Enhancement of the Probabilistic CEramic Matrix Composite ANalyzer (PCEMCAN) Computer Code

Ashwin Shah
Sest, Inc., North Royalton, Ohio

February 2000

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Forward

This report represents a final technical report for Order No. C-78019-J entitled "Enhancement of the Probabilistic Ceramic Matrix Composite Analyzer (PCEMCAN) Computer Code." The scope of the enhancement relates to including the probabilistic evaluation of the D-Matrix terms in MAT2 and MAT9 material properties card (available in CEMCAN code) for the MSC/NASTRAN. Technical activities performed during the time period of June 1, 1999 through September 3, 1999 have been summarized, and the final version of the enhanced PCEMCAN code and revisions to the User's Manual is delivered along with. Discussions related to the performed activities were made to the NASA Project Manager during the performance period. The enhanced capabilities have been demonstrated using sample problems.

Summary of Activities

Previous version of the PCEMCAN computer code was received from the NASA Project Manager. PCEMCAN code was modified to include the following additional capabilities:

(i)   Probabilistic evaluation of the D-Matrix (stiffness matrix) terms related to the plate element for the MSC/NASTRAN MAT2 card as available in the CEMCAN code.

(ii) Probabilistic evaluation of the D-Matrix (stiffness matrix) terms related to the solid element for the MSC/NASTRAN MAT9 card as available in the CEMCAN code.

Modifications to the PCEMCAN computer code for the above additional capabilities were made to obtain cumulative distribution function of the respective MAT9 and/or MAT2 card terms as well as their respective sensitivities to the input random variable terms. The input format to the PCEMCAN code has been retained according to the previous version except that the symbols for MAT2 and MAT9 card terms have been included in the probabilistic output definition. Revised Table 5.1.3.3.1 of the PCEMCAN User's Manual (Reference 1), listing all the symbols for which probabilistic evaluation can be performed, is given in Appendix A. Since the input format to the code, the execution procedure and the output file format have not changed, no special training is needed for the previous users of PCEMCAN code. The probabilistic output and the CDF as well as sensitivity information are stored in the files xxx.out and xxx.mov respectively; where xxx denote the output symbol for which the evaluation is requested.

Probabilistic analyses of the (-45/45) and (0/45/-45/90)$_s$ laminates made of silicon carbide (SCS-6) fibers in a reaction bonded silicon nitride matrix has been performed in order to demonstrate the additional capabilities. The fiber volume ratio is 0.3, no voids are present and

each ply has a thickness of 0.01 in. There is an interphase with a thickness of 3 percent of fiber diameter (or approx. 4mm thick). The interfacial bonding around the fiber diameter is 1.0, indicating the perfect bond. The stress free temperature is taken as 1200°F. The composite is cooled down from this stress free temperature to room temperature (70°F), and then and then subjected to a monotonic loading in the longitudinal direction at room-temperature as shown in figure 1. The representative input files for the MAT2 and MAT9 capabilities are given in Appendix B.

Uncertainties in the fiber volume ratio, interface thickness, fiber modulus in 11 direction, matrix modulus and interface modulus with 7, 5, 5, 5 and 5 percent have been assumed with normal distribution. In each sample problem case the probabilistic evaluation of all the MAT2 and MAT9 card terms have been requested using mat2 and mat9 symbols (probabilistic evaluation of the individual terms of mat2 and mat9 cards can also be requested using symbols given in the Table in appendix A).

A typical output file containing the mean value, standard deviation, median, cumulative distribution function and the sensitivity of the random variables for the G11 term of the MAT9 card is given in Appendix C (file g11.mov).

Results for MAT2 card terms:
A cross-ply laminate, (45/45), was used to generate probabilistic MAT2 card stiffness matrix terms. Figures 2a through 10a show cumulative distribution function (CDF) for the MAT2 stiffness matrix terms PMG11, PMG22, PMG12, PMG33, PBG11, PBG33, PBG12, PMBG13 and PSG11 respectively and figures 2b through 10b show their corresponding sensitivity to the random variables. Their respective mean and standard deviations are listed in Table I. It is seen that the in-plane membrane modulii uncertainties are dominated by the matrix modulus (E_m), fiber normal modulus in 11 direction (E_{f11}), interphase thickness (t_i), interphase modulus (E_i) and the fiber volume ratio (FVR) (Figures 2b, 3b). However, E_{f11}, FVR, and E_m dominate the in plane membrane-shear (Figures 4b) uncertainties whereas E_m, E_{f11}, FVR, t_i and t_m control the out of plane modulus uncertainties (Figure 5b). Similar pattern of sensitivity is observed for the bending modulii uncertainties as well (Figure 6b through 8b). The FVR and E_{f11} dominate uncertainties in the out of plane bending modulus (Figure 9b). As expected, the plate shear is sensitive to the E_m, FVR, t_i and E_i.

Results for MAT9 card terms:
A quasi-isotropic laminate configuration was used to generate the probabilistic MAT9 card related stiffness matrix terms of a solid element. Figures 11a through 15a show CDF for the MAT9 stiffness matrix terms G11, G12, G13, G44 and G55 respectively and Figures 11b through 15b show sensitivity of these terms to the random variables. Their respective means and standard deviations are listed in Table II. E_m, E_{f11}, t_i, E_i, and FVR dominate the uncertainties in the modulii 11, 12 and 44 (Figures 11b, 12b and 15b) whereas the E_m, FVR, E_i, and t_i dominate the uncertainties in the modulii 13, 33 and 55 (Figures 13b, 14b, and 16b).

Summary

PCEMCAN computer code has been modified and upgraded to perform the probabilistic evaluation of MSC/NASTRAN MAT2 and MAT9 card terms for plate and solid element respectively. The code computes the mean, median, standard deviation, cumulative probability distribution function and sensitivities to the random variable for each of the term. The results for each term are stored in separate files. Also, the source listing of the final version of the PCEMCAN computer code, typical input data and output files have been delivered along with the report.

References

1. Shah, A.R., Mital, S.K., and Murthy, P.L.N., "PCEMCAN-Probabilistic Ceramic Matrix Composite Analyzer User's Guide, Version 1.0", NASA/TM—1998-206984, July 1998.

Table I.—Mean and Standard deviation of the MAT2 related Stiffness matrix terms.

Term symbol	Mean (mpsi)	Std. Deviation (mpsi)
PMG11	14.972	0.504
PMG22	14.972	0.504
PMG12	6.328	0.292
PMG33	8.272	0.310
PBG11	14.972	0.504
PBG12	6.328	0.292
PBG33	8.272	0.310
PMBG13	0.972	0.079
PSG11	4.322	0.204

Table II.—Mean and Standard deviation of the MAT9 related Stiffness matrix terms.

| Term symbol	Mean (mpsi)	Std. Deviation (mpsi)
G11	17.684	0.588
G12	5.088	0.173
G13	2.957	0.157
G33	11.820	0.569
G44	6.298	0.209
G55	4.322	0.204
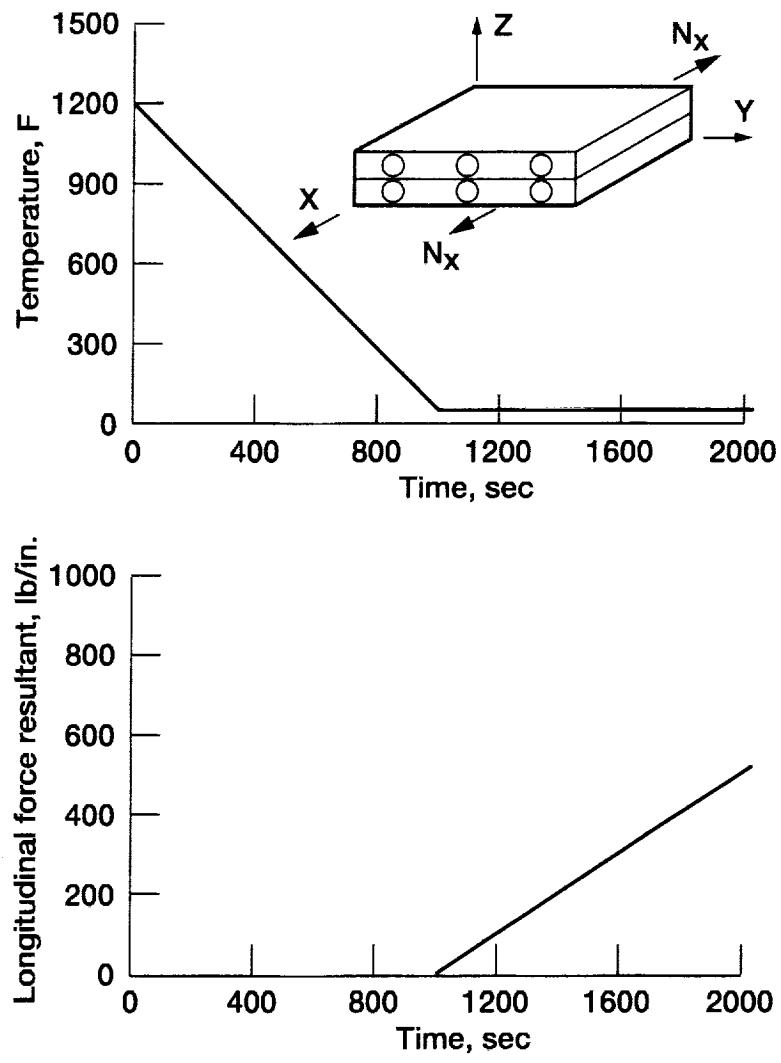
Figure 1.—Sample case loading history.
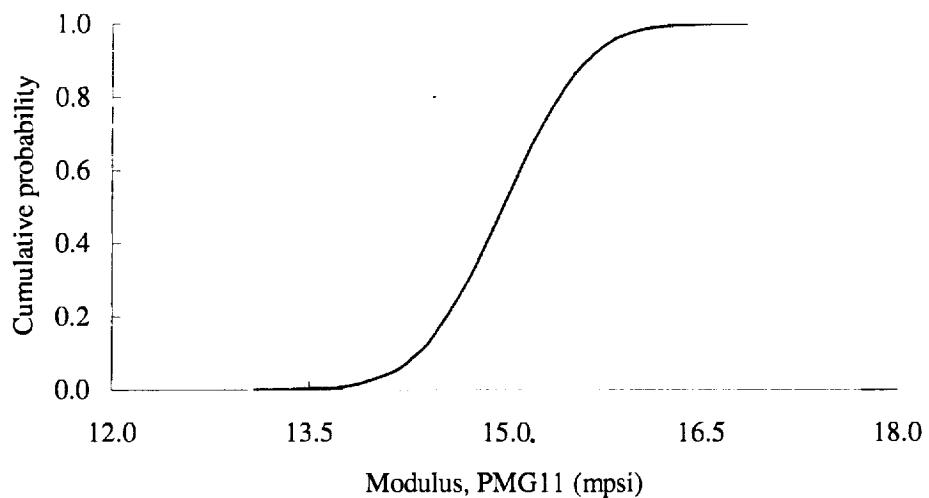
Figure 2a.—Cumulative distribution function of the plate membrane modulus 11.
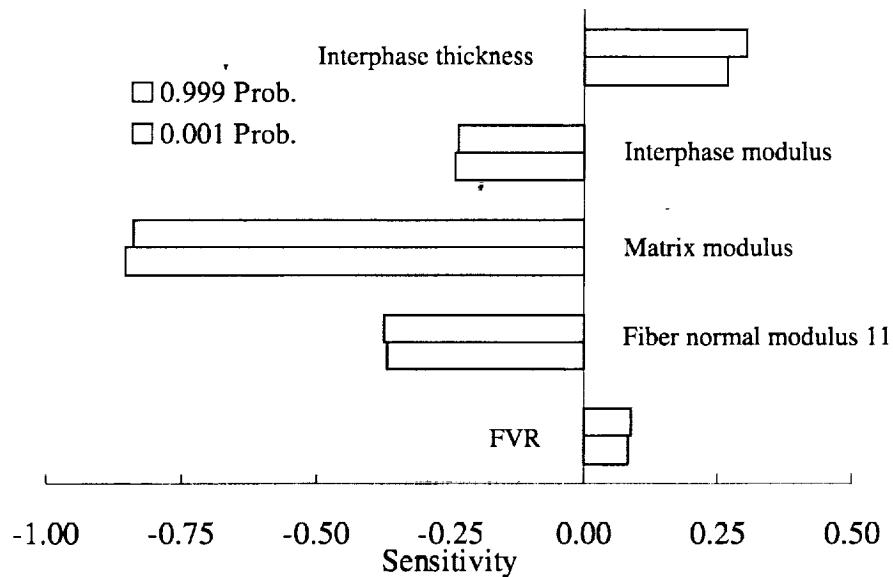

