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INSTRUCTIONS FOR THE USE OF THE CIVM-JET 4C FINITE-STRAIN COMPUTER CODE TO CALCULATE THE TRANSIENT STRUCTURAL RESPONSES OF PARTIAL AND/OR COMPLETE ARBITRARILY-CURVED RINGS SUBJECTED TO FRAGMENT IMPACT

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December 1979

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Prepared for
AEROSPACE SAFETY RESEARCH AND DATA INSTITUTE
LEWIS RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CLEVELAND, OHIO 44135

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16. Abstract

The CIVM-JET 4C computer program for the finite strain analysis of 2-d transient structural responses of complete or partial rings and beams subjected to fragment impact has been stored on tape as a series of individual files. This document describes in detail which subroutines are found in these files. All references to the CIVM-JET 4C program are made assuming that the user has a copy of NASA CR-134907 (ASRL TR 154-9) which serves as a user's guide to (1) the CIVM-JET 4B computer code and (2) the CIVM-JET 4C computer code with the use of the modified input instructions attached hereto.

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FOREWORD

This report was prepared by the Aeroelastic and Structures Research Laboratory, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 under Grant No. NGR 22-009-339 from the Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio 44135. Dr. Arthur G. Holms served as technical monitor.

The authors wish to thank Dr. Holms for his advice and guidance.

The use of SI units (NASA Policy Directive NPD 2220.4, September 14, 1970) was waived for the present document in accordance with provisions of paragraph 5d of that Directive by the authority of the Director of the Lewis Research Center.

In July 1979 an informal memorandum report ASRL MR 154-1 titled "Use of the CIVM-JET 4C Tape" was issued. NASA-Lewis reviewed this informal report and recommended that it be made somewhat more inclusive and issued as a NASA Contractor Report. Hence, revisions resulting in the present report (and reproduction thereof) were carried out in June 1980. The present report NASA CR-159873 (also ASRL MR 154-1) is dated as 1979 since the computer code and description CIVM-JET 4C bears a 1979 copyright date.

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SECTION 1

INTRODUCTION

In March 1976 Ref. 1 "A User's Guide to Computer Program CIVM-JET 4B to Calculate the Transient Structural Responses of Partial and/or Complete Structural Rings to Engine-Rotor-Fragment Impact" was published. The general capabilities of that two-dimensional (2-D) structural-response finite-element computer code are summarized in Table 1. Although large displacements and elastic-inelastic behavior of initially-isotropic ductile-metal Bernoulli-Euler structures are taken into account, the code is not valid for arbitrarily large strains and arbitrarily large rotations for several reasons. First, the strain-displacement relation used (see Appendix A of Ref. 1; also called Type B in Refs. 2 and 3) is valid for arbitrarily large membrane strains but only for small bending strains; the accompanying assumed displacement field employed for Bernoulli-Euler behavior is valid also only for small strains since no structural thinning is taken into account. In addition, the stress-strain description used in CIVM-JET 4B is appropriate for small strains but is not valid for arbitrarily large strains. Subsequently, the analysis has been extended to account properly for large strain behavior of ductile-metal 2-D Bernoulli-Euler structures; these developments [2,3] have led to modifications to CIVM-JET 4B resulting in the finite-strain computer code now called CIVM-JET 4C. Since CIVM-JET 4C is similar in many respects to CIVM-JET 4B+, Ref. 1 can serve also as a user's guide for CIVM-JET 4C (thereby avoiding unnecessary duplication of elaborate documentation) -- together with specific user information included in the present report for CIVM-JET 4C.

Since March 1976, various additions, modifications, and corrections have been made to CIVM-JET 4B; most are applicable also to CIVM-JET 4C. In particular, in June 1976 some additions (addenda to Ref. 1) were prepared and forwarded to the recipients of Ref. 1; these items are contained in Section 2 of the present report. Section 3 contains a description of subsequent additions which are applicable to both CIVM-JET 4B and CIVM-JET 4C. Next, modifications of the

+See Table 1.

input and output instructions which are pertinent to CIVM-JET 4C (the finite-strain code) are given in Section 4. Additional user instructions for CIVM-JET 4C are given in Section 5.

Finally, it is emphasized that CIVM-JET 4C supersedes and replaces CIVM-JET 4B completely since CIVM-JET 4C accommodates finite-strain behavior properly for (a) membrane and bending behavior, (b) the material stress-strain description, and (c) Bernoulli-Euler deflection behavior including structural thinning -- whereas CIVM-JET 4B does not account for these features and is restricted to "small strains" of undefined size.

SECTION 2

JUNE 1976 ADDITIONS TO CIVM-JET 4B

In June 1976 the following two additions to the CIVM-JET 4B code of Ref. 1 were issued, and are repeated here for completeness; they are applicable also to CIVM-JET 4C. All cited items have been included in the present versions of both codes.* These two additions include: (1) the reactions at structural support locations and (2) the translational, rotational, and total kinetic energy of each fragment following each impact; these items and the associated printed output are discussed in the following under, respectively, Addendum 1 and Addendum 2. Also added to the printed output immediately prior to the printing of the solution data is the following (example) output reminder and confirmation of user-specified output options:

```
THE FOLLOWING IS THE TIME SOLUTION OF THE FRAGMENT- RING IMPACT.
OUTPUT WILL BE PRINTED EVERY   40  CYCLES USING OUTPUT OPTION 3.
REACTION FORCES WILL BE PRINTED AT EACH OUTPUT CYCLE FOR NODES AT WHICH
BOUNDARY CONDITIONS ARE SPECIFIED. D.O.F. THAT ARE NOT RESTRAINED AT
THAT NODE WILL HAVE A REACTION FORCE = 0.0.  ALL IMPACTS WILL BE DESIGNATED
AND ALL THE FRAGMENT ENERGIES WILL BE LISTED AFTER EACH IMPACT.
```

Included in Addendum 1 and Addendum 2 are example output data associated with these changes for the example problem given in Subsection 6.1 of Ref. 1.

