An engineering simulator

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INTRODUCTION

The engineering simulator

These notes are for the Mod IV Engineering Simulator as used on the IBM 7040. The simulator is a digital differential analyzer designed primarily for ease of programming.

Most items included have been checked out and actually used. The original version of this paper served as a user's manual.

Applicability

The system may be used for three distinct purposes:

1. To simulate anything describable by differential equations
2. To compute solutions to mathematical problems
3. To test proposed differential equations before completion of the special computer designed to use them.

MIDAS type computer systems

This system differs from the various MIDAS type systems available, in that it uses the problem oriented approach of the digital differential analyzer as developed in the author's text. We are primarily interested in the engineering approach in which the computer represents an engineering model rather than a computed solution. The program system is considered a tool immediately usable by anyone who has used digital differential analyzers, rather than a digital means of simulating analog equipment or solving analog type problems.

BRIEF form

The BRIEF form of integrator is intended for maximum programmer convenience at the expense of flexibility and computer running time. The form requires only integrator name, initial integrand, and input sources and usage. Sequence list is standard, and iteration size of the independent variable may be specified.

A standard tabulation interval may be specified in terms of the independent variable. All integrator data are tabulated. FIRST and LAST integrator must be specified in the sequence.

The BRIEF form may be intermixed with various other standard and special forms.

In the example following, PI/18 is a remark only. Whenever a blank space occurs after data, all following items become remarks.

Form

BRIEF NAME, YSTRT, INPUT

Example

```
SEQUEN  (FIRST,FACTOR,DEGREE,SINE,COSINE,LAST)                  AAAA0002
INDEPB  0.001                                                   BRIEF020
TAB     5.72958  PI/8                                           BRIEF030
BRIEF   SINE,0.0,((COSINE,DY),(INDEP,DX))                      BRIEF040
BRIEF   COSINE,1.0,((SINE,MDY),(INDEP,DX))                     BRIEF050
BRIEF   FACTOR,57.2958,((INDEP,DX))                            BRIEF060
BRIEF   DEGREE,0.0,((FACTOR,DY))                               BRIEF070
```

The BRIEF form was designed with maximum bias in favor of ease of programming. However, it lacks flexibility and is inefficient computerwise, so other integrator forms have been made available. The system described below is based on three compromises in decreasing order of importance.

1. Ease of use by DDA programmer
2. Expandability and flexibility of the basic system
3. Efficient use of the IBM 7040 using the Macro-Sap system.

The programmer is expected to be acquainted with DDA techniques but not with the IBM system. Familiarity with the IBM installation will improve efficiency, but the system is intended to be independent of all factors except those related to DDA methods.

Intregrator forms for data fill

Sequence

The sequence of integration is specified in the following way:

```
SEQUEN  (NAMEA,NAMEB,NAMEC,NAMED,NAMEE)                         PAAA00000
SEQUEN  (NAMEF,NAMEG,NAMEH,NAMEI,NAMEJ,NAMEX)                   PAAA00010
```

An integrator will not be processed unless it is listed in the SEQUEN list.

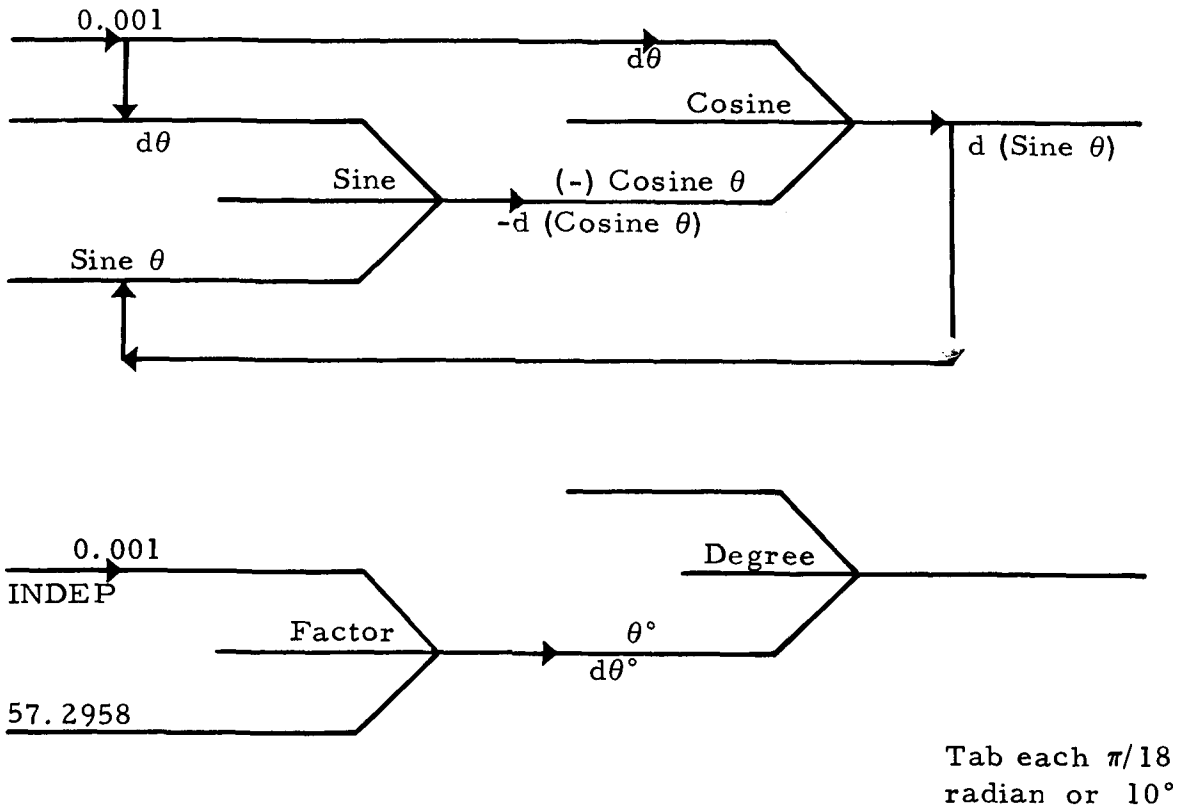

Figure 1 — Schematic for brief form problem

Integrator names may have up to and including six letters or numbers. The first character must be a letter. The name must include at least one vowel. The letter O should be avoided because it tabulates too nearly like the numeral 0.

SHORT form

This form contains minimum flexibility. It permits filling the integrator type, integrator name, mode, initial integrand value, heading words, the input sources, and their use. The decimal point must always appear in the integrand but never in the mode. (See mode section for mode usage.)

The standard form is:

```
SHORT  TYPE, NAME, MODE, YSTRT, (HDG1),
    (HDG2), SCALE                    PNAME — 00
ETC     , ((NAME1, D–), NAME2, D–),
    - - - etc - - -)                 PNAME — 01
```

As an example: (where scale is not used)

```
SHORT  SIMPLE,INTEG4,0,1.35,(ALPHA 1,(RADIAN),^,          PINTEG400
ETC    ((INTEG1,DX),(INTEGC,DY),(INTEG4,MDY))              PINTEG401
```

An unlimited number of inputs may be used. This form is used for all routine applications. It is not suitable when initialization of slope is needed, because it does not include access to the DZ. When such access is needed, the SHORTZ form should be used. If mode 2 is used a unity DX input will occur. When no input is coded, use ((0,0)).

HDG1 and HDG2 are 6-letter alphanumeric words. If less than six characters are used, the missing characters become spaces at the end of the word. In use, both words will run together as a single word or phrase.

The SHORT form with initialization

SHORTZ Form

This form differs from the SHORT form only in that it contains provision for initializing DZ. This is necessary when feedback connections occur and when transient effects make the slow start system impractical. (See INDEP form.)

The MEDIUM form

MEDIUM Form

This form contains, in addition to the provisions of the SHORTZ form, access to KF, KDX, and SPRL.

