
  15  C
  16  C
  17  C
  18  READ (5,22) A,B,C,R,ALPHA,CONFIG
  19  WRITE (6,23) A,B,C,R,ALPHA,CONFIG
  20  READ (5,24) EREST,LAMBDA,DELTA
  21  WRITE (6,25) EREST,LAMBDA,DELTA
  22  READ (5,26) M1,M2,M3,MP
  23  WRITE (6,27) M1,M2,M3,MP
  24  READ (5,26) I1,I2,I3,IP
  25  WRITE (6,28) I1,I2,I3,IP
  26  READ (5,29) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MUI
  27  WRITE (6,30) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MUI
  28  READ (5,31) PSUBD1,PSUBD2,NG1,NG2,NP2,NP3,CAPR81,CAPR82,RP2,RP3,TH
  29  ETA1,THETA2
  30  WRITE (6,34) PSUBD1,PSUBD2,NG1,NG2,NP2,NP3,CAPR81,CAPR82,RP2,RP3,T
  31  HETA1,THETA2
  32  READ (5,32) R1,R2,R3,R4
  33  WRITE (6,35) R1,R2,R3,R4
  34  READ (5,24) RHO1,RHO2,RHO3
  35  WRITE (6,36) RHO1,RHO2,RHO3
  36  READ (5,32) CAPR81,CAPR82,RB2,RB3
  37  WRITE (6,37) CAPR81,CAPR82,RB2,RB3
  38  READ (5,32) CAPR81,CAPR82,RB2,RB3
  39  WRITE (6,38) CAPR81,CAPR82,RB2,RB3
  40  READ (5,33) J1,J2
  41  WRITE (6,39) J1,J2
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| 60 | OM2=OMEGA*OMEGA<br>PH11C=PH11CD*ZZ<br>PS1CC=PS1CCO*ZZ<br>PS1C=PS1CC<br>ALPHA=ALPHA*ZZ                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | C |
| 65 | DETERMINATION OF SIGNUM FUNCTION S6<br><br>IF (CONFIG.EQ.1.) S6=1.<br>IF (CONFIG.EQ.2.) S6=-1.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | C |
| 70 | COMPUTATION OF GEAR RATIOS<br><br>N31=NP2*NP3/(NG1*NG2)<br>N32=-NP3/NG2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | C |
| 75 | COMPUTATION OF GAMMAS AND BETAS<br><br>GAMMA2=S6*ACOS((R1*R1+R2*R2-(CAPRP1+RP2)**2)/(2.*R1*R2))<br>GAMMA3P=ACOS((R2*R2+R3*R3-(CAPRP2+RP3)**2)/(2.*R2*R3))<br>GAMMA3=GAMMA2+S6*GAMMA3P<br>GAMMA4P=ACOS((R3*R3+R4*R4-A*A)/(2.*R3*R4))<br>GAMMA4=GAMMA3+S6*GAMMA4P<br>GAMMA2D=GAMMA2/ZZ<br>GAMMA3D=GAMMA3/ZZ<br>GAMMA4D=GAMMA4/ZZ<br>DELTA2=ACOS(((CAPRP1+RP2)**2+R1*R1-R2*R2)/(2.*R1*(CAPRP1+RP2)))<br>DELTA3=ACOS(((CAPRP2+RP3)**2+R2*R2-R3*R3)/(2.*R2*(CAPRP2+RP3)))<br>DELTA4=ACOS(((A*A+R3*R3-R4*R4)/(2.*A*R3))<br>BETA1=PI-S6*DELTA2<br>BETA2=GAMMA2*PI-S6*DELTA3<br>BETA3=GAMMA3*PI-S6*DELTA4<br>IF (CONFIG.EQ.1.) GAMAPP=DELTA4+GAMMA4P<br>IF (CONFIG.EQ.2.) GAMAPP=2.*PI-DELTA4-GAMMA4P<br>BETA1D=BETA1/ZZ<br>BETA2D=BETA2/ZZ<br>BETA3D=BETA3/ZZ<br>WRITE (6,40) BETA1D,BETA2D,BETA3D,GAMMA2D,GAMMA3D,GAMMA4D | C |
| 80 | CONVERSION OF PRESSURE ANGLES TO RADIANs<br><br>THETA1=THETA1*ZZ<br>THETA2=THETA2*ZZ                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | C |
| 85 | COMPUTATION OF CENTRIFUGAL FORCES<br><br>T2=M2*R2*OM2<br>T3=M3*R3*OM2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | C |
| 90 | DETERMINATION OF GEAR TRAIN CONSTANTS<br><br>TEST1=TAN(THETA1)<br>TEST2=TAN(THETA2)<br>D1=(CAPRP1+RB2)*TAN(THETA1)<br>D2=(CAPRP2+RB3)*TAN(THETA2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | C |
| 95 | DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | C |

Computer program SANDA2 (cont)

PROGRAM SANDA2 74/74 OPT=1 FTN 4.8\*508 08/07/81 13.56.05 PAGE 3

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115 C CALL ALFA (CAPR1,RB2,THETA1,CAPR01,R02,AL1IN,AL1FIN) A 115
    C CALL ALFA (CAPR2,RB3,THETA2,CAPR02,R03,AL2IN,AL2FIN) A 116
    C INITIALIZATION OF ALPHAS A 117
    C ALPHA1=AL1IN*(AL1FIN-AL1IN)*J1 A 118
    C ALPHA2=AL2IN*(AL2FIN-AL2IN)*J2 A 119
    C DATA FOR RUNGE KUTTA A 120
    C PRNT(2)=3. A 121
    C PRNT(4)=.01 A 122
    C NDIW=2 A 123
    C NDIW2=4 A 124
    C PHI(1)=PHID*ZZ A 125
    C PHI(2)=0. A 126
    C COUPLED MOTION A 127
    C 1 PRNT(1)=TIME A 128
    C PRNT(3)=.00001 A 129
    C DPHI(1)=.5 A 130
    C DPHI(2)=.5 A 131
    C IF (PHITOT.GT.55..AND.PHITOT.LT.1785.) GO TO 2 A 132
    C WRITE (6,41) A 133
    C 2 CALL RKGS (PRMT,PHI,DPHI,NDIW,INLF,FCT,OUTP,AUX) A 134
    C IF (PHITOT.GE.PHICUTD) GO TO 21 A 135
    C TEST FOR ENTRANCE OR EXIT ACTION A 136
    C IF (G.LE.2.) GO TO 5 A 137
    C PHID=PHI(1)/ZZ A 138
    C IF (PHID.GE.135.00.AND.PHID.LE.160.) GO TO 3 A 139
    C GO TO 4 A 140
    C 3 PHI(1)=PHI(1)+DELTA*ZZ A 141
    C PHIPR=PHI(1)/ZZ A 142
    C PSI=PSI+2.*PI-LAMBDA*ZZ A 143
    C PSIC=PSICC+LAMBDA*ZZ A 144
    C GO TO 5 A 145
    C 4 PHI(1)=PHI(1)-DELTA*ZZ*2. A 146
    C PHIPR=PHI(1)/ZZ A 147
    C PSI=PSI-2.*PI+LAMBDA*ZZ A 148
    C PSIC=PSICC A 149
    C FREE MOTION A 150
    C 5 PRMT(1)=TIME A 151
    C X(1)=PHI(1) A 152
    C X(2)=PHI(2) A 153
    C X(3)=PSI A 154
    C X(4)=DPSI A 155
    C DX(1)=.25 A 156
    C DX(2)=.25 A 157
    C DX(3)=.25 A 158
    C DX(4)=.25 A 159
    C PRMT(3)=.00001 A 160
    C A 161
    C A 162
    C A 163
    C A 164
    C A 165
    C A 166
    C A 167
    C A 168
    C A 169
    C A 170
    C A 171

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175 IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 6
    WRITE (6,42)
    6 CALL RKGS (PRMT,X,DX,NDIM2,IMLF,FCIF,OUTPF,AUX2)
    IF (PHITOT.GE.PHICUTD) GO TO 21
    PHI(1)=X(1)
    PHI(2)=X(2)
    H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
    K=A+A*B+R-R-C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
180 PHI(1)-ALPHR)
    GONE=(-H+SQRT(H*H-4.*K))/2.
    GTWO=(-H-SQRT(H*H-4.*K))/2.
    IF (ABS(GONE).LT.ABS(GTWO)) GO TO 7
    G=GTWO
    GO TO 8
185 7 G=GONE
    8 PHID=PHI(1)/ZZ
    IF (GP.LT.0.) GO TO 11
    IF (PHID.GE.135.0..AND.PHID.LE.160.) GO TO 9
    GO TO 10
    9 PHI(1)=PHI(1)+DELTA*ZZ
    PHIPR=PHI(1)/ZZ
    PSI=PSI+2.*PI-LAMBDA*ZZ
    PSIG=PSICC+LAMBDA*ZZ
    GO TO 5
195 10 PHI(1)=PHI(1)-DELTA*ZZ*2.
    PHIPR=PHI(1)/ZZ
    PSI=PSI-2.*PI+LAMBDA*ZZ
    PSIG=PSICC
    GO TO 5
200 11 IF (PHID.LE.160.0) GO TO 13
    EXIT ACTION
    C
    C
    C
    C
205 COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION
    AONE=B*COS(ALPHR)+G
    DONE=C*COS(PHI(1)-ALPHR-PSI)
    VP=DONE*DPSI
    VS=AONE*PHI(2)
    IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 12
    WRITE (6,43) VP,VS
    C
    C
215 EXIT ACTION TESTS
    12 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 15
    IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
    IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15
    IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
    IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
    IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
    IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
    IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
    C
    C
225 COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
    13 AONE=B*COS(ALPHR)+G
    DONE=C*COS(PHI(1)-ALPHR-PSI)

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Computer program SANDA2 (cont)

| PROGRAM SANDA2 | 74/74 | OPT=1 | FTN 4.8+508                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 08/07/81 | 13.56.05 | PAGE | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------|-------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 230            |       |       | VP=DONE*DPSI<br>VS=AONE*PHI(2)<br>IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 14<br>WRITE (6,43) VP,VS                                                                                                                                                                                                                                                                                                                                                                                                      |          |          |      | A 229<br>A 230<br>A 231<br>A 232<br>A 233<br>A 234<br>A 235                                                                                                                                                                                                                                                                                                                                                                                                    |
| 235            | C     |       | ENTRANCE ACTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |          |      | A 236<br>A 237<br>A 238<br>A 239<br>A 240<br>A 241<br>A 242<br>A 243<br>A 244<br>A 245<br>A 246<br>A 247<br>A 248<br>A 249<br>A 250<br>A 251<br>A 252<br>A 253<br>A 254<br>A 255<br>A 256<br>A 257<br>A 258<br>A 259<br>A 260<br>A 261<br>A 262<br>A 263<br>A 264<br>A 265<br>A 266<br>A 267<br>A 268<br>A 269<br>A 270<br>A 271<br>A 272<br>A 273<br>A 274<br>A 275<br>A 276<br>A 277<br>A 278<br>A 279<br>A 280<br>A 281<br>A 282<br>A 283<br>A 284<br>A 285 |
| 240            | C     |       | 14 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5<br>IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1<br>IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15<br>IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5<br>IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 15<br>IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5<br>IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15<br>IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1 |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 245            | C     |       | IMPACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 250            | C     |       | 15 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)<br>H=2.*(B-COS(ALPHR))+A-COS(PHI(1)-ALPHR)<br>K=A**2+B**2+C**2-2.*B*R*SIN(ALPHR)+2.*A*B-COS(PHI(1))-2.*A*R*<br>1SIN(PHI(1)-ALPHR)<br>GONE=(-H+SQRT(H**2-4.*K))/2.<br>GWO=(-H-SQRT(H**2-4.*K))/2.<br>IF (ABS(GONE).LT.ABS(GWO)) GO TO 16<br>G=GTWO<br>GO TO 17                                                                                                                                                                                                        |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 255            | C     |       | 16 G=GONE<br>17 IF (TIME.GT.5.0) GO TO 21                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 260            | C     |       | TEST FOR EXIT ACTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 265            | C     |       | PHID=PHI(1)/ZZ<br>IF (PHID.LE.160.0) GO TO 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 270            | C     |       | EXIT ACTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 275            | C     |       | COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION<br>AONE=B-COS(ALPHR)+G<br>DONE=C-COS(PHI(1)-ALPHR-PSI)<br>VP=DONE*DPSI<br>VS=AONE*PHI(2)<br>IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 18<br>WRITE (6,43) VP,VS<br>18 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1                                                                                                                                                                                                                                         |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 280            | C     |       | EXIT ACTION TESTS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 285            | C     |       | IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1<br>IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5<br>IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1<br>IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1<br>IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5<br>IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1<br>IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1                                                   |          |          |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

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C      COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
C
19  AONE=B*COS(ALPHR)+G
    DONE=C*COS(PHI(1)-ALPHR-PSI)
    VP=DONE*D-SI
    VS=ACNE*PHI(2)
    IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 20
    WRITE (6,43) VP,VS
20  IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C      ENTRANCE ACTION TESTS
C
    IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
    IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
    IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
    IF (PHI(2).LC.0..AND.DPSI.GE.0.) GO TO 5
    IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 1
    IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
    IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
    IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
21  TURNS=TIME*RPW/60.
    WRITE (6,44) F23MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,TURNS
    STOP
C
C
22  FORMAT (6F10.5)
23  FORMAT (1H1,5X,2HA=,F13.5,5X,2HB=,F13.5,5X,2HC=,F13.5,5X,2HR=,F13.
    15,5X,6HALPHA=,F9.4,5X,14HCONFIGURATION=,F3.0/)
24  FORMAT (3F10.5)
25  FORMAT (1H 5X,6HEREST=,F5.2,3X,7HLAMBDA=,F8.3,3X,6HOELTA=,F8.3/)
26  FORMAT (4E12.5)
27  FORMAT (1H 5X,4HM1 =,E15.5,3X,4HM2 =,E15.5,3X,4HM3 =,E15.5,3X,4HM
    1P =,E15.5/)
28  FORMAT (1H 5X,4HI1 =,E15.5,3X,4HI2 =,E15.5,3X,4HI3 =,E15.5,3X,4HI
    1P =,E15.5/)
29  FORMAT (7F10.4/3F10.4)
30  FORMAT (6X,SHRC1 =,F7.4,3X,5HRCP =,F7.4,3X,6HRHOP =,F7.4,3X,5HRPM
    1=,F6.0,3X,6HSHICD =,F9.4,3X,8HPSICD =,F9.4,3X,6HPHID =,F9.4//6X,
    29HPHICUD =,F6.0//6X,4HMU =,F4.2,3X,5HMU1 =,F4.2/)
31  FORMAT (2F10.4/4F10.0/4F10.5/2F10.4)
32  FORMAT (4F10.4)
33  FORMAT (2F10.2)
34  FORMAT (1H 5X,8HPSUBD1 =,F5.1,3X,8HPSURD2 =,F5.1//6X,5HNG1 =,F4.0
    1,3X,5HN2 =,F4.0,3X,5HN3 =,F4.0,3X,5HNP3 =,F4.0//6X,8HCAPR1 =,F8
    2,5,3X,8HCAPR2 =,F8.5//6X,5HRP2 =,F8.5,3X,5HRP3 =,F8.5//6X,8HHTETA
    31 =,F8.3,3X,8HHTETA2 =,F8.3/)
35  FORMAT (6X,4HR1 =,F7.5,3X,4HR2 =,F7.5,3X,4HR3 =,F7.5,3X,4HR4 =,F7.
    15/)
36  FORMAT (6X,6HRH01 =,F7.5,3X,6HRH02 =,F7.5,3X,6HRH03 =,F7.5/)
37  FORMAT (6X,8HCAPR01 =,F7.5,3X,8HCAPR02 =,F7.5,3X,5HRB2 =,F7.5,3X,5
    1HRB3 =,F7.5/)
38  FORMAT (6X,8HCAPR01 =,F7.5,3X,8HCAPR02 =,F7.5,3X,5HR02 =,F7.5,3X,5
    1HR03 =,F7.5/)
39  FORMAT (1H0,5X,4HU1 =,F4.2,3X,4HU2 =,F4.2/)
40  FORMAT (6X,8HBETA1D =,F7.2,3X,8HBETA2D =,F7.2,3X,8HBETA3D =,F7.2/6
    1X,9HGAMMA2D =,F7.2,3X,9HGAMMA3D =,F7.2,3X,9HGAMMA4D =,F7.2/)

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Computer program SANDA2 (cont)

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FTN 4.8+508

PROGRAM SANDA2 74/74 OPT=1

41 FORMAT (1H0,5X,14HCOUPLED MOTION)  
 42 FORMAT (1H0,5X,11HFREE MOTION//)  
 43 FORMAT (4H0VP=,F8.3,3X,3HVS=,F8.3)  
 44 FORMAT (1H0,6X,8HF23MAX =,F6.2/1H0,6X,8HF12MAX =,F6.2/1H0,6X,9HFF2  
 13MAX =,F6.2/1H0,6X,9HFF12MAX =,F6.2/1H0,6X,7HPNMAX =,F6.2/1H0,6X,6  
 2HTURNS=,F6.2)  
 END

A 343  
 A 344  
 A 345  
 A 346  
 A 347  
 A 348  
 A 349-

345

Computer program SANDA2 (cont)

SUBROUTINE IMPACT 74/74 OPT=1 FTH 4.B+508 08/07/81 13.58.05 PAGE 1

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1  SUBROUTINE IMPACT (PHI,DPHI,PSI,DPSI)
   COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
1LTA,PHITOT,PHICR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
5  2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THEIA,THEIA2,R1,R2,R3,R4,RH01,RH02,R
   3H03,RHOP,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,DELTA2,DE
4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL2IN,AL2FIN,ALPH
5A1,ALPHA2,IN,I2,I3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
623MAX,F12MAX,FF20MAX,FF12MAX,FNMAX,PHICUTD
   REAL I1,I2,I3,IP,LAMBDA,N31,N32,ISTOT,K
10  ISTOT=I3+I2+N32+I1+N31+N31
   H=2.*(B+COS(ALPHR)+A+COS(PHI-ALPHR))
   K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI)-2.*A*R*SIN
   1(PHI-ALPHR)
   GONE=(-H+SQRT(H**2-4.*K))/2.
15  GTWO=(-H-SQRT(H**2-4.*K))/2.
   IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1
   G=GTWO
   GO TO 2
   1 G=GONE
20  AONE=B+COS(ALPHR)+G
   DONE=C+COS(PHI-ALPHR-PSI)
   DPHIIN=DPHI
   DPHI=(IP*AONE*DPSI+ISTOT*DONE*DPHI+IP*AONE*EREST/DONE*(DPSI*DONE-D
25  1PHI*AONE))/(IP*AONE**2/DONE+ISTOT*DONE)
   DPSI=(DPHI*AONE-EREST*(DPSI*DONE-DPHIIN*AONE))/DONE
   PHID=PHI/ZZ
   PSID=PSI/ZZ
   IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 3
30  WRITE (6,4)
   WRITE (6,5) PHID,DPHI,PSID,DPSI,PHITOT
   3 RETURN
C
C
C
35  4 FORMAT (1H0,5X,6HIMPACT)
   5 FORMAT (1H0,18X,4HDPHI=,F8.3,3X,7HDPHIDOT=,F8.3,3X,4HPHI=,F8.3,3X,7H
   1PSIDOT=,F8.3,3X,8HPHITOT =,F8.3)
   END

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Computer program SANDA2 (cont)

