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TACT: A Set of MSC/PATRAN- & MSC/NASTRAN-based Modal Correlation Tools

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ABSTRACT

This paper describes the functionality and demonstrates the utility of the Test Analysis Correlation Tools (TACT), a suite of MSC/PATRAN Command Language (PCL) tools which automate the process of correlating finite element models to modal survey test data. The initial release of TACT provides a basic yet complete set of tools for performing correlation totally inside the PATRAN/NASTRAN environment. Features include a step-by-step menu structure, pre-test accelerometer set evaluation and selection, analysis and test result export/import in Universal File Format, calculation of frequency percent difference and cross-orthogonality correlation results using NASTRAN, creation and manipulation of mode pairs, and five different ways of viewing synchronized animations of analysis and test modal results. For the PATRAN-based analyst, TACT eliminates the repetitive, time-consuming and error-prone steps associated with transferring finite element data to a third-party modal correlation package, which allows the analyst to spend more time on the more challenging task of model updating. The usefulness of this software is presented using a case history, the correlation for a NASA Langley Research Center (LaRC) low aspect ratio research wind tunnel model. To demonstrate the improvements that TACT offers the MSC/PATRAN- and MSC/NASTRAN-based structural analysis community, a comparison of the modal correlation process using TACT within PATRAN versus external third-party modal correlation packages is presented.

NOMENCLATURE

ASET	Analysis Set in NASTRAN used to represent an Accelerometer Set
BDF	Bulk Data File
DMAP	Direct Matrix Abstraction Programming
DOF	Degrees-of-Freedom
FEM	Finite Element Model
PCL	PATRAN Command Language
$[\delta_x]$	Test / Analysis Cross-Orthogonality Matrix
$[\Phi_A]$	Mass-normalized Analysis Eigenvectors
$[\Phi_X]$	Mass-normalized Test Eigenvectors
$[M_A]$	Analytical Mass Matrix

1. BACKGROUND

The software backbone of the structural analysis capability in the Engineering Analysis Branch (EAB) at NASA LaRC is MacNeal Schwendler's PATRAN [1] finite element pre-/post-processor and NASTRAN [2] finite element solver. For the past several years, the branch has been searching for a software tool to aid its analysts in the process of correlating finite element models (FEMs) to modal survey test data. The branch had several criteria (presented in no particular order) in evaluating potential packages: (1) compatibility and integration with PATRAN/NASTRAN, (2) training required, (3) cost, and (4) improved efficiency over EAB's current correlation process. All of the packages that the branch reviewed were found lacking in at least one of these areas. Ideally, EAB wanted an inexpensive full-featured correlation tool inside the PATRAN/NASTRAN environment. An internal correlation tool would allow the analysts to perform the model updating process inside the PATRAN/NASTRAN environment where they already had a wealth of analysis experience. The cost to the branch to code such a tool would be limited to the development cost, which were estimated to be substantially less than the price of many commercial packages. Therefore, EAB decided to develop its own PATRAN/NASTRAN-based suite of correlation tools, now called "Test - Analysis Correlation Tools" (TACT), using the PATRAN Command Language (PCL).

2. PURPOSE

TACT is intended to be a correlation aid for PATRAN/ NASTRAN-based structural analysts who must develop a test-verified math model. For these structural analysts, TACT offers a complete, though basic, functionality for performing the entire correlation process completely inside the pre-/post-processor and solver that these analysts already know, understand and trust.

There are many methods available to the analyst for determining the degree to which analytical results correlate with test results. Ewins [3] has a detailed discussion of the orthogonality requirement, and also discusses other methods of comparing test and analysis results such as the Modal Assurance Criterion. The initial release of TACT only supports the cross-orthogonality criterion since this is the criterion normally specified for space-flight projects at NASA; however, other methods are planned for inclusion in future releases. The orthogonality between the mass and eigenvector matrices is evaluated by performing the following calculation:

$$[\Phi]^T[M][\Phi] = [\delta]$$

If the mass normalized eigenvectors, $[\Phi]$, are orthogonal with respect to the mass matrix, $[M]$, $[\delta]$ will be the identity matrix. The cross-orthogonality calculation for analysis and test eigenvectors is given as:

$$[\Phi_X]^T[M_A][\Phi_A] = [\delta_X]$$

If the test eigenvectors, $[\Phi_X]$, and the analysis eigenvectors, $[\Phi_A]$, represent the same mode shapes, $[\delta_X]$ will be close to the identity matrix. The cross-orthogonality criterion places constraints on the values of the diagonal and off-diagonal terms of $[\delta_X]$.

The TACT software was "beta-tested" during the modal correlation for a NASA LaRC low aspect ratio research wind tunnel model. The purpose of this analysis was to provide an accurate correlated FEM for the wind tunnel model on the sting support system. Stiffness and mode shape predictions from the correlated FEM were then used to validate new LaRC computational fluid dynamics software that includes structural characteristics in its solution. The FEM of this structure included the sting and wind tunnel model and is shown in Figure 1. This model contained 1,017 nodes, 1,275 elements, and over 6,000 degrees-of-freedom.