The standard form is:

```
MEDIUM SIMPLE,INTEG4,0,1.35,.135,0.0,0.0,0.0,0.0,(ALPHA 1,(RADIAN) PINTEG400
ETC    ,0,((INTEG1,DX),(INTEGC,DY),(INTEG4,MDY))                  PINTEG401
```

Example: Same case as in SHORTZ example. (SCALE not used.)

```
MEDIUM   SIMPLE,INTEG4,0,1.35,.135,0.0,0.0,(ALPHA  )                PINTEG400
ETC      ,(RADIAN),0, ((INTEG1,DX), (INTEGC,DY),(INTEG4,MDY))       PINTEG401
```

The LONG form without headings

LONG Form

This form contains additional provisions, mostly related to servos and limiting devices. None is used in the example.

The DETAIL form

DETAIL Form

This form contains complete access to all parts of the integrator memory. It should rarely be used.

Other forms may be constructed to suit.

Special forms

Independent Variable

INDEP Form

This form is used to set up a special slow start system. Actually, it consists of several integrators. This device is a convenient method of avoiding *DZ* initialization. Slow start cannot be used when real time is required.

The standard form is:

```
INDEP   A, RCP, C, XINCRM,
  SCALE                                  PINDEP000
```

The internal sequence for INDEP form is automatically set at the beginning of the cycle and need not be programmed.

RCP will be reciprocal of A. A will be a decimal, usually 0.1, 0.01, 0.001, or 0.001. XINCRM is the maximum increment size of the independent variable. The first nonzero increment will be approximately A times XINCRM. The independent variable rate will decay exponentially to XINCRM.

Example:

```
INDEP   0.01,100.0,1.0,0.1,0,SCM06                                   PINDEP000
```

When constant rate is needed,
A = 0.0, RCP = 0.0, C = 1.0

When slow start is used;
A = A, RCP = 1/A, C = 1.0

When S-slow start is used
A = A, RCP = 1/A, C = A

When tabulating, XINCRM is in integrator NCR2 (maximum increment size)

When tabulating, RCP is in integrator NCR1. (It decreases to approach zero.)

Interval trigger

INTRVL Form

This form is used when an integrator is to be used to cause something (an EFFECT) to happen at equal intervals of some variable. The standard form is:

```
INTRVL  TYPE, NAME, MODE, YSTRT,
   EFFECT, FOUND, HDG1          PNAME — 00
ETC     , HDG2, INTERVAL ((INPTA,
   DY), (INPUTB, DY) - - etc - -)  PNAME — 01
```

The EFFECT, integrator dump (IDUMP), and the integrator type (BCKTRK) are used in the illustrative example:

```
INTRVL  BCKTRK,THETA,0,0.0,IDUMP,1C,(THETA),(DUMPER),(2.01,      PTHETA000
ETC     ((THETA1,DY))                                            PTHETA001
```

This example will cause the entire problem to be tabulated if the accumulated DY input changes by an amount greater than two units of the variable. Available integrator types and effects for use with this form are as follows:

Type BCKTRK — In testing the variable, the back-track system is used to anticipate the next iteration and cause nearly exact effect intervals (MOD IIIB).

Type NBCKTR — The back-track system is not used. Effect will occur when the interval is matched or exceeded. (MOD IIIA.)

(NOTE: ROUND is a no-decimal-point decimal, integral number that specifies the number of significant figures used in the round-off test. The number in INTERVAL is the required decimal interval value.)

EFFECTS

TBCHA — Change to alternative A printout system. (ALTENA)

TBCHB — Change to alternative B printout system. (ALTENB)

TBCHC — Change to alternative C printout system. (ALTENC)

TBCHD — Change to alternative D printout system. (ALTEND)

TBCHE — Change to alternative E printout system. (ALTENE)

TBPRNA, TBPRNB, TBPRNC, TBPRND, TBPRNE — Trigger tabulation system when in corresponding alternative. TBPRNA in MOD IIIA.

IDUMP — Trigger integrator dump system. (See Table I-3.

STOP — Stop computation and signal operator that run is over.

NOTESA — Trigger printout of remarks filled under remarks forms, NOTESA, NOTESB, etc. (See NOTES on Remarks form instructions.)

REINIT — See below.

Use Mode 4 for general remarks related to the interval test.

Use Mode 10 for special remarks related to the specific effect.

Use Mode 20 to disable after first effect.

INIT — Initialize and restart.

The modes have special meanings as follows:

0 — No effect

4 — Print out integrator name and general remarks

10 — Print out integrator name and special remarks

20 — The INTRVL form will cause the effect only once.

Interval trigger with reset

INTRVL Form with Reset

The INTRVL form may be used with a reinitializing refinement, which can cause reinitialization or some other change in the problem.

When the affirmative test occurs, then information is transferred from some part of one integrator to some part of another. That is, a pair of integrators, source and destination, are used in transferring numbers.

The standard form is:

```
INTRVL  TYPE,NAME,MODE,YSTART,EFFECT,ROUND,HDG1,HDG2,INTERVAL,   PNAME0000
ETC     ((INPUT1,DY),(INPUT2,DY),-----(SRC1,0,DS1),(SRC2,0,052)) NAME0001
```

This causes information to be transferred from working Y of SRC1 and SRC2, respectively, to initial Y of DST1 and DST2.

As an example, REINIT is the effect that permits setting up a new case on the basis of the answer obtained from the old case:

```
INTRVL  BCKTRK,MISSDI,0,0.0,REINIT,10,(MISS C),(CORRECT),(12.0),  PMISSDI00
ETC     ((INTEG1,DY),(INTEGC,0,INTEG7),(SINEAD,0,SINCH))          PMISSDI01
```

In the example, integrator MISSDI, when the integrand variable goes through four units, with integrand input from INTEG1, the REINIT is triggered. REINIT places the contents of integrand INTEGC in the initial value location of integrand INTEG7. It places the contents of integrand SINEAD in the initial value location of integrand SINCH. The major application of the REINIT effect is in the classical double-end-point problem where we make successive tries on the evaluation of a definite interval.

Tabulation

TABULN and NTGRTB Form

The tabulation system is programmed with the use of two basic commands, "tabulate" and "integrator tabulation."

One command selects the alternative used and specifies tabulation groupings. The other command specifies the items to be tabulated.

The system automatically supplies the headings and tabulations in the corresponding locations.

The second command is used once for each line desired. The first command is used once for each alternative system to be used. The method of selecting alternatives is listed in the effects section.

The commands are as follows:

```
TABULN  ALTENA,DATLNS,PGELNS                                      PALTENA00
NTGRTB  A,B,C,D,E,F,G                                             PALTENA01
NTGRTB  A,B,C,D,E,F,G                                             PALTENA02
```

For example: (Two alternative systems in use)

```
TABULN  ALTENA,1.0,35.0                                           PALTENA00
NTGRTB  INTEGA,INTEGD,SINET,COSAL,CNT,INDEP,CONST                 PALTENA01
TABULN  ALTENB,2.0,30.0                                           PALTENB00
NTGRTB  INTEGA,INTEGB,INTEGC,INTEGD,SINET,COST                    PALTENB01
NTGRTB  SINEAL,COSAL,SBETA,CBETA,CNT,INDEP,CONST                  PALTENB02
```

ALTENA, ALTENB, ALTENC, ALTEND, and ALTENE are selected through the INTRVL command

DTLNS Number of data lines (decimal)
PGELNS Number of page lines (decimal)

REMARKS Form

REMARKS related to the nature of the DDA problem being run may be made as follows:

```
NOTES   BCI     5,INSERT HERE REMARKS RELATED TO                  PNOTES001
        BCI     5,THE PROBLEM BEING RUN.                          PNOTES002
        BCI     5,                                                PNOTES003
        BCI     5,                                                PNOTES004
```

Each line holds exactly 30 characters, including blank spaces. A total of 150 characters is permitted.

Example:

```
NOTES   BCI     5,THIS IS THE OPERATION MANUAL T                  PNOTES001
        BCI     5,EST PROBLEM FOR USE IN THE INS                  PNOTES002
        BCI     5,TRUCTION MANUAL. PREPARED BY V                  PNOTES003
        BCI     5,. ASPENSON AND G. FORBES. 3/66                  PNOTES004
```

If all five lines are not used, the system will print out nonsense in the missing lines.

The notes will follow the system identification on the page before the heading for the start of tabulation.

The supplementary notes differ only in that NOTESA, NOTESB, NOTESC, etc. are used in place of NOTES. The effects, (NOTESA, NOTESB, NOTESC, etc.) occur in the INTRVL form only. See interval section.

