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AFFDL-TR-76-11  
VOLUME II

**STRESS ANALYSIS OF AIRCRAFT TIRES**  
**Volume II. User's Manual**

*MATHEMATICAL SCIENCES NORTHWEST, INC.*  
*P. O. BOX 1887*  
*BELLEVUE, WASHINGTON 98009*

FEBRUARY 1976

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Final Report for Period June 1974 - January 1976

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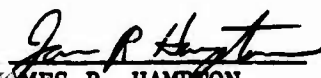
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This technical report has been reviewed and is approved.

  
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## FOREWORD

This report documents the work accomplished by Mathematical Sciences Northwest, P. O. Box 1887, Bellevue, Washington, under Contract No. F33615-74-C-3102, under Project No. 1369, Task No. 01. Volume I contains the Analytical Formulations.

This work was sponsored by the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio. Mr. J. R. Hampton (AFFDL/FEM) was the technical monitor for the Air Force.

This report covers the research conducted from 24 June 1974 through 8 January 1976. The manuscript was released by the author in February 1976 for publication as a technical report.

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SECTION I  
INTRODUCTION

The computer code for the stress analysis of aircraft tires is designed to solve the following problems:

- Inflation of a lifted but unloaded tire, and
- Rotation of an inflated but unloaded tire.

The code is subdivided into six overlays within the framework of dynamic storage allocation. In the first three overlays, the input data is reduced to set up quantities associated with the geometrical configuration. The fourth overlay calculates the element stiffness and load matrices, which are assembled in the fifth overlay. The sixth overlay contains a direct equation solver with one right-hand side.

In the following section, the structure and modulation of the code will be described in detail.

A. Storage Allocation and Input/Output Characteristics

The data management of the computer code incorporates those primary features of the CDC 6600 system which are necessary for the efficient flow of large sets of information. Information storage and retrieval procedures were designed to minimize:

- Central memory required,
- Input/output access time, and
- Program maintenance and modifications.

The following main features of the CDC 6600 system were used to achieve the above objectives:

- Random access input/output subroutines,
- Unblocked, unbuffered files, and
- Blank common.

The random access subroutines are library input/output routines, supported by CDC, which provide the capability for direct storage and retrieval of records on a file, as opposed to sequential files which require accessing the records preceding the desired one. In the computer code, these mass storage routines are used extensively to store:

- Input data, and
- Computed data

between overlays, which allows the program to

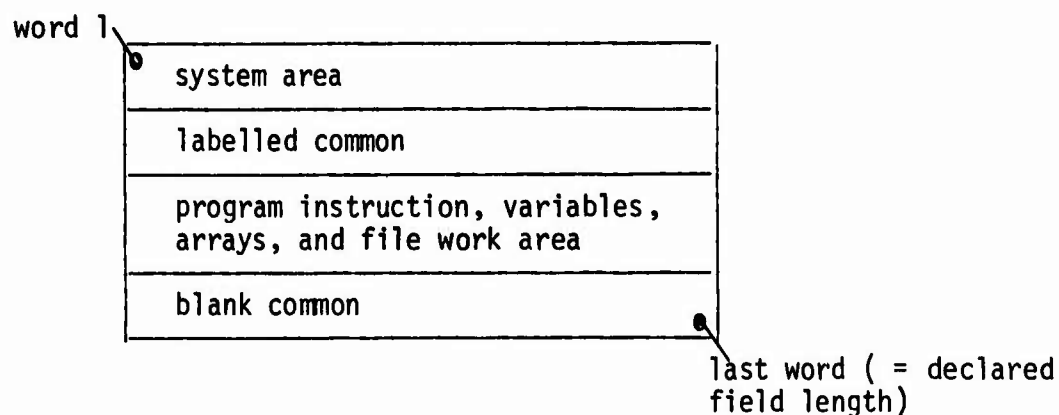
- Select,
- Input, and
- Output

only those data which are necessary in the particular overlay under consideration.

