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ICAN/Damp-Integrated Composite Analyzer With Damping Analysis Capabilities

Users Manual

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Summary

This manual describes the use of the computer code ICAN/DAMP (Integrated Composite Analyzer with Damping Analysis Capabilities) for the prediction of damping in polymer-matrix composites. The code is written in FORTRAN 77 and is a version of ICAN (Integrated Composite ANalyzer) computer program. The code incorporates a new module for synthesizing the materials damping from micromechanics to laminate level. Explicit micromechanics equations based on hysteretic damping are programmed relating the on-axis damping capacities to the fiber and matrix properties and fiber volume ratio. The damping capacities of unidirectional composites subjected to off-axis loading are synthesized from on-axis damping values. The hygrothermal effect on the damping performance of unidirectional composites caused by temperature and moisture variation is modeled along with the damping contributions from interfacial friction between broken fibers and matrix. The temperature rise in continuously vibrating composite plies and composite laminates is also estimated. The ICAN/DAMP users manual provides descriptions of the damping analysis module's functions, structure, input requirements, output interpretation, and execution requirements. It only addresses the changes required to conduct the damping analysis and should be used in conjunction with the "Second Generation Integrated Composite Analyzer (ICAN) Computer Code" users manual.

Introduction

ICAN/DAMP (Damping Analysis of Composite Laminates), a version of the ICAN (refs. 1 and 2) computer code, incorporates a new module for predicting damping in polymer-matrix composites. The new module allows ICAN to synthesize material damping at all scale levels of the composite—from micromechanics to laminate level—thus, providing the required data for simulating the damped vibrational characteristics of composite structures.

This manual provides a step-by-step guide to using the new damping module and only addresses those changes required to conduct the damping analysis. Therefore, users should be familiar with the input requirements and analysis capabilities of the standard ICAN code as described in references 1 and 2. The ICAN/DAMP users manual describes the damping analysis module's functions, structure, input requirements, output interpretation, and execution requirements. The ICAN/DAMP code is compatible with FORTRAN 77 standards; however, the system requirements of various hardware environments may differ, and the user should consult computer support personnel in the event of installation problems. Although the results of the damping module have been sufficiently tested, the user is solely responsible for the interpretation and application of the obtained results. Questions regarding the damping module should be directed to the authors of the manual.

Damping Module Overview

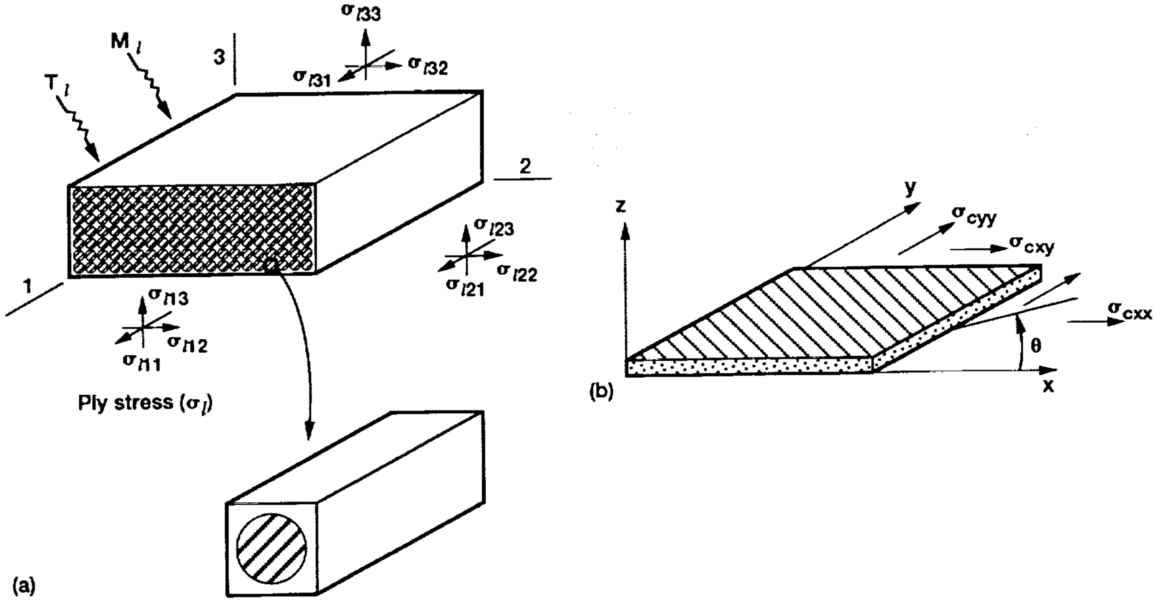
Background

A brief overview of the theoretical background of the damping theory for composites and fiber composite laminates is discussed in this section. Detailed descriptions of the damping theory, including equations and their application in the analysis, are provided in references 3 and 4. Although some micromechanical damping and laminate damping equations are included in appendix F, we strongly suggest that the user read references 3 and 4 for further understanding of the integrated damping theory.

The damping of composite materials is anisotropic and depends on several micromechanical, laminate, and structural parameters. The damping of on-axis composites (unidirectional composites loaded along the material axes as shown in fig. 1(a)) is expressed in terms of six specific damping capacities (SDC), of which only four are independent. These SDC's are defined as the dissipated strain energy of the material over the maximum stored strain energy during one vibration cycle. These SDC's are longitudinal (ψ_{l11}), transverse in-plane normal (ψ_{l22}), in-plane shear (ψ_{l12}), through-the-fibers normal (ψ_{l33}), through-the-fibers shear (ψ_{l13}), and out-of-plane shear (ψ_{l23}). The on-axis SDC's are related to the mechanical properties of the constituents (fiber and matrix), the fiber volume ratio (FVR), temperature, moisture, and existing microdamage (percentage of broken fibers). In addition to the previous parameters, the SDC's of off-axis composites (unidirectional composites loaded at an angle with respect to the fiber direction) depend on the fiber orientation angle (see fig. 1(b)).

The damping of composite laminates includes the damping contributions of all plies. In addition to the previously described parameters affecting on-axis SDC's, the damping of composite laminates depends on ply angles, ply thicknesses, and the overall ply stacking sequence. A unique feature of the encoded theory is its capacity to predict the damping of general laminates as it includes the damping effects of extension, flexure, and extension-flexure coupling. These different sources of laminate damping are best described by the extensional $[A_D]$, flexural $[D_D]$, and extension-flexure coupling $[C_D]$ damping matrices. The overall damping capacity of a composite laminate is related to these three damping matrices and the local deformation expressed by midplane strains and curvatures.

Increased temperatures may be observed in vibrating composite laminates as a



(a) On axis.
(b) Off-axis.

Figure 1.—Unidirectional composites.

result of strain-energy dissipation, including the friction effects. It is well known that damping represents the strain/kinetic energy losses that are dissipated in the composite material in the form of heat. For extended periods of vibration, it is possible that a significant temperature rise may occur, which affects such mechanical properties of the laminate as stiffness and strength. It is desirable, then, to predict both the temperature rise in composite laminates during prolonged vibrations, and its effect on the mechanical properties. The damping module provides this capability by calculating the temperature profiles developed through the thickness of the vibrating laminate.

Module Functions

The present module was developed for analyzing the damping capacity of unidirectional composites and/or composite laminates. The modeling of damping is performed in two levels: (1) the micromechanics level, where the SDC's of unidirectional on-axis composites and/or off-axis composites are synthesized, and (2) the laminate level, where the damping capacity of composite laminates is calculated.

The input information for the damping analysis requires additional card groups to control the output of the module and to provide additional input parameters. These damping analysis card groups are part of the input data file of the main ICAN code. Detailed descriptions of the damping analysis card groups are provided in the "Input Data"section of this manual. In addition to the damping analysis card groups, the module uses the standard input parameters previously available through the ICAN input file. These parameters are

(1) Data defining the laminate configuration and environmental conditions such as ply angles, ply thicknesses, ply composite materials, ply cure temperature, ply use temperature, and ply moisture content

(2) Definition of the basic composite material systems in terms of fiber volume ratios (FVR's), fiber material, and matrix material

(3) Mechanical loads applied on the laminate.

Details of these parameters are addressed in the input data sections of the ICAN user's manuals (refs. 1 and 2).

The properties of the fibers and matrix for each composite material, including specific damping capacities, are provided in a separate data base of material properties (see appendix C). The user can easily incorporate additional constituent materials based on need. A detailed description of the material data base is included in the "Data Bank" section of this manual.

The calculated SDC's of the constituent (fiber and matrix) materials, the composite plies, and the composite laminate, and the resultant temperature profiles through the thickness of the laminate are printed in a separate section of the output file. Details about the damping analysis output are given in the output section of this manual. Also, a brief description of the damping module's subroutines is given in appendix G.

Input Data

Input to the damping module is provided by two files: (1) the ICAN/DAMP input data file and (2) the constituent materials data base. Typical examples of these files are shown in appendices B and C, respectively.