For example:

```
NOTESA BCI    5,THIS IS AN ERROR DUE TO THE IN                    PNOTESA01
      BCI     5,TEGRAND CONTAINING AN ABSOLUTE                    PNOTESA02
      BCI     5, VELOCITY EXCEEDING SPECIFIED                     PNOTESA03
      BCI     5,LIMITS.                                           PNOTESA04
```

Integrator types

(Charts on B- pages following)

ACCUM — This type is used only for accumulating DZ. It has no output and no DX inputs. The SHORT form is usually used with this type.

CONST — This type is used only for multiplication by a constant. It has no DY inputs. It may be used for single precision add of DZ, however, a servo adder should be used for double precision adding of DZ. (Form SERVAD).

SIMPLE — This type performs a simple integration without adding the second-order term to the output. Both DX and DY inputs are processed.

2NDORD — This type is used only when there are both DX and DY inputs. The second-order term, minus (Delta X) (Delta Y)/2, is added to the R but not to the Y. In general, it should be used with all integrators having both DX and DY.

AMBLE — This type divides DX/Y before adding to R. That is, the output will be DX/Y rather than YDX. The DZLMT must be filled with some maximum acceptable value of DX/Y to limit the division by zero) infinity.

NBCKTR — This type makes an interval test and inserts a signal when affirmative.

BCKTRK — NBCKTRA plus provision for changing next increment to prevent overshoot.

NOTE: If binary Z-line is desired, operator will insert new end card in the binary deck. This changes all operation modes to minus.

SLEW — DZ = Sign ((R— Y)) DX

SGNSER — DZ = (SIGN(Y)) DX

The mode code

The mode position in the integrator form is used for special capabilities and alternatives that may, in general, be applied to most types of integrator or device. A list of modes is given below. If two are to be used at the same time, add octally. The number filled is an octal number. Note that the mode number contains no octal point.

MODE (Octal Number)		BIT NUMBER
Minus is reserved for binary scaled runs.		
1	The output of integrator INDEP is used as a DX input	35
2	The contents of KDX is used as a DX input	34
4	Used with INTRVL form to obtain general remarks	33
10	Used with INTRVL form to obtain special remarks	32
20	Used with INTRVL form to limit the effect to only once	32
40	Used with INTRVL form to cause sheet eject after remarks	30
1000000	The output is multiplied by the contents of KF	17
2000000	If $\|DZ\| > DZLMT$, then set $\|DZ\| = DZLMT$ with sign of DZ	16
4000000	Limit DZ so that $SPR1 \leqq DZ \leqq SPR2$	15
10000000	Limit Y so that $SPR1 \leqq Y \leqq SPR2$ (Y is retained but not used)	14
20000000	DZ has the sign of DX. ($DZ = \|Y\|$ DX)	13
40000000	DZ is zero if $SPR1 \leqq Y \leqq SPR2$, otherwise DZ = YDX	12
100000000	DZ is DX if $SPR2 \leqq Y \leqq SPRL$, otherwise DZ = 0	11
200000000	Signal if $\|DZ\| \geqq DZLMT$	10
400000000	Signal if not $SPR1 \leqq DZ \leqq SPR2$	9
1000000000	Signal if not $SPR1 \leqq Y \leqq SPR2$	8
2000000000	Stop and integrator dump if $\|DZ\| \geqq DZLMT$ (use as 2200000000)	7
4000000000	Stop and integrator dump if $SPR1 \leqq DZ \leqq SPR2$ (use as 4400000000)	6
10000000000	Stop and integrator dump if $SPR1 \leqq Y \leqq SPR2$ (use as 11000000000)	5

Appendix I

Sample test problem

The sample test problem is designed to give an operational example and to provide an accuracy check on the various methods and factors involved. An analysis of errors is not presented here. A tabulated error of within one iteration is considered adequate for

engineering use on the basis that the nature of feedback delays prevents the effective value being tabulated any closer.

Figure 1a through 1g presents the schematic of the sample test programs. Table I-1 is the data list, Table I-2 is the run tabulation, and Table I-3 is the integrator dump.

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Vivian Aspenson performed the major part of the actual detail programming of the system and most of the checkout.

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TABLE I-1
Test Problem — Card Listing

```
REM       THIS IS THE DETAIL TEST PROBLEM FOR MOD IIIA SIMULATOR TAAAAAAAA
SEQUEN  (PI,PIR,UNITY,ACMUN,INTCHB,INTDP,INSTP)                    T   AAA00000
SEQUEN  (ACMDX,INTPRA,INTPRB)                                      T   AAAC0010
SEQUEN  (LNCONV,RCPCON,LNCSIM,RSPSIM,XDREC,RECDX,ACMC1)            T   AAA00020
SEQUEN  (LNAMN,RCP2ND,XDREC2,RECDX2,ACMA1,RCPSIM,ACMRCP)           T   AAA00030
SEQUEN  (THETA,COSTH,SINTH,DTH1,DTH2,ACMTH)                        T   AAA00040
SEQUEN  (DU,D3DER,D2DER,D1DER,DOFW,ACU4,ACMU)                      T   AAA00041
SEQUEN  (LNSER,AMSRV,ACMLN)                                        T   AAA00050
SEQUEN  (SRV11,SRV12,ACM11,ACM12)                                  T   AAA00055
SEQUEN  (INTRES)                                                   T   AAAOC056
SEQUEN  (FACT1,FACTOR,DEGREE,SINE,COSINE)                          T   AAA00059
SEQUEN  (LAST)                                                     T   AAA00060
SHORT   ACCUM,ACM11,0,0.0,-FROM-,SERVO-,SCP00,                      T  ACM11000
ETC ((SRV11,MDY))                                                     TACM11001
SHORT   ACCUM,ACM12,0,0.0,-FROM-,SERVO-,SCP00,                      T  ACM12000
ETC ((SRV12,MDY))                                                     TACM12001
SHORT   ACCUM,ACMA1,0,1.0,( X/X T),(EST 2 ),                        T  ACMA1000
ETC 0,((XDREC2,DY),(RECDX2,DY))                                       TACMA1001
SHORT   ACCUM,ACMC1,0,1.0,( X/X T),(EST 1 ),                        T  ACMC1000
ETC C,((XDREC,DY),(RECDX,DY))                                         TACMC1001
SHORT   ACCUM,ACMDX,0,100.0,( CORRE),(CT X  ),0,                    T  ACMDX000
ETC ((INDEP,DY))                                                      TACMDX001
SHORT   ACCUM,ACMLN,0,0.0,( DIFF ),(LOG X ),                        T  ACMLN00C
ETC C,((LNCONV,DY),(LNSER,MDY))                                       TACMLN001
SHORT   ACCUM,ACMRCP,0,0.0,( RECIP),( DIFF ),                       T  ACMRCPC0
ETC C,((RCPSIM,MDY),(RCP2ND,DY))                                      TACMRCP01
SHORT   ACCUM,ACMTH,0,0.0,( THETA),( DIFF ),0,                      T  ACMTH000
ETC ((DTH1,DY),(DTH2,DY),(THETA,MDY))                                 TACMTH001
SHORT   ACCUM,ACMU,0,0.0,(ACCUMU),(LATE U),SCP00                    T  ACMU0001
ETC ,((DU,DY))                                                        TACMUC002
SHORT   ACCUM,ACMUN,0,0.0,(PI/PI ),(-UNITY),SCP00,                  T  ACMUN000
ETC ((UNITY,MDY),(PIR,DY))                                            TACMUN001
SHORT   ACCUM,ACU4,0,0.0,(ACCUMU),(LATE W),SCP17                    T  ACU40001
ETC ,((DOFW,DY))                                                      TACU40002
TABULN  ALTENA,1.0,30.0                                            T   ALTENA00
NTGRTB  ACMUN,ACMDX,ACMC1,ACMA1,ACMRCP,ACMTH,ACMLN                 T   ALTENA01
TABULN  ALTENB,3.0,30.0                                            T   ALTENB00
NTGRTB  ACMUN,ACMDX,ACMC1,ACMA1,ACMRCP,ACMTH,ACMLN                 T   ALTENB01
NTGRTB  LNCONV,RCPCON,RECDX,RECDX2,RCP2ND,RCPSIM,CNT               T   ALTENB02
NTGRTB  XDREC,XDREC2,LNAMN,COSTH,DTH2,SINTH,DTH1                   T   ALTENB03
SHORT   2NDORD,AMSRV,0,100.0,( CORRE),(CT X 5),                     T  AMSRV000
ETC SCM05,((LNSER,MDX),(INDEP,DY))                                    TAMSRV001
BRIEF   FACT1,0.001,((INDEP,DX))                                    T  BRIEFC20
BRIEF   SINE,0.0,((COSINE,DY),(FACT1,DX))                           T  BRIEF040
BRIEF   COSINE,1.0,((SINE,MDY),(FACT1,DX))                          T  BRIEFC50
BRIEF   FACTOR,57.2958,((FACT1,DX))                                 T  BRIEF060
```