3. DESCRIPTION OF SOFTWARE

To make TACT an intuitive tool for PATRAN-based analysts, emphasis was placed on making TACT look like an integrated part of PATRAN. Just like other PATRAN tools, the user enters the TACT tools through a pull-down menu from the PATRAN main menu bar. All of the individual utilities in TACT are PATRAN forms; these forms look the same as all the other PATRAN forms and have the same widgets (buttons, slide bars, list boxes, select data boxes) that the PATRAN user is already knowledgeable in manipulating. The TACT on-line help is written in the native PATRAN help documentation format (FrameMaker) and has a hyperlinked table-of-contents that looks like MSC's on-line PATRAN documentation.

The TACT main menu was designed to be a step-by-step guide for analysts unfamiliar with the correlation process. There are four main sections in the TACT main menu: Pre-Test Modules, Post-Test Modules, 'View Results' Modules, and TACT Help. These sections are described in detail in the following sections. The overall organization of the TACT utilities is shown in the software map in Figure 2.

3.1 Pre-Test Modules

The successful process of correlating a FEM to modal survey test data begins long before the test ever takes place. The analyst will never be successful in achieving correlation of the FEM to the test data if steps are not taken to make sure that the test data is adequate for the analyst's needs. It is critical that the analyst and test engineer work together to define a set of accelerometers for the test that are physically accessible yet analytically adequate to capture the necessary test results.

After creating a FEM of the test article, the analyst is ready to use the Pre-Test Modules in TACT to analytically evaluate candidate accelerometer locations and orientations for the test. TACT uses NASTRAN to calculate a cross-orthogonality matrix between results from the full FEM and results from a reduced math model that describes the modal behavior that a particular accelerometer set would be capable of capturing. There are five utilities in the Pre-Test Modules: Run Full FEM Job, Create/Modify ASET, Create/Modify Stick Model, Run Full FEM/ASET Job, and Export ASET UFF.

Run Full FEM Job. After the analyst has created and is satisfied with a FEM of the test article, the first step in the Pre-Test process is to "baseline" the full FEM. TACT modifies the full FEM NASTRAN Bulk Data File (BDF) to include the NASTRAN DMAP in Figure 3, and automatically executes NASTRAN; the DMAP causes NASTRAN to punch the full FEM eigenvalue and eigenvector matrices to DMI cards. The DMI cards are included in future analysis BDFs, and additional DMAP is used to compare results for a particular accelerometer set to these full FEM results.

Create / Modify ASET. After the full FEM has been baselined, the analyst is ready to define sets of accelerometers, which are abbreviated in TACT as 'ASETs'. Analysts can create and modify ASETs using the form shown in Figure 4 by manually entering or 'screen picking' nodes they wish to identify as candidate accelerometers. The user can select the degrees-of-freedom (DOF) to be measured at each accelerometer location; the default DOF assignment is a triaxial accelerometer (XYZ). Accelerometer numbers can be manually or automatically assigned, and the user can modify them at any time. External to PATRAN, TACT establishes and manages directories and results file storage for each ASET.

Create / Modify Stick Model. This tool helps the analyst to define a "stick model" which simply "connects the dots" between accelerometers for easy test result visualization. Definition of the stick model can be done using manual data entry or by selecting entities from the viewport. Figure 5 shows a PATRAN viewport of the research wind tunnel model FEM after stick model creation; notice that the accelerometer numbers and DOF are shown in the viewport along with the stick model.

Run Full FEM / ASET Job. After the analyst has created an ASET and a stick model, the next step in the Pre-Test process is to analytically determine the adequacy of the ASET for capturing the desired modes during the modal survey test. The 'Run Full FEM/ASET Job' form prepares and submits a NASTRAN deck that uses the DMAP in Figure 6 to calculate frequency differences and a cross-orthogonality matrix between the full FEM results and the ASET results. The analyst can view the results of this analysis using the tools in the 'View Results' Modules. The analyst then modifies the ASET and reviews results in an iterative fashion (shown in Figure 2) until an acceptable ASET has been defined.

Export Analysis Data. Once the analyst and test engineer have settled on the accelerometer DOF and locations, the analyst is ready to export the analytical predictions to the test engineer. The Export Analysis Data form exports a single Universal File Format (UFF) file containing accelerometer locations (U15), "stick model" connectivity (U82), reduced analytical mass matrix (U247 & U252), and eigenvalue/vector results (U55), which can be imported into many test manager software codes, such as I-DEAS.

3.2 Post-Test Modules

Once the modal survey has been completed, the test engineer will post-process the results and deliver them to the analyst. Assuming the test results are valid, the analyst then begins the process of modifying the FEM so that the analytical results match the test results. Normally, changes to the FEM are made incrementally, and the effect of a particular FEM modification on the correlation is evaluated after each change.

To aid the analyst in performing this evaluation, TACT provides two Post-Test utilities, Import Test Results and Run ASET/Test Job, which are discussed in the sections that follow.