Input Data Requirements

The following input parameters are used by the damping module. This information should be known by the user before executing the code. These parameters are

(1) Data defining the laminate configuration and environmental conditions such as ply angles, ply thicknesses, ply composite materials, ply cure temperature, ply use temperature, and ply moisture content

(2) Definition of the basic composite material systems in terms of fiber volume ratios (FVR's), fiber material, and matrix material

(3) Mechanical loads applied on the laminate

(4) Properties of the fibers and matrix for each composite material, including specific damping capacities.

Optional input data parameters may be needed for the damping analysis as explained in the following subsections. Optional input may include

(1) Amplitudes of cyclic mechanical loads (or laminate strains) applied on the laminate and the corresponding forcing frequency. The mechanical loads will affect only the equivalent laminate damping, temperature rise, and friction results.

(2) Data describing the percentage of broken fibers and friction coefficients if friction damping contributions due to broken fibers are requested.

ICAN/DAMP Input File

The data cards of the input file are summarized in table I. The ICAN/DAMP input file is divided in two data sections. The first section is the standard ICAN input described in reference 2 and table I. Again, it is suggested that the user consult reference 2 for descriptions of other cards included in the input data file. The second data section incorporates the damping analysis card groups as shown in appendix B. The following is a detailed description of the damping analysis card groups with examples taken from appendix B.

Damping option card group V. — This set of three cards controls various options of the damping module:

```
Damping option value   Optional description

 -1-     -2-     -3-     -4-     -5-     -6-     -7-     -8-     -9-
-------|-------|-------|-------|-------|-------|-------|-------|-------|
 FRICTN        0  IF:    1 - Include Friction Effects
TEMPRIS        0         1 - Temp's from Individual Ply Heat Generation
DAMPOUT        0         1 - Suspends Damping's Output Printout
```

Each card has a format (8X,I8) beginning with "FRICTN", "TEMPRIS", and "DAMPOUT" as their first entry, followed by the damping option value under field -2-. The default values of the integer flags are 0. These flag values have the following functions:

(1) FRICTN = 1: The friction effects on damping due to broken fibers is included; otherwise, it is neglected (FRICTN = 0). (The default value of FRICTN is 0).

(2) TEMPRIS = 1: The temperature rise is obtained from calculations of the dissipated strain energy in each ply; otherwise, the temperature profiles are calculated from the average laminate dissipated energy default value of TEMPRIS = 0.

(3) DAMPOUT = 1: The printout of the damping output is suspended.

TABLE I.—SUMMARY OF DETAILS FOR PREPARING ICAN/DAMP INPUT DATA CARDS

Card group	Identification	Code symbol	Number of entries	List of entries	Card field columns	Format	Comments
1	Title card	TITLE	80	Alphabetic character	1 to 80	(10A8)	------------------
2	Booleans	COMSAT	1		1 to 16	(A8,L8)	T(true) if laminate analysis is desired; otherwise F (false)
		CSANB	1		〃		T (true) if symmetry exists; otherwise F (false)
		BIDE	1		〃		T (true) if interply contributions are desired; otherwise F (false)
		RINDV	1		〃		T (true) if disps. are input; otherwise F (false)
		NONUDF	1		〃		T (true) if Poisson's ratio differences chart is not desired; otherwise F (false)
		DEFECT	1		〃		T (true) if durability analysis with defect is desired; otherwise F (false)
3	Ply (ply desired)	INP1,IP1, TU, TCU, DELM, TETA, THICKNS	7	i, j, T_u, T_{cu}, ΔM, θ_l, t_l	1 to 64	(A8,2I8, 5F8.3)	Ply layup, temperature and moisture conditions
4	MATCRD (material)	IP1, CODES (1,1,J), CODES (1,2,J), VFP, VVP, CODES (2,1,J), CODES (2,2,J), VFS, VVS, VSC	8	Primary composite code names for fiber and matrix, k_f, k_v; secondary composite code names for fiber and matrix k_{sc}, k_f, k_v	1 to 72	(A8,I8, 2A4, 2E8.2, 2A4, 3E8.2)	Descriptions of the material system to be used

TABLE I.—Concluded.

Card group	Identification	Code symbol	Number of entries	List of entries	Card field columns	Format	Comments
5	**FRICTN**	**IOPT(1)**	**1**	**0 (Default value) or 1**	**1 to 16**	**(8X,I8)**	**Integer flag to include friction due to broken fibers**
	TEMPRIS	**IOPT(2)**	**1**	″	″	″	**Integer flag to include temperature rise from individual ply heat generation**
	DAMPOUT	**IOPT(3)**	**1**	″	″	″	**Integer flag to suspend the damping's output printout**
6	**FREQ**	**FREQ**	**1**	**f**	**1 to 16**	**(8X,F8.3)**	**Forcing frequency in hertz**
7	**STRAINS**	**E0(1),E0(2), E0(3)**	**3**	$\epsilon_x,\epsilon_y,\gamma_{xy}$	**1 to 32**	**(8X,3F8.3)**	**User-defined midplane strains for the damping analysis**
	CURVTUR	**CURV(1), CURV(2), CURV(3)**	**3**	$\kappa_x,\kappa_y,\kappa_{xy}$	**1 to 32**	″	**User-defined curvatures for the damping analysis**
8	**PLY (Same mnemonic as in card group 3)**	**IL,MU, KFB**	**3**	i,μ, N_{fb}	**1 to 32**	**(8X, I8, 2F8.3)**	**Ply identification number, fiber/matrix friction coefficient and fraction of broken fibers in a ply**
9	PMEMB	NX,NY, NXY, THCS	4	N_x,N_y,N_{xy},O_{cs}	1 to 40	(A8, 4E8.4)	Membrane loads and angle to structural axis
	PBEND	MX,MY, MXY	3	M_x,M_y,M_{xy}	1 to 32	″	Bending loads
	PTRAN	DMX, DMY, PU,PL	4	Q_{xy},Q_{yz}, P_u,P_1	1 to 40	″	Traverse loads
10	Cyclic loads cards	CNXX, CNYY, CNXY CMXX, CMYY, CMXY	4	Upper limit, lower limit, No. cyc. and β_1	1 to 40	(A8,4E8.4)	Description of cyclic loads
11	PRINT (output option cards)	IDECHO, INPTSUM, -------------- -------------- ALL	1		1 to 16	(2A8)	Select output items

Forcing frequency: card group VI. — The card in this group has a format (8X,F8.3) beginning with the mnemonic "FREQ" as the first entry and is followed by the value of the forcing frequency f (in hertz) as its second entry:

Frequency value

```
  -1-     -2-
-------|-------|
  FREQ    50.0
```

Note that the laminate loads in the input are considered in the damping analysis as amplitudes of cyclic loads of frequency f, which are used in the calculation of the equivalent laminate SDC. Even though this frequency value is needed only for the calculation of the temperature profiles, the presence of a forcing frequency card is required in the input file. For this example, the forcing frequency is equal to 50.0 Hz.

Deformation: card group VII. — These two cards provide the option to calculate the laminate damping and temperature profiles for a user-defined harmonic laminate deformation (expressed by the midplane strain and curvature amplitudes) of frequency f:

	ε_x	ε_y	γ_{xy}

```
  -1-      -2-      -3-      -4-
-------|-------|-------|-------|
STRAINS    0.0     0.0     0.0
```

	κ_x	κ_y	κ_{xy}

```
  -1-      -2-      -3-      -4-
-------|-------|-------|-------|
CURVTUR    0.0     0.0     0.0
```

In the default option, the laminate deformation is calculated from the sinusoidal load of frequency f defined in the loads card group. The default option is assumed when all entries in the previous two cards are set equal to 0.0 (as in this example). The format of each card is (8X,3F8.3).

The entries for the midplane strains begin with the mnemonic "STRAINS" as the first entry under field -1-, followed by three real entries consisting of the prescribed values of ε_x, ε_y, and γ_{xy}, respectively. Each real field is entered in format F8.3. The entries for the curvature card begin with the mnemonic "CURVTUR," followed by the values of κ_x, κ_y, and κ_{xy}, entered also in format F8.3.

Friction data: card group VIII. — The last group of cards in the damping analysis input file consists of friction data for each ply used in the calculation of friction damping due to broken fibers.

	Ply id	μ	N_{fb}
-1-	-2-	-3-	-4-
-------|	-------|	-------|	-------|
PLY	1	0.30	0.20
PLY	2	0.30	0.20
PLY	3	0.30	0.20
PLY	4	0.30	0.20
PLY	5	0.30	0.20
PLY	6	0.30	0.20
PLY	7	0.30	0.20
PLY	8	0.30	0.20

The format of each card is (8X,I8,2F8.3) and consists of the ply identification number (second entry), the friction coefficient between matrix and fibers (μ) for the ply (third entry), and the fraction of broken to total fibers (N_{fb}) in the ply (fourth entry). The friction effects are accounted for on the laminate SDC, and the programmed formulation is valid for uniaxial cyclic stress only. It is assumed that the modulus of the composite does not change with the percentage of broken fibers. Therefore, the stiffness of the ply/laminate will not be affected. The ply identification numbers should be in sequential order starting from 1, and the values of μ and N_{fb} should be specified for each ply. The number of plies in this card group should match the number of plies specified in the laminate configuration card group. The values for μ and N_{fb} used in the example are $\mu = 0.30$ and $N_{fb} = 0.20$. This option is activated through the damping option card group by setting FRICTN = 1.