TABLE I-1 (cont)

```
        BRIEF   DEGREE,0.0,((FACTOR,DY))                                T  BRIEFOT
        SHORT   ACCUM,CNT,0,0.0,( ITERA),( COUNT),SCMC6,((NTY,DY))         NCNTCCCC
        SHORT   2NDORD,COSTH,0,0.0,( SINE ),(THETA ),SCM15,             T  COSTHCC
        ETC ((THETA,MDX),(SINTH,DY))                                       TCOSTHCC
        SHORT   2NDORD,D1DER,0,0.0,(2ND DE),(R OF W),SCPC8              T  D1DERCC
        ETC ,((D2DER,DY),(DU,DX))                                          TD1DERCC
        SHORT   2NDORD,D2DER,0,0.0,(3RD DE),(R OF W),SCPC8              T  D2DERCC
        ETC ,((D3DER,DY),(DU,DX))                                          TD2DERCC
        SHORT   CONST,D3DER,0,24.0,(4TH DE),(R OF W),SCMC4              T  D3DERCC
        ETC ,((DU,DX))                                                     TD3DERCC
        SHORT   2NDORD,DOFW,0,0.0,(1ST DE),(R OF W),SCP11               T  DOFWCCC
        ETC ,((DU,DX),(D1DER,DY))                                          TDOFWCCC
        SHORT   2NDORD,DTH1,0,1.0,(COSINE),( THETA),SCM15,              T  DTH1CCC
        ETC ((SINTH,DX),(COSTH,DY))                                        TDTH1CCC
        SHORT   2NDORD,DTH2,0,0.0,( SINE ),(THETA ),SCM15,              T  DTH2CCC
        ETC ((COSTH,MDX),(SINTH,DY))                                       TDTH2CCC
        SHORT   CONST,DU,0,0.1,( DERIV),( OF U ),SCMC9                  T  DUCCCCC
        ETC ,((INDEP,DX))                                                  TDUCCCCC
        SHORT   SIMPLE,INDEP,0,1.0,(   UNI),(TY    ),SCMC6,               NINDEPC
        ETC     ((NCR2,DX),(LAST,DX))                                      NINDEPC
        INTRVL  NBCKTR,INSTP,4,0.1,STOP,6,(STOP A),(T 2000),2000.0,     T  INSTPC
        ETC ((PIR,DY))                                                     TINSTPC
        INTRVL  NBCKTR,INTCHB,24,0.1,TBCHB,6,( TC B ),(AT 100)          T  INTCHB
        ETC ,100.0,((PIR,DY))                                              TINTCHB
        INTRVL  NBCKTR,INTDP,4,.1,IDUMP,6,(DUMP A),(T 1000),1000.0,     T  INTDPC
        ETC ((PIR,DY))                                                     TINTDPC
        INTRVL  NBCKTR,INTPRA,4,0.0,TBPRNA,10,(PRINA ),(AT 10 ),        T  INTPRA
        ETC 10.0,((INDEP,DY))                                              TINTPRA
        INTRVL  NBCKTR,INTPRB,0,0.0,TBPRNB,10,(PRINB ),(AT 100),        T  INTPRB
        ETC 100.0,((INDEP,DY))                                             TINTPRB
        INTRVL  NBCKTR,INTRES,34,0,REINIT,10,(PI TO ),(UNITY ),            TINTRES
        ETC     10.0,((INDEP,DY),(PI,0,UNITY))                             TINTRES
        LONGH   AMBLE,LNAMN,0,100.0,0.0,1.0,0.0,0.0,(  AMBL),          T  LNAMNC
        ETC (E X 4 ),0.0,0.01,SCM12,((INDEP,DX),(INDEP,DY))                TLNAMNC
        SHORT   2NDORD,LNCONV,1,0.01,(RECIP1),( OF X ),                 T  LNCONV
        ETC SCM12,((RCPCON,DY))                                            TLNCONV
        SHORT   SIMPLE,LNCSIM,1,0.01,(RECIPA),( OF X ),                 T  LNCSIM
        ETC SCM12,((RSPSIM,DY))                                            TLNCSIM
        MEDIUM  SIMPLE,LNSER,2,0.0,0.0,1.0,0.001,0.0,                   T  LNSERO
        ETC (AMBLE ),(SERVO ),SCM12,((INDEP,DY),(AMSRV,DY))                TLNSERO
        MEDIUM  SIMPLE,NCR1,2,100.0,0.0,1.0,0.01,0.0,( RATE ),             NNCR100
        ETC     (TERM  ),SCP00,((NCR1,MDY))                                NNCR100
        SHORT   CONST,NCR2,0,1.00,(INDEP ),(INCREM),SCM06,                 NNCR200
        ETC     ((SMK,DX))                                                 NNCR200
NOTES   BCI 5, THIS IS THE OPERATION MANUAL                                 NOTESC
        BCI 5,TEST PROBLEM FOR USE IN THE IN                                NOTESC
        BCI 5,STRUCTION MANUAL. PREPARED BY                                 NOTESC
```

TABLE I-1 (cont)

```
   BCI 5,V. ASPENSON AND G. FORBES.  Y                                          NCTES004
   BCI 5, DATED AUG, 1964. (SCALE INCL)                                         NCTES005
   SHORT   CONST,NTY,2,1.0,(   UNI),(TY     ),SCM06,((0,0))                   NNTY00001
   SHORT   CONST,PI,2,3.1415927,(CONSTA),(NT, PI),SCP02,((0,0))         T  PI0C0000
   SHORT   CONST,PIR,0,0.3183099,(CONST ),(REC PI),SCP00,               T  PIRC0000
   ETC ((PI,DX))                                                             TPIRCC001
   SHORT   2NDORD,RCPCON,0,0.01,(RECIP2),( OF X ),                      T  RCPCCN00
   ETC SCM18,((LNCONV,MDX),(RCPCON,DY))                                      TRCPCCN01
   SHORT   SIMPLE,RCPSIM,0,0.01,(RECIP6),( OF XS),                      T  RCPSIM00
   ETC SCM18,((RCPSIM,DY),(LNAMN,DX))                                        TRCPSIM01
   SHORT   2NDORD,RCP2ND,0,0.01,(RECIP4),( OF X ),                      T  RCP2NDC0
   ETC SCM18,((LNAMN,DX),(RCP2ND,DY))                                        TRCP2ND01
   SHORT   2NDORD,RECDX,0,0.01,(RECIP3),( OF X ),                       T  RECDXC0C
   ETC SCM11,((INDEP,DX),(RCPCON,DY))                                        TRECDX001
   SHORT   2NDORD,RECDX2,0,0.01,(RECIP5),( OF X ),                      T  RECDX200
   ETC SCM11,((INDEP,DX),(RCP2ND,DY))                                        TRECDX201
   SHORT   SIMPLE,RSPSIM,0,0.01,(RECIP8),( OF X ),                      T  RSPSIM01
   ETC SCM18,((LNCSIM,MDX),(RSPSIM,DY))                                      TRSPSIM02
   SHORT   2NDORD,SINTH,0,1.0,(COSINE),( THETA),SCM15,                  T  SINTHCCC
   ETC ((THETA,DX),(COSTH,DY))                                               TSINTH001
   MEDIUM  SIMPLE,SMR,2,0.0,0.0,1.0,0.01,0.0,(RATE S),                       NSMRCC001
   ETC     (UMMER),SCP00,((NCR1,MDY),(NTY,DY),(SMR,MDY))                     NSMRCC002
   SHORT   SGNSER,SRV11,2,0.0,-SIGN-,SERVO-,SCP0C,                      T  SRV11000
   ETC ((INDEP,DY),(SRV11,MDY))                                              TSRV11001
   SHORT   SLEW,SRV12,2,0.0,--Y-R-,SERVO-,SCP00,                        T  SRV12000
   ETC ((INDEP,DY),(INDEP,DY),(INDEP,DR),(SRV12,MDY))                        TSRV120C1
   SHORT   CONST,THETA,0,0.0C174532925,(DEG-RA),(DIANS )                T  THETA000
   ETC ,SCM15,((INDEP,DX))                                                   TTHETA001
   SHORT   CONST,UNITY,2,1.0,(CONST,),( UNITY),SCP00,((0,0))            T  UNITYCC0
   SHORT   2NCORD,XDREC,0,100.0,( CORRE),(CT X 2),                      T  XDRECCC0
   ETC SCM11,((RCPCCN,DX),(INDEP,DY))                                        TXDREC001
   SHORT   2NDORD,XDREC2,0,100.0,( CORRE),(CT X 3),                     T  XDREC200
   ETC SCM11,((RCP2ND,DX),(INDEP,DY))                                        TXDREC201
NC PZE                                                                       ZZ90CC000
ND PZE                                                                       ZZ90CC001
NE PZE                                                                       ZZ90CCC02
   REM END BNRYC IS USED FOR BINARY RUNS                                     ZZ9999995

   REM END CT IS STANDARD                                                    ZZ9999997

   END CT                                                                    ZZ9999999
```

