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APPLICATION OF THE MEAN STRAIN CRITERION (MSC)

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by

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INTRODUCTION

Research for establishing a head injury criterion has been going on for more than twenty years. As a consequence, there has been a number of criteria published. One of these criteria, the Mean Strain Criterion (MSC) is the only one based on an experimentally determined head model and validated on living subhuman primates over the full AIS scale of 0 to 6.

The MSC model was first published by Stalnaker et al. in 1970 (1) and the MSC criterion was then published by Stalnaker et al. in 1971 (2). These two papers describe in detail the experiments using subhuman primates which established the MSC. Dimensional analysis techniques were then used to extrapolate the MSC to humans.

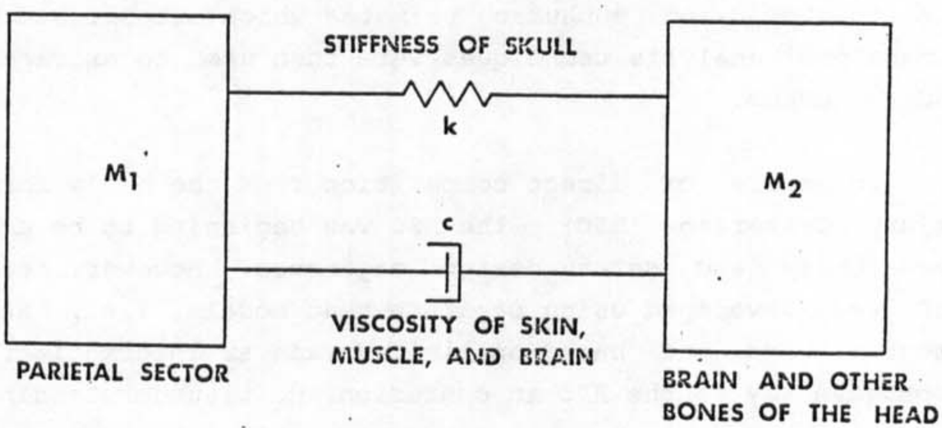
In spite of direct competition from the newly formed Head Injury Criterion (HIC), the MSC was beginning to be used among researchers and safety-design engineers. However, because the MSC was developed using separate head models, i.e., lateral and frontal, and was based on limited cadaver information, the MSC soon gave way to the HIC in confusion and misunderstanding.

In the last few years increased interest in the cost effectiveness of automotive interior design changes has renewed interest in the MSC, mainly, because the MSC is a continuous criterion with respect to head injury.

The confusion and misunderstanding of the MSC can be solved by up-dating the criterion into a three directional model and showing examples of how to utilize it. This up-dating procedure consists of (a) recalculating the injury criterion based on the AIS-80(3) injury scale; (b) establishing anterior-posterior (A-P), left-right (L-R), and superior-inferior (S-I) model parameters; and finally (c) demonstrating the use of the criterion on thirteen dummy tests to predict head injury. The results of this study shows that the MSC can be used inexpensively and uniquely to evaluate dummy response.

METHOD

The MSC criterion is based on a series of mechanical impedance experiments which allowed the conceptual characterization of the head as two masses coupled by a spring and dashpot (Figure 1). The parameter D (cranium distance) reported in the original work was based on the single cadaver used in the dimensional analysis (4).



M_1 (kg)	M_2 (kg)	C(N-sec/m)	K(N/m)	D(m)
0.1814	4.0823	420.30	4553300	0.146

FIGURE 1 -- MSC Model and Parameters.

For head impacts of a known magnitude, the resulting injuries could be grouped by comparing the mean strain as predicted by the model with injury levels, (where mean strain is defined as the displacement of one mass of the model relative to the other mass, divided by the distance across the cranium). By assuming that the brain is equally vulnerable to strain in all directions, the relationship between the strain value and the injury in any direction was plotted (Figure 2).