Data Bank

A sample data base of constituent properties is provided with the source code to facilitate the user's initial interaction with the program. After getting acquainted with the damping module, the user may want to expand the data bank of constituent properties based on his/her specific applications. Among other things, the resident data bank reduces the burden of repeatedly preparing input for the fiber and matrix properties. The data bank is structured in the same way as described in the "Second Generation ICAN Computer Code Users Manual" (ref. 2). This section is written with the assumption that the user is already familiar with ICAN's revised data bank structure and features; therefore, only the additional cards will be discussed. The additions to this data bank consist of the fiber and matrix damping capacities cards necessary for the damping analysis. These additional cards are described below.

Fiber material properties. — There are four additional cards that were added to the block of fiber properties, corresponding to their specific damping capacities in the longitudinal (ψ_{f11}), shear (ψ_{f12}), and transverse directions (ψ_{f22}, ψ_{f23}). These four cards are included after the property fiber compressive strength, and their numerical values are entered starting from column 42 in format E9.3. This will increase the total number of cards in the fiber properties "block" to 24. An example of the fiber properties with the additional fiber damping capacities cards (identified by bold print) is shown in the following table:

Description	Symbol	Value	Units
`-1-     -2-     -3-     -4-     -5-     -6-     -7-     -8-`			
`-------|-------|-------|-------|-------|-*-----|-------|-------|`			
HMSF HIGH MODULUS SURFACE TREATED FIBER.			
$			
$			
$			
Number of fibers per end	Nf	10000	number
Filament equivalent diameter	df	0.300E-03	inches
Weight density	Rhof	0.703E-01	lb/in**3
Normal moduli (11)	Ef11	0.550E+08	psi
Normal moduli (22)	Ef22	0.900E+06	psi
Poisson's ratio (12)	Nuf12	0.200E+00	non-dim
Poisson's ratio (23)	Nuf23	0.250E+00	non-dim
Shear moduli (12)	Gf12	0.110E+07	psi
Shear moduli (23)	Gf23	0.700E+06	psi
Thermal expansion coef. (11)	Alfaf11	-.550E-06	in/in/F
Thermal expansion coef. (22)	Alfaf22	0.560E-05	in/in/F
Heat conductivity (11)	Kf11	0.403E+01	BTU-in/hr/in**2/F
Heat conductivity (22)	Kf22	0.403E+00	BTU-in/hr/in**2/F
Heat capacity	Cf	0.170E+00	BTU/lb/F
Fiber tensile strength	SfT	0.280E+06	psi
Fiber compressive strength	SfC	0.200E+06	psi
Fiber damping capacity (11)	**Zetaf11**	**0.400E-02**	**non-dim**
Fiber damping capacity (22)	**Zetaf22**	**0.400E-02**	**non-dim**
Fiber damping capacity (12)	**Zetaf12**	**0.400E-02**	**non-dim**
Fiber damping capacity (23)	**Zetaf23**	**0.400E-02**	**non-dim**

Matrix material properties. — Two additional cards were included in the block of matrix properties. These cards correspond to the matrix normal (ψ_{mn}) and shear (ψ_{ms}) specific damping capacities, which are included after the property glass transition temperature. Again, the numerical values are entered starting from column 42 in format E9.3. The total number of cards in this block of matrix properties increased to 21. An example depicting the matrix properties available in the data bank is shown in the list below:

Description	Symbol	Value	Units
`   -1-     -2-     -3-     -4-     -5-     -6-     -7-     -8-`			
`-------|-------|-------|-------|-------|-*-----|-------|-------|`			
D210 DX210 RESIN.			
$			
$			
$			
Weight density	Rhom	0.440E-01	lb/in**3
Normal modulus	Em	0.500E+06	psi
Poisson's ratio	Num	0.350E+00	non-dim
Thermal expansion coef.	Alfa m	0.360E-04	in/in/F
Matrix heat conductivity	Km	0.868E-02	BTU-in/hr/in**2/F
Heat capacity	Cm	0.250E+00	BTU/lb/F
Matrix tensile strength	SmT	0.150E+05	psi
Matrix compressive strength	SmC	0.350E+05	psi
Matrix shear strength	SmS	0.130E+05	psi
Allowable tensile strain	eps mT	0.200E-01	in/in
Allowable compr. strain	eps mC	0.500E-01	in/in
Allowable shear strain	eps mS	0.350E-01	in/in
Allowable torsional strain	eps mTOR	0.350E-01	in/in
Void heat conductivity	kv	0.225E+00	BTU-in/hr/in**2/F
Glass transition temperature	Tgdr	0.420E+03	F
Matrix damp. capacity-Normal	**Zeta mn**	**0.103E+00**	**non-dim**
Matrix damp. capacity-Shear	**Zeta ms**	**0.118E+00**	**non-dim**

Output

The output is organized in four sections describing (1) the on-axis damping SDC's of each composite material, (2) the off-axis SDC's of each ply, (3) the equivalent damping characteristics of the laminate, and (4) the calculated temperature profiles. A typical output sample is provided in appendix D. More analytical descriptions of the damping output section are given in the following sections:

On-axis Damping

This portion of the output provides details of the on-axis SDC's of each composite material under a use temperature and moisture content. The following SDC's of the fibers, matrix, and the composite material are obtained:

Specific Damping Capacities		
Fiber	Matrix	Composite
ZF11 = ψ_{f11}	ZMN = ψ_{mn}	ZL11 = ψ_{l11}
ZF12 = ψ_{f12}	ZMS = ψ_{ms}	ZL12 = ψ_{l12}
ZF13 = ψ_{f13}		ZL13 = ψ_{l13}
ZF22 = ψ_{f22}		ZL21 = ψ_{l21}
ZF23 = ψ_{f23}		ZL22 = ψ_{l22}
ZF33 = ψ_{f33}		ZL23 = ψ_{l23}
		ZL31 = ψ_{l31}
		ZL32 = ψ_{l32}
		ZL33 = ψ_{l33}

Off-axis Damping

The off-axis damping matrix and the axial damping with respect to the structural axes (x,y) of each ply are printed out. The axial SDC's represent the global damping of the ply when it is subjected to uniaxial cyclic normal and shear stress in the x-y plane (ref. 3).

Damping Matrix Terms	Axial Damping
ZC(1,1) = ψ_{cxx} ZC(1,2) = ψ_{cxy} ZC(1,3) = ψ_{cxs} ZC(2,1) = ψ_{cyx} ZC(2,2) = ψ_{cyy} ZC(2,3) = ψ_{cys} ZC(3,1) = ψ_{csx} ZC(3,2) = ψ_{csy} ZC(3,3) = ψ_{css}	ZCAXLX = $\psi_{x,axial}$ ZCAXLY = $\psi_{y,axial}$ ZCAXLS = $\psi_{s,axial}$

Laminate Damping

This section of the output provides data related to the total damping capacity of the laminate. The laminate's midplane strain and curvature are first printed, followed by the equivalent SDC of the laminate, the dissipated strain energy per unit area, and the maximum stored strain energy per unit area. These values are all related to the previously mentioned generalized laminate strains.

Laminate mechanical strains	
Midplane strains	Curvature
E01 = ϵ_x E02 = ϵ_y E03 = γ_{xy}	K1 = κ_x K2 = κ_y K3 = κ_{xy}

SDC of laminate for above strains	$\psi = \delta W / W$
Dissipated strain energy	δW
Stored strain energy	W

The laminate damping matrices $[A_D]$, $[D_D]$, and $[C_D]$ representing, respectively, the laminate damping capacities in extension, flexure, and extension-flexure action are also provided in this output section.

Laminate Damping Matrices

Extensional Damping $[A_D]$	Coupling Damping $[C_D]$	Flexural Damping $[D_D]$
ACD(1,1) ... ACD(1,3)	CCD(1,1) ... CCD(1,3)	DCD(1,1) ... DCD(1,3)
ACD(2,1) ... ACD(2,3)	CCD(2,1) ... CCD(2,3)	DCD(2,1) ... DCD(2,3)
ACD(3,1) ... ACD(3,3)	CCD(3,1) ... CCD(3,3)	DCD(3,1) ... DCD(3,3)

Temperature Profiles

The developed temperature differentials in each ply of the vibrating laminate due to the dissipated strain energy are provided in this output portion. The initial temperature, the average temperature differential, and the temperature differential at the bottom and top of the ply are printed for each ply. Currently, the heat dissipation is being done by heat conduction through the material. The air convection rate is neglected at this time.

Execution and General Remarks

ICAN/DAMP has been compiled using a variety of Fortran 77 compilers on hardware ranging from microcomputers to supercomputers with relative ease; therefore, it is not foreseen that the user would have any great difficulty compiling the code. ICAN/DAMP was primarily compiled and executed on the VM/SP operating system, residing in an Amdahl 5870 mainframe computer at NASA Lewis Research Center. The same REXX EXEC files that compile and run the ICAN code under the VM system are applicable to the ICAN/DAMP code. The input and output files are associated to the following I/O units:

(1) ICAN/DAMP input file	I/O unit 5
(2) Data bank file	I/O unit 8
(3) ICAN/DAMP output file	I/O unit 6

These JCL (job control language) files are shown in appendix E. Also, a DCL (digital command language) command procedures file is provided to execute the code in a VAX/VMS environment.