| SUBROUTINE FCT | 74/74                                                               | OPT=1 | FIN 4.8+508 | 08/07/81 | 19.56.05 | PAGE | 1  |
|----------------|---------------------------------------------------------------------|-------|-------------|----------|----------|------|----|
| 1              | SUBROUTINE FCT (T, PHI, DPHI)                                       |       |             |          |          |      | 1  |
|                | COMMON A,B,C,R,ALPHA,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE  |       |             |          |          |      | 2  |
|                | 1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N |       |             |          |          |      | 3  |
| 5              | 2P2,MP3,CAPR81,CAPR82,RB2,RB3,THEIA1,THEIA2,R1,R2,R3,R4,RHO1,RHO2,R |       |             |          |          |      | 4  |
|                | 3HO3,RHOP,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,   |       |             |          |          |      | 5  |
|                | 4LTA3,DELTA4,BETA1,BETA2,BETA3,O1,D2,AL1IN,AL2IN,AL3IN,ALPH         |       |             |          |          |      | 6  |
|                | 5A1,ALPHA2,IN,T2,I3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F |       |             |          |          |      | 7  |
|                | 623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX                                 |       |             |          |          |      | 8  |
|                | DIMENSION PHI(2),DPHI(2)                                            |       |             |          |          |      | 9  |
| 10             | REAL M1,M2,M3,MP,I1,I2,I3,IP,K,I1R,N31,N32,MU,MU1,IPR               |       |             |          |          |      | 10 |
|                | PHID=PHI(1)/ZZ                                                      |       |             |          |          |      | 11 |
|                | DELPHI=PHID-PHIPR                                                   |       |             |          |          |      | 12 |
|                | PHIT=(PHITOT+DELPHI)*ZZ                                             |       |             |          |          |      | 13 |
|                | IN=1                                                                |       |             |          |          |      | 14 |
| 15             | CALL KINEM (A,B,ALPHA,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,ACONE,BONE,CONE |       |             |          |          |      | 15 |
|                | 1,DONE,U,V,Z)                                                       |       |             |          |          |      | 16 |
|                | CALL IN2 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,ACONE,BONE,CONE,DONE,AA1,AA |       |             |          |          |      | 17 |
|                | 12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A |       |             |          |          |      | 18 |
|                | 2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA |       |             |          |          |      | 19 |
| 20             | 330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4 |       |             |          |          |      | 20 |
|                | 43,AA44)                                                            |       |             |          |          |      | 21 |
|                | IF (DPSI-DPSI2.GE.O.) IPR=IP+AA22                                   |       |             |          |          |      | 22 |
|                | IF (DPSI-DPSI2.LT.O.) IPR=IP-AA22                                   |       |             |          |          |      | 23 |
|                | IF (PHI(2)*DPHI2.GE.O.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)             |       |             |          |          |      | 24 |
| 25             | IF (PHI(2)*DPHI2.LT.O.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)             |       |             |          |          |      | 25 |
|                | IF (I1R.LT.O.) I1R=0.                                               |       |             |          |          |      | 26 |
|                | IF (IPR.LT.O.) IPR=0.                                               |       |             |          |          |      | 27 |
|                | AA45=I3*AA18+IPR*AA17*U-(I2*N32-AA42*I1R*N31/AA31)*AA15*AA18/AA44   |       |             |          |          |      | 28 |
|                | AA46=IPR*AA17*V+AA17*AA21*Z+AA15*AA18*AA34*AA42*N31/(AA31*AA        |       |             |          |          |      | 29 |
| 30             | 144)                                                                |       |             |          |          |      | 30 |
|                | AA47=2.*OM2*AA17*AA20*Z/ABS(OMEGA)+AA15*AA18*AA33*AA42*N31/(AA31*A  |       |             |          |          |      | 31 |
|                | 1A44)                                                               |       |             |          |          |      | 32 |
|                | AA48=-AA15*AA18*AA32*AA42/(AA31*AA44)-AA15*AA18*AA43*T2/AA44-AA16*  |       |             |          |          |      | 33 |
|                | 1AA18*T3-OM2*AA17*AA19                                              |       |             |          |          |      | 34 |
| 35             | AA49=AA15*AA18*AA35*AA42/(AA31*AA44)                                |       |             |          |          |      | 35 |
|                | AA50=MP*RCR*AA17*OM2                                                |       |             |          |          |      | 36 |
|                | DPHI(1)=PHI(2)                                                      |       |             |          |          |      | 37 |
|                | DPHI(2)=(-AA46*PHI(2)*PHI(2)-AA47*PHI(2)+AA48-AA49*SIN(PHI1C+N31*(  |       |             |          |          |      | 38 |
|                | 1PHITOT+ZZ+PHI(1)-PHIPR*ZZ))+AA50*SIN(GAMMA*PSI-PSIC))/AA45         |       |             |          |          |      | 39 |
| 40             | RETURN                                                              |       |             |          |          |      | 40 |
|                | END                                                                 |       |             |          |          |      | 41 |

```

1 SUBROUTINE OUTP ( I, PHI, DPHI, IHLF, NDIN, PRMT )
2 REAL M1,M2,M3,M4,M5,M6,M7,M8,M9,M10,M11,M12,M13,M14,M15,M16,M17,M18,M19,M20,M21,M22,M23,M24,M25,M26,M27,M28,M29,M30,M31,M32,M33,M34,M35,M36,M37,M38,M39,M40,M41,M42,M43,M44,M45,M46,M47,M48,M49,M50,M51,M52,M53,M54,M55,M56,M57,M58,M59,M60,M61,M62,M63,M64,M65,M66,M67,M68,M69,M70,M71,M72,M73,M74,M75,M76,M77,M78,M79,M80,M81,M82,M83,M84,M85,M86,M87,M88,M89,M90,M91,M92,M93,M94,M95,M96,M97,M98,M99,M100,M101,M102,M103,M104,M105,M106,M107,M108,M109,M110,M111,M112,M113,M114,M115,M116,M117,M118,M119,M120,M121,M122,M123,M124,M125,M126,M127,M128,M129,M130,M131,M132,M133,M134,M135,M136,M137,M138,M139,M140,M141,M142,M143,M144,M145,M146,M147,M148,M149,M150,M151,M152,M153,M154,M155,M156,M157,M158,M159,M160,M161,M162,M163,M164,M165,M166,M167,M168,M169,M170,M171,M172,M173,M174,M175,M176,M177,M178,M179,M180,M181,M182,M183,M184,M185,M186,M187,M188,M189,M190,M191,M192,M193,M194,M195,M196,M197,M198,M199,M200,M201,M202,M203,M204,M205,M206,M207,M208,M209,M210,M211,M212,M213,M214,M215,M216,M217,M218,M219,M220,M221,M222,M223,M224,M225,M226,M227,M228,M229,M230,M231,M232,M233,M234,M235,M236,M237,M238,M239,M240,M241,M242,M243,M244,M245,M246,M247,M248,M249,M250,M251,M252,M253,M254,M255,M256,M257,M258,M259,M260,M261,M262,M263,M264,M265,M266,M267,M268,M269,M270,M271,M272,M273,M274,M275,M276,M277,M278,M279,M280,M281,M282,M283,M284,M285,M286,M287,M288,M289,M290,M291,M292,M293,M294,M295,M296,M297,M298,M299,M300,M301,M302,M303,M304,M305,M306,M307,M308,M309,M310,M311,M312,M313,M314,M315,M316,M317,M318,M319,M320,M321,M322,M323,M324,M325,M326,M327,M328,M329,M330,M331,M332,M333,M334,M335,M336,M337,M338,M339,M340,M341,M342,M343,M344,M345,M346,M347,M348,M349,M350,M351,M352,M353,M354,M355,M356,M357,M358,M359,M360,M361,M362,M363,M364,M365,M366,M367,M368,M369,M370,M371,M372,M373,M374,M375,M376,M377,M378,M379,M380,M381,M382,M383,M384,M385,M386,M387,M388,M389,M390,M391,M392,M393,M394,M395,M396,M397,M398,M399,M400,M401,M402,M403,M404,M405,M406,M407,M408,M409,M410,M411,M412,M413,M414,M415,M416,M417,M418,M419,M420,M421,M422,M423,M424,M425,M426,M427,M428,M429,M430,M431,M432,M433,M434,M435,M436,M437,M438,M439,M440,M441,M442,M443,M444,M445,M446,M447,M448,M449,M450,M451,M452,M453,M454,M455,M456,M457,M458,M459,M460,M461,M462,M463,M464,M465,M466,M467,M468,M469,M470,M471,M472,M473,M474,M475,M476,M477,M478,M479,M480,M481,M482,M483,M484,M485,M486,M487,M488,M489,M490,M491,M492,M493,M494,M495,M496,M497,M498,M499,M500,M501,M502,M503,M504,M505,M506,M507,M508,M509,M510,M511,M512,M513,M514,M515,M516,M517,M518,M519,M520,M521,M522,M523,M524,M525,M526,M527,M528,M529,M530,M531,M532,M533,M534,M535,M536,M537,M538,M539,M540,M541,M542,M543,M544,M545,M546,M547,M548,M549,M550,M551,M552,M553,M554,M555,M556,M557,M558,M559,M560,M561,M562,M563,M564,M565,M566,M567,M568,M569,M570,M571,M572,M573,M574,M575,M576,M577,M578,M579,M580,M581,M582,M583,M584,M585,M586,M587,M588,M589,M590,M591,M592,M593,M594,M595,M596,M597,M598,M599,M600,M601,M602,M603,M604,M605,M606,M607,M608,M609,M610,M611,M612,M613,M614,M615,M616,M617,M618,M619,M620,M621,M622,M623,M624,M625,M626,M627,M628,M629,M630,M631,M632,M633,M634,M635,M636,M637,M638,M639,M640,M641,M642,M643,M644,M645,M646,M647,M648,M649,M650,M651,M652,M653,M654,M655,M656,M657,M658,M659,M660,M661,M662,M663,M664,M665,M666,M667,M668,M669,M670,M671,M672,M673,M674,M675,M676,M677,M678,M679,M680,M681,M682,M683,M684,M685,M686,M687,M688,M689,M690,M691,M692,M693,M694,M695,M696,M697,M698,M699,M700,M701,M702,M703,M704,M705,M706,M707,M708,M709,M710,M711,M712,M713,M714,M715,M716,M717,M718,M719,M720,M721,M722,M723,M724,M725,M726,M727,M728,M729,M730,M731,M732,M733,M734,M735,M736,M737,M738,M739,M740,M741,M742,M743,M744,M745,M746,M747,M748,M749,M750,M751,M752,M753,M754,M755,M756,M757,M758,M759,M760,M761,M762,M763,M764,M765,M766,M767,M768,M769,M770,M771,M772,M773,M774,M775,M776,M777,M778,M779,M780,M781,M782,M783,M784,M785,M786,M787,M788,M789,M790,M791,M792,M793,M794,M795,M796,M797,M798,M799,M800,M801,M802,M803,M804,M805,M806,M807,M808,M809,M810,M811,M812,M813,M814,M815,M816,M817,M818,M819,M820,M821,M822,M823,M824,M825,M826,M827,M828,M829,M830,M831,M832,M833,M834,M835,M836,M837,M838,M839,M840,M841,M842,M843,M844,M845,M846,M847,M848,M849,M850,M851,M852,M853,M854,M855,M856,M857,M858,M859,M860,M861,M862,M863,M864,M865,M866,M867,M868,M869,M870,M871,M872,M873,M874,M875,M876,M877,M878,M879,M880,M881,M882,M883,M884,M885,M886,M887,M888,M889,M890,M891,M892,M893,M894,M895,M896,M897,M898,M899,M900,M901,M902,M903,M904,M905,M906,M907,M908,M909,M910,M911,M912,M913,M914,M915,M916,M917,M918,M919,M920,M921,M922,M923,M924,M925,M926,M927,M928,M929,M930,M931,M932,M933,M934,M935,M936,M937,M938,M939,M940,M941,M942,M943,M944,M945,M946,M947,M948,M949,M950,M951,M952,M953,M954,M955,M956,M957,M958,M959,M960,M961,M962,M963,M964,M965,M966,M967,M968,M969,M970,M971,M972,M973,M974,M975,M976,M977,M978,M979,M980,M981,M982,M983,M984,M985,M986,M987,M988,M989,M990,M991,M992,M993,M994,M995,M996,M997,M998,M999,M1000,M1001,M1002,M1003,M1004,M1005,M1006,M1007,M1008,M1009,M1010,M1011,M1012,M1013,M1014,M1015,M1016,M1017,M1018,M1019,M1020,M1021,M1022,M1023,M1024,M1025,M1026,M1027,M1028,M1029
```

Computer program SANDA2 (cont)

| SUBROUTINE | OUTP | 74/74 | OPT=1 | FTN 4.8+508 | 08/07/81 | 13.56.05 | PAGE | 2     |
|------------|------|-------|-------|-------------|----------|----------|------|-------|
| 60         | C    |       |       |             |          |          |      | D 58  |
|            | C    |       |       |             |          |          |      | D 59  |
|            | C    |       |       |             |          |          |      | D 60  |
|            | C    |       |       |             |          |          |      | D 61  |
|            |      |       |       |             |          |          |      | D 62  |
|            |      |       |       |             |          |          |      | D 63  |
| 65         |      |       |       |             |          |          |      | D 64  |
|            |      |       |       |             |          |          |      | D 65  |
|            |      |       |       |             |          |          |      | D 66  |
|            |      |       |       |             |          |          |      | D 67  |
|            |      |       |       |             |          |          |      | D 68  |
|            |      |       |       |             |          |          |      | D 69  |
| 70         | C    |       |       |             |          |          |      | D 70  |
|            | C    |       |       |             |          |          |      | D 71  |
|            |      |       |       |             |          |          |      | D 72  |
|            |      |       |       |             |          |          |      | D 73  |
|            |      |       |       |             |          |          |      | D 74  |
| 75         |      |       |       |             |          |          |      | D 75  |
|            |      |       |       |             |          |          |      | D 76- |

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IF (.NOT.(G.LT.O..AND.PNPSI.GT.O.)) PRMT(5)=1.
WRITE OUTPUT
IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 1
PSID=PSI/ZZ
WRITE (6,2) T,PHID,PHI(2),G,GOOT,PSID,DPSI,PHITOT,F23,F12,PN,PNSI
1,DPHI2
1 TIME=T
IF(PHITOT.GE.PHICUTD)PRMT(5)=1.
RETURN
2 FORMAT (6X,3HT =,F8.5,3X,8HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,3HG =,
1FG.4,3X,6HGDOT =,F6.2,3X,6HPSID =,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHI
2TOT =,F7.2/20X,5HF23 =,F7.4,3X,5HF12 =,F7.4,3X,4HPN =,F7.4,3X,7HPN
3PSI =,F7.4,3X,7HDPHI2 =,E12.4)
END

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1      SUBROUTINE FCTF (I,X,DX)
2      COMMON A,B,C,R,ALPHA,P1,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
3      1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OK2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
4      2P2,NP3,CAPR1,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
5      3MO3,PHOP,U1,U2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,DELTA2,DE
6      4LTA,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
7      5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
8      623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
9      DIMENSION X(4),DX(4),PRMT(5)
10     REAL M1,M2,M3,MP,I1,I2,I3,IP,I1R,N31,N32,MU,MU1,IPR
11     PHID=X(1)/ZZ
12     DELPHI=PHID-PHIPR
13     PHIT=(PHITOT+DELPHI)*ZZ
14     IN=1
15     CALL IN2 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
16     1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
17     219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
18     32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44)
19     IF (X(4)*DPSI2.GE.0.) IPR=IP+AA22
20     IF (X(4)*DPSI2.LT.0.) IPR=IP-AA22
21     IF (X(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
22     IF (X(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
23     IF (I1R.LT.0.) I1R=0.
24     IF (IPR.LT.0.) IPR=0.
25     IF (IPR.EQ.0.) WRITE (6,1)
26     AA51=IPR
27     AA52=2.*OM2*AA20/ABS(OMEGA)
28     AA53=OM2*AA19
29     AA54=OM2*MP*RCP*R4
30     AA55=I3-AA15*N32*I2/AA44+AA15*AA42+I1R*N31/(AA31*AA44)
31     AA56=AA15*AA34*AA42*N31*N31/(AA31*AA44)
32     AA57=AA15*AA33*AA42*N31/(AA31*AA44)
33     AA58=-AA16*T3-AA15*AA43*T2/AA44-AA15*AA32*AA42/(AA31*AA44)
34     AA59=AA15*AA35*AA42/(AA31*AA44)
35     DX(1)=X(2)
36     DX(3)=X(4)
37     DX(2)=(-AA56*X(2)+X(2)-AA57*X(2)+AA58-AA59*SIN(PHITC+N31*(PHITOT-Z
38     1Z+X(1)-PHIPR*ZZ)))/AA55
39     DX(4)=(-AA21*X(4)+X(4)-AA52*X(4)-AA53*AA54*SIN(GAMAPP-X(3)-PSIC))/
40     1AA51
41     RETURN
42
43
44
45
1      FORMAT ('40HO1PR EQUALS ZERO - SIMULATION TERMINATED')
2      END

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| SUBROUTINE | OUTPF | 74/74 | OPT=1 | FTN 4.8+508                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 08/07/81                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 13.56.05 | PAGE | 1 |
|------------|-------|-------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|------|---|
| 1          |       |       |       | SUBROUTINE OUTPF (T,X,DX,IHLF,INDIM,PRMT)<br>COMMON A,B,C,R,ALPHR,P1,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LANEDA,DE<br>1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N<br>2P2,NF3,CAPR81,CAPR82,R32,R83,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R<br>3RC3,RHOP,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,<br>4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH<br>5A1,ALPHA2,IN,T2,I3,MU,MU1,RCF,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F<br>623MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD<br>REAL M1,M2,M3,MP,I1,I2,I3,IP,I1R,N31,N32,MU,MU1,IPR<br>DIMENSION X(4),DX(4),PRMT(5)<br>COMMON /ZETA/ PSI,TIME,Q,DPSI,GP<br>PHID=X(1)/ZZ<br>PSID=X(3)/ZZ<br>DELPHI=PHID-PHIPR<br>PHITOT=PHITOT+DELPHI<br>PHIPR=PHID<br>IN=0<br>CALL IN2 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,0.,0.,AA1,AA2,AA3,AA4,A<br>1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA<br>219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3<br>32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44)<br>IF (X(4)-DPSI2-GE.0.) IPR=IP+AA22<br>IF (X(4)-DPSI2-LT.0.) IPR=IP-AA22<br>IF (X(2)-DPHI2-GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)<br>IF (X(2)-DPHI2-LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)<br>IF (I1R-LT.0.) I1R=0.<br>IF (IPR-LT.0.) IPR=0.<br>AA51=IPR<br>AA52=2.*OM2*AA20/ABS(OMEGA)<br>AA53=OM2*AA19<br>AA54=OM2*MP*RCF*R4<br>AA55=13-AA15*N32*I2/AA44+AA15*AA42*I1R*N31/(AA31*AA44)<br>AA56=AA15*AA34*AA42*N31*N31/(AA31*AA44)<br>AA57=AA15*AA33*AA42*N31/(AA31*AA44)<br>AA58=-AA16*T3-AA15*AA43*T2/AA44-AA15*AA32*AA42/(AA31*AA44)<br>AA59=AA15*AA35*AA42/(AA31*AA44)<br>PSI=X(3)<br>DPSI=X(4)<br>DPSI2=(-AA21*X(4)+X(4)-AA52*X(4)-AA53+AA54*SIN(GAMAPP-X(3)-PSIC))/<br>1AA51<br>DPHI2=(-AA56*X(2)+X(2)-AA57*X(2)+AA58-AA59*SIN(PHI1C+N31*(PHITOT+Z<br>12*X(1)-PHIPR+ZZ)))/AA55 | F 1<br>F 2<br>F 3<br>F 4<br>F 5<br>F 6<br>F 7<br>F 8<br>F 9<br>F 10<br>F 11<br>F 12<br>F 13<br>F 14<br>F 15<br>F 16<br>F 17<br>F 18<br>F 19<br>F 20<br>F 21<br>F 22<br>F 23<br>F 24<br>F 25<br>F 26<br>F 27<br>F 28<br>F 29<br>F 30<br>F 31<br>F 32<br>F 33<br>F 34<br>F 35<br>F 36<br>F 37<br>F 38<br>F 39<br>F 40<br>F 41<br>F 42<br>F 43<br>F 44<br>F 45<br>F 46<br>F 47<br>F 48<br>F 49<br>F 50<br>F 51<br>F 52<br>F 53<br>F 54<br>F 55<br>F 56<br>F 57 |          |      |   |
| 5          |       |       |       | COMPUTATION OF CONTACT FORCES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                             |          |      |   |
| 10         |       |       |       | FF23=(13-DPHI2+T3-AA16)/AA15<br>FF12=(FF23-AA44+T2-AA43-I2*N32-DPHI2)/AA42<br>IF (FF23-GT.FF23MAX) FF23MAX=FF23<br>IF (FF12-GT.FF12MAX) FF12MAX=FF12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                             |          |      |   |
| 15         |       |       |       | WRITE OUTPUT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                             |          |      |   |
| 50         |       |       |       | IF (PHITOT-GT.55. AND PHITOT-LT.1765.) GO TO 1<br>WRITE (6,4) T,PHID,X(2),PSID,X(4),PHITOT,FF12,FF23<br>1 IF (T.EQ.TIME) GO TO 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                             |          |      |   |
| 55         |       |       |       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                             |          |      |   |

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SUBROUTINE OUTPF

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C
C CHECK FOR CONTINUED FREE MOTION
F=A*SIN(X(1)-ALPHR)-B*SIN(ALPHR)-C*SIN(X(1)-ALPHR-PSI)-R
GP=C*COS(X(1)-ALPHR-PSI)-B*COS(ALPHR)-A*COS(X(1)-ALPHR)
IF (F.GT.0.) GO TO 2
PRMT(5)=1.
GO TO 3
2 IF (GP.GT.0.) PRMT(5)=1.
3 TIME=T
IF(PHITOT.GE.PHICUTD)PRMT(5)=1.
RETURN
C
C
4 FORMAT (6X,3HT =,F8.5,3X,5HPH1 =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI
1=,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F7.2/20X,6HFF12 =,F7.3,3X,
26HFF23 =,F7.3)
END

```

F 58  
F 59  
F 60  
F 61  
F 62  
F 63  
F 64  
F 65  
F 66  
F 67  
F 68  
F 69  
F 70  
F 71  
F 72  
F 73  
F 74-

Computer program SAJDA2 (cont)

| SUBROUTINE KINEM | 74/74 | OPT=1 | FTN 4.8+508 | 08/07/81 | 13.58.05 | PAGE | 1   |
|------------------|-------|-------|-------------|----------|----------|------|-----|
| 1                |       |       |             |          |          |      | 1   |
|                  |       |       |             |          |          |      | 2   |
|                  |       |       |             |          |          |      | 3   |
|                  |       |       |             |          |          |      | 4   |
|                  |       |       |             |          |          |      | 5   |
| 5                |       |       |             |          |          |      | 6   |
|                  |       |       |             |          |          |      | 7   |
|                  |       |       |             |          |          |      | 8   |
|                  |       |       |             |          |          |      | 9   |
|                  |       |       |             |          |          |      | 10  |
| 10               |       |       |             |          |          |      | 11  |
|                  |       |       |             |          |          |      | 12  |
|                  |       |       |             |          |          |      | 13  |
|                  |       |       |             |          |          |      | 14  |
|                  |       |       |             |          |          |      | 15  |
| 15               |       |       |             |          |          |      | 16  |
|                  |       |       |             |          |          |      | 17  |
|                  |       |       |             |          |          |      | 18  |
|                  |       |       |             |          |          |      | 19  |
| 20               |       |       |             |          |          |      | 20  |
|                  |       |       |             |          |          |      | 21  |
|                  |       |       |             |          |          |      | 22  |
|                  |       |       |             |          |          |      | 23  |
|                  |       |       |             |          |          |      | 24  |
| 25               |       |       |             |          |          |      | 25  |
|                  |       |       |             |          |          |      | 26  |
|                  |       |       |             |          |          |      | 27  |
|                  |       |       |             |          |          |      | 28  |
|                  |       |       |             |          |          |      | 29  |
| 30               |       |       |             |          |          |      | 30  |
|                  |       |       |             |          |          |      | 31  |
|                  |       |       |             |          |          |      | 32  |
|                  |       |       |             |          |          |      | 33  |
| 35               |       |       |             |          |          |      | 34  |
|                  |       |       |             |          |          |      | 35- |

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SUBROUTINE KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BON
1E,CONE,DONE,U,V,Z)
DIMENSION PHI(2)
REAL K
PI=3.14159
H=2.*(B+COS(ALPHR)+A+COS(PHI(1)-ALPHR))
K=A*A+8*B+R-C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
PHI(1)-ALPHR)
GONE=(-H+SQRT(H*H-4.*K))/2.
GTWO=(-H-SQRT(H*H-4.*K))/2.
IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1
G=GTWO
GO TO 2
1 G=GONE
2 P=B*SIN(PHI(1))+G*SIN(PHI(1)-ALPHR)+R*COS(PHI(1)-ALPHR)
Q=B*COS(PHI(1))+G*COS(PHI(1)-ALPHR)-R*SIN(PHI(1)-ALPHR)
S=G+B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)
GDOT=PHI(2)*A*P/S
PSI=ASIN(P/C)
IF (PSI.LT.0.) GO TO 3
GO TO 4
3 PSI=2.*PI-ABS(PSI)
4 DPSI=(Q*PHI(2)+GDOT*SIN(PHI(1)-ALPHR))/(C+COS(PSI))
AONE=B+COS(ALPHR)+G
BONE=B*SIN(ALPHR)
CONE=- (R+C*SIN(PHI(1)-ALPHR-PSI))
DONE=C*COS(PHI(1)-ALPHR-PSI)
Z=(Q*A*P/S+SIN(PHI(1)-ALPHR))/(C+COS(PSI))
U=(Q+SIN(PHI(1)-ALPHR)*P*A/S)/(C+COS(PSI))
V=(Q+A*P*SIN(PHI(1)-ALPHR)/S)+2*TAN(PSI)/(C+2*(COS(PSI))+2)
1/(C+COS(PSI))*2.*A*P*COS(PHI(1)-ALPHR)/S-P*2.*A*2*P*(SIN(PHI(1)
2-ALPHR))+2/S*2*A*Q*SIN(PHI(1)-ALPHR)/S-A*2*P*2*SIN(PHI(1)-ALPH
3R)/S**3)
RETURN
END

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SUBROUTINE IN2

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1  SUBROUTINE IN2 (ZZZ,PHI1,DELPHI,GOOT,PSI,DPSI,AO,EBONE,CONE,CONE,
2  1AA1,AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,
3  2AA16,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA
4  JA29,AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA
5  442,AA43,AA44)
6  COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,11,12,13,1P,EREST,LAMBDA,DE
7  1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
8  2P3,NF3,CAPR81,CAPR82,RB3,RB3,THETA1,THETA2,RI,R2,R3,R4,RHO1,RHO2,R
9  3H03,RHOP,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8,DE
10  4LTA3,DELTA4,BETA1,BETA2,BETA3,O1,O2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
11  5A1,ALPHA2,IN,T2,I3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
12  623MAX,F12MAX,FF2JMAX,FF12MAX,PNMAX,PHICUTD
13  DIMENSION ZZZ(4)
14  REAL M1,M2,M3,MP,MU,MU1,N31,N32,11
15  PHI=ZZZ(1)
16  DPHI=ZZZ(2)
17  IF (DPHI.EQ.0.) GO TO 1
18  MU=ABS(MU)*DPHI/ABS(DPHI)
19  1 IF (IN.EQ.0) GO TO 2
20  C
21  C
22  C
23  C
24  C
25  C
26  C
27  C
28  C
29  C
30  C
31  C
32  C
33  C
34  C
35  C
36  C
37  C
38  C
39  C
40  C
41  C
42  C
43  C
44  C
45  C
46  C
47  C
48  C
49  C
50  C
51  C
52  C
53  C
54  C
55  C
56  C
57  C

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SUBROUTINE IN2

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      60      AA2=ABS((MP*(R4*(SIN(GAMMA3)-MU*SS+COS(GAMMA3)))+RCP*(SIN(PSI+PSIC
      1)-MU*SS+COS(PSI+PSIC)))/DENOM1)
      AA3=ABS((MP*RCP*(SIN(PSI+PSIC)-MU*SS+COS(PSI+PSIC)))/DENOM1)
      AA4=ABS((MP*RCP*(COS(PSI+PSIC)+MU*SS+COS(PSI+PSIC)))/DENOM1)
      AA5=ABS((MU*(S4-S5)*COS(PHI-ALPHA)+1+S4*SS-MU*S4)*SIN(PHI-ALP
      1HI))/DENOM1)
      AA6=ABS((MP*(R4*(COS(GAMMA3)+MU*SS+SIN(GAMMA3))-RCP*(COS(PSI+PSI
      1C)+MU*SS+SIN(PSI+PSIC)))/DENOM1)
      AA7=ABS((MP*RCP*(COS(PSI+PSIC)+MU*SS+SIN(PSI+PSIC)))/DENOM1)
      AA8=ABS((MP*RCP*(SIN(PSI+PSIC)-MU*SS+COS(PSI+PSIC)))/DENOM1)
      AA9=ABS((1-(MU*(S4-MU)*SIN(PHI-ALPHA+BETA3)+(1+MU*MU*S4)*COS(PHI-
      1ALPHA+BETA3))/DENOM1)
      AA10=ABS((1-MU*(1-S2)*SIN(BETA2+THETA2)-(1+MU*MU*S2)*COS(BETA2+TH
      1ETA2))/DENOM1)
      AA11=ABS((SIN(GAMMA3)-MU*COS(GAMMA3))/DENOM1)
      AA12=ABS((1-(MU*MU*S4)*SIN(PHI-ALPHA+BETA3)+(S4*MU-MU)*COS(PHI-
      1ALPHA+BETA3))/DENOM1)
      AA13=ABS((1-(1+MU*MU*S2)*SIN(BETA2+THETA2)+MU*(1-S2)*COS(BETA2+TH
      1ETA2))/DENOM1)
      AA14=ABS((COS(GAMMA3)+MU*SIN(GAMMA3))/DENOM1)
      AA15=ABS((S2*(D2-A2)+RHO3*(AA10+AA13))
      AA16=ABS((RHO3*(AA11+AA14)
      AA17=ABS((MU*(S4-BONE+MU*RHO3*(AA9+AA12)
      AA18=DONE+COE*(MU*S4-RHOP+MU*SS*(AA1+AA5)
      AA19=RHOP*(MU*SS*(AA2+AA6)
      AA20=RHOP*(MU*(AA3+AA7)
      AA21=SS+AA20
      AA22=RHOP*(MU*(AA4+AA6)
      AA23=ABS((1-(MU*MU*S1)*SIN(BETA1-THETA1)-MU*(1-S1)*COS(BETA1-TH
      1ETA1))/DENOM1)
      AA24=ABS((M1*(R1+RC1*(COS(PHI1C+N31*PHIT)+MU*SIN(PHI1C+N31*PHIT))
      1)/DENOM1)
      AA25=ABS((M1*RC1*(COS(PHI1C+N31*PHIT)+MU*SIN(PHI1C+N31*PHIT)))/DEN
      1OM1)
      AA26=ABS((M1*RC1*(SIN(PHI1C+N31*PHIT)-MU*COS(PHI1C+N31*PHIT)))/DEN
      1OM1)
      AA27=ABS((MU*(1-S1)*SIN(BETA1-THETA1)+(1-MU*MU*S1)*COS(BETA1-TH
      1ETA1))/DENOM1)
      AA28=ABS((MU*M1*(R1+RC1*(MU*COS(PHI1C+N31*PHIT)-SIN(PHI1C+N31*PH
      1IT))/DENOM1)
      AA29=ABS((M1*RC1*(MU*COS(PHI1C+N31*PHIT)-SIN(PHI1C+N31*PHIT)))/DEN
      1OM1)
      AA30=ABS((M1*RC1*(MU*SIN(PHI1C+N31*PHIT)+COS(PHI1C+N31*PHIT)))/DEN
      1OM1)
      AA31=C*PRB1*(MU*(S1+1+MU*RHO1*(AA23+AA27)
      AA32=OV2*(RHO1*(MU*(AA24+AA28)
      AA33=OV2*(B3*LOWCA)*2.*ABS(MU)*RHO1*(AA25+AA29)
      AA34=MU*(RHO1*(AA25+AA29)
      AA35=M1*(R1+RC1*(W2
      AA36=ABS((1-(MU*MU*S2)*SIN(BETA2+THETA2)+MU*(1-S2)*COS(BETA2+TH
      1ETA2))/DENOM1)
      AA37=ABS((1-(MU*MU*S1)*SIN(BETA1-THETA1)+MU*(1-S1)*COS(BETA1-TH
      1ETA1))/DENOM1)
      AA38=ABS((COS(GAMMA2)-MU*SIN(GAMMA2))/DENOM1)
      AA39=ABS((MU*(1-S2)*SIN(BETA2+THETA2)-(1-MU*MU*S2)*COS(BETA2+TH
      1ETA2))/DENOM1)
      AA40=ABS((MU*(1-S1)*SIN(BETA1-THETA1)-(1+MU*MU*S1)*COS(BETA1-TH

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SUBROUTINE IN2

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1TA1))/DENOM)
AA41=ABS((MU* COS(GAMMA2)+SIN(GAMMA2)))/DENOM)
AA42=RB2-MU*(S1*(D1-A1)+RHO2*(AA37+AA40))
AA43=MU*RHO2*(AA38+AA41)
AA44=CAPR82-MU*(S2*A2-RHO2*(AA38+AA39))
RETURN
END

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120

H 115  
H 116  
H 117  
H 118  
H 119  
H 120  
H 121-

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**SUBROUTINE ALFA**

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      SUBROUTINE ALFA (CAPRB,RB,THETA,CAPRO,RO,ALIN,ALFIN)
C
C THIS SUBROUTINE COMPUTES THE INITIAL AND FINAL VALUES OF ALPHAS
C
      ALIN=((CAPRB+RB)*TAN(THETA)-SQRT(RO*RO-RB*RB))/CAPRB
      ALFIN=SQRT(CAPRO-CAPRO*CAPRB)/CAPRB
      RETURN
      END