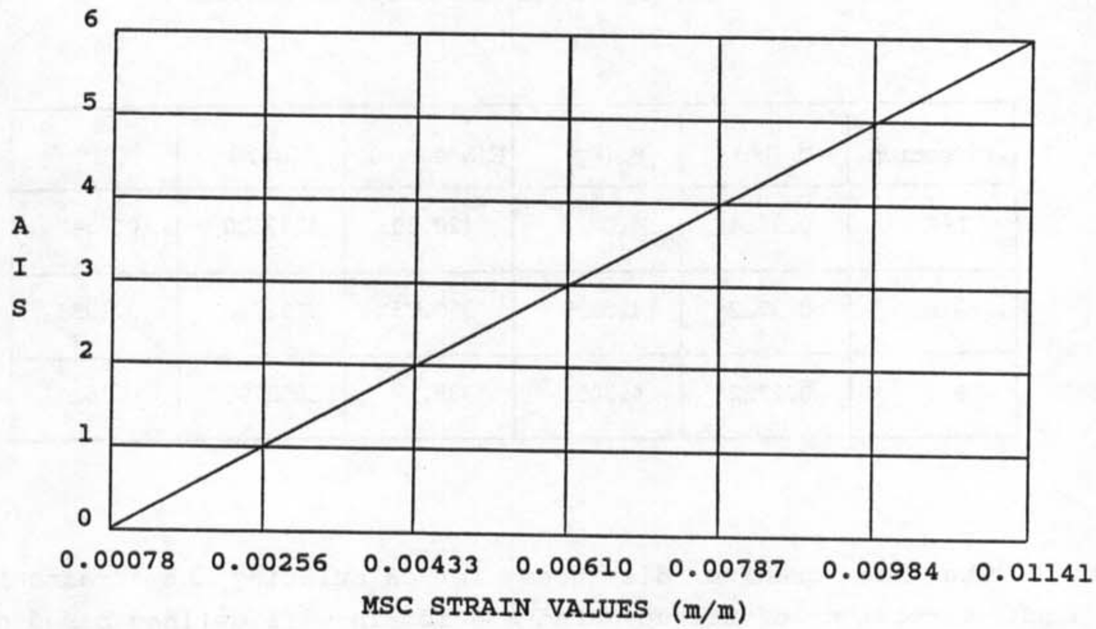


FIGURE 2 -- MSC Injury Equivalent.

In up-dating the MSC criterion, there were two steps to be taken. First, the model had to be extended to three directions, X(A-P), Y(L-R), and Z(S-I). Second, the injury criterion versus AIS relationship had to be redefined to accommodate a more realistic human population. The existing MSC criteriion already had X and Y directional models; the only direction needing to be considered was the Z-model. The model damping was assumed to be the average of the damping for the lateral and frontal models. By reviewing the head impedance models and human skull compression test which were done by Stalnaker et al. in 1977 (5), in S-I direction, the masses and stiffnesses were determined. The results of the formation of the Z (S-I) model parameter are given along with X (A-P) and the Y (L-R) in Table 1.

TABLE 1 -- The Up-Dated MSC Model Parameters

Direction	M_1 (kg)	M_2 (kg)	C(N-sec/m)	K(N/m)	D(m)
L-R	0.1814	4.0823	420.30	4553300	0.154
A-P	0.2722	4.5359	350.25	8756340	0.195
S-I	0.2722	4.3091	385.28	3852790	0.152

The new cranium distances for calculating the strains in each direction of the up-dated MSC models were defined based on Hubbard's (6) study of head geometry. These numbers are lsited as the last column on Table 1.