Figure 2b.—Sensitivity of plate membrane modulus 11 to the random variables.
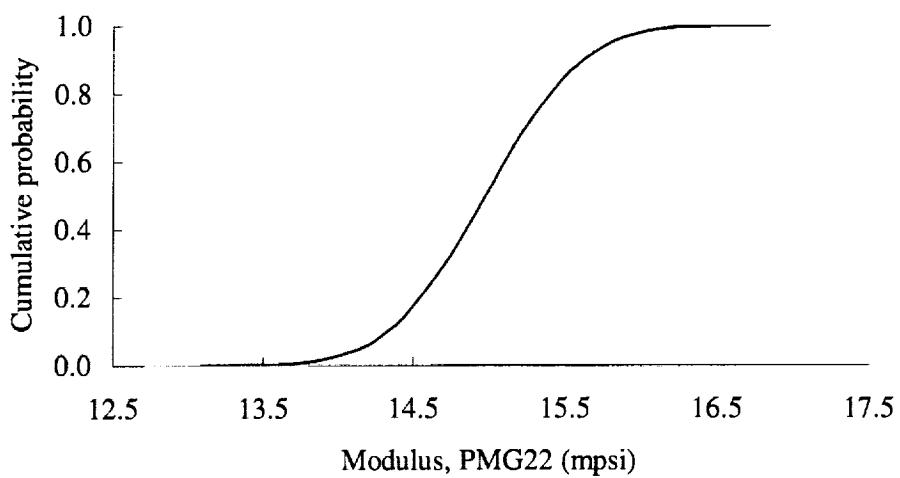
Figure 3a.—Cumulative distribution function of the plate membrane modulus 22.
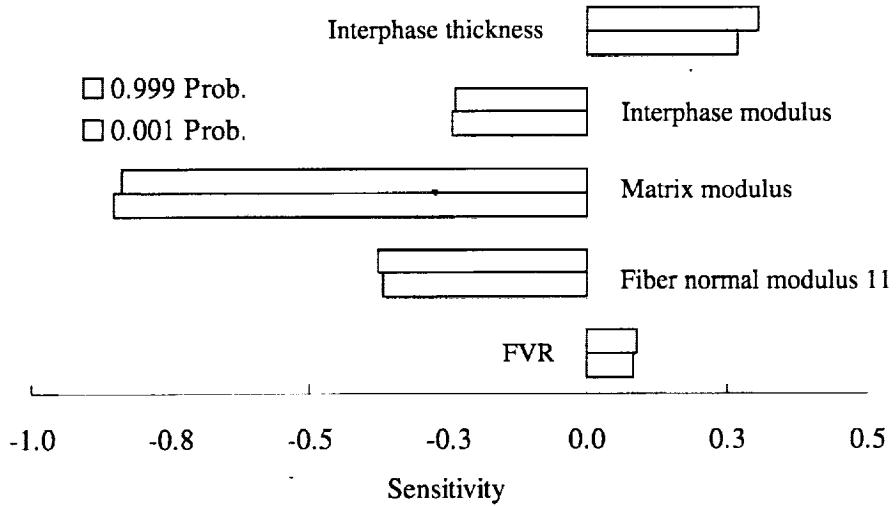
Figure 3b.—Sensitivity of plate membrane modulus 22 to the random variables.
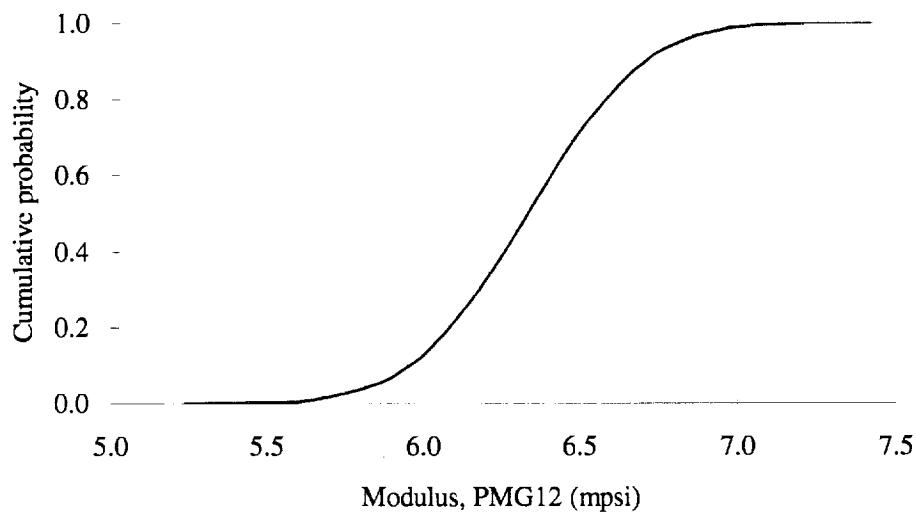
Figure 4a.—Cumulative distribution function of the plate membrane modulus 12.
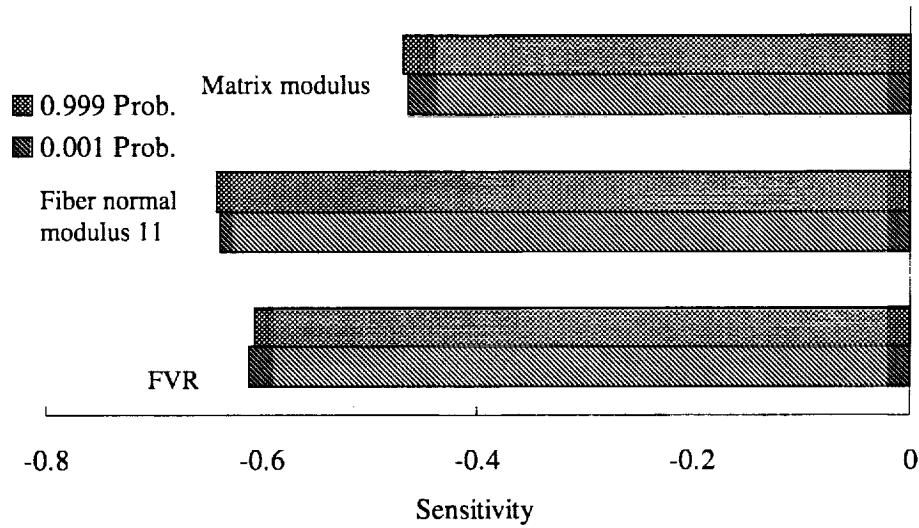
Figure 4b.—Sensitivity of plate membrane modulus 12 to the random variables.
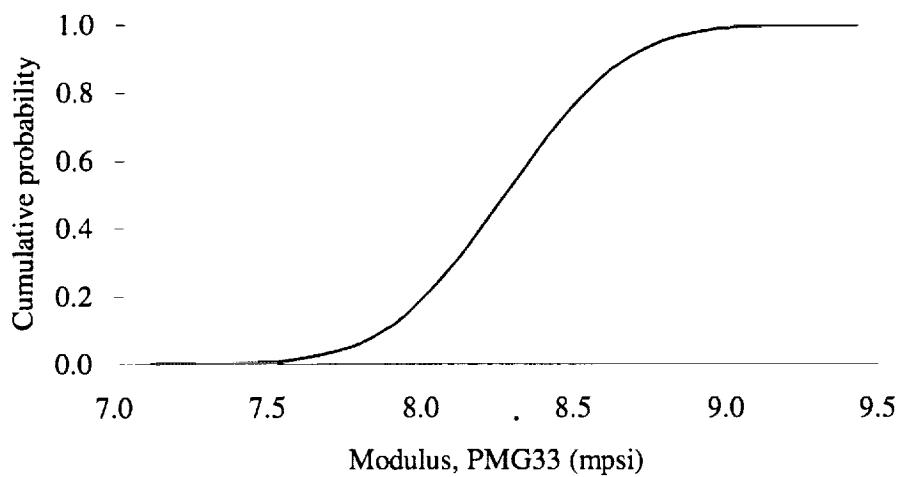
Figure 5a.—Cumulative distribution function of the plate membrane modulus 33.
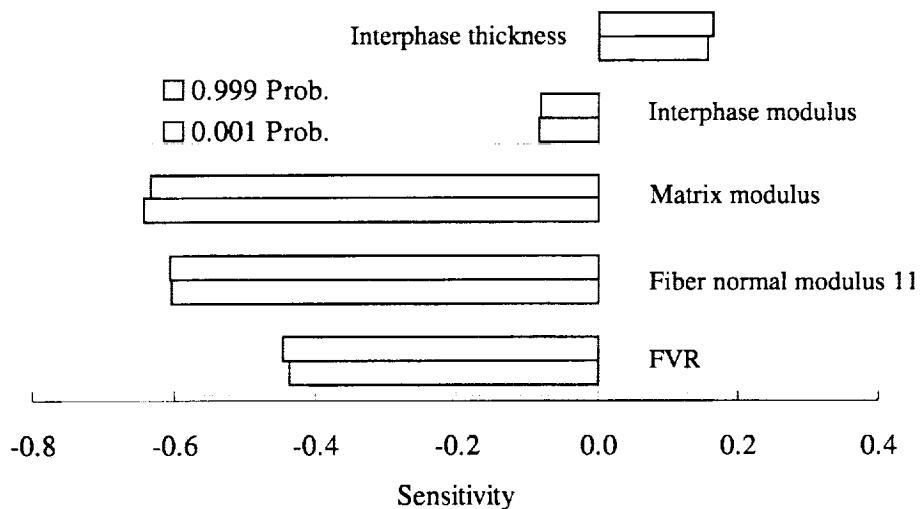
Figure 5b.—Sensitivity of plate membrane modulus 33 to the random variables.