```

A = .20970 B = .19300 C = .07880 R = .01500 ALPHA = 52.0000 CONFIGURATION = 2.

EREST = 0.00 LAMBDA = 152.144 DELTA = 30.000

M1 = .35310E-04 M2 = .32260E-05 M3 = .26560E-05 MP = .24510E-05

I1 = .33500E-05 I2 = .37500E-07 I3 = .24900E-07 IP = .65720E-07

RC1 = .1150 RCP = 0.0000 RHOP = .0155 RPM = 30000. PHICU = -122.2300 PSICCO = 0.0000 PHID = 150.0000

PHICUTO = 1600.

MU = .15 MU1 = .15

PSUB01 = 44.0 PSUB02 = 63.5

NG1 = 41 NG2 = 29 NP2 = 6 NP3 = 5

CAPRP1 = .46591 CAPRP2 = .22835

RP2 = .06818 RP3 = .04724

THETA1 = 20.000 THETA2 = 20.000

R1 = .22500 R2 = .40800 R3 = .36800 R4 = .36100

RHO1 = .04650 RHO2 = .01550 RHO3 = .01550

CAPRB1 = .43781 CAPRB2 = .21458 RB2 = .06407 RB3 = .04439

CAPR01 = .47388 CAPR02 = .23387 R02 = .09373 R03 = .07321

J1 = 0.00 J2 = 0.00

BETA1D = 225.18 BETA2D = 129.80 BETA3D = 98.46  
GAMMA2D = -111.79 GAMMA3D = -152.99 GAMMA4D = -186.41

## COUPLED MOTION

|              |                |               |               |              |                    |                |               |
|--------------|----------------|---------------|---------------|--------------|--------------------|----------------|---------------|
| T = 0.00000  | PHI = 150.00   | PHIDOT = 0.00 | G = -.0221    | GDOT = 0.00  | PSID = 67.01       | PSIDOT = 0.00  | PHITOT = -.00 |
| F23 = 3.7149 | F12 = 16.2589  | PN = .7247    | PNPSI = .7247 | GDOT = .35   | DPH12 = .1552E+06  | PSIDOT = 2.22  | PHITOT = .00  |
| PHI = 150.00 | PHIDOT = 1.55  | G = -.0221    | GDOT = .7248  | PSID = 67.01 | PSIDOT = .1553E+06 |                |               |
| F23 = 3.7151 | F12 = 16.2589  | PN = .7248    | PNPSI = .7248 | GDOT = .70   | DPH12 = .1552E+06  | PSIDOT = 4.45  | PHITOT = .00  |
| PHI = 150.00 | PHIDOT = 3.10  | G = -.0221    | GDOT = .7248  | PSID = 67.01 | PSIDOT = .1552E+06 |                |               |
| F23 = 3.7151 | F12 = 16.2589  | PN = .7248    | PNPSI = .7248 | GDOT = 1.05  | DPH12 = .1552E+06  | PSIDOT = 5.67  | PHITOT = .00  |
| PHI = 150.00 | PHIDOT = 4.65  | G = -.0221    | GDOT = .7255  | PSID = 67.02 | PSIDOT = .1556E+06 |                |               |
| F23 = 3.7159 | F12 = 16.2590  | PN = .7255    | PNPSI = .7255 | GDOT = 1.40  | DPH12 = .1555E+06  | PSIDOT = 8.90  | PHITOT = .01  |
| PHI = 150.01 | PHIDOT = 6.21  | G = -.0221    | GDOT = .7254  | PSID = 67.02 | PSIDOT = .1555E+06 |                |               |
| F23 = 3.7159 | F12 = 16.2590  | PN = .7254    | PNPSI = .7254 | GDOT = 1.75  | DPH12 = .1562E+06  | PSIDOT = 11.13 | PHITOT = .01  |
| PHI = 150.01 | PHIDOT = 7.77  | G = -.0220    | GDOT = .7265  | PSID = 67.03 | PSIDOT = .1562E+06 |                |               |
| F23 = 3.7173 | F12 = 16.2592  | PN = .7265    | PNPSI = .7265 | GDOT = 2.10  | DPH12 = .1560E+06  | PSIDOT = 13.37 | PHITOT = .02  |
| PHI = 150.02 | PHIDOT = 9.33  | G = -.0220    | GDOT = 2.45   | PSID = 67.03 | PSIDOT = .1560E+06 |                |               |
| F23 = 3.7173 | F12 = 16.2593  | PN = .7265    | PNPSI = .7265 | GDOT = 2.81  | DPH12 = .1569E+06  | PSIDOT = 15.61 | PHITOT = .02  |
| PHI = 150.02 | PHIDOT = 10.83 | G = -.0220    | GDOT = 3.16   | PSID = 67.04 | PSIDOT = .1569E+06 |                |               |
| F23 = 3.7192 | F12 = 16.2595  | PN = .7281    | PNPSI = .7281 | GDOT = 3.51  | DPH12 = .1579E+06  | PSIDOT = 20.11 | PHITOT = .04  |
| PHI = 150.03 | PHIDOT = 12.46 | G = -.0220    | GDOT = 3.51   | PSID = 67.05 | PSIDOT = .1579E+06 |                |               |
| F23 = 3.7152 | F12 = 16.2596  | PN = .7280    | PNPSI = .7280 | GDOT = 3.51  | DPH12 = .1579E+06  | PSIDOT = 22.38 | PHITOT = .04  |
| PHI = 150.04 | PHIDOT = 14.03 | G = -.0219    | GDOT = 3.51   | PSID = 67.06 | PSIDOT = .1579E+06 |                |               |
| F23 = 3.7218 | F12 = 16.2601  | PN = .7301    | PNPSI = .7301 | GDOT = 3.51  | DPH12 = .1579E+06  | PSIDOT = 22.38 | PHITOT = .04  |
| PHI = 150.04 | PHIDOT = 15.60 | G = -.0219    | GDOT = 3.51   | PSID = 67.07 | PSIDOT = .1579E+06 |                |               |

## Computer program SADA2 (cont.)

|            |              |               |            |              |                   |              |
|------------|--------------|---------------|------------|--------------|-------------------|--------------|
| T = .00011 | F23 = 3.7218 | F12 = 16.2601 | PN = .7299 | PNP1 = .7299 | DPM12 = .1577E+06 | PHITOT = .05 |
| T = .00012 | F23 = 3.7249 | F12 = 16.2607 | PN = .7325 | PNP1 = .7325 | PSID = 67.09      | PHITOT = .06 |
| T = .00013 | F23 = 3.7249 | F12 = 16.2607 | PN = .7323 | PNP1 = .7323 | PSID = 67.10      | PHITOT = .08 |
| T = .00014 | F23 = 3.7287 | F12 = 16.2614 | PN = .7355 | PNP1 = .7355 | PSID = 67.12      | PHITOT = .09 |
| T = .00015 | F23 = 3.7287 | F12 = 16.2615 | PN = .7352 | PNP1 = .7352 | PSID = 67.14      | PHITOT = .10 |
| T = .00016 | F23 = 3.7330 | F12 = 16.2622 | PN = .7388 | PNP1 = .7388 | PSID = 67.15      | PHITOT = .11 |
| T = .00017 | F23 = 3.7331 | F12 = 16.2624 | PN = .7386 | PNP1 = .7386 | PSID = 67.17      | PHITOT = .13 |
| T = .00018 | F23 = 3.7380 | F12 = 16.2632 | PN = .7427 | PNP1 = .7427 | PSID = 67.20      | PHITOT = .15 |
| T = .00019 | F23 = 3.7381 | F12 = 16.2631 | PN = .7424 | PNP1 = .7424 | PSID = 67.22      | PHITOT = .16 |
| T = .00020 | F23 = 3.7436 | F12 = 16.2644 | PN = .7471 | PNP1 = .7471 | PSID = 67.24      | PHITOT = .18 |
| T = .00021 | F23 = 3.7437 | F12 = 16.2645 | PN = .7468 | PNP1 = .7468 | PSID = 67.27      | PHITOT = .20 |
| T = .00022 | F23 = 3.7493 | F12 = 16.2656 | PN = .7519 | PNP1 = .7519 | PSID = 67.30      | PHITOT = .22 |
| T = .00023 | F23 = 3.7500 | F12 = 16.2658 | PN = .7516 | PNP1 = .7516 | PSID = 67.32      | PHITOT = .24 |
| T = .00024 | F23 = 3.7568 | F12 = 16.2670 | PN = .7573 | PNP1 = .7573 | PSID = 67.35      | PHITOT = .26 |
| T = .00025 | F23 = 3.7644 | F12 = 16.2685 | PN = .7631 | PNP1 = .7631 | PSID = 67.42      | PHITOT = .28 |
| T = .00026 | F23 = 3.7645 | F12 = 16.2688 | PN = .7627 | PNP1 = .7627 | PSID = 67.45      | PHITOT = .31 |
| T = .00027 | F23 = 3.7726 | F12 = 16.2702 | PN = .7695 | PNP1 = .7695 | PSID = 67.49      | PHITOT = .33 |
| T = .00028 | F23 = 3.7727 | F12 = 16.2705 | PN = .7690 | PNP1 = .7690 | PSID = 67.52      | PHITOT = .36 |
| T = .00029 | F23 = 3.7816 | F12 = 16.2720 | PN = .7764 | PNP1 = .7764 | PSID = 67.56      | PHITOT = .38 |
| T = .00030 | F23 = 3.7817 | F12 = 16.2723 | PN = .7759 | PNP1 = .7759 | PSID = 67.60      | PHITOT = .41 |
| T = .00031 | F23 = 3.8017 | F12 = 16.2743 | PN = .7833 | PNP1 = .7833 | PSID = 67.63      | PHITOT = .44 |
| T = .00032 | F23 = 3.8017 | F12 = 16.2743 | PN = .7833 | PNP1 = .7833 | PSID = 67.69      | PHITOT = .47 |
| T = .00033 | F23 = 3.8017 | F12 = 16.2743 | PN = .7833 | PNP1 = .7833 | PSID = 67.73      | PHITOT = .50 |
| T = .00034 | F23 = 3.8017 | F12 = 16.2743 | PN = .7833 | PNP1 = .7833 | PSID = 67.78      | PHITOT = .53 |
| T = .00035 | F23 = 3.8127 | F12 = 16.2784 | PN = .8005 | PNP1 = .8005 | PSID = 67.83      | PHITOT = .56 |
| T = .00036 | F23 = 3.8129 | F12 = 16.2788 | PN = .7999 | PNP1 = .7999 | PSID = 67.87      | PHITOT = .60 |
| T = .00037 | F23 = 3.8247 | F12 = 16.2808 | PN = .8097 | PNP1 = .8097 | PSID = 67.93      | PHITOT = .63 |
| T = .00038 | F23 = 3.8248 | F12 = 16.2812 | PN = .8090 | PNP1 = .8090 | PSID = 67.98      | PHITOT = .67 |
| T = .00039 | F23 = 3.8373 | F12 = 16.2834 | PN = .8195 | PNP1 = .8195 | PSID = 68.03      | PHITOT = .71 |
| T = .00040 | F23 = 3.8375 | F12 = 16.2839 | PN = .8187 | PNP1 = .8187 | PSID = 68.09      | PHITOT = .74 |

|              |               |                 |              |              |                 |                 |               |
|--------------|---------------|-----------------|--------------|--------------|-----------------|-----------------|---------------|
| T = .00041   | PHI = 150.78  | PHIDOT = 69.87  | G = -.0190   | GDOT = 15.80 | PSID = 68.15    | PSIDOT = 102.87 | PHITOT = .78  |
| F23 = 3.8533 | F12 = 16.2862 | PHI = .8293     | GDOT = 16.27 | PSID = 68.21 | PSIDOT = 106.00 | PHITOT = .82    |               |
| T = .00042   | PHI = 150.82  | PHIDOT = 71.89  | G = -.0189   | GDOT = 16.27 | PSID = 68.21    | PSIDOT = 106.00 | PHITOT = .82  |
| F23 = 3.8510 | F12 = 16.2866 | PHI = .8291     | GDOT = 16.74 | PSID = 68.27 | PSIDOT = 109.19 | PHITOT = .87    |               |
| T = .00043   | PHI = 150.87  | PHIDOT = 73.95  | G = -.0187   | GDOT = 16.74 | PSID = 68.27    | PSIDOT = 109.19 | PHITOT = .87  |
| F23 = 3.8452 | F12 = 16.2891 | PHI = .8410     | GDOT = 17.21 | PSID = 68.33 | PSIDOT = 112.41 | PHITOT = .91    |               |
| T = .00044   | PHI = 150.91  | PHIDOT = 76.02  | G = -.0185   | GDOT = 17.21 | PSID = 68.33    | PSIDOT = 112.41 | PHITOT = .91  |
| F23 = 3.8454 | F12 = 16.2896 | PHI = .8401     | GDOT = 17.69 | PSID = 68.40 | PSIDOT = 115.71 | PHITOT = .95    |               |
| T = .00045   | PHI = 150.95  | PHIDOT = 78.13  | G = -.0183   | GDOT = 17.69 | PSID = 68.40    | PSIDOT = 115.71 | PHITOT = .95  |
| F23 = 3.8404 | F12 = 16.2922 | PHI = .8527     | GDOT = 18.18 | PSID = 68.47 | PSIDOT = 119.04 | PHITOT = 1.00   |               |
| T = .00046   | PHI = 151.00  | PHIDOT = 80.26  | G = -.0182   | GDOT = 18.18 | PSID = 68.47    | PSIDOT = 119.04 | PHITOT = 1.00 |
| F23 = 3.8206 | F12 = 16.2927 | PHI = .8518     | GDOT = 18.67 | PSID = 68.53 | PSIDOT = 122.44 | PHITOT = 1.04   |               |
| T = .00047   | PHI = 151.04  | PHIDOT = 82.42  | G = -.0180   | GDOT = 18.67 | PSID = 68.53    | PSIDOT = 122.44 | PHITOT = 1.04 |
| F23 = 3.8056 | F12 = 16.2955 | PHI = .8651     | GDOT = 19.17 | PSID = 68.61 | PSIDOT = 125.88 | PHITOT = 1.09   |               |
| T = .00048   | PHI = 151.09  | PHIDOT = 84.59  | G = -.0178   | GDOT = 19.17 | PSID = 68.61    | PSIDOT = 125.88 | PHITOT = 1.09 |
| F23 = 3.8378 | F12 = 16.2961 | PHI = .8641     | GDOT = 19.67 | PSID = 68.68 | PSIDOT = 129.39 | PHITOT = 1.14   |               |
| T = .00049   | PHI = 151.14  | PHIDOT = 86.81  | G = -.0176   | GDOT = 19.67 | PSID = 68.68    | PSIDOT = 129.39 | PHITOT = 1.14 |
| F23 = 3.8136 | F12 = 16.2990 | PHI = .8782     | GDOT = 20.19 | PSID = 68.75 | PSIDOT = 132.95 | PHITOT = 1.19   |               |
| T = .00050   | PHI = 151.19  | PHIDOT = 89.04  | G = -.0174   | GDOT = 20.19 | PSID = 68.75    | PSIDOT = 132.95 | PHITOT = 1.19 |
| F23 = 3.9138 | F12 = 16.2996 | PHI = .8772     | GDOT = 20.71 | PSID = 68.83 | PSIDOT = 136.58 | PHITOT = 1.24   |               |
| T = .00051   | PHI = 151.24  | PHIDOT = 91.32  | G = -.0172   | GDOT = 20.71 | PSID = 68.83    | PSIDOT = 136.58 | PHITOT = 1.24 |
| F23 = 3.9317 | F12 = 16.3026 | PHI = .8921     | GDOT = 21.23 | PSID = 68.91 | PSIDOT = 140.26 | PHITOT = 1.30   |               |
| T = .00052   | PHI = 151.30  | PHIDOT = 93.61  | G = -.0170   | GDOT = 21.23 | PSID = 68.91    | PSIDOT = 140.26 | PHITOT = 1.30 |
| F23 = 3.9319 | F12 = 16.3033 | PHI = .8910     | GDOT = 21.77 | PSID = 68.99 | PSIDOT = 144.03 | PHITOT = 1.35   |               |
| T = .00053   | PHI = 151.35  | PHIDOT = 95.95  | G = -.0168   | GDOT = 21.77 | PSID = 68.99    | PSIDOT = 144.03 | PHITOT = 1.35 |
| F23 = 3.9507 | F12 = 16.3065 | PHI = .9067     | GDOT = 22.31 | PSID = 69.08 | PSIDOT = 147.84 | PHITOT = 1.41   |               |
| T = .00054   | PHI = 151.41  | PHIDOT = 98.30  | G = -.0165   | GDOT = 22.31 | PSID = 69.08    | PSIDOT = 147.84 | PHITOT = 1.41 |
| F23 = 3.9509 | F12 = 16.3072 | PHI = .9056     | GDOT = 22.86 | PSID = 69.16 | PSIDOT = 151.73 | PHITOT = 1.46   |               |
| T = .00055   | PHI = 151.46  | PHIDOT = 100.70 | G = -.0163   | GDOT = 22.86 | PSID = 69.16    | PSIDOT = 151.73 | PHITOT = 1.46 |
| F23 = 3.9708 | F12 = 16.3106 | PHI = .9221     | GDOT = 23.41 | PSID = 69.25 | PSIDOT = 155.68 | PHITOT = 1.52   |               |
| T = .00056   | PHI = 151.52  | PHIDOT = 103.12 | G = -.0161   | GDOT = 23.41 | PSID = 69.25    | PSIDOT = 155.68 | PHITOT = 1.52 |
| F23 = 3.9710 | F12 = 16.3113 | PHI = .9209     | GDOT = 23.98 | PSID = 69.34 | PSIDOT = 159.72 | PHITOT = 1.58   |               |
| T = .00057   | PHI = 151.58  | PHIDOT = 105.58 | G = -.0158   | GDOT = 23.98 | PSID = 69.34    | PSIDOT = 159.72 | PHITOT = 1.58 |
| F23 = 3.5749 | F12 = 16.3147 | PHI = .9395     | GDOT = 24.55 | PSID = 69.43 | PSIDOT = 163.82 | PHITOT = 1.64   |               |
| T = .00058   | PHI = 151.64  | PHIDOT = 108.07 | G = -.0156   | GDOT = 24.55 | PSID = 69.43    | PSIDOT = 163.82 | PHITOT = 1.64 |
| F23 = 3.5751 | F12 = 16.3155 | PHI = .9382     | GDOT = 25.13 | PSID = 69.53 | PSIDOT = 167.94 | PHITOT = 1.71   |               |
| T = .00059   | PHI = 151.71  | PHIDOT = 110.56 | G = -.0153   | GDOT = 25.13 | PSID = 69.53    | PSIDOT = 167.94 | PHITOT = 1.71 |
| F23 = 3.5800 | F12 = 16.3234 | PHI = .9259     | GDOT = 25.69 | PSID = 69.62 | PSIDOT = 172.01 | PHITOT = 1.77   |               |
| T = .00060   | PHI = 151.77  | PHIDOT = 113.00 | G = -.0151   | GDOT = 25.69 | PSID = 69.62    | PSIDOT = 172.01 | PHITOT = 1.77 |
| F23 = 3.5803 | F12 = 16.3242 | PHI = .9246     | GDOT = 26.24 | PSID = 69.72 | PSIDOT = 176.02 | PHITOT = 1.84   |               |
| T = .00061   | PHI = 151.84  | PHIDOT = 115.39 | G = -.0148   | GDOT = 26.24 | PSID = 69.72    | PSIDOT = 176.02 | PHITOT = 1.84 |
| F23 = 3.5854 | F12 = 16.3325 | PHI = .9117     | GDOT = 26.78 | PSID = 69.83 | PSIDOT = 179.98 | PHITOT = 1.90   |               |
| T = .00062   | PHI = 151.90  | PHIDOT = 117.72 | G = -.0146   | GDOT = 26.78 | PSID = 69.83    | PSIDOT = 179.98 | PHITOT = 1.90 |
| F23 = 3.5856 | F12 = 16.3333 | PHI = .9103     | GDOT = 27.30 | PSID = 69.93 | PSIDOT = 183.87 | PHITOT = 1.97   |               |
| T = .00063   | PHI = 151.97  | PHIDOT = 120.00 | G = -.0143   | GDOT = 27.30 | PSID = 69.93    | PSIDOT = 183.87 | PHITOT = 1.97 |
| F23 = 3.5909 | F12 = 16.3419 | PHI = .8970     | GDOT = 27.82 | PSID = 70.04 | PSIDOT = 187.70 | PHITOT = 2.04   |               |
| T = .00064   | PHI = 152.04  | PHIDOT = 122.23 | G = -.0141   | GDOT = 27.82 | PSID = 70.04    | PSIDOT = 187.70 | PHITOT = 2.04 |
| F23 = 3.5912 | F12 = 16.3428 | PHI = .8956     | GDOT = 28.32 | PSID = 70.15 | PSIDOT = 191.47 | PHITOT = 2.11   |               |
| T = .00065   | PHI = 152.11  | PHIDOT = 124.39 | G = -.0137   | GDOT = 28.32 | PSID = 70.15    | PSIDOT = 191.47 | PHITOT = 2.11 |
| F23 = 3.5965 | F12 = 16.3517 | PHI = .8818     | GDOT = 28.81 | PSID = 70.26 | PSIDOT = 195.19 | PHITOT = 2.18   |               |
| T = .00066   | PHI = 152.18  | PHIDOT = 126.51 | G = -.0135   | GDOT = 28.81 | PSID = 70.26    | PSIDOT = 195.19 | PHITOT = 2.18 |
| F23 = 3.5969 | F12 = 16.3525 | PHI = .8803     | GDOT = 29.15 | PSID = 70.37 | PSIDOT = 197.86 | PHITOT = 2.26   |               |
| T = .00067   | PHI = 152.26  | PHIDOT = 127.94 | G = -.0132   | GDOT = 29.15 | PSID = 70.37    | PSIDOT = 197.86 | PHITOT = 2.26 |
| F23 = 3.9623 | F12 = 16.3768 | PHI = .7546     | GDOT = 29.46 | PSID = 70.48 | PSIDOT = 200.38 | PHITOT = 2.33   |               |
| T = .00068   | PHI = 152.33  | PHIDOT = 129.27 | G = -.0129   | GDOT = 29.46 | PSID = 70.48    | PSIDOT = 200.38 | PHITOT = 2.33 |
| F23 = 3.9625 | F12 = 16.3775 | PHI = .7533     | GDOT = 29.78 | PSID = 70.60 | PSIDOT = 203.01 | PHITOT = 2.40   |               |
| T = .00069   | PHI = 152.40  | PHIDOT = 130.65 | G = -.0126   | GDOT = 29.78 | PSID = 70.60    | PSIDOT = 203.01 | PHITOT = 2.40 |
| F23 = 3.9879 | F12 = 16.3821 | PHI = .7736     | GDOT = 30.11 | PSID = 70.72 | PSIDOT = 205.70 | PHITOT = 2.48   |               |
| T = .00070   | PHI = 152.48  | PHIDOT = 132.07 | G = -.0123   | GDOT = 30.11 | PSID = 70.72    | PSIDOT = 205.70 | PHITOT = 2.48 |
| F23 = 3.9882 | F12 = 16.3828 | PHI = .7722     | GDOT = 30.46 | PSID = 70.83 | PSIDOT = 208.50 | PHITOT = 2.55   |               |
| T = .00071   | PHI = 152.55  | PHIDOT = 133.55 | G = -.0120   | GDOT = 30.46 | PSID = 70.83    | PSIDOT = 208.50 | PHITOT = 2.55 |

