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COMPUTER ANIMATION OF MODAL AND TRANSIENT VIBRATIONS

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SUMMARY

An interactive computer graphics postprocessor is described that is capable of generating input to animate modal and transient vibrations of finite element models on an interactive graphics system. The results from NASTRAN can be postprocessed such that a three-dimensional (3-D) wire-frame picture, in perspective, of the finite element mesh is drawn on the graphics display. Modal vibrations of any mode shape or transient motions over any range of time steps can be animated. The finite element mesh can be color-coded by any component of displacement. Viewing parameters and the rate of vibration of the finite element model can be interactively updated while the structure is vibrating.

INTRODUCTION

As the computational power of computers has increased, the size of finite element models that an engineer can analyze in a reasonable amount of time has also increased. Finite element models that are analyzed overnight on an average computer can now be analyzed routinely in under an hour on a supercomputer. However, an engineer is still faced with the task of assimilating and drawing meaningful conclusions from large amounts of output generated by the finite element analysis programs. Output from these programs is presented as almost endless values of stress, strain, and displacement associated with nodes and/or elements. The interpretation of the finite element results is made even more difficult when real and imaginary values are considered. Structural deformations or color contours of nodal results for various mode shapes or time steps can be plotted in addition to graphs of the response of a finite element node versus time or frequency. However, the engineer is still depending on static plots to understand the dynamic behavior of a structure.

A postprocessing computer program, CANDI (Color Animation of Nastran DIsplacements) for NASTRAN finite element analysis results has been developed. CANDI generates input for an interactive graphics system so that modal and transient vibrations of finite element models can be animated. Providing the capability to animate finite element results has greatly improved the engineer's ability to interpret dynamic results that were previously viewed with static plots.

Unfortunately, the black and white reproduction of this paper cannot show the color animation that is generated by the hardware and software to be described. The reader will have to use his imagination.

HARDWARE

The hardware that is used to display the animation of finite element analysis results is an Evans & Sutherland PS-330 interactive graphics system (ref. 1). The PS-330 has the ability to process a large number of vectors, as would be dictated by complex finite element meshes, and to perform real-time 3-D interactive transformation of those vectors. The user can manipulate the PS-330 graphics display by means of a display data structure, a function network, and various input devices. The display data structure represents the finite element mesh and transformations applied to the mesh for scaling, rotation, translation, and other viewing purposes.

The function network represents a user-programmable system for describing the processing of interactive input and output local to the PS-330. The function network determines the effect of input from interactive devices on the display data structure (in the form of a finite element mesh). The user interacts with the function network through programmable interactive control dials and function keys. The display processor refreshes the screen image in real-time by traversing the display data structure which the function network is potentially modifying.

The graphics display consists of a 19-inch color vector refresh display. Finite element meshes are displayed in color or with depth-cueing. Depth-cueing enhances the illusion of depth and three dimensions by drawing vectors lighter the "farther away" they are from the viewer. Also, to enhance the illusion of three dimensions, perspective viewing of the finite element mesh is used.

FUNCTION NETWORKS

Function networks on the PS-330 are an example of data flow programming (ref. 2). An operator of a data flow program is known as a function instance. The PS-330 has a predefined set of over 100 function instances such as add, multiply, and rotate. Each function has a fixed number of inputs and outputs with predefined meanings. Data flow programming is accomplished by creating function instances and connecting inputs and outputs of the function instances to create the desired effect.

Function networks are data driven. A function becomes active only when data arrive at its inputs to be processed. Once a function has executed its task, it becomes dormant again until another set of input arrives. The entire function network is dormant until activity occurs at the interactive device to which it is connected.

Figure 1 shows a small part of the function network used in the animation of finite element model

```
WS_ROT := F:CMUL;
WS_MULX := F:MULC;
WS_XROT := F:XROTATE;
SEND 'X-ROT' TO <1>DLABEL1;
CONNECT DIALS<1>:<1>WS_MULX;
SEND 180 TO <2>WS_MULX;
CONNECT WS_MULX<1>:<1>WS_XROT;
CONNECT WS_XROT<1>:<2>WS_ROT;
CONNECT WS_ROT<1>:<1>WS_ROT;
CONNECT WS_ROT<1>:WORLD.ROT;
```

Fig. 1. Rotation function network

vibrations. This part of the function network sets up a control dial to control the X rotation of the finite element model on the display screen. Figure 2 shows a schematic of that function network. The first three lines, of the rotation function network, instance (refer to) some of the PS-330 functions. The fourth line sends a label to the LED lights on Control Dial 1. The fifth line connects the output of the control dial to the first input of one of the function instances. The sixth line sends a constant value of 180 to the second input of the same function instance. The remaining four lines connect the inputs

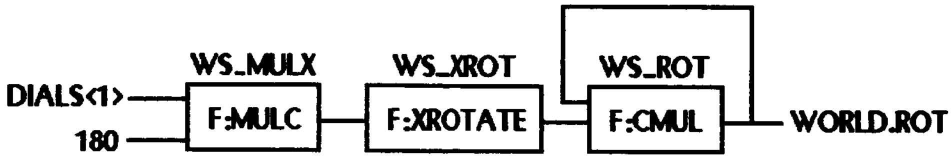

Fig. 2. Schematic of rotation function network

and outputs of the function instances in the correct manner. When the user rotates Control Dial 1, the end result is that the finite element model on the display screen will rotate about the screen's X axis.