Demonstration Problems

In addition to the input file, the following demonstration problems are also provided in order to aid the user in becoming familiar with some of the code's features and capabilities.

Problem 1

This problem illustrates the interfacial frictional damping contribution caused by broken fibers in an off-axis composite. A two-ply, 0.02-in.-thick continuous-fiber composite is subjected to an off-axis, axial stress amplitude σ_{cxx} of 20 ksi ($N_x = 400$ lb/in.). The composite is made of HMSF (high modulus surface treated graphite fibers) and IMHS (intermediate modulus high strength) matrix with a 0.50 fiber volume ratio. The coefficient of friction between fiber and matrix was assumed to be 0.30; the percentage of broken fibers per ply to equal 20 percent; and the fiber orientation angle θ_l to be 20 . The input data set for this problem is given below:

```
$
$ This problem illustrates the interfacial frictional damping
$ contribution in the case of off-axis loading.
$
ICAN/DAMP: Demonstration Problem No. 1
  COMSAT        T
   CSANB        F
    BIDE        F
   RINDV        F
  NONUDF        T
  DEFECT        F
$ The composite is 0.02 inches thick and the fiber orientation
$ angle is equal to 20 degrees.
     PLY        1       1     70.0    70.0     0.0    20.0   0.01
     PLY        2       1     70.0    70.0     0.0    20.0   0.01
$ HMSF fiber in Intermediate Modulus High Strength matrix (IMHS).
  MATCRD        1HMSFIMHS     0.50    0.00T300IMHS    0.00    0.00    0.00
$ Friction effect is considered in this problem.
  FRICTN        1    IF:  1 - Include Friction Effects
 TEMPRIS        0         1 - Temp's from Individual Ply Heat Generation
 DAMPOUT        0         1 - Suspends Damping's Output Printout
  FREQ       50.0
 STRAINS      0.0      0.0      0.0
 CURVTUR      0.0      0.0      0.0
$ Coefficient of friction is equal to 0.30 and the percentage of
$ broken fibers is equal to 20 %.
  PLY           1    0.30     0.20
  PLY           2    0.30     0.20
$ Axial stress amplitude of 20 ksi, (In-plane Loads Only).
   FMEMB    400.0    00.      0.0     0.0
   PBEND      0.0    0.0      0.0     0.0
   PTRAN      0.0    0.0        0.     00.
$
   PRINT      ALL   Output request for complete results    (OPTION 0)
```

Problem 2

This problem includes the temperature rise option based on the individual strain energy dissipation per ply. The off-axis composite is a HT-S fiber/IMHS matrix with a 0.50 fiber volume ratio, subjected to a continuous sinusoidal excitation of σ_{cxx} equal to 10 ksi and a frequency of 50 Hz. The thickness of the unidirectional composite is 0.04 in., hence, N_x equals 400 lb/in., and the fiber orientation angle, θ_l, equals 60 . Friction effects from broken fibers are ignored (FRICTN = 0). The input data file is listed below:

```
$
$ The temperature rise based on the individual strain energy
$ dissipation per ply is considered in this example.  The temperature
$ difference is measured versus the room temperature of 70 degrees F.
$
ICAN/DAMP: Demonstration Problem No. 2
  COMSAT        T
   CSANB        F
    BIDE        F
   RINDV        F
  NONUDF        T
  DEFECT        F
$ The composite is 0.04 inches thick and the fiber orientation
$ angle is equal to 60 degrees.
     PLY        1       1    70.0     70.0      0.0     60.0    0.02
     PLY        2       1    70.0     70.0      0.0     60.0    0.02
$ HT-S fiber in Intermediate Modulus High Strength matrix (IMHS).
  MATCRD        1HT-SIMHS     0.50    0.00T300IMHS     0.00     0.00     0.00
  FRICTN        0    IF:  1 - Include Friction Effects
 TEMPRIS        1         1 - Temp's from Individual Ply Heat Generation
 DAMPOUT        0         1 - Suspends Damping's Output Printout
$ Frequency is equal to 50 Hz.
  FREQ        50.0
 STRAINS       0.0       0.0       0.0
 CURVTUR       0.0       0.0       0.0
  PLY           1      0.00      0.00
  PLY           2      0.00      0.00
$ Axial stress amplitude of 10 ksi, (In-plane Loads Only).
   PMEMB     400.0    00.       0.0      0.0
   PBEND       0.0    0.0       0.0      0.0
   PTRAN       0.0    0.0        0.     00.
$
   PRINT      ALL    Output request for complete results     (OPTION 0)
```

Problem 3

The variations of temperature and moisture will influence the damping performance of composite laminates. These hygrothermal effects on the flexural SDC of a 0.50 fiber-volume-ratio, HMSF/DX209 resin, quasi-isotropic $(40/130/85/-5)_s$ laminate are modeled as follows: The temperature difference is selected as 200 F above reference temperature (70 F) by assigning a use temperature of 270 F while the cure temperature remains constant. The amount of moisture percent in the composite is 2 percent by weight. The laminate is subjected to an in-plane bending moment (free flexure) of $M_x = 2$ lb·in./in., and the thickness of each ply is 0.01 in. This example is illustrated in the following input data set:

```
$
$ This problem illustrates the hygrothermal effects on the flexural
$ SDC of a (TH/90+TH/45+TH/-45+TH)s  laminate.  The temperature differ-
$ ence is equal to 200 F and the moisture content is equal to 2 %.
$
ICAN/DAMP: Demonstration  Problem No. 3
  COMSAT       T
   CSANB       F
    BIDE       F
   RINDV       F
  NONUDF       T
  DEFECT       F
$ Each ply is 0.01 inches thick and the fiber orientation angle is
$ equal  to 40 degrees.
     PLY       1       1   270.0     70.0     2.0    40.0    0.01
     PLY       2       1   270.0     70.0     2.0   130.0    0.01
     PLY       3       1   270.0     70.0     2.0    85.0    0.01
     PLY       4       1   270.0     70.0     2.0    -5.0    0.01
     PLY       5       1   270.0     70.0     2.0    -5.0    0.01
     PLY       6       1   270.0     70.0     2.0    85.0    0.01
     PLY       7       1   270.0     70.0     2.0   130.0    0.01
     PLY       8       1   270.0     70.0     2.0    40.0    0.01
$ HMSF fiber in DX209 epoxy resin (0.50 fiber volume ratio).
  MATCRD       1HMSFD209     0.50     0.00T300IMHS     0.00     0.00     0.00
  FRICTN       0    IF:  1 - Include Friction Effects
 TEMPRIS       0         1 - Temp's from Individual Ply Heat Generation
 DAMPOUT       0         1 - Suspends Damping's Output Printout
  FREQ      50.0
 STRAINS     0.0      0.0      0.0
 CURVTUR     0.0      0.0      0.0
  PLY          1    0.00     0.00
  PLY          2    0.00     0.00
  PLY          3    0.00     0.00
  PLY          4    0.00     0.00
  PLY          5    0.00     0.00
  PLY          6    0.00     0.00
  PLY          7    0.00     0.00
  PLY          8    0.00     0.00
$ In-plane bending moment of 2 lb in/in.
   PMEMB     0.0    0.0     0.0     0.0
   PBEND     2.0    0.0     0.0     0.0
   PTRAN     0.0    0.0      0.     00.
$
   PRINT     ALL    Output request for complete results    (OPTION 0)
```

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 14, 1992

Appendix A.—Symbols

$[A_D]$,$[A]$	3 × 3 extensional damping and stiffness matrices, respectively
$[C_D]$,$[C]$	3 × 3 coupling damping and stiffness matrices, respectively
$[D_D]$,$[D]$	3 × 3 flexural damping and stiffness matrices, respectively
C	thermal capacity
E	normal modulus
$[E_c]$	off-axis ply stiffness matrix
G	shear modulus
f	forcing frequency, Hz
K	thermal conductivity
k	volume ratio
N_{fb}	fraction of broken fibers in a ply
N_l	number of plies
S	strength
T	temperature
t	ply thickness
W,δW	stored and dissipated strain energies
z	distance from laminate midplane surface
α	thermal expansion coefficient
ε	engineering strain
$\boldsymbol{\varepsilon}^o$	midplane engineering strain vector
$\boldsymbol{\kappa}$	curvature vector
μ	fiber-matrix friction coefficient
ν	Poisson's ratio
ρ	mass density
σ	stress
ψ	specific damping capacity
Subscripts:	
b	ply bottom
C	compression
c	(ply) off-axis composite
D	damping
f	fibers

l	(ply) on-axis composite
m	matrix
n	normal direction
o	reference
s	shear direction
t	ply top
x,y,z	structural axes
xx,yy	in-plane normal, off-axis, x and y directions, respectively
ss	in-plane shear, off-axis
1,2,3	material axes
11	normal longitudinal direction
22	normal in-plane transverse direction
33	normal out-of-plane transverse direction
12	shear in-plane direction
23,13	shear out-of-plane directions