Based on the new cranium distance, the Mean Strain Criterion value for each injury level were modified. The up-dated criterion for each direction is shown in Figure 3. The relationship between MSC value and AIS is expressed by the following equation.

$$AIS = 595.238 * msc - 0.44 \quad (1)$$

Where, AIS:Abbreviation of Injury Scale
MSC:Mean Strain Criterion

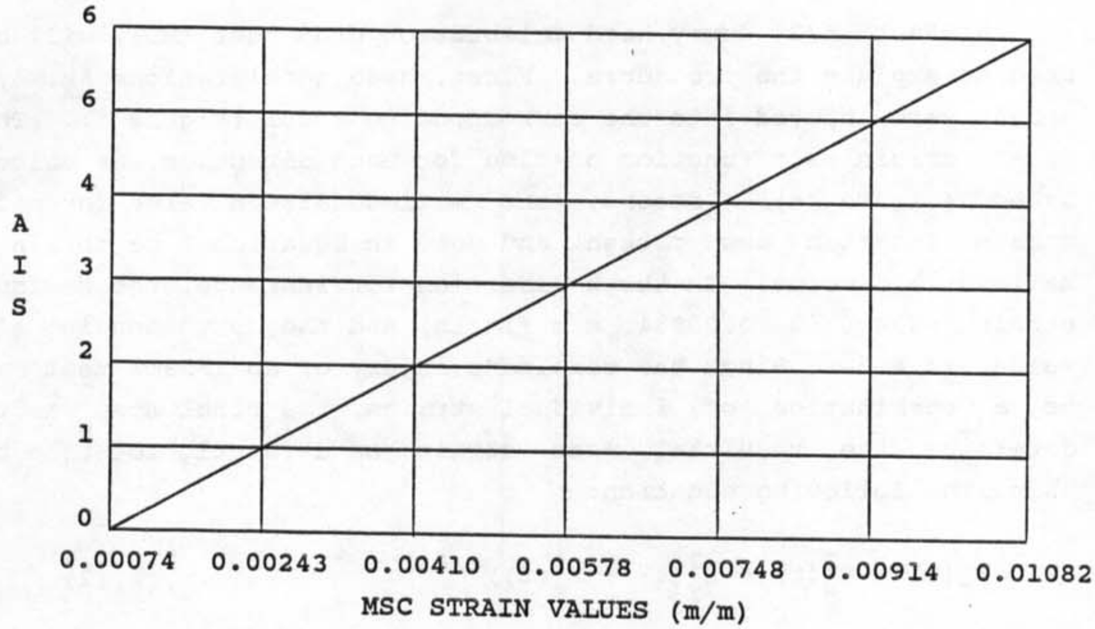


FIGURE 3 -- Up-Dated MSC Injury Equivalent.

HOW TO APPLY UP-DATED MSC

The up-dated MSC is now ready to be utilized. The concept of applying the MSC to a dummy head impact tests is shown in Figure 4.

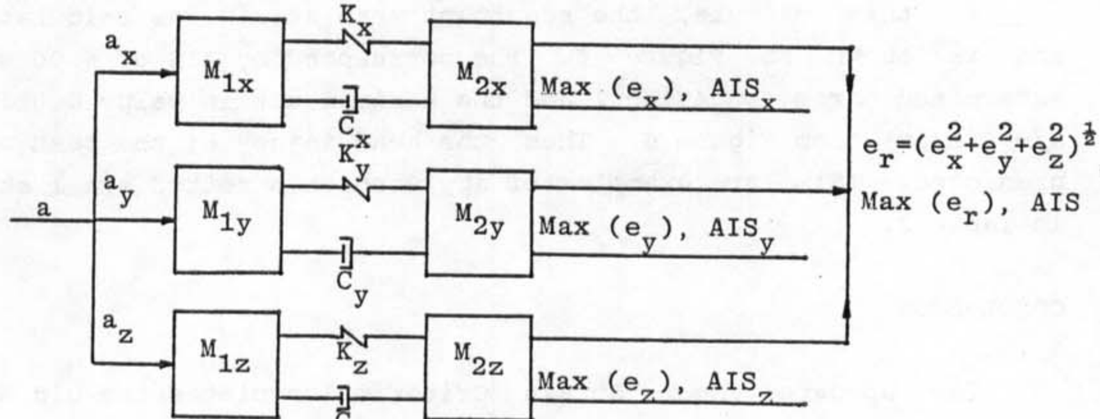


FIGURE 4 -- Implementation of Up-Dated MSC.