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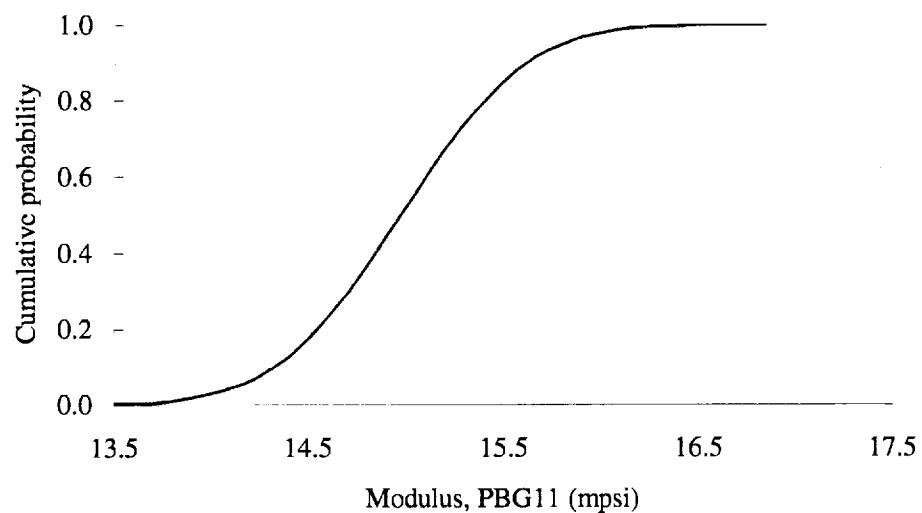
Figure 6a.—Cumulative distribution function of the plate bending modulus 11.
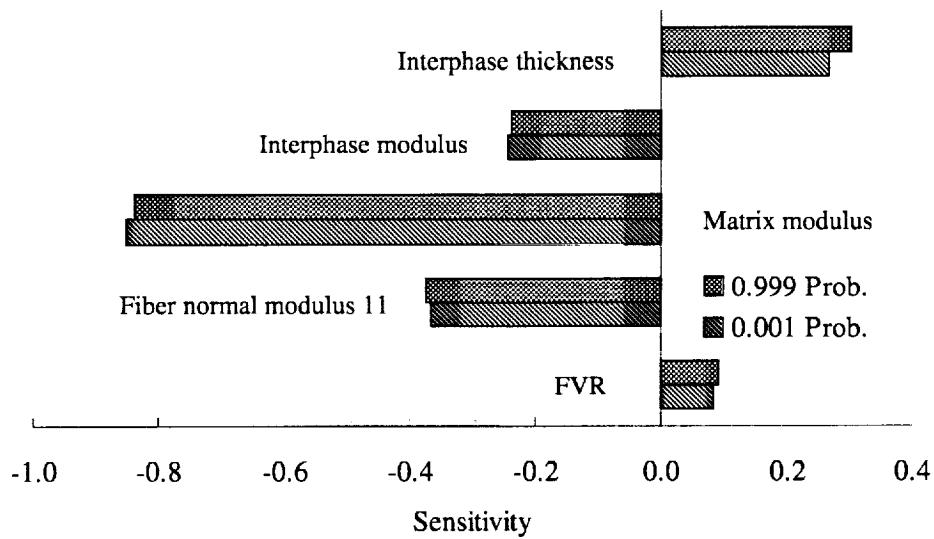
Figure 6b.—Sensitivity of plate bending modulus 11 to the random variables.
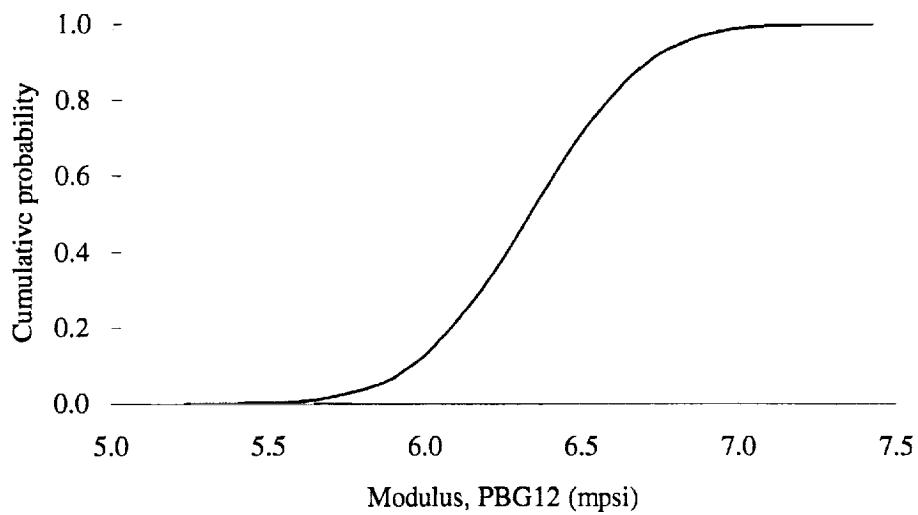
Figure 7a.—Cumulative distribution function of the plate bending modulus 12.
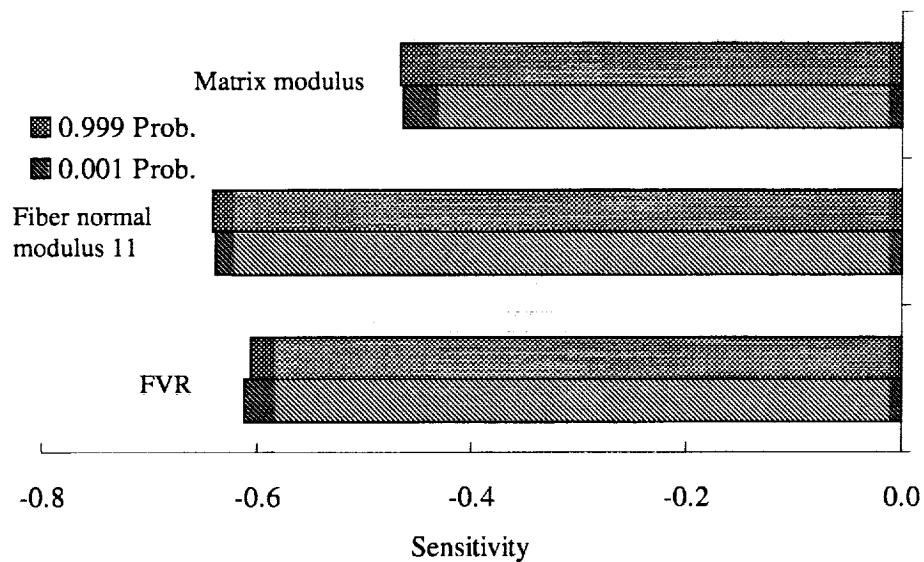
Figure 7b.—Sensitivity of plate bending modulus 12 to the random variables.
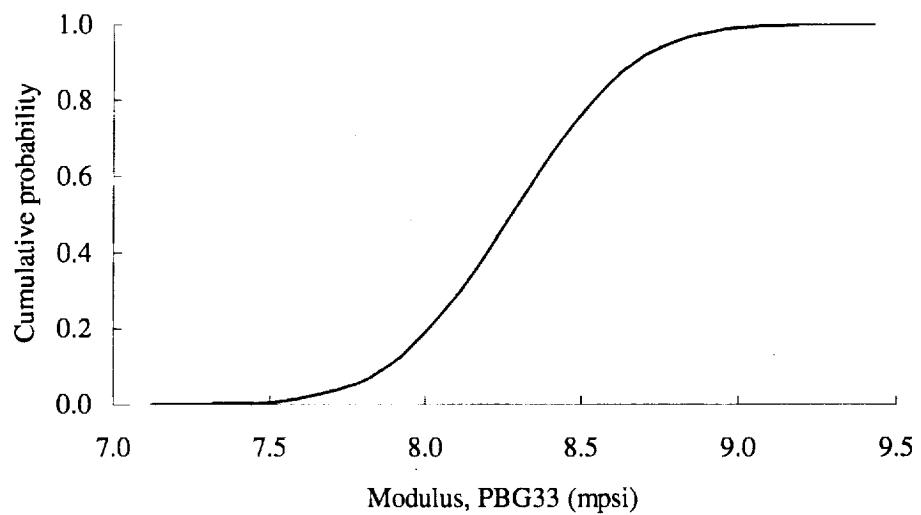
Figure 8a.—Cumulative distribution function of the plate bending modulus 33.
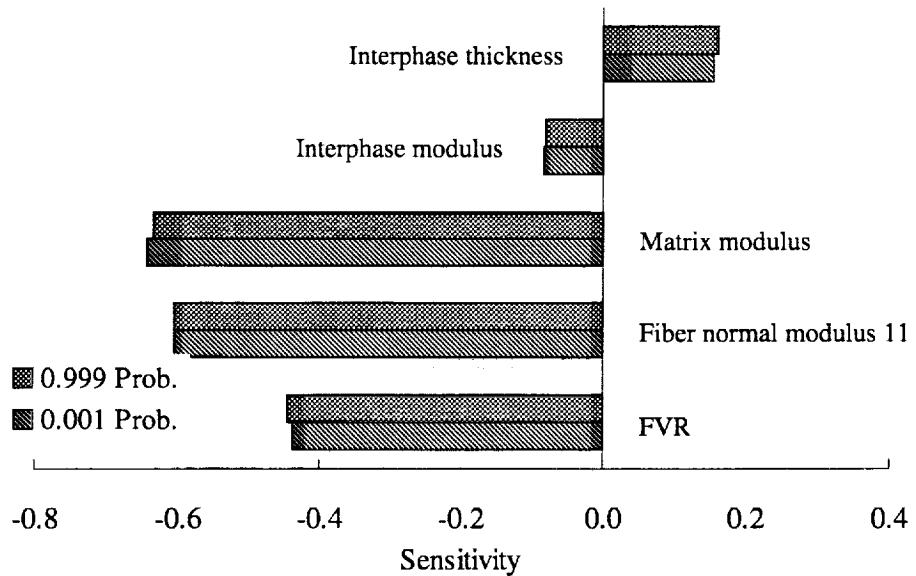
Figure 8b.—Sensitivity of plate bending modulus 33 to the random variables.
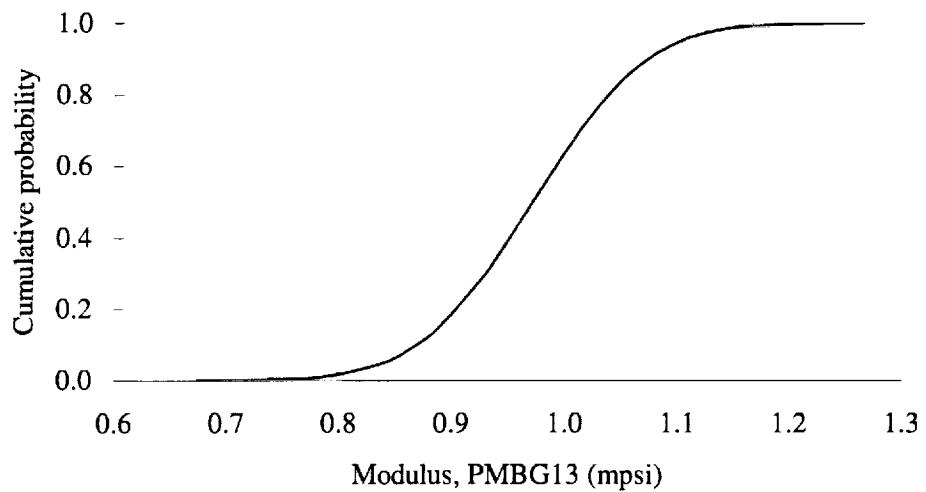
Figure 9a.—Cumulative distribution function of the plate membrane bending modulus 13.
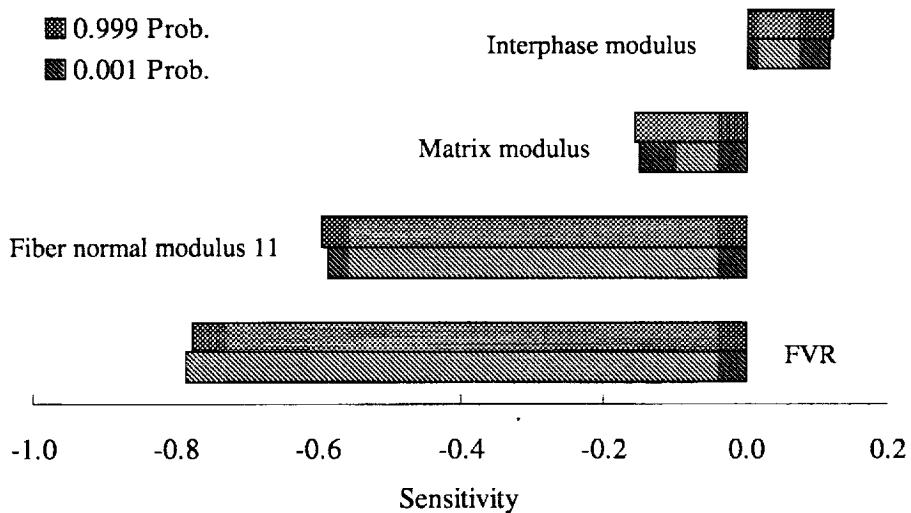
Figure 9b.—Sensitivity of plate membrane bending modulus 13 to the random variables.
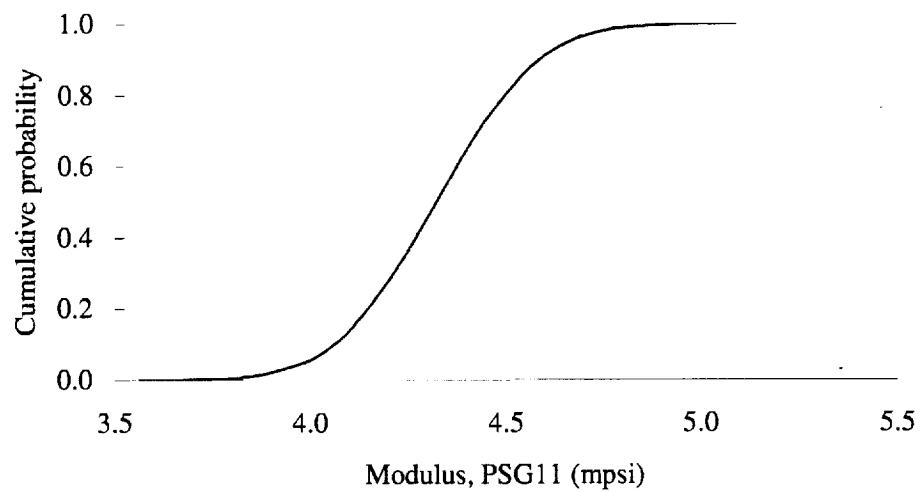
Figure 10a.—Cumulative distribution function of the plate shear modulus 11.
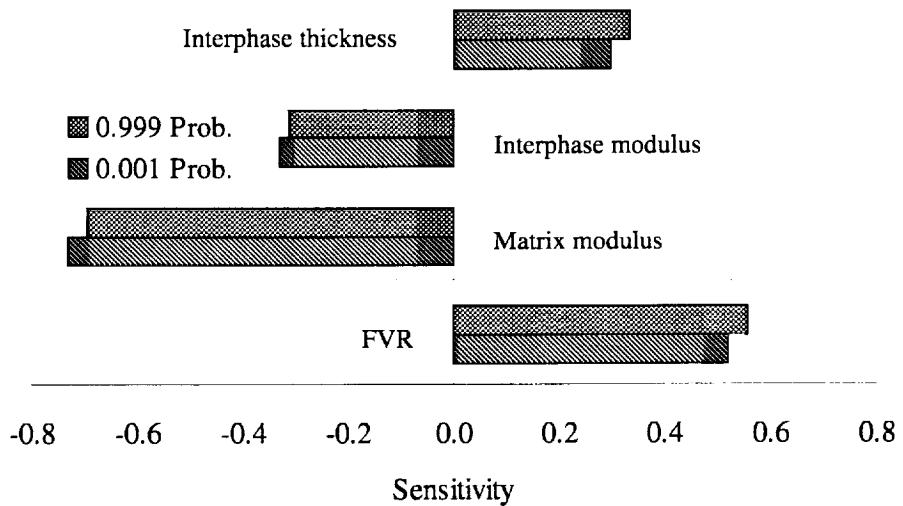
Figure 10b.—Sensitivity of plate shear modulus 11 to the random variables.
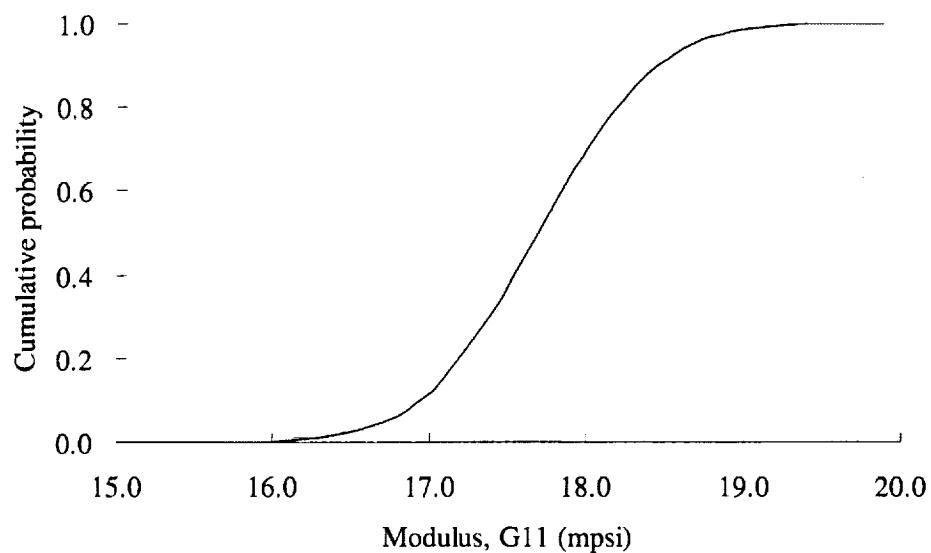
Figure 11a.—Cumulative distribution function of the solid element modulus 11.
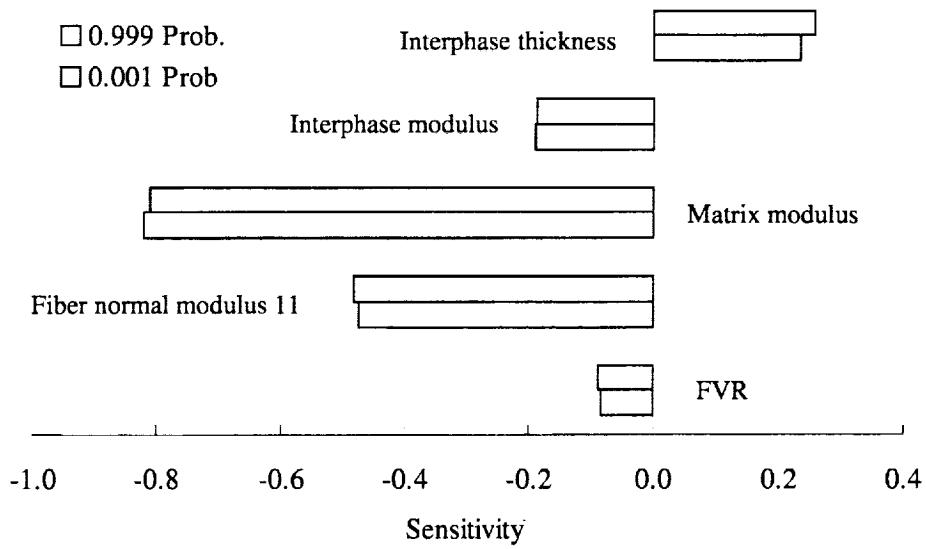
Figure 11b.—Sensitivity of solid element modulus 11 to the random variables.
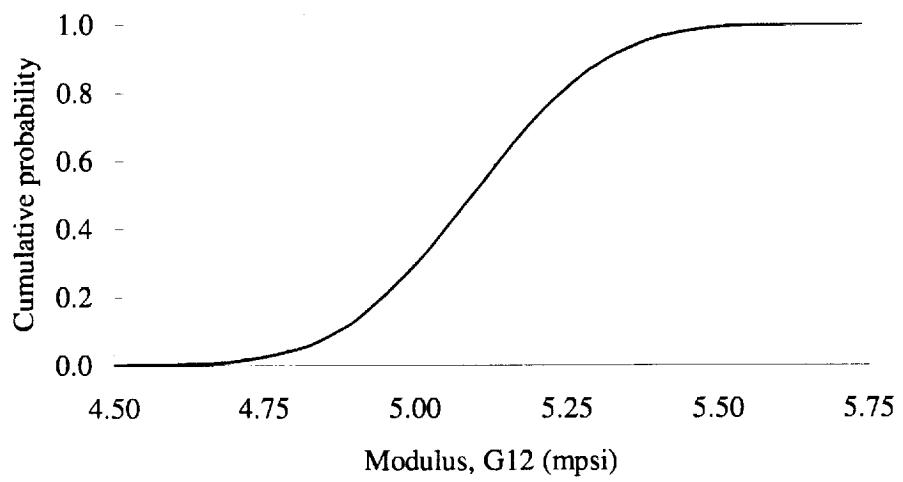
Figure 12a.—Cumulative distribution function of the solid element modulus 12.
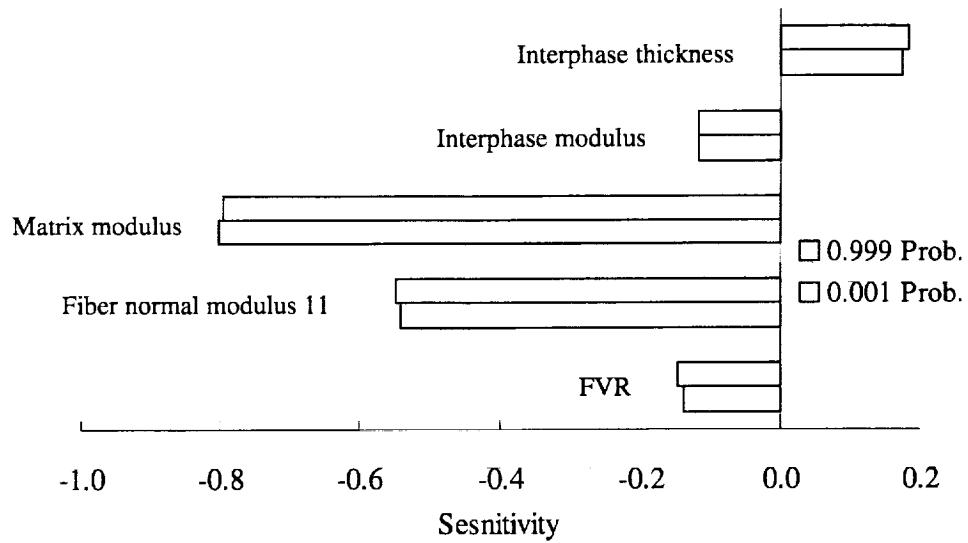
Figure 12b.—Sensitivity of solid element modulus 12 to the random variables.
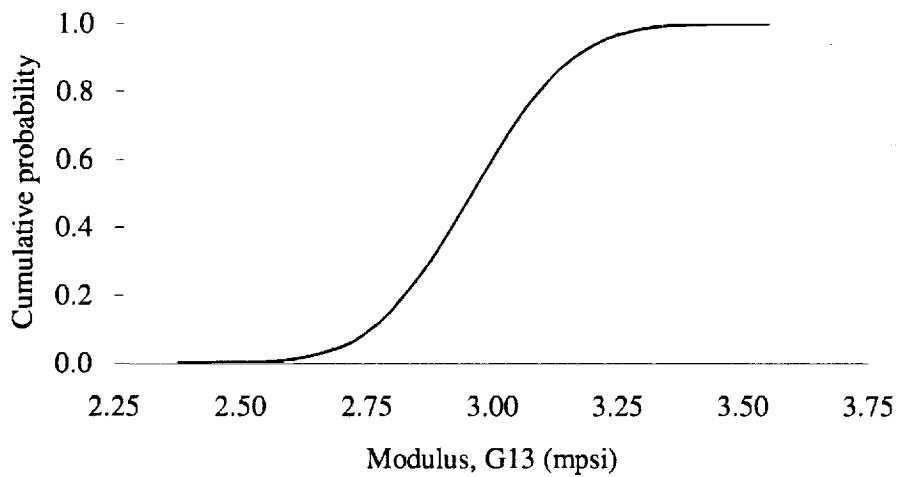