Appendix B.—Sample ICAN/DAMP Input Data Set

```
$  ---  Title Card --- Card Group I.
$
ICAN/DAMP:   QUASI-ISOTROPIC  LAMINATE,8 'PLIES,DT=000  F,M=0%
$
$  ---  Boolean Card Group --- Card Group II.
$
  COMSAT         T
   CSANB         F
$   The logical variable BIDE is Not being used, (Interply Layer
$   Distortion Energy Coefficient (ILDC = 0)).
    BIDE         F
   RINDV         F
  NONUDF         T
  DEFECT         F
$
$  ---  Laminate Configuration Card Group --- Card Group III.
$  The following is the PLY card group.  The laminate configuration is
$  specified as follows:
$
     PLY        1       1     70.0     70.0      0.0     00.0    0.01
     PLY        2       1     70.0     70.0      0.0     90.0    0.01
     PLY        3       1     70.0     70.0      0.0     45.0    0.01
     PLY        4       1     70.0     70.0      0.0    -45.0    0.01
     PLY        5       1     70.0     70.0      0.0    -45.0    0.01
     PLY        6       1     70.0     70.0      0.0     45.0    0.01
     PLY        7       1     70.0     70.0      0.0     90.0    0.01
     PLY        8       1     70.0     70.0      0.0     00.0    0.01
$
$  ---  Material Data Card Group --- Card Group IV.
$  The details of the materials to be used in the analysis are
$  described as follows:
$
  MATCRD        1HMSFD210     0.50     0.00T300IMHS     0.00     0.00     0.00
$
$  ***********************************************************************
$  *** Damping Analysis Card Groups. ***
$  The input data cards needed to perform the damping analysis are
$  specified below:
$
$  --- Damping Option Card Group --- Card Group V.
$
  FRICTN        0   IF:  1 - Include Friction Effects
 TEMPRIS        0        1 - Temp's from Individual Ply Heat Generation
 DAMPOUT        0        1 - Suspends Damping's Output Printout
$
$  --- Forcing Frequency   --- Card Group VI.
$
  FREQ       50.0
$
$  --- Deformation  --- Card Group VII.
$
 STRAINS      0.0      0.0      0.0
 CURVTUR      0.0      0.0      0.0
$
$  --- Friction Data, (MU and NFB) --- Card Group VIII.
$
  PLY           1     0.30     0.20
  PLY           2     0.30     0.20
  PLY           3     0.30     0.20
  PLY           4     0.30     0.20
  PLY           5     0.30     0.20
  PLY           6     0.30     0.20
  PLY           7     0.30     0.20
  PLY           8     0.30     0.20
$
$  *** END of Damping Analysis Card Groups. ***
$  ***********************************************************************
$
$  --- Loads Card Group --- Card Group IX.
```

```
$  In-plane  Membrane  Loads.
   PMEMB     00.0    00.      0.0     0.0
$  In-plane  Bending  Loads.
   PBEND      2.0    0.0      0.0     0.0
$  Transverse  Loads.
   PTRAN      0.0    0.0        0.     00.
$
$   --- Cyclic  or Fatigue  Load  Data  Group --- Card  Group  X.
$   Loading  for  the Durability  Analysis.   Mechanical/Thermal  Fatigue.
    CNXX   200.    100.     100.     0.1
    CNYY   -50.    -100.    10.     0.1
    CNXY   20.      10.     100.     0.2
    CMXX   10.       5.      10.     0.01
    CMYY    4.       2.      1000.    0.15
    CMXY    2.       1.      100.     0.01
$
$   --- Output  Selection  Data  Group --- Card  Group  XI.
$   The output  can  be  tailor.   OPTION  0 is  the  output  request  for
$   complete  results.
$
   PRINT      ALL    Output  request  for  complete  results     (OPTION  0)
```