A Part 572 dummy head calibration drop test (HD1) will be used to explain the procedure. First, head accelerations Ax, Ay, and Az were inputed into the corresponding model (Figure 5). The model strain as a function of time for each direction was calculated (Figure 6). Second, the maximum strain value for each strain function was chosen and used in Equation 1 to obtain a maximum AIS value. In the x direction for instance, the maximum strain value is 0.00854 m/m (in/in) and the corresponding AIS value is 4.64. Since the resultant injury of an impact test may be a combination of individual strains, the final step was to determine the resultant mean strain as a function of time by using the following equation:

$$E_r(t) = E_x^2(t) + E_y^2(t) + E_z^2(t))^{1/2} \quad (2)$$

Where, $E_x(t)$: Mean strain in x direction

$E_y(t)$: Mean strain in y direction

$E_z(t)$: Mean strain in z direction

$E_r(t)$: Resultant mean strain

In this example, the resultant mean strain was calculated and is shown in Figure 6. The corresponding AIS of 6.00 was determined from equation 1 and the maximum strain value 0.01338 m/m (in/in) from Figure 6. Thus, the head injury of the test was predicted. Similar examples of applying this method are listed in Table 2.

CONCLUSION

The up-dated Mean Strain Criterion completes the old MSC which was first published ten years ago. The three dimensional MSC model now offers an overall head injury analysis never before offered. A threshold of injury value based on an AIS 3

FIGURE 5 -- Acceleration functions. (572 head drop test HD1)

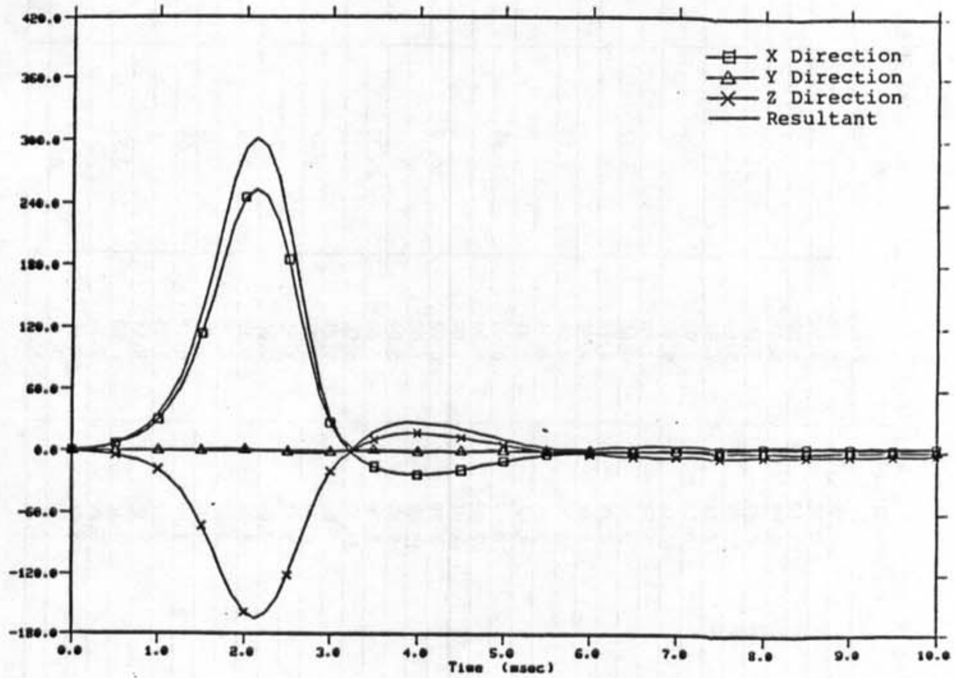


FIGURE 6 -- Mean strain functions. (572 head drop test HD1)