TABLE I-2
Run Tabulation

PI/PI -UNITY RECIP1 OF X CORRECT X 2	CORRECT X RECIP2 OF X CORRECT X 3	X/X TEST 1 RECIP3 OF X AMBLE X 4	X/X TEST 2 RECIP5 OF X SINE THETA	RECIP DIFF RECIP4 OF X SINE THETA	THETA DIFF RECIP6 OF XS COSINE THETA	DIFF LOG X ITERA COUNT COSINE THETA
.16048551 -04	.20058972 03	.99653842 00	.27999531 01	-.27567499 -05	.61768842 -05	.29338171 -01
.49867409 -02	.49867409 -02	.49680389 -02	.13958610 -01	.14010944 -01	.14013813 -01	.26800000 03
.20058972 03	.20058972 03	.20058972 03	.17338550 00	.17467342 00	.98478863 00	.98478863 00
.23245811 -04	.30088708 03	.99544284 00	.49663562 01	-.40158146 -05	.38425152 -04	.25378307 -01
.33183001 -02	.33183001 -02	.33083560 -02	.16505718 -01	.16456620 -01	.16460556 -01	.38800000 03
.30088708 03	.30088708 03	.30088708 03	.34205823 00	.34353513 00	.93956251 00	.93956251 00
.29653311 -04	.40079409 03	.99524482 00	.77546481 01	-.71992073 -05	.10910009 -03	.22865095 -01
.24891311 -02	.24891311 -02	.24831778 -02	.19348208 -01	.19394593 -01	.19401873 -01	.49500000 03
.40079409 03	.40079409 03	.40079409 03	.49990186 00	.50135130 00	.86597083 00	.86597083 00
.35822391 -04	.50095454 03	.99533066 00	.10944284 02	-.99856403 -05	.22576984 -03	.21264008 -01
.19907662 -02	.19907662 -02	.19868638 -02	.21846862 -01	.21804089 -01	.21814106 -01	.59800000 03
.50095454 03	.50095454 03	.50095454 03	.64303019 00	.64434464 00	.76581652 00	.76581652 00
.41872263 -04	.60079685 03	.99550919 00	.14437037 02	-.11693153 -04	.39164452 -03	.20168027 -01
.16597168 -02	.16597168 -02	.16569773 -02	.24029812 -01	.23990232 -01	.24001881 -01	.69900000 03
.60079685 03	.60079685 03	.60079685 03	.76826562 00	.76738047 00	.64271443 00	.64271443 00
.47877431 -04	.70032253 03	.99571208 00	.17385796 02	-.12192502 -04	.60821041 -03	.19366512 -01
.14238106 -02	.14238106 -02	.14217864 -02	.24825405 -01	.24790111 -01	.24802323 -01	.79900000 03
.70032253 03	.70032253 03	.70032253 03	.86605765 00	.86693006 00	.50058496 00	.50058496 00
.53867698 -04	.80012782 03	.99591463 00	.20898342 02	-.13096804 -04	.87763967 -03	.18746965 -01
.12462431 -02	.12462431 -02	.12446898 -02	.26118747 -01	.26151392 -01	.26164538 -01	.89900000 03
.80012782 03	.80012782 03	.80012782 03	.93998132 00	.94058046 00	.34288564 00	.34288564 00
.59857964 -04	.90004871 03	.99610682 00	.25042597 02	-.14278378 -04	.12001825 -02	.18251033 -01
.11079494 -02	.11079494 -02	.11067211 -02	.27823594 -01	.27792730 -01	.27807025 -01	.99900000 03
.90004871 03	.90004871 03	.90004871 03	.98550958 00	.98581558 00	.17456041 00	.17456041 00
.65848231 -04	.10000166 04	.99628529 00	.28832527 02	-.14866289 -04	.15758968 -02	.17843024 -01
.99725980 -03	.99725980 -03	.99626448 -03	.28832046 -01	.28860901 -01	.28875811 -01	.10990000 04
.10000166 04	.10000166 04	.10000166 04	.10011506 01	.10011535 01	.80556248 -03	.80556248 -03
.71838498 -04	.11000028 04	.99644947 00	.31888156 02	-.14948606 -04	.20046871 -02	.17499963 -01
.90667909 -03	.90667909 -03	.90585634 -03	.28989135 -01	.29015511 -01	.29030500 -01	.11990000 04
.11000028 04	.11000028 04	.11000028 04	.98638584 00	.98608532 00	-.17305915 00	-.17305915 00
.77828765 -04	.11999959 04	.99660015 00	.34734433 02	-.14854058 -04	.24866619 -02	.17206438 -01
.83118920 -03	.83118920 -03	.83049777 -03	.28945419 -01	.28921319 -01	.28936182 -01	.12990000 04
.11999959 04	.11999959 04	.11999959 04	.94164467 00	.94104970 00	-.34173146 00	-.34173146 00
.83819032 -04	.12999928 04	.99673842 00	.37260229 02	-.14761248 -04	.30218536 -02	.16951717 -01
.76731003 -03	.76731003 -03	.76672082 -03	.28661831 -01	.28683895 -01	.28698689 -01	.13990000 04
.12999928 04	.12999928 04	.12999928 04	.86827452 00	.86740305 00	-.50007581 00	-.50007581 00
.89868903 -04	.14009897 04	.99686660 00	.40070158 02	-.14775547 -04	.36164386 -02	.16725974 -01
.71204600 -03	.71204600 -03	.71153862 -03	.28601250 -01	.28621680 -01	.28636484 -01	.15000000 04
.14009897 04	.14009897 04	.14009897 04	.76737411 00	.76625022 00	-.64461405 00	-.64461405 00
.95874071 -04	.15009867 04	.99698330 00	.42995523 02	-.14779957 -04	.42586651 -02	.16527853 -01
.66465412 -03	.66465412 -03	.66421206 -03	.28644742 -01	.28625684 -01	.28640459 -01	.16000000 04
.15009867 04	.15009867 04	.15009867 04	.64399487 00	.64265528 00	-.76809277 00	-.76809277 00
.10186434 -03	.16009836 04	.99709119 00	.46447638 02	-.14944829 -04	.49541935 -02	.16350637 -01
.62318044 -03	.62318044 -03	.62279184 -03	.29011808 -01	.28993710 -01	.29008655 -01	.17000000 04
.16009836 04	.16009836 04	.16009836 04	.50100762 00	.49949298 00	-.86826775 00	-.86826775 00
.10785460 -03	.17009806 04	.99719087 00	.48984237 02	-.14860418 -04	.57030611 -02	.16190952 -01
.58658120 -03	.58658120 -03	.58623691 -03	.28797485 -01	.28780575 -01	.28795436 -01	.18000000 04
.17009806 04	.17009806 04	.17009806 04	.34275188 00	.34110816 00	-.94208756 00	-.94208756 00
.11384487 -03	.18009775 04	.99728345 00	.51626064 02	-.14836009 -04	.65053072 -02	.16046160 -01
.55404450 -03	.55404450 -03	.55373736 -03	.28665393 -01	.28681327 -01	.28696180 -01	.19000000 04
.18009775 04	.18009775 04	.18009775 04	.17403217 00	.17230927 00	-.98730087 00	-.98730087 00
.11983514 -03	.19009744 04	.99736966 00	.54430034 02	-.14833947 -04	.73609601 -02	.15914136 -01
.52492936 -03	.52492936 -03	.52465367 -03	.28632491 -01	.28647568 -01	.28662421 -01	.20000000 04
.19009744 04	.19009744 04	.19009744 04	-.27501090 -04	-.17772296 -02	-.10025250 01	-.10025250 01