Appendix C.—Sample Data Bank

```
FIBER  PROPERTIES
T300   GRAPHITE  FIBER.
$
$
$
Number  of  fibers  per  end        Nf          3000         number
Filament  equivalent  diameter      df          0.300E-03    inches
Weight  density                     Rhof        0.640E-01    lb/in**3
Normal  moduli  (11)                Ef11        0.320E+08    psi
Normal  moduli  (22)                Ef22        0.200E+07    psi
Poisson's  ratio  (12)              Nuf12       0.200E+00    non-dim
Poisson's  ratio  (23)              Nuf23       0.250E+00    non-dim
Shear  moduli  (12)                 Gf12        0.130E+07    psi
Shear  moduli  (23)                 Gf23        0.700E+06    psi
Thermal  expansion  coef.  (11)     Alfaf11     -.550E-06    in/in/F
Thermal  expansion  coef.  (22)     Alfaf22     0.560E-05    in/in/F
Heat  conductivity  (11)            Kf11        0.403E+01    BTU-in/hr/in**2/F
Heat  conductivity  (22)            Kf22        0.403E+00    BTU-in/hr/in**2/F
Heat  capacity                      Cf          0.170E+00    BTU/lb/F
Fiber  tensile  strength            SfT         0.350E+06    psi
Fiber  compressive  strength        SfC         0.300E+06    psi
Fiber  damping  capacity  (11)      Zetaf11     0.100E-02    non-dim
Fiber  damping  capacity  (22)      Zetaf22     0.000E+00    non-dim
Fiber  damping  capacity  (12)      Zetaf12     0.000E+00    non-dim
Fiber  damping  capacity  (23)      Zetaf23     0.000E+00    non-dim


HMSF   HIGH  MODULUS  SURFACE  TREATED  FIBER.
$
$
$
Number  of  fibers  per  end        Nf          10000        number
Filament  equivalent  diameter      df          0.300E-03    inches
Weight  density                     Rhof        0.703E-01    lb/in**3
Normal  moduli  (11)                Ef11        0.550E+08    psi
Normal  moduli  (22)                Ef22        0.900E+06    psi
Poisson's  ratio  (12)              Nuf12       0.200E+00    non-dim
Poisson's  ratio  (23)              Nuf23       0.250E+00    non-dim
Shear  moduli  (12)                 Gf12        0.110E+07    psi
Shear  moduli  (23)                 Gf23        0.700E+06    psi
Thermal  expansion  coef.  (11)     Alfaf11     -.550E-06    in/in/F
Thermal  expansion  coef.  (22)     Alfaf22     0.560E-05    in/in/F
Heat  conductivity  (11)            Kf11        0.403E+01    BTU-in/hr/in**2/F
Heat  conductivity  (22)            Kf22        0.403E+00    BTU-in/hr/in**2/F
Heat  capacity                      Cf          0.170E+00    BTU/lb/F
Fiber  tensile  strength            SfT         0.280E+06    psi
Fiber  compressive  strength        SfC         0.200E+06    psi
Fiber  damping  capacity  (11)      Zetaf11     0.400E-02    non-dim
Fiber  damping  capacity  (22)      Zetaf22     0.400E-02    non-dim
Fiber  damping  capacity  (12)      Zetaf12     0.400E-02    non-dim
Fiber  damping  capacity  (23)      Zetaf23     0.400E-02    non-dim


HT-S
$
$
$
Number  of  fibers  per  end        Nf          10000        number
Filament  equivalent  diameter      df          0.300E-03    inches
Weight  density                     Rhof        0.640E-01    lb/in**3
Normal  moduli  (11)                Ef11        0.320E+08    psi
Normal  moduli  (22)                Ef22        0.250E+07    psi
Poisson's  ratio  (12)              Nuf12       0.200E+00    non-dim
Poisson's  ratio  (23)              Nuf23       0.250E+00    non-dim
Shear  moduli  (12)                 Gf12        0.150E+07    psi
Shear  moduli  (23)                 Gf23        0.100E+07    psi
Thermal  expansion  coef.  (11)     Alfaf11     -.550E-06    in/in/F
Thermal  expansion  coef.  (22)     Alfaf22     0.560E-05    in/in/F
Heat  conductivity  (11)            Kf11        0.403E+01    BTU-in/hr/in**2/F
```

```
Heat conductivity (22)          Kf22       0.403E+00     BTU-in/hr/in**2/F
Heat capacity                   Cf         0.170E+00     BTU/lb/F
Fiber tensile strength          SfT        0.350E+06     psi
Fiber compressive strength      SfC        0.300E+06     psi
Fiber damping capacity (11)     Zetaf11    0.700E-02     non-dim
Fiber damping capacity (22)     Zetaf22    0.700E-02     non-dim
Fiber damping capacity (12)     Zetaf12    0.600E-02     non-dim
Fiber damping capacity (23)     Zetaf23    0.600E-02     non-dim


KEVL   KEVLAR FIBER.
$
$
$
Number of fibers per end        Nf           580         number
Filament equivalent diameter    df         0.460E-03     inches
Weight density                  Rhof       0.530E-01     lb/in**3
Normal moduli (11)              Ef11       0.220E+08     psi
Normal moduli (22)              Ef22       0.600E+06     psi
Poisson's ratio (12)            Nuf12      0.350E+00     non-dim
Poisson's ratio (23)            Nuf23      0.350E+00     non-dim
Shear moduli (12)               Gf12       0.420E+06     psi
Shear moduli (23)               Gf23       0.220E+06     psi
Thermal expansion coef. (11)    Alfaf11    -.220E-05     in/in/F
Thermal expansion coef. (22)    Alfaf22    0.300E-04     in/in/F
Heat conductivity (11)          Kf11       0.118E-01     BTU-in/hr/in**2/F
Heat conductivity (22)          Kf22       0.118E-01     BTU-in/hr/in**2/F
Heat capacity                   Cf         0.250E+00     BTU/lb/F
Fiber tensile strength          SfT        0.400E+06     psi
Fiber compressive strength      SfC        0.750E+05     psi
Fiber damping capacity (11)     Zetaf11    0.180E-01     non-dim
Fiber damping capacity (22)     Zetaf22    0.180E-01     non-dim
Fiber damping capacity (12)     Zetaf12    0.180E-01     non-dim
Fiber damping capacity (23)     Zetaf23    0.180E-01     non-dim


EGLA   E-GLASS FIBER.
$
$
$
Number of fibers per end        Nf           204         number
Filament equivalent diameter    df         0.360E-03     inches
Weight density                  Rhof       0.900E-01     lb/in**3
Normal moduli (11)              Ef11       0.105E+08     psi
Normal moduli (22)              Ef22       0.105E+08     psi
Poisson's ratio (12)            Nuf12      0.200E+00     non-dim
Poisson's ratio (23)            Nuf23      0.200E+00     non-dim
Shear moduli (12)               Gf12       0.437E+07     psi
Shear moduli (23)               Gf23       0.437E+07     psi
Thermal expansion coef. (11)    Alfaf11    0.280E-05     in/in/F
Thermal expansion coef. (22)    Alfaf22    0.280E-05     in/in/F
Heat conductivity (11)          Kf11       0.521E-01     BTU-in/hr/in**2/F
Heat conductivity (22)          Kf22       0.521E-01     BTU-in/hr/in**2/F
Heat capacity                   Cf         0.170E+00     BTU/lb/F
Fiber tensile strength          SfT        0.360E+06     psi
Fiber compressive strength      SfC        0.360E+06     psi
Fiber damping capacity (11)     Zetaf11    0.110E-01     non-dim
Fiber damping capacity (22)     Zetaf22    0.110E-01     non-dim
Fiber damping capacity (12)     Zetaf12    0.600E-02     non-dim
Fiber damping capacity (23)     Zetaf23    0.600E-02     non-dim


OVER END OF FIBER PROPERTIES


MATRIX PROPERTIES
LMLS LOW MODULUS LOW STRENGTH MATRIX.
$
$
$
Weight density                  Rhom       0.420E-01     lb/in**3
Normal modulus                  Em         0.320E+06     psi
Poisson's ratio                 Num        0.430E+00     non-dim
```

```
Thermal expansion coef.             Alfa m     0.570E-04    in/in/F
Matrix heat conductivity            Km         0.868E-02    BTU-in/hr/in**2/F
Heat capacity                       Cm         0.250E+00    BTU/lb/F
Matrix tensile strength             SmT        0.800E+04    psi
Matrix compressive strength         SmC        0.150E+05    psi
Matrix shear strength               SmS        0.800E+04    psi
Allowable tensile strain            eps mT     0.810E-01    in/in
Allowable compr. strain             eps mC     0.150E+00    in/in
Allowable shear strain              eps mS     0.100E+00    in/in
Allowable torsional strain          eps mTOR   0.100E+00    in/in
Void heat conductivity              kv         0.225E+00    BTU-in/hr/in**2/F
Glass transition temperature        Tgdr       0.350E+03    F
Matrix damp. capacity-Normal        Zeta mn    0.850E-01    non-dim
Matrix damp. capacity-Shear         Zeta ms    0.138E+00    non-dim


IMLS   INTER. MODULUS LOW STRENGTH (SIMILAR TO 3508)
$
$
$
Weight density                      Rhom       0.460E-01    lb/in**3
Normal modulus                      Em         0.500E+06    psi
Poisson's ratio                     Num        0.410E+00    non-dim
Thermal expansion coef.             Alfa m     0.570E-04    in/in/F
Matrix heat conductivity            Km         0.868E-02    BTU-in/hr/in**2/F
Heat capacity                       Cm         0.250E+00    BTU/lb/F
Matrix tensile strength             SmT        0.700E+04    psi
Matrix compressive strength         SmC        0.210E+05    psi
Matrix shear strength               SmS        0.700E+04    psi
Allowable tensile strain            eps mT     0.140E-01    in/in
Allowable compr. strain             eps mC     0.420E-01    in/in
Allowable shear strain              eps mS     0.320E-01    in/in
Allowable torsional strain          eps mTOR   0.320E-01    in/in
Void heat conductivity              kv         0.225E+00    BTU-in/hr/in**2/F
Glass transition temperature        Tgdr       0.420E+03    F
Matrix damp. capacity-Normal        Zeta mn    0.850E-01    non-dim
Matrix damp. capacity-Shear         Zeta ms    0.138E+00    non-dim


IMHS  INTERMEDIATE MODULUS HIGH STRENGTH MATRIX.
$
$
$
Weight density                      Rhom       0.440E-01    lb/in**3
Normal modulus                      Em         0.500E+06    psi
Poisson's ratio                     Num        0.350E+00    non-dim
Thermal expansion coef.             Alfa m     0.360E-04    in/in/F
Matrix heat conductivity            Km         0.868E-02    BTU-in/hr/in**2/F
Heat capacity                       Cm         0.250E+00    BTU/lb/F
Matrix tensile strength             SmT        0.150E+05    psi
Matrix compressive strength         SmC        0.350E+05    psi
Matrix shear strength               SmS        0.130E+05    psi
Allowable tensile strain            eps mT     0.200E-01    in/in
Allowable compr. strain             eps mC     0.500E-01    in/in
Allowable shear strain              eps mS     0.350E-01    in/in
Allowable torsional strain          eps mTOR   0.350E-01    in/in
Void heat conductivity              kv         0.225E+00    BTU-in/hr/in**2/F
Glass transition temperature        Tgdr       0.420E+03    F
Matrix damp. capacity-Normal        Zeta mn    0.660E-01    non-dim
Matrix damp. capacity-Shear         Zeta ms    0.690E-01    non-dim


D209  DX209 RESIN
$
$
$
Weight density                      Rhom       0.440E-01    lb/in**3
Normal modulus                      Em         0.500E+06    psi
Poisson's ratio                     Num        0.350E+00    non-dim
Thermal expansion coef.             Alfa m     0.360E-04    in/in/F
Matrix heat conductivity            Km         0.868E-02    BTU-in/hr/in**2/F
Heat capacity                       Cm         0.250E+00    BTU/lb/F
Matrix tensile strength             SmT        0.150E+05    psi
```

```
Matrix  compressive  strength     SmC         0.350E+05     psi
Matrix  shear  strength           SmS         0.130E+05     psi
Allowable  tensile  strain        eps  mT     0.200E-01     in/in
Allowable  compr.  strain         eps  mC     0.500E-01     in/in
Allowable  shear  strain          eps  mS     0.350E-01     in/in
Allowable  torsional  strain      eps  mTOR   0.350E-01     in/in
Void  heat  conductivity          kv          0.225E+00     BTU-in/hr/in**2/F
Glass  transition  temperature    Tgdr        0.420E+03     F
Matrix  damp.  capacity-Normal    Zeta  mn    0.172E+00     non-dim
Matrix  damp.  capacity-Shear     Zeta  ms    0.168E+00     non-dim


D210   DX210  RESIN
$
$
$
Weight  density                   Rhom        0.440E-01     lb/in**3
Normal  modulus                   Em          0.500E+06     psi
Poisson's  ratio                  Num         0.350E+00     non-dim
Thermal  expansion  coef.         Alfa  m     0.360E-04     in/in/F
Matrix  heat  conductivity        Km          0.868E-02     BTU-in/hr/in**2/F
Heat  capacity                    Cm          0.250E+00     BTU/lb/F
Matrix  tensile  strength         SmT         0.150E+05     psi
Matrix  compressive  strength     SmC         0.350E+05     psi
Matrix  shear  strength           SmS         0.130E+05     psi
Allowable  tensile  strain        eps  mT     0.200E-01     in/in
Allowable  compr.  strain         eps  mC     0.500E-01     in/in
Allowable  shear  strain          eps  mS     0.350E-01     in/in
Allowable  torsional  strain      eps  mTOR   0.350E-01     in/in
Void  heat  conductivity          kv          0.225E+00     BTU-in/hr/in**2/F
Glass  transition  temperature    Tgdr        0.420E+03     F
Matrix  damp.  capacity-Normal    Zeta  mn    0.103E+00     non-dim
Matrix  damp.  capacity-Shear     Zeta  ms    0.118E+00     non-dim

OVER  END  OF  MATRIX  PROPERTIES
```