Import Test Results. This TACT utility reads in Universal File Format U15, U55, and U82 data types from a single UFF file, and stores the data for animation and correlation calculation in PATRAN and NASTRAN. TACT has a user-selectable "Auto-transform" import capability that automatically transforms test data to match the analytical model's units and coordinate system orientation.

Run ASET / Test Job. After the analyst has imported test results, the next step in the Post-Test process is to calculate the correlation between the test results and the current FEM. The 'Run ASET/Test Job' form prepares and submits a NASTRAN deck that uses the DMAP in Figure 7 to calculate frequency differences and a cross-orthogonality matrix between the ASET and test results. The analyst can then view the results of this analysis using the tools in the 'View Results' Modules. The analyst makes adjustments to the FEM that will improve the correlation, recreates the BDF, and reviews results in an iterative fashion (shown in Figure 2) until acceptable correlation has been achieved.

3.3 'View Results' Modules

Any time the analyst wishes to compare ASET modal results to either the full FEM or test results, the same basic capabilities are needed. First, the analyst needs to be able to view and post-process the frequency percent difference and cross-orthogonality calculations. Secondly, the analyst needs to be able to view the mode shapes and be able to visually compare ASET results to either the full FEM or test results. In the first several iterations of trying to determine where the FEM should be changed or updated to better reflect test data, most analysts use information from visual inspection of the mode shapes in conjunction with the correlation calculations. The two 'View Results' modules in TACT, Mode Pairs & Correlation and Animated Mode Shapes, are intended to provide a core set of tools for performing this function.

Mode Pairs & Correlation. This form, shown in Figure 8 using the low aspect ratio wind tunnel model results, provides the user with a single place to manipulate mode pairs and view the effects on the frequencies and cross-orthogonality results. TACT has an 'Auto Pair' capability, which calculates which modes form likely mode pairs based on user defined thresholds of frequency percent difference and on- and off-diagonal values in the cross-orthogonality matrix; Figure 8 actually shows mode pairs predicted by TACT's Auto-Pair function. TACT also has built-in Mode Pair Reports, which are optionally exported text files containing all mode pair results that are easily imported into test report or correlation report documents.

Animated Mode Shapes. The control panel for mode shape animation is shown in Figure 9. The user can display ASET and test mode combinations to the viewport based either on mode pairs or by selecting modes individually. The widgets on the form change depending upon this selection; in Figure 9, the user has selected Mode Pairs as the mode pairing method for display. All animation parameters on the form can be modified while animating or stepping through an animation.

TACT currently offers five different options for displaying animated mode shape results, including synchronized analysis and test results side-by-side, synchronized analysis and test results overlaid, and an animation of the difference between analysis and test results. Analysts might use any combination of these viewing methods to obtain an understanding of the differences between the ASET and test results. Figure 10 shows the viewport for the research wind tunnel model results using the overlay display method where both the ASET and test results are overlaid on the same undeformed stick model. Figure 11 shows the research wind tunnel model results using the adjacent display method where the results are shown next to each other on top of separate undeformed stick models.

3.4 On-line Help

TACT comes with an extensive 74-page on-line Reference Manual. This document was developed in FrameMaker, PATRAN's chosen format for help documents, to ensure that all potential users would have access to the software (the FrameMaker viewer is distributed with PATRAN) and be familiar with its use. The TACT Reference Manual contains a hyperlinked table-of-contents to make it simple for users to locate their topic of interest. In addition to screen shots/explanations of every form and widget available in TACT, the Reference Manual includes installation instructions and system requirements, file structure descriptions, a trouble-shooting guide, and a list of planned enhancements.

4. EVALUATION OF CORRELATION SOFTWARE

To demonstrate the improvements that TACT offers the MSC/PATRAN- and MSC/NASTRAN-based structural analysis community, an evaluation of the modal correlation process using TACT within PATRAN and external third-party modal correlation packages was performed. Three external third-party modal correlation packages were included in this review: Microdyne, Inc.'s DYNAVIEW marketed by Practical Systems and Technology, Inc. (1-410-758-2008), Structural Dynamics Research Corporation's (1-703-713-0006) I-DEAS Correlation, and LMS International's (1-578-453-4100) CADA-X Link. All software was assessed based on the following criteria: (1) compatibility/integration with PATRAN/NASTRAN, (2) training required, (3) cost, and (4) improved efficiency over EAB's current correlation process. Correlation of a NASA LaRC low aspect ratio research wind tunnel model was used as the case history for this study.

4.1 Compatibility / Integration with PATRAN / NASTRAN

For EAB analysts, software must be compatible and integrate well with their primary structural analysis codes, MSC/PATRAN and MSC/NASTRAN. TACT was developed to allow analysts the ability to perform all modal correlation tasks totally within the PATRAN/NASTRAN environment. Third-party packages such as DYNAVIEW, I-DEAS Correlation, and CADA-X Link are somewhat compatible with these analysis codes; however, this integration and compatibility is complicated by data translation and transfer, operation on/in different and sometimes unfamiliar computer platforms/environments, and the inability to perform internal model updating in PATRAN.