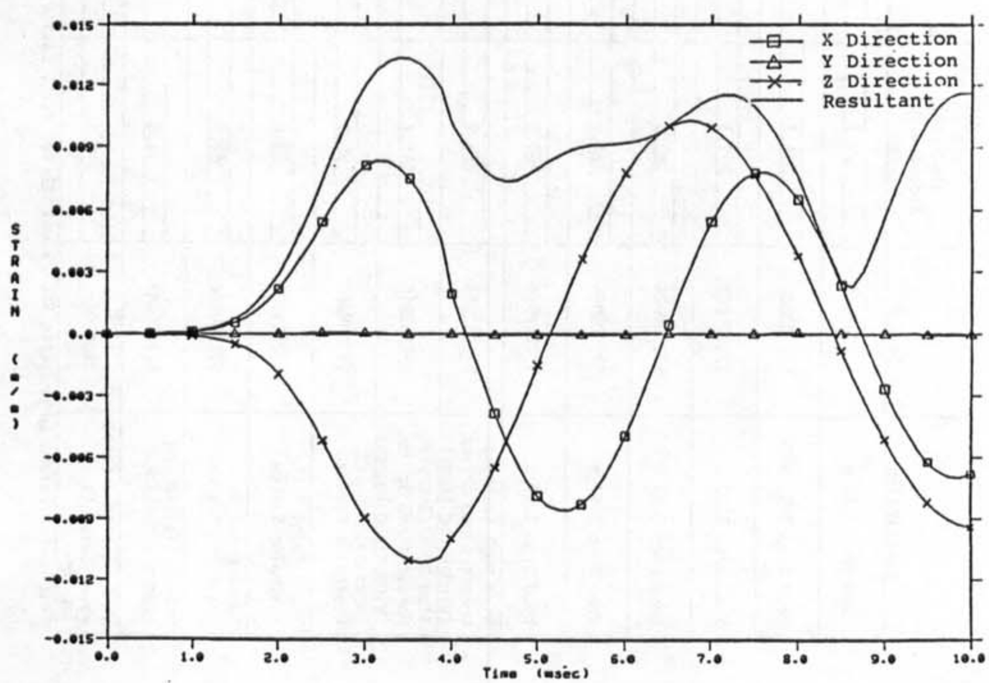


TABLE 2 -- Summary of Part 572 Dummy Tests

Description	Test #*	Peak Resultant Acceleration (g)	Maximum Strain for Each Direction: Direction	Maximum Strain for Each Direction: Maximum Strain (10^{-3} m/m)	Maximum Strain for Each Direction: AIS	Resultant Strain: Maximum Strain (10^{-3} m/m)	Resultant Strain: AIS
Head Drop 0.33 m	572COHD01	302.2	X	8.54	4.64	13.38	6.00
			Y	0.10	0.00		
			Z	11.12	6.00		
Head Drop 0.33 m	572COHD02	291.6	X	8.31	4.51	12.62	6.00
			Y	0.31	0.00		
			Z	10.23	5.65		
Head Drop 0.33 m	572COHD03	291.3	X	8.34	4.52	12.56	6.00
			Y	0.11	0.00		
			Z	10.14	5.60		
Head Drop 0.19 m	572COHD04	182.5	X	5.57	2.88	9.17	5.02
			Y	0.06	0.00		
			Z	7.75	4.17		
Head Drop 0.19 m	572COHD05	184.9	X	5.65	2.92	9.13	4.99
			Y	0.09	0.00		
			Z	7.65	4.11		
Head Drop 0.19 m	572COHD06	180.0	X	5.56	2.87	8.95	4.89
			Y	0.07	0.00		
			Z	7.50	4.02		
Sled Buck (Zephyr) Unrestrained Driver (Windshield Impact)	572SDZU14	273.9	X	3.91	1.89	16.10	6.00
			Y	2.29	0.92		
			Z	15.85	6.00		
Sled Buck (Zephyr) Unrestrained Driver (Windshield Impact)	572SDZU15	316.7	X	5.84	3.04	26.30	6.00
			Y	5.20	2.66		
			Z	25.87	6.00		
Three-point Belt Restraint System	572SDVB02	55.0	X	1.09	0.21	3.64	1.73
			Y	0.84	0.06		
			Z	3.51	1.65		
Three-Point Belt Restraint System	572SDVB03	53.8	X	0.69	0.00	3.74	1.79
			Y	1.04	0.18		
			Z	3.67	1.74		
Three-Point Belt Restraint System	572SDVB04	62.9	X	0.82	0.05	4.59	2.29
			Y	1.02	0.17		
			Z	4.52	2.25		
Driver Distributed Load Air Cushion	572SDWA13	96.8	X	1.43	0.41	6.37	3.35
			Y	0.36	0.00		
			Z	6.29	3.30		
VW Rabbit Into Fixed Pole (Lateral) SRL-92	840629	219.3	X	8.16	4.42	8.28	4.49
			Y	2.17	0.85		
			Z	4.68	2.35		