Figure 13a.—Cumulative distribution function of the solid element modulus 13.
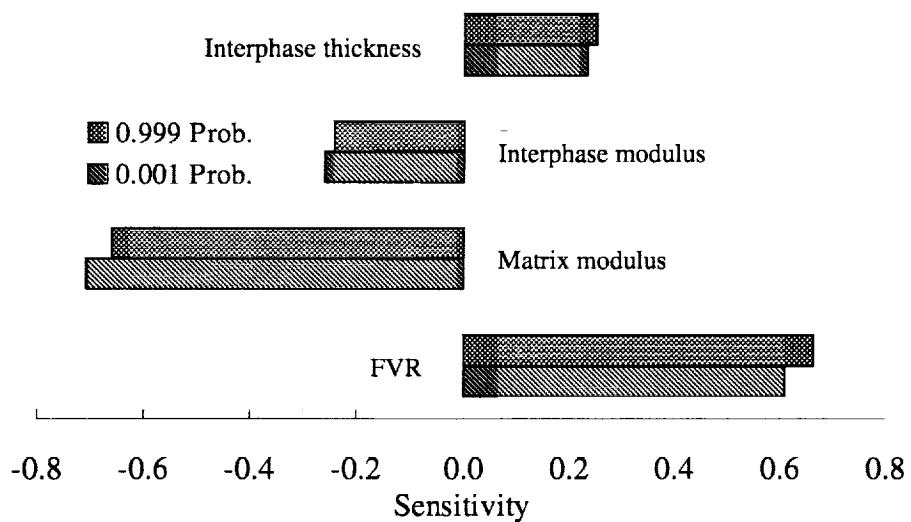
Figure 13b.—Sensitivity of solid element modulus 13 to the random variables.
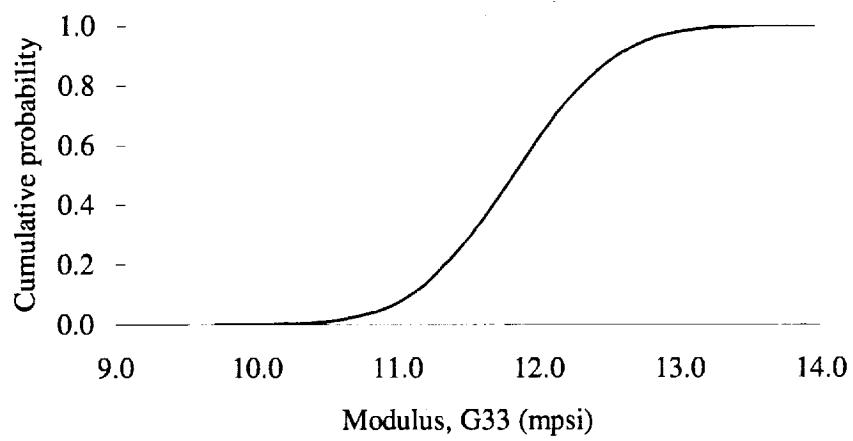
Figure 14a.—Cumulative distribution function of the solid element modulus 33.
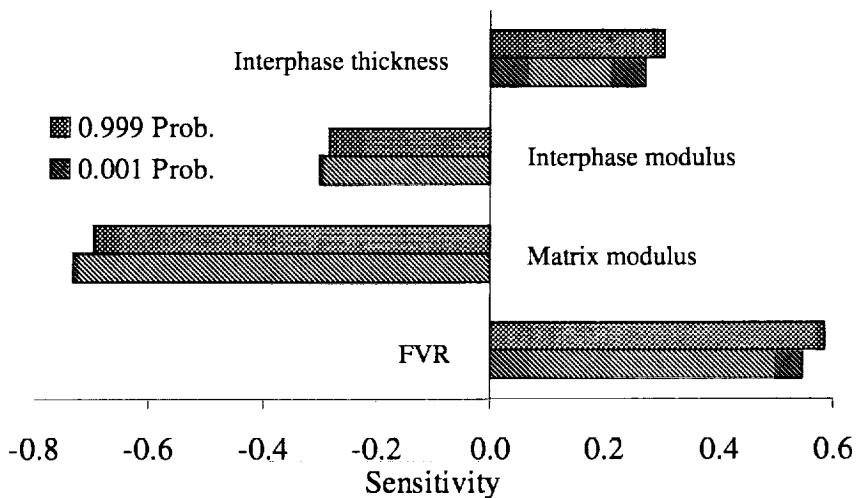
Figure 14b.—Sensitivity of solid element modulus 33 to the random variables.
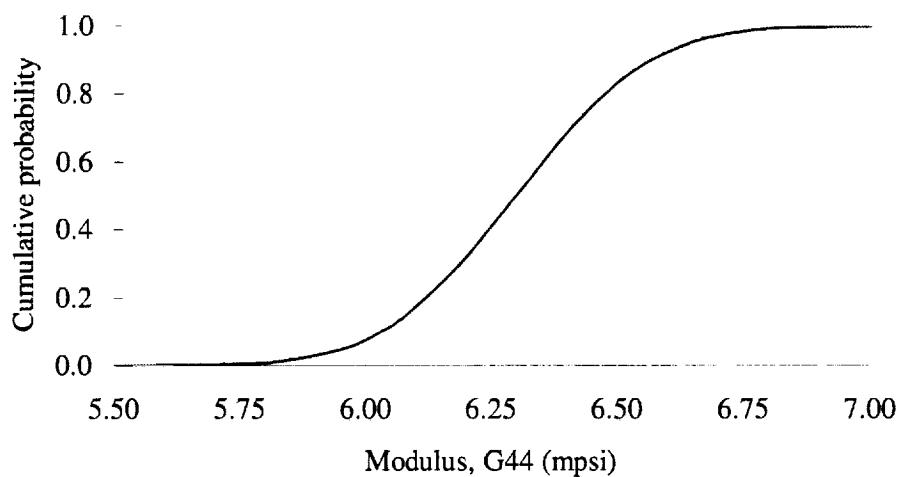
Figure 15a.—Cumulative distribution function of the solid element modulus 44.
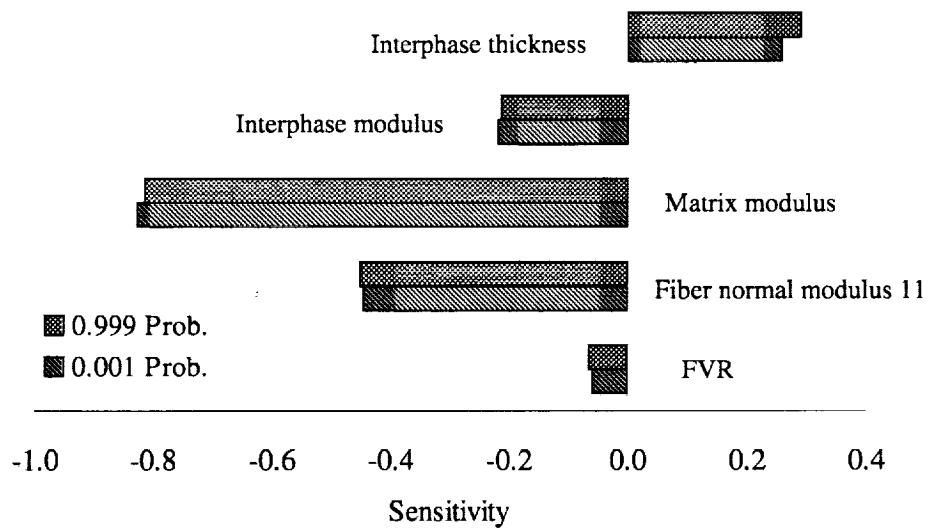
Figure 15b.—Sensitivity of solid element modulus 44 to the random variables.
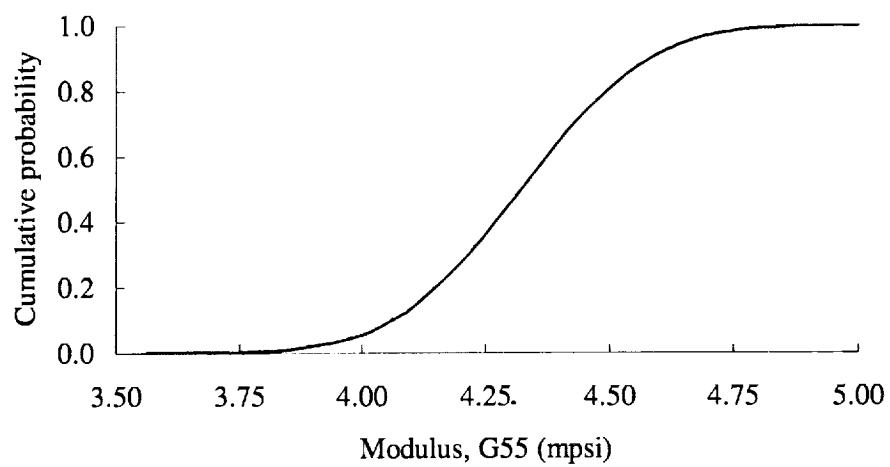
Figure 16a.—Cumulative distribution function of the solid element modulus 55.
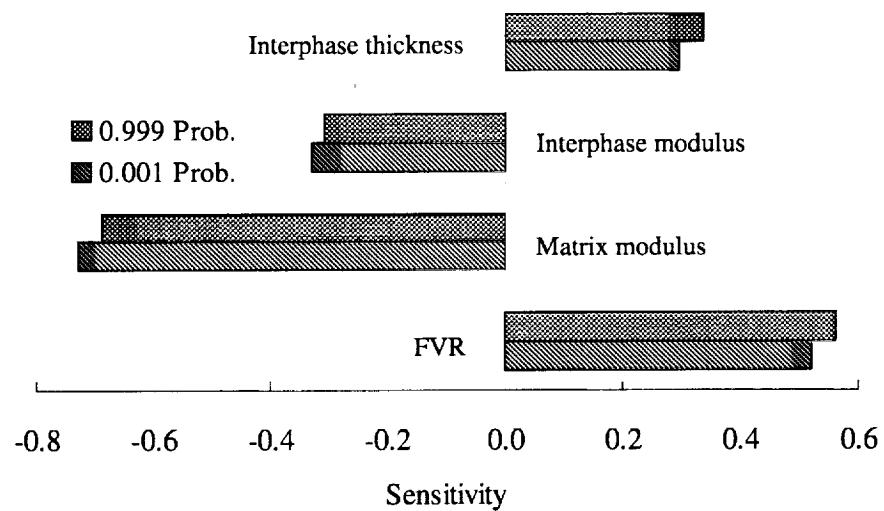
Figure 16b.—Sensitivity of solid element modulus 55 to the random variables.