Before the development of TACT, modal correlation tasks were performed in EAB using DYNAVIEW. DYNAVIEW is a PC-based modal correlation package that provides the user with the capability to display, animate, and correlate modal data obtained from experimental and analytical sources using two modules – Modal Manager and Correlation Manager. To utilize this software, analytical models and results, generated in EAB on a Silicon Graphics Indigo2 workstation using MSC/PATRAN and MSC/NASTRAN, were transferred via ftp software to the PC. This required the analyst to operate on an entirely different computer platform, physically moving between computers often located in different rooms. Since DYNAVIEW only imports files written in either Enterprise Software Products, Inc.'s Finite Element Modeling and Post-processing (FEMAP) neutral or universal file format, FEMAP was used to convert MSC/NASTRAN analytical models and results to this file format. Both the analytical and test data were then individually brought into the Model Manager. Once DYNAVIEW analytical and test models were created, they were correlated using the Correlation Manager. During the entire modal correlation process, data was transferred four different times using four different software tools. If model updating was necessary, the user returned to the workstation, modified the analytical FEM in PATRAN, and then started the modal correlation process over again.

I-DEAS Correlation and CADA-X Link are robust workstation-based modal correlation packages that offer the analyst a complete set of tools for comparing modal data obtained from experimental and analytical sources. These tools include pre-test accelerometer set selection and evaluation, excitation setup, geometric mapping, visual comparison, MAC, orthogonality, frequency comparison, COMAC, and frequency response synthesis. Both packages have additional products that can be purchased to allow for optimization of accelerometer and excitation locations, design sensitivity, and modal updating – features currently not available in TACT or DYNAVIEW.

Similar to DYNAVIEW, I-DEAS Correlation and CADA-X Link require data translation of MSC/NASTRAN FEM and results; however, unlike DYNAVIEW, data translation is performed within these packages. Before translation, the MSC/NASTRAN deck must be run with a 'PARAM, POST' card in the case control section to output the appropriate files for these codes. While CADA-X Link is run on a Silicon Graphics workstation, I-DEAS Correlation must be run on a Hewlett-Packard 45I workstation because of its compatibility with LaRC's test data acquisition system. This system provides PATRAN users with two challenges: (1) transfer of analytical and test models and results across platforms and (2) operation in a different computer environment. Finally, these packages, like DYNAVIEW, require the user to perform model updating by returning to PATRAN, modifying the analytical FEM, and restarting the modal correlation process over again.

4.2 Training Required

Another criterion in evaluating potential software packages is the amount of training required. At NASA, training and travel budgets have sharply declined over the years, pressuring organizations like EAB to cut their training and travel costs. Sending employees to software training performed either on- or off-site can cost these organizations thousands of dollars. In addition to these costs, there is lost productivity while the employee is training.

Training on TACT and DYNAVIEW is unnecessary. Analysts acquainted with the modal correlation process will find these codes intuitive and easy to use. For analysts unfamiliar with modal correlation, TACT and DYNAVIEW provide step-by-step instruction through their main menu organization and on-line help.

For most PATRAN-based analysts, training on I-DEAS Correlation and CADA-X Link is a necessity. These packages are complex and sometimes operate in unfamiliar computer environments. For example, MSC/PATRAN users unacquainted with I-DEAS will find working with Correlation very difficult; I-DEAS users unfamiliar with MSC/PATRAN will also find working with TACT challenging. Although the basic functionality is the same for PATRAN and I-DEAS, structuring of each code is extremely different.

4.3 Cost

As with training and travel, EAB has a limited amount of money available for purchasing and maintaining software, making cost an important criterion in assessing potential software packages. In EAB, modal correlation is only one of the many tasks performed; therefore, spending a significant amount of monetary resources on software used for a small percentage of work is unjustified.

The results of a cost evaluation of TACT and the above third-party packages with their necessary modules and translators are presented in Table 1. For each software package, the government fees (as of September 1997) associated with licensing/software development and annual maintenance are listed. It should be noted that these are the fees that NASA is charged by these companies. In some cases, these prices may differ from the fees charged to other companies and government agencies as part of technology exchange agreements that have been established between the two parties.

Table 1: Cost Evaluation of TACT Versus Other Third-Party Modal Correlation Packages

Cost Item	TACT	DYNAVIEW	I-DEAS Correlation	CADA-X Link
One Paid-Up License/ Software Development	$8,100 (270 hrs)	$4,400	$19,000	$19,300
Annual Maintenance/ Development	$1500 (50 hrs)	$995	$2,565	$2,895

The first cost item shown above is, for TACT, the software development cost (also shown in hours), or, for third-party packages, the purchase price for one license. The software development cost of TACT is substantially lower than the price of one license of I-DEAS Correlation or CADA-X Link. There are times when two or more analysts need to simultaneously use modal correlation software. TACT allows users to access the software when needed; however, additional users of third-party packages require additional licenses. For a fairly inexpensive package like DYNAVIEW, purchasing two or more licenses will exceed the cost of developing TACT. It is important to note that since TACT was developed at LaRC, this code is free to other organizations within NASA; organizations outside NASA will eventually have free access to the software through the Langley Software Server (LSS).