*Test number refers to projects SRL-29 and SRL-92, VRTC, East Liberty, Ohio was determined to be 0.00578 m/m (in/in). Thirteen examples using the up-dated MSC were presented and could be used to compare with other criteria.

However, the fundamental concept of up-dated MSC and old MSC were not fully proven. The MSC was not only extended to human application through dimensional analysis from primate experiments, but also made a major assumption of using acceleration of mass 1 as the model input. These weaknesses can be corrected. New studies are going on now to correct these weaknesses and will be reported in the 1985 International IRCOBI Conference, Goteborg, Sweden.

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3. Petrucelli, E., States, J.D., Huelke, D.F., and Hames, L.M., "Injury Coding Manual-1980," Health and Safety Asso., Inc., 1980.

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5. Stalnaker, R.L., Alem, N.M., and Benson, J.B., "Validation Studies for Head Impact Injury Model," Highway Safety

Research Institute, The University of Michigan, Ann Arbor, Michigan, Report No. DOT HS-802566, 1977.

6. Hubbard, R.P. and McLeod, D.G., "Definition and Development of a Crash Dummy Head," Proceedings of the 18th Stapp Car Crash Conference, 741193, pp.599-628, 1974.

APPENDIX

```
C               ****************************************
C               *        UP-DATED MSC PROGRAM          *
C               *                                      *
C               *  This program calculates mean strain *
C               * by input acceleration to up-dated MSC *
C               * head injury model. The output is a   *
C               * mean strain function.                *
C               *                                      *
C               *  Written by: Chichjung Alex Lin      *
C               *              10-10-83                *
C               *                                      *
C               *  Operating system: VRTC RSX-11M V4.1 *
C               *                                      *
C               ****************************************
C
        INCLUDE 'LB:[200,200]RAINFOCOM'
        PARAMETER(LDATA=1900)
        COMMON /LOVE/ DX,YOUP
        COMMON /BIG/ OUT(LDATA)
        COMMON /LAST/ACCNEW(LDATA)
        COMMON /PARAM/ STF,DAMP,DIS,MASS1,MASS2
        REAL MASS1,MASS2,NUMDI
C
        DIMENSION PRMT(5),ACC(1000),IFILTR(5),Y(2),DERY(2),AUX(16,2)
        DIMENSION YOUP(100),YY(2),XX(2)
        CHARACTER DATTIM*18,IMNEM*6,IFSP*32,ISTRNG*81
C
        PARAMETER (IFI=1,NDIM=2,IFO=2,LUNIN=1,LUNOUT=2)