Addendum 1: Addition of Reaction Force Calculation and Output to CIVM-JET 4B

For the complete assembled but unrestrained discretized structure subject to fragment impact, the equations of motion at time instant t_m for the containment/deflector structure are (pg. 8, Ref. 1):

*The program statement sequence numbers shown in this section pertain to the CIVM-JET 4B numbers used in Ref. 1. In the CIVM-JET 4C program, many program statements have resequenced.

$$[M^*]\{\ddot{q}^*\}_m + \{P^*\}_m + [H^*]_m\{q^*\}_m + [K_s^*]\{q^*\}_m = \{0\} \quad (2.1)$$

where the mass matrix $[M^*]$ is a lumped (diagonalized) matrix. If the structure were supported (that is, certain degrees of freedom i were constrained to experience zero displacements, velocities, and accelerations), the governing equation for any such ith degree of freedom would read:

$$M_i^* \underbrace{\ddot{q}^*_{m_i}}_{\shortparallel \atop 0} + P^*_{m_i} + \lfloor H^* \rfloor_{m_i}\{q^*\}_m + \lfloor K_s^* \rfloor_i \{q^*\}_m = 0 + R_i^* \quad (2.2)$$

Hence,

$$R_i^* = P^*_{m_i} + \lfloor H^* \rfloor_{m_i}\{q^*\}_m + \lfloor K_s^* \rfloor_i \{q^*\}_m \quad (2.2a)$$

where R_i^*, the reaction force resultant, is the force (or moment) resultant applied to the structure by the support; its positive sign is in the direction of the defined positive direction of the associated ith pre-constrained degree of freedom.

In order to compute and to print these reaction forces at each printout cycle, the following (indicated "added") statements have been added to MAIN of the CIVM-JET 4B program:

In the dimension statement list, added was:

```
IMPLICIT REAL*8(A-H,C-Z)                                              MAIN0030
DIMENSION CINETP(6),TRANEN(6),ROTEN(6),REF(7,3)      ]added           MAIN0032
DIMENSION                BEPS(3,3),EPI(3),EPO(3),HNIN(51)             MAIN0040
```

Between statements MAIN 5450 and MAIN 5530, the following changes were made:

```
686    IF(NBCOND.EQ.0)GO TO 889                                       MAIN5400
       DO 888 I=1,NBCOND                                              MAIN5410
       NXY=NODEB(I)                                                   MAIN5420
       IF(NBC(I).EQ.1)GO TO 886                                       MAIN5430
       IF(NBC(I).EQ.2)GO TO 887                                       MAIN5440
       IF(NBC(I).EQ.3)GO TO 885                                       MAIN5450
  886  REF(I,1)= FLVA(NXY*4-3)     ]                                  MAIN5451
       REF(I,2) = 0.0              ] added                            MAIN5452
       REF(I,3) = FLVA(NXY*4-1)    ]                                  MAIN5453
       FLVA(NXY*4-3) = 0.0                                            MAIN5460
       FLVA(NXY*4-1)=0.0                                              MAIN5470
       GO TO 888                                                      MAIN5480
  887  REF(I,1) = FLVA(NXY*4-3)    ]                                  MAIN5481
       REF(I,2) = FLVA(NXY*4-2)    ] added                            MAIN5482
       REF(I,3) = FLVA(NXY*4-1)    ]                                  MAIN5483
       FLVA(NXY*4-3) = 0.0                                            MAIN5490
       FLVA(NXY*4-2)=0.0                                              MAIN5500
       FLVA(NXY*4-1)=0.0                                              MAIN5510
       GO TO 888                                                      MAIN5520
  885  REF(I,1)= FLVA(NXY*4-3)     ]                                  MAIN5521
       REF(I,2)= FLVA(NXY*4-2)     ] added                            MAIN5522
       REF(I,3)= 0.0               ]                                  MAIN5523
       FLVA(NXY*4-3) = 0.0                                            MAIN5530
       FLVA(NXY*4-2)=0.0                                              MAIN5540
888    CONTINUE                                                       MAIN5550
```

Between FORTRAN cards MAIN 7780 and MAIN 7790, the following FORTRAN statements have been added:

```
7182 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6)                        MAIN7780
     IF(NBCOND.EQ.0) GOTO 1254                                         ]     MAIN7781
     WRITE(MWRITE,1256)                                                ]     MAIN7782
1256 FORMAT('0',6X,'REACTIONS AT NODE',15X,'RV(LBS)',13X,'RW(LBS)',    ]     MAIN7783
    @11X,'PM(IN-LBS)')                                                 ]     MAIN7784
     DO 1252 I=1,NBCOND                                                ]     MAIN7785
     NXY= NODEB(I)                                                     ]     MAIN7786
     WRITE(MWRITE,1253) NXY,(REF(I,J),J=1,3)                           ] added MAIN7787
1253 FORMAT(' ',18X,I4,5X,3D20.6)                                      ]     MAIN7788
1252 CONTINUE                                                          ]     MAIN7789
1254 CONTINUE                                                          ]     MAIN778A
     WRITE(MWRITE,11100)                                                     MAIN7790
```

These modifications will print out the reaction force resultants RV (tangential, lbs), RW (normal, lbs), and RM (moment, in-lbs) for each constrained node at each user-designated printout cycle. The physical positive orientation of each reaction force (applied to the structure) is the same as the orientation of the corresponding local degree of freedom depicted in Fig. 3 of Ref. 1 (page 224). Note that the reaction force is set equal to 0.0 for each unconstrained degree of freedom at a "constrained" node; see FORTRAN statements MAIN 5452 and MAIN 5523 above.

These modifications result in the following output for the Subsection 6.1 example of Ref. 1; the output occurs for cycle 1100 at 132.2 microseconds after initial impact (see pages 171 and 189 of Ref. 1):

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	0.162271D+C4	-0.595815D+01	0.0
13	0.157820D+03	-0.149160D+04	0.292786D+04

****

Addendum 2: Printout of Kinetic Energies of Every Fragment After Each Impact

For every fragment after each impact, the kinetic energies in inch-pounds: translational (TE), rotational (RE), and sum or total (TOE) are printed out. This has been accomplished by adding the indicated statements between FORTRAN cards MAIN 5630 and MAIN 5640. The correct dimension statement MAIN 0032 of Addendum 1 has been included; variables CINETF(6), TRANEN(6), and ROTEN(6) from that dimension statement apply to this addendum.

```
      IF (IMCO.EQ.0) GOTO 527                                      MAIN5620
      IMCO= 0                                                      MAIN5630
      DO 6301 I=1,NF                                               MAIN5631
      TRANEN(I)= FMASS(I)/2.0*(UDOT(I)**2+WDOT(I)**2)              MAIN5632
      ROTEN(I)= FMOI(I)/2.0 * ADOT(I)**2                           MAIN5633
      CINETF(I)= TRANEN(I)+ROTEN(I)                                MAIN5634
      J=I-2                                                        MAIN5635
      GOTO 6307                                                    MAIN5636
 6303 J=J-2                                                        MAIN5637
 6307 IF(J) 6304,6305,6303                                         MAIN5638
 6304 WRITE(MWRITE,6302) I,TRANEN(I),ROTEN(I),CINETF(I)            MAIN5639
 6302 FORMAT(' FRAG',I2,': TE=', D12.4,'  RE=',D12.4,'  TOE=',D12.4)  MAIN563A
      GOTO 6301                                                    MAIN563B
 6305 WRITE(MWRITE,6306) I,TRANEN(I),ROTEN(I),CINETF(I)            MAIN563C
 6306 FORMAT('+',62X,'FRAG',I2,': TE=',D12.4,'  RE=',D12.4,'  TOE=',  MAIN563D
     @D12.4)                                                       MAIN563E
 6301 CONTINUE                                                     MAIN563F
      DO 526 J=1,NS                                                MAIN5640
```