The second cost item included in Table 1 is the annual software maintenance fee. This fee encompasses technical support, software upgrades, and error corrections. Higher-priced correlation packages, such as I-DEAS Correlation and CADA-X Link, have higher annual maintenance costs. These higher costs further tap limited software funds.

I-DEAS Correlation and CADA-X Link have additional software products that can be purchased to allow for optimization of accelerometer and excitation locations, design sensitivity analysis, and model updating - features currently not available in TACT or DYNAVIEW. For EAB analysts, these features are nice, but unnecessary; however, if they are ever needed, these features will either have to be incorporated into TACT or correlation packages like I-DEAS Correlation and CADA-X Link purchased.

4.4 Improved Efficiency Over EAB's Previous Correlation Process

The final criterion used in the evaluation of potential modal correlation packages is improved efficiency over EAB's previous correlation process. Prior to the development of TACT, EAB analysts performed modal correlation tasks using DYNAVIEW. Challenges already presented with using third-party software include data transfer/translation, operation on/in different computer platforms/environments, and external model updating with PATRAN. Other inefficiencies MSC/PATRAN and MSC/NASTRAN users encounter when using third-party software are external editing, bookkeeping, computer modeling, and manual analysis-to-test transformation tasks.

A time comparison of the entire modal correlation process for a NASA LaRC low aspect ratio research wind tunnel model was performed using TACT and DYNAVIEW to illustrate how inefficient and time-consuming third-party correlation packages are for MSC/PATRAN and MSC/NASTRAN analysts. The modal correlation process consisted of pre-test accelerometer set selection and evaluation, correlation of the reduced baseline FEM and test, model updating, and correlation of the reduced updated FEM and test. The results of this comparison were that the entire modal correlation process took 20% longer using DYNAVIEW than TACT. With TACT, MSC/PATRAN and MSC/NASTRAN users perform modal correlation tasks in less time because they never have to perform inefficient tasks such as data translation/transfer, operating on/in unfamiliar computer platforms/environments, external model updating/editing, and manual analysis-to-test transformation tasks.

5. FUTURE ENHANCEMENTS

NASA LaRC is a NASA Center of Excellence for Structures and Materials. In this role, LaRC pursues research in many structural dynamics topics, including accelerometer placement, and model updating. It is envisioned that TACT will provide the graphical user interface for these new technologies for LaRC's PATRAN-based modal correlation community. Major planned enhancements to TACT include:

- Inclusion of Modal Assurance Criteria (MAC), and Coordinate Modal Assurance Criteria (COMAC) calculations.
- Incorporating an optimization and/or design sensitivity solution to assist the analyst with model updating during correlation. This analysis would use minimizing frequency deltas or maximizing diagonal terms of the cross-orthogonality matrix as the objective function and user selected parameters in the FEM as design variables.

6. CONCLUSIONS

For the PATRAN-based analysis community, TACT is potentially a more attractive set of modal correlation tools over third-party modal correlation packages for many reasons. Many of the third-party packages have substantial costs associated with them, including purchase price, software maintenance, and training. For MSC/PATRAN and MSC/NASTRAN users, either on-the-job or formal training is required to learn the complex third-party software as well as a different computer environment. Even after the user is fluent in the third-party correlation software, the user must frequently perform inefficient and time-consuming tasks such as data transfer and translation into and out of PATRAN, bookkeeping and file organization, and manual analysis-to-test transformation tasks. TACT eliminates all of these issues for the PATRAN-based analyst, since it has no cost, is an intuitive add-on to PATRAN, and automates the mundane, clerical tasks in the correlation process. TACT streamlines the PATRAN-based correlation process, allowing the structural analyst to focus on the more complicated aspects of model updating.

7. ACKNOWLEDGEMENTS

The development of TACT would not have been possible without the support of several additional key people. Thanks go to Dr. John Whitesides, Director of the Joint Institute for the Advancement of Flight Sciences, for mentoring this project in partial fulfillment of the requirements for a Professional Degree Program, Degree of Engineer at George Washington University. Additional thanks go to Michael Lindell, also of the Engineering Analysis Branch, for developing the original NASTRAN DMAP correlation technique, which is the foundation for the modified correlation calculations performed by TACT.

8. REFERENCES

1. The MacNeal Schwendler Corporation. MSC/PATRAN User's Manual, Version 6.0. August 1996. Electronic Manual.
2. Reymond, Michael, and Mark Miller, Editors. MSC/NASTRAN V69 Quick Reference Guide. The MacNeal Schwendler Corporation. 1995. Electronic Manual.
3. Ewins, D. J. Modal Testing: Theory and Practice. Letchworth, England: Research Studies Press Ltd., 1984.