        LOGICAL*1 LZEOF
        DATA DATTIM/' '/
C
C-------EXTERNAL FUNCTIONS
C
        EXTERNAL FCT, OUTP
C
C#########################################################################
C
        CALL ERRSET (63,,,,.FALSE.)      !Suppress 'Output Conversion Error'
        CALL ATTACH
        DATTIM = ' '
        CALL DATE (DATTIM(1:9))
        CALL TIME (DATTIM(11:18))
C
        TYPE 1, DATTIM
1       FORMAT ('OMSCRIT--CALCULATE MEAN STRAIN ',9X,A18)
C
C-------- ENTER INPUT, OUTPUT RANDOM ACCESS FILES ----------------
C
20      CALL IGTLIN (ISTRNG,'ENTER INPUT, OUTPUT FILE')
        IPTR=0
        IF (IFFFSP(ISTRNG,IPTR,IFSP,32) .LT. 0)  GO TO 20
        CALL RAOPEN (IFI,LUNIN,'RO',IFSP,ISTAT)
        IF (ISTAT.NE.0)  THEN
          CALL CLSICF
          GO TO 20
        ENDIF
        IF(IFFFSP(ISTRNG,IPTR,IFSP,32).LT.0) GO TO 20
        CALL RAFCRE(IFO,LUNOUT,IFSP,IFI,ISTAT)
        IF(ISTAT.NE.0)THEN
        CALL CLSICF
```

```
      GO TO 20
      ENDIF
      CALL XSCALF(IFI,I,P)
      ICO=0
C
C-------INPUT DATA :
C-------INPUT MODEL PARAMETERS:MASS 1,2, STIFFNESS, DAMPING COEFFICIENT,
C-------                       CRANIUM DISTANCE, AND NUMDI.
C-------NUMDI=ORIGINAL INCREMENT/NEW INCREMENT
C
2     CALL IGTLIN(ISTRNG,'ENTER MASS 1')
      IPTR=0
      IF(IFFFLT(ISTRNG,IPTR,MASS1).LT.0)GO TO 2
      TYPE * ,MASS1
4     CALL IGTLIN(ISTRNG,'ENTER MASS 2')
      IPTR=0
      IF(IFFFLT(ISTRNG,IPTR,MASS2).LT.0)GO TO 4
      TYPE * ,MASS2
6     CALL IGTLIN(ISTRNG,'ENTER NUMDI')
      IPTR=0
      IF(IFFFLT(ISTRNG,IPTR,NUMDI).LT.0)GO TO 6
      TYPE * ,NUMDI
7     CALL IGTLIN(ISTRNG,'ENTER STF')
      IPTR=0
      IF(IFFFLT(ISTRNG,IPTR,STF).LT.0)GO TO 7
      TYPE * ,STF
9     CALL IGTLIN(ISTRNG,'ENTER DAMP')
      IPTR=0
      IF(IFFFLT(ISTRNG,IPTR,DAMP).LT.0)GO TO 9
      TYPE * ,DAMP
11    CALL IGTLIN(ISTRNG,'ENTER DIS')
      IPTR=0
      IF(IFFFLT(ISTRNG,IPTR,DIS).LT.0)GO TO 11
      TYPE * ,DIS
C
C-------INPUT ACCELERATION DATA FILE
C
 100  L=IGTLIN(ISTRNG,'ENTER CHANNEL',,LZEOF)
      IF (LZEOF)  GO TO 900
      IPTR=0
      IF (IFFSTR(ISTRNG,IPTR,IMNEM,6) .LT. 0)  GO TO 100
      ICI=NUMCHN(IMNEM,IFI)
      IF (ICI.LE.0)  GO TO 7005
      NUMPTS=NWRDS(ICI,IFI)
      IF (NUMPTS.GT.LDATA)  GO TO 7000
C
C-------READ FILE
C
 120  CALL RAREAD (IFI,ICI,ACC,ISTAT,IUNITS,IFILTR)
      IF (ISTAT.NE.0)  GO TO 7005
      DELT=DELTAX(ICI,IFI)
C
      IF(NUMDI.EQ.1.)THEN
      DX=DELT
      INEW=NUMPTS-1
      DO 130 I=1,NUMPTS
130   ACCNEW(I)=ACC(I)
      GO TO 500
      ENDIF
C
C-------USE RK4 METHOD TO SOLVE THE SECOND ORDER DIFFERENTIAL EQ.
```

```