Added

An example of this added output is shown as follows for the example problem in Subsection 6.1 of Ref. 1 (see pages 171 and 186):

```
IMPACT NO.    1    TIME   0.967796D-03     DURING CYCLE  968      ELEM     9
FRAG 1: TE=  0.1465D+04  RE=  0.0          TCE=  0.1465D+04
```

SECTION 3

SUBSEQUENT ADDITIONS APPLICABLE TO BOTH CIVM-JET 4B AND CIVM-JET 4C

First, note the following clarifications pertinent to Ref. 1 (with the page number of Ref. 1 cited):

<u>Page</u>	
39	TPRIM(I) must be a multiple of the Δt actually used.
50	The (circumferential*) "strain" (such as SI or SO) is denoted by ε (or γ_{11}) and is identified by Eqs. A.12 through A.14.
118	In Subroutine IMPACT, statement IMPA0720 has been changed to include a print message before CALL EXIT to remind the user that the number of impacts occurring during a single Δt time step has exceeded the specified 50 "allowable impacts".
153	Note that statements ROOT0510 and ROOT0570 in Subroutine ROOT4 may need to be changed if your computer does not accommodate numbers up to 10^{+50}; the user should change accordingly.
257	The quantity e in Eqs. A.50 and A.51 is the coefficient of restitution: perfectly-elastic impact $e = 1$; perfectly inelastic impact $e = 0$; and intermediate $0 < e < 1$.

The following "subsequent" additions (since June 1976) are identified for convenience and consistency as Addendum 3 through Addendum 7; pages cited refer to Ref. 1. All of these items have been included in the present versions of both codes+.

---

*Since this report deals with both initially-curved and initially-straight 2-D structures (rings and beams, respectively), the term "circumferential strain" is used throughout this report to denote (a) circumferential strain for rings and (b) spanwise strain for beams.

+Footnote on page 3 applies.

Addendum 3: User Specified Impact-Affected Length L_{eff}

The impact-affected length L_{eff}^{+} (named EFLN(L) in the program) in inches may be specified by the user, or the value $\Delta t[E/\rho_o]^{1/2}$ described on page 59 may be chosen as a default option. Accordingly, the following changes have been made, and the new input card requirements are:

Card 5A on page 32 should now read:

NSF(L),B(L),DENS(L),DS(L),P(L),EFLN(L) with format I5,5D15.6

Card 6 on page 36 should now read:

DELTAT,DS(1),P(1),NTOVR,EFLN(1) with format 3D15.6,I5,D15.6

If EFLN(I) for I = 1, 2, ... NBR+1 is input as zero or as a negative number, the program will use the default value $\Delta t[E/\rho_o]^{1/2}$.

In the MAIN program, replace statements MAIN1210 and MAIN1220 with the following three cards:

```
      READ(MREAD,2)  DELTAT,DS(1),P(1),NTOVR,EFLN(1),(EPS(1,L),SIG(1,L),  MAIN1210
     1 L=1,M)                                                            MAIN1215
    2 FORMAT(3D15.6,I5,D15.6/(4D15.6))                                   MAIN1220
```

Also, replace card MAIN4690 by the following three cards:

```
      IF(EFLN(I) .GT. 0.) GO TO 5551                                     MAIN4685
      EFLN(I)=(YOUNG(I)/DENS(I))**0.5*DELTAT                             MAIN4690
 5551 CONTINUE                                                           MAIN4695
```

In Subroutine Bran, replace BRAN0380 and BRAN0390 with the following two cards:

```
      READ(MREAD,5500) NSFL(IB),B(IB),DENS(IB),DS(IB),P(IB),EFLN(IB)     BRAN0380
 5500 FORMAT(I5,5D15.6)                                                  BRAN0390
```

+See also Subsections 2.2 and 2.5.2 of Ref. 2.

Addendum 4: Addition of Clamped-Sliding Nodal-Displacement Condition

The following third type of prescribed-displacement nodal condition should be added to page 4 of Ref. 1:

(3) Clamped-Sliding ($w = \psi = 0$)

Card 14B on pages 41 and 42

Use NBC(I) = 4 for clamped-sliding condition; will set $w = 0$ and $\psi = 0$ at NODEB(I).

In the MAIN program after MAIN5450, add the following card:

```
      IF(NBC(I) .EQ. 4) GO TO 8855                                 MAIN545A
```

In MAIN after MAIN5540, insert these six cards:

```
      GO TO 888                                                     MAIN5541
 8855 REF(I,1)=0.                                                   MAIN5542
      REF(I,2)=FLVA(NXY*4-2)                                        MAIN5543
      REF(I,3)=FLVA(NXY*4-1)                                        MAIN5544
      FLVA(NXY*4-2)=0.                                              MAIN5545
      FLVA(NXY*4-1)=0.                                              MAIN5546
```

In Subroutine IDENT after IDNT0910, insert:

```
      IF(NBC(I) .EQ. 4) WRITE(MWRITE,24) NODEB(I)                   IDNT0915
```

In Subroutine IDENT after IDNT0950, insert:

```
   24 FORMAT(' CLAMPED SLIDING DISPLACEMENT CONDITION AT NODE =',I5)  IDNT0955
```

In Subroutine QREM replace QREM2710, QREM2720, and QREM2730 with these three cards:

```
IF(NBC(I) .NE. 4) CALL ERC(JT4M3,SPRIN,NI,ICOL)                 QREM2710
 IF(NBC(I).NE.3) CALL ERC(JT4M1,SPRIN,NI,ICOL)                  QREM2720
 IF(NBC(I).NE.1) CALL ERC(JT4M2,SPRIN,NI,ICOL)                  QREM2730
```

In Subroutine TSTEP, replace TSTP0480 through TSTP0530 with:

```
IF(NBC(I).NE.4) CALL ERC(JT4M3,STIFK,NI,ICOL)                   TSTP0480
IF(NBC(I).NE.4) TRIAL(JT4M3)=0.0                                TSTP0490
IF(NBC(I).NE.3) CALL ERC(JT4M1,STIFK,NI,ICOL)                   TSTP0500
IF(NBC(I).NE.1) CALL ERC(JT4M2,STIFK,NI,ICOL)                   TSTP0510
IF(NBC(I).NE.3) TRIAL(JT4M1)=0.0                                TSTP0520
IF(NBC(I).NE.1) TRIAL(JT4M2)=0.0                                TSTP0530
```

Addendum 5: Definition of Variable NS in Subroutine IMPCTE

The following two cards should be added to subroutine IMPCTE after statement IMPT0200 to correct an omission:

```
NS=IK                                                           IMPT0201
IF(ICP .GT. 0) NS=IK+1                                          IMPT0202
```

Addendum 6: Additional Strain and Relative Elongation Output

Heretofore the circumferential strain and relative elongation have been computed and provided as output as, respectively, SO and EO at the outer surface, and as SI and EI at the inner surface of the structure at locations designated as "additional strain points" -- see page 50 of Ref. 1. Added now is the circumferential strain $\overset{o2}{\gamma}_2$ (called SM) and relative elongation $\overset{o2}{E}_2$ (called EM) at the <u>midsurface</u> ($\zeta^o = 0$) at each "additional strain point". Accordingly, the following changes are needed (have been made in the CIVM-JET 4C source code and tape):

The cards sequenced MAIN7080 and MAIN7090 were changed to read:

```
8707  FORMAT('STRAIN AT ADDITIONAL POINTS',9X,'SI',14X,'SO',14X,'SM',     MAIN7080
      @14X,'EI',14X,'EO',14X,'EM')                                        MAIN7090
```

After the card sequenced MAIN7550, insert:

```
      EM=DSQRT(1.0+2.*FARE)-1.0                                           MAIN7551
```

The card sequenced MAIN7560 was changed to read

```
      WRITE(MWRITE,8781)IS,EPASI,EPASO,FARE,EI,EO,EM                      MAIN7560
```

The card sequenced MAIN7570 was changed to read

```
8781  FORMAT(' ',10X,I3,16X,6D16.7)                                       MAIN7570
```

<u>Addendum 7: Corrections to Impact Calculations</u>

In Subroutine IMPCTE after statement IMPT0180, insert:

```
            COMMON /COU/ IMCOU                                            IMPT0185
```

In subroutine IMPCTE after statement IMPT3300, insert:

```
            IMCOU=IMCOU-1                                                 IMPT3305
```

In Subroutine IMPACT modify statement IMPA0060 to read:

```
            2NTSD(6),NEF(6),EL(50),EFLN(6),EPCC(51,6)                     IMPA0060
```

In subroutine IMPACT after statement IMPA0300, insert:

```
            DDELD= 0.1D-16                                                IMPA0305
```

In Subroutine IMPACT after statement IMPA0340, insert:

```
      JJJ=0                                                     IMPA0345
```

In Subroutine IMPACT after statement IMPA0760, insert:

```
      JF1=JF                                                    IMPA0761
      PAL1=PAL                                                  IMPA0762
      IBIG1=IBIG                                                IMPA0763
```

In Subroutine IMPACT after statement IMPA0820, add the following 16 cards:

```
      IF(DELTR.GE.DDELD) GOTO 149                               IMPA0821
      WRITE(MWRITE,2000) DELTR                                  IMPA0822
 2000 FORMAT(/,36H DELTR LESS THAN DDELD AND EQUAL TO   ,D15.6,13H   ***IMPA0823
     2*******,/)                                                IMPA0824
      DO 2010 I=1,IK                                            IMPA0825
      DO 2010 J=1,NF                                            IMPA0826
      IF(IFLAG(I,J).NE.2) GOTO  2010                            IMPA0827
      IBIG=I                                                    IMPA0828
      JF=J                                                      IMPA0829
      PAL=RPCC(I,J)                                             IMPA082A
      TMIN=0.0                                                  IMPA082B
      IFLAG(I,J)= 1.0                                           IMPA082C
      GOTO 100                                                  IMPA082D
 2010 CONTINUE                                                  IMPA082E
      GOTO 150                                                  IMPA082F
  149 CONTINUE                                                  IMPA082G
```

In Subroutine IMPACT, modify statement IMPA0950 to read:

```
     2TMIN,LNTMIN,RPC,JF,IFLAG,H,FH,NF,AY,AZ,RPCC)              IMPA0950
```

In Subroutine IMPACT after statement IMPA0990, insert the following 5 cards:

```
      IF(LNTMIN.EQ.0) CALL UPDATE(1.0D0,TU,TW,VY,VZ,TFCGU,TFCGW,TALFA,  IMPA0991
     * VELFU,VELFW,VELFA,DELTR,IKK,NF,ICP,AY,AZ)                  IMPA0992
C                                                               IMPA0993
C    IF NO ACCEPTABLE CONTACT TIMES HAVE BEEN FOUND, GO TO END OF ROUTINEIMPA0994
      IF(LNTMIN.EQ.0)GO TO 150                                  IMPA0995
```

In Subroutine IMPACT, remove statements IMPA1030, IMPA1040, and IMPA1050.

In Subroutine IMPACT after statement IMPA1080 add:

```
      JJJ=1                                                             IMPA1085
```

In Subroutine IMPACT after statement IMPA1330, add these 13 cards:

```
      IF(NPP.GT.0 .AND. JJJ.EQ.0) GO TO 4000                            IMPA1331
      GO TO 4020                                                        IMPA1332
 4000 WRITE(MWRITE,4010) PMAX                                           IMPA1333
 4010 FORMAT(/,10(1H*),'WARNING! PENETRATION HAS OCCURED WITHOUT IMPACT IMPA1334
     *CORRECTION.'/1H ,10(1H*),' OVERRIDE ENACTED. PMAX=  ',D15.6)      IMPA1335
      TT=TB+DELTR                                                       IMPA1336
      TMIN=DELTR                                                        IMPA1337
      JF=JF1                                                            IMPA1338
      PAL=PAL1                                                          IMPA1339
      IBIG=IBIG1                                                        IMPA133A
      IFLAG(IBIG,JF)=1                                                  IMPA133B
      GO TO 100                                                         IMPA133C
 4020 CONTINUE                                                          IMPA133D
```

In Subroutine TCONT, modify statement TCON0020 to read:

```
     2LNTMIN,RPC,NPTMIN,IFLAG,H,FH,NF,AY,AZ,RPCC)                       TCON0020
```

In Subroutine TCONT, modify statement TCON0070 to read:

```
     2VELFW(1),IFLAG(51,6),H(1),FH(1),RPCC(51,6)                        TCON0070
```

In Subroutine TCONT, delete statement TCON1090.

In Subroutine TCONT after statement TCON1120, add:

```
      IF(TM.GT.XY) IFLAG(INUM,IF)=0                                     TCON1125
```

In Subroutine TCONT after statement TCON1310, add:

```
      IF(P2CT.LT.0.0.OR.P2CT.GT.P1) IFLAG(INUM,IF)=0                    TCON1315
```

In Subroutine TCONT after statement TCON1320, add:

```
      RPCC(LNUM,IP) = P2CT/P1                                   TCON1325
```

In Subroutine TCONT after statement TCON1360, add:

```
      IF(TM.GT.TMIN) GOTO 100                                   TCON1365
```

The message

******WARNING! PENETRATION HAS OCCURRED WITHOUT IMPACT CORRECTION.

******OVERRIDE ENACTED. PMAX = some number

may printout just before the line which specified the IMPACT NO., TIME, CYCLE, ELEMENT, FRAG, and distance for an impact. This message indicates that an impact occurred numerically so close to the end of a timestep that the exact time-of-contact solution failed to detect the impact. However, a geometric penetration was detected and the impact interaction calculations were performed at the end of the time cycle.

After the line which describes the impact is printed, a message which says

AINT = a negative number NO IMPACT -- LEAVING IMPCTE

may print. This message indicates that a pseudo impact was erroneously detected by Subroutine IMPCTE and should be ignored. AINT is the relative velocity between the fragment and the ring. A negative value of AINT indicates separation. This situation may occur at the initial point of fragment rebound. When this message prints, no impact interaction calculations have been performed.

SECTION 4

MODIFICATIONS OF THE INPUT AND OUTPUT INSTRUCTIONS PERTINENT TO CIVM-JET 4C

The input and output instructions given in Ref. 1 apply also to CIVM-JET 4C except for the following modifications (numbered 1 through 7):

1. Cards 7AA for the static "stress-strain" pairs for the mechanical sublayer material model for the "main structure" (called structure 1) are

   EPS(1,1) and SIG(1,1) for the <u>first</u> coordinate pair

   EPS(2,1) and SIG(2,1) for the <u>second</u> coordinate pair

   etc.

   are now defined by coordinate pairs denoting piecewise linear fits to:

   $\tau_{u_o} \equiv$ SIG versus $\varepsilon_u^* \equiv$ EPS

   where $\tau_{u_o} = \sigma_E(1+E_u)$ = Kirchhoff uniaxial stress (subscript "o" denotes static conditions)

   $\varepsilon_u^* = \ell n(1+E_u)$ = uniaxial logarithmic strain

   and $\sigma_E = \frac{P}{A_o}$ = engineering stress of a uniaxial static tensile test specimen; P is the applied load and A_o is the pre-test cross-sectional area of the specimen

   E_u = the measured axial relative elongation of the <u>uniaxial test specimen</u>

   $= \frac{\text{change in gage length}}{\text{original gage length}}$

   = output which strain gages or extensometers can provide

In preparing the uniaxial test data in τ_{u_o} vs. ε^*_u form, the data in the strain region where necking occurs (that is, beyond the peak in $\sigma_E = P/A_o$) should be modified appropriately to "correct for necking". Various schemes for making such corrections have been developed. See, for example, the procedure and correction factor proposed by Bridgman [4] based upon extensive experimental and theoretical work. For more information on necking, see the book by Lubahn and Felgar [5]. Recent work on computer simulations of tension tests of ductile metals is reported by Norris et al. [6] and by Saje [7]. An excellent recent survey article on this subject was prepared by Hutchinson [8].

One approach to approximate the uniaxial behavior beyond the incipient necking condition (peak in σ_E) is to assume a straight line fit between that point and the rupture condition which can be characterized by the load P_f at rupture and the cross-sectional area A_f of the specimen measured at the rupture station after the test (ignoring any elastic recovery). Hence, one can estimate the true stress at rupture as $(\sigma_T)_f = P_f/A_f$; since at the associated very large strains, the material may be regarded as behaving in an incompressible fashion -- one may use the approximation $\rho/\rho_o \doteq 1$. Accordingly at rupture (failure) $(\tau_{u_o})_f \doteq (\sigma_{T_o})_f$ since $\sigma_T = \frac{P}{A} = \frac{\rho}{\rho_o}\frac{P}{A_o}(1+E_u) = \frac{\rho}{\rho_o}\tau_u$. The associated $(\varepsilon^*_u)_f = \ell n[1+(E_u)_f]$, where $(E_u)_f$ is given by $[1+(E_u)_f] = \frac{\rho_o A_o}{\rho A_f} \doteq \frac{A_o}{A_f}$. Finally, the "corrected" value to be used for $(\tau_{u_o})_f$ is called $(\tau_{u_o})_{fc}$ and may be computed, for example, by using Bridgman's [4] correction factor by (see Eq. 5-8 of Ref. 5):

$$(\tau_{u_o})_{fc} = \frac{P_f/A_f}{\left(1+2\frac{R}{a}\right)\ell n\left(1+\frac{1}{2}\frac{a}{R}\right)} \tag{4.1}$$

where

a = radius of the (assumed to be circular) rupture cross section

R = lateral final radius of curvature of the tensile test specimen at the rupture station.

Bridgman [4] presents data plots (from extensive experiments) from which one can determine the ratio a/R from a knowledge of A_o/A_f. Other correction alternatives may be found in Refs. 5-8.

2. The strain-displacement relation (called Type F for finite strain) from which the circumferential strain ε (or γ_{11} of Ref. 1 hereafter called γ_2^2) for the ring or beam structure is computed [2(p. 339); 3 (Section 4)]:

$$\epsilon \equiv \gamma_2^2 = \overset{o}{\gamma}{}_2^2 + \frac{\zeta^o}{\left(1 + 2\,\overset{o}{\gamma}{}_2^2\right)} \mathcal{K} \tag{4.2}$$

The through-the-thickness normal strain γ_3^3 is given by

$$\gamma_3^3 = \frac{1}{2}\left[\frac{1}{\left(1 + 2\,\overset{o}{\gamma}{}_2^2\right)} - 1\right] \tag{4.3}$$

since the material behavior is approximated as being incompressible, and it is assumed that the across-the-width strain of the ring is zero; that is, $\gamma_1^1 = 0$. In the above, $\overset{o}{\gamma}{}_2^2$ represents the circumferential (membrane) strain at the reference axis $\zeta^o = 0$; ζ^o refers to the ζ-location of particles before deformation (superscript "o"); and κ denotes the "change of curvature":

$$\overset{o}{\gamma}{}_2^2 = \chi + \frac{1}{2}\chi^2 + \frac{1}{2}\psi^2 \tag{4.4}$$

$$\mathcal{K} = \left(-\frac{\partial\psi}{\partial\eta}\right)(1+\chi) + \psi\frac{\partial\chi}{\partial\eta} \tag{4.5}$$

Figure 1 illustrates the geometry, coordinates, displacements, and generalized displacements for a curved-beam finite element, including the reference-surface displacements v and w as well as the quantities ψ and χ. Note that indices 1, 2, 3 correspond to directions ξ, η, ζ. The present procedure used in CIVM-JET 4C accounts for finite strains and arbitrarily large rotations, and also accounts approximately for thickness changes accompanying finite strains in the plastic range, unlike CIVM-JET 4B which is valid only for small strains[a] and moderately small rotations[b].

3. In CIVM-JET 4C, the uniaxial τ_{u_o} vs. ε^*_u data are represented by piecewise-linear segments which in turn are used in the mechanical-sublayer material model. Time-dependent plasticity is employed whereby it is assumed that strain rate affects the yield stress of the kth elastic, perfectly-plastic sublayer ${}^k\tau^y_u$ according to:

$$ {}^k\tau^y_u = {}^k\tau^y_{u_o}\left[1 + \left|\frac{D^2_2}{d}\right|^{\frac{1}{p}}\right] \tag{4.6}$$

where d and p are material "strain rate" constants, ${}^k\tau^y_{u_o}$ is the static yield stress of the kth sublayer, the rate of deformation is

$$D^2_2 = \frac{\dot{\gamma}^2_2}{(1+2\,\gamma^2_2)} \tag{4.7}$$

and

$$\dot{\gamma}^2_2 = \frac{d}{dt}\,\gamma^2_2 \doteq \frac{\Delta\gamma^2_2}{\Delta t} \tag{4.8}$$

---

a: Defined by $1 + 2\,\gamma^2_2 \approx 1$, where γ^2_2 is the circumferential strain.

b: Defined by $\sin\theta \approx \theta$ and $\cos\theta \approx 1$, where θ is the angle of rotation.

$$\Delta\gamma_2^2 = \gamma_2^2 \text{ at time } t \text{ minus } \gamma_2^2 \text{ at time } (t - \Delta t). \tag{4.9}$$

4. The elastic and plastic energies as calculated by the ENERGY subroutine in CIVM-JET 4B and in CIVM-JET 4C are meaningful only for small strains. However, the "Total Strain Energy" calculated by the STRESS subroutine and printed in CIVM-JET 4C just after the Elastic and Plastic Energies is valid for finite (and small) strains.

5. The treatment of the continuity between the "main structure material" and the "branch material" as presently handled by the BRAN subroutine in CIVM-JET 4B and in CIVM-JET 4C is incorrect for the case in which the elastic modulus of the branch material differs from that of the main-structure material (both for small and finite strains).

6. The behavior for the rotational springs of subroutine QREM (in both CIVM-JET 4B and CIVM-JET 4C) is valid only for the case of small strains and moderately small rotations at the locations of the rotational springs.

7. To permit the user to label the printed output with a header line describing the case being run, one additional input card is required. Before Card #1 of the input, insert a Card #0 which should contain a description of the case in columns 1 through 80. This card will be the first line of the printed output. If the user does not want a header line, this card should be left blank but it must be provided.

   In front of card 1, inserted the following card (called Card 0):

   NEDI(J) for J = 1,2,3 ... 20 with format 20A4

where

   the array NEDI is an 80 character heading.

In the CIVM-JET 4C MAIN program, these 4 cards should be inserted before card MAIN0770:

```
5555    READ(MREAD,5556)(NEDI(J),J=1,20)                 MAIN0761
5556    FORMAT (20A4)                                    MAIN0762
        WRITE(MWRITE,5557)(NEDI(J),J=1,20)               MAIN0763
5557    FORMAT(1H1,20A4)                                 MAIN0764
```

and card MAIN0770 should be changed to read:

```
        READ(MREAD,1)B(1),DENS(1),EXANG,.....            MAIN0770
```

Finally, the reader is reminded that for both CIVM-JET 4B and CIVM-JET 4C, an assumed-displacement type of finite element is used. A cubic polynominal in the circumferential reference-surface coordinate η is used for each of the reference-surface displacements v and w (see Fig. 1); this is called a cubic-cubic (CC) displacement element. Although this is a "compact" and satisfactory element, it accommodates at the element nodal junctions membrane strain continuity, but the bending contributions to the strain are not continuous. Higher order elements which provide continuity in (a) both of these strain contributions and (b) the η-direction derivative of each of these strain contributions have been investigated; the results are reported in Ref. 9. Although improved strain predictions result from using these higher-order elements, the storage and computing requirements also increase. Consequently, it was concluded [9] that it is more effective and efficient to employ a greater number of structural-model degrees of freedom (DOF) and CC elements than to use a comparable number of DOF's together with a smaller number of higher-order elements. Hence, the use of CC elements has been retained in both CIVM-JET 4B and CIVM-JET 4C.

SECTION 5

ADDITIONAL USER INSTRUCTIONS FOR CIVM-JET 4C

The CIVM-JET 4C computer program for the finite-strain analysis of 2-D transient structural responses of complete or partial rings and beams subjected to fragment impact has been stored on tape as a series of individual files. The attached Appendix A describes in detail which subroutines are found in these files. All references to the CIVM-JET 4C program are made assuming that the user has a copy of Ref. 1: NASA CR-134907 (ASRL TR 154-9) which serves as a user's guide to (1) the CIVM-JET 4B computer code and (2) the CIVM-JET 4C computer code with the use of the modified input instructions given in the present report. All of the subroutines for CIVM-JET 4C are the same as those for CIVM-JET 4B except for Subroutines MAIN, ELMPP, ENERGY, IMPACT, PRINT, and STRESS; these latter subroutines have been given new sequence numbers. A complete FORTRAN IV source listing of the CIVM-JET 4C subroutines accompanies the tape which is available from MIT under a copyright licensing agreement.[+]

This is usually a 9-track tape with the program stored in card-image format: IBM EBCDIC code, 80 characters to a record, 1600 characters to a block, and 1600 bits per inch. The tape does not contain any labels; therefore, a no-label format must be used when accessing the tape. A magnetic tape with other characteristics such as 7-track, ASCII code, 800 bits per inch, etc. could be provided; the desired format should be requested.

This program was formulated and run on the IBM 370/168 computer facility at MIT. The tape is set up to be compiled and run immediately on an IBM machine by either direct access or by being transferred to disc storage. However, if a non-IBM system is used, care should be taken to make sure that the program is compatible with the operating system. The CIVM-JET 4C program assumes that the operating system uses code 5 for a reader, code 6 for a line printer, and a code 7 for a card punch. If your computer uses a different convention, it will be necessary to obtain a card deck from the tape and

---

[+] To obtain CIVM-JET 4C, please contact Prof. E.A. Witmer, Room 41-219, MIT, Cambridge, Mass. 02139.

change the code numbers in the MAIN program; see page 62 of Ref. 1 for the cards that would need to be changed. Note also that the symbol @ has been employed to denote a continuation card; if this is unacceptable for your computer facility, change this appropriately.

To check the operation of this tape, it is suggested that the user run the two examples (6.1 and 6.2) listed in Ref. 1. Input data for each of the two examples have been included on the tape for this purpose; outputs from CIVM-JET 4C for both of these examples are supplied to acquirers of the tape.+ Because of the large number of computational steps used in the solution of each of these problems and because of the ever-changing IBM systems and subroutine libraries, the user should be forewarned that exact duplication of these example runs with the results attached hereto probably will not be obtained. Instead, slight variances will be detected because of roundoff; Table 2 illustrates a sample of the differences in certain solution quantities for each of problems 6.1 and 6.2 between IBM 370/168 calculations at MIT and UNIVAC calculations carried out at NASA-Lewis [10]. The purpose of this exercise is to be certain that all of the options of the CIVM-JET 4C computer code are compatible with the user's computer system.

In order to run the program, any one of three methods may be utilized:

(1) Direct Access: From Appendix A find the files that are needed for a particular run and compile each one, concatenating the compiled codes into one block in your computer code.

(2) Using Disc: The same as above, except after compiling the files, they are stored on disc in object format form for future use without further compilation. Concatenation will still be necessary.

(3) Card Format: Having the programs punched onto cards directly from the tape, and use the cards to run the program. This is necessary if any changes are to be made in any of the subroutines. The subroutines that are to be changed must then be punched onto cards, but the rest of the program can still be accessed by using methods (1) or (2) listed above.

+See footnote on page 22.

REFERENCES

1. Stagliano, T.R., Spilker, R.L. and Witmer, E.A., "User's Guide to Computer Program CIVM-JET 4B to Calculate the Transient Structural Responses of Partial and/or Complete Structural Rings to Engine-Rotor-Fragment Impact", MIT ASRL TR 154-9, March 1976 (Available as NASA CR-134907).

2. Stagliano, T.R., Witmer, E.A. and Rodal, J.J.A., "Two-Dimensional Finite-Element Analyses of Simulated Rotor-Fragment Impacts Against Rings and Beams Compared with Experiments", MIT ASRL TR 154-13, December 1979 (Available as NASA CR-159645).

3. Rodal, J.J.A. and Witmer, E.A., "Finite-Strain Large-Deflection Elastic-Viscoplastic Finite-Element Transient Response Analysis of Structures", MIT ASRL TR 154-15, July 1979 (Available as NASA CR-159874).

4. Bridgman, P.W., "The Stress Distribution at the Neck of a Tension Specimen", Trans. ASM, Vol. 32, 1944, P. 553.

5. Lubahn, J.D. and Felgar, R.P., Plasticity and Creep of Metals, John Wiley, 1961, pp. 114-127.

6. Norris, D., Moran, B., Scudder, J. and Quiñones, D., "A Computer Simulation of the Tension Test", Journal of the Mechanics and Physics of Solids, Vol. 26, 1978, pp. 1-19.

7. Saje, M., "Necking of a Cylindrical Bar in Tension", Int. Journal of Solids and Structures, Vol. 15, 1979, pp. 731-742.

8. Hutchinson, J.W., "Survey of Some Recent Work on the Mechanics of Necking", Proceedings of the Eight U.S. National Congress of Applied Mechanics, Los Angeles, June 26-30, 1978, Editor: R.E. Kelly, Western Periodicals Co., North Hollywood, 1979.

9. Rodal, J.J.A. and Witmer, E.A., "Finite Element Transient Response Analysis of Simple 2-D Structures Subjected to Impulse or Impact Loads", MIT ASRL TR 182-1 (also called MIT-EL 76-004), June 1976.

10. Private communication from A.G. Holms and C.C. Chamis of the NASA Lewis Research Center, June 5, 1980.

TABLE 1

FEATURES AND CAPABILITIES OF THE CURRENT CIVM-JET 4B AND CIVM-JET 4C COMPUTER PROGRAMS

Feature	CIVM-JET 4B	CIVM-JET 4C
Spatial Approximation		
Finite Element	x	x
Timewise Central		
Difference Operator	x	x
<u>Ring Geometry</u>		
Complete Ring	x	x
Partial Ring	x	x
<u>Initial Configuration</u>		
Circular	x	x
Arb. Curved	x	x
Constant Thickness	x	x
Variable Thickness	x	x
Single Layer	x	x
<u>Boundary Conditions</u>		
Ideally Clamped	x	x
Hinged Fixed	x	x
Free	x	x
Clamped-Sliding	x	x
<u>Other Support Conditions</u>		
Distributed Elastic Foundation	x	x
Point Elastic Springs	x	x
Structural Branch	x	x

TABLE 1 (CONTINUED)

	CIVM-JET 4B	CIVM-JET 4C
Material		
Single Material for Each Branch	x	x
Homogeneous	x	x
Initially Isotropic	x	x
Temperature Independent	x	x
EL	x	x
EL-PP	x	x
EL-LSH	x	x
EL-SH	x	x
EL-SH-SR	x	x
Small Strain	x	x
Finite Strain	-	x
Stimulii		
Impacting Fragments		
Single	x	x
Multiple	x	x
Friction	x	x
Elastic (e=1)	x	x
Inelastic (e=0)	x	x
Intermediate 0<e<1	x	x
Deflections: Bernoulli-Euler Type Only		
Small	x	x
Large	x	x
Strains		
Membrane		
Small	x	x
Finite	x	x
Bending		
Small	x	x
Finite	-	x

TABLE 1 (CONTINUED)

	CIVM-JET 4B	CIVM-JET 4C
Strains (Continued)		
Overall		
Small	x	x
Finite	–	x
OUTPUT INFORMATION		
At Selected Times		
Energy/Work Type and Amount		
Structure Kinetic Energy	x	x
Structure Strain Energy	x	x
Elastic: Small Strain	x	x
Plastic: Small strain	x	x
Strain Energy of Elastic Restraints	x	x
Total		
Small Strain	x	x
Finite Strain	–	x
Fragment Kinetic Energy (Each)		
Translational	x	x
Rotational	x	x
Total	x	x
Circumferential Strains		
Inner Surface	x	x
Midsurface	–	x
Outer Surface	x	x
At Gaussian Stations	x	x
At Nodal Stations	x	x
At Additional Stations	x	x
Location where Prescribed Strain is Exceeded	x	x
Support Reactions	x	x

TABLE 1 (CONCLUDED)

	CIVM-JET 4B	CIVM-JET 4C
Time, Location, and Value of Largest Strain Reached During Run	x	x
CAPACITY INFORMATION		
Max. No. of Finite Elements*	50	50
Max. No. of Fragments*	6	6

*These limits can be circumvented by altering the dimensions of appropriate program variables (see each source reference).