FIGURES

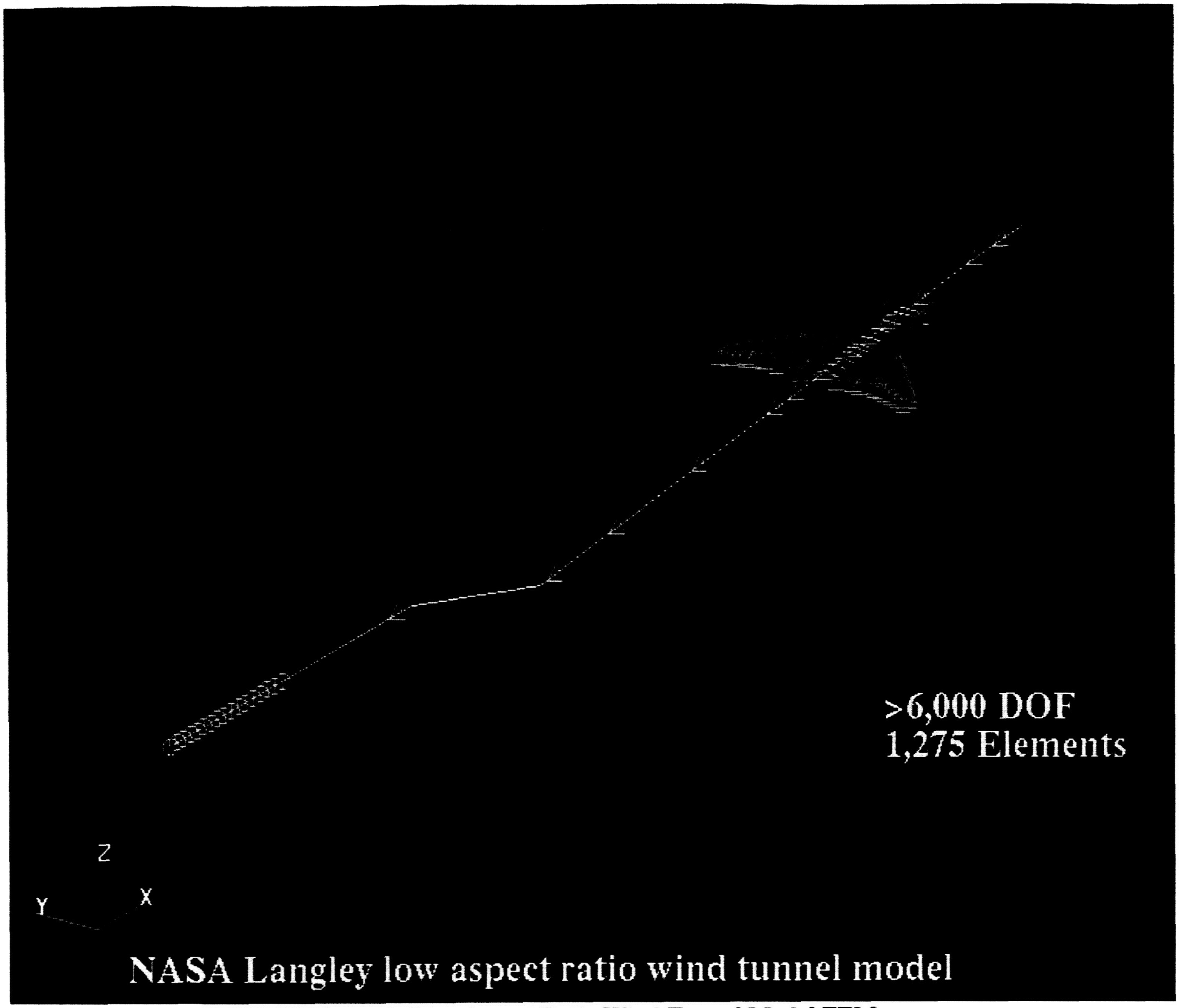

Figure 1: Low Aspect Ratio Wind Tunnel Model FEM

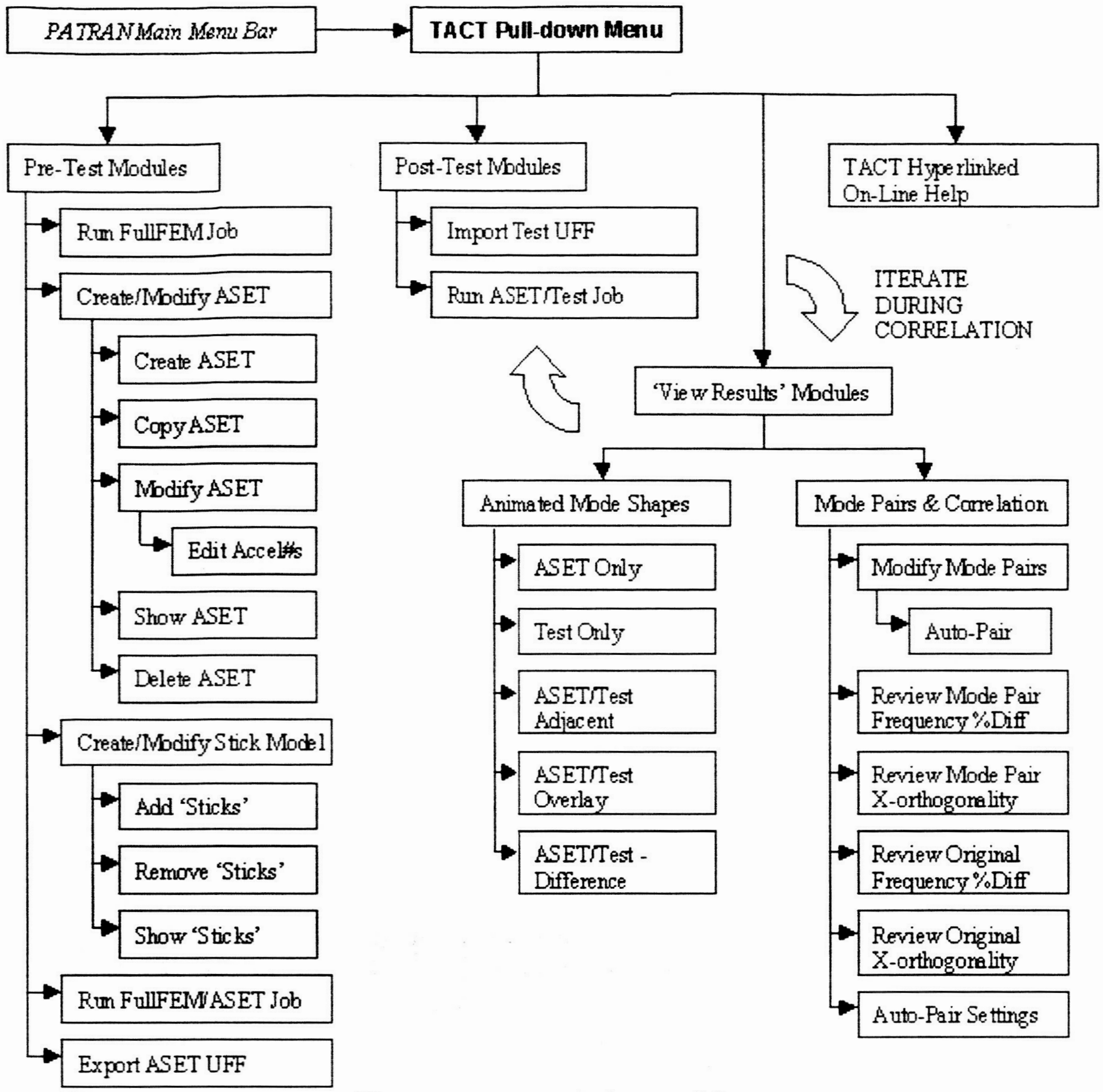

Figure 2: TACT Software Map

```
COMPILE SEMODES SOUIN=MSCSOU NOREF NOLIST
$ First, dump out full FEM eigenvalues
ALTER 152
LAMX, ,LAMA/LMAT/-1$
EQUIVX LMAT/FULLEIG/-1$
$ Then, dump out full FEM eigenvectors
ALTER 154
EQUIVX PHG/PHGF/-1$
MATPCH FULLEIG,PHGF,,,// $
```