To animate modal or transient vibrations of finite element models, a function network must be loaded into the PS-330. The basic function network used with CANDI sets up: (1) the control dials to do rotations and translations of the finite element model about the X, Y, and Z axes, and (2) function keys or control dials to both control the rate of vibration and cycle through the animation sequence. For transient vibrations, the animation sequence consists of deformed shapes of the finite element model over a range of time steps. For modal vibrations, the animation sequence consists of a sinusoidal variation of the deformation of the finite element model.

In addition to controlling the function of the control dials and function keys, the function network also contains the geometry of the finite element model that is to be animated. The geometry is written in a vector list function. The vector list contains the necessary XYZ coordinate information to draw the finite element mesh. A coordinate value in the vector list will be computed from the undeformed XYZ coordinates of the finite element model plus the product of displacement of that coordinate and a scale factor. An example of a vector list is shown in figure 3.

```
BEAM := VEC COLOR ITEM
P 1.000, 0.000, 0.000 H=120.
L 1.500, 0.000, 0.000 H=120.
L 2.000, 0.000, 0.000 H=120.
L 2.500, 0.000, 0.000 H=120.
L 3.000, 0.000, 0.000 H=120.
L 3.500, 0.000, 0.000 H=120.
L 4.000, 0.000, 0.000 H=120.
L 4.500, 0.000, 0.000 H=120.
L 5.000, 0.000, 0.000 H=120.;
```

Fig. 3. Example vector list

The first line of the vector list establishes a name for the vector list function instance. The remaining lines give the XYZ coordinates of the finite element mesh. The "P" means move to that coordinate. The "L" means draw to that coordinate. Associated with each coordinate is a color, "H=", which is specified by a value between zero and 360. The colors blue, magenta, red, yellow, green, and cyan have values of 0, 60, 120, 180, 240, and 300, respectively. If a line has the same color specified at the beginning and end, the entire line will be drawn with that single color. If the beginning and end of a line have different color values, then the color of the line will change between the beginning and end of the line. The finite element mesh can be color-coded by assigning a color value to each XYZ coordinate according to a nodal value of displacement.

Rather than have the host computer calculate the sinusoidal variation of the deformations for modal vibrations, the function network computes the animation sequence locally on the PS-330 according to the following equation (ref. 3):

$$F_i = V_u + DSF \left[V_{re}\sin\theta_i - V_{im}\cos\theta_i \right]$$

where F_i is one frame in the animation sequence, V_u is the undeformed vector list, V_{re} is the real deformation vector list, V_{im} is the imaginary deformation vector list, DSF is the deformation scale factor, and θ_i is the angle for F_i. Usually a value of i between 12 and 16 is an acceptable number of frames for smooth animation.

POSTPROCESSING OF NASTRAN RESULTS

The program CANDI can postprocess results from several different NASTRAN analyses: static, eigenvalue, direct frequency response, direct transient response, and modal frequency response. (A static analysis is handled in CANDI as a transient analysis with only one time step.) The NASTRAN analysis must generate a file that CANDI will postprocess. To write out that file, DMAP ALTER statements must be included in the NASTRAN executive control deck. Figure 4 shows an example of the

```
ALTER 83 $ Apr 86 Version
OUTPUT2 CASECC,BGPDT,ECT,LAMA,PPHIG $
ENDALTER $
```

Fig. 4. NASTRAN ALTER statments

ALTER statements required for an eigenvalue analysis. The data blocks that are written by these ALTER statements contain the following information: CASECC - case control information, BGPDT - XYZ nodal coordinates, ECT - element connectivity, LAMA - eigenvalues, and PPHIG - eigenvectors. There are similar ALTER statements to write the appropriate data blocks for the other types of analyses.

The data block that contains nodal displacements, for example PPHIG, is only generated when plotting is requested in the NASTRAN run. Therefore, plotting cards are required in the NASTRAN case control deck. This displacement data block is used rather than other displacement data blocks within NASTRAN, because the displacements are already in a basic XYZ cartesian coordinate system. Displacement in other data blocks would have to be transformed to that system.