C-------DIVIDED INCREMENT, DELT, BY 'NUDIM' TO AVOID RUNOFF ERROR
C
C-------KEY: THE NUMBER OF INTERVALS
C
        KEY=NUMPTS-1
        DO 499 IDEX=1,KEY
C
C-------VALUI :INITIAL VALUE OF INDEPENDENT VARIABLE
C
        VALUI=IDEX*DELT-DELT
C
C-------XX(1),XX(2): THE ENDS OF INTERVAL
C
        XX(1)=DELT*IDEX-DELT
        XX(2)=XX(1)+DELT
C
C-------YY(1),YY(2): THE Y VALUES OF THE INTERVAL
C
        YY(1)=ACC(IDEX)
        IA=IDEX+1
        YY(2)=ACC(IA)
C
C-------DX: NEW INCREMENT AFTER DIVIDED BY 'NUMDI'
C
        DX=DELT/NUMDI
        JNUM=INT(NUMDI)
        JBB=JNUM+1
        NPO=LDATA
        CALL INTERP(XX,YY,2,YOUP,NPO,DX,VALUI)
        IF(IDEX.EQ.1)ACCNEW(1)=YOUP(1)
        DO 488 KKK=2,JBB
        IF(NPO.EQ.JNUM)YOUP(JBB)=ACC(IA)
        INEW=(IDEX-1)*JNUM+KKK
        ACCNEW(INEW)=YOUP(KKK)
488     CONTINUE
499     CONTINUE
C
C-------PARAMETERS OF USING RKGS SUBROUTINE(RK4 METHOD)
C
500     PRMT(1)=0.
        PRMT(2)=DX*INEW
        PRMT(3)=DX
        PRMT(4)=0.00001
        PRMT(5)=0.
        DO 25 I=1,NDIM
        Y(I)=0.
25      DERY(I)=0.
C
        CALL RKGS(PRMT,Y,DERY,NDIM,IHLF,FCT,OUTP,AUX)
C
C-------OUTPUT MEAN STRAIN FUNCTION
C
        ICO=ICO+1
        NCHAN(IFO)=ICO
        NWRDS(ICO,IFO)=INEW
        DELTAX(ICO,IFO)=DX
        MNEM(ICO,IFO)=IMNEM
        CALL RAWRIT(IFO,ICO,OUT,ISTAT,0,IFILTR)
        IF(ISTAT.NE.0)STOP
        GO TO 100
C
```

```
C-------END PROCESSING THIS FILE
C
  900   CALL RACLOS (IFI,ISTAT)
        CALL RAHWRT(IFO,ISTAT)
        CALL RACLOS(IFO,ISTAT)
        GO TO 20
C-----------------------------------------------------ERROR MESSAGES-----
 7000   CALL MESSGS ('CHANNEL TOO LONG')
 7005   CALL CLSICF
        GO TO 100
        END
C
C-----------------------------------------------------------------------
C
        SUBROUTINE FCT (X,Y,DERY)
        REAL N,MASS1,MASS2,DAMP,STF,Y(2),DERY(2)
        INTEGER TIME
        COMMON /PARAM/ STF,DAMP,DIS,MASS1,MASS2
        COMMON /LOVE/ DX,YOUP
        COMMON /LAST/ ACCNEW(1900)
        TIME = IFIX ( X / DX )
        IF ( TIME .LE. 1 ) TIME = 1
        DERY(1) = Y(2)
20      DERY(2)=-DAMP/MASS2*DERY(1)-STF/MASS2*Y(1)-ACCNEW(TIME)*9.80621
        RETURN
        END
C
C-----------------------------------------------------------------------
C
        SUBROUTINE OUTP (X,Y,DERY,IHLF,NDIM,PRMT)
        INTEGER TIME
        COMMON /PARAM/ STF,DAMP,DIS,MASS1,MASS2
        COMMON /LOVE/ DX,YOUP
        COMMON /BIG/OUT(1900)
        DIMENSION PRMT(5),Y(2),DERY(2)
        TIME=IFIX(X/DX)
        IF(TIME.LE.1) TIME=1
        OUT(TIME)=-Y(1)/DIS
        RETURN
        END
>
```