INTERVAL TEST TRIGGERED BY INTEGRATOR -- INTDP

TABLE I-3
Integration Dump

NAME	TITLE	Y	Y NEW - Y OLD	DX	DZ	R
NCR1	RATE TERM	.18825620 -06	-.19015811 -08	.10000000 -01	.18825620 -08	.23973722 -16
NTY	UNITY	.10000000 01	.00000000 -39	.10000000 01	.10000000 01	.00000000 -39
SMR	RATE SUMMER	.99999635 02	.00000000 -39	.10000000 -01	.99999634 00	.13328055 -07
CNT	ITERA COUNT	.20000000 04	.10000000 01	.00000000 -39	.00000000 -39	.00000000 -39
NCR2	INDEP INCREM	.10000000 01	.00000000 -39	.99999634 00	.99999634 00	.00000000 -39
INDEP	UNITY	.10000000 01	.00000000 -39	.99999634 00	.99999634 00	.00000000 -39
PI	CONSTANT PI	.31415927 01	.00000000 -39	.10000000 01	.31415927 01	.00000000 -39
PIR	CONST REC PI	.31830990 00	.00000000 -39	.31415927 01	.10000001 01	.98900207 -08
UNITY	CONST UNITY	.10000000 01	.00000000 -39	.10000000 01	.10000000 01	.00000000 -39
ACMUN	PI/PI -UNITY	.11983514 -03	.59604645 -07	.00000000 -39	.00000000 -39	.00000000 -39
INTDP	DUMP AT 1000	.99998474 -01	.10000000 01	.00000000 -39	.00000000 -39	.10000000 04
INSTP	STOP AT 2000	.99998845 -01	.10000000 01	.00000000 -39	.00000000 -39	.20000000 04
ACMDX	CORRECT X	.19009744 04	.99996948 00	.00000000 -39	.00000000 -39	.00000000 -39
INTPRA	PRINA AT 10	.99680316 00	.99999630 00	.00000000 -39	.00000000 -39	.10000000 02
INTPRB	PRINB AT 100	.99636936 00	.99999619 00	.00000000 -39	.00000000 -39	.10000000 03
LNCONV	RECIP1 OF X	.52492936 -03	-.27599890 -06	.99999634 00	.52506544 -03	.52504861 -11
RCPCON	RECIP2 OF X	.52492936 -03	-.27599890 -06	-.52506544 -03	-.27569473 -06	-.26207787 -14
LNCSIM	RECIPA OF X	.52562191 -03	-.27657370 -06	.99999634 00	.52561998 -03	.89071771 -11
RSPSIM	RECIPB OF X	.52562191 -03	-.27657370 -06	-.52561998 -03	-.27627737 -06	-.33470229 -14
XDREC	CORRECT X 2	.19009744 04	.99996948 00	-.27569473 -06	-.52395079 -03	-.84581973 -11
RECDX	RECIP3 OF X	.52465367 -03	-.27569331 -06	.99999634 00	.52478960 -03	.78808508 -11
ACMC1	X/X TEST 1	.99736966 00	.82701444 -06	.00000000 -39	.00000000 -39	.00000000 -39
LNAMN	AMBLE X 4	.19009744 04	.99996948 00	.99999634 00	-.52618250 -03	-.14722801 -11
RCP2ND	RECIP4 OF X	.28647568 -01	-.15085796 -04	-.52618250 -03	-.15077818 -04	-.80669564 -13
XDREC2	CORRECT X 3	.19009744 04	.99996948 00	-.15077818 -04	-.28655008 -01	-.34229626 -09
RECDX2	RECIP5 OF X	.28632491 -01	-.15077880 -04	.99999634 00	.28639925 -01	.10040550 -09
ACMA1	X/X TEST 2	.54430034 02	-.15735626 -04	.00000000 -39	.00000000 -39	.00000000 -39
RCPSIM	RECIP6 OF XS	.28662421 -01	-.15097903 -04	-.52618250 -03	-.15081664 -04	-.60595695 -13
ACMRCP	RECIP DIFF	-.14833947 -04	.38461394 -08	.00000000 -39	.00000000 -39	.00000000 -39
THETA	DEG-RADIANS	.17453293 -02	.00000000 -39	.99999634 00	.17453229 -02	.11051087 -10
COSTH	SINE THETA	-.27501090 -04	-.17497233 -02	-.17453229 -02	-.14789178 -05	-.28497844 -14
SINTH	COSINE THETA	-.10025250 01	-.14752150 -05	.17453229 -02	-.17497285 -02	-.13639877 -10
DTH1	COSINE THETA	-.10025250 01	-.14752150 -05	-.17497285 -02	.17541454 -02	.79210375 -11
DTH2	SINE THETA	-.17772296 -02	-.17497285 -02	.14789178 -05	-.13345241 -08	-.10185440 -16
ACMTH	THETA DIFF	.73609601 -02	.88210217 -05	.00000000 -39	.00000000 -39	.00000000 -39
DU	DERIV OF U	.10000000 00	.00000000 -39	.99999634 00	.99999634 -01	.38592848 -09
D3DER	4TH DER OF W	.24000000 02	.00000000 -39	.99999634 -01	.23999912 01	.42024112 -07
D2DER	3RD DER OF W	.43223568 04	.23999023 01	.99999634 -01	.43211410 03	.46683981 -05
D1DER	2ND DER OF W	.38922754 06	.43210938 03	.99999634 -01	.38901005 05	.44091909 -03
D0FW	1ST DER OF W	.23366590 08	.38901000 05	.99999634 -01	.23347054 07	.16867405 -01
ACU4	ACCUMULATE W	.10520793 10	.23346960 07	.00000000 -39	.00000000 -39	.00000000 -39
ACMU	ACCUMULATE U	.18009851 03	.99998474 -01	.00000000 -39	.00000000 -39	.00000000 -39
LNSER	AMBLE SERVO	.52632820 00	-.27722865 -03	.10000000 -02	.52632820 -03	.20763345 -11
AMSRV	CORRECT X 5	.19009744 04	.99996948 00	-.52632820 -03	-.10002733 01	-.24864510 -07
ACMLN	DIFF LOG X	.15914136 -01	-.12631062 -05	.00000000 -39	.00000000 -39	.00000000 -39
SRV11	-SIGN-SERVO-	.99683852 00	-.36582351 -05	.10000000 01	.10000000 01	.00000000 -39
SRV12	--Y-H-SERVO-	.18019473 04	.99993896 00	.10000000 01	.10000000 01	.18009865 04
ACM11	-FROM-SERVO-	-.18010000 04	-.10000000 01	.00000000 -39	.00000000 -39	.00000000 -39
ACM12	-FROM-SERVO-	-.18010000 04	-.10000000 01	.00000000 -39	.00000000 -39	.00000000 -39
FACT1	INTGR FACT1	.10000000 -02	.00000000 -39	.99999634 00	.99999634 -03	.23154424 -10
FACTOR	INTGR FACTOR	.57295800 02	.00000000 -39	.99999634 -03	.57295590 -01	.54295017 -09
DEGREE	INTGR DEGREE	.10318887 03	.57294845 -01	.00000000 -39	.00000000 -39	.00000000 -39
SINE	INTGR SINE	.97464302 00	-.22640824 -03	.99999634 -03	.97475265 -03	.56736425 -11
COSINE	INTGR COSINE	-.22787853 00	-.97475387 -03	.99999634 -03	-.22739032 -03	-.23812346 -11

INTERVAL TEST TRIGGERED BY INTEGRATOR -- INSTP

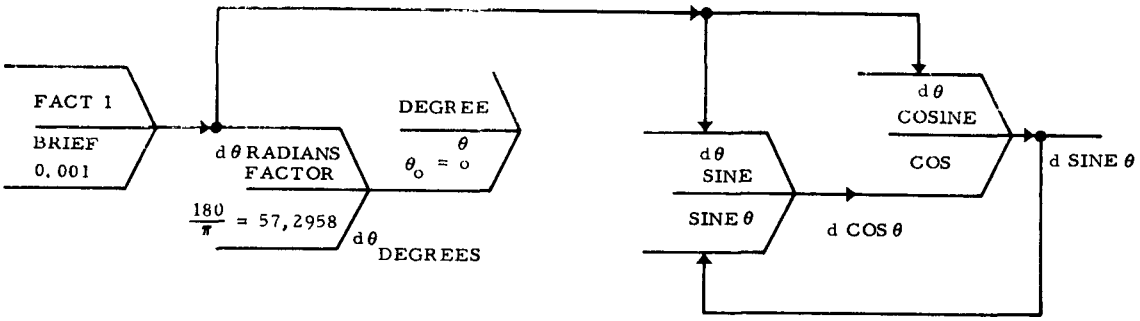

Figure 1a — Sample test problem schematic

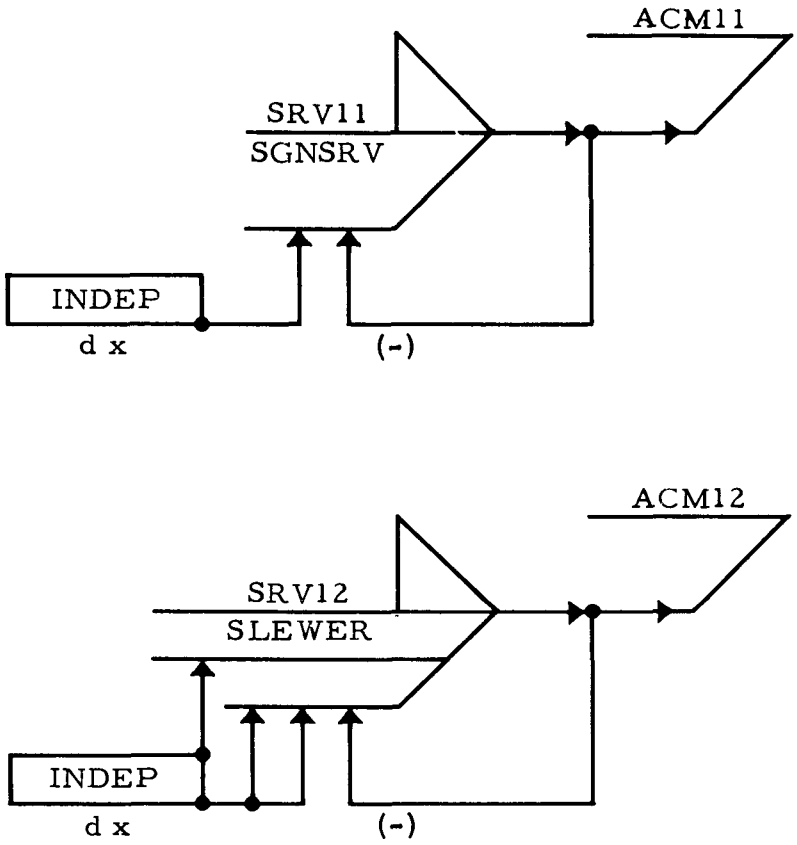

Figure 1b — Sample test problem schematic

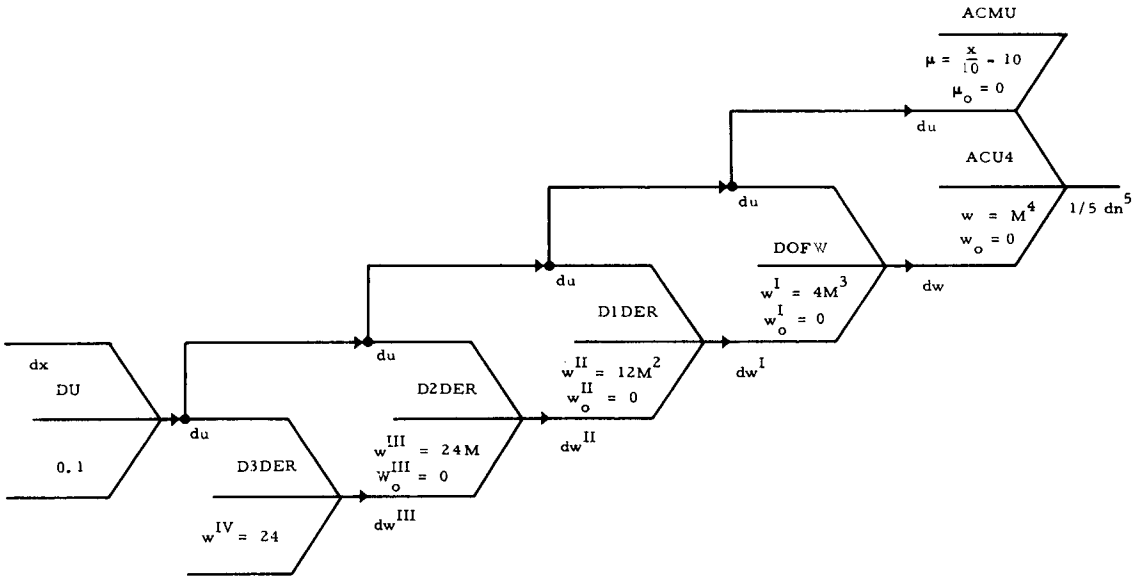

Figure 1c — Sample test problem schematic