CANDI USAGE

CANDI is an interactive program that prompts the user for various inputs and generates undeformed shape and displacement vector lists. All possible responses are listed with each question. A sample interactive session with CANDI is shown in figure 5. The user has many options to control the parts of the finite element model to be written to the vector lists. Elements can be excluded by element type or element identification number. Given a range of XYZ coordinate values, any element not within that range can also be excluded. Elements can be color-coded by element type; for example, plate elements may be green and solid elements cyan. The finite element mesh can also be color-coded by a nodal value of displacement. A user-modifiable deformation scale factor is computed. This scale factor multiplies the real displacements so that their magnitude will be similar to the dimensions of the finite element model. For a transient analysis, any range of time steps can be written to the displacement vector list. For an eigenvalue or frequency response analysis, any frequency also can be written to the displacement vector list.

DISPLAYING THE ANIMATION

Before the finite element model vibrations can be animated, the function network that sets up the function of the control dials and function keys must be sent from the host computer to the PS-330. The definition of the control dials and function keys for modal vibrations is shown in figure 6 and, for transient vibrations, in figure 7. Once either function network has been transmitted to the PS-330, the undeformed shape and displacement vector lists can be sent to the PS-330 from the host computer. Usually, the user will generate one undeformed shape and multiple displacement vector lists during one interactive session with CANDI. To animate different displacement vector lists, the desired vector list is downloaded to the PS-330. Once the required vector lists reside on the PS-330, the user has complete control over the animation through the use of the control dials and function keys.

REFERENCES

1. "PS-300 User's Manual," Evans & Sutherland Computer Corporation, Salt Lake City, Utah, 1985.
2. McGraw, J.R., "Data Flow Computing - Software Development," in: *IEEE Transactions on Computers,* Vol. C-29, No. 12, December 1980.
3. Ehlers, R., "Modal Vibration Simulation Package," Evans & Sutherland Computer Corporation, Salt Lake City, Utah, 1984.

```
$ candi

CANDI - Color Animation of Nastran DIsplacements

ENTER FILE NAME OF THE UT1 FILE ? fs.ut1

COORDINATE LIMITS OF THE STRUCTURE
XMIN=-2.39E+02  YMIN= 0.00E+00  ZMIN= 1.03E+03
XMAX= 2.39E+02  YMAX= 2.39E+02  ZMAX= 1.38E+03

DO YOU WANT TO EXCLUDE ELEMENTS BY COORDINATE RANGES (Y/N) ? n

3 ELEMENT TYPES, CURRENTLY RECOGNIZED BY CANDI, WERE FOUND IN THE FEM.
180-CBAR    58-CQUAD2   53-CTRIA2

DO YOU WANT TO EXCLUDE ELEMENTS BY ELEMENT TYPE (Y/N) ? n

DO YOU WANT TO EXCLUDE ELEMENTS BY ELEMENT ID (Y/N) ? n
READING CBAR
READING CQUAD2
READING CTRIA2

DO YOU WANT THE VECTOR LISTS TO BE WRITTEN
1 - COLOR CODED BY ELEMENT TYPE
2 - DEPTH CUED
? 1

ENTER FILE NAME FOR THE UNDEFORMED FEM VECTOR LIST ? fs.und
WRITING VECTOR LIST

DO YOU WANT TO GENERATE ANY DISPLACEMENT VECTOR LISTS (Y/N) ? y

NUMBER OF SUBCASES = 1, SUBCASE IDS -  1
NUMBER OF EIGENVECTORS =  3 (MODE-FREQUENCY)
 1-3.65E+01   2-3.83E+01   3-5.00E+01

ENTER A MODE NUMBER ? 2

ENTER FILE NAME FOR THE DISPLACEMENT VECTOR LIST ? fs.m2
ENTER NUMBER OF FRAMES OF ANIMATION ? 16
WRITING VECTOR LIST
MAXIMUM DEFORMATION = 1.1632E+00
DEFORMATION SCALE FACTOR = 2.0553E+01

DO YOU WANT TO WRITE ANOTHER DISPLACEMENT VECTOR LIST (Y/N) ? n
FORTRAN STOP
```

Fig. 5. Sample interactive session of CANDI

CD(1) - X rotation
CD(2) - Y rotation
CD(3) - Z rotation
CD(5) - X translation
CD(6) - Y translation
CD(7) - Z translation
CD(8) - Scale

FK(1) - Start modal vibration
FK(2) - Stop modal vibration
FK(4) - Step through animation sequence
FK(5) - Slow down rate of vibration
FK(6) - Speed up rate of vibration
FK(9) - Reset all rotations and translations
FK(10) - Toggle on/off undeformed shape
FK(11) - Toggle on/off coordinate axes
FK(12) - Calculate animation sequence from the undeformed vector list and the displacement vector lists

Fig. 6. Modal vibration control dial and function key definitions

CD(1) - X rotation
CD(2) - Y rotation
CD(3) - Z rotation
CD(4) - Control rate of vibration
CD(5) - X translation
CD(6) - Y translation
CD(7) - Z translation
CD(8) - Scale

FK(1) - Start/stop transient vibration
FK(9) - Reset all rotations and translations
FK(10) - Toggle on/off undeformed shape
FK(11) - Toggle on/off coordinate axes

Fig. 7. Transient vibration control dial and function key definitions