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Appendix A

The following section is a revision to the PCEMCAN User's Guide to reflect the upgrade made in the present scope of work. Replace the Section 5.1.3.3 by the following.

5.1.3.3 Probabilistic Output Definition

Cumulative probability distribution function (CDF) of the composite properties listed in Table 5.1.3.3.1 can be computed upon requesting for their probabilistic output. Also, the sensitivity of primitive random variables to the composite property probability are computed. Probabilistic output for more than one composite property can be computed in one single run. The probabilistic output is printed in 'symbol.out' file and the summarized CDF and sensitivity are printed in the 'symbol.mov' file. The format for the probabilistic output request record group is given below:

Record 1: PRIN
Record 2: SYMB1
Record 3: SYMB2

.   .
.   .
.   .

n: SYMBn

Where PRIN - mnemonic for print option and is always = PRIN
SYMBn - is the composite material property symbol name from Table 5.1.3.3.1

Table 5.1.3.3.1.—List of Composite Material Properties Symbols.

Composite material property	Symbol
Coefficient of thermal expansion 11	CTE11
Coefficient of thermal expansion 22	CTE22
Coefficient of thermal expansion 33	CTE33
Heat conductivity 11	HK11
Heat conductivity 22	HK22
Heat conductivity 33	HK33
Heat capacity	HHC
Composite modulus 11	EC11
Composite modulus 22	EC22
Composite modulus 33	EC33
Composite modulus 12	EC12

Composite modulus 23	EC23
Composite modulus 31	EC31
Composite Poisson's ratio 12	NUC12
Composite Poisson's ratio 21	NUC21
Composite Poisson's ratio 13	NUC13
Composite Poisson's ratio 31	NUC31
Composite Poisson's ratio 23	NUC23
Composite Poisson's ratio 32	NUC32
NASTRAN MAT9 Card terms (All the next listed 21 terms)	MAT9
NASTRAN Solid element material property G11	G11
NASTRAN Solid element material property G12	G12
NASTRAN Solid element material property G13	G13
NASTRAN Solid element material property G14	G14
NASTRAN Solid element material property G15	G15
NASTRAN Solid element material property G16	G16
NASTRAN Solid element material property G22	G22
NASTRAN Solid element material property G23	G23
NASTRAN Solid element material property G24	G24
NASTRAN Solid element material property G25	G25
NASTRAN Solid element material property G26	G26
NASTRAN Solid element material property G33	G33
NASTRAN Solid element material property G34	G34
NASTRAN Solid element material property G35	G35
NASTRAN Solid element material property G36	G36
NASTRAN Solid element material property G44	G44
NASTRAN Solid element material property G45	G45
NASTRAN Solid element material property G46	G46
NASTRAN Solid element material property G55	G55
NASTRAN Solid element material property G56	G56
NASTRAN Solid element material property G66	G66
NASTRAN MAT2 Card terms (All the terms listed below)	MAT2
NASTRAN plate element material property membrane G11	PMG11
NASTRAN plate element material property membrane G12	PMG12
NASTRAN plate element material property membrane G13	PMG13
NASTRAN plate element material property G22	PMG22
NASTRAN plate element material property G23	PMG23
NASTRAN plate element material property G33	PMG33
NASTRAN plate element material property bending G11	PBG11

NASTRAN plate element material property bending G12	PBG12
NASTRAN plate element material property bending G13	PBG13
NASTRAN plate element material property bending G22	PBG22
NASTRAN plate element material property bending G23	PBG23
NASTRAN plate element material property bending G33	PBG33
NASTRAN plate element material property membrane/bending G11	PMBG11
NASTRAN plate element material property membrane/bending G12	PMBG12
NASTRAN plate element material property membrane/bending G13	PMBG13
NASTRAN plate element material property membrane/bending G22	PMBG22
NASTRAN plate element material property membrane/bending G23	PMBG23
NASTRAN plate element material property membrane/bending G33	PMBG33
NASTRAN plate element material property transverse shear G11	PSG11
NASTRAN plate element material property transverse shear G12	PSG12
NASTRAN plate element material property transverse shear G22	PSG22

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Appendix B

Sample input file used to demonstrate the additional capability to perform probabilistic evaluation of the MSC/NASTRAN MAT2 card terms.

```
SAMPLE CASE FOR A TWO PLY SiC/RBSN COMPOSITE
PROB
$ NPLY,NMS,NDIV(NFBDIV+2)
     2    1    7
PLY       1    1   -45.0   0.01
PLY       2    1    45.0   0.01
$ Material Information here
MATCRD       1  .300   0.000SICRRBSN
$ PRINT OPTIONS HERE
    PRINT    ALL
$ PRINTING FREQUENCY HERE
PRINTOPT    ALL
INTRFACE     1  .03
$ Interfacial Bonding 2 lines per ply
    1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00
    1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00
    1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00
    1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00
$ Load Information has two segments process and loading
  TMLOAD    -2
    0.0   10.    2
  1200.  1200.
    70.    70.
     0.     0.  0.0   0.0    0.0   0.0   0.0   0.0   0.0   0.0
     0.    0.0  0.0   0.0    0.0   0.0   0.0   0.0   0.0   0.0
  1000.0  2000.    2
    70.    70.
    70.    70.
     0.     0.  0.0   0.0    0.0   0.0   0.0   0.0   0.0   0.0
   500.    0.0  0.0   0.0    0.0   0.0   0.0   0.0   0.0   0.0
$ End Data
$ Input for the probabilistic analysis data.
METHOD        1
Fiber  volume ratio
                   1    0.07  2
Interface thickness
                   1    0.05  2
Fiber             1
Normal Modulus 11          0.05   2
Matrix             1
Normal modulus             0.05   2
Interphase        1
normal modulus             0.05   2
PRIN
mat2
$ End Data
```

Sample input file used to demonstrate the additional capability to perform probabilistic
evaluation of the MSC/NASTRAN MAT9 card terms.

```
SAMPLE CASE FOR A TWO PLY SiC/RBSN COMPOSITE
PROB
$ NPLY,NMS,NDIV(NFBDIV+2)
$2345678123456781234567812345678
     8    1    7
PLY       1    1    90.0   0.01
PLY       2    1   -45.0   0.01
PLY       3    1    45.0   0.01
PLY       4    1     0.0   0.01
PLY       5    1     0.0   0.01
PLY       6    1    45.0   0.01
PLY       7    1   -45.0   0.01
PLY       8    1    90.0   0.01
$ Material Information here
MATCRD       1   .300   0.000SICRRBSN
$ PRINT OPTIONS HERE
    PRINT    ALL
$ PRINTING FREQUENCY HERE
PRINTOPT    ALL
INTRFACE     1   .03
$ Interfacial Bonding 2 lines per ply
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
  1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
$ Load Information has two segments process and loading
 TMLOAD    -2
  0.0   10.     2
$2345678123456781234567812345678
 1200.  1200.  1200.  1200.  1200.  1200.  1200.  1200.
  70.    70.    70.    70.     70.    70.     70.    70.
   0.     0.   0.0   0.0    0.0    0.0    0.0    0.0    0.0    0.0
   0.    0.0   0.0   0.0    0.0    0.0    0.0    0.0    0.0    0.0
 1000.0 2000.    10
  70.    70.
  70.    70.
   0.     0.   0.0   0.0    0.0    0.0    0.0    0.0    0.0    0.0
 500.    0.0   0.0   0.0    0.0    0.0    0.0    0.0    0.0    0.0
$ End Data
$ Input for the probabilistic analysis data.
METHOD        1
Fiber  volume ratio
              1    0.07   2
```

```
Interface thickness
                        1    0.05  2
Fiber                   1
Normal Modulus 11            0.05  2
Matrix              1
Normal modulus               0.05  2
Interphase          1
normal modulus               0.05  2
PRIN
mat9
$ End Data
```
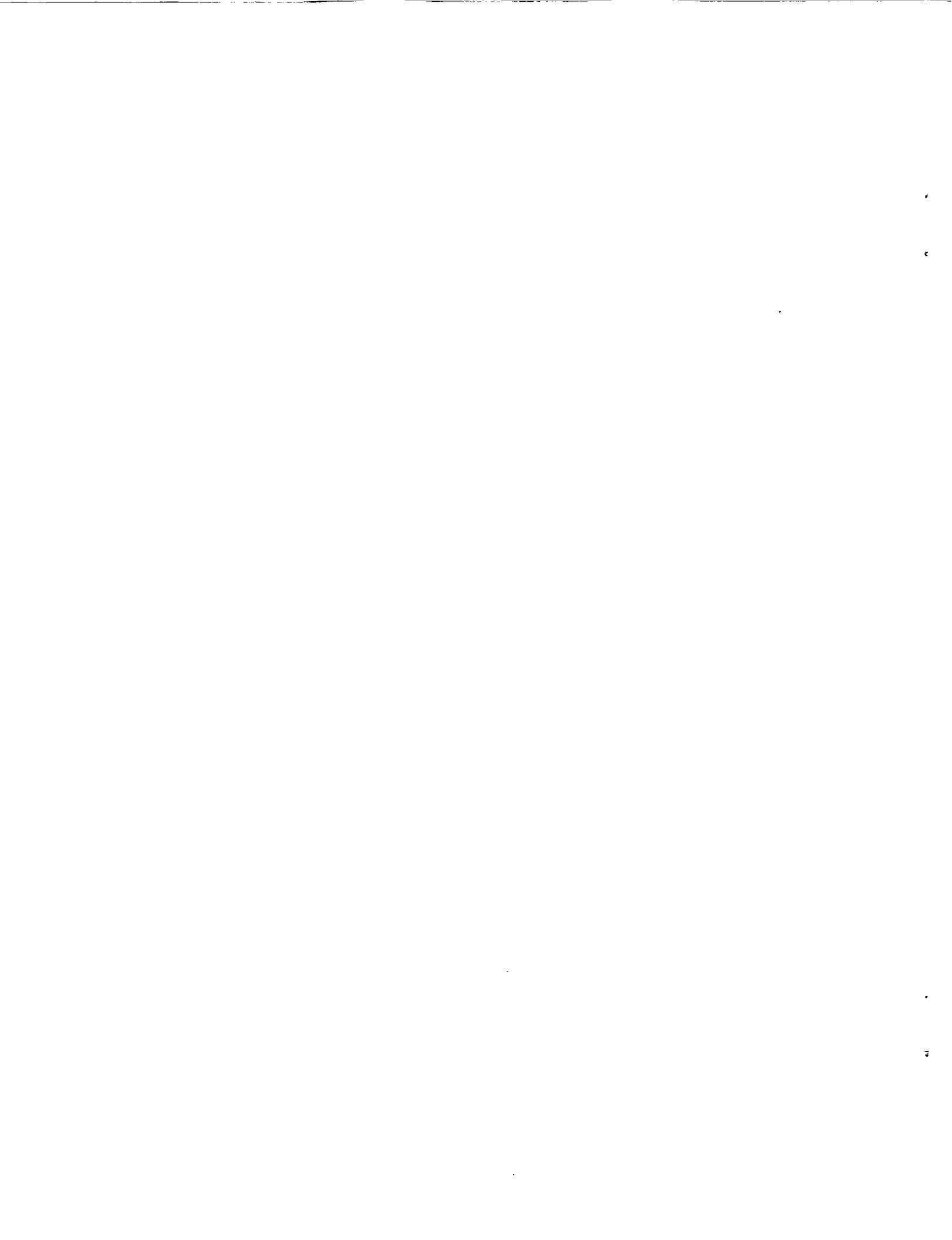
Appendix C
Typical sample output file (g11.mov) for the MAT9 card modulus G11

Response (Z) median, mean, and std. dev. based on mean-value method
 0.176891E+08   0.176840E+08   0.588357E+06

```
Response/Probability level:   18
Level      Z-value              u(std. normal)    Probability
  1        0.154934E+08           -3.71909        0.000100000
  2        0.158664E+08           -3.09025        0.001000000
  3        0.163192E+08           -2.32635        0.010000000
  4        0.167225E+08           -1.64485        0.050000000
  5        0.169372E+08           -1.28155        0.100000000
  6        0.170821E+08           -1.03643        0.150000000
  7        0.173816E+08           -0.52440        0.300000000
  8        0.176905E+08            0.00000        0.500000000
  9        0.179172E+08            0.38532        0.650000000
 10        0.180875E+08            0.67449        0.750000000
 11        0.183027E+08            1.03643        0.850000000
 12        0.184467E+08            1.28155        0.900000000
 13        0.185395E+08            1.43953        0.925000000
 14        0.186609E+08            1.64485        0.950000000
 15        0.187992E+08            1.88079        0.970000000
 16        0.190599E+08            2.32635        0.990000000
 17        0.195063E+08            3.09025        0.999000000
 18        0.198740E+08            3.71909        0.999900000
```

Most probable point (MPP) or design point

```
Level 1: (Z-value = 0.15493E+08, u = -3.7191, Probability = 0.000100000)
R.V. name                       X-value         Std. Dev.    Sensitivity
                                                from Mean    factor
MAT. 1 FVR                      0.2935756E+00   -0.305922    -0.082403
MAT. 1 FIBER NORM MODU 11       0.5162058E+08   -1.759511    -0.473944
MAT. 1 MATRIX NORM MODU         0.1351123E+08   -3.058017    -0.823710
MAT. 1 INTERPHASE NORM MODU     0.4823446E+06   -0.706217    -0.190227
MAT. 1 INTERPHASE THICK.        0.3129288E-01    0.861921     0.232168


Level 2: (Z-value = 0.15866E+08, u = -3.0903, Probability = 0.001000000)
R.V. name                       X-value         Std. Dev.    Sensitivity
                                                from Mean    factor
MAT. 1 FVR                      0.2946261E+00   -0.255899    -0.082971
MAT. 1 FIBER NORM MODU 11       0.5245648E+08   -1.464143    -0.474724
MAT. 1 MATRIX NORM MODU         0.1392658E+08   -2.537203    -0.822646
MAT. 1 INTERPHASE NORM MODU    .0.4853568E+06   -0.585728    -0.189913
MAT. 1 INTERPHASE THICK.        0.3108437E-01    0.722911     0.234392


Level 3: (Z-value = 0.16319E+08, u = -2.3263, Probability = 0.010000000)
R.V. name                       X-value         Std. Dev.    Sensitivity
                                                from Mean    factor
MAT. 1 FVR                      0.2959232E+00   -0.194136    -0.083670
MAT. 1 FIBER NORM MODU 11       0.5347665E+08   -1.103656    -0.475661
MAT. 1 MATRIX NORM MODU         0.1443021E+08   -1.905697    -0.821330
MAT. 1 INTERPHASE NORM MODU     0.4890063E+06   -0.439748    -0.189526
MAT. 1 INTERPHASE THICK.        0.3082539E-01    0.550261     0.237155
```

Level 4: (Z-value = 0.16722E+08, u = -1.6449, Probability = 0.050000000)