## Computer program SANDA2 (cont)

|              |                 |            |               |                   |                  |                  |               |
|--------------|-----------------|------------|---------------|-------------------|------------------|------------------|---------------|
| F23 = 4.0143 | F12 = 16.3875   | PH = .7931 | PNP51 = .7931 | DPH12 = .1557E+06 | PSID = 70.95     | PSIDOOT = 211.37 | PHITOT = 2.63 |
| PHI = 152.63 | PH1OOT = 135.05 | G = -.0117 | GOOT = 30.81  | PSID = 70.95      | PSIDOOT = 211.37 | PHITOT = 2.63    |               |
| F23 = 4.0146 | F12 = 16.3883   | PN = .7917 | PNP51 = .7917 | DPH12 = .1540E+06 | PSID = 71.08     | PSIDOOT = 214.36 | PHITOT = 2.71 |
| PHI = 152.71 | PH1OOT = 136.63 | G = -.0114 | GOOT = 31.18  | PSID = 71.08      | PSIDOOT = 214.36 | PHITOT = 2.71    |               |
| F23 = 4.0414 | F12 = 16.3930   | PN = .8132 | PNP51 = .8132 | DPH12 = .1653E+06 | PSID = 71.20     | PSIDOOT = 217.41 | PHITOT = 2.79 |
| PHI = 152.79 | PH1OOT = 138.23 | G = -.0110 | GOOT = 31.56  | PSID = 71.20      | PSIDOOT = 217.41 | PHITOT = 2.79    |               |
| F23 = 4.0417 | F12 = 16.3938   | PN = .8117 | PNP51 = .8117 | DPH12 = .1636E+06 | PSID = 71.33     | PSIDOOT = 220.58 | PHITOT = 2.87 |
| PHI = 152.87 | PH1OOT = 139.90 | G = -.0107 | GOOT = 31.95  | PSID = 71.33      | PSIDOOT = 220.58 | PHITOT = 2.87    |               |
| F23 = 4.0194 | F12 = 16.3987   | PN = .8339 | PNP51 = .8339 | DPH12 = .1750E+06 | PSID = 71.45     | PSIDOOT = 223.82 | PHITOT = 2.95 |
| PHI = 152.95 | PH1OOT = 141.60 | G = -.0104 | GOOT = 32.34  | PSID = 71.45      | PSIDOOT = 223.82 | PHITOT = 2.95    |               |
| F23 = 4.0697 | F12 = 16.3995   | PN = .8323 | PNP51 = .8323 | DPH12 = .1732E+06 | PSID = 71.58     | PSIDOOT = 227.18 | PHITOT = 3.03 |
| PHI = 153.03 | PH1OOT = 143.36 | G = -.0101 | GOOT = 32.75  | PSID = 71.58      | PSIDOOT = 227.18 | PHITOT = 3.03    |               |
| F23 = 4.0982 | F12 = 16.4045   | PN = .8552 | PNP51 = .8552 | DPH12 = .1850E+06 | PSID = 71.71     | PSIDOOT = 230.62 | PHITOT = 3.11 |
| PHI = 153.11 | PH1OOT = 145.16 | G = -.0090 | GOOT = 33.18  | PSID = 71.71      | PSIDOOT = 230.62 | PHITOT = 3.11    |               |
| F23 = 4.0585 | F12 = 16.4054   | PN = .8536 | PNP51 = .8536 | DPH12 = .1830E+06 | PSID = 71.85     | PSIDOOT = 234.18 | PHITOT = 3.20 |
| PHI = 153.20 | PH1OOT = 147.02 | G = -.0094 | GOOT = 33.61  | PSID = 71.85      | PSIDOOT = 234.18 | PHITOT = 3.20    |               |
| F23 = 4.1280 | F12 = 16.4105   | PN = .8772 | PNP51 = .8772 | DPH12 = .1951E+06 | PSID = 71.98     | PSIDOOT = 237.82 | PHITOT = 3.28 |
| PHI = 153.28 | PH1OOT = 148.92 | G = -.0091 | GOOT = 34.05  | PSID = 71.98      | PSIDOOT = 237.82 | PHITOT = 3.28    |               |
| F23 = 4.1283 | F12 = 16.4115   | PN = .8755 | PNP51 = .8755 | DPH12 = .1931E+06 | PSID = 72.12     | PSIDOOT = 241.59 | PHITOT = 3.37 |
| PHI = 153.37 | PH1OOT = 150.89 | G = -.0087 | GOOT = 34.51  | PSID = 72.12      | PSIDOOT = 241.59 | PHITOT = 3.37    |               |
| F23 = 4.1588 | F12 = 16.4167   | PN = .9000 | PNP51 = .9000 | DPH12 = .2054E+06 | PSID = 72.26     | PSIDOOT = 245.43 | PHITOT = 3.45 |
| PHI = 153.45 | PH1OOT = 152.88 | G = -.0084 | GOOT = 34.98  | PSID = 72.26      | PSIDOOT = 245.43 | PHITOT = 3.45    |               |
| F23 = 4.1591 | F12 = 16.4177   | PN = .8981 | PNP51 = .8981 | DPH12 = .2032E+06 | PSID = 72.40     | PSIDOOT = 249.42 | PHITOT = 3.54 |
| PHI = 153.54 | PH1OOT = 154.95 | G = -.0080 | GOOT = 35.46  | PSID = 72.40      | PSIDOOT = 249.42 | PHITOT = 3.54    |               |
| F23 = 4.1906 | F12 = 16.4231   | PN = .9234 | PNP51 = .9234 | DPH12 = .2159E+06 | PSID = 72.54     | PSIDOOT = 253.48 | PHITOT = 3.63 |
| PHI = 153.63 | PH1OOT = 157.05 | G = -.0077 | GOOT = 35.95  | PSID = 72.54      | PSIDOOT = 253.48 | PHITOT = 3.63    |               |
| F23 = 4.1910 | F12 = 16.4241   | PN = .9215 | PNP51 = .9215 | DPH12 = .2136E+06 | PSID = 72.69     | PSIDOOT = 257.68 | PHITOT = 3.72 |
| PHI = 153.72 | PH1OOT = 159.22 | G = -.0073 | GOOT = 36.46  | PSID = 72.69      | PSIDOOT = 257.68 | PHITOT = 3.72    |               |
| F23 = 3.7848 | F12 = 16.4289   | PN = .9537 | PNP51 = .9537 | DPH12 = .2299E+06 | PSID = 72.84     | PSIDOOT = 261.97 | PHITOT = 3.81 |
| PHI = 153.81 | PH1OOT = 161.43 | G = -.0070 | GOOT = 36.97  | PSID = 72.84      | PSIDOOT = 261.97 | PHITOT = 3.81    |               |
| F23 = 3.7851 | F12 = 16.4300   | PN = .9517 | PNP51 = .9517 | DPH12 = .2275E+06 | PSID = 72.99     | PSIDOOT = 266.33 | PHITOT = 3.91 |
| PHI = 153.91 | PH1OOT = 163.67 | G = -.0066 | GOOT = 37.49  | PSID = 72.99      | PSIDOOT = 266.33 | PHITOT = 3.91    |               |
| F23 = 3.7319 | F12 = 16.4417   | PN = .9331 | PNP51 = .9331 | DPH12 = .2160E+06 | PSID = 73.15     | PSIDOOT = 270.62 | PHITOT = 4.00 |
| PHI = 154.00 | PH1OOT = 165.84 | G = -.0052 | GOOT = 38.00  | PSID = 73.15      | PSIDOOT = 270.62 | PHITOT = 4.00    |               |
| F23 = 3.7923 | F12 = 16.4428   | PN = .9311 | PNP51 = .9311 | DPH12 = .2136E+06 | PSID = 73.30     | PSIDOOT = 274.81 | PHITOT = 4.10 |
| PHI = 154.10 | PH1OOT = 167.94 | G = -.0058 | GOOT = 38.49  | PSID = 73.30      | PSIDOOT = 274.81 | PHITOT = 4.10    |               |
| F23 = 3.7992 | F12 = 16.4540   | PN = .9121 | PNP51 = .9121 | DPH12 = .2020E+06 | PSID = 73.46     | PSIDOOT = 278.94 | PHITOT = 4.19 |
| PHI = 154.19 | PH1OOT = 169.98 | G = -.0054 | GOOT = 38.97  | PSID = 73.46      | PSIDOOT = 278.94 | PHITOT = 4.19    |               |
| F23 = 3.7995 | F12 = 16.4553   | PN = .9100 | PNP51 = .9100 | DPH12 = .1997E+06 | PSID = 73.62     | PSIDOOT = 282.95 | PHITOT = 4.29 |
| PHI = 154.29 | PH1OOT = 171.93 | G = -.0050 | GOOT = 39.42  | PSID = 73.62      | PSIDOOT = 282.95 | PHITOT = 4.29    |               |
| F23 = 4.1694 | F12 = 16.4667   | PN = .7491 | PNP51 = .7491 | DPH12 = .1116E+06 | PSID = 73.78     | PSIDOOT = 286.90 | PHITOT = 4.39 |
| PHI = 154.39 | PH1OOT = 173.83 | G = -.0046 | GOOT = 39.87  | PSID = 73.78      | PSIDOOT = 286.90 | PHITOT = 4.39    |               |
| F23 = 4.1697 | F12 = 16.4876   | PN = .7474 | PNP51 = .7474 | DPH12 = .1097E+06 | PSID = 73.95     | PSIDOOT = 289.61 | PHITOT = 4.49 |
| PHI = 154.49 | PH1OOT = 174.97 | G = -.0042 | GOOT = 40.14  | PSID = 73.95      | PSIDOOT = 289.61 | PHITOT = 4.49    |               |
| F23 = 4.2047 | F12 = 16.4939   | PN = .7744 | PNP51 = .7744 | DPH12 = .1237E+06 | PSID = 74.12     | PSIDOOT = 292.40 | PHITOT = 4.59 |
| PHI = 154.59 | PH1OOT = 176.15 | G = -.0038 | GOOT = 40.42  | PSID = 74.12      | PSIDOOT = 292.40 | PHITOT = 4.59    |               |
| F23 = 4.2050 | F12 = 16.4948   | PN = .7725 | PNP51 = .7725 | DPH12 = .1222E+06 | PSID = 74.28     | PSIDOOT = 295.35 | PHITOT = 4.69 |
| PHI = 154.69 | PH1OOT = 177.41 | G = -.0034 | GOOT = 40.72  | PSID = 74.28      | PSIDOOT = 295.35 | PHITOT = 4.69    |               |
| F23 = 4.2408 | F12 = 16.5012   | PN = .8002 | PNP51 = .8002 | DPH12 = .1364E+06 | PSID = 74.45     | PSIDOOT = 298.39 | PHITOT = 4.79 |
| PHI = 154.79 | PH1OOT = 178.72 | G = -.0030 | GOOT = 41.02  | PSID = 74.45      | PSIDOOT = 298.39 | PHITOT = 4.79    |               |
| F23 = 4.2411 | F12 = 16.5022   | PN = .7982 | PNP51 = .7982 | DPH12 = .1347E+06 | PSID = 74.63     | PSIDOOT = 301.58 | PHITOT = 4.90 |
| PHI = 154.90 | PH1OOT = 180.11 | G = -.0026 | GOOT = 41.35  | PSID = 74.63      | PSIDOOT = 301.58 | PHITOT = 4.90    |               |
| F23 = 4.2778 | F12 = 16.5086   | PN = .8266 | PNP51 = .8266 | DPH12 = .1491E+06 | PSID = 74.80     | PSIDOOT = 304.86 | PHITOT = 5.00 |
| PHI = 155.00 | PH1OOT = 181.54 | G = -.0022 | GOOT = 41.68  | PSID = 74.80      | PSIDOOT = 304.86 | PHITOT = 5.00    |               |
| F23 = 4.2781 | F12 = 16.5096   | PN = .8245 | PNP51 = .8245 | DPH12 = .1473E+06 | PSID = 74.98     | PSIDOOT = 308.30 | PHITOT = 5.11 |
| PHI = 155.11 | PH1OOT = 183.05 | G = -.0018 | GOOT = 42.04  | PSID = 74.98      | PSIDOOT = 308.30 | PHITOT = 5.11    |               |
| F23 = 4.3156 | F12 = 16.5162   | PN = .8536 | PNP51 = .8536 | DPH12 = .1620E+06 | PSID = 75.15     | PSIDOOT = 311.84 | PHITOT = 5.21 |
| PHI = 155.21 | PH1OOT = 184.61 | G = -.0014 | GOOT = 42.40  | PSID = 75.15      | PSIDOOT = 311.84 | PHITOT = 5.21    |               |
| F23 = 4.3160 | F12 = 16.5172   | PN = .8515 | PNP51 = .8515 | DPH12 = .1601E+06 | PSID = 75.33     | PSIDOOT = 315.54 | PHITOT = 5.32 |
| PHI = 155.32 | PH1OOT = 186.25 | G = -.0009 | GOOT = 42.79  | PSID = 75.33      | PSIDOOT = 315.54 | PHITOT = 5.32    |               |
| F23 = 4.3545 | F12 = 16.5239   | PN = .8813 | PNP51 = .8813 | DPH12 = .1750E+06 | PSID = 75.50E+06 | PSIDOOT = 315.54 | PHITOT = 5.32 |

T = .00102 PHI = 155.42 PHIDOT = 187.94 G = -.0005 GDOT = 43.18 PSID = 75.52 PSIDOT = 319.34 PHITOT = 5.42  
 FF23 = 4.3549 F12 = 16.5250 PN = .8791 PNPSI = .1729E+06  
 T = .00103 PHI = 155.53 PHIDOT = 189.71 G = -.0001 GDOT = 43.59 PSID = 75.70 PSIDOT = 323.30 PHITOT = 5.53  
 FF23 = 4.3944 F12 = 16.5318 PN = .9097 PNPSI = .1881E+06  
 T = .00104 PHI = 155.64 PHIDOT = 191.53 G = .0004 GDOT = 44.02 PSID = 75.89 PSIDOT = 327.37 PHITOT = 5.64  
 FF23 = 4.3948 F12 = 16.5320 PN = .9074 PNPSI = .1859E+06

## FREE MOTION

T = .00104 PHI = 185.64 PHIDOT = 191.53 PSI = 283.74 PSIDOT = 327.37 PHITOT = 5.64  
 FF23 = 15.422 PHIDOT = 203.82 PSI = 283.79 PSIDOT = 326.37 PHITOT = 5.67  
 T = .00104 PHI = 185.67 PHIDOT = 216.22 PSI = 283.84 PSIDOT = 325.36 PHITOT = 5.70  
 FF23 = 13.764 PHIDOT = 220.66 PSI = 283.88 PSIDOT = 324.36 PHITOT = 5.73  
 T = .00105 PHI = 185.73 PHIDOT = 241.17 PSI = 283.93 PSIDOT = 323.35 PHITOT = 5.77  
 FF23 = 13.758 PHIDOT = 253.60 PSI = 283.97 PSIDOT = 322.35 PHITOT = 5.80  
 T = .00105 PHI = 185.80 PHIDOT = 265.99 PSI = 284.02 PSIDOT = 321.34 PHITOT = 5.84  
 FF23 = 13.766 PHIDOT = 278.29 PSI = 284.07 PSIDOT = 320.34 PHITOT = 5.88  
 T = .00106 PHI = 185.88 PHIDOT = 290.55 PSI = 284.11 PSIDOT = 319.34 PHITOT = 5.92  
 FF23 = 13.775 PHIDOT = 302.72 PSI = 284.16 PSIDOT = 318.33 PHITOT = 5.96  
 T = .00106 PHI = 185.96 PHIDOT = 314.83 PSI = 284.20 PSIDOT = 317.33 PHITOT = 6.00  
 FF23 = 13.784 PHIDOT = 326.85 PSI = 284.25 PSIDOT = 316.32 PHITOT = 6.05  
 T = .00107 PHI = 186.05 PHIDOT = 338.81 PSI = 284.29 PSIDOT = 315.32 PHITOT = 6.10  
 FF23 = 13.795 PHIDOT = 350.67 PSI = 284.34 PSIDOT = 314.31 PHITOT = 6.15  
 T = .00107 PHI = 186.10 PHIDOT = 362.46 PSI = 284.38 PSIDOT = 313.31 PHITOT = 6.20  
 FF23 = 13.806 PHIDOT = 374.15 PSI = 284.43 PSIDOT = 312.30 PHITOT = 6.25  
 T = .00107 PHI = 186.20 PHIDOT = 385.77 PSI = 284.47 PSIDOT = 311.30 PHITOT = 6.31  
 FF23 = 13.806 PHIDOT = 395.60 PSI = 284.52 PSIDOT = 310.30 PHITOT = 6.36  
 T = .00108 PHI = 186.31 PHIDOT = 405.48 PSI = 284.56 PSIDOT = 309.29 PHITOT = 6.42  
 FF23 = 13.973 PHIDOT = 415.46 PSI = 284.61 PSIDOT = 308.29 PHITOT = 6.48  
 T = .00108 PHI = 186.36 PHIDOT = 425.50 PSI = 284.65 PSIDOT = 307.28 PHITOT = 6.54  
 FF23 = 13.957 PHIDOT = 435.63 PSI = 284.69 PSIDOT = 306.28 PHITOT = 6.60  
 T = .00109 PHI = 186.42 PHIDOT = 445.83 PSI = 284.74 PSIDOT = 305.27 PHITOT = 6.66  
 FF23 = 13.939 PHIDOT = 456.12 PSI = 284.78 PSIDOT = 304.27 PHITOT = 6.73  
 T = .00109 PHI = 186.54 PHIDOT = 466.48 PSI = 284.83 PSIDOT = 303.27 PHITOT = 6.79  
 FF23 = 13.922 PHIDOT = 476.94 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 T = .00109 PHI = 186.60 PHIDOT = 486.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 FF23 = 13.922 PHIDOT = 496.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 T = .00110 PHI = 186.73 PHIDOT = 506.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 FF23 = 13.922 PHIDOT = 516.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 T = .00110 PHI = 186.79 PHIDOT = 526.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 FF23 = 13.903 PHIDOT = 536.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 T = .00110 PHI = 186.86 PHIDOT = 546.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86  
 FF23 = 13.832 PHIDOT = 556.86 PSI = 284.87 PSIDOT = 302.26 PHITOT = 6.86

## Computer program SANDA2 (cont.)

|            |               |                 |              |                 |               |
|------------|---------------|-----------------|--------------|-----------------|---------------|
| T = .00110 | FF12 = 13.884 | FF23 = 3.823    | PSI = 284.91 | PSIDOT = 301.26 | PHITOT = 6.93 |
|            | PHI = 186.93  | PHIDOT = 487.47 |              |                 |               |
| T = .00111 | FF12 = 13.884 | FF23 = 3.823    | PSI = 284.96 | PSIDOT = 300.25 | PHITOT = 7.00 |
|            | PHI = 187.00  | PHIDOT = 498.11 |              |                 |               |
| T = .00111 | FF12 = 13.863 | FF23 = 3.813    | PSI = 285.00 | PSIDOT = 299.25 | PHITOT = 7.07 |
|            | PHI = 187.07  | PHIDOT = 500.82 |              |                 |               |
| T = .00111 | FF12 = 13.864 | FF23 = 3.813    | PSI = 285.04 | PSIDOT = 298.24 | PHITOT = 7.15 |
|            | PHI = 187.15  | PHIDOT = 519.64 |              |                 |               |
| T = .00111 | FF12 = 13.842 | FF23 = 3.803    | PSI = 285.08 | PSIDOT = 297.24 | PHITOT = 7.22 |
|            | PHI = 187.22  | PHIDOT = 530.53 |              |                 |               |
| T = .00112 | FF12 = 13.843 | FF23 = 3.803    | PSI = 285.13 | PSIDOT = 296.23 | PHITOT = 7.30 |
|            | PHI = 187.30  | PHIDOT = 541.54 |              |                 |               |
| T = .00112 | FF12 = 13.821 | FF23 = 3.793    | PSI = 285.17 | PSIDOT = 295.23 | PHITOT = 7.38 |
|            | PHI = 187.38  | PHIDOT = 552.63 |              |                 |               |
| T = .00112 | FF12 = 13.821 | FF23 = 3.793    | PSI = 285.21 | PSIDOT = 294.23 | PHITOT = 7.46 |
|            | PHI = 187.46  | PHIDOT = 563.83 |              |                 |               |
| T = .00112 | FF12 = 13.798 | FF23 = 3.782    | PSI = 285.25 | PSIDOT = 293.22 | PHITOT = 7.54 |
|            | PHI = 187.54  | PHIDOT = 575.12 |              |                 |               |
| T = .00113 | FF12 = 13.798 | FF23 = 3.782    | PSI = 285.29 | PSIDOT = 292.22 | PHITOT = 7.62 |
|            | PHI = 187.62  | PHIDOT = 586.52 |              |                 |               |
| T = .00113 | FF12 = 13.775 | FF23 = 3.771    | PSI = 285.34 | PSIDOT = 291.21 | PHITOT = 7.71 |
|            | PHI = 187.71  | PHIDOT = 598.01 |              |                 |               |
| T = .00113 | FF12 = 13.775 | FF23 = 3.771    | PSI = 285.38 | PSIDOT = 290.21 | PHITOT = 7.79 |
|            | PHI = 187.79  | PHIDOT = 609.63 |              |                 |               |
| T = .00113 | FF12 = 13.751 | FF23 = 3.759    | PSI = 285.42 | PSIDOT = 289.20 | PHITOT = 7.88 |
|            | PHI = 187.88  | PHIDOT = 621.33 |              |                 |               |
| T = .00114 | FF12 = 13.751 | FF23 = 3.760    | PSI = 285.46 | PSIDOT = 288.20 | PHITOT = 7.97 |
|            | PHI = 187.97  | PHIDOT = 633.15 |              |                 |               |
| T = .00114 | FF12 = 13.755 | FF23 = 3.354    | PSI = 285.50 | PSIDOT = 287.20 | PHITOT = 8.06 |
|            | PHI = 188.06  | PHIDOT = 644.90 |              |                 |               |
| T = .00114 | FF12 = 13.756 | FF23 = 3.354    | PSI = 285.54 | PSIDOT = 286.19 | PHITOT = 8.16 |
|            | PHI = 188.16  | PHIDOT = 656.46 |              |                 |               |
| T = .00114 | FF12 = 13.776 | FF23 = 3.339    | PSI = 285.58 | PSIDOT = 285.19 | PHITOT = 8.25 |
|            | PHI = 188.25  | PHIDOT = 667.89 |              |                 |               |
| T = .00115 | FF12 = 13.776 | FF23 = 3.340    | PSI = 285.59 | PSIDOT = 284.94 | PHITOT = 8.28 |
|            | PHI = 188.28  | PHIDOT = 670.45 |              |                 |               |
| T = .00115 | FF12 = 15.530 | FF23 = 3.436    | PSI = 285.60 | PSIDOT = 284.68 | PHITOT = 8.30 |
|            | PHI = 188.30  | PHIDOT = 672.65 |              |                 |               |
| T = .00115 | FF12 = 15.530 | FF23 = 3.436    | PSI = 285.61 | PSIDOT = 284.43 | PHITOT = 8.32 |
|            | PHI = 188.32  | PHIDOT = 674.76 |              |                 |               |
| T = .00115 | FF12 = 15.524 | FF23 = 3.441    | PSI = 285.63 | PSIDOT = 284.18 | PHITOT = 8.35 |
|            | PHI = 188.35  | PHIDOT = 676.87 |              |                 |               |
| T = .00115 | FF12 = 15.525 | FF23 = 3.441    | PSI = 285.64 | PSIDOT = 283.93 | PHITOT = 8.37 |
|            | PHI = 188.37  | PHIDOT = 679.00 |              |                 |               |
| T = .00115 | FF12 = 15.519 | FF23 = 3.445    | PSI = 285.65 | PSIDOT = 283.68 | PHITOT = 8.40 |
|            | PHI = 188.40  | PHIDOT = 681.14 |              |                 |               |
| T = .00115 | FF12 = 15.519 | FF23 = 3.445    | PSI = 285.66 | PSIDOT = 283.43 | PHITOT = 8.42 |
|            | PHI = 188.42  | PHIDOT = 683.28 |              |                 |               |
| T = .00115 | FF12 = 15.513 | FF23 = 3.450    | PSI = 285.67 | PSIDOT = 283.18 | PHITOT = 8.44 |
|            | PHI = 188.44  | PHIDOT = 685.44 |              |                 |               |
| T = .00115 | FF12 = 15.513 | FF23 = 3.450    | PSI = 285.68 | PSIDOT = 282.93 | PHITOT = 8.47 |
|            | PHI = 188.47  | PHIDOT = 687.61 |              |                 |               |
| T = .00115 | FF12 = 15.508 | FF23 = 3.455    | PSI = 285.69 | PSIDOT = 282.68 | PHITOT = 8.49 |
|            | PHI = 188.49  | PHIDOT = 689.79 |              |                 |               |
| T = .00115 | FF12 = 15.508 | FF23 = 3.455    | PSI = 285.70 | PSIDOT = 282.42 | PHITOT = 8.52 |
|            | PHI = 188.52  | PHIDOT = 691.98 |              |                 |               |
| T = .00115 | FF12 = 15.502 | FF23 = 3.460    | PSI = 285.71 | PSIDOT = 282.17 | PHITOT = 8.54 |
|            | PHI = 188.54  | PHIDOT = 694.17 |              |                 |               |
| T = .00115 | FF12 = 15.502 | FF23 = 3.460    | PSI = 285.72 | PSIDOT = 281.92 | PHITOT = 8.57 |
|            | PHI = 188.57  | PHIDOT = 696.38 |              |                 |               |
|            | FF12 = 15.496 | FF23 = 3.465    |              |                 |               |

|            |               |                 |              |                 |               |
|------------|---------------|-----------------|--------------|-----------------|---------------|
| T = .00115 | PHI = 188.59  | PHIDOT = 698.60 | PSI = 285.73 | PSIDOT = 281.67 | PHITOT = 8.59 |
|            | FF12 = 15.496 | FF23 = 3.465    |              |                 |               |
| T = .00115 | PHI = 188.62  | PHIDOT = 700.84 | PSI = 285.74 | PSIDOT = 281.42 | PHITOT = 8.62 |
|            | FF12 = 15.490 | FF23 = 3.470    |              |                 |               |
| T = .00115 | PHI = 188.64  | PHIDOT = 703.08 | PSI = 285.75 | PSIDOT = 281.17 | PHITOT = 8.64 |
|            | FF12 = 15.490 | FF23 = 3.470    |              |                 |               |
| T = .00116 | PHI = 188.67  | PHIDOT = 705.33 | PSI = 285.76 | PSIDOT = 280.92 | PHITOT = 8.67 |
|            | FF12 = 15.484 | FF23 = 3.474    |              |                 |               |
| T = .00116 | PHI = 188.69  | PHIDOT = 707.59 | PSI = 285.77 | PSIDOT = 280.67 | PHITOT = 8.69 |
|            | FF12 = 15.484 | FF23 = 3.474    |              |                 |               |
| T = .00116 | PHI = 188.72  | PHIDOT = 709.87 | PSI = 285.78 | PSIDOT = 280.42 | PHITOT = 8.72 |
|            | FF12 = 15.478 | FF23 = 3.479    |              |                 |               |
| T = .00116 | PHI = 188.75  | PHIDOT = 712.15 | PSI = 285.79 | PSIDOT = 280.16 | PHITOT = 8.75 |
|            | FF12 = 15.478 | FF23 = 3.479    |              |                 |               |
| T = .00116 | PHI = 188.77  | PHIDOT = 714.44 | PSI = 285.80 | PSIDOT = 279.91 | PHITOT = 8.77 |
|            | FF12 = 15.472 | FF23 = 3.484    |              |                 |               |
| T = .00116 | PHI = 188.80  | PHIDOT = 716.75 | PSI = 285.81 | PSIDOT = 279.66 | PHITOT = 8.80 |
|            | FF12 = 15.472 | FF23 = 3.484    |              |                 |               |
| T = .00116 | PHI = 188.82  | PHIDOT = 719.07 | PSI = 285.82 | PSIDOT = 279.41 | PHITOT = 8.82 |
|            | FF12 = 15.466 | FF23 = 3.489    |              |                 |               |
| T = .00116 | PHI = 188.85  | PHIDOT = 721.40 | PSI = 285.83 | PSIDOT = 279.16 | PHITOT = 8.85 |
|            | FF12 = 15.466 | FF23 = 3.489    |              |                 |               |
| T = .00116 | PHI = 188.87  | PHIDOT = 723.74 | PSI = 285.84 | PSIDOT = 278.91 | PHITOT = 8.87 |
|            | FF12 = 15.460 | FF23 = 3.494    |              |                 |               |
| T = .00116 | PHI = 188.90  | PHIDOT = 726.08 | PSI = 285.85 | PSIDOT = 278.66 | PHITOT = 8.90 |
|            | FF12 = 15.460 | FF23 = 3.494    |              |                 |               |
| T = .00116 | PHI = 188.93  | PHIDOT = 728.45 | PSI = 285.86 | PSIDOT = 278.41 | PHITOT = 8.93 |
|            | FF12 = 15.454 | FF23 = 3.500    |              |                 |               |
| T = .00116 | PHI = 188.95  | PHIDOT = 730.82 | PSI = 285.87 | PSIDOT = 278.16 | PHITOT = 8.95 |
|            | FF12 = 15.454 | FF23 = 3.500    |              |                 |               |
| T = .00116 | PHI = 188.98  | PHIDOT = 733.20 | PSI = 285.88 | PSIDOT = 277.90 | PHITOT = 8.98 |
|            | FF12 = 15.448 | FF23 = 3.505    |              |                 |               |
| T = .00116 | PHI = 189.00  | PHIDOT = 735.60 | PSI = 285.89 | PSIDOT = 277.65 | PHITOT = 9.00 |
|            | FF12 = 15.448 | FF23 = 3.505    |              |                 |               |
| T = .00116 | PHI = 189.03  | PHIDOT = 738.01 | PSI = 285.90 | PSIDOT = 277.40 | PHITOT = 9.03 |
|            | FF12 = 15.441 | FF23 = 3.510    |              |                 |               |
| T = .00116 | PHI = 189.06  | PHIDOT = 740.42 | PSI = 285.91 | PSIDOT = 277.15 | PHITOT = 9.06 |
|            | FF12 = 15.441 | FF23 = 3.510    |              |                 |               |
| T = .00117 | PHI = 189.08  | PHIDOT = 742.85 | PSI = 285.92 | PSIDOT = 276.90 | PHITOT = 9.08 |
|            | FF12 = 15.435 | FF23 = 3.515    |              |                 |               |
| T = .00117 | PHI = 189.11  | PHIDOT = 745.29 | PSI = 285.93 | PSIDOT = 276.65 | PHITOT = 9.11 |
|            | FF12 = 15.435 | FF23 = 3.515    |              |                 |               |
| T = .00117 | PHI = 189.14  | PHIDOT = 747.75 | PSI = 285.94 | PSIDOT = 276.40 | PHITOT = 9.14 |
|            | FF12 = 15.428 | FF23 = 3.520    |              |                 |               |
| T = .00117 | PHI = 189.16  | PHIDOT = 750.21 | PSI = 285.95 | PSIDOT = 276.15 | PHITOT = 9.16 |
|            | FF12 = 15.428 | FF23 = 3.520    |              |                 |               |
| T = .00117 | PHI = 189.19  | PHIDOT = 752.69 | PSI = 285.96 | PSIDOT = 275.90 | PHITOT = 9.19 |
|            | FF12 = 15.422 | FF23 = 3.525    |              |                 |               |
| T = .00117 | PHI = 189.22  | PHIDOT = 755.18 | PSI = 285.97 | PSIDOT = 275.64 | PHITOT = 9.22 |
|            | FF12 = 15.422 | FF23 = 3.525    |              |                 |               |
| T = .00117 | PHI = 189.25  | PHIDOT = 757.68 | PSI = 285.98 | PSIDOT = 275.39 | PHITOT = 9.25 |
|            | FF12 = 15.415 | FF23 = 3.531    |              |                 |               |
| T = .00117 | PHI = 189.27  | PHIDOT = 760.19 | PSI = 285.99 | PSIDOT = 275.14 | PHITOT = 9.27 |
|            | FF12 = 15.415 | FF23 = 3.531    |              |                 |               |
| T = .00117 | PHI = 189.30  | PHIDOT = 762.71 | PSI = 286.00 | PSIDOT = 274.89 | PHITOT = 9.30 |
|            | FF12 = 15.409 | FF23 = 3.536    |              |                 |               |
| T = .00117 | PHI = 189.33  | PHIDOT = 765.25 | PSI = 286.01 | PSIDOT = 274.64 | PHITOT = 9.33 |
|            | FF12 = 15.409 | FF23 = 3.536    |              |                 |               |
| T = .00117 | PHI = 189.35  | PHIDOT = 767.79 | PSI = 286.02 | PSIDOT = 274.39 | PHITOT = 9.35 |
|            | FF12 = 15.402 | FF23 = 3.541    |              |                 |               |
| T = .00117 | PHI = 189.38  | PHIDOT = 770.35 | PSI = 286.02 | PSIDOT = 274.14 | PHITOT = 9.38 |

Computer program SANDA2 (cont)

|            |               |                 |              |                 |                |
|------------|---------------|-----------------|--------------|-----------------|----------------|
| T = .00117 | FF12 = 15.402 | FF23 = 3.541    | PSI = 286.03 | PSIDOT = 273.89 | PHITOT = 9.41  |
|            | PHI = 189.41  | PHIDOT = 772.92 |              |                 |                |
| T = .00117 | FF12 = 15.395 | FF23 = 3.547    | PSI = 286.04 | PSIDOT = 273.64 | PHITOT = 9.44  |
|            | PHI = 189.44  | PHIDOT = 775.51 |              |                 |                |
| T = .00117 | FF12 = 15.395 | FF23 = 3.547    | PSI = 286.05 | PSIDOT = 273.38 | PHITOT = 9.46  |
|            | PHI = 189.46  | PHIDOT = 778.10 |              |                 |                |
| T = .00117 | FF12 = 15.388 | FF23 = 3.552    | PSI = 286.06 | PSIDOT = 273.13 | PHITOT = 9.49  |
|            | PHI = 189.49  | PHIDOT = 780.71 |              |                 |                |
| T = .00118 | FF12 = 15.388 | FF23 = 3.552    | PSI = 286.07 | PSIDOT = 272.88 | PHITOT = 9.52  |
|            | PHI = 189.52  | PHIDOT = 783.33 |              |                 |                |
| T = .00118 | FF12 = 15.381 | FF23 = 3.558    | PSI = 286.08 | PSIDOT = 272.63 | PHITOT = 9.55  |
|            | PHI = 189.55  | PHIDOT = 785.96 |              |                 |                |
| T = .00118 | FF12 = 15.381 | FF23 = 3.558    | PSI = 286.09 | PSIDOT = 272.38 | PHITOT = 9.58  |
|            | PHI = 189.58  | PHIDOT = 788.61 |              |                 |                |
| T = .00118 | FF12 = 15.374 | FF23 = 3.563    | PSI = 286.10 | PSIDOT = 272.13 | PHITOT = 9.61  |
|            | PHI = 189.61  | PHIDOT = 791.27 |              |                 |                |
| T = .00118 | FF12 = 15.374 | FF23 = 3.563    | PSI = 286.11 | PSIDOT = 271.88 | PHITOT = 9.63  |
|            | PHI = 189.63  | PHIDOT = 793.94 |              |                 |                |
| T = .00118 | FF12 = 15.367 | FF23 = 3.568    | PSI = 286.12 | PSIDOT = 271.63 | PHITOT = 9.66  |
|            | PHI = 189.66  | PHIDOT = 796.62 |              |                 |                |
| T = .00118 | FF12 = 15.367 | FF23 = 3.568    | PSI = 286.13 | PSIDOT = 271.38 | PHITOT = 9.69  |
|            | PHI = 189.69  | PHIDOT = 799.32 |              |                 |                |
| T = .00118 | FF12 = 15.360 | FF23 = 3.574    | PSI = 286.14 | PSIDOT = 271.12 | PHITOT = 9.72  |
|            | PHI = 189.72  | PHIDOT = 802.02 |              |                 |                |
| T = .00118 | FF12 = 15.360 | FF23 = 3.574    | PSI = 286.15 | PSIDOT = 270.87 | PHITOT = 9.75  |
|            | PHI = 189.75  | PHIDOT = 804.75 |              |                 |                |
| T = .00118 | FF12 = 15.353 | FF23 = 3.580    | PSI = 286.16 | PSIDOT = 270.62 | PHITOT = 9.78  |
|            | PHI = 189.78  | PHIDOT = 807.48 |              |                 |                |
| T = .00118 | FF12 = 15.353 | FF23 = 3.580    | PSI = 286.17 | PSIDOT = 270.37 | PHITOT = 9.81  |
|            | PHI = 189.81  | PHIDOT = 810.23 |              |                 |                |
| T = .00118 | FF12 = 15.345 | FF23 = 3.585    | PSI = 286.18 | PSIDOT = 270.12 | PHITOT = 9.84  |
|            | PHI = 189.84  | PHIDOT = 812.99 |              |                 |                |
| T = .00118 | FF12 = 15.346 | FF23 = 3.585    | PSI = 286.19 | PSIDOT = 269.87 | PHITOT = 9.86  |
|            | PHI = 189.86  | PHIDOT = 815.76 |              |                 |                |
| T = .00118 | FF12 = 15.332 | FF23 = 3.216    | PSI = 286.20 | PSIDOT = 269.62 | PHITOT = 9.89  |
|            | PHI = 189.89  | PHIDOT = 818.54 |              |                 |                |
| T = .00118 | FF12 = 15.332 | FF23 = 3.216    | PSI = 286.21 | PSIDOT = 269.37 | PHITOT = 9.92  |
|            | PHI = 189.92  | PHIDOT = 821.35 |              |                 |                |
| T = .00118 | FF12 = 15.340 | FF23 = 3.220    | PSI = 286.22 | PSIDOT = 269.12 | PHITOT = 9.95  |
|            | PHI = 189.95  | PHIDOT = 824.15 |              |                 |                |
| T = .00119 | FF12 = 15.340 | FF23 = 3.220    | PSI = 286.24 | PSIDOT = 268.61 | PHITOT = 10.01 |
|            | PHI = 190.01  | PHIDOT = 829.72 |              |                 |                |
| T = .00119 | FF12 = 15.357 | FF23 = 3.228    | PSI = 286.26 | PSIDOT = 268.11 | PHITOT = 10.07 |
|            | PHI = 190.07  | PHIDOT = 835.26 |              |                 |                |
| T = .00119 | FF12 = 15.357 | FF23 = 3.228    | PSI = 286.28 | PSIDOT = 267.61 | PHITOT = 10.13 |
|            | PHI = 190.13  | PHIDOT = 840.78 |              |                 |                |
| T = .00119 | FF12 = 15.374 | FF23 = 3.236    | PSI = 286.30 | PSIDOT = 267.11 | PHITOT = 10.19 |
|            | PHI = 190.19  | PHIDOT = 846.26 |              |                 |                |
| T = .00119 | FF12 = 15.374 | FF23 = 3.236    | PSI = 286.32 | PSIDOT = 266.61 | PHITOT = 10.25 |
|            | PHI = 190.25  | PHIDOT = 851.72 |              |                 |                |
| T = .00119 | FF12 = 15.391 | FF23 = 3.244    | PSI = 286.33 | PSIDOT = 266.10 | PHITOT = 10.31 |
|            | PHI = 190.31  | PHIDOT = 857.15 |              |                 |                |
| T = .00119 | FF12 = 15.391 | FF23 = 3.244    | PSI = 286.35 | PSIDOT = 265.60 | PHITOT = 10.38 |
|            | PHI = 190.38  | PHIDOT = 862.54 |              |                 |                |
| T = .00119 | FF12 = 15.408 | FF23 = 3.253    | PSI = 286.37 | PSIDOT = 265.10 | PHITOT = 10.44 |
|            | PHI = 190.44  | PHIDOT = 867.91 |              |                 |                |
| T = .00120 | FF12 = 15.409 | FF23 = 3.253    | PSI = 286.38 | PSIDOT = 264.85 | PHITOT = 10.47 |
|            | PHI = 190.47  | PHIDOT = 870.25 |              |                 |                |
| T = .00120 | FF12 = 15.559 | FF23 = 3.635    | PSI = 286.39 | PSIDOT = 264.60 | PHITOT = 10.50 |
|            | PHI = 190.50  | PHIDOT = 872.55 |              |                 |                |
|            | FF12 = 15.560 | FF23 = 3.635    |              |                 |                |

|            |               |                 |              |                 |                |
|------------|---------------|-----------------|--------------|-----------------|----------------|
| T = .00120 | PHI = 190.53  | PHIDOT = 874.86 | PSI = 286.40 | PSIDOT = 264.35 | PHITOT = 10.53 |
|            | FF12 = 15.552 | FF23 = 3.641    |              |                 |                |
| T = .00120 | PHI = 190.56  | PHIDOT = 877.18 | PSI = 286.41 | PSIDOT = 264.09 | PHITOT = 10.56 |
|            | FF12 = 15.552 | FF23 = 3.641    |              |                 |                |
| T = .00120 | PHI = 190.59  | PHIDOT = 879.51 | PSI = 286.42 | PSIDOT = 263.84 | PHITOT = 10.59 |
|            | FF12 = 15.544 | FF23 = 3.647    |              |                 |                |
| T = .00120 | PHI = 190.63  | PHIDOT = 881.86 | PSI = 286.43 | PSIDOT = 263.59 | PHITOT = 10.63 |
|            | FF12 = 15.544 | FF23 = 3.648    |              |                 |                |
| T = .00120 | PHI = 190.66  | PHIDOT = 884.22 | PSI = 286.44 | PSIDOT = 263.34 | PHITOT = 10.66 |
|            | FF12 = 15.536 | FF23 = 3.654    |              |                 |                |
| T = .00120 | PHI = 190.69  | PHIDOT = 886.60 | PSI = 286.45 | PSIDOT = 263.09 | PHITOT = 10.69 |
|            | FF12 = 15.536 | FF23 = 3.654    |              |                 |                |
| T = .00120 | PHI = 190.72  | PHIDOT = 888.99 | PSI = 286.46 | PSIDOT = 262.84 | PHITOT = 10.72 |
|            | FF12 = 15.528 | FF23 = 3.660    |              |                 |                |
| T = .00120 | PHI = 190.75  | PHIDOT = 891.40 | PSI = 286.47 | PSIDOT = 262.59 | PHITOT = 10.75 |
|            | FF12 = 15.528 | FF23 = 3.660    |              |                 |                |
| T = .00120 | PHI = 190.78  | PHIDOT = 893.82 | PSI = 286.48 | PSIDOT = 262.34 | PHITOT = 10.78 |
|            | FF12 = 15.520 | FF23 = 3.666    |              |                 |                |
| T = .00120 | PHI = 190.82  | PHIDOT = 896.25 | PSI = 286.49 | PSIDOT = 262.09 | PHITOT = 10.82 |
|            | FF12 = 15.520 | FF23 = 3.666    |              |                 |                |
| T = .00120 | PHI = 190.85  | PHIDOT = 898.70 | PSI = 286.50 | PSIDOT = 261.83 | PHITOT = 10.85 |
|            | FF12 = 15.512 | FF23 = 3.672    |              |                 |                |
| T = .00120 | PHI = 190.88  | PHIDOT = 901.16 | PSI = 286.50 | PSIDOT = 261.58 | PHITOT = 10.88 |
|            | FF12 = 15.512 | FF23 = 3.672    |              |                 |                |
| T = .00120 | PHI = 190.91  | PHIDOT = 903.64 | PSI = 286.51 | PSIDOT = 261.33 | PHITOT = 10.91 |
|            | FF12 = 15.504 | FF23 = 3.679    |              |                 |                |
| T = .00120 | PHI = 190.95  | PHIDOT = 906.13 | PSI = 286.52 | PSIDOT = 261.08 | PHITOT = 10.95 |
|            | FF12 = 15.504 | FF23 = 3.679    |              |                 |                |
| T = .00121 | PHI = 190.98  | PHIDOT = 908.63 | PSI = 286.53 | PSIDOT = 260.83 | PHITOT = 10.98 |
|            | FF12 = 15.496 | FF23 = 3.685    |              |                 |                |
| T = .00121 | PHI = 191.01  | PHIDOT = 911.15 | PSI = 286.54 | PSIDOT = 260.58 | PHITOT = 11.01 |
|            | FF12 = 15.496 | FF23 = 3.685    |              |                 |                |
| T = .00121 | PHI = 191.04  | PHIDOT = 913.69 | PSI = 286.55 | PSIDOT = 260.33 | PHITOT = 11.04 |
|            | FF12 = 15.488 | FF23 = 3.691    |              |                 |                |
| T = .00121 | PHI = 191.08  | PHIDOT = 916.23 | PSI = 286.56 | PSIDOT = 260.08 | PHITOT = 11.08 |
|            | FF12 = 15.488 | FF23 = 3.691    |              |                 |                |
| T = .00121 | PHI = 191.11  | PHIDOT = 918.80 | PSI = 286.57 | PSIDOT = 259.83 | PHITOT = 11.11 |
|            | FF12 = 15.479 | FF23 = 3.697    |              |                 |                |
| T = .00121 | PHI = 191.14  | PHIDOT = 921.38 | PSI = 286.58 | PSIDOT = 259.57 | PHITOT = 11.14 |
|            | FF12 = 15.479 | FF23 = 3.698    |              |                 |                |
| T = .00121 | PHI = 191.17  | PHIDOT = 923.97 | PSI = 286.59 | PSIDOT = 259.32 | PHITOT = 11.17 |
|            | FF12 = 15.471 | FF23 = 3.704    |              |                 |                |
| T = .00121 | PHI = 191.21  | PHIDOT = 926.58 | PSI = 286.60 | PSIDOT = 259.07 | PHITOT = 11.21 |
|            | FF12 = 15.471 | FF23 = 3.704    |              |                 |                |
| T = .00121 | PHI = 191.24  | PHIDOT = 929.20 | PSI = 286.61 | PSIDOT = 258.82 | PHITOT = 11.24 |
|            | FF12 = 15.462 | FF23 = 3.710    |              |                 |                |
| T = .00121 | PHI = 191.27  | PHIDOT = 931.84 | PSI = 286.62 | PSIDOT = 258.57 | PHITOT = 11.27 |
|            | FF12 = 15.462 | FF23 = 3.710    |              |                 |                |
| T = .00121 | PHI = 191.31  | PHIDOT = 934.50 | PSI = 286.63 | PSIDOT = 258.32 | PHITOT = 11.31 |
|            | FF12 = 15.454 | FF23 = 3.717    |              |                 |                |
| T = .00121 | PHI = 191.34  | PHIDOT = 937.16 | PSI = 286.63 | PSIDOT = 258.07 | PHITOT = 11.34 |
|            | FF12 = 15.454 | FF23 = 3.717    |              |                 |                |
| T = .00121 | PHI = 191.37  | PHIDOT = 939.85 | PSI = 286.64 | PSIDOT = 257.82 | PHITOT = 11.37 |
|            | FF12 = 15.445 | FF23 = 3.723    |              |                 |                |
| T = .00121 | PHI = 191.41  | PHIDOT = 942.55 | PSI = 286.65 | PSIDOT = 257.57 | PHITOT = 11.41 |
|            | FF12 = 15.445 | FF23 = 3.723    |              |                 |                |
| T = .00121 | PHI = 191.44  | PHIDOT = 945.26 | PSI = 286.66 | PSIDOT = 257.31 | PHITOT = 11.44 |
|            | FF12 = 15.436 | FF23 = 3.730    |              |                 |                |
| T = .00121 | PHI = 191.48  | PHIDOT = 947.99 | PSI = 286.67 | PSIDOT = 257.06 | PHITOT = 11.48 |
|            | FF12 = 15.436 | FF23 = 3.730    |              |                 |                |
| T = .00122 | PHI = 191.51  | PHIDOT = 950.74 | PSI = 286.68 | PSIDOT = 256.81 | PHITOT = 11.51 |

Computer program SANDAL2 (cont)

|            |                                                                   |              |                 |                |
|------------|-------------------------------------------------------------------|--------------|-----------------|----------------|
| T = .00122 | FF12 = 15.427<br>PHI = 191.54<br>FF23 = 3.736<br>PH100T = 953.50  | PSI = 286.69 | PS100T = 256.56 | PHITOT = 11.54 |
| T = .00122 | FF12 = 15.427<br>PHI = 191.58<br>FF23 = 3.736<br>PH100T = 956.28  | PSI = 286.70 | PS100T = 256.31 | PHITOT = 11.58 |
| T = .00122 | FF12 = 15.418<br>PHI = 191.61<br>FF23 = 3.743<br>PH100T = 959.07  | PSI = 286.71 | PS100T = 256.06 | PHITOT = 11.61 |
| T = .00122 | FF12 = 15.419<br>PHI = 191.65<br>FF23 = 3.743<br>PH100T = 961.88  | PSI = 286.72 | PS100T = 255.81 | PHITOT = 11.65 |
| T = .00122 | FF12 = 15.409<br>PHI = 191.68<br>FF23 = 3.749<br>PH100T = 964.70  | PSI = 286.73 | PS100T = 255.56 | PHITOT = 11.68 |
| T = .00122 | FF12 = 15.409<br>PHI = 191.72<br>FF23 = 3.750<br>PH100T = 967.54  | PSI = 286.74 | PS100T = 255.31 | PHITOT = 11.72 |
| T = .00122 | FF12 = 15.400<br>PHI = 191.75<br>FF23 = 3.756<br>PH100T = 970.40  | PSI = 286.74 | PS100T = 255.05 | PHITOT = 11.75 |
| T = .00122 | FF12 = 15.400<br>PHI = 191.79<br>FF23 = 3.756<br>PH100T = 973.27  | PSI = 286.75 | PS100T = 254.80 | PHITOT = 11.79 |
| T = .00122 | FF12 = 15.391<br>PHI = 191.82<br>FF23 = 3.763<br>PH100T = 976.16  | PSI = 286.76 | PS100T = 254.55 | PHITOT = 11.82 |
| T = .00122 | FF12 = 15.391<br>PHI = 191.86<br>FF23 = 3.763<br>PH100T = 979.07  | PSI = 286.77 | PS100T = 254.30 | PHITOT = 11.86 |
| T = .00122 | FF12 = 15.392<br>PHI = 191.89<br>FF23 = 3.770<br>PH100T = 981.98  | PSI = 286.78 | PS100T = 254.05 | PHITOT = 11.89 |
| T = .00122 | FF12 = 15.382<br>PHI = 191.93<br>FF23 = 3.770<br>PH100T = 984.92  | PSI = 286.79 | PS100T = 253.80 | PHITOT = 11.93 |
| T = .00122 | FF12 = 15.372<br>PHI = 191.96<br>FF23 = 3.776<br>PH100T = 987.87  | PSI = 286.80 | PS100T = 253.55 | PHITOT = 11.96 |
| T = .00122 | FF12 = 15.372<br>PHI = 192.00<br>FF23 = 3.776<br>PH100T = 990.85  | PSI = 286.81 | PS100T = 253.30 | PHITOT = 12.00 |
| T = .00122 | FF12 = 15.368<br>PHI = 192.03<br>FF23 = 3.387<br>PH100T = 993.84  | PSI = 286.82 | PS100T = 253.05 | PHITOT = 12.03 |
| T = .00123 | FF12 = 15.368<br>PHI = 192.07<br>FF23 = 3.387<br>PH100T = 996.81  | PSI = 286.83 | PS100T = 252.79 | PHITOT = 12.07 |
| T = .00123 | FF12 = 15.378<br>PHI = 192.10<br>FF23 = 3.392<br>PH100T = 999.78  | PSI = 286.84 | PS100T = 252.54 | PHITOT = 12.10 |
| T = .00123 | FF12 = 15.378<br>PHI = 192.14<br>FF23 = 3.392<br>PH100T = 1002.74 | PSI = 286.84 | PS100T = 252.29 | PHITOT = 12.14 |
| T = .00123 | FF12 = 15.389<br>PHI = 192.18<br>FF23 = 3.397<br>PH100T = 1005.69 | PSI = 286.85 | PS100T = 252.04 | PHITOT = 12.18 |
| T = .00123 | FF12 = 15.389<br>PHI = 192.21<br>FF23 = 3.402<br>PH100T = 1008.63 | PSI = 286.86 | PS100T = 251.79 | PHITOT = 12.21 |
| T = .00123 | FF12 = 15.399<br>PHI = 192.25<br>FF23 = 3.402<br>PH100T = 1011.56 | PSI = 286.87 | PS100T = 251.54 | PHITOT = 12.25 |
| T = .00123 | FF12 = 15.400<br>PHI = 192.28<br>FF23 = 3.407<br>PH100T = 1014.48 | PSI = 286.88 | PS100T = 251.29 | PHITOT = 12.28 |
| T = .00123 | FF12 = 15.410<br>PHI = 192.32<br>FF23 = 3.407<br>PH100T = 1017.39 | PSI = 286.89 | PS100T = 251.04 | PHITOT = 12.32 |
| T = .00123 | FF12 = 15.410<br>PHI = 192.36<br>FF23 = 3.412<br>PH100T = 1020.30 | PSI = 286.90 | PS100T = 250.79 | PHITOT = 12.36 |
| T = .00123 | FF12 = 15.421<br>PHI = 192.39<br>FF23 = 3.412<br>PH100T = 1023.19 | PSI = 286.91 | PS100T = 250.54 | PHITOT = 12.39 |
| T = .00123 | FF12 = 15.421<br>PHI = 192.43<br>FF23 = 3.418<br>PH100T = 1026.07 | PSI = 286.92 | PS100T = 250.28 | PHITOT = 12.43 |
| T = .00123 | FF12 = 15.412<br>PHI = 192.47<br>FF23 = 3.418<br>PH100T = 1028.95 | PSI = 286.93 | PS100T = 250.03 | PHITOT = 12.47 |
| T = .00123 | FF12 = 15.432<br>PHI = 192.50<br>FF23 = 3.423<br>PH100T = 1031.81 | PSI = 286.93 | PS100T = 249.78 | PHITOT = 12.50 |
| T = .00123 | FF12 = 15.443<br>PHI = 192.54<br>FF23 = 3.423<br>PH100T = 1034.66 | PSI = 286.94 | PS100T = 249.53 | PHITOT = 12.54 |
| T = .00123 | FF12 = 15.443<br>PHI = 192.56<br>FF23 = 3.423<br>PH100T = 1035.91 | PSI = 286.95 | PS100T = 249.41 | PHITOT = 12.56 |
|            | FF12 = 15.607<br>FF23 = 3.621                                     |              |                 |                |

## Computer program SANDA2 (cont)

|            |               |                  |              |                 |                |
|------------|---------------|------------------|--------------|-----------------|----------------|
| T = .00123 | PHI = 192.58  | PHIDOT = 1037.13 | PSI = 286.95 | PSIDOT = 249.28 | PHITOT = 12.58 |
|            | FF12 = 15.607 | FF23 = 3.821     |              |                 |                |
| T = .00123 | PHI = 192.60  | PHIDOT = 1038.35 | PSI = 286.96 | PSIDOT = 249.15 | PHITOT = 12.60 |
|            | FF12 = 15.602 | FF23 = 3.824     |              |                 |                |
| T = .00123 | PHI = 192.62  | PHIDOT = 1039.57 | PSI = 286.96 | PSIDOT = 249.03 | PHITOT = 12.62 |
|            | FF12 = 15.602 | FF23 = 3.824     |              |                 |                |
| T = .00124 | PHI = 192.65  | PHIDOT = 1042.03 | PSI = 286.97 | PSIDOT = 248.78 | PHITOT = 12.65 |
|            | FF12 = 15.593 | FF23 = 3.831     |              |                 |                |
| T = .00124 | PHI = 192.69  | PHIDOT = 1044.51 | PSI = 286.98 | PSIDOT = 248.53 | PHITOT = 12.69 |
|            | FF12 = 15.593 | FF23 = 3.831     |              |                 |                |
| T = .00124 | PHI = 192.73  | PHIDOT = 1047.01 | PSI = 286.99 | PSIDOT = 248.28 | PHITOT = 12.73 |
|            | FF12 = 15.593 | FF23 = 3.839     |              |                 |                |
| T = .00124 | PHI = 192.76  | PHIDOT = 1049.52 | PSI = 287.00 | PSIDOT = 248.02 | PHITOT = 12.76 |
|            | FF12 = 15.583 | FF23 = 3.839     |              |                 |                |
| T = .00124 | PHI = 192.80  | PHIDOT = 1052.05 | PSI = 287.01 | PSIDOT = 247.77 | PHITOT = 12.80 |
|            | FF12 = 15.573 | FF23 = 3.846     |              |                 |                |
| T = .00124 | PHI = 192.84  | PHIDOT = 1054.60 | PSI = 287.01 | PSIDOT = 247.52 | PHITOT = 12.84 |
|            | FF12 = 15.573 | FF23 = 3.846     |              |                 |                |
| T = .00124 | PHI = 192.88  | PHIDOT = 1057.17 | PSI = 287.02 | PSIDOT = 247.27 | PHITOT = 12.88 |
|            | FF12 = 15.563 | FF23 = 3.853     |              |                 |                |
| T = .00124 | PHI = 192.92  | PHIDOT = 1059.75 | PSI = 287.03 | PSIDOT = 247.02 | PHITOT = 12.92 |
|            | FF12 = 15.563 | FF23 = 3.853     |              |                 |                |
| T = .00124 | PHI = 192.95  | PHIDOT = 1062.35 | PSI = 287.04 | PSIDOT = 246.77 | PHITOT = 12.95 |
|            | FF12 = 15.553 | FF23 = 3.860     |              |                 |                |
| T = .00124 | PHI = 192.99  | PHIDOT = 1064.96 | PSI = 287.05 | PSIDOT = 246.52 | PHITOT = 12.99 |
|            | FF12 = 15.553 | FF23 = 3.860     |              |                 |                |
| T = .00124 | PHI = 193.03  | PHIDOT = 1067.60 | PSI = 287.06 | PSIDOT = 246.27 | PHITOT = 13.03 |
|            | FF12 = 15.543 | FF23 = 3.868     |              |                 |                |
| T = .00124 | PHI = 193.07  | PHIDOT = 1070.25 | PSI = 287.07 | PSIDOT = 246.02 | PHITOT = 13.07 |
|            | FF12 = 15.543 | FF23 = 3.868     |              |                 |                |
| T = .00124 | PHI = 193.11  | PHIDOT = 1072.93 | PSI = 287.08 | PSIDOT = 245.76 | PHITOT = 13.11 |
|            | FF12 = 15.532 | FF23 = 3.875     |              |                 |                |
| T = .00124 | PHI = 193.15  | PHIDOT = 1075.61 | PSI = 287.09 | PSIDOT = 245.51 | PHITOT = 13.15 |
|            | FF12 = 15.533 | FF23 = 3.875     |              |                 |                |
| T = .00124 | PHI = 193.18  | PHIDOT = 1078.32 | PSI = 287.09 | PSIDOT = 245.26 | PHITOT = 13.18 |
|            | FF12 = 15.522 | FF23 = 3.883     |              |                 |                |
| T = .00124 | PHI = 193.22  | PHIDOT = 1081.04 | PSI = 287.10 | PSIDOT = 245.01 | PHITOT = 13.22 |
|            | FF12 = 15.522 | FF23 = 3.883     |              |                 |                |
| T = .00125 | PHI = 193.26  | PHIDOT = 1083.79 | PSI = 287.11 | PSIDOT = 244.76 | PHITOT = 13.26 |
|            | FF12 = 15.512 | FF23 = 3.890     |              |                 |                |
| T = .00125 | PHI = 193.30  | PHIDOT = 1086.55 | PSI = 287.12 | PSIDOT = 244.51 | PHITOT = 13.30 |
|            | FF12 = 15.512 | FF23 = 3.890     |              |                 |                |
| T = .00125 | PHI = 193.34  | PHIDOT = 1089.33 | PSI = 287.13 | PSIDOT = 244.26 | PHITOT = 13.34 |
|            | FF12 = 15.501 | FF23 = 3.897     |              |                 |                |
| T = .00125 | PHI = 193.38  | PHIDOT = 1092.13 | PSI = 287.14 | PSIDOT = 244.01 | PHITOT = 13.38 |
|            | FF12 = 15.501 | FF23 = 3.897     |              |                 |                |
| T = .00125 | PHI = 193.42  | PHIDOT = 1094.94 | PSI = 287.15 | PSIDOT = 243.76 | PHITOT = 13.42 |
|            | FF12 = 15.490 | FF23 = 3.905     |              |                 |                |
| T = .00125 | PHI = 193.46  | PHIDOT = 1097.78 | PSI = 287.16 | PSIDOT = 243.50 | PHITOT = 13.46 |
|            | FF12 = 15.491 | FF23 = 3.905     |              |                 |                |
| T = .00125 | PHI = 193.50  | PHIDOT = 1100.63 | PSI = 287.16 | PSIDOT = 243.25 | PHITOT = 13.50 |
|            | FF12 = 15.480 | FF23 = 3.912     |              |                 |                |
| T = .00125 | PHI = 193.54  | PHIDOT = 1103.50 | PSI = 287.17 | PSIDOT = 243.00 | PHITOT = 13.54 |
|            | FF12 = 15.480 | FF23 = 3.912     |              |                 |                |
| T = .00125 | PHI = 193.58  | PHIDOT = 1106.39 | PSI = 287.18 | PSIDOT = 242.75 | PHITOT = 13.58 |
|            | FF12 = 15.469 | FF23 = 3.920     |              |                 |                |
| T = .00125 | PHI = 193.61  | PHIDOT = 1109.30 | PSI = 287.19 | PSIDOT = 242.50 | PHITOT = 13.61 |
|            | FF12 = 15.469 | FF23 = 3.920     |              |                 |                |
| T = .00125 | PHI = 193.65  | PHIDOT = 1112.23 | PSI = 287.20 | PSIDOT = 242.25 | PHITOT = 13.65 |
|            | FF12 = 15.458 | FF23 = 3.928     |              |                 |                |
| T = .00125 | PHI = 193.69  | PHIDOT = 1115.18 | PSI = 287.21 | PSIDOT = 242.00 | PHITOT = 13.69 |

Computer program SANDA2 (cont)

|            |               |                  |              |                 |                |
|------------|---------------|------------------|--------------|-----------------|----------------|
| T = .00125 | FF12 = 15.458 | FF23 = 3.928     | PSI = 287.22 | PSIDOT = 241.75 | PHITOT = 13.73 |
|            | PHI = 193.73  | PHIDOT = 1118.14 |              |                 |                |
| T = .00125 | FF12 = 15.447 | FF23 = 3.935     | PSI = 287.23 | PSIDOT = 241.50 | PHITOT = 13.77 |
|            | PHI = 193.77  | PHIDOT = 1121.13 |              |                 |                |
| T = .00125 | FF12 = 15.447 | FF23 = 3.935     | PSI = 287.23 | PSIDOT = 241.24 | PHITOT = 13.81 |
|            | PHI = 193.81  | PHIDOT = 1124.14 |              |                 |                |
| T = .00125 | FF12 = 13.820 | FF23 = 3.937     | PSI = 287.24 | PSIDOT = 240.99 | PHITOT = 13.85 |
|            | PHI = 193.85  | PHIDOT = 1127.16 |              |                 |                |
| T = .00126 | FF12 = 13.820 | FF23 = 3.937     | PSI = 287.25 | PSIDOT = 240.74 | PHITOT = 13.90 |
|            | PHI = 193.90  | PHIDOT = 1130.19 |              |                 |                |
| T = .00126 | FF12 = 13.808 | FF23 = 3.932     | PSI = 287.26 | PSIDOT = 240.49 | PHITOT = 13.94 |
|            | PHI = 193.94  | PHIDOT = 1133.24 |              |                 |                |
| T = .00126 | FF12 = 13.809 | FF23 = 3.932     | PSI = 287.27 | PSIDOT = 240.24 | PHITOT = 13.98 |
|            | PHI = 193.98  | PHIDOT = 1136.30 |              |                 |                |
| T = .00126 | FF12 = 13.797 | FF23 = 3.926     | PSI = 287.28 | PSIDOT = 239.99 | PHITOT = 14.02 |
|            | PHI = 194.02  | PHIDOT = 1139.37 |              |                 |                |
| T = .00126 | FF12 = 13.797 | FF23 = 3.926     | PSI = 287.29 | PSIDOT = 239.74 | PHITOT = 14.06 |
|            | PHI = 194.06  | PHIDOT = 1142.46 |              |                 |                |
| T = .00126 | FF12 = 13.785 | FF23 = 3.921     | PSI = 287.29 | PSIDOT = 239.49 | PHITOT = 14.10 |
|            | PHI = 194.10  | PHIDOT = 1145.56 |              |                 |                |
| T = .00126 | FF12 = 13.785 | FF23 = 3.921     | PSI = 287.30 | PSIDOT = 239.24 | PHITOT = 14.14 |
|            | PHI = 194.14  | PHIDOT = 1148.68 |              |                 |                |
| T = .00126 | FF12 = 13.784 | FF23 = 3.505     | PSI = 287.31 | PSIDOT = 238.98 | PHITOT = 14.18 |
|            | PHI = 194.18  | PHIDOT = 1151.79 |              |                 |                |
| T = .00126 | FF12 = 13.784 | FF23 = 3.505     | PSI = 287.33 | PSIDOT = 238.48 | PHITOT = 14.26 |
|            | PHI = 194.26  | PHIDOT = 1157.95 |              |                 |                |
| T = .00126 | FF12 = 13.803 | FF23 = 3.493     | PSI = 287.35 | PSIDOT = 237.98 | PHITOT = 14.35 |
|            | PHI = 194.35  | PHIDOT = 1164.06 |              |                 |                |
| T = .00126 | FF12 = 13.804 | FF23 = 3.493     | PSI = 287.36 | PSIDOT = 237.48 | PHITOT = 14.43 |
|            | PHI = 194.43  | PHIDOT = 1170.08 |              |                 |                |
| T = .00126 | FF12 = 13.823 | FF23 = 3.480     | PSI = 287.38 | PSIDOT = 236.98 | PHITOT = 14.51 |
|            | PHI = 194.51  | PHIDOT = 1176.05 |              |                 |                |
| T = .00127 | FF12 = 13.823 | FF23 = 3.480     | PSI = 287.40 | PSIDOT = 236.47 | PHITOT = 14.60 |
|            | PHI = 194.60  | PHIDOT = 1181.92 |              |                 |                |
| T = .00127 | FF12 = 13.843 | FF23 = 3.468     | PSI = 287.41 | PSIDOT = 235.97 | PHITOT = 14.68 |
|            | PHI = 194.68  | PHIDOT = 1187.75 |              |                 |                |
| T = .00127 | FF12 = 13.843 | FF23 = 3.468     | PSI = 287.43 | PSIDOT = 235.47 | PHITOT = 14.77 |
|            | PHI = 194.77  | PHIDOT = 1192.81 |              |                 |                |
| T = .00127 | FF12 = 13.974 | FF23 = 3.851     | PSI = 287.45 | PSIDOT = 234.97 | PHITOT = 14.86 |
|            | PHI = 194.86  | PHIDOT = 1197.77 |              |                 |                |
| T = .00127 | FF12 = 13.975 | FF23 = 3.851     | PSI = 287.46 | PSIDOT = 234.46 | PHITOT = 14.94 |
|            | PHI = 194.94  | PHIDOT = 1202.79 |              |                 |                |
| T = .00127 | FF12 = 13.950 | FF23 = 3.839     | PSI = 287.48 | PSIDOT = 233.96 | PHITOT = 15.03 |
|            | PHI = 195.03  | PHIDOT = 1207.86 |              |                 |                |
| T = .00127 | FF12 = 13.950 | FF23 = 3.840     | PSI = 287.50 | PSIDOT = 233.46 | PHITOT = 15.11 |
|            | PHI = 195.11  | PHIDOT = 1213.00 |              |                 |                |
| T = .00127 | FF12 = 13.925 | FF23 = 3.828     | PSI = 287.51 | PSIDOT = 232.96 | PHITOT = 15.20 |
|            | PHI = 195.20  | PHIDOT = 1218.17 |              |                 |                |
| T = .00128 | FF12 = 13.925 | FF23 = 3.828     | PSI = 287.53 | PSIDOT = 232.46 | PHITOT = 15.29 |
|            | PHI = 195.29  | PHIDOT = 1223.42 |              |                 |                |
| T = .00128 | FF12 = 13.900 | FF23 = 3.816     | PSI = 287.55 | PSIDOT = 231.95 | PHITOT = 15.38 |
|            | PHI = 195.38  | PHIDOT = 1228.71 |              |                 |                |
| T = .00128 | FF12 = 13.901 | FF23 = 3.816     | PSI = 287.56 | PSIDOT = 231.45 | PHITOT = 15.46 |
|            | PHI = 195.46  | PHIDOT = 1234.07 |              |                 |                |
| T = .00128 | FF12 = 13.876 | FF23 = 3.804     | PSI = 287.58 | PSIDOT = 230.95 | PHITOT = 15.55 |
|            | PHI = 195.55  | PHIDOT = 1239.47 |              |                 |                |
| T = .00128 | FF12 = 13.876 | FF23 = 3.804     | PSI = 287.60 | PSIDOT = 230.45 | PHITOT = 15.64 |
|            | PHI = 195.64  | PHIDOT = 1244.94 |              |                 |                |
| T = .00128 | FF12 = 13.851 | FF23 = 3.792     | PSI = 287.61 | PSIDOT = 229.95 | PHITOT = 15.73 |
|            | PHI = 195.73  | PHIDOT = 1250.46 |              |                 |                |
|            | FF12 = 13.851 | FF23 = 3.792     |              |                 |                |

T = .00128 PHI = 195.82 PHIDOT = 1255.04 PSI = 287.63 PSIDOT = 229.44 PHITOT = 15.82  
 FF12 = 13.826  
 T = .00128 PHI = 195.81 PHIDOT = 1261.66 PSI = 287.65 PSIDOT = 228.94 PHITOT = 15.91  
 FF12 = 13.826  
 T = .00129 PHI = 196.00 PHIDOT = 1267.36 PSI = 287.66 PSIDOT = 228.44 PHITOT = 16.00  
 FF12 = 13.801  
 T = .00129 PHI = 196.09 PHIDOT = 1273.10 PSI = 287.68 PSIDOT = 227.94 PHITOT = 16.09  
 FF12 = 13.801  
 T = .00129 PHI = 196.18 PHIDOT = 1278.90 PSI = 287.70 PSIDOT = 227.43 PHITOT = 16.18  
 FF12 = 13.776  
 T = .00129 PHI = 196.28 PHIDOT = 1284.75 PSI = 287.71 PSIDOT = 226.93 PHITOT = 16.28  
 FF12 = 13.776  
 T = .00129 PHI = 196.37 PHIDOT = 1290.66 PSI = 287.73 PSIDOT = 226.43 PHITOT = 16.37  
 FF12 = 13.784  
 T = .00129 PHI = 196.46 PHIDOT = 1296.51 PSI = 287.74 PSIDOT = 225.93 PHITOT = 16.46  
 FF12 = 13.784  
 T = .00129 PHI = 196.55 PHIDOT = 1302.27 PSI = 287.76 PSIDOT = 225.43 PHITOT = 16.55  
 FF12 = 15.381  
 T = .00129 PHI = 196.65 PHIDOT = 1307.88 PSI = 287.78 PSIDOT = 224.92 PHITOT = 16.65  
 FF12 = 15.382  
 T = .00130 PHI = 196.74 PHIDOT = 1312.98 PSI = 287.79 PSIDOT = 224.42 PHITOT = 16.74  
 FF12 = 15.407  
 T = .00130 PHI = 196.84 PHIDOT = 1318.05 PSI = 287.81 PSIDOT = 223.92 PHITOT = 16.84  
 FF12 = 15.407  
 T = .00130 PHI = 196.88 PHIDOT = 1320.27 PSI = 287.82 PSIDOT = 223.67 PHITOT = 16.88  
 FF12 = 15.546  
 T = .00130 PHI = 196.93 PHIDOT = 1322.45 PSI = 287.82 PSIDOT = 223.42 PHITOT = 16.93  
 FF12 = 15.546  
 T = .00130 PHI = 196.98 PHIDOT = 1324.65 PSI = 287.83 PSIDOT = 223.17 PHITOT = 16.98  
 FF12 = 15.535  
 T = .00130 PHI = 197.02 PHIDOT = 1326.86 PSI = 287.84 PSIDOT = 222.91 PHITOT = 17.02  
 FF12 = 15.535  
 T = .00130 PHI = 197.07 PHIDOT = 1329.10 PSI = 287.85 PSIDOT = 222.66 PHITOT = 17.07  
 FF12 = 15.523  
 T = .00130 PHI = 197.12 PHIDOT = 1331.35 PSI = 287.86 PSIDOT = 222.41 PHITOT = 17.12  
 FF12 = 15.524  
 T = .00130 PHI = 197.17 PHIDOT = 1333.63 PSI = 287.86 PSIDOT = 222.16 PHITOT = 17.17  
 FF12 = 15.512  
 T = .00130 PHI = 197.22 PHIDOT = 1335.93 PSI = 287.87 PSIDOT = 221.91 PHITOT = 17.22  
 FF12 = 15.512  
 T = .00130 PHI = 197.26 PHIDOT = 1338.25 PSI = 287.88 PSIDOT = 221.66 PHITOT = 17.26  
 FF12 = 15.501  
 T = .00130 PHI = 197.31 PHIDOT = 1340.58 PSI = 287.89 PSIDOT = 221.41 PHITOT = 17.31  
 FF12 = 15.501  
 T = .00130 PHI = 197.36 PHIDOT = 1342.94 PSI = 287.90 PSIDOT = 221.16 PHITOT = 17.36  
 FF12 = 15.489  
 T = .00130 PHI = 197.41 PHIDOT = 1345.32 PSI = 287.90 PSIDOT = 220.91 PHITOT = 17.41  
 FF12 = 15.490  
 VP = -13.809 VS = 148.198

IMPACT  
 PHI = 137.408 PHIDOT = 60.802 PSI = 287.904 PSIDOT = -107.144 PHITOT = 17.408  
 VS = 6.699

COUPLED MOTION  
 T = .00130 PHI = 197.41 PHIDOT = 60.80 GDUT = 15.31 PSID = 287.85 PSIDOT = -107.22 PHITOT = 17.41  
 F12 = 3.8780 PN = .7646 PNP1 = .7646 DPH12 = .1525E+06  
 T = .00131 PHI = 197.44 PHIDOT = 62.33 GDUT = 15.72 PSID = 287.79 PSIDOT = -110.22 PHITOT = 17.44  
 F12 = 3.8903 PN = .7743 PNP1 = .7743 DPH12 = .1551E+06  
 T = .00132 PHI = 197.48 PHIDOT = 63.86 GDUT = 16.13 PSID = 287.72 PSIDOT = -113.23 PHITOT = 17.48

## Computer program SANDA2 (cont)

|            |              |                 |            |              |                   |                  |
|------------|--------------|-----------------|------------|--------------|-------------------|------------------|
| T = .00133 | F23 = 3.8905 | F12 = 16.3374   | PN = .7739 | NP51 = .7739 | DPH12 = .1529E+06 | PHITOT = 17.52   |
|            | PH1 = 197.52 | PH100T = 65.39  | G = -.0082 | GD0T = 16.55 | PS10 = 287.66     | PS100T = -116.28 |
| T = .00134 | F23 = 3.9035 | F12 = 16.4003   | PN = .7842 | NP51 = .7842 | DPH12 = .1556E+06 | PHITOT = 17.55   |
|            | PH1 = 197.55 | PH100T = 66.92  | G = -.0080 | GD0T = 16.97 | PS10 = 287.59     | PS100T = -119.35 |
| T = .00135 | F23 = 3.9037 | F12 = 16.4010   | PN = .7838 | NP51 = .7838 | DPH12 = .1532E+06 | PHITOT = 17.59   |
|            | PH1 = 197.59 | PH100T = 68.45  | G = -.0078 | GD0T = 17.39 | PS10 = 287.52     | PS100T = -122.46 |
| T = .00136 | F23 = 3.9173 | F12 = 16.4041   | PN = .7946 | NP51 = .7946 | DPH12 = .1560E+06 | PHITOT = 17.63   |
|            | PH1 = 197.63 | PH100T = 69.99  | G = -.0077 | GD0T = 17.81 | PS10 = 287.45     | PS100T = -125.59 |
| T = .00137 | F23 = 3.9176 | F12 = 16.4048   | PN = .7941 | NP51 = .7941 | DPH12 = .1534E+06 | PHITOT = 17.67   |
|            | PH1 = 197.67 | PH100T = 71.52  | G = -.0075 | GD0T = 18.24 | PS10 = 287.38     | PS100T = -128.76 |
| T = .00138 | F23 = 3.9319 | F12 = 16.4080   | PN = .8055 | NP51 = .8055 | DPH12 = .1562E+06 | PHITOT = 17.71   |
|            | PH1 = 197.71 | PH100T = 73.05  | G = -.0073 | GD0T = 18.67 | PS10 = 287.30     | PS100T = -131.94 |
| T = .00139 | F23 = 3.9322 | F12 = 16.4089   | PN = .8050 | NP51 = .8050 | DPH12 = .1535E+06 | PHITOT = 17.76   |
|            | PH1 = 197.76 | PH100T = 74.59  | G = -.0071 | GD0T = 19.10 | PS10 = 287.23     | PS100T = -135.17 |
| T = .00140 | F23 = 3.9471 | F12 = 16.4122   | PN = .8169 | NP51 = .8169 | DPH12 = .1564E+06 | PHITOT = 17.80   |
|            | PH1 = 197.90 | PH100T = 76.13  | G = -.0069 | GD0T = 19.53 | PS10 = 287.15     | PS100T = -138.42 |
| T = .00141 | F23 = 3.9474 | F12 = 16.4131   | PN = .8163 | NP51 = .8163 | DPH12 = .1535E+06 | PHITOT = 17.84   |
|            | PH1 = 197.84 | PH100T = 77.66  | G = -.0067 | GD0T = 19.97 | PS10 = 287.07     | PS100T = -141.72 |
| T = .00142 | F23 = 3.9630 | F12 = 16.4166   | PN = .8288 | NP51 = .8288 | DPH12 = .1564E+06 | PHITOT = 17.89   |
|            | PH1 = 197.89 | PH100T = 79.20  | G = -.0065 | GD0T = 20.41 | PS10 = 286.99     | PS100T = -145.03 |
| T = .00143 | F23 = 3.9634 | F12 = 16.4176   | PN = .8282 | NP51 = .8282 | DPH12 = .1534E+06 | PHITOT = 17.93   |
|            | PH1 = 197.93 | PH100T = 80.73  | G = -.0063 | GD0T = 20.85 | PS10 = 286.90     | PS100T = -148.39 |
| T = .00144 | F23 = 3.9797 | F12 = 16.4212   | PN = .8412 | NP51 = .8412 | DPH12 = .1563E+06 | PHITOT = 17.98   |
|            | PH1 = 197.98 | PH100T = 82.26  | G = -.0061 | GD0T = 21.30 | PS10 = 286.82     | PS100T = -151.77 |
| T = .00145 | F23 = 3.9801 | F12 = 16.4222   | PN = .8406 | NP51 = .8406 | DPH12 = .1532E+06 | PHITOT = 18.03   |
|            | PH1 = 198.03 | PH100T = 83.80  | G = -.0059 | GD0T = 21.75 | PS10 = 286.73     | PS100T = -155.19 |
| T = .00146 | F23 = 3.9971 | F12 = 16.4261   | PN = .8541 | NP51 = .8541 | DPH12 = .1561E+06 | PHITOT = 18.08   |
|            | PH1 = 198.08 | PH100T = 85.32  | G = -.0057 | GD0T = 22.20 | PS10 = 286.64     | PS100T = -158.64 |
| T = .00147 | F23 = 3.9975 | F12 = 16.4271   | PN = .8535 | NP51 = .8535 | DPH12 = .1528E+06 | PHITOT = 18.13   |
|            | PH1 = 198.13 | PH100T = 86.85  | G = -.0054 | GD0T = 22.65 | PS10 = 286.55     | PS100T = -162.13 |
| T = .00148 | F23 = 4.0122 | F12 = 16.4311   | PN = .8676 | NP51 = .8676 | DPH12 = .1557E+06 | PHITOT = 18.18   |
|            | PH1 = 198.18 | PH100T = 88.37  | G = -.0052 | GD0T = 23.11 | PS10 = 286.45     | PS100T = -165.65 |
| T = .00149 | F23 = 4.0156 | F12 = 16.4322   | PN = .8669 | NP51 = .8669 | DPH12 = .1522E+06 | PHITOT = 18.23   |
|            | PH1 = 198.23 | PH100T = 89.90  | G = -.0050 | GD0T = 23.57 | PS10 = 286.36     | PS100T = -169.21 |
| T = .00150 | F23 = 4.0340 | F12 = 16.4364   | PN = .8816 | NP51 = .8816 | DPH12 = .1551E+06 | PHITOT = 18.28   |
|            | PH1 = 198.28 | PH100T = 91.41  | G = -.0047 | GD0T = 24.03 | PS10 = 286.26     | PS100T = -172.80 |
| T = .00151 | F23 = 4.0344 | F12 = 16.4375   | PN = .8809 | NP51 = .8809 | DPH12 = .1514E+06 | PHITOT = 18.33   |
|            | PH1 = 198.33 | PH100T = 92.92  | G = -.0045 | GD0T = 24.49 | PS10 = 286.16     | PS100T = -176.43 |
| T = .00152 | F23 = 3.6700 | F12 = 16.4418   | PN = .8970 | NP51 = .8970 | DPH12 = .1546E+06 | PHITOT = 18.39   |
|            | PH1 = 198.39 | PH100T = 94.43  | G = -.0043 | GD0T = 24.96 | PS10 = 286.06     | PS100T = -180.09 |
| T = .00153 | F23 = 3.6304 | F12 = 16.4430   | PN = .8962 | NP51 = .8962 | DPH12 = .1508E+06 | PHITOT = 18.44   |
|            | PH1 = 198.44 | PH100T = 95.91  | G = -.0040 | GD0T = 25.43 | PS10 = 285.95     | PS100T = -183.74 |
| T = .00154 | F23 = 3.6347 | F12 = 16.4501   | PN = .8862 | NP51 = .8862 | DPH12 = .1430E+06 | PHITOT = 18.50   |
|            | PH1 = 198.50 | PH100T = 97.33  | G = -.0038 | GD0T = 25.88 | PS10 = 285.85     | PS100T = -187.34 |
| T = .00155 | F23 = 3.6351 | F12 = 16.4513   | PN = .8854 | NP51 = .8854 | DPH12 = .1391E+06 | PHITOT = 18.55   |
|            | PH1 = 198.55 | PH100T = 98.69  | G = -.0035 | GD0T = 26.32 | PS10 = 285.74     | PS100T = -190.86 |
| T = .00156 | F23 = 3.6395 | F12 = 16.4595   | PN = .8751 | NP51 = .8751 | DPH12 = .1314E+06 | PHITOT = 18.61   |
|            | PH1 = 198.61 | PH100T = 99.99  | G = -.0032 | GD0T = 26.75 | PS10 = 285.63     | PS100T = -194.32 |
| T = .00157 | F23 = 3.6399 | F12 = 16.4528   | PN = .8743 | NP51 = .8743 | DPH12 = .1275E+06 | PHITOT = 18.67   |
|            | PH1 = 198.67 | PH100T = 101.24 | G = -.0030 | GD0T = 27.17 | PS10 = 285.52     | PS100T = -197.70 |
| T = .00158 | F23 = 3.6444 | F12 = 16.4672   | PN = .8636 | NP51 = .8636 | DPH12 = .1197E+06 | PHITOT = 18.73   |
|            | PH1 = 198.73 | PH100T = 102.43 | G = -.0027 | GD0T = 27.57 | PS10 = 285.40     | PS100T = -201.03 |
| T = .00159 | F23 = 3.6448 | F12 = 16.4684   | PN = .8628 | NP51 = .8628 | DPH12 = .1158E+06 | PHITOT = 18.78   |
|            | PH1 = 198.78 | PH100T = 103.55 | G = -.0024 | GD0T = 27.97 | PS10 = 285.28     | PS100T = -204.28 |
| T = .00160 | F23 = 3.6493 | F12 = 16.4759   | PN = .8519 | NP51 = .8519 | DPH12 = .1081E+06 | PHITOT = 18.84   |
|            | PH1 = 198.84 | PH100T = 104.63 | G = -.0021 | GD0T = 28.35 | PS10 = 285.17     | PS100T = -207.46 |
| T = .00161 | F23 = 3.6498 | F12 = 16.4772   | PN = .8510 | NP51 = .8510 | DPH12 = .1043E+06 | PHITOT = 18.90   |
|            | PH1 = 198.90 | PH100T = 105.64 | G = -.0018 | GD0T = 28.72 | PS10 = 285.05     | PS100T = -210.57 |
| T = .00162 | F23 = 4.0030 | F12 = 16.4970   | PN = .7074 | NP51 = .7074 | DPH12 = .4582E+05 | PHITOT = 18.97   |
|            | PH1 = 199.97 | PH100T = 106.51 | G = -.0015 | GD0T = 29.06 | PS10 = 284.93     | PS100T = -213.45 |
|            | F23 = 4.0034 | F12 = 16.4981   | PN = .7066 | NP51 = .7066 | DPH12 = .4368E+05 |                  |

|            |               |                 |              |                 |                  |
|------------|---------------|-----------------|--------------|-----------------|------------------|
| T = .05584 | PHI = 183.81  | PHIDOT = 760.80 | PSI = 285.70 | PSIDOT = 270.26 | PHITOT = 1598.84 |
|            | FF12 = 16.925 | FF23 = 4.260    |              |                 |                  |
| T = .05584 | PHI = 183.62  | PHIDOT = 763.10 | PSI = 285.71 | PSIDOT = 270.01 | PHITOT = 1598.86 |
|            | FF12 = 16.966 | FF23 = 4.266    |              |                 |                  |
| T = .05584 | PHI = 183.49  | PHIDOT = 767.40 | PSI = 285.72 | PSIDOT = 269.76 | PHITOT = 1598.89 |
|            | FF12 = 16.916 | FF23 = 4.266    |              |                 |                  |
| T = .05584 | PHI = 183.02  | PHIDOT = 770.73 | PSI = 285.73 | PSIDOT = 269.51 | PHITOT = 1598.92 |
|            | FF12 = 16.943 | FF23 = 4.271    |              |                 |                  |
| T = .05584 | PHI = 183.95  | PHIDOT = 774.07 | PSI = 285.74 | PSIDOT = 269.26 | PHITOT = 1598.95 |
|            | FF12 = 16.908 | FF23 = 4.271    |              |                 |                  |
| T = .05584 | PHI = 183.97  | PHIDOT = 777.42 | PSI = 285.75 | PSIDOT = 269.01 | PHITOT = 1598.97 |
|            | FF12 = 16.910 | FF23 = 4.277    |              |                 |                  |
| T = .05584 | PHI = 189.00  | PHIDOT = 780.79 | PSI = 285.76 | PSIDOT = 268.76 | PHITOT = 1599.00 |
|            | FF12 = 16.979 | FF23 = 4.277    |              |                 |                  |
| T = .05584 | PHI = 183.03  | PHIDOT = 784.17 | PSI = 285.77 | PSIDOT = 268.51 | PHITOT = 1599.03 |
|            | FF12 = 16.970 | FF23 = 4.283    |              |                 |                  |
| T = .05584 | PHI = 183.05  | PHIDOT = 787.56 | PSI = 285.78 | PSIDOT = 268.25 | PHITOT = 1599.06 |
|            | FF12 = 16.970 | FF23 = 4.283    |              |                 |                  |
| T = .05584 | PHI = 189.03  | PHIDOT = 790.98 | PSI = 285.79 | PSIDOT = 268.00 | PHITOT = 1599.09 |
|            | FF12 = 16.961 | FF23 = 4.289    |              |                 |                  |
| T = .05584 | PHI = 183.11  | PHIDOT = 794.40 | PSI = 285.80 | PSIDOT = 267.75 | PHITOT = 1599.11 |
|            | FF12 = 16.961 | FF23 = 4.289    |              |                 |                  |
| T = .05585 | PHI = 189.14  | PHIDOT = 797.84 | PSI = 285.81 | PSIDOT = 267.50 | PHITOT = 1599.14 |
|            | FF12 = 16.952 | FF23 = 4.295    |              |                 |                  |
| T = .05585 | PHI = 189.17  | PHIDOT = 801.29 | PSI = 285.81 | PSIDOT = 267.25 | PHITOT = 1599.17 |
|            | FF12 = 16.951 | FF23 = 4.294    |              |                 |                  |
| T = .05585 | PHI = 189.20  | PHIDOT = 804.77 | PSI = 285.82 | PSIDOT = 267.00 | PHITOT = 1599.20 |
|            | FF12 = 16.942 | FF23 = 3.851    |              |                 |                  |
| T = .05585 | PHI = 183.23  | PHIDOT = 808.26 | PSI = 285.83 | PSIDOT = 266.75 | PHITOT = 1599.23 |
|            | FF12 = 16.942 | FF23 = 3.851    |              |                 |                  |
| T = .05585 | PHI = 189.26  | PHIDOT = 811.75 | PSI = 285.84 | PSIDOT = 266.50 | PHITOT = 1599.26 |
|            | FF12 = 16.951 | FF23 = 3.855    |              |                 |                  |
| T = .05585 | PHI = 189.29  | PHIDOT = 815.23 | PSI = 285.85 | PSIDOT = 266.25 | PHITOT = 1599.29 |
|            | FF12 = 16.951 | FF23 = 3.855    |              |                 |                  |
| T = .05585 | PHI = 183.32  | PHIDOT = 818.70 | PSI = 285.86 | PSIDOT = 265.99 | PHITOT = 1599.32 |
|            | FF12 = 16.961 | FF23 = 3.859    |              |                 |                  |
| T = .05585 | PHI = 183.35  | PHIDOT = 822.16 | PSI = 285.87 | PSIDOT = 265.74 | PHITOT = 1599.35 |
|            | FF12 = 16.960 | FF23 = 3.859    |              |                 |                  |
| T = .05585 | PHI = 183.33  | PHIDOT = 825.62 | PSI = 285.88 | PSIDOT = 265.49 | PHITOT = 1599.38 |
|            | FF12 = 16.970 | FF23 = 3.864    |              |                 |                  |
| T = .05595 | PHI = 183.41  | PHIDOT = 829.05 | PSI = 285.89 | PSIDOT = 265.24 | PHITOT = 1599.41 |
|            | FF12 = 16.970 | FF23 = 3.864    |              |                 |                  |
| T = .05585 | PHI = 183.34  | PHIDOT = 832.50 | PSI = 285.90 | PSIDOT = 264.99 | PHITOT = 1599.44 |
|            | FF12 = 16.979 | FF23 = 3.868    |              |                 |                  |
| T = .05585 | PHI = 183.45  | PHIDOT = 835.93 | PSI = 285.91 | PSIDOT = 264.74 | PHITOT = 1599.46 |
|            | FF12 = 16.979 | FF23 = 3.868    |              |                 |                  |
| T = .05585 | PHI = 183.73  | PHIDOT = 839.34 | PSI = 285.92 | PSIDOT = 264.49 | PHITOT = 1599.49 |
|            | FF12 = 16.939 | FF23 = 3.873    |              |                 |                  |
| T = .05585 | PHI = 183.52  | PHIDOT = 842.75 | PSI = 285.93 | PSIDOT = 264.24 | PHITOT = 1599.52 |
|            | FF12 = 16.989 | FF23 = 3.873    |              |                 |                  |
| T = .05585 | PHI = 183.56  | PHIDOT = 846.15 | PSI = 285.94 | PSIDOT = 263.99 | PHITOT = 1599.56 |
|            | FF12 = 16.999 | FF23 = 3.878    |              |                 |                  |
| T = .05585 | PHI = 183.60  | PHIDOT = 849.55 | PSI = 285.95 | PSIDOT = 263.73 | PHITOT = 1599.59 |
|            | FF12 = 16.973 | FF23 = 3.878    |              |                 |                  |
| T = .05586 | PHI = 183.62  | PHIDOT = 852.93 | PSI = 285.96 | PSIDOT = 263.48 | PHITOT = 1599.62 |
|            | FF12 = 16.989 | FF23 = 3.882    |              |                 |                  |
| T = .05586 | PHI = 183.61  | PHIDOT = 856.30 | PSI = 285.97 | PSIDOT = 263.23 | PHITOT = 1599.65 |
|            | FF12 = 16.989 | FF23 = 3.882    |              |                 |                  |
| T = .05586 | PHI = 183.63  | PHIDOT = 859.66 | PSI = 285.98 | PSIDOT = 262.98 | PHITOT = 1599.68 |
|            | FF12 = 16.978 | FF23 = 3.887    |              |                 |                  |
| T = .05586 | PHI = 183.61  | PHIDOT = 863.02 | PSI = 285.99 | PSIDOT = 262.73 | PHITOT = 1599.71 |
|            | FF12 = 16.971 | FF23 = 3.887    |              |                 |                  |

Computer program SATDAZ (cont)

|            |               |                 |              |                 |                  |
|------------|---------------|-----------------|--------------|-----------------|------------------|
| I = .05586 | FF12 = 17.018 | FF23 = 3.887    | PSI = 286.00 | PSIDOT = 262.48 | PHITOT = 1599.74 |
|            | PHI = 189.74  | PHIDOT = 866.35 |              |                 |                  |
|            | FF12 = 15.247 | FF23 = 3.836    | PSI = 286.00 | PSIDOT = 262.23 | PHITOT = 1599.77 |
| T = .05586 | PHI = 189.77  | PHIDOT = 869.70 |              |                 |                  |
|            | FF12 = 15.247 | FF23 = 3.896    | PSI = 286.01 | PSIDOT = 261.98 | PHITOT = 1599.80 |
| T = .05586 | PHI = 189.80  | PHIDOT = 872.62 |              |                 |                  |
|            | FF12 = 15.411 | FF23 = 4.336    | PSI = 286.02 | PSIDOT = 261.73 | PHITOT = 1599.83 |
| I = .05586 | PHI = 189.83  | PHIDOT = 875.47 |              |                 |                  |
|            | FF12 = 15.411 | FF23 = 4.336    | PSI = 286.03 | PSIDOT = 261.47 | PHITOT = 1599.86 |
| T = .05586 | PHI = 189.86  | PHIDOT = 878.33 |              |                 |                  |
|            | FF12 = 15.401 | FF23 = 4.331    | PSI = 286.04 | PSIDOT = 261.22 | PHITOT = 1599.90 |
| T = .05586 | PHI = 189.90  | PHIDOT = 881.20 |              |                 |                  |
|            | FF12 = 15.401 | FF23 = 4.331    | PSI = 286.05 | PSIDOT = 260.97 | PHITOT = 1599.93 |
| I = .05586 | PHI = 189.93  | PHIDOT = 884.09 |              |                 |                  |
|            | FF12 = 15.330 | FF23 = 4.326    | PSI = 286.06 | PSIDOT = 260.72 | PHITOT = 1599.96 |
| T = .05586 | PHI = 189.96  | PHIDOT = 886.98 |              |                 |                  |
|            | FF12 = 15.390 | FF23 = 4.326    | PSI = 286.07 | PSIDOT = 260.47 | PHITOT = 1599.99 |
| T = .05586 | PHI = 189.99  | PHIDOT = 889.89 |              |                 |                  |
|            | FF12 = 15.379 | FF23 = 4.321    | PSI = 286.08 | PSIDOT = 260.22 | PHITOT = 1600.02 |
| T = .05586 | PHI = 190.02  | PHIDOT = 892.80 |              |                 |                  |
|            | FF12 = 15.379 | FF23 = 4.321    |              |                 |                  |

F23MAX = 5.20

F12MAX = 19.32

FF23MAX = 4.60

FF12MAX = 18.19

PNMAX = 1.20

URNS = 27.93

APPENDIX E

FRICTION FORCES DURING GEAR  
TRAIN MOTION REVERSAL

Since all friction forces of the escape wheel to rotor gear train reverse direction during a possible motion reversal following an impact, the introduction of a negative coefficient of friction, i.e., a  $-\mu$ , will satisfy for computational purposes the associated force and moment equilibrium expressions. (This method need not be resorted to for the pallet-escape wheel interface, since there motion reversal is accounted for by the signum function  $s_4$ .)

The above will be proven to hold for both the tooth contact and the pivot friction.

#### Tooth Contact Friction

The direction of the friction force of the pinion on a gear of a mesh is the same as that of the relative velocity of the contact point on the pinion with respect to the contact point on the gear (ref E-1). This relative velocity is obtained by way of the vector equation

$$\bar{v}_{C_p} = \bar{v}_{C_p/C_g} + \bar{v}_{C_g} \quad (E-1)$$

where (fig. E-1)

$$\begin{aligned} \bar{v}_{C_p} &= \text{absolute velocity of contact point } C_p \text{ of pinion tooth, with} \\ &\quad \text{direction normal to line connecting pivot point } O_p \text{ and contact} \\ &\quad \text{point } C_p \text{ (contact points } C_p \text{ and } C_g \text{ are coincident)} \\ \bar{v}_{C_g} &= \text{absolute velocity of contact point } C_g \text{ of gear tooth with} \\ &\quad \text{direction normal to the line connecting the pivot point } O_g \\ &\quad \text{and the contact point } C_g \\ \bar{v}_{C_p/C_g} &= \text{relative velocity between contact points } C_p \text{ and } C_g. \text{ The} \\ &\quad \text{direction of this velocity is normal to the line of action} \\ &\quad T_g - T_p. \end{aligned}$$

Velocity triangles according to equation E-1 for contact of a simple mesh above and below the pitch point for two cases is shown in figure E-1. In figure E-1(a), the gear is the driver. In figure E-1(b), where the motion is reversed, the pinion becomes the driver. Figures E-1(a) and E-1(b) differ with respect to the direction of the relative motion, and with that, the direction of the contact friction force for comparable contact. This difference in the direction of the friction force may be expressed by reversing the sign of the friction force. For computer purposes, this is best accomplished by making  $\mu$  positive when the gear is the driver and making it negative when the pinion becomes the driver. The normal force between the gear and the pinion, which has the direction of the line of action, is not dependent on the driver.

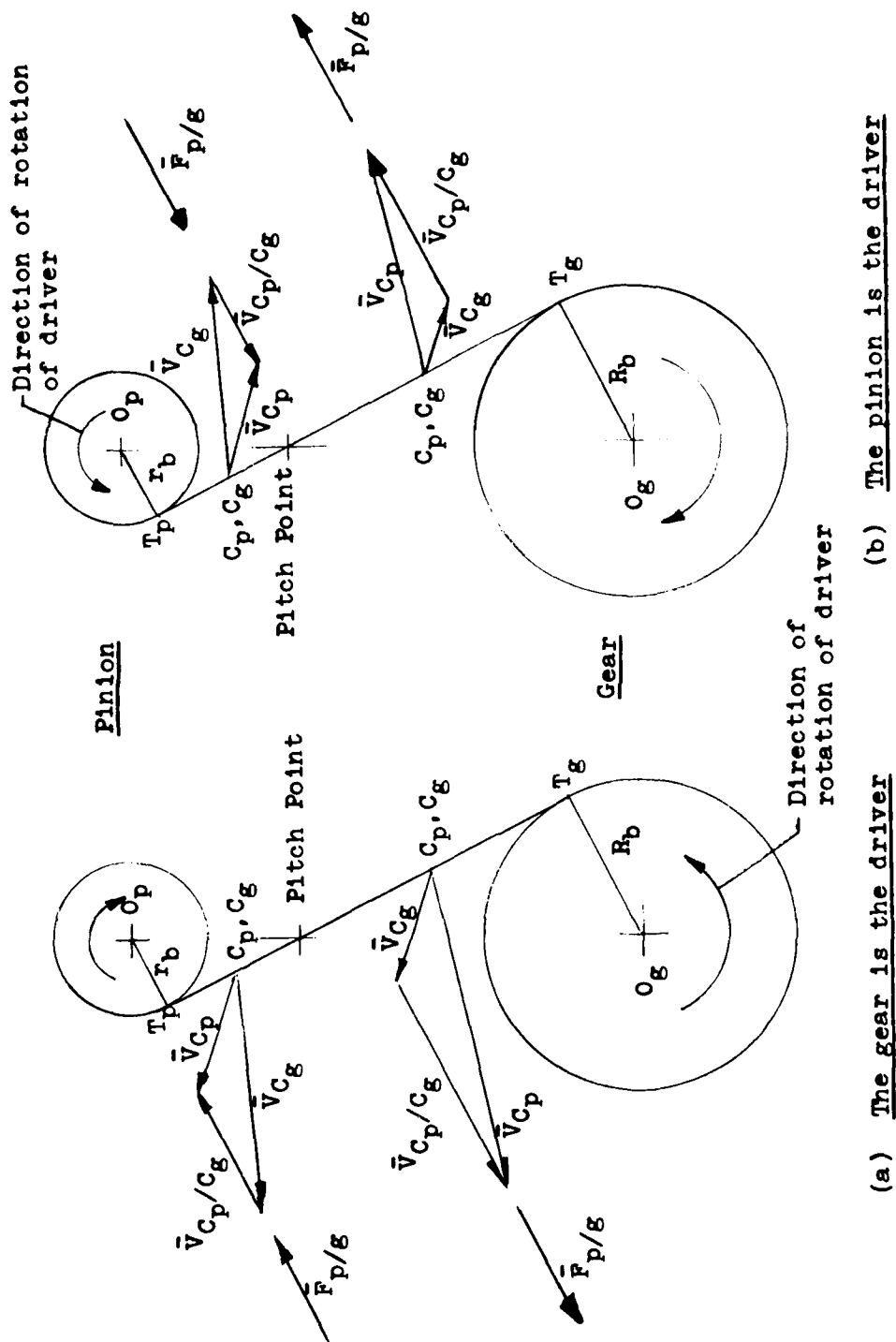


Figure E-1. Direction of friction force  $\bar{F}_{p/g}$  of pinion on gear above and below pitch point as a function of driver

### Pivot Friction

The free body diagram of the combined gear and pinion set no. 2 in clockwise rotation is shown in figure E-2. The associated equilibrium equations B-59 and B-60, which are used here as a general example, may be rewritten in the following manner:

$$F_x + \mu F_y = A_1 + \mu F_{23} \cos 2 - \mu F_{12} \cos 1 \quad (E-2)$$

and

$$-\mu F_x + F_y = A_2 + \mu F_{23} \sin 2 - \mu F_{12} \sin 1 \quad (E-3)$$

where  $A_1$  and  $A_2$  stand for the normal tooth contact and pivot forces which do not contain the coefficients of friction and do not change direction on motion reversal.\* The trigonometric functions refer to the associated angles  $\beta_1 - \theta_1$  and  $\beta_2 + \theta_2$ . The signum functions  $s_1$  and  $s_2$  are omitted for the present discussion since their influence is not relevant in this context. They change the signs of all friction terms on the right sides of equations E-2 and E-3, depending on whether contact is made before or after the pitch point.

Assume now that the direction of the gear set is changed to be counterclockwise. This causes the tooth contact friction forces (as shown earlier) to be reversed in sign. Furthermore, the two pivot friction forces are also reversed in sign. The above force equilibrium equations now have changed signs in all friction terms, i.e.,

$$F_x - \mu F_y = A_1 - \mu F_{23} \cos 2 + \mu F_{12} \cos 1 \quad (E-4)$$

and

$$\mu F_x + F_y = A_2 - \mu F_{23} \sin 2 + \mu F_{12} \sin 1 \quad (E-5)$$

Clearly, this effect of the change of the direction of all friction forces can be expressed by making the coefficient of friction negative for computational purposes.

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\* Equation A-2, reference E-1 shows that if the assumptions of the directions of the normal pivot forces prove wrong, the associated friction forces still furnish friction moments which have the appropriate direction of rotation.



Figure E-2. Free body diagram of gear and pinion set no. 2

This idea also holds true in general for the moment equation and is illustrated with the help of the moment equation B-58 for gear and pinion set no. 2, which for clockwise rotation is of the following general form:

$$B - \mu F_{23} a_2 + \mu F_{12} (d_1 - a_1) + \mu \rho_2 (\tilde{F}_{x2} + \tilde{F}_{y2}) = I_{2N} \ddot{\phi} \quad (E-6)$$

where B is similar to  $A_1$  and  $A_2$  in equations E-2 and E-3 by representing moment terms which do not contain the coefficient of friction, and whose sign does not change on motion reversal. In the same vein, the signum functions  $s_1$  and  $s_2$  are omitted.

If the direction of rotation is counterclockwise, the above expression becomes

$$B + \mu F_{23} a_2 - \mu F_{12} (d_1 - a_1) - \mu \rho_2 (\tilde{F}_{x2} + \tilde{F}_{y2}) = I_{2N} \ddot{\phi} \quad (E-7)$$

Thus, the change in the direction of the friction moments can also be expressed by making the coefficient of friction negative for computational purposes.

Finally, the results of these new force and moment equations for the various components may be obtained by changing the signs of all coefficients of friction in the results of the original expressions which were derived for forward motion of the train.

#### REFERENCE

- E-1. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, US Army ARRADCOM, Dover, NJ, December 1979.

APPENDIX F

A COMPUTATIONAL RULE FOR THE DETERMINATION OF THE SIGN  
IN THE EFFECTIVE MOMENT OF INERTIA  $I_{1R}$

Whenever the center of mass of a fuze train component, such as a pallet or a rotor, does not coincide with its pivot axis, there will be a pivot friction moment which is proportional to the angular acceleration of the component. Just like any other friction moment, its direction must be opposite to the angular velocity of such a rotating part. The following shows how the appropriate choice of the sign in the expression for the effective moment of inertia  $I_{iR}^*$  of the component assures that this friction moment will always retard motion. While this discussion holds in general, it makes specific use of the pallet moment equation A-78, appendix A. This expression becomes in condensed form

$$M_S \pm M_{AA} = I_p \ddot{\psi} \quad (F-1)$$

where

$M_S$  = the sum of all moments on the pallet, with the exception of the friction moment  $M_{AA}$  which is proportional to the angular acceleration  $\ddot{\psi}$  of the pallet. The moment  $M_S$  is sufficiently larger than the moment  $M_{AA}$  so that it will at all times decide the direction of the angular acceleration  $\ddot{\psi}$

$$M_{AA} = \mu_1 \rho_p (A_4 + A_8) \ddot{\psi} = A_{22} \ddot{\psi} \quad (F-2)$$

i.e.,  $A_{22}$  is always positive. Note also that the signum function  $s_5$  has been omitted.

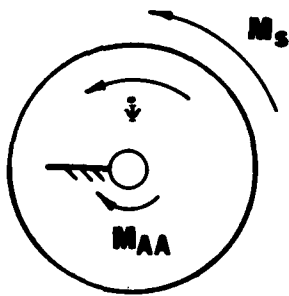
Figure F-1, a through d represents free body diagrams of a simplified pallet, or rotor, with various directions of  $\psi$ ,  $M_S$ , and  $M_{AA}$ .

In figure F-1a the moment  $M_S$  is assumed to be CCW, i.e., positive. The angular velocity  $\dot{\psi}$  is also assumed to be positive and therefore the friction moment must be negative. Equation F-1 becomes

$$M_S - M_{AA} = I_p \ddot{\psi} \quad (F-3)$$

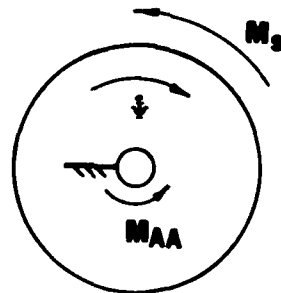
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\* The letter i in the subscript stands for the component number or letter.



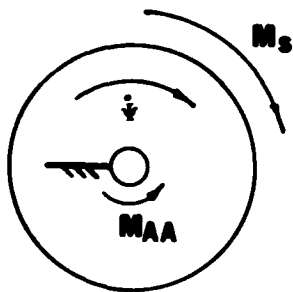
$$M_s - M_{AA} = I_p \ddot{\psi}$$

a



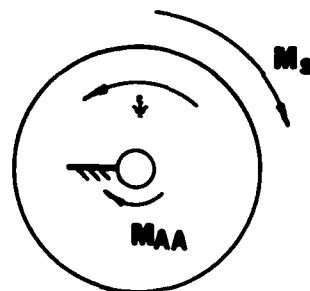
$$M_s + M_{AA} = I_p \ddot{\psi}$$

b



$$-M_s + M_{AA} = I_p \ddot{\psi}$$

c



$$-M_s - M_{AA} = I_p \ddot{\psi}$$

d

Figure F-1. Free body diagram of simplified pallet or rotor

In general, the sign of  $\ddot{\psi}$  is never predetermined in a differential equation of this type, but it is decided by the sign of the resultant moment. In this specific work it must be remembered that the direction of  $\ddot{\psi}$  is decided by  $M_S$  alone and that the friction moment  $M_{AA}$  must act opposite to the direction of the angular velocity  $\dot{\psi}$ .

If equation F-2 is substituted into the above expression with a positive  $\ddot{\psi}$ , it becomes

$$M_S = \ddot{\psi}(I_p + A_{22}) \quad (F-4)$$

Let equations F-3 and F-4 now be used to find equivalent expressions for the angular acceleration  $\ddot{\psi}$ . Thus, from equation F-3

$$\ddot{\psi} = \frac{M_S - M_{AA}}{I_p} \quad (F-5)$$

and from equation F-4

$$\ddot{\psi} = \frac{M_S}{I_p + A_{22}} \quad (F-6)$$

In the first form the absolute value of the angular acceleration is reduced, from the value it would attain due to the moment  $M_S$  alone, by the presence of  $M_{AA}$ . In the second form, which must be used in the computations,  $\ddot{\psi}$  is reduced in absolute magnitude by the equivalent presence of a larger effective moment of inertia  $I_{PR} = I_p + A_{22}$ . (The subscript PR is used for the pallet.)

Now consider the condition of figure F-1b where  $M_S$  is also positive, but  $\dot{\psi}$  is negative, and with that  $M_{AA}$  must be positive. This leads to the following moment equation:

$$M_S + M_{AA} = I_p \ddot{\psi} \quad (F-7)$$

or, with equation F-2 and a positive  $\ddot{\psi}$

$$M_S = \ddot{\psi}(I_p - A_{22}) \quad (F-8)$$

The above expressions are again used to find two equivalent forms for  $\ddot{\psi}$ . From equation F-7 one obtains

$$\ddot{\psi} = \frac{M_S + M_{AA}}{I_p} \quad (F-9)$$

while equation F-8 gives

$$\ddot{\psi} = \frac{M_S}{I_p - A_{22}} \quad (F-10)$$

In the first form the absolute value of  $\ddot{\psi}$  is increased by the added presence of  $M_{AA}$  over that due to  $M_S$  alone. The second form shows this increase in  $\ddot{\psi}$  by way of the reduced effective moment of inertia  $I_{PR} = I_p - A_{22}$ .

In figures F-1c and F-1d  $M_S$  is shown to act in a clockwise, i.e., negative direction, and with that  $\ddot{\psi}$  is also negative. Consider the condition of figure F-1c first. The moment equation must take the negative  $\ddot{\psi}$  into account by way of a positive  $M_{AA}$ . Thus, from the free body diagram

$$-M_S + M_{AA} = I_p \ddot{\psi} \quad (F-11)$$

To keep all signs correct on substitution of equation F-2 and the negative  $\ddot{\psi}$ , the above expression must take the form

$$-M_S - A_{22}(-\ddot{\psi}) = I_p(-\ddot{\psi}) \quad (F-12)$$

or

$$-M_S = -\ddot{\psi}(I_p + A_{22}) \quad (F-13)$$

The absolute value of  $\ddot{\psi}$  is then given by

$$\ddot{\psi} = \frac{M_S}{I_p + A_{22}} \quad (F-14)$$

Again, this value is reduced in absolute magnitude by the increase of the effective moment of inertia to  $I_{PR} = I_p + A_{22}$ . This is the equivalent to a decrease in the absolute value of the resultant moment.

Figure F-1d shows the pivot friction moment  $M_{AA}$  in the same direction as  $M_S$  since  $\ddot{\psi}$  is positive. The moment equation becomes

$$-M_S - M_{AA} = I_p \ddot{\psi} \quad (F-15)$$

Upon substitution of equation F-2 together with the negative  $\ddot{\psi}$ , one finds

$$-M_S + A_{22} (-\ddot{\psi}) = I_p (-\ddot{\psi}) \quad (F-16)$$

or

$$-M_S = -\ddot{\psi}(I_p - A_{22}) \quad (F-17)$$

The absolute value of  $\ddot{\psi}$  now becomes

$$\ddot{\psi} = \frac{M_S}{I_p - A_{22}} \quad (F-18)$$

It is increased by the decrease in the effective moment of inertia to  $I_{PR} = I_p - A_{22}$ .

These four cases allow the following computational rule for the determination of the sign of the parameter  $A_{22}$  in the effective moment of inertia.

From the equations F-6 and F-14, together with the associated figures F-1a and F-1c, respectively

$$I_{PR} = I_p + A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have identical signs} \quad (F-19)$$

Further, from equations F-10 and F-18, together with the associated figures F-1b and F-1d, respectively

$$I_{PR} = I_p - A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have opposite signs} \quad (F-20)$$

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