Figure 3: 'Run Full FEM' DMAP

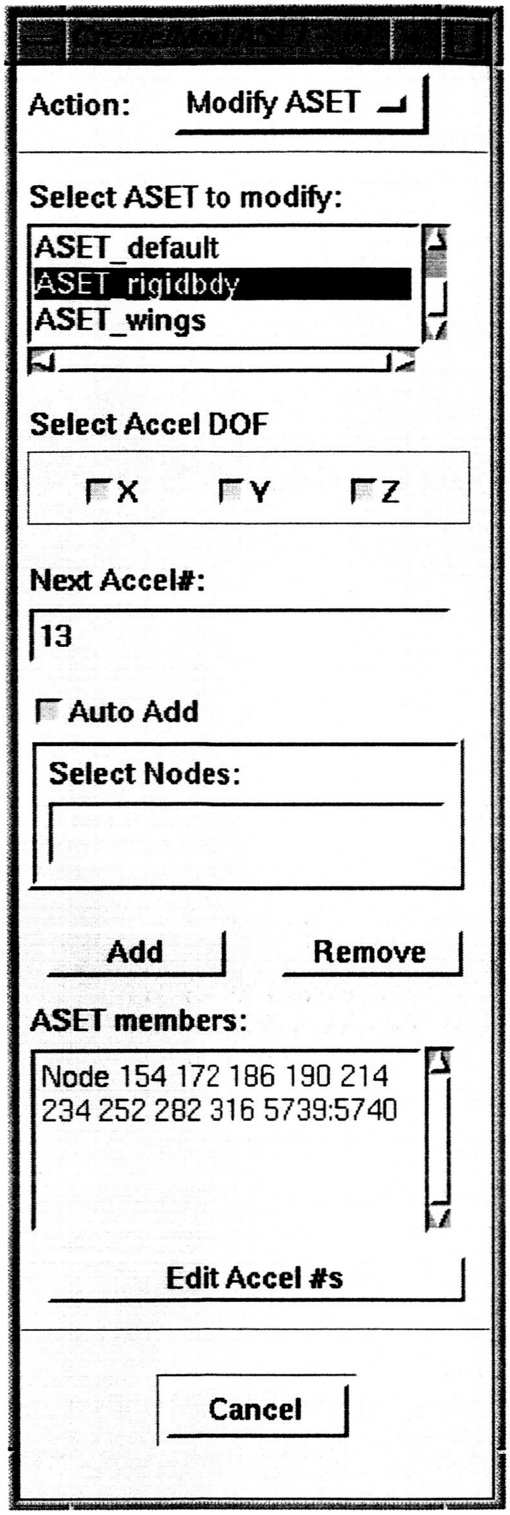

Figure 4: Create/Modify ASET Form

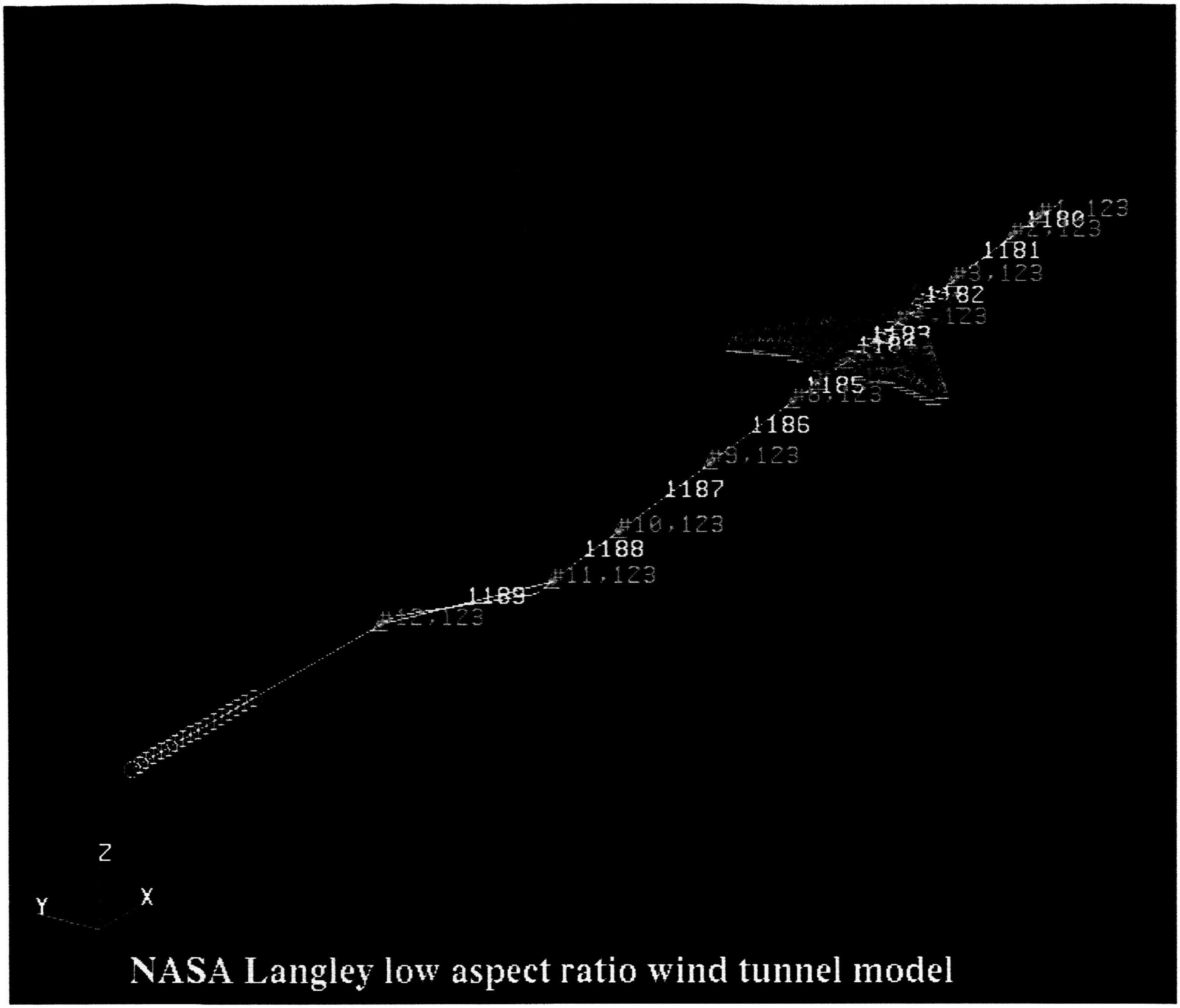

Figure 5: PATRAN Viewport Showing Accelerometer and 'Stick Model ' Labels

```
ASSIGN OUTPUT4 = `ASET_1st_try.f15', UNIT = 15, DELETE, FORM=FORMATTED
ASSIGN OUTPUT4 = `ASET_1st_try.f16', UNIT = 16, DELETE, FORM=FORMATTED
SOL 103
TIME 1000
COMPILE SEMODES SOUIN=MSCSOU NOREF NOLIST
ALTER 152
DMIