FINAL

Jet Propulsiuon Laboratory
California Institute of Technology

PLM WORLD 2005
Innovative Computing Techniques for NX Analysis and Post Processing To Fill Emerging Needs

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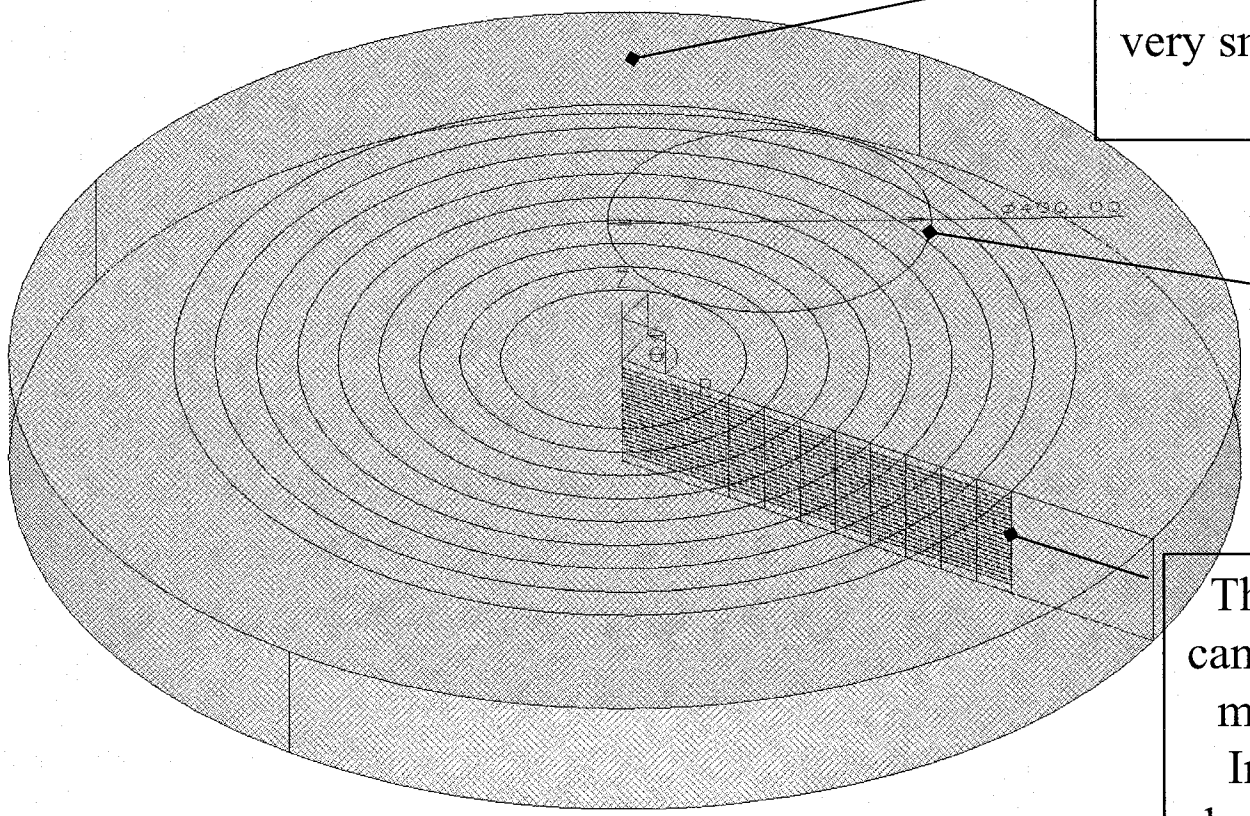
Introduction

- Three case studies were derived from real projects to illustrate specialized analysis interests as well as the methods utilized to achieve novel results using NX Nastran and I-deas.
  - Case 1: Modeling material property spatial distribution to match as-built: mapping measured coefficient of thermal expansion material properties for a high precision mirror. Workflow included I-deas NX, TMG, and NX Nastran.
  - Case 2: Customized layered composite failure analysis with NX Nastran, XML Spreadsheet, and the I-deas NX Visualizer.
  - Case 3: Desire for computation of optical wavefront metrics directly in I-deas NX.

Overview of Three NX Analysis Case Examples Derived from Project Interests

- Case 1: Visualizing and Applying Measured Spatial Variations of Coefficient of Thermal Expansion (CTE) to a High Precision Optic Mirror Finite Element Model.
  - Example Motivated by JPL Analysis Interests on Space Interferometry Mission (SIM).
  - To Read about SIM, see http://planetquest.jpl.nasa.gov/SIM/sim_index.html
  - Post-processing techniques for this case enable analysis to visualize and apply spatial Coefficient of Thermal Expansion (CTE) variations.
  - Case tool usage presented here includes I-deas, TMG, NX nastran and universal files.
- Case 2: Customized Composite Ply Failure Analysis
  - This Example is Motivated by ATA Project Work with Composites.
  - Customized layered composite failure analysis with NX Nastran, I-deas Visualizer, and Plyable.
  - Post-processing techniques described for this case enable quick, customized and formatted summaries of ply failure and stress states for laminated composites for large NX Nastran models.
  - To read more about ATA see http://www.ata-e.com/
- Case 3: Optic Metric Evaluation From FE Displacement Data
  - A JPL example motivated by the desire to quickly and easily take FEM displacement data from I-deas (or Nastran) and directly apply optic metric calculations such as Optical Path Difference (OPD).
  - The benefit is to reduce handoffs with optics for structural design evaluations.
- Presented Examples do not use actual project geometry or model data.

Boule of Glass Material for High Precision Optic Mirror Manufacture, Case 1 Motivation



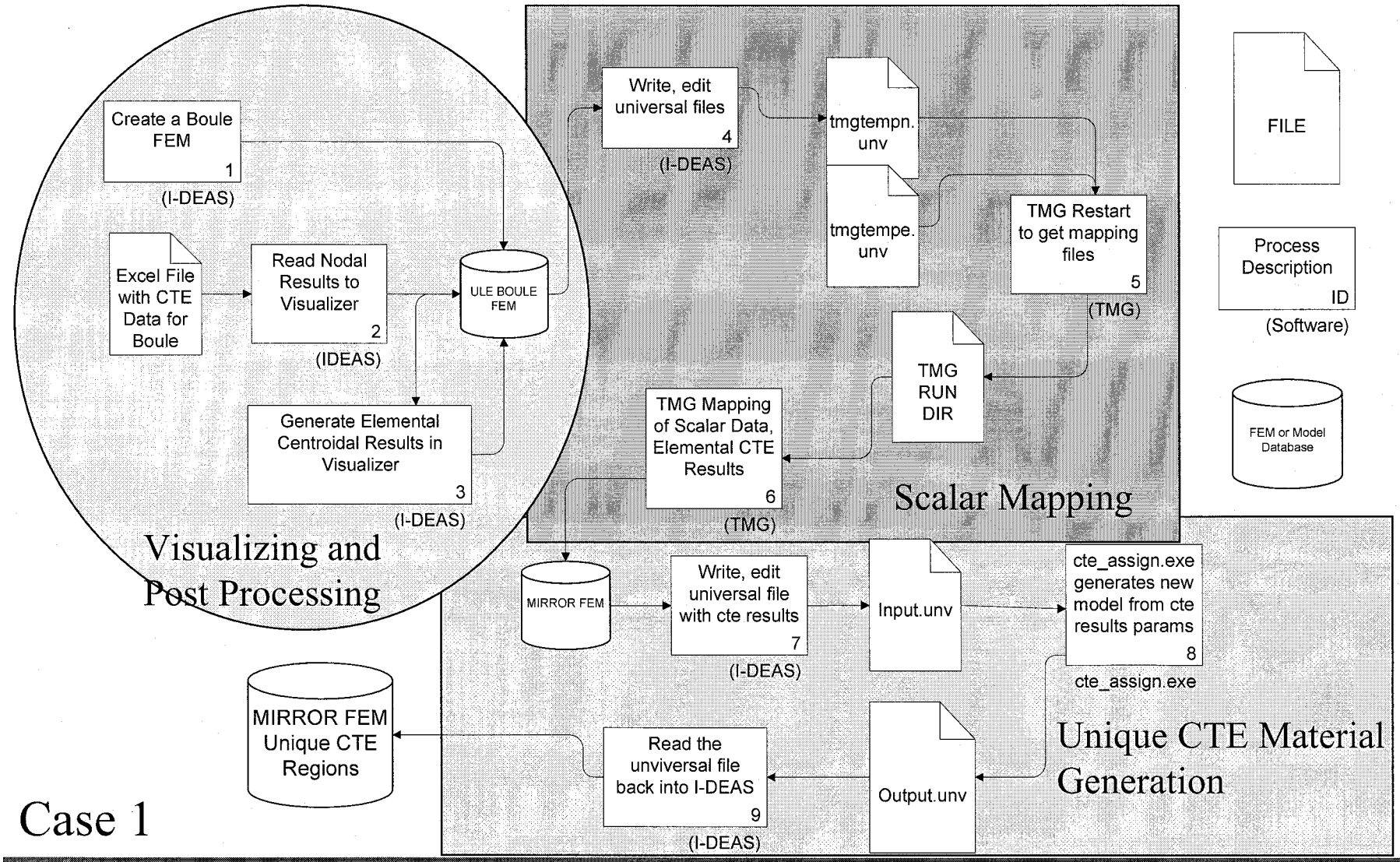
Glass material is isotropic with very small Coefficient of Thermal Expansion (CTE).

Mirror "blank" region where a mirror will be cut from the Boule for manufacture.

The CTE within the boule can vary significantly due to manufacturing processes. Intersecting lines shown here indicate measurement locations.

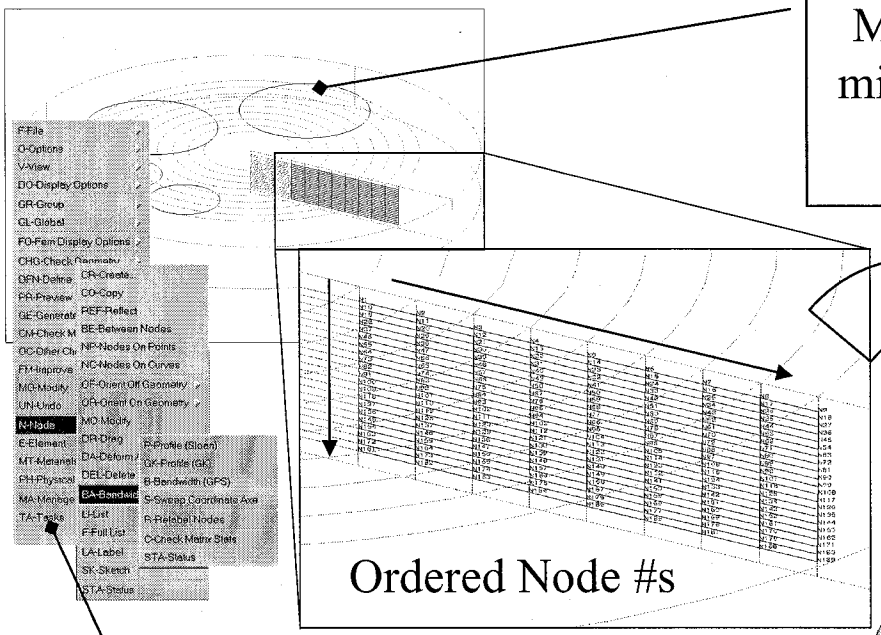
Case 1

Process Diagram for Using Measured Data to Get As Manufactured CTE Variations Included in Mirror Distortion Analysis



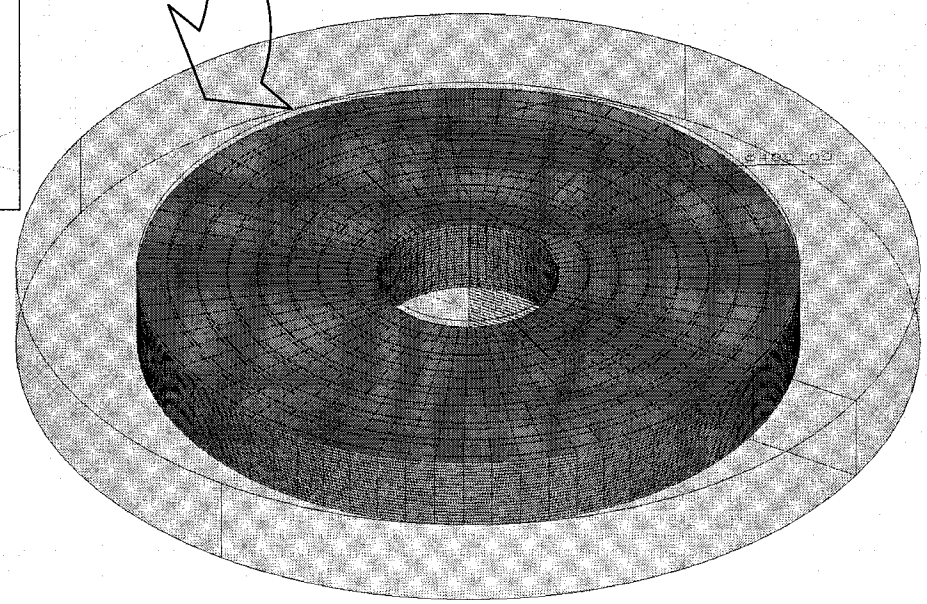
Case 1

(1) Create Boule Finite Element Model Using I-deas Node Spacing, Numbering Created to Match CTE Measurement Data Locations



Mirror "blank" regions where mirrors will be cut from a glass cylinder for manufacture.

Solid mesh with nodes representing CTE measurement or statistical locations.



Any I-deas manual or automatic mesh can be renumbered using menus in I-deas and coordinate systems. Menus can also be used to revolve a simple surface mesh.

Case 1

Hypothetical Excel CTE Data for Glass Material Data Presented Here is Constructed From Random Seed Functions to Establish a Generic Example.

Coefficent of Thermal Expansion (CTE) Matrix units are ppb/ deg C, 189 point matrix (1st station pairs constructed from psuedo random seeds, varying from 1.0 to 20.0)

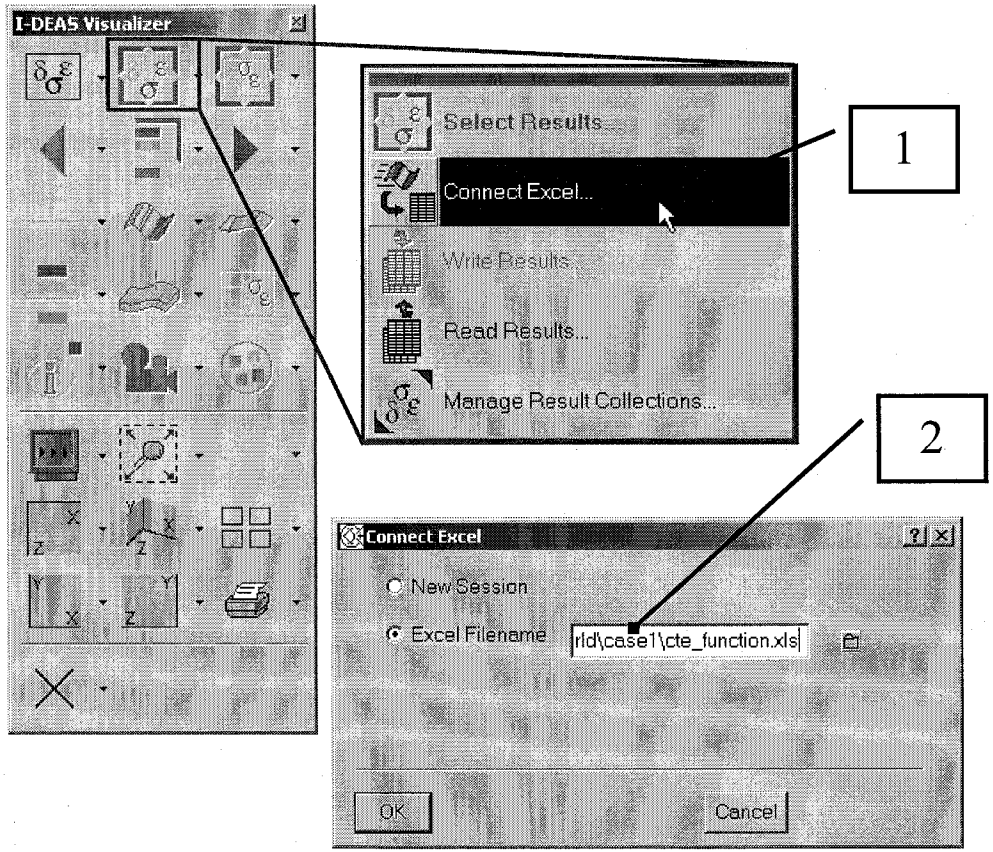
Depth Station in a Boule of Glass	Radial Station in Boule of Glass 1	2	3	4	5	6	7	8	9	
1	18.3	19.2	13.9	4.5	1.4	16.4	1.8	13.1	7.4	<= Random Seeds
2	19.3	20.2	14.9	5.5	2.4	17.4	2.8	14.1	8.4	<= previous row +1
3	20.3	21.2	15.9	6.5	3.4	18.4	3.8	15.1	9.4	<= previous row +1
4	21.3	22.2	16.9	7.5	4.4	19.4	4.8	16.1	10.4	etc.
5	22.3	23.2	17.9	8.5	5.4	20.4	5.8	17.1	11.4	
6	23.3	24.2	18.9	9.5	6.4	21.4	6.8	18.1	12.4	
7	24.3	25.2	19.9	10.5	7.4	22.4	7.8	19.1	13.4	
8	25.3	26.2	20.9	11.5	8.4	23.4	8.8	20.1	14.4	
9	26.3	27.2	21.9	12.5	9.4	24.4	9.8	21.1	15.4	
10	27.3	28.2	22.9	13.5	10.4	25.4	10.8	22.1	16.4	
11	28.3	29.2	23.9	14.5	11.4	26.4	11.8	23.1	17.4	
12	29.3	30.2	24.9	15.5	12.4	27.4	12.8	24.1	18.4	
13	30.3	31.2	25.9	16.5	13.4	28.4	13.8	25.1	19.4	
14	31.3	32.2	26.9	17.5	14.4	29.4	14.8	26.1	20.4	
15	32.3	33.2	27.9	18.5	15.4	30.4	15.8	27.1	21.4	
16	33.3	34.2	28.9	19.5	16.4	31.4	16.8	28.1	22.4	
17	34.3	35.2	29.9	20.5	17.4	32.4	17.8	29.1	23.4	
18	35.3	36.2	30.9	21.5	18.4	33.4	18.8	30.1	24.4	
19	36.3	37.2	31.9	22.5	19.4	34.4	19.8	31.1	25.4	
20	37.3	38.2	32.9	23.5	20.4	35.4	20.8	32.1	26.4	
21	38.3	39.2	33.9	24.5	21.4	36.4	21.8	33.1	27.4	

Node Number	depth station (row)	radial station (column)	cte (ppb/deg C)
1	1	1	18.3
2	1	2	19.2
3	1	3	13.9
4	1	4	4.5
5	1	5	1.4
6	1	6	16.4
7	1	7	1.8
8	1	8	13.1
9	1	9	7.4
10	2	1	19.3

Use Excel to assign station CTE data to I-deas nodal locations in glass model.

Case 1

(2) Read Nodal CTE Scalar Data into I-deas Visualizer Directly from Microsoft Excel



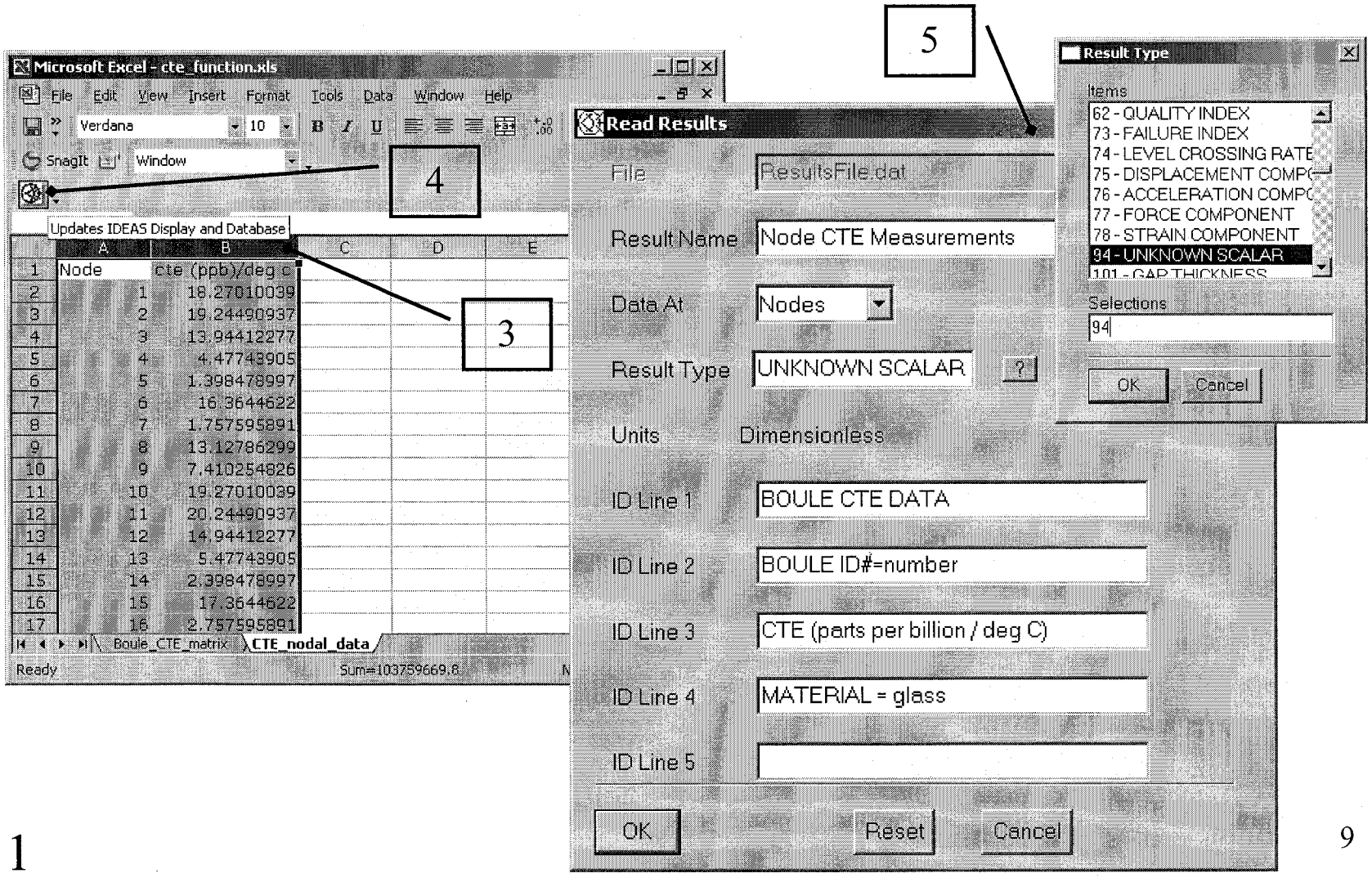
Steps to read user data as results into an I-deas model directly from Excel:

1. Start Visualizer and Hold Down Stack with "Select Results", then use "Connect Excel". Hit "Cancel" on message about results not existing if you get it.
2. Specify an existing Microsoft Excel (.xls) workbook that is not already open.
3. Highlight columns in Excel containing nodal numbers and scalar values (they don't need to be adjacent).
4. Push I-deas Icon in Excel to load data into I-deas.
5. Specify results type and useful results attributes and nomenclature.
6. May need to leave Visualizer and "Start New Visualizer" to Select and view new results.

Note that "Read Results…" can be used to read a formatted text file into ideas in the same fashion.

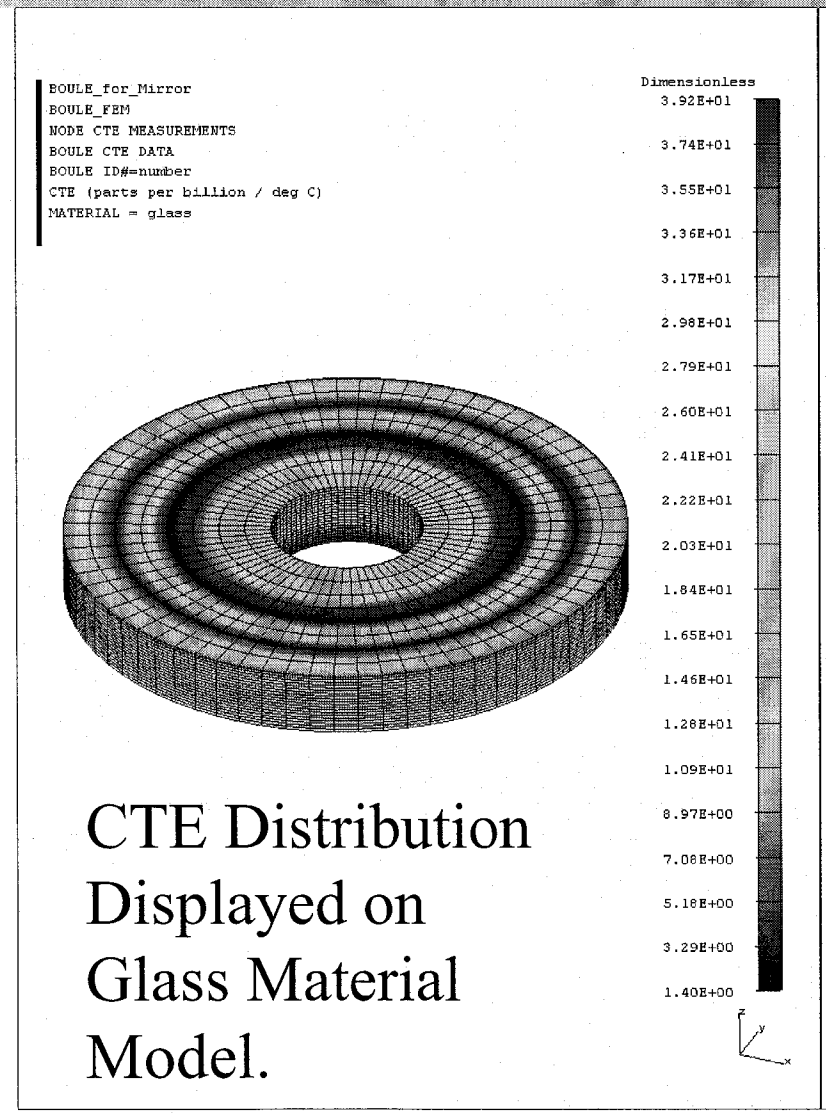
Case 1

(2) Read Nodal CTE Scalar Data into I-deas Visualizer directly from Microsoft Excel (Con't)

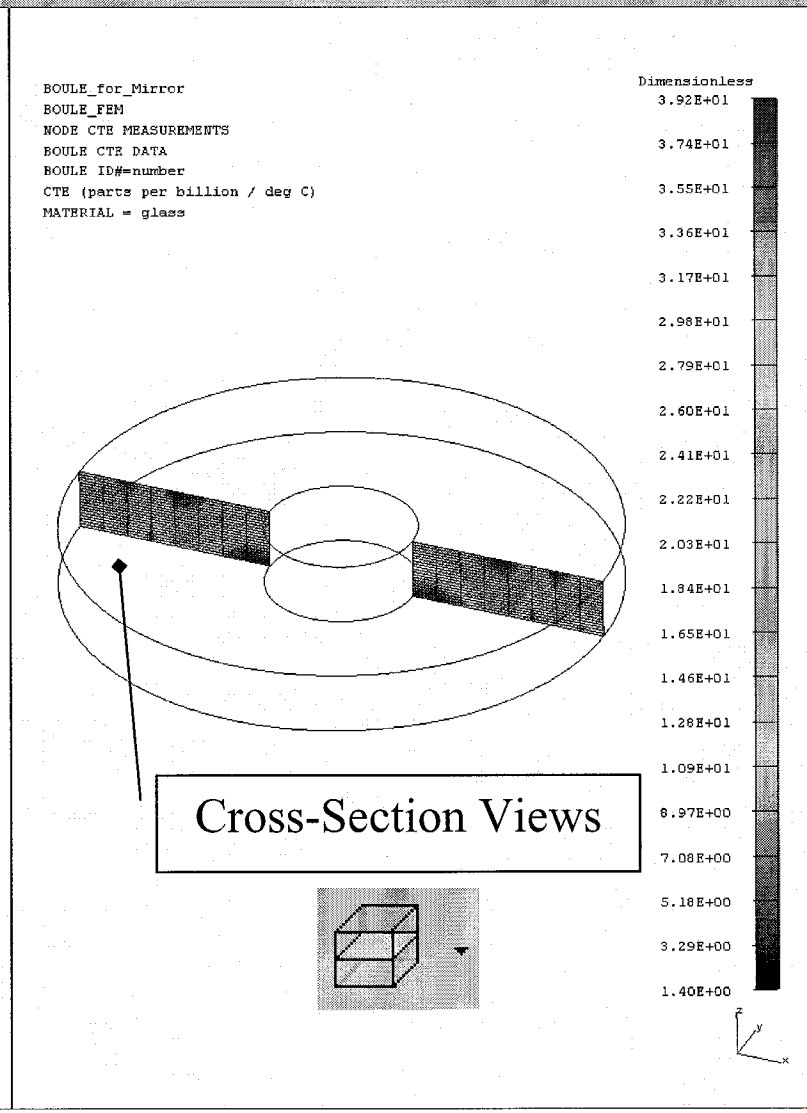


Case 1

Example Display of Nodal CTE Scalar Data in I-deas Visualizer on Glass Boule



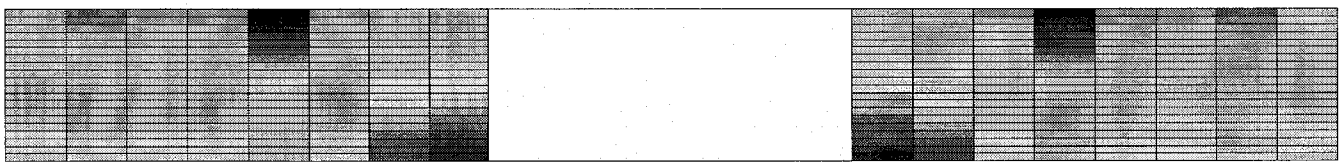
CTE Distribution Displayed on Glass Material Model.

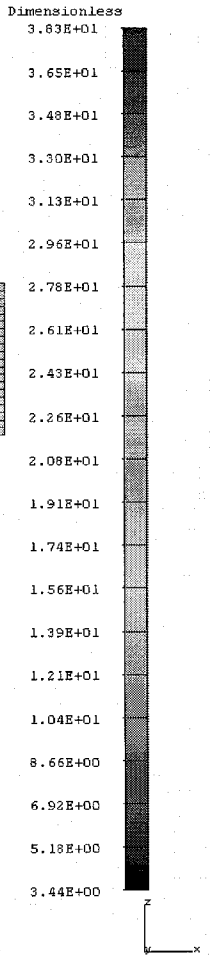


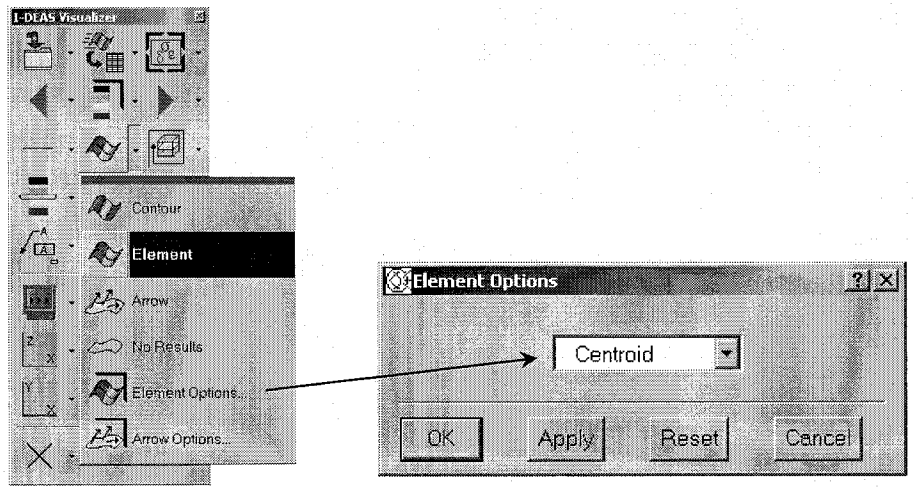
(3) Use Visualizer Options to Visualize and Create Elemental CTE Data

BOULE_FEM
ELEMENT CTE MEASUREMENTS (MATRIX)
BOULE CTE DATA
BOULE ID#=number
CTE (parts per billion / deg C)
MATERIAL=glass

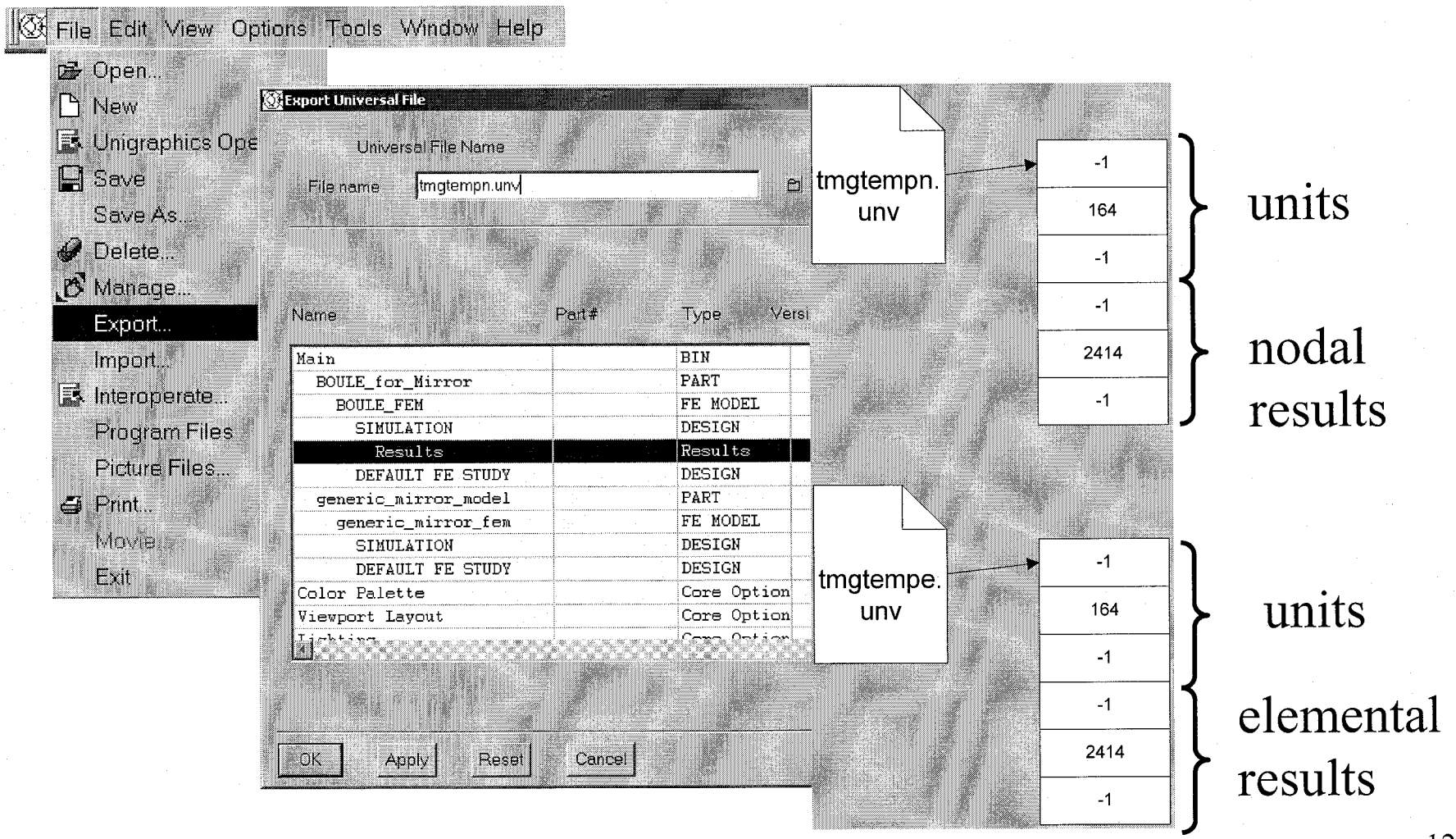
Use nodal data to write/read to/from Excel to Create an Element Dataset.







(4) Edit Universal Text Files to Create Results Files in TMG Universal File Format for Mapping



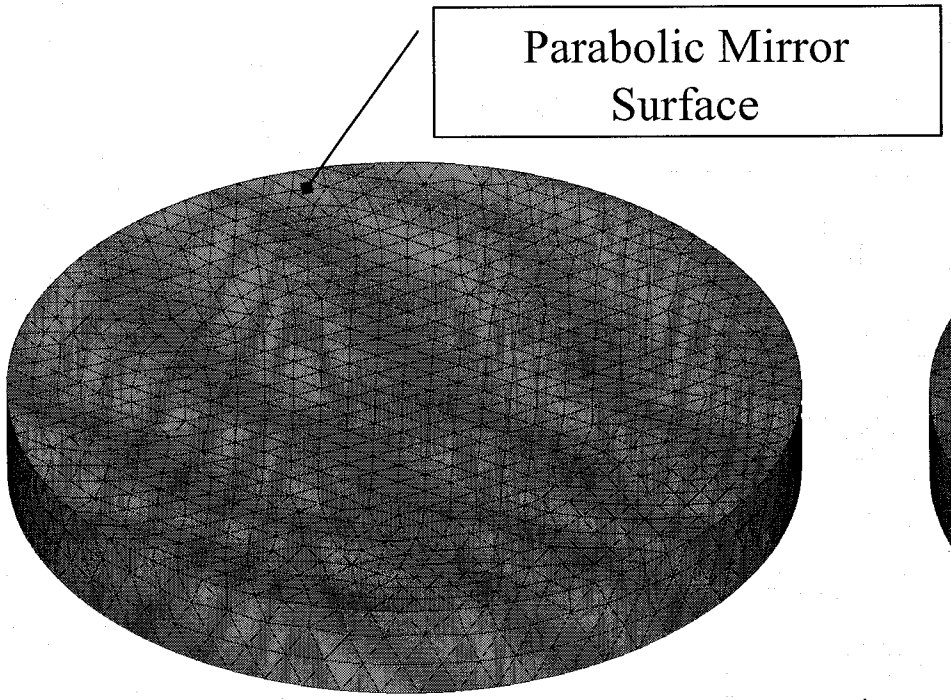
Case 1

Universal Files Can Be a Powerful and Flexible Interface for Making Model Changes, Storing Groups, or Loading Results

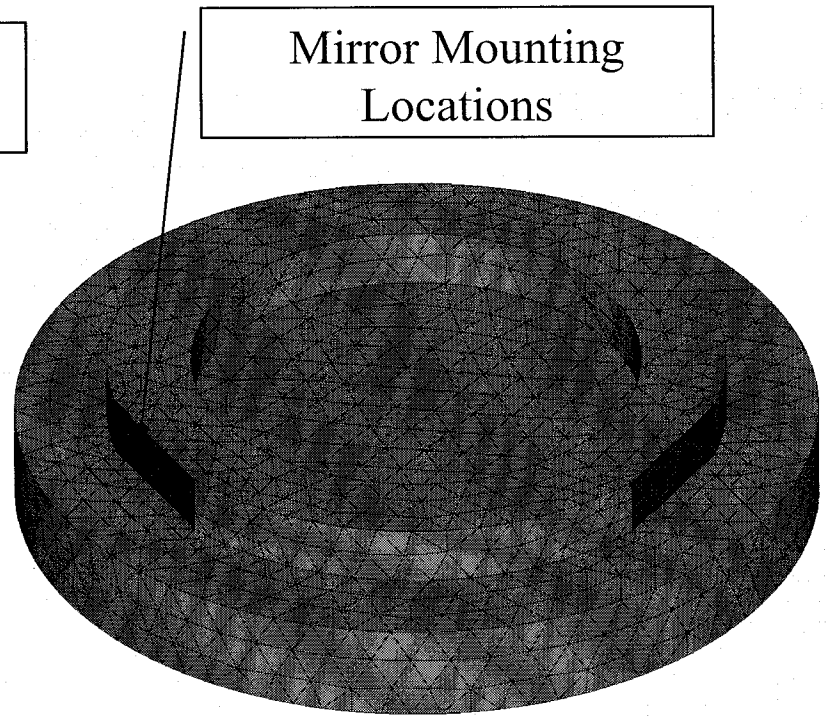
- Some useful examples of leveraging universal file datasets, I11
  - 164, units
  - 2414, results

    } TMG results files use these sets
  - 2412, elements
    - Can use to load element data, or easily text edit to flip rigids to constraints, etc.
  - 2477, permanent groups
    - Store useful group definitions in a text file.
    - Using this approach, can load model from NX Nastran .op2 file solve, and recover groups by simply loading this text file.
    - Change this to 2435 and FEMAP version 8 and higher will also read the groups
- Textual interface means that specific sets can be easy to use.
  - Start and end of datasets delimited with -1.
  - Many text editors can jump to/from specific datasets by including newline character in search expressions.
  - A useful programming approach is to build a directory of universal file contents and then read specific sets of interest.
  - Detailed documentation in I-deas help.