Appendix D.—Sample Damping Module Output

```
*****************************************************************************************
   D A M P I N G   A N A L Y S I S   O F   C O M P O S I T E   L A M I N A T E S
*****************************************************************************************


     SUPRESSED  OUTPUT  OPTIONS:

          - FRICTION  EFFECT  ON  ZETAL11
          - TEMPERATURE  PROFILES  BASED  ON  INDIVIDUAL  PLY  DISSIPATION

 -----------------------------------------------------------------------------
                 **  O N - A X I S   D A M P I N G  **
 -----------------------------------------------------------------------------

 MATERIAL  SYSTEM   1: (HMSF/D210  @ DT=    0.00,  M=0.00)
 --------------------

      FIBER  DAMPING  CAPACITY  (HMSF)  :

                     ZF11  =      0.4000E-02
                     ZF12  =      0.4000E-02
                     ZF13  =      0.4000E-02
                     ZF22  =      0.4000E-02
                     ZF23  =      0.4000E-02
                     ZF33  =      0.4000E-02

      MATRIX  DAMPING  CAPACITY  (D210)  :

                     ZMN   =      0.1030E+00
                     ZMS   =      0.1180E+00


      COMPOSITE  DAMPING  CAPACITY  (W/O  FRICTION):
      --------------------------

                     ZL11  =      0.4892E-02
                     ZL12  =      0.7041E-01
                     ZL13  =      0.7041E-01
                     ZL21  =      0.7041E-01
                     ZL22  =      0.4202E-01
                     ZL23  =      0.4817E-01
                     ZL31  =      0.7041E-01
                     ZL32  =      0.4817E-01
                     ZL33  =      0.4202E-01
```

```
-----------------------------------------------------------------------
                   ** O F F - A X I S   D A M P I N G **
-----------------------------------------------------------------------

                              PLY # 1      PLY # 2      PLY # 3      PLY # 4
                             HMSF/D210    HMSF/D210    HMSF/D210    HMSF/D210
                              0.0 DEG     90.0 DEG     45.0 DEG     -45.0 DEG

DAMPING MATRIX:  ZCXX       0.4892E-02   0.4202E-01   0.4693E-01   0.4693E-01
                 ZCXY       0.0000E+00   -.1509E-12   -.2347E-01   -.2347E-01
                 ZCXS       0.0000E+00   0.3598E-07   -.9283E-02   0.9283E-02
                 ZCYX       0.0000E+00   -.1509E-12   -.2347E-01   -.2347E-01
                 ZCYY       0.4202E-01   0.4892E-02   0.4693E-01   0.4693E-01
                 ZCYS       0.0000E+00   -.8304E-07   -.9283E-02   0.9283E-02
                 ZCSX       0.0000E+00   0.7195E-07   -.1857E-01   0.1857E-01
                 ZCSY       0.0000E+00   -.1661E-06   -.1857E-01   0.1857E-01
                 ZCSS       0.7041E-01   0.7041E-01   0.2346E-01   0.2346E-01
AXIAL DAMPING: ZCAXLX       0.4892E-02   0.4202E-01   0.5923E-01   0.5923E-01
               ZCAXLY       0.4202E-01   0.4892E-02   0.5923E-01   0.5923E-01
               ZCAXLS       0.7041E-01   0.7041E-01   0.4083E-01   0.4083E-01

                              PLY # 5      PLY # 6      PLY # 7      PLY # 8
                             HMSF/D210    HMSF/D210    HMSF/D210    HMSF/D210
                             -45.0 DEG     45.0 DEG     90.0 DEG      0.0 DEG

DAMPING MATRIX:  ZCXX       0.4693E-01   0.4693E-01   0.4202E-01   0.4892E-02
                 ZCXY       -.2347E-01   -.2347E-01   -.1509E-12   0.0000E+00
                 ZCXS       0.9283E-02   -.9283E-02   0.3598E-07   0.0000E+00
                 ZCYX       -.2347E-01   -.2347E-01   -.1509E-12   0.0000E+00
                 ZCYY       0.4693E-01   0.4693E-01   0.4892E-02   0.4202E-01
                 ZCYS       0.9283E-02   -.9283E-02   -.8304E-07   0.0000E+00
                 ZCSX       0.1857E-01   -.1857E-01   0.7195E-07   0.0000E+00
                 ZCSY       0.1857E-01   -.1857E-01   -.1661E-06   0.0000E+00
                 ZCSS       0.2346E-01   0.2346E-01   0.7041E-01   0.7041E-01
AXIAL DAMPING: ZCAXLX       0.5923E-01   0.5923E-01   0.4202E-01   0.4892E-02
               ZCAXLY       0.5923E-01   0.5923E-01   0.4892E-02   0.4202E-01
               ZCAXLS       0.4083E-01   0.4083E-01   0.7041E-01   0.7041E-01
```

```
------------------------------------------------------------------------
                     **   L A M I N A T E    D A M P I N G   **
------------------------------------------------------------------------

               ---> LAMINATE  MECHANICAL  STRAINS  <---

          MIDPLANE  STRAIN,  {E0}           CURVATURE,  {K}

           E01  =    0.1989E-10          K1  =    0.2777E-02
           E02  =   -0.2072E-10          K2  =   -0.2107E-03
           E03  =    0.1596E-10          K3  =   -0.1279E-02


          SPECIFIC  DAMPING  CAPACITY   = 0.601601601E-02
          FOR  ABOVE  STRAINS.

          DISSIPATED  STRAIN  ENERGY    = 0.167041144E-04
              (PER  AREA-CYCLE)
          STORED  STRAIN  ENERGY        = 0.277660601E-02
              (PER  AREA-CYCLE)



                       ---> LAMINATE  DAMPING  MATRICES  <---

         EXTENSIONAL  DAMPING:  {ACD}                COUPLING  DAMPING:  {BCD}

    0.6362E+04   0.6840E+03   0.8377E-03      0.1526E-04   0.4768E-05   0.1514E-06
    0.6840E+03   0.6362E+04   0.1623E-02      0.4411E-05   0.1526E-04   0.3414E-06
    0.1009E-02   0.1642E-02   0.2839E+04      0.6083E-06   0.7982E-06   0.4005E-04

         COUPLING  DAMPING:  {CCD}                 FLEXURAL  DAMPING:  {DCD}

    0.1526E-04   0.4768E-05   0.1514E-06      0.4148E+01   0.2868E+00   0.9786E-01
    0.4411E-05   0.1526E-04   0.3414E-06      0.1973E+00   0.2884E+01   0.9786E-01
    0.6083E-06   0.7982E-06   0.4005E-04      0.1128E+00   0.1128E+00   0.1391E+01
```

```
-----------------------------------------------------------------------
 **  P L Y   T E M P E R A T U R E   D I S T R I B U T I O N  **
-----------------------------------------------------------------------

     FREQUENCY  (HZ) =     50.00

     PLY          INITIAL         T - TO          T - TO          T - TO
                 TEMP (TO)      (AVERAGE)       (BOTTOM)          (TOP)
                 (DEG. F)       (DEG. F)        (DEG. F)        (DEG. F)

       1          70.000          0.000           0.000           0.000
       2          70.000          0.001           0.000           0.001
       3          70.000          0.001           0.001           0.001
       4          70.000          0.001           0.001           0.001
       5          70.000          0.001           0.001           0.001
       6          70.000          0.001           0.001           0.001
       7          70.000          0.001           0.001           0.000
       8          70.000          0.000           0.000           0.000


***********************************************************************
     E N D   O F   D A M P I N G   A N A L Y S I S
***********************************************************************
```

Appendix E.—Files for Compiling and Executing ICAN/DAMP Under VM/SP Operating System and VAX/VMS Environment

"REXX EXEC" file for compiling ICAN/DAMP under
VM/SP Operating System.

```
/* COMPILE EXEC */
ARG phylen phytyp phymod junk
"set cmstype ht"
FORTVS2 phylen "(MAP FLAG (E) opt(2) NOPRINT"
rcode = rc
if rcode = 4 then rcode = 0
"set cmstype rt"
load phylen "(clear"
genmod phylen
erase phylen text phymod
exit rcode
```

"REXX EXEC" file for executing ICAN/DAMP under
VM/SP Operating System.

```
/*   X----------------------------------------------X      */
/*   X                                                 X   */
/*   X              ICAN/DAMP    EXEC                  X   */
/*   X                                                 X   */
/*   X   This is a REXX EXEC file to run ICAN/DAMP     X   */
/*   X   File unit 7 is for INHYD.                     X   */
/*   X   File unit 5 is for Input.                     X   */
/*   X   File unit 8 is for Data Bank.                 X   */
/*   X   File unit 6 is for Output.                    X   */
/*   X                                                 X   */
/*   X      Fortran code filename: "icndamp".          X   */
/*   X         Data bank filename: "tbledam".          X   */
/*   X                                                 X   */
/*   X   NOTE: The data bank filename is specified     X   */
/*   X         in subroutine OPENFL.                   X   */
/*   X----------------------------------------------X      */
parse arg fn fm ft fout .
if fout = " " then fout = "dampout"
"FILEDEF FT07F001 DISK JUNK DAT D1 (LRECL 132 XTENT 9999"
"FILEDEF FT05F001 DISK "fn" DATA D1"
"FILEDEF FT06F001 DISK "fout" LISTING D1 (LRECL 132 XTENT 9999"
"icndamp"
"fil * clear"
"ERASE JUNK DAT D1"
exit rc
```

DCL Command Procedures File for executing ICAN/DAMP under VAX/VMS Operating System.

```
$! -----------------------------------------------------------------------------------------------
$!         COM FILE FOR THE EXECUTION OF ICAN/DAMP ON VAX
$! -----------------------------------------------------------------------------------------------
$!
$!         Input files
$ assign icninp.dat   for005
$ assign junk.dat     for007
$! NOTE:  The data bank file is specified
$! in subroutine OPENFL.
$!         Output files
$ assign dampout.dat  for006
$ assign sys$output   for001
$!         run icndmp.exe
$ run icndmp
$!
$ delete junk.dat;*
$ exit
```

Appendix F.—On-Axis Damping, Off-Axis Damping, and Laminate Damping Equations

Damping Micromechanics

Longitudinal normal ply SDC ψ_{l11}:

$$\psi_{l_{11}} = \psi_{f_{11}} k_f \frac{E_{f11}}{E_{l11}} + \psi_{mn} k_m \frac{E_m}{E_{l11}} \tag{1}$$

Transverse normal ply SDC's ψ_{l22}, ψ_{l33}:

$$\psi_{l22} = \psi_{f22} \sqrt{k_f} \frac{E_{22}}{E_{f22}} + \psi_{mn} (1 - \sqrt{k_f}) \frac{E_{22}}{E_m} \tag{2}$$

$$\psi_{l33} = \psi_{l22} \tag{3}$$

where

$$E_{22} = (1 - \sqrt{k_f}) E_m + \frac{\sqrt{k_f} E_m}{1 - \sqrt{k_f} [1 - (E_m/E_{f22})]} \tag{4}$$

In-plane shear ply SDC ψ_{l12}:

$$\psi_{l12} = \psi_{f12} \sqrt{k_f} \frac{G_{12}}{G_{f12}} + \psi_{ms} (1 - \sqrt{k_f}) \frac{G_{12}}{G_m} \tag{5}$$

where

$$G_{12} = (1 - \sqrt{k_f}) G_m + \frac{\sqrt{k_f} G_m}{1 - \sqrt{k_f} [1 - (G_m/G_{f12})]} \tag{6}$$

Out-of-plane shear ply SDC's ψ_{l23}, ψ_{l13}:

$$\psi_{l23} = \psi_{f23} \sqrt{k_f} \frac{G_{l23}}{G_{f23}} + \psi_{ms} \left(1 - \sqrt{k_f}\right) \frac{G_{l23}}{G_m} \tag{7}$$

$$\psi_{l13} = \psi_{l12} \tag{8}$$

where

$$G_{l23} = \frac{E_{l22}}{2(1 + \nu_{l23})} \tag{9}$$

$$E_{l22} = \frac{E_m}{1 - \sqrt{k_f}\left[1 - (E_m/E_{f22})\right]} \tag{10}$$

$$\nu_{l23} = \frac{\nu_m}{1 - k_f \nu_m} + k_f \left[\nu_{f23} - \frac{(1 - k_f)\,\nu_m}{1 - k_f \nu_m}\right] \tag{11}$$

In-Plane Damping

Off-axis composite damping $[\psi_c]$:

$$[\psi_c] = [R_\sigma]^T [\psi_l] [R_\sigma^{-1}]^T \tag{12}$$

where

$$[R_\sigma] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \sin 2\theta \\ \sin^2\theta & \cos^2\theta & -\sin 2\theta \\ -0.5\sin 2\theta & 0.5\sin 2\theta & \cos 2\theta \end{bmatrix} \tag{13}$$

On-axis damping matrix $[\psi_l]$

$$[\psi_l] = \begin{bmatrix} \psi_{l11} & 0 & 0 \\ 0 & \psi_{l22} & 0 \\ 0 & 0 & \psi_{l12} \end{bmatrix} \quad (14)$$

hence, the off-axis damping matrix is:

$$[\psi_c] = \begin{bmatrix} \psi_{cxx} & \psi_{cxy} & \psi_{cxs} \\ \psi_{cyx} & \psi_{cyy} & \psi_{cys} \\ \psi_{csx} & \psi_{csy} & \psi_{css} \end{bmatrix} \quad (15)$$

Laminate Damping

Extensional Damping Matrix $[A_D]$:

$$[A_D] = \sum_{i=1}^{N_l} (z_t - z_b)_i [E_c]_i [\psi_c]_i \quad (16)$$

Coupling Damping Matrix $[C_D]$:

$$[C_D] = \sum_{i=1}^{N_l} \frac{1}{2} (z_t^2 - z_b^2)_i [E_c]_i [\psi_c]_i \quad (17)$$

Flexural Damping Matrix $[D_D]$:

$$[D_D] = \sum_{i=1}^{N_l} \frac{1}{3} (z_t^3 - z_b^3)_i [E_c]_i [\psi_c]_i \quad (18)$$

where

$$[E_c]^{-1} = \begin{bmatrix} \dfrac{1}{E_{cxx}} & -\dfrac{\nu_{cyx}}{E_{cyy}} & -\dfrac{\nu_{csx}}{G_{cxy}} \\ -\dfrac{\nu_{cxy}}{E_{cxx}} & \dfrac{1}{E_{cyy}} & -\dfrac{\nu_{csy}}{G_{cxy}} \\ \dfrac{\nu_{cxs}}{E_{cxx}} & \dfrac{\nu_{cys}}{E_{cyy}} & \dfrac{1}{G_{cxy}} \end{bmatrix} \tag{19}$$

Dissipated Strain Energy (Per area-cycle) δW:

$$\delta W = \frac{1}{2} \; \varepsilon^o \; \kappa \begin{bmatrix} [A_D] & [C_D] \\ [C_D] & [D_D] \end{bmatrix} \begin{Bmatrix} \varepsilon^o \\ \kappa \end{Bmatrix} \tag{20}$$

Stored Strain Energy (Per area-cycle) W:

$$W = \frac{1}{2} \; \varepsilon^o \; \kappa \begin{bmatrix} [A] & [C] \\ [C] & [D] \end{bmatrix} \begin{Bmatrix} \varepsilon^o \\ \kappa \end{Bmatrix} \tag{21}$$

Laminate SDC ψ:

$$\psi = \frac{\delta W}{W} \tag{22}$$

Appendix G.—Damping Module Structure

Subroutine DAMP is the main subroutine of the damping module and is called from subroutine ICANSB of the main ICAN/DAMP code. A brief description of the module's basic subroutines is given as follows:

(1) Subroutine DBNKR2—This subroutine reads the data base of constituent materials and retrieves the fiber and matrix specific damping capacities.

(2) Subroutine ORTDMP—Calculates the on-axis ply damping capacities from the basic composite material constituent properties and fiber content (micromechanics).

(3) Subroutine LAMDMP—Calculates the off-axis SDC's of each ply, the laminate damping matrices $[A_D]$, $[C_D]$, and $[D_D]$, and the temperature rise (optional) based on the individual strain energy dissipation in each ply.

(4) Subroutine LAMLOS—Calculates the laminate SDC for a given local deformation and the temperature rise through-the-thickness based on the average strain energy loss.

References

1. Murthy P.L.N.; and Chamis C.C.: Integrated Composite Analyzer (ICAN): Users and Programmers Manual. NASA TP–2515, 1986.
2. Murthy P.L.N.; Ginty C.A.; and Sanfeliz J.G.: Second Generation Integrated Composite Analyzer (ICAN) Computer Code. NASA TP–3290, 1992.
3. Saravanos D.A.; and Chamis C.C.: Unified Micromechanics of Damping for Unidirectional and Off-Axis Fiber Composites. J. Compos. Technol. Res., vol. 12, no. 1, 1990, pp. 31-40.
4. Saravanos D.A.; and Chamis C.C.: Mechanics of Damping for Fiber Composite Laminates Including Hygrothermal Effects. AIAA J., vol. 28, no. 10, Oct. 1990, pp. 1813-1819.

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13. ABSTRACT ***(Maximum 200 words)***

This manual describes the use of the computer code ICAN/DAMP (Integrated Composite Analyzer with Damping Analysis Capabilities) for the prediction of damping in polymer-matrix composites. The code is written in FORTRAN 77 and is a version of the ICAN (Integrated Composite ANalyzer) computer program. The code incorporates a new module for synthesizing the material damping from micromechanics to laminate level. Explicit micromechanics equations based on hysteretic damping are programmed relating the on-axis damping capacities to the fiber and matrix properties and fiber volume ratio. The damping capacities of unidirectional composites subjected to off-axis loading are synthesized from on-axis damping values. The hygrothermal effect on the damping performance of unidirectional composites caused by temperature and moisture variation is modeled along with the damping contributions from interfacial friction between broken fibers and matrix. The temperature rise in continuously vibrating composite plies and composite laminates is also estimated. The ICAN/DAMP users manual provides descriptions of the damping analysis module's functions, structure, input requirements, output interpretation, and execution requirements. It only addresses the changes required to conduct the damping analysis and is used in conjunction with the "Second Generation Integrated Composite Analyzer (ICAN) Computer Code" users manual (NASA TP-3290).

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