Unblocked, unbuffered files are used to store the intermediate data; for instance, in the calculation of the element stiffness and element load matrix. These files are accessed repeatedly in a sequential manner. These unblocked, unbuffered files are efficient for reading and writing large records, since the information is read directly from the disk into the program array area. Note that the records in blocked and buffered files would first be read into an intermediate system storage of the central memory area, and then transferred into the program array area.

The proper use of blank common allows the code to have a general work area available, whose length depends only on the field length declared on the job card. This area is dynamically divided among the arrays needed in executing the current overlay.

Thus, the central memory disposition of the codes has the following structure:



The above construction allows the user to specify a field length tailored to the data size.

In the current code, each overlay determines the length of the arrays used and stacks them nose-to-tail in blank common.

#### B. Fortran Extended Code

The code is originally developed under Scope 3.3 for the FTN compiler. It contains both Fortran and Compass routines.

#### C. Library Routines

Besides the standardized library routines, the codes employ the following special features of the CDC-6600 library:

- BUFFER IN,
- BUFFER OUT,
- READMS, and
- WRITMS.

D. Assembly Language Subroutines

The CDC-6600 assembly language, Compass (COMPrehensive ASSEMBly language), is particularly suited to substantially reducing the computation time of looped operations. The improvements are realized by:

- More efficient retrieval of array elements,
- Overlapping of data storage and retrieval from central memory with multiplication, addition, and subtraction, and
- Efficient use of the instruction stack which holds seven words (up to 28 instructions) in the central processor.

Well-coded Compass routines will execute computational do-loops from five to six times faster than normal Fortran IV on the CDC-6600.

In the present code, six of the heavily used matrix manipulation subroutines are written in Compass:

- MATMPY,
- MATADD,
- MATSMP,
- INPRDS,
- VECMAT, and
- EMULT.

There are six special Compass subroutines to perform tasks which standard Fortran IV is not designed to handle. These are listed below:

- KFL,
- SSZERO,
- MSTG,
- GET,
- PUT, and
- STRMOV.

KFL is a Compass subroutine which retrieves the field length requested by the job. This information allows the program to use all central memory available. Furthermore, for each data set, a minimum field length requirement may be tailored.

SSZERO is designed to set array values to zero during execution in a minimum amount of time. The routine is used extensively throughout the code.

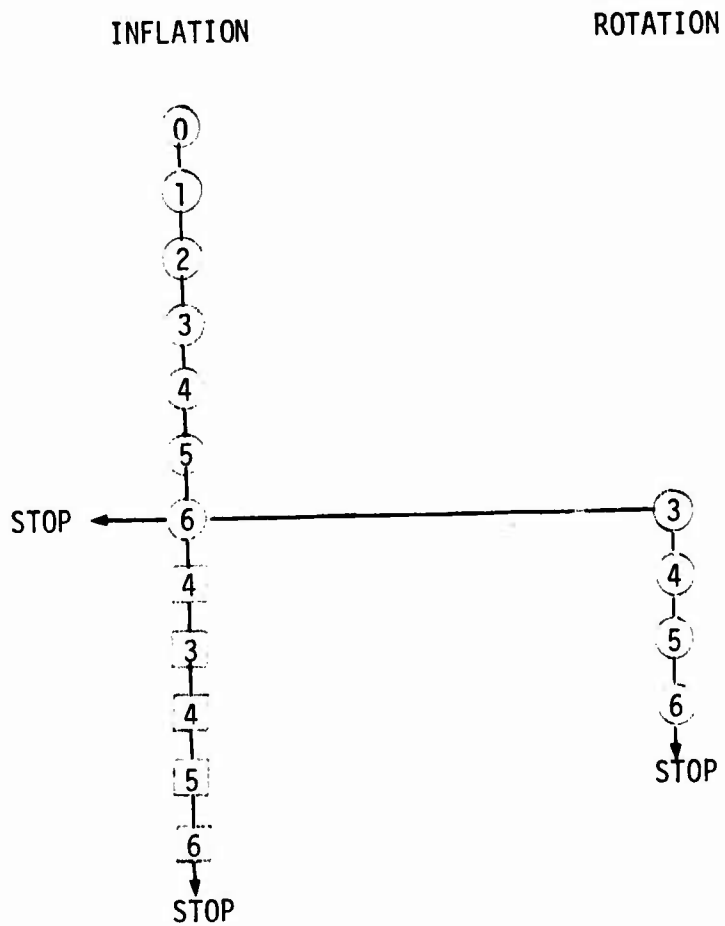
MSTG, GET, PUT, and STRMOV are Compass subroutines which perform character and string manipulation. They are used in dynamic storage allocation and by the free field input reader which reduces considerably the time required by the user to enter and debug his input data.