Generic Mirror Model for Example CTE Data Will be Mapped from Glass Data to This Mesh



Iso View of Generic Mirror Model

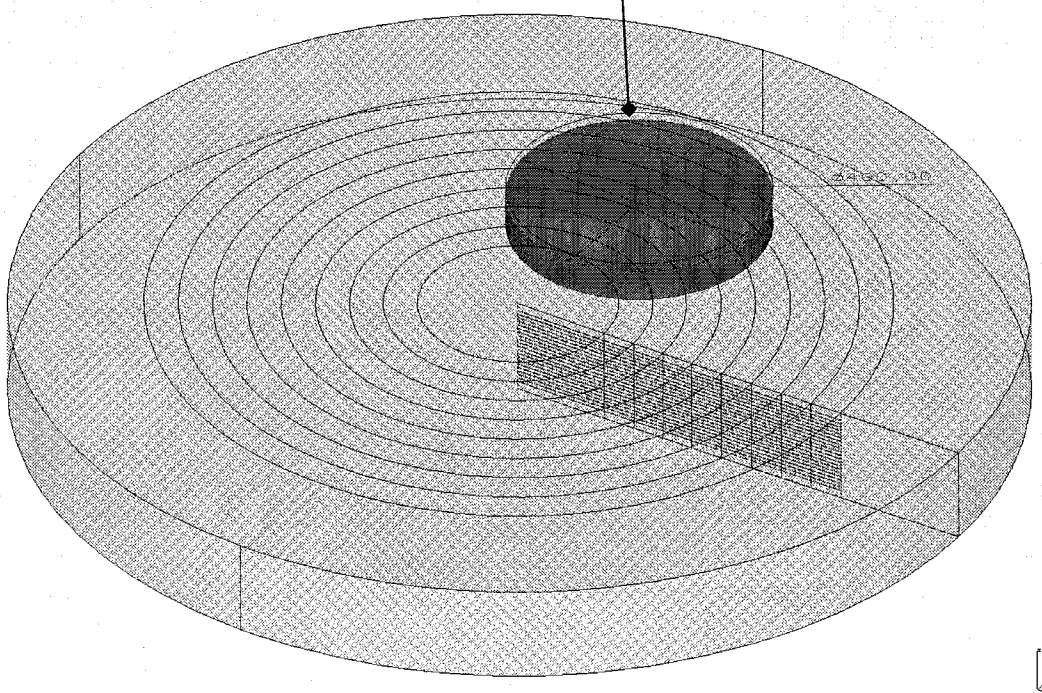


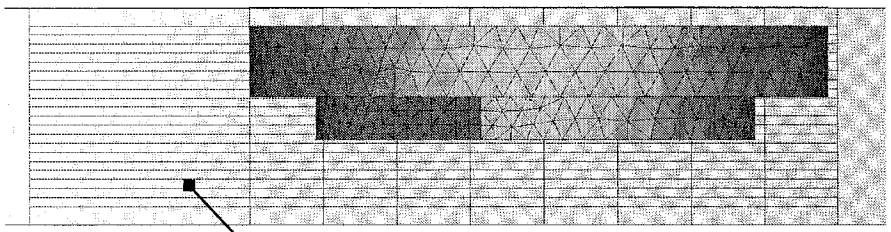
Reverse Iso View of Generic Mirror Model

8,609 Parabolic Tetrahedral Elements, 14,924 Nodes.

In Example, Mirror Manufactured From a Blank of Glass Material Within a Boule with Relative Orientation as Shown

Mirror Blank and Mirror shown within glass material for manufacture.





Overlay of Mirror Mesh with measurement locations; want to map CTE measurement data to detailed mirror finite element model.

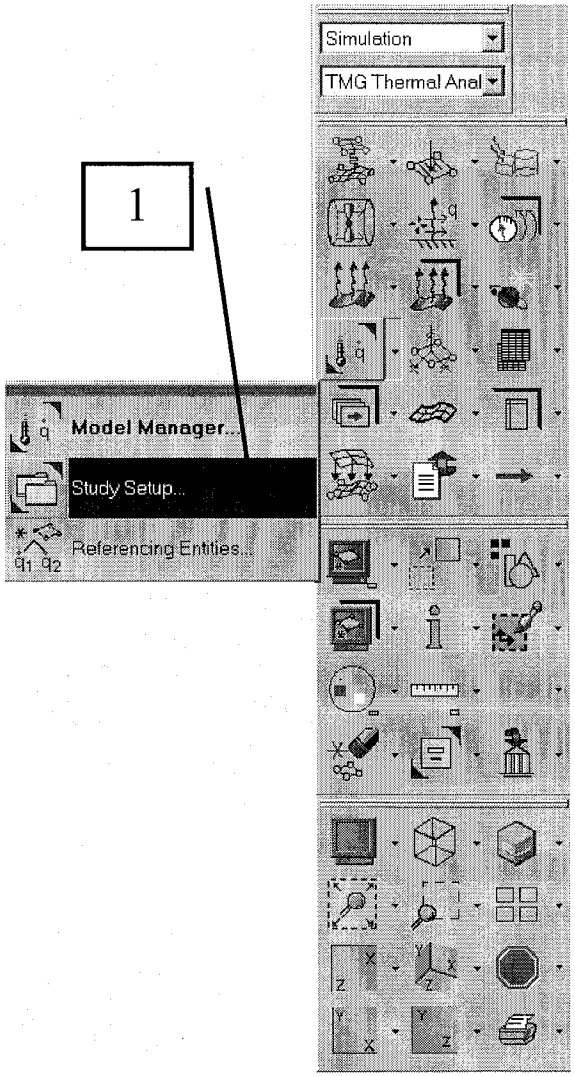
Description of Mapping (Temperatures) from a Thermal Mesh to a Structural Mesh With TMG

1. Given a thermal mesh and a targeted structural mesh.
2. Temperature data exists for thermal mesh to be mapped to the structural mesh.
3. Each node and element centroid in structural mesh is associated with an element in the thermal model.
4. For each structural mesh location, TMG selects i temperature calculation locations, (nodes and centroids) that are closest for "mapping" temperature data.
5. If the target node is located inside the associated thermal element, its temperature is interpolated using the CG and two (for shells), or three (for solids) nodal temperatures of closest thermal nodes.
6. If the target node is located outside the closest associated thermal element, then projection and extrapolation methods are applied for shells and solids, respectively.
7. Mapping weighting functions (Mi) are constructed for each ith thermal location associated to the structural location and the temperature for the nth structural location can be expressed as:

$$T_n = \sum M_i T_i$$

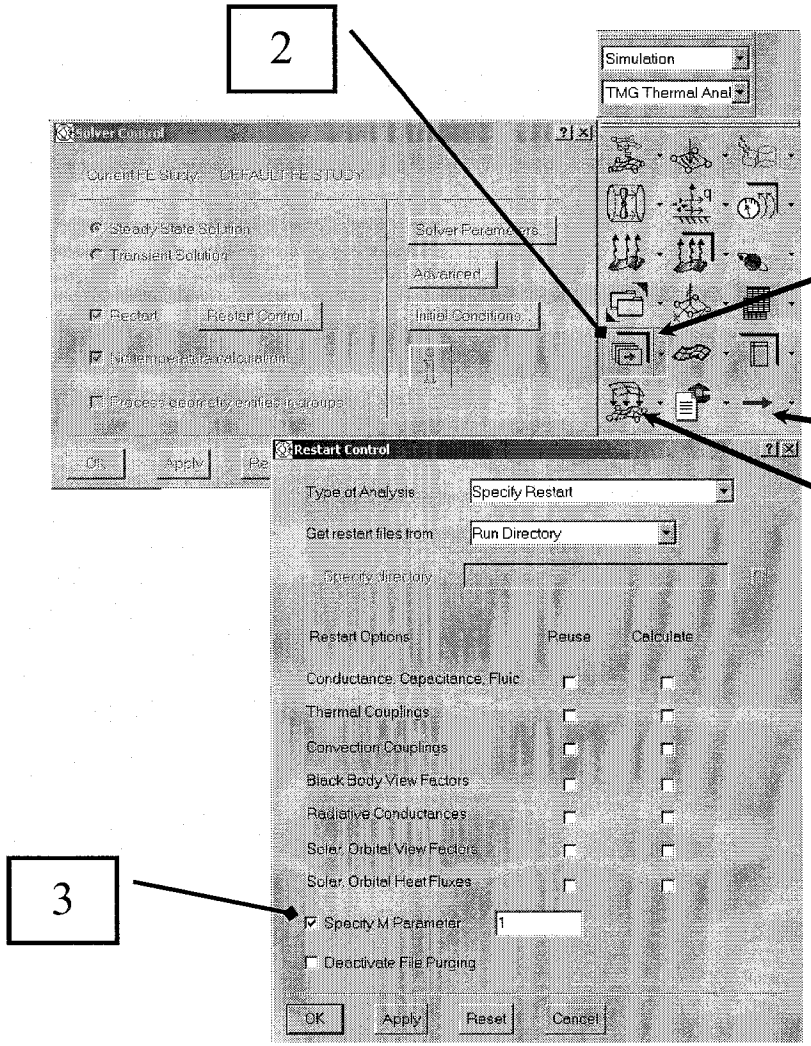
8. For a more detailed description, consult the <u>TMG Thermal Analysis User's Guide, "Mapping Temperatures to Another Model"</u>.

(5) TMG Restart to Get Mapping Files
Goal of this Step is to Create Files Necessary for the Scalar Mapping of CTE Data



1. With Glass material model out on workbench, use study setup to define a thermal run directory.
2. Click solver control, Specify Restart, No Temperature Calculation. Goal is to create files necessary for scalar mapping.
3. On Restart Control Form, specify M parameter of 1.
4. Solve with TMG to get mapping files.
5. Copy tmgtempn.unv and tmgtempe.unv that were created from CTE results sets to the run directory.

(5) TMG Restart to Get Mapping Files (cont'd)



Solver Control

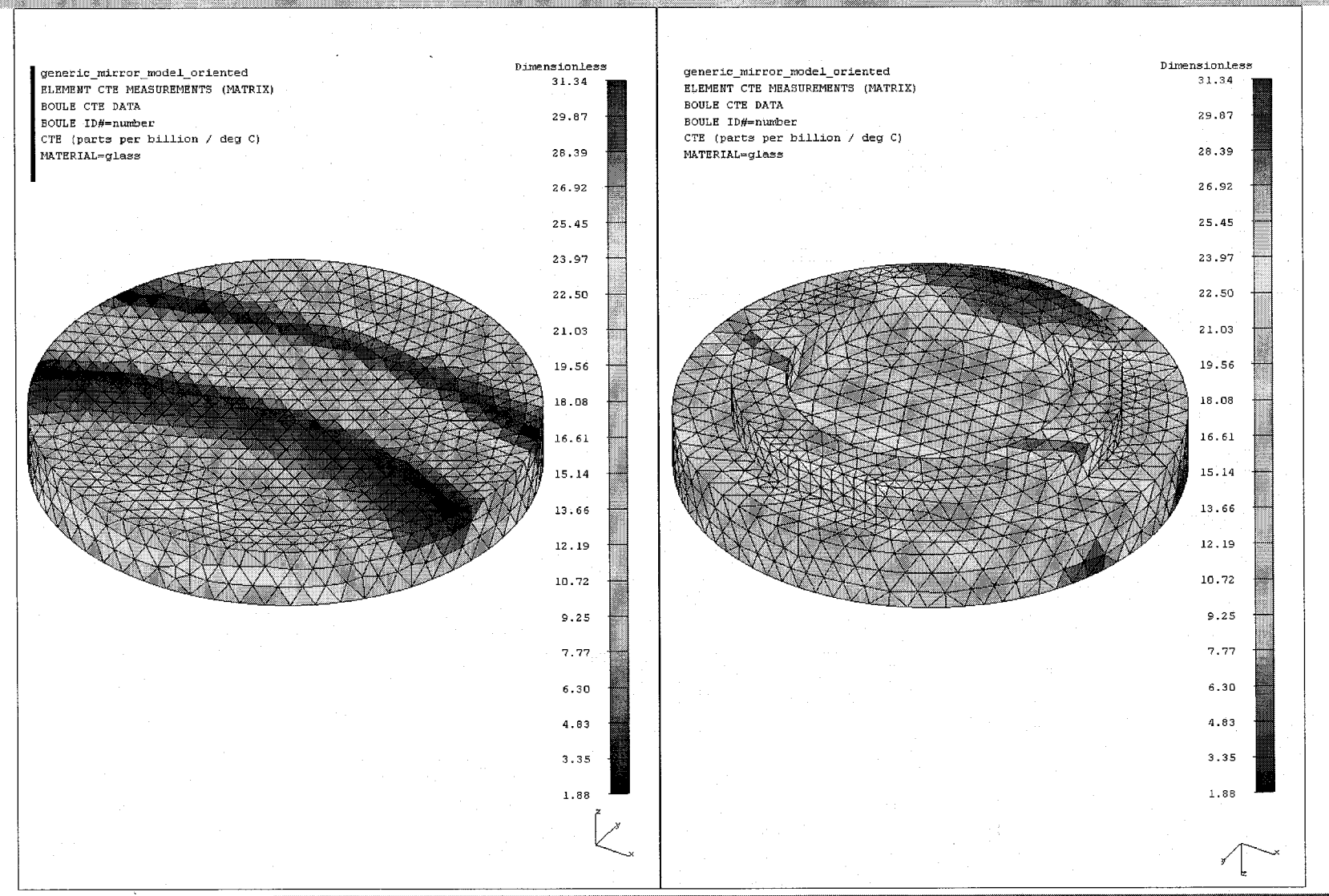
Solve

Temperature Mapping

(6) TMG Mapping of Scalar Data: Mapping the CTE data from the Glass Material Model to the Generic Mirror Finite Element Model

- With the temperature mapping files created, the TMG temperature mapping code can be used to map a set of nodal and elemental scalar results from one mesh to another.
- Now the same process is followed, except CTE scalar data replaces temperature data and the glass material model replaces a thermal model.

Image of Mapped CTE Results Displayed on the Generic Mirror Model Using the I-deas Visualizer



(8) A User Program Called cte_assign.exe Was Written to Read Universal File Data and Assign CTE Material Bands From Results

```
cte_assign.exe input.unv -r=1 -m=5 -n=1000 -b=1000 -sf=1.0E-9 -f=output.unv
```

Source model

Executable

CTE Result Set ID

Basic Material with Elems to Replace

New Staring Material ID

# of Material Bands to Create

Scale factor

Output model

Summary of Case 1 Benefits and Useful Software Features

- Commercial software features leveraged for custom tasks.
  - I-deas visualizer made reading and visualizing spatially varying CTE user data in FE models easier.
  - I-deas/TMG was flexible enough to allow temperature mapping process to be leveraged for mapping other scalar data from one model to another. TMG was already being utilized to perform thermal analysis and mapping to these structural models.
- Universal file programming enabled custom material generation from visualized results.
- Measured and statistical CTE variations can be applied to detailed mirror finite element models or to multiple optics in a system model.
- Models can be solved in I-deas or exported and solved in NX Nastran.

Suggestions for Future Software Features of Interest, Case 1

- Direct mapping of scalar results fields from one model to another with less interaction.
- Integrated abilities to generate spatial FE material and property variations from user defined data in results sets or user functions. These models will not necessarily have geometry associations.

Case2: Streamlining Laminate Composite Failure Calculations

- This case deals with streamlining ply failure calculations and providing strength ratios.
- Typical In-Plane Laminated Composite Failure Theories
  - Max Stress
  - Max Strain
  - Tsai-Hill
  - Hoffman
  - Tsai-Wu

  Quadratic Failure Criteria
- Inter-Ply Failure, a Root Sum Square (RSS) of shear stresses between plies is compared to an allowable.
- Brief Discussion on Failure Nomenclature, Strength Ratio and Failure Index.

Nomenclature for Strengths of Composite Materials

- Nomenclature for directional strengths.
  - X1t, X, primary direction tensile strength.
  - X1c, X', primary direction compressive strength.
  - X2t, Y, secondary direction tensile strength.
  - X2c, Y', secondary direction compressive strength.
  - S12, S, in plane shear strength.
  - Sil, Inter-laminar shear strength, typically specified on a laminate or pcomp card as a bonding allowable.

Overview of Quadratic Failure Criteria Equations in Stress Space in Terms of Strength Parameters, F

$$F_{ij}\sigma_i\sigma_j + F_i\sigma_i = 1$$

$$\downarrow$$

$$F_{xx}\sigma_x^{\ 2} + 2F_{xy}\sigma_x\sigma_y + F_{yy}\sigma_y^{\ 2} + F_{ss}\sigma_s^{\ 2} + F_x\sigma_x + F_y\sigma_y = 1$$

Where $F_{xx} = \frac{1}{XX'}$ $F_x = \frac{1}{X} - \frac{1}{X'}$ $F_{yy} = \frac{1}{YY'}$ $F_y = \frac{1}{Y} - \frac{1}{Y'}$ $F_{SS} = \frac{1}{S^2}$

$$F_{xy} = InteractionTerm$$

And Max Stresses in stress space are planar $\sigma_x = \sigma_1$ $\sigma_y = \sigma_2$ $\sigma_{xy} = \sigma_{12}$

See Source [6] for detailed background of the quadratic failure theories and strength ratio calculations.

Brief Summary of Quadratic Failure Theories

Summary of Quadratic Failure Criteria		
Criteria	Uniaxial Strengths	Interaction Term, Fxy
Tsai-Hill	X=X', Y=Y'	$-\frac{1}{2X^2}$
Hoffman	X≠X', Y≠Y'	$-\frac{1}{2XX'}$
Tsai-Wu	X≠X', Y≠Y'	$\frac{FXY^*}{\sqrt{XX'YY'}}$

Fxy* is a parameter from testing. In the special case where Fxy* is -1/2, the Tsai-Wu criterion is called the Generalized Von Mises Theory.

Strength Ratio and Failure Index Versus FEA Index

- FEA Index (K) or typically called FI
  - This is most commonly implemented in most commercial FEA codes and not a very good index to use.
  - An FI=2/3 indicates failure has not occurred but doesn't give an indication of the safety margin when used with a quadratic failure criterion.
  - For the maximum stress and strain and transverse stress theories, K=k=1/R. This is not true for quadratic failure theories such as Hill, Hoffman and Tsai-Wu.
- Better evaluations
  - Strength Ratio is
    - (R) = Stress Allowable/Calculated Stress
    - Strength Ratio of 3/2 indicates load can be 1.5 times before failure occurs.
    - Value less than 1 indicates failure for criterion.
    - Strength Ratios can be evaluated for all of the in-plane failure criteria and also for the inter-laminar criterion described.
  - Failure Index (k)
    - If failure index is defined as the inverse of R, then again, if k=2/3, load can be increased 1.5 times before failure.

Summary of Strength Ratio Calculations for Quadratic Failure Criteria

- *The strength ratio can be expressed for a quadratic failure criteria by:*
  - *Substituting components of applied stress as:*

$$R\sigma_i(applied) = \sigma_i Max$$

  - *For a given material the strengths are specified.*
  - *A quadratic equation of the form below can then be solved to get the strength ratio, R.*

$$aR^2 + bR - 1 = 0$$

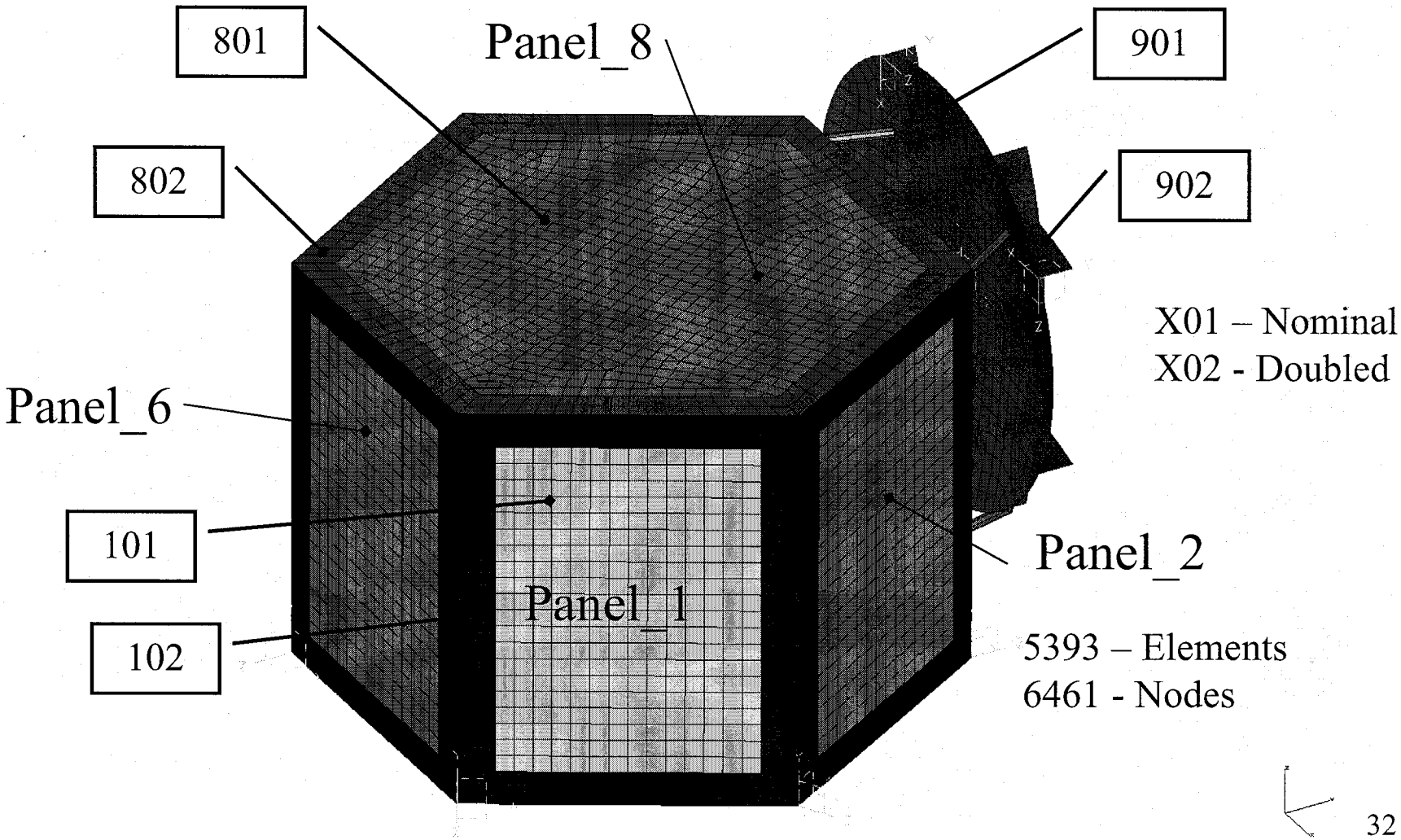
$$a = F_{ij}\sigma_i\sigma_j, b = F_i\sigma_i$$

Case 2

Composite Analysis Notes

- Composite testing is very important and necessary part of analyzing composite structures.
- Honeycomb composite structures and specialized joints are very common composite structures for analysis and have been excluded from discussion here. Refer also to references for background.
- Similar stress component processing methods from .op2 files have been used to perform custom failure analysis from Nx Nastran shell and solid stress data for specific failure modes of honeycomb structures.

Case 2: Example, Generic Laminated Composite Model (GLCM) For Demonstration - Six unique composite regions, 18 PCOMP Cards



Case 2: Example, Ply Material Data

		PLY MATERIALS (Inch lbf Units)		
ID		1001	1002	1003
Property	Units	T300/934 Carbon/Epoxy Uni	GY70/934 Carbon Epoxy Uni	Kevlar 49/Epoxy Uni
E1	[psi]	2.1466E+07	4.2641E+07	1.2618E+07
E2	[psi]	1.3996E+06	9.2824E+05	7.9771E+05
v12		0.30	0.23	0.34
G12	[psi]	6.5992E+05	7.1068E+05	3.1908E+05
G13	[psi]	6.5992E+05	7.1068E+05	3.1908E+05
G23	[psi]	1.8500E+05	1.8500E+05	1.8500E+05
weight density	lb/in^3	5.4191E-02	5.7442E-02	4.9856E-02
ref temp	F	68	68	68
X1t	[psi]	1.9058E+05	8.5427E+04	1.8565E+05
X1c	[psi]	1.7695E+05	7.1214E+04	4.8588E+04
X2t	[psi]	6.2366E+03	4.2641E+03	4.3511E+03
X2c	[psi]	2.4366E+04	1.4228E+04	2.2916E+04
S12	[psi]	6.9618E+03	7.1214E+03	7.1068E+03
Sil	[psi]	1.4504E+04	1.4504E+04	1.4504E+04
Primary Source		http://composite.about.com/	http://composite.about.com/	http://composite.about.com/

Value Color Code
Material ID numbers for example.
Data obtained from primary source.
Data not in primary source; assumed or other reference.
Material data entered for example.
Allowable data.

Material Data is for Example Only.

Case 2, Panel Laminate Shown Being Defined in Excel

Microsoft Excel - Case2LaminateProperties.xls

C3 T300/934 Carbon/Epoxy Uni

	A	B	C	D	E	F
1	PCOMP	101	PANEL_1_B			
2	Layer	Material ID	Material Name	Thickness (in)	Angle (°)	
3	1	1001	T300/934 Carbon/Epoxy Uni	0.00400	0	
4	2	1001	T300/934 Carbon/Epoxy Uni	0.00400	45	
5	3	1001	GY70/934 Carbon Epoxy Uni	0.00400	-45	
6	4	1001	Kevlar 49/Epoxy Uni	0.00400	90	
7	5	1001	T300/934 Carbon/Epoxy Uni	0.00400	0	
8	6	1001	T300/934 Carbon/Epoxy Uni	0.00400	45	
9	7	1001	T300/934 Carbon/Epoxy Uni	0.00400	-45	
10	8	1001	T300/934 Carbon/Epoxy Uni	0.00400	90	
11	9	1001	T300/934 Carbon/Epoxy Uni	0.00400	0	symmetric
12	10	1001	T300/934 Carbon/Epoxy Uni	0.00400	0	
13	11	1001	T300/934 Carbon/Epoxy Uni	0.00400	90	
14	12	1001	T300/934 Carbon/Epoxy Uni	0.00400	-45	
15	13	1001	T300/934 Carbon/Epoxy Uni	0.00400	45	
16	14	1001	T300/934 Carbon/Epoxy Uni	0.00400	0	
17	15	1001	T300/934 Carbon/Epoxy Uni	0.00400	90	
18	16	1001	T300/934 Carbon/Epoxy Uni	0.00400	-45	
19	17	1001	T300/934 Carbon/Epoxy Uni	0.00400	45	
20	18	1001	T300/934 Carbon/Epoxy Uni	0.00400	0	
21			Total Thickness (in)=	0.072		
22			Bottom Fiber (in) =	-0.036		
23	Part Name		PANEL_1			
24	Drawing					

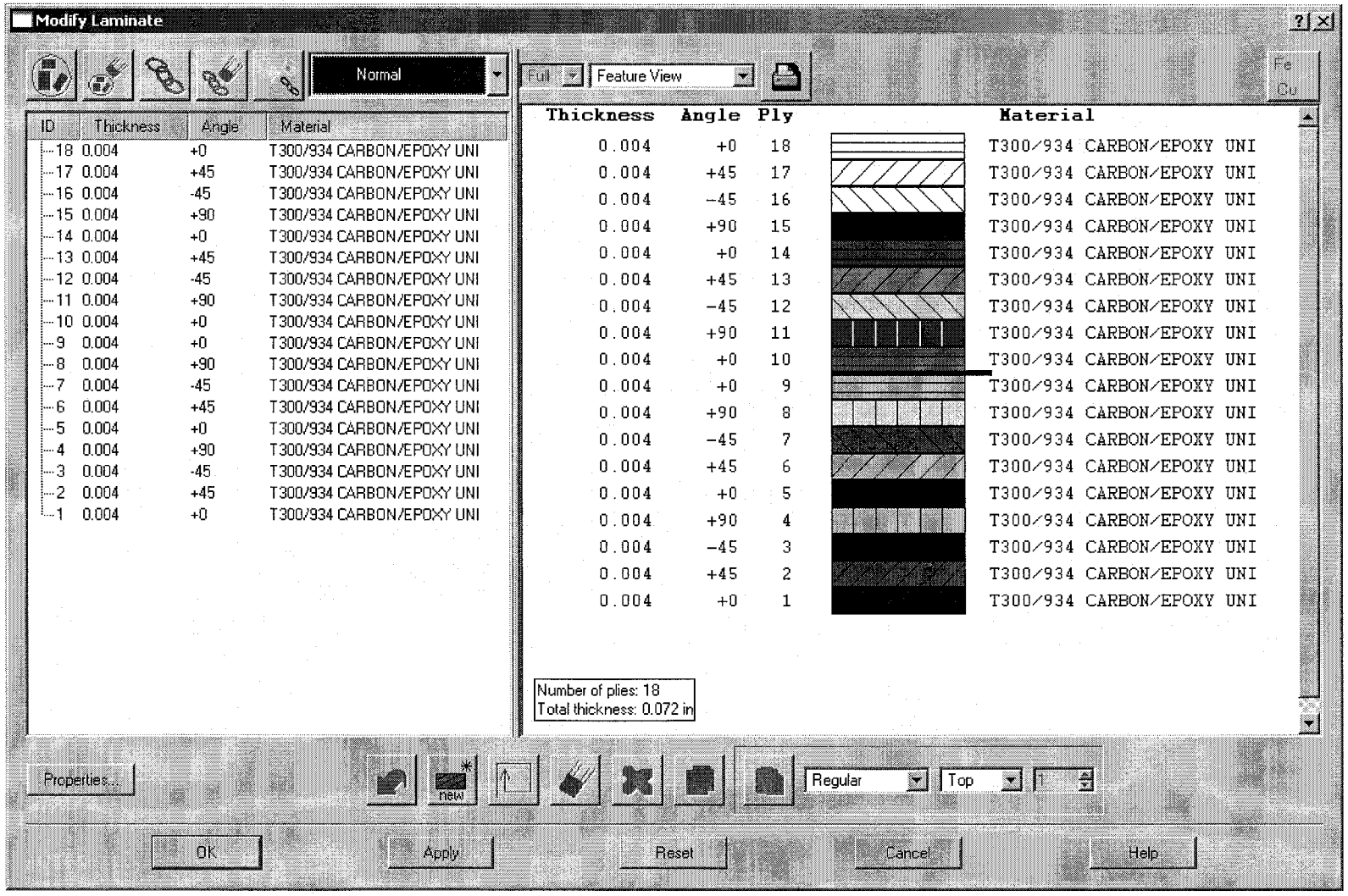
Laminate Materials | PLY Material IDS | angles & thk | MODEL_IMAGES | 101 | 102 | 201 | 202 | 301 | 30

Ready NUM

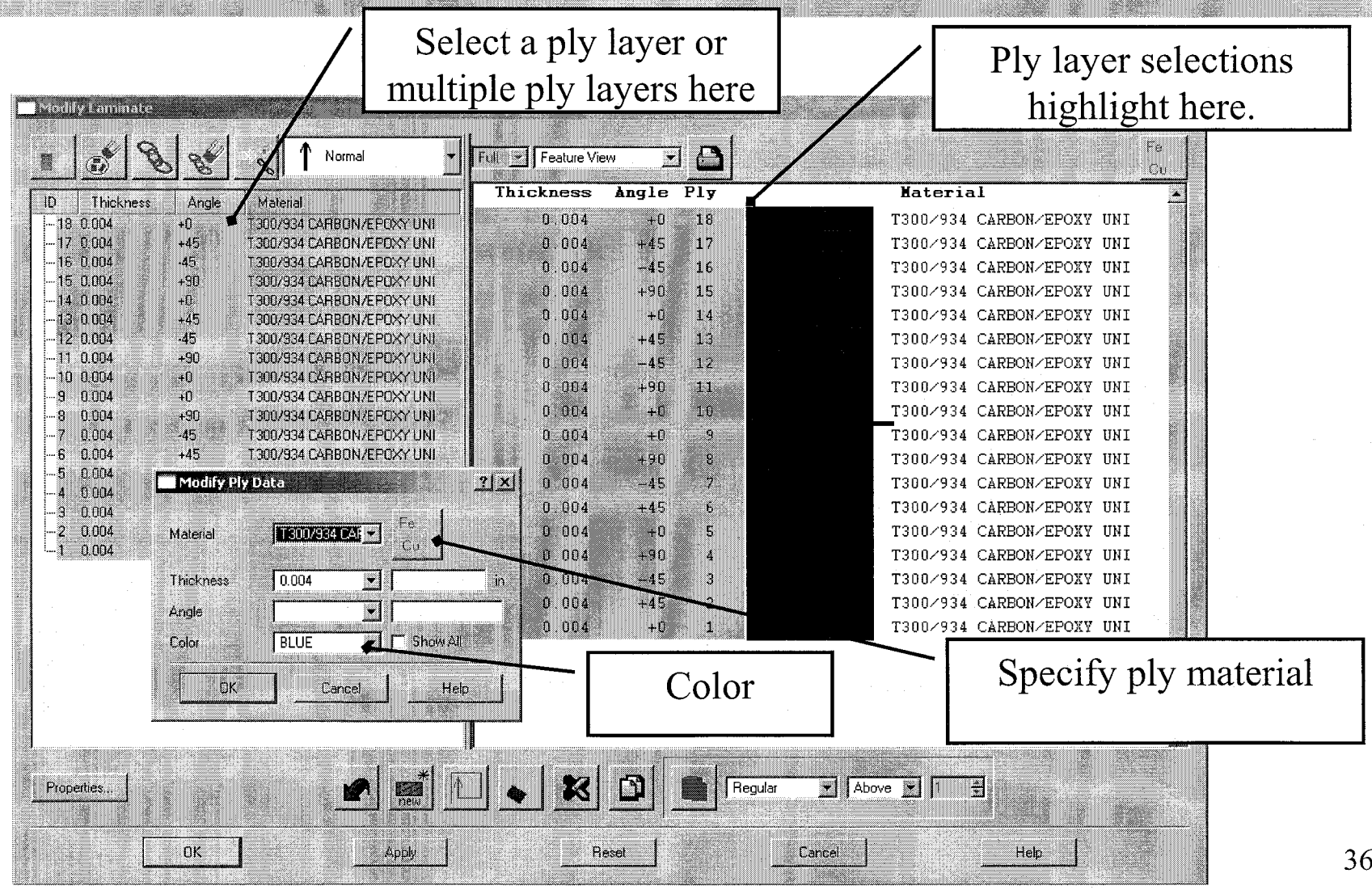
Excel worksheets can be useful to define and review PCOMP cards, with the use of user Visual Basic Macros, they can be written out to an open FEMAP model or Nastran.

When you define or keep track of the materials in an Excel spreadsheet, you can also use Visual Basic Macros to program A,B,D matrix calculations.

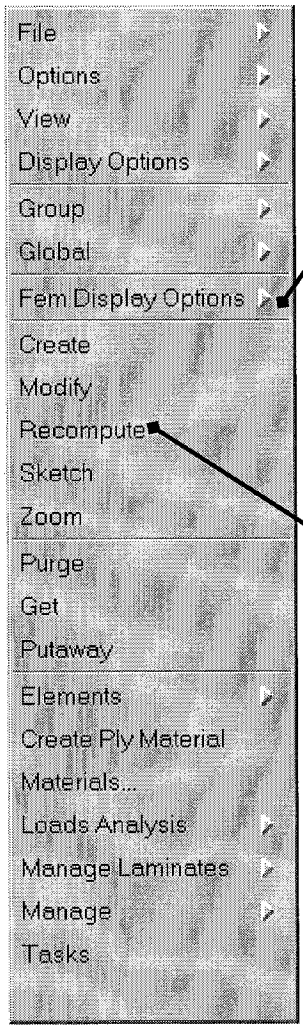
(1) I-deas 11 Modify Laminate Form for Viewing/Editing Laminates



I-deas 11 Forms for Ply Modifications, Easily Select and Change Ply Data

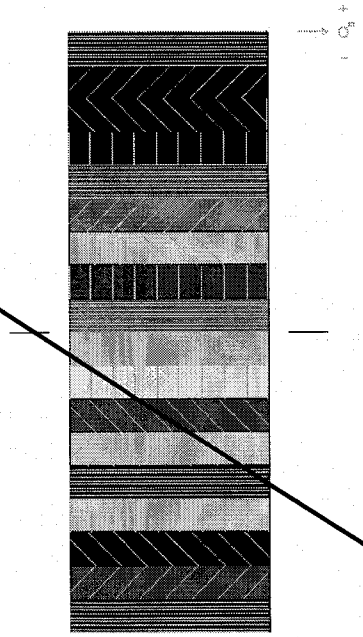


Calculate A,B,D,S Matricies and Display to Screen Using I-deas Menus



To Display Useful Laminate Matricies, use "Fem Display Options" from menus, click laminates and turn on text.

PCOMP 101



A - Matrix (Membrane)

7.52631E+05	1.86539E+05	0.0
1.86539E+05	5.91152E+05	0.0
0.0	0.0	2.03644E+05

B - Matrix (Membrane - Bending)

0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0

D - Matrix (Bending)

362.369	86.4138	12.9183
86.4138	206.488	12.9183
12.9183	12.9183	93.8029

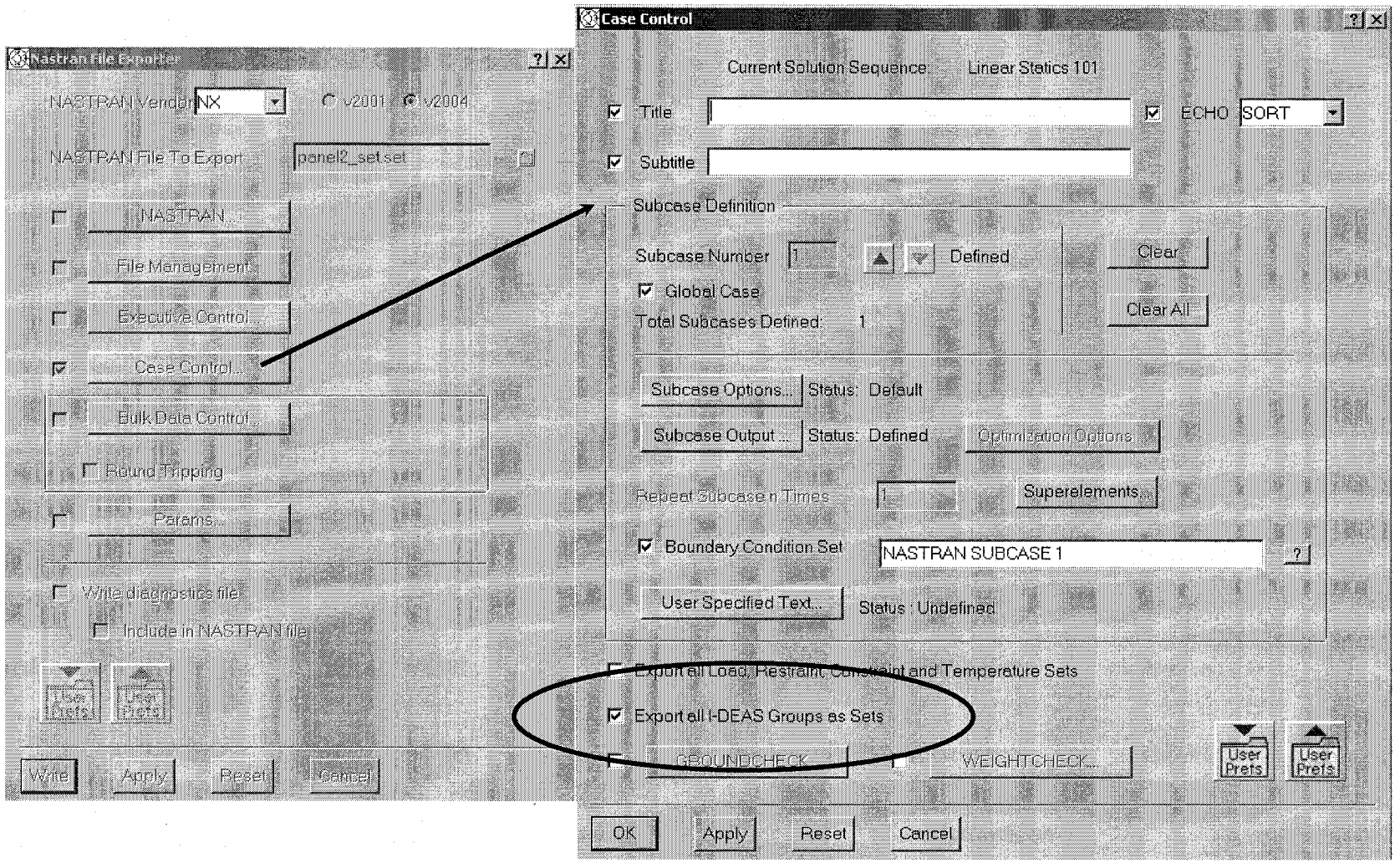
S - Matrix (Transverse Shear)

19092.5	-364.534
-364.534	14759.6

Laminate thickness = 0.07200 in

When loading Nastran data, be sure to "recompute" first, then use "Sketch" from menu.

(2) Export useful I-deas Groups as Sets
Sets Can Be Used to Organize Output Data as Separate .op2 Files From Restarts



(3) Use NX Nastran to Solve for Ply Stresses
Brief Annotated Descriptions of Nastran Deck

```
$*  FILE MANAGEMENT
$ Change master and database file names for restart
ASSIGN MASTER='glcm_040305.MASTER', DELETE
ASSIGN DBALL ='glcm_040305.DBALL',  DELETE
$ Uncomment following two lines for a restart
$ASSIGN RESULT='glcm_040305.MASTER'
$RESTART LOGICAL=RESULT
$*  EXECUTIVE CONTROL
SOL SESTATIC
CEND
$*  CASE CONTROL
TITLE    = GENERIC LAMINATED COMPOSITE MODEL
SUBTITLE = Static Load Analysis
ECHO     = SORT
$*
$* GLOBAL CASE
$*
SPC = 1
DISPLACEMENT=ALL
$Example of stress recovery set, for restart for set 1
$include 'sets\set_01.set'
$STRESS(PLOT,PRINT) = 1
$
SUBCASE 1
  LABEL = 60.00 G X LOAD
  LOAD  = 1
$
SUBCASE 2
  LABEL = 60.00 G Y LOAD
  LOAD  = 2
$
SUBCASE 3
  LABEL = 60.00 G Z LOAD
  LOAD  = 3
```

Specify new files here if restarting.

Uncomment these lines to restart by pointing to an existing database in subsequent runs this way.

Uncommenting this set usage example on a restart can be used to limit output to a specific model region or data chunk. This can be useful for failure calculations to limit domain to a specific "part" or useful for large models and easily scripted.

(3) Use NX Nastran to Solve for Ply Stresses Brief Annotated Descriptions of Nastran Deck (cont'd)

```
$*  BULK DATA
BEGIN BULK
/,1,9999999
$  Above Line is Useful syntax for restarts,
$  replace all bulk in database.
$*
$*  PARAM CARDS
$*
PARAM   AUTOSPC YES
PARAM   GRDPNT         0
PARAM   K6ROT   100.0000
PARAM   POST          -2
PARAM   POSTEXT YES
PARAM   WTMASS  2.5900-3
$
$ 60.00 G load on whole structure
GRAV 1  0       60.00   386.1   0.0     0.0
GRAV 2  0       60.00   0.0     386.1   0.0
GRAV 3  0       60.00   0.0     0.0     386.1
$
$ Include files for model
INCLUDE 'glcm_cords_01.blk'
INCLUDE 'glcm_grids_01.blk'
INCLUDE 'glcm_elems_01.blk'
INCLUDE 'glcm_matprop_01.blk'
$*
$*  RESTRAINT CARDS
$*
SPC             1     552  123456     0.0
SPC             1    1098  123456     0.0
SPC             1    2863  123456     0.0
SPC             1    2868  123456     0.0
$*
ENDDATA
```

One way to make sure new bulk data is being supplied whether restarting or not is to remove all lines in database with current bulk.

60 g static load applied in 3 orthogonal model directions, for example.

Include files is a useful way to make the nastran deck easy to document and read as well as version model changes.

Notes on Custom Analysis with NX Nastran

- DMAP (Direct Matrix Abstraction Program)
- Other Nastran Interfaces
  - Text input (.dat, .blk)
  - Text output (.pch, .f06)
  - Binary Results Files (.op2)
  - Database Files (.xdb)
- Case 2 Example read specific .op2 file datablocks and records of interest to produce custom analysis capabilities.
  - Details are out of presentation scope.
  - Basically the .op2 file is scanned to identify locations of blocks of interest. Records of specific blocks are then read to construct useful and efficient user data-structures for sorting, failure calculations, and formatting.
  - Significant documentation of the block names and their contents can be found from the DMAP Programmer Reference.

(4) Define Failure Methods and Allowable Data With a Simple Commented Text File - Excel Was Used for this Purpose

Comments

Ply Material Failure Methods, and Allowable Data

```
$        Example allowable file for Plyable.
$        Current methods available are TSAI-WU, VM, IL, or NONE
$        TSAI-WU, checks TSAI-WU in-plane failure criteria and interlaminar if interlaminar allowable is specified
$        VM checks Von Mises in plane using tensile allowable (X) only (isotropic) and interlaminar if interlaminar allowable is specified
$         IL checks Interlaminar failure only
$         NONE disables failure index calculations for that ply material
$        Allowable units are psi
```

$				X1t	X1c	X2t	X2c	S12	Sil	
$Card	ID	Description	Method	Tensile Allow (X)	Compressive Allow (X')	Tensile Allow (Y)	Compressive Allow (Y')	S	Sil	Fxy*
PMATA	1001	T300/934 Carbon/Epoxy Uni	TSAI-WU	1.91E+05	1.77E+05	6.24E+03	2.44E+04	6.96E+03	1.45E+04	-0.5
PMATA	1002	GY70/934 Carbon Epoxy Uni	TSAI-WU	8.54E+04	7.12E+04	4.26E+03	1.42E+04	7.12E+03	1.45E+04	-0.5
PMATA	1003	Kevlar 49/Epoxy Uni	TSAI-WU	1.86E+05	4.86E+04	4.35E+03	2.29E+04	7.11E+03	1.45E+04	-0.5
$	Other allowable examples									
$PMATA	1004	glue	VM	1.00E+03						
$PMATA	1005	ply for interlaminar failure onl	IL						1.00E+03	
$PMATA	1006	other ply to be ignored	NONE							

What is XML?

- XML stands for E**X**tensible **M**arkup **L**anguage
- XML is language similar to HTML but it was designed to describe data and not provide formatting
- XML tags are not predefined, they must be created
- Content in an XML document can be described by an XML schema - which is also an XML document

What is XML Spreadsheet?

- To get started, make a simple worksheet in Excel, then save it as .xml (XML Spreadsheet).
- The XML spreadsheet contains the raw column data as well as formatting data - this data is interpreted by Excel.
- It allows the ability to describe many features that are in a spreadsheet.
- Microsoft has a published XML Reference Schema.

  http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnexcl2k2/html/odc_xlsmlinss.asp
  http://www.microsoft.com/downloads/details.aspx?familyid=fe118952-3547-420a-a412-00a2662442d9&displaylang=en

(5) Use Plyable to Process Ply Stresses and Apply Failure Methods to Calculate Strength Ratios and Create Useful Analysis Summaries

```
rem summarize_plys.cmd
rem Kurt Knutson, 04/03/05
rem Create multiple document view summaries of ply stress/strength ratios from .op2 file.
rem Command Line User Code Allows Easy Scripting for Processing Multiple Restart Files.
rem
plyable.exe glcm_set20 -sa glcm_plyallow -m=11 -uf=1.0
plyable.exe glcm_set20 -sa glcm_plyallow -m=13 -uf=1.0
plyable.exe glcm_set20 -sa glcm_plyallow -m=14 -uf=1.0
plyable.exe glcm_set20 -sa glcm_plyallow -m=5 -uf=1.0
```

Command line switch for type of processing

Allowable File

Load factor needed to get from loads applied in FEM to ultimate loads. If ultimate loads already applied, use 1.0.

Processing output method, controls document type, view, and style

.op2 file with ply stresses

Scriptable Executable.

Example Output Direct From NX Nastran .op2 File to Excel Via XML Spreadsheet Ply Material Failure View

Predefined Equations

Hidden Columns Have More Details

Load Factor

Microsoft Excel - glcm_set2C_11.xml

S3 =R3/T1

	A	B	C	D	E	K	M	N	P	R	S	T	U
1	Ply Material Summary										Load Factor:	1	
2	Mat	Ply	Pcomp	Case	Elem	Method	SR	IL ply	SRil	SRmin	SRmin Ult.	Failure Mode	
3	1001	36	302	3	3555	TSAI-WU	0.87	35	1145.52	0.87	0.87	TSAI-WU	
4	1002	4	701	3	2669	TSAI-WU	1.35	5	160.94	1.35	1.35	TSAI-WU	
5	1003	18	901	1	4985	TSAI-WU	1.83	17	104.53	1.83	1.83	TSAI-WU	
6													

Material_Summary / Material_Allowables

Minimum Strength Ratio. Conditional Formatting.

Ply Material ID, Ply number, PCOMP ID, Load Case, Element for Strength Ratio Summary

Failure Methods and Allowable data output from analysis.

Example Output Direct From NX Nastran .op2 file to Excel Via XML Spreadsheet PCOMP Failure View

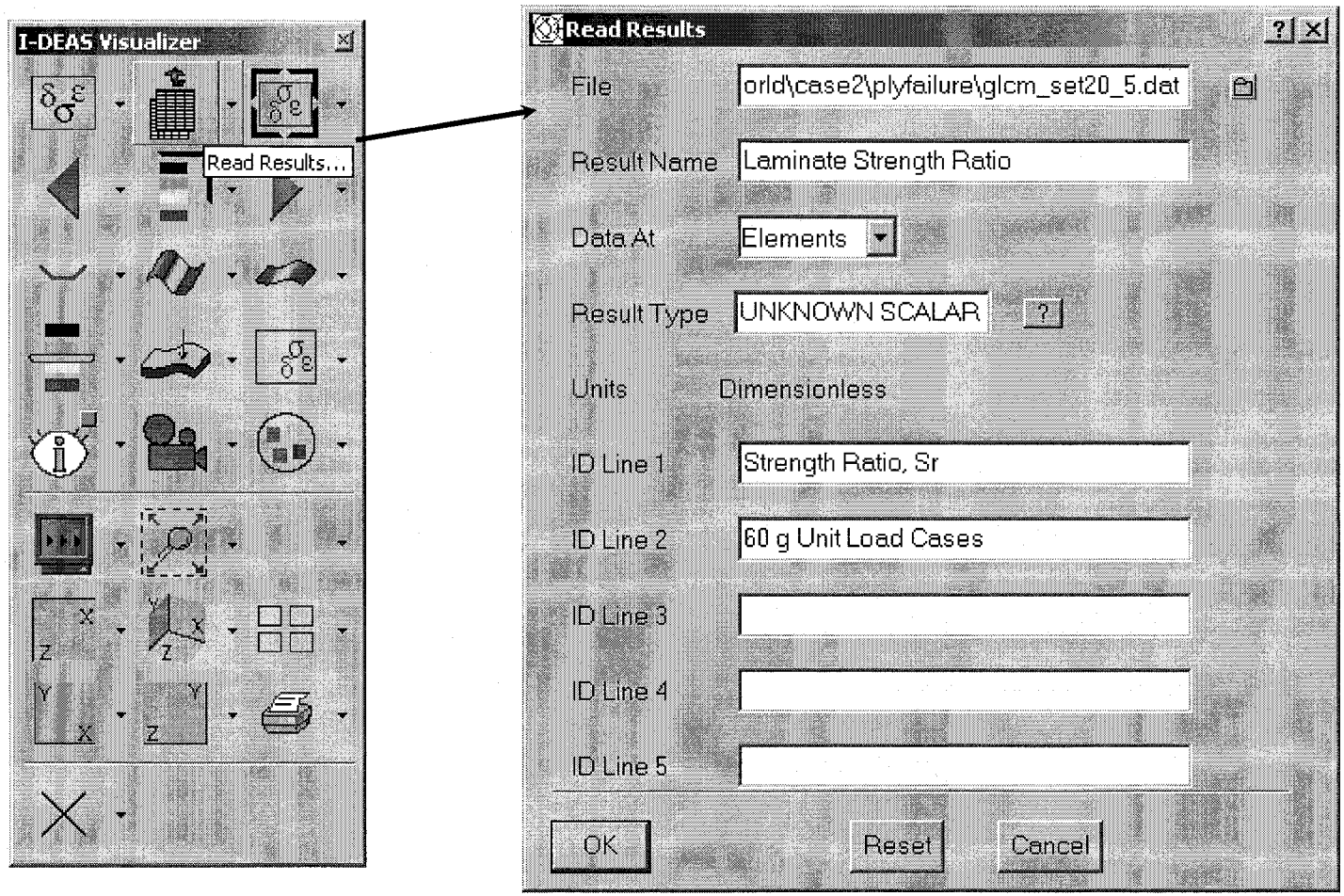
Microsoft Excel - glcm_set20_13.xml

PCOMP	101				PLY STRENGTH RATIOS						Load Factor:	1
Layer	Material ID	Thickness (in)	Angle (°)	Case	Elem	Method	SR	IL ply	SRil	SRmin	SRmin Ult.	Failure Mode
1	1001	0.00400	0	3	377	TSAI-WU	2.94	2	4939.51	2.94	2.94	TSAI-WU
2	1001	0.00400	45	3	379	TSAI-WU	3.73	3	989.10	3.73	3.73	TSAI-WU
3	1001	0.00400	-45	3	375	TSAI-WU	4.74	4	1211.16	4.74	4.74	TSAI-WU
4	1001	0.00400	90	1	391	TSAI-WU	6.53	5	397.30	6.53	6.53	TSAI-WU
5	1001	0.00400	0	3	377	TSAI-WU	5.50	6	502.28	5.50	5.50	TSAI-WU
6	1001	0.00400	45	3	379	TSAI-WU	7.86	7	315.96	7.86	7.86	TSAI-WU
7	1001	0.00400	-45	3	375	TSAI-WU	12.07	8	480.38	12.07	12.07	TSAI-WU
8	1001	0.00400	90	1	391	TSAI-WU	22.78	9	266.73	22.78	22.78	TSAI-WU
9	1001	0.00400	0	3	378	TSAI-WU	42.09	10	327.26	42.09	42.09	TSAI-WU
10	1001	0.00400	0	2	408	TSAI-WU	56.65	9	694.15	56.65	56.65	TSAI-WU
11	1001	0.00400	90	2	423	TSAI-WU	25.84	10	374.14	25.84	25.84	TSAI-WU
12	1001	0.00400	-45	3	405	TSAI-WU	12.01	11	353.89	12.01	12.01	TSAI-WU
13	1001	0.00400	45	3	409	TSAI-WU	8.58	12	464.54	8.58	8.58	TSAI-WU
14	1001	0.00400	0	3	407	TSAI-WU	5.67	13	537.51	5.67	5.67	TSAI-WU
15	1001	0.00400	90	2	423	TSAI-WU	7.08	14	557.27	7.08	7.08	TSAI-WU
16	1001	0.00400	-45	3	405	TSAI-WU	4.50	15	838.41	4.50	4.50	TSAI-WU
17	1001	0.00400	45	3	409	TSAI-WU	3.96	16	1615.00	3.96	3.96	TSAI-WU
18	1001	0.00400	0	3	407	TSAI-WU	2.97	17	9798.67	2.97	2.97	TSAI-WU

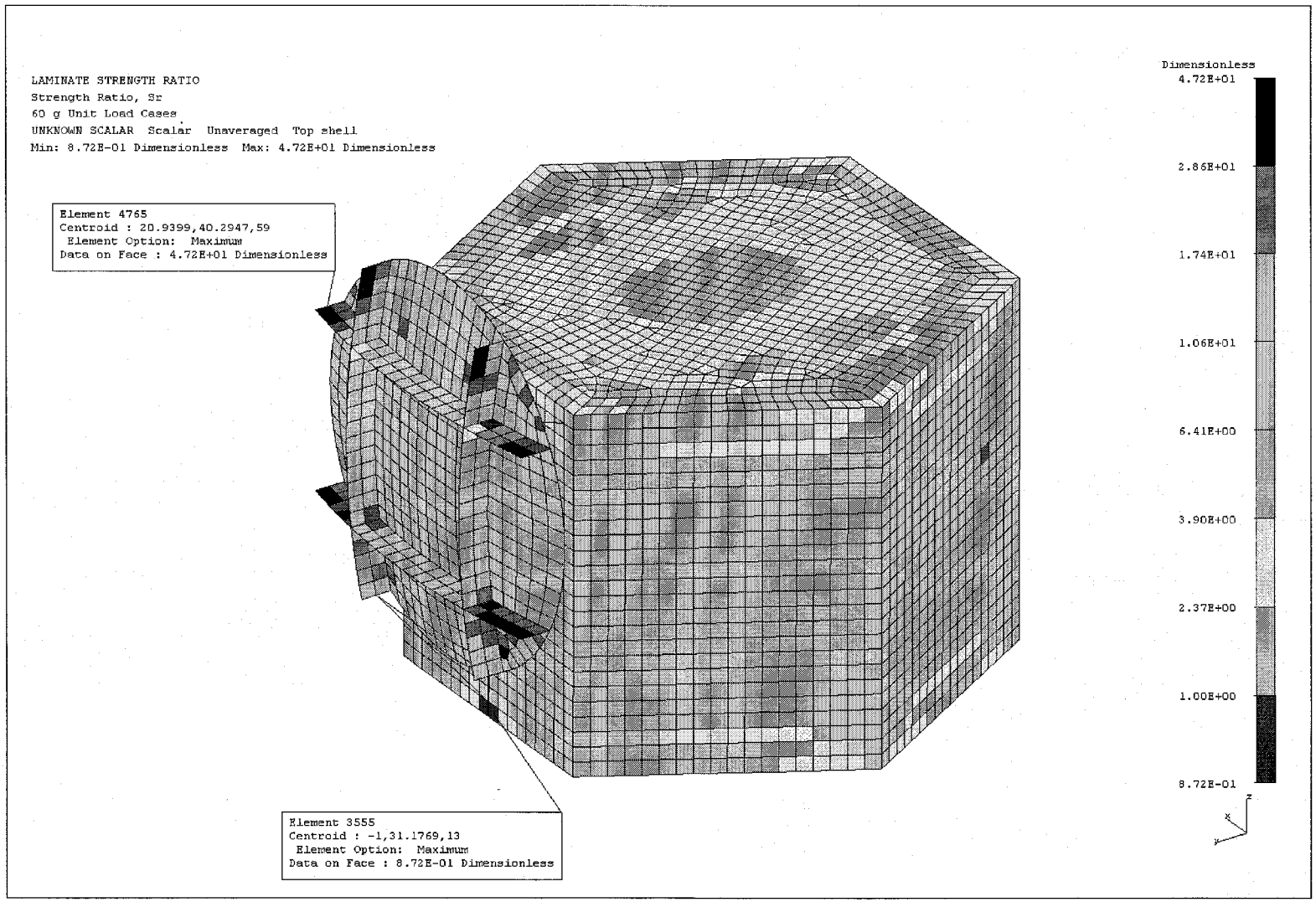
PCOMP Stacking Sequence and Minimum Strength Ratio for Each Ply

Each PCOMP in .op2 file set written to a worksheet

(6) Read Minimum Strength Ratio into I-deas Visualizer



Minimum Strength Ratios Contours Viewed in I-deas for Case 2 Example - Minimum Strength Ratio for All Laminates, Plies, and Loads



Interactive Demonstration With XML Spreadsheet from Case Example Results Using Excel

- Generated XML Spreadsheet output from example contains:
  - Predefined equations for load factor scaling.
  - Multiple worksheets to organize data, summary of allowable and failure methods.
  - Automated printing and page setup to optimize page use for printing long stacking sequences.
  - Document properties and automated footers.
  - Hidden columns with detailed data such as stress state associated to minimum strength ratio, etc.
  - Conditional formatting to highlight regions not passing failure criteria.

Notes on XML Spreadsheet Implementation Versus Traditional or Other XML Approaches for Custom Analysis Tasks

- Current XML Spreadsheet approach as described here requires list or selection of useful predefined formats.
- Advantages / Disadvantages
  - Efficient processing direct from large binary data and data reduction to summaries in useful formats without intermediate steps.
  - New levels of analysis documentation and automation can be made available.
  - Direct loads into Excel which is very useful for table summaries and graphing.
  - A developer needs to decide what views and format options are useful.
  - Solution is limited to Windows, Excel, unless XML Spreadsheet is transformed.
- Alternative to approach may be to provide user options for many common format options, or generate .xml data and provide .xml schemas and use transforms to get different data summaries and uses

Summary of Case 2 Benefits and Useful Software Features

- NX Commercial analysis software features leveraged for custom tasks.
  - I-deas for
    - Meshing and model creation, Materials, Laminate Review/Modification.
    - Quickly creating groups/recovery sets.
    - General post processing, displacements, stress and strength ratio contours.
  - NX Nastran for solving / restarts.
    - Restart to output various regions of interest to .op2 files gives an interface to ply stress data that is very scalable. Only need to read regions in a particular set.
- Use of the commercial software features allowed quick creation of a tool to fill specific laminate composite analysis needs.
- Reading the .op2 file datablocks with plyable offered significant benefits:
  - Solve model without allowable definitions embedded in FE code.
  - Define failure criteria of interest per ply usage rather than for PCOMP.
  - Use Strength Ratio rather than FEA Failure Index.
  - Quickly and easily summarize results in various views of interest.
    - Formatted Excel Material and PCOMP views as well as I-deas contour plots.
    - Summary of allowable data used in failure criteria.
    - Documentation of the equations and methods applied as well as stress states.
    - Scale loads in spreadsheet to see the effects at important ply locations.

Suggestions for Future Direction Software NX Features of Interest, Case 2.

- Laminate strength ratio calculations with NX Nastran.
- Customized XML spreadsheet approach offers some substantial customized formatting and increased insight into analysis methods in final documents for the customized approach. Interest for these approaches in NX?
  - NX Nastran results sent to .XML as an output option? For example, how about an ability for user to directly request specific formatted SPC or Bar force summaries for Excel.
  - User ability to direct specific output and customize results presentation and formatting?
- Recognize a need for easy, efficient, post-processing commands that access specific datablocks and allow users to interact with FE output in mathematical expressions for small or large models and create custom formatted and graphical summaries.

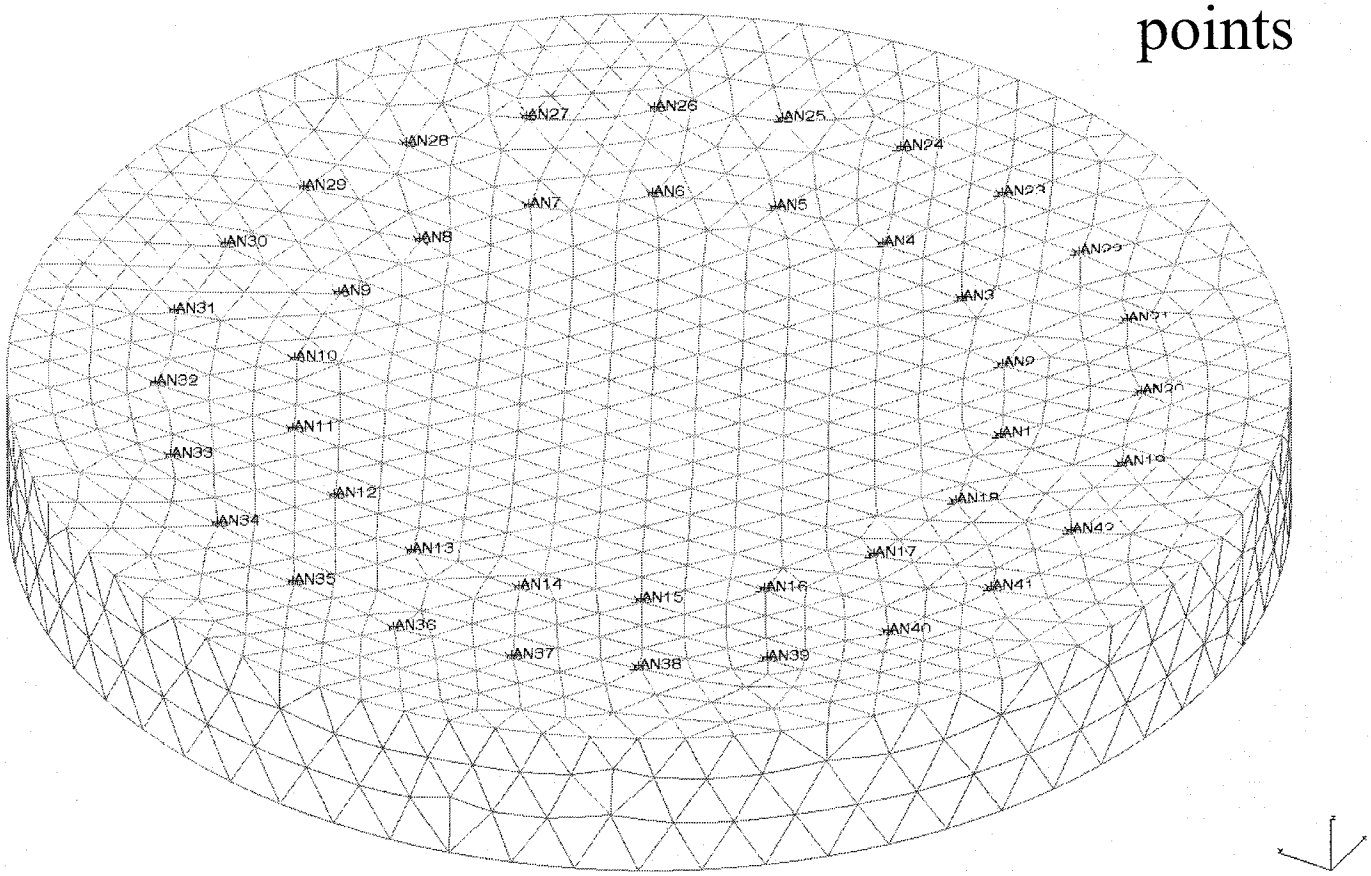
Case3: Optic Metric Evaluation Example.

- Case 1 Presented a Generic Mirror Model.
- Now same model is solved for displacements from a static case.
- Specific mirror face point displacements at ray mesh points are desired to be captured and organized into a vector, {*Nd*} and used for matrix multiplication with a predefined optic transformation matrix, [C].

$$[OpticMetric] = [C]\{Nd\}$$

Case 3: Generic Example Model With Specific Nodal Points for Displacement Vector Recovery.

42 “ray mesh” points



Example of Optics Evaluation.

- For Example of 42 Rays and rays parallel to optical axis:

$$\begin{Bmatrix} OPD1 \\ OPD2 \\ \dots \\ OPD42 \end{Bmatrix} = \begin{bmatrix} -2 & & & \\ & -2 & & \\ & & \dots & \\ & & & -2 \end{bmatrix} \begin{Bmatrix} DZ1 \\ DZ2 \\ \dots \\ DZ42 \end{Bmatrix}$$

- [C] can be computed by optical analysis tools using geometric optics assumptions for small displacements appropriate for linear structural analysis, filled with constants, computed in undeformed geometry.
- Candidate Optical Metrics
  - OPD – useful for interferometry
  - Spot Diagrams – Ray lateral motion in deflection => image quality.

Case 3: Discussion of Optic Metric Evaluation Methods (solving with I-deas)

- Desire to easily access result components for use with matrix math calculations directly with FE post processing tools.
- All the data exists already in the FE Model except the C matrix. The idea would be to easily load a user specified matrix and perform the matrix calculations and display/store them too.
- Nastran DMAP could be used to do this task.
- Challenges with I-deas hypermatrix math on FE model for a direct method.
  - We couldn't see how to do the custom math easily in the solve sequence.
  - We didn't see an existing function to reduce displacement data to components and construct the nodal vector.
  - Trying hypermatrix examples we found it difficult to see how to store calculation data on the FEM.
  - We hope to revisit this technique in the future.
- Other non-direct methods to evaluate optic metrics include:
  - Use I-deas visualizer to dump data or excel text files that can be read into Matlab or transferred to optics codes.
  - Use of a custom or commercial code to translate universal file data to Matlab (IMAT).

Related Subject References

- TMG Mapping:

  [1] TMG Thermal Analysis User's Guide, "Mapping Temperatures to Another Model".

- XML & XML Spreadsheet:

  [2] http://www.w3schools.com/xml/default.asp
  [3] http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnexcl2k2/html/odc_xlsmlinss.asp
  [4] http://www.microsoft.com/downloads/details.aspx?familyid=fe118952-3547-420a-a412-00a2662442d9&displaylang=en

- NX Nastran .op2 file block descriptions:

  [5] NX Nastran 3.0 Documentation, DMAP Programmer's Guide.

- Composite Failure Analysis:

  [6] Theory of Composites Design, Stephen W. Tsai

  [7] Engineering Mechanics of Composite Materials, Isacc M. Daniel and Ori Ishai.

- Honeycomb sandwich failure and background:

  [8] Bruhn, Analysis and Design of Flight Vehicle Structures, Chapter C12, "Sandwich Construction and Design"

  [9] Mil-Hdbk-23A, "Structural Sandwich Composites"

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  - Paul Rapacz
  - Georg Seibes
- Other
  - Jamie Laflen

Questions?