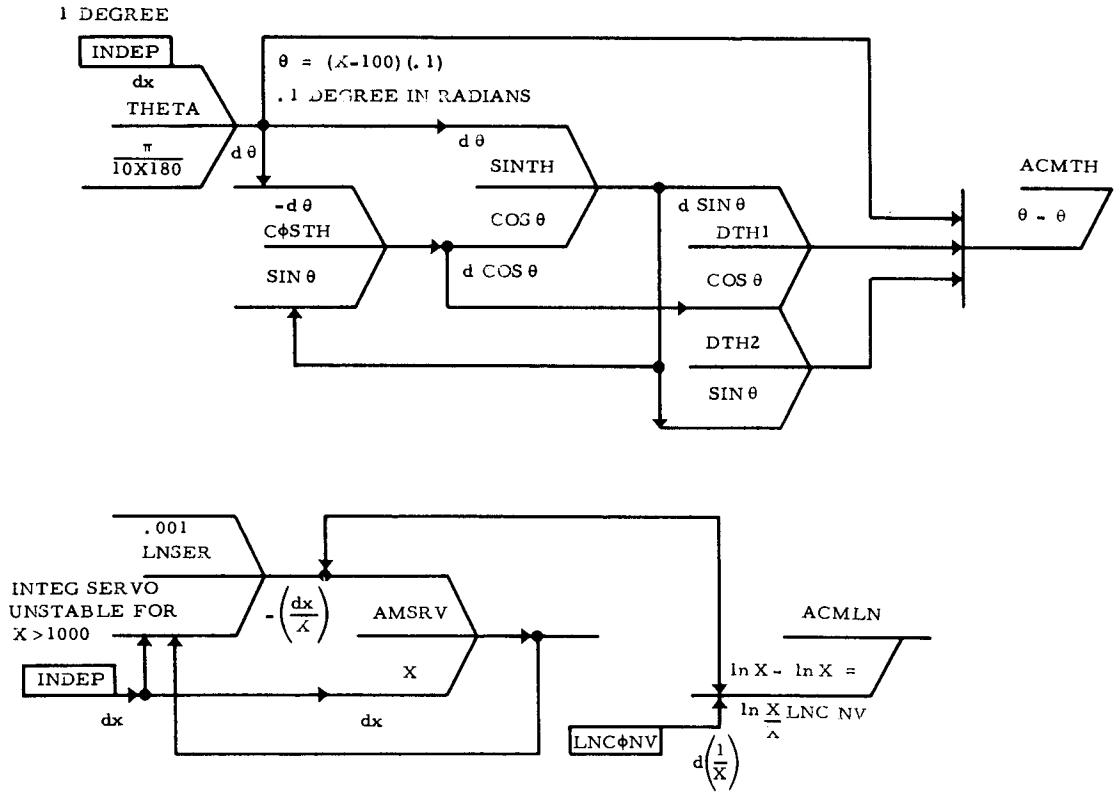

Figure 1d — Sample test problem schematic

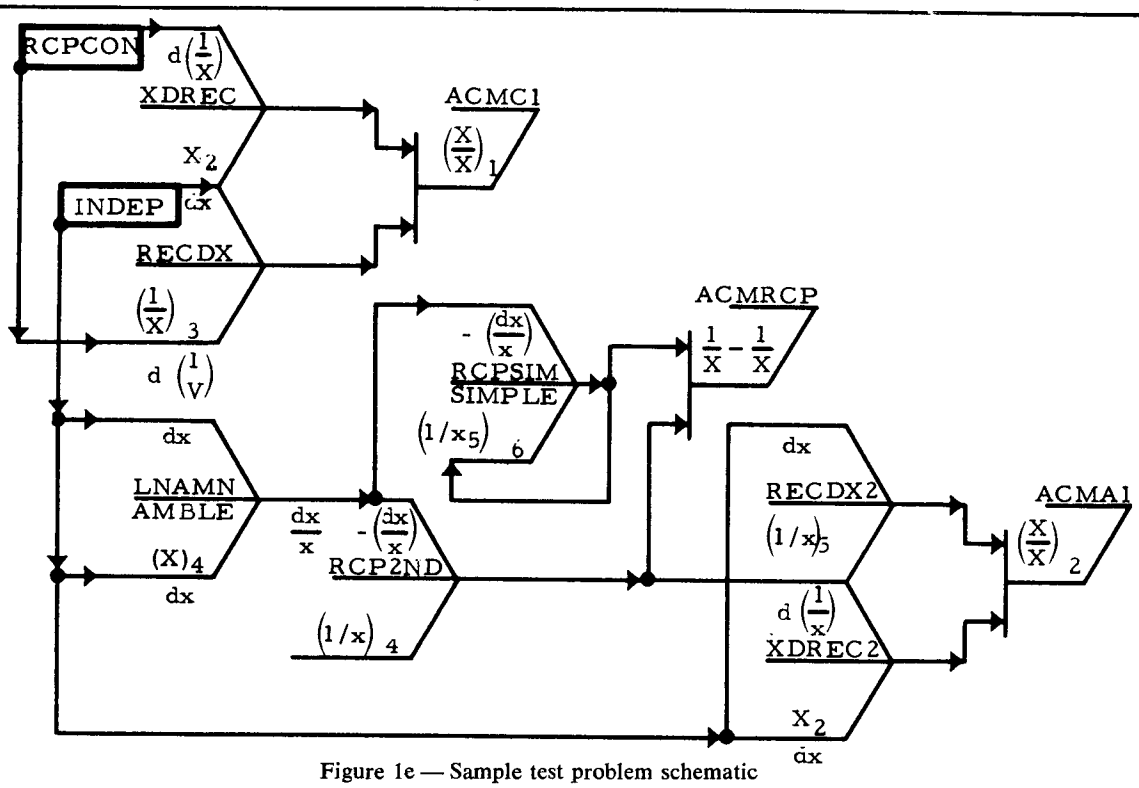

Figure 1e — Sample test problem schematic

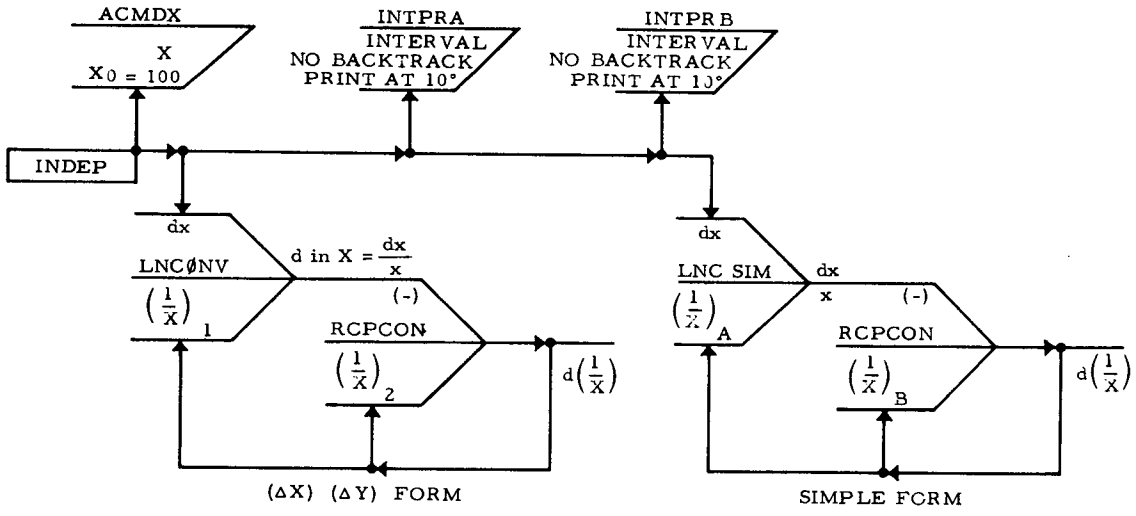

Figure 1f — Sample test problem schematic

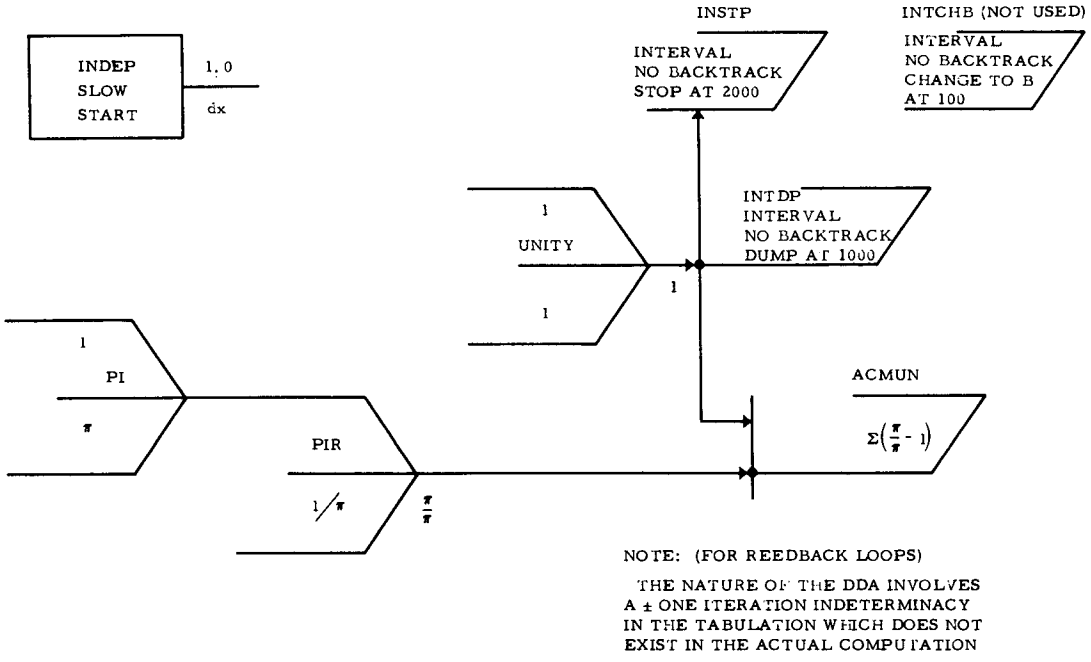

Figure 1g — Sample test problem schematic