SECTION II  
PROGRAM ORGANIZATION

The program is organized according to the following problem types:

- Inflation, and
- Inflation and rotation.

The general data flow is shown below, where the numbers refer to the overlays under consideration.



SECTION III  
OVERLAY DESCRIPTION

A. Overlay (KTIRE, 0,0)

This overlay controls the general data flow as described in Section II. It performs the initialization of labeled common blocks, opens random access mass storage files, and facilitates the storage requirements within the framework of dynamic storage allocation. This overlay also contains various utility programs and assembly language routines for vector and character manipulations.

B. Overlay (KTIRE, 1,0)

All the input data are read from cards in this overlay and then they are placed on random access mass storage files. The input data are checked for logical errors which are summarized at the end of the data processing phase, using the subprograms RANGE, WRDCHK, and COMPCHK. The primary control parameters are also set up here in the labelled common blocks SIZE and CONTACT.

C. Overlay (KTIRE, 2,0)

This overlay performs the preliminary nodal calculations such as

- Cartesian and curvilinear coordinates,
- Surface vectors of the undeformed reference surface, and
- Cord angle distribution along the meridian.

The resulting data are placed on random access mass storage files.



D. Overlay (KTIRE, 3,0)

The intrinsic reference element properties, such as

- Element area,
- Element centroid,
- Local unit vectors,
- Local element vertex coordinates, and
- Average cord angles,

are generated here and then placed on random access mass storage files.

E. Overlay (KTIRE, 4,0)

This overlay sets up the element stiffness matrix and load vector according to the finite element formulation outlined in [1].

F. Overlay (KTIRE, 5,0)

This overlay constructs the structure stiffness matrix for all the problems under consideration, and the structure load vectors for inflation and rotation problems.

G. Overlay (KTIRE, 6,0)

A standard gaussian elimination routine is contained in this overlay.

SECTION IV  
FILES AND COMMON BLOCKS

The program control variables are transmitted via labelled common blocks, while the relevant input or calculated data are placed on sequential or random access mass storage files.

A. Common Blocks

BCINDEX contains the information for dynamic storage allocation:

- NOPOS or number of positions available for allocation,
- KSPACE or space available for allocation, and
- INDEX or pointers to currently defined arrays.

CONTACT consists of the information for the iterative contact algorithm:

- NORING or number of contact rings,
- KRING or current ring number,
- NODMAX or maximum number of nodes in a ring, and
- KSZAX or total number of candidate contact nodes.

ERROR accounts for all logical input data errors and includes:

- NERR or running count of input errors,
- NERRS or record numbers of those with errors,
- NERLIM or maximum number of errors to be counted, and
- KERR or indicator as to whether current block has errors.

FILES contains the names of all data files defined by Fortran IV

Hollerith form:

INDTA consists of information about the last record read by the input reader:

- NWRD or number of items present,
- ITYP or type of each item present,
- NREC or record number,
- NCRD or card number, and
- DTA or value of each item in the record.

MATSIZ consists of the structure stiffness matrix characteristics:

- NUMBK or number of blocks,
- NBKSI or block size,
- NMIQ or bandwidth including right-hand side,
- NPB or nodal points per blocks,
- NEQ or number of equations per blocks,
- NMAX or total number of equations,
- NORHS or number of right-hand sides, and
- NRBKSI or the size of the flexibility matrix block.