R.V. name	X-value	Std. Dev. from Mean	Sensitivity factor
MAT. 1 FVR	0.2970991E+00	-0.138137	-0.084300
MAT. 1 FIBER NORM MODU 11	0.5439037E+08	-0.780786	-0.476489
MAT. 1 MATRIX NORM MODU	0.1487824E+08	-1.343899	-0.820139
MAT. 1 INTERPHASE NORM MODU	0.4922503E+06	-0.309990	-0.189177
MAT. 1 INTERPHASE THICK.	0.3058906E-01	0.392708	0.239657

Level 5: (Z-value = 0.16937E+08, u = -1.2816, Probability = 0.100000000)

R.V. name	X-value	Std. Dev. from Mean	Sensitivity factor
MAT. 1 FVR	0.2977336E+00	-0.107926	-0.084640
MAT. 1 FIBER NORM MODU 11	0.5487896E+08	-0.608140	-0.476926
MAT. 1 MATRIX NORM MODU	0.1511665E+08	-1.044958	-0.819496
MAT. 1 INTERPHASE NORM MODU	0.4939754E+06	-0.240985	-0.188989
MAT. 1 INTERPHASE THICK.	0.3046098E-01	0.307319	0.241012

Level 6: (Z-value = 0.17082E+08, u = -1.0364, Probability = 0.150000000)

R.V. name	X-value	Std. Dev. from Mean	Sensitivity factor
MAT. 1 FVR	0.2981648E+00	-0.087392	-0.084870
MAT 1 FIBER NORM MODU 11	0.5520933E+08	-0.491402	-0.477220
MAT. 1 MATRIX NORM MODU	0.1527739E+08	-0.843399	-0.819059
MAT. 1 INTERPHASE NORM MODU	0.4951381E+06	-0.194475	-0.188862
MAT. 1 INTERPHASE THICK.	0.3037368E-01	0.249124	0.241934

Level 7: (Z-value = 0.17382E+08, u = -0.5244, Probability = 0.300000000)

R.V. name	X-value	Std. Dev. from Mean	Sensitivity factor
MAT. 1 FVR	0.2990643E+00	-0.044557	-0.085349
MAT. 1 FIBER NORM MODU 11	0.5589405E+08	-0.249453	-0.477823
MAT. 1 MATRIX NORM MODU	0.1560937E+08	-0.427122	-0.818146
MAT. 1 INTERPHASE NORM MODU	0.4975385E+06	-0.098459	-0.188597
MAT. 1 INTERPHASE THICK.	0.3019097E-01	0.127311	0.243863

Level 8: (Z-value = 0.17690E+08, u = 0.0000, Probability = 0.500000000)

R.V. name	X-value	Std. Dev. from Mean	Sensitivity factor
MAT. 1 FVR	0.3000040E+00	0.000192	-0.085849
MAT. 1 FIBER NORM MODU 11	0.5660303E+08	0.001070	-0.478439
MAT. 1 MATRIX NORM MODU	0.1595146E+08	0.001828	-0.817192
MAT. 1 INTERPHASE NORM MODU	0.5000105E+06	0.000421	-0.188321
MAT. 1 INTERPHASE THICK.	0.2999917E-01	-0.000550	0.245884

Level 9: (Z-value = 0.17917E+08, u = 0.3853, Probability = 0.650000000)

R.V. name	X-value	Std. Dev. from Mean	Sensitivity factor
MAT. 1 FVR	0.3007017E+00	0.033414	-0.086218
MAT. 1 FIBER NORM MODU 11	0.5712523E+08	0.185593	-0.478887
MAT. 1 MATRIX NORM MODU	0.1620235E+08	0.316429	-0.816483
MAT. 1 INTERPHASE NORM MODU	0.5018226E+06	0.072905	-0.188117
MAT. 1 INTERPHASE THICK.	0.2985619E-01	-0.095875	0.247388

```
Level 10: (Z-value = 0.18087E+08, u =  0.6745, Probability = 0.750000000)
R.V. name                      X-value        Std. Dev.   Sensitivity
                                              from Mean   factor
MAT.  1 FVR                     0.3012299E+00   0.058568   -0.086498
MAT.  1 FIBER NORM MODU 11      0.5751828E+08   0.324482   -0.479222
MAT.  1 MATRIX NORM MODU        0.1639060E+08   0.552478   -0.815946
MAT.  1 INTERPHASE NORM MODU    0.5031817E+06   0.127269   -0.187962
MAT.  1 INTERPHASE THICK.       0.2974758E-01  -0.168279    0.248529

Level 11: (Z-value = 0.18303E+08, u =  1.0364, Probability = 0.850000000)
R.V. name                      X-value        Std. Dev.   Sensitivity
                                              from Mean   factor
MAT.  1 FVR                     0.3019031E+00   0.090624   -0.086853
MAT.  1 FIBER NORM MODU 11      0.5801632E+08   0.500467   -0.479642
MAT.  1 MATRIX NORM MODU        0.1662840E+08   0.850659   -0.815262
MAT.  1 INTERPHASE NORM MODU    0.5048980E+06   0.195918   -0.187766
MAT.  1 INTERPHASE THICK.       0.2960874E-01  -0.260839    0.249985

Level 12: (Z-value = 0.18447E+08, u =  1.2816, Probability = 0.900000000)
R.V. name                      X-value        Std. Dev.   Sensitivity
                                              from Mean   factor
MAT.  1 FVR                     0.3023569E+00   0.112234   -0.087092
MAT.  1 FIBER NORM MODU 11      0.5835025E+08   0.618463   -0.479922
MAT.  1 MATRIX NORM MODU        0.1678738E+08   1.050012   -0.814800
MAT.  1 INTERPHASE NORM MODU    0.5060450E+06   0.241798   -0.187634
MAT.  1 INTERPHASE THICK.       0.2951488E-01  -0.323415    0.250968

Level 13: (Z-value = 0.18540E+08, u =  1.4395, Probability = 0.925000000)
R.V. name                      X-value        Std. Dev.   Sensitivity
                                              from Mean   factor
MAT.  1 FVR                     0.3026508E+00   0.126227   -0.087247
MAT.  1 FIBER NORM MODU 11      0.5856572E+08   0.694599   -0.480101
MAT.  1 MATRIX NORM MODU        0.1688977E+08   1.178401   -0.814501
MAT.  1 INTERPHASE NORM MODU    0.5067835E+06   0.271340   -0.187548
MAT.  1 INTERPHASE THICK.       0.2945398E-01  -0.364016    0.251605

Level 14: (Z-value = 0.18661E+08, u =  1.6449, Probability = 0.950000000)
R.V. name                      X-value        Std. Dev.   Sensitivity
                                              from Mean   factor
MAT. 1 FVR                      0.3030368E+00   0.144611   -0.087450
MAT. 1 FIBER NORM MODU 11       0.5884787E+08   0.794302   -0.480335
MAT. 1 MATRIX NORM MODU         0.1702363E+08   1.346243   -0.814108
MAT. 1 INTERPHASE NORM MODU     0.5077488E+06   0.309952   -0.187436
MAT. 1 INTERPHASE THICK.        0.2937383E-01  -0.417449    0.252442

Level 15: (Z-value = 0.18799E+08, u =  1.8808, Probability = 0.970000000)
R.V. name                      X-value        Std. Dev.   Sensitivity
                                              from Mean   factor
MAT.  1 FVR                     0.3034792E+00   0.165674   -0.087682
MAT.  1 FIBER NORM MODU 11      0.5916988E+08   0.908086   -0.480600
MAT.  1 MATRIX NORM MODU        0.1717607E+08   1.537394   -0.813658
MAT.  1 INTERPHASE NORM MODU    0.5088479E+06   0.353914   -0.187307
MAT.  1 INTERPHASE THICK.       0.2928180E-01  -0.478800    0.253402
```

```
Level 16: (Z-value = 0.19060E+08, u =  2.3263, Probability = 0.990000000)
R.V. name                    X-value         Std. Dev.    Sensitivity
                                             from Mean    factor
MAT.  1 FVR                   0.3043199E+00    0.205710   -0.088122
MAT.  1 FIBER NORM MODU 11    0.5977824E+08    1.123052   -0.481096
MAT.  1 MATRIX NORM MODU      0.1746316E+08    1.897374   -0.812802
MAT.  1 INTERPHASE NORM MODU  0.5109169E+06    0.436674   -0.187063
MAT.  1 INTERPHASE THICK.     0.2910630E-01   -0.595800    0.255230


Level 17: (Z-value = 0.19506E+08, u =  3.0903, Probability = 0.999000000)
R.V. name                    X-value         Std. Dev.    Sensitivity
                                             from Mean    factor
MAT.  1 FVR                   0.3057816E+00    0.275312   -0.088886
MAT.  1 FIBER NORM MODU 11    0.6082437E+08    1.492710   -0.481930
MAT.  1 MATRIX NORM MODU      0.1795405E+08    2.512911   -0.811308
MAT.  1 INTERPHASE NORM MODU  0.5144523E+06    0.578091   -0.186640
MAT.  1 INTERPHASE THICK.     0.2879931E-01   -0.800458    0.258433


Level 18: (Z-value = 0.19874E+08, u =  3.7191, Probability = 0.999900000)
R.V. name                    X-value         Std. Dev.    Sensitivity
                                             from Mean    factor
MAT.  1 FVR                   0.3070061E+00    0.333622   -0.089523
MAT.  1 FIBER NORM MODU 11    0.6168982E+08    1.798522   -0.482606
MAT.  1 MATRIX NORM MODU      0.1835751E+08    3.018824   -0.810056
MAT.  1 INTERPHASE NORM MODU  0.5173558E+06    0.694232   -0.186287
MAT.  1 INTERPHASE THICK.     0.2854034E-01   -0.973108    0.261119
```

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13. ABSTRACT (Maximum 200 words)

This report represents a final technical report for Order No. C–78019–J entitled "Enhancement of the Probabilistic Ceramic Matrix Composite Analyzer (PCEMCAN) Computer Code." The scope of the enhancement relates to including the probabilistic evaluation of the DMatrix terms in MAT2 and MAT9 material properties card (available in CEMCAN code) for the MSC/NASTRAN. Technical activities performed during the time period of June 1, 1999 through September 3, 1999 have been summarized, and the final version of the enhanced PCEMCAN code and revisions to the User's Manual is delivered along with. Discussions related to the performed activities were made to the NASA Project Manager during the performance period. The enhanced capabilities have been demonstrated using sample problems.

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