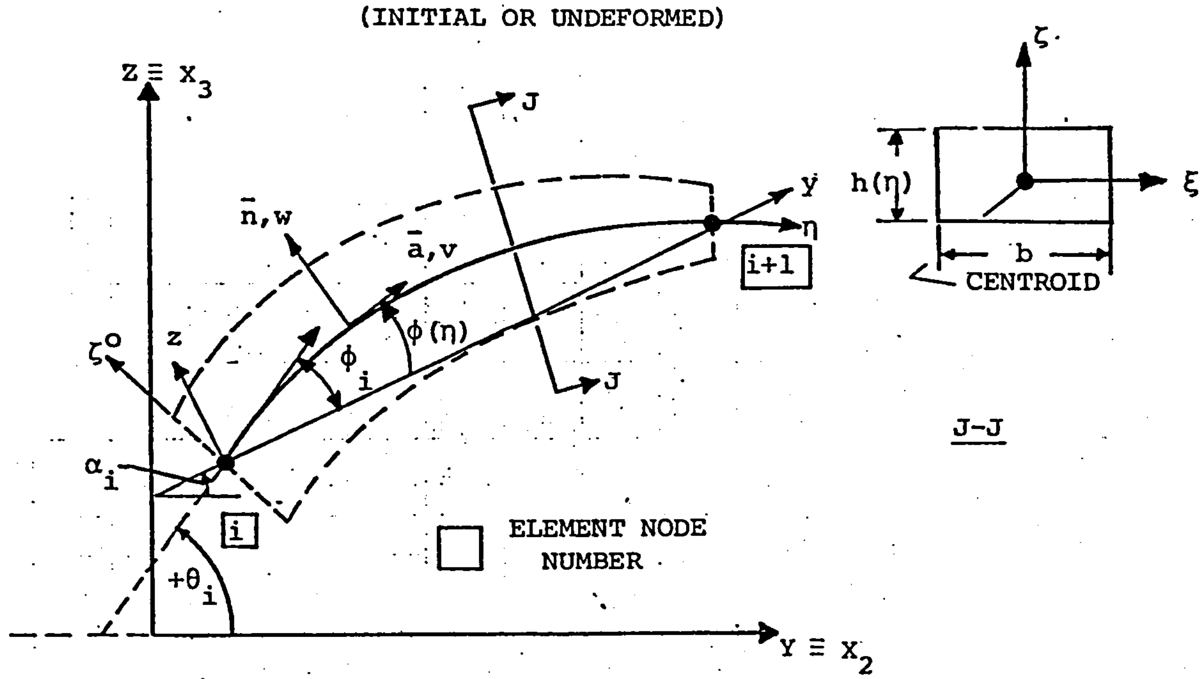
TABLE 2

COMPARISON OF CIVM-JET 4C RESULTS FROM USING DIFFERENT COMPUTERS

System	Compiler	Site	Example[+]	MSTR		Largest Added Pt. Strain		Largest Nodal Strain	
				Substructure					
				1	2	1	2	1	2
IBM 370	H	MIT	6.1	.0596839	.0129698	.0179878	.00184006	.0648378	.0142004
UNIVAC	ASCII	NASA-Lewis	6.1	.0596839	.0129094	.0179878	.00184006	.0648371	.0140876
IBM 370	H	MIT	6.2	.154770		.0968485		.185669	
UNIVAC	ASCII	NASA-Lewis	6.2	.154863		.0958849		.185654	

[+]These are the examples defined in Ref. 1 but with input appropriate for CIVM-JET 4C as noted in Section 5 of the present report.

REFERENCE CONFIGURATION
(INITIAL OR UNDEFORMED)



$$-15° \leq \phi_{i+1} - \phi_i \leq 0$$

$$-180° < \phi_i \leq 180°$$

$$\phi(\eta) = b_o + b_1\, \eta + b_2\, \eta^2$$

$$R(\eta) = -(\partial\phi/\partial\eta)^{-1} \qquad \text{NODE } i\text{:} \quad \eta = 0$$

$$h(\eta) = h_i\ (1 - \frac{\eta}{\eta_i}) + h_{i+1}\, \frac{\eta}{\eta_i} \qquad \text{NODE } i+1\text{:} \quad \eta = \eta_i$$

LOCAL SYSTEM

$\xi,\ \eta,\ \zeta$ — COORDINATES

v, w, ψ, χ — DISPLACEMENTS

$q_1, q_2, \cdots q_8$ — ELEMENT GENERALIZED DISPLACEMENTS

$$q_1\ q_2\ q_3\ q_4 = v_i\ w_i\ \psi_i\ \chi_i$$

$$\psi = \frac{\partial w}{\partial \eta} - \frac{v}{R} \qquad \chi = \frac{\partial v}{\partial \eta} + \frac{w}{R}$$

CARTESIAN REFERENCE

Y,Z — GLOBAL COORDINATES

y,z — LOCAL COORDINATES

FIG. 1 NOMENCLATURE FOR GEOMETRY, COORDINATES, AND DISPLACEMENTS OF A CURVED-BEAM FINITE ELEMENT

APPENDIX A

TAPE FILES FOR CIVM-JET 4C

The CIVM-JET 4C program consists of the following main program and 23 subroutines; the file numbers associated with each subroutine are indicated:

File	Subroutine	File	Subroutine	File	Subroutine
1	MAIN	9	FICOL	17	CUBIC
2	ASSEF	10	IDENT	18	IMPACT
3	ASSEM	11	MINV	19	IMPCTE
4	BRAN	12	OMULT	20	PENTRN
5	DINIT	13	PRINT	21	ROOT4
6	ELMPP	14	QREM	22	ROTAT
7	ENERGY	15	STRESS	23	TCONT
8	ERC	16	TSTEP	24	UPDATE

File 25 Input Data for Example 6.1 of Ref. 1; applicable to both CIVM-JET 4B and CIVM-JET 4C.

File 26 Input Data for Example 6.2 of Ref. 1; applicable to both CIVM-JET 4B and CIVM-JET 4C.

The program is written in double precision arithmetic. The number of memory locations required on the IBM 370/168 computer at MIT is approximately 440,000 bytes; this includes locations for the MIT computer library subroutines.

Subroutines Related to the Finite Element Solution Procedure:

ASSEF	ENERGY	OMULT
ASSEM	ERC	PRINT
BRAN	FICOL	QREM
DINIT	IDENT	STRESS
ELMPP	MINV	TSTEP

Subroutines Related to Fragment-Ring-Impact Interaction:

CUBIC	PENTRN	TCONT
IMPACT	ROOT4	UPDATE
IMPCTE	ROTAT	