PRINTS controls all optional intermediate printing:

- KPRINT or an array indicating which intermediate values the user wants printed, and
- LINLIM or the maximum number of single spaced lines per page.

RECORD contains the variable names for all named random access records.

RETRIV consists of information to determine the blocksize of the structure stiffness matrix.

SIZE is comprised of the input control parameters:

- NOEL or number of elements,
- NNODE or number of nodes,
- RADIUS or radius of meridian reference curve rotation,
- NRHO or number of fitting coefficients for the meridian reference curve,
- NPRHO or number of data points for the meridian reference curve,
- MAXLAY or maximum number of layers,
- GREEN or green angle,
- SPEED or rotational speed, and
- INCR or number of increments for nonlinear inflation.

B. Random Access Files

Following in Table 1 is a description of all records of all random access files. The fourth table entry indicates whether the information is input or calculated by the code.

Table 1.  
Random Access Files

FILE NAME	RECORD NAME	CONTENTS	I/C	SIZE
KCTMAT	KCTC	contact data	I	NORING * (NODMAX +2)
KCTMAT	KCTC2	x-coordinate array-contact case	C	KSZAX
KCTMAT	KCTC3	contact case ALPHA array	C	maximum KSZAX
KCTMAT	KCTC5	total nodal load vector- contact case	C	maximum KSZAX
KHMAT	numbered one/layer	decomposition of the HB matrix	C	maximum 378
KLADAT	numbered one/element	element layer data	I	maximum MAXLAY *10
KONDAT	KAR	elements areas	C	NOEL *1
KONDAT	KAV	average cord angles	C	NOEL *1
KONDAT	KBETA	curvefit betas	I	NPBETA *2
KONDAT	KCA	cord angles	C	NNODE *1
KONDAT	KCAR	cartesian coordinates	C	NNODE *3
KONDAT	KCARC	cartesian data	I	NNODE *6
KONDAT	KCEN	centroid	C	NOEL *3
KONDAT	KCLC	curvilinear coordinates	I	NNODE *2
KONDAT	KDIS	displacements	I	NNODE *6

Table 1 (con't)

FILE NAME	RECORD NAME	CONTENTS	I/C	SIZE
KONDAT	KELN	elements' nodes	I	NOEL *3
KONDAT	KFOR	forces	I	NNODE *3
KONDAT	KINCR	nonlinear increment data	I	INCR *2
KONDAT	KIPV	in-plane vertex coordinates	C	NOEL *6
KONDAT	KLUV	local unit vectors	C	NOEL *9
KONDAT	KRHO	curvefit Rhos	I	NPRHO *2
KONDAT	KSV	surface vectors	C	NNODE *9
KPMAR	numbered one/element	upper half element load and stiffness matrix	C	135 words
KRMAT	numbered one/layer	$H^{-1}$ matrix after forward substitution	C	maximum (NOLAY *21-7) *21
KSLMAT	KSLV	solution vector	C	NNODE *5
KSTFIL	numbered one/merged block	output merged K matrices	C	maximum NEQ * (KBAND + KSZAX)
2	numbered one/block	SOLVMOR solution	C	maximum NEQ *KSZAX

SECTION V  
INPUT DATA PREPARATION

There are no inherent units assigned to any of the variables. Thus, the user is free to use any desired set; however, once defined, the units must be consistent for all parameters.

Format-free processing is employed for both floating point and integer variables.

Numeric specifications must be separated from each other by at least one blank column.

A. Title Cards

No restriction is imposed on the number of title cards. Each of these cards must start with a slash in column 1. Example:

```
/ DATA SET NUMBER 1  
/ PREPARED 10/1/72  
/ AIRCRAFT TIRE  
/
```

B. Control Cards

A name is assigned to each of the control variables. The name is followed by the appropriate numerical specification. The last character on each of these cards must be the slash symbol, which is separated from the words or numeric specifications by any number of blank columns.

These control cards follow the schedule below:

```
BEGIN DATA INPUT /  
BEGIN CONTROL PARAMETERS /
```

NODES N /  
ELEMENTS E /  
RADIUS R /  
NRHO M /  
NPRHO N /  
LAYERS L /  
GREEN  $\alpha$  /  
SPEED  $\omega$  /  
INCREMENTS IN /  
END CONTROL PARAMETERS /  
/  
/

The above numeric control variables are defined as follows:

N = Number of nodes (integer),  
E = Number of elements (integer),  
R = Rotation radius,  
M = Number of curvefitting parameters for the median section (integer),  
N = Number of prescribed data points for the meridian section (integer),  
L = Maximum layer number (integer),  
 $\alpha$  = Green angle,  
 $\omega$  = Rotational speed, and  
IN = Number of increments for nonlinear inflation.

C. Nodal Data

The node number and the corresponding curvilinear coordinates are specified here:



```
BEGIN NODAL DATA /
```

```
i  $\Theta$   $\phi$ 
```

```
.
```

```
.
```

```
END NODAL DATA /
```

```
/
```

```
/
```

The numeric variables  $i$ ,  $\Theta$ , and  $\phi$  are

$i$  = Node number (integer),

$\Theta$  = Parallel in radians (floating point), and

$\phi$  = Meridian in radians (floating point).

#### D. Element Data

There are three nodes associated with each surface element. The node assignments must follow the right-hand rule according to the outward normal direction. Furthermore, the first node number must be the smallest.

Within this record, the elastic constants are also specified for each layer within the element in a principal reference frame. Thus,

```
BEGIN ELEMENT DATA /
```

```
E j N1 N2 N3 N4 /
```

```
L l t r ER  $\nu$ R EC  $\nu$ C b SC SR f /
```

```
.
```

```
.
```

```
.
```

```
L k t r ER  $\nu$ R EC  $\nu$ C b SC SR f /
```

```
END ELEMENT DATA /
```

The numeric characters in the above records are:

- $j$  = Element number (integer),
- $N_1, N_2, \dots$  = Node numbers, assigned according to the right-hand rule dictated by the outward normal (integer) ( $N_1$  must be the smallest),
- $N_4$  = Total number of layers for this element,
- $k$  = Layer number (integer),
- $t$  = Layer thickness,
- $r$  = Cord versus matrix area fraction per inch,
- $E_R$  = Matrix Young's modulus,
- $\nu_R$  = Matrix Poisson ratio,
- $E_C$  = Cord Young's modulus,
- $\nu_C$  = Cord Poisson ratio,
- $b$  = Bias multiplier,
- $S_R$  = Rubber mass density,
- $S_C$  = Cord mass density, and
- $f$  = Dummy variable for future use ( $f = 0$ ).

For identification purposes, the letter E must precede the nodal information and the letter L must precede the layer flexibility information.

#### E. Prescribed Forces

At a given node, one may specify three external force components.

The input records read as

BEGIN FORCE DATA

k P<sub>1</sub> P<sub>2</sub> P<sub>3</sub>

END FORCE DATA

/

/

where

$k$  = Node number (integer), and

$P_i$  = Prescribed force components (floating point).

#### F. Prescribed Displacements

At each node, three rectilinear and two rotational displacement components may be restrained (i.e., equal to zero). These components are referred to as the base vectors of the undeformed reference and labelled according to the following schedule for a rotationally symmetric problem:

$q_1$  = Component along the parallel,

$q_2$  = Component along the meridian,

$q_3$  = Component along the normal,

$q_4$  = Rotation component along the meridian, and

$q_5$  = Rotation component along the parallel.

The input records are exhibited as follows:

BEGIN DISPLACEMENT DATA /

$k$   $m$   $N_1$   $N_2$  ...  $N_M$  /

END DISPLACEMENT DATA /

where

$k$  = Node number (integer),

$M$  = Total number of displacements restrained at the node under consideration (integer), and

$N_1, N_2, \dots$  = Number of displacements being restrained (integer).

G. Curvefitting the Meridian Reference Surface

The cartesian coordinates of the meridian section are defined in this record. Thus,

```
BEGIN CURVEFIT RHOS /  
  i  x1 x2 /  
END CURVEFIT RHOS /  
/  
/
```

where

i = Sequence number of data points (i = 1,2,...NPRHO)(integer), and  
x<sub>1</sub>,x<sub>2</sub> = Cartesian coordinates (floating point).

H. Increment Data

In this record, the increment numbers with the corresponding incremental pressure are defined as follows:

```
BEGIN INCREMENT DATA /  
  1  P1 /  
  i  Pi /  
  IN  PIN /  
END INCREMENT DATA /
```

where

i = Increment number, and  
P<sub>i</sub> = Incremental pressure.

I. Print Options

The output information is governed by the following control cards:

```
BEGIN PRINT OPTIONS /
ALL /
CONTROL PARAMETERS /
NODAL DATA /
ELEMENT DATA /
CURVEFIT RHOS /
LOCAL UNIT VECTORS /
NODAL OUTPUT TABLE /
INCREMENT DATA /
CONTACT DATA /
END PRINT OPTIONS /
/
/
END DATA INPUT /
```

J. Commenting the Input Records

Following the slash on the input data cards, comments may be inserted. These comments may be continued on any number of cards, having a slash for the first character. Thus,

.  
.
.

```
BEGIN NODAL DATA /
1 0.5 0.8 -0.6 / UPDATED, NOV. 11, 1971
2 0.6 1.0 -0.5 / COMMENTS
/ COMMENTS
```

/ COMMENTS  
/ COMMENTS  
3 0.8 2.0 0.5 /

.  
. .

BEGIN ELEMENT DATA /  
1 2 3 10 / COMMENTS  
/ COMMENTS  
/ COMMENTS  
/ COMMENTS  
2 4 5 11 /

.  
. .

K. Input Table Summary

The input data card set-up is summarized in this section.

/ DATA SET NUMBER 1  
/ PREPARED 10/1/72  
/ AIRCRAFT TIRE  
/  
/

BEGIN DATA INPUT /  
BEGIN CONTROL PARAMETERS /  
NODES N /

```

ELEMENTS E /
RADIUS R /
NRHO M /
NPRHO K /
LAYERS L /
END CONTROL PARAMETERS /
/
/
BEGIN NODAL DATA
i  $\theta$   $\phi$  /
END NODAL DATA /
/
/
BEGIN ELEMENT DATA /
E j N1 N2 N3 N4 /
L k t r ER  $\nu$ R EC  $\nu$ C b SC SR f /
END ELEMENT DATA /
/
/
BEGIN FORCE DATA
k P1 P2 P3 /
END FORCE DATA /
/
/
BEGIN DISPLACEMENT DATA /

```

```
k M N1 N2 N3 /  
END DISPLACEMENT DATA /  
/  
/  
BEGIN CURVEFIT RHOS /  
i x1 x2 /  
END CURVEFIT RHOS /  
/  
/  
BEGIN CURVEFIT BETAS /  
i x1 x2 /  
END CURVEFIT BETAS /  
/  
/  
BEGIN INCREMENT DATA /  
I P /  
END INCREMENT DATA /  
/  
/  
BEGIN PRINT OPTIONS /  
ALL /  
CONTROL PARAMETERS /  
NODAL DATA /  
ELEMENT DATA /  
CURVEFIT RHOS /
```



```
LOCAL UNIT VECTORS /  
NODAL OUTPUT TABLE /  
ELEMENT OUTPUT TABLE /  
END PRINT OPTIONS /  
/  
/  
END DATA INPUT
```

For future extensions, the code angle variation may be described by experimental data points. This phase of the code is not yet implemented, however, as the corresponding input data must be present. Thus, augment the control parameter block by

```
NBETA 2 /  
NPBETA 2 /
```

SECTION VI  
OUTPUT DESCRIPTION

A. Output Data

During the data processing phase, associated with geometrical characterization, the user may exercise the print options described in Section V.

The corresponding output information contains the following records:

- Input data - the user's input is listed - to each card image a record number and a card sequence number are assigned for error detection purposes,
- Control parameters,
- Curvilinear coordinates of the nodes,
- Element and layer data,
- Cartesian coordinates of the data points of the reference meridian,
- Increment data for nonlinear inflation,
- Nodal output table,
- Element output table, and
- Local unit vectors.

For each incremental step, the generalized nodal displacements are tabulated as follows:

SOLUTION VECTOR DUE TO INFLATION

Node	U1	U2	U3	S1	S2
1	*	*	*	*	*
2	*	*	*	*	*
.					
.					

where

U1 = displacement in the parallel direction,

U2 = displacement in the meridian direction,

U3 = displacement along the outward normal to the reference surface,

S1 = rotation with respect to the base vector along the meridian surface, and

S2 = rotation with respect to the base vector along the parallel direction.

The above information is then followed by the detailed description of the state of stress associated with each element.

#### ELEMENT NUMBER

n

#### LOCAL DISPLACEMENTS

U	V	W	RX	RY
---	---	---	----	----

*	*	*	*	*
---	---	---	---	---

*	*	*	*	*
---	---	---	---	---

*	*	*	*	*
---	---	---	---	---

where

U = displacement vector in the  $\bar{g}_1$  direction,

V = displacement vector in the  $\bar{g}_2$  direction,

W = displacement vector in the  $\bar{g}_3$  direction,

RX = rotation with respect to  $\bar{g}_2$ , and

RY = rotation with respect to  $\bar{g}_1$ ,

where  $\bar{g}_1$ ,  $\bar{g}_2$ , and  $\bar{g}_3$  are local unit vectors described in Volume I.

This information is then followed by the list of stress resultants and reference surface strains and the stress distribution across the thickness as follows:

STRESS RESULTANTS

N11	N22	N12	M11	M22	M12	Q1	Q2
*	*	*	*	*	*	*	*

REFERENCE SURFACE STRAINS

E11	E22	E12	K11	K22	K12	E13	E23
*	*	*	*	*	*	*	*

STRESS DISTRIBUTION

Layer Number	S11	S22	S12	S13	S23
1	*	*	*	*	*
2	*	*	*	*	*
.					
.					
.					

where the stress resultants and reference surface strains are calculated at the centroid of the reference surface element. The corresponding layer stresses are calculated at the midpoints of the layers in the thickness direction.

The same type of information is then repeated for the rotation if requested by the SPEED control card.

## B. Error Exits

Extensive input error checks are provided in the data preparation phase. Each input card is traced according to its internal sequence number in the input deck. For cross reference, appropriate record numbers are also internally assigned to the input cards. Some of the most frequent error types are listed below:

RECORD 1) BEGIN DATE INPUT / MISSPELLED DATA  
---ERROR 10010 INPUTD - FIRST DATA CARD MUST CONTAIN BEGIN  
DATA INPUT - PROGRAM TERMINATES

RECORD 2) BEGIN DATA INPUT (FORGOT SLASH)  
---ERROR 10020 INPUTD - BLOCK NAME MUST CONTAIN EXACTLY THREE  
WORDS - NEXT INTENDED RECORD IS IGNORED AND PROGRAM TERMINATES

RECORD 3) NODES 8. / DECIMAL POINT ..CARD 7  
---ERROR 10040 INPUTD - THE INPUT VALUE FOR ELEMENTS MUST BE  
TYPE INTEGER

RECORD 4) ELEMENT 12. / DECIMAL POINT ..CARD 8  
---ERROR 10040 INPUTD - THE INPUT VALUE FOR ELEMENTS MUST BE  
TYPE INTEGER

ERROR SUMMARY - THERE ARE (IS) TWO ERROR IN INPUT DATA - THE  
RECORD NUMBERS AT WHICH ERRORS ARE DETECTED ARE PRINTED  
BELOW - ONLY THE FIRST 100 DETECTED ERRORS ARE LISTED

3 4

Similar logical errors are detected and summarized at the end of the program so that the user may correct several input errors in the same run.

## C. Timing and Field Length

The field length requirements may easily be established based on the available blank common in the overlays, whose lengths are listed below

(Scope 3.3):

OVERLAY (KTIRE,0,0)	100 - 25116 (OCTAL)
OVERLAY (KTIRE,1,0)	25116 - 37220
OVERLAY (KTIRE,2,0)	25116 - 30400
OVERLAY (KTIRE,3,0)	25116 - 27257
OVERLAY (KTIRE,4,0)	25116 - 40754
OVERLAY (KTIRE,5,0)	25116 - 27002
OVERLAY (KTIRE,6,0)	25116 - 27034

Since overlays 0 to 3 deal with input data processing only, the actual field length requirements for execution will be estimated from the blank common length calculations for overlays 4 to 6.

$$\text{Blank common length for overlay 4} = 24 \times \text{NOEL} + 18 \times \text{NNODE} \\ + \text{INCR} \times 2 + \text{MAXLAY} \times 10$$

$$\text{Blank common length for overlay 5} = 3 \times \text{NOEL} + 12 \times \text{NNODE} \\ + \text{NEL} + \text{MAXD}$$

$$\text{Blank common length for overlay 6} = \text{NEL} + 2 \times \text{MAXD}$$

where

NOEL = number of elements,

NNODE = number of nodes,

INCR = number of increments,

MAXLAY = maximum number of layers per element,

NRES = number of restrained generalized displacements,

$MAXD = 5 \times NNODE - NRES$ , and

$NEL = (MAXD \times (MAXD + 1))/2$ .

Based on the above schedule, the following table provides sufficient data to establish the field length requirements for execution for a rotationally symmetric problem. Note that the current version of the code employs in-core processing in the fifth and sixth overlays. Approximately 11,000<sub>g</sub> should be added to these figures on the Scope 3.4.3 system.

At this time, only limited data are available to accurately estimate execution times. Approximately 250 CP seconds were used on the CDC-6600 machine under Scope 3.4.3 to perform 8 increments for the following problem size:

Number of elements = 80,

Number of nodes = 62, and

Number of layers = 6.

Thus, as a preliminary estimate, one may consider 4 CP seconds per iteration for 10 elements. The IO time is roughly twice the CP time requirement.

## SECTION VII

### OPTIONAL OUTPUT AND PLOT GENERATION

At each incremental step, the following data are written on TAPE2 of the TIRE code:

1. SOLUTION VECTOR DUE TO INFLATION AND/OR ROTATION
2. STRESS RESULTANTS
3. REFERENCE SURFACE STRAINS
4. STRESS DISTRIBUTION
5. PRESSURE INCREMENTS
6. CROWN DISPLACEMENT

The above data are then used in an independent computer code called WRITE, which may be used to select the desired output and plotting routine according to the following schedule.

The first input card contains the overall characteristics of the problem:

NOEL NNODE NOLAY INCR NCROWN

where NCROWN is the crown node number.

The next card contains the print and plot option keys:

KREF KSTRES KDISP KCROWN KPRES KCRPLT KSELCT

where

KREF = 1: Provides resultants and reference strains for each element.

KSTRES = 1: Provides layer stresses for each element.

KDISP = 1: Provides nodal displacements.

KCROWN = 1: Provides crown displacement.



- KPRES = 1: Provides pressure increments.
- KCRPLT = 1: Crown displacement is plotted versus inflation pressure.
- KSELCT = 0: Stress resultants, Strains and Layer Stresses are provided at all incremental steps.
- KSELCT = N: Stress resultants, Strains and Layer Stresses are provided only at the N<sup>th</sup> increment.

Any combinations of the above keys may be activated.  
Input zero if a particular option is not desired, with the exception of the KSELCT key.

## REFERENCES

1. A. L. Deak, "Stress Analysis of Aircraft Tires", Volume I. Analytical Formulation, MSNW Report No. 75-317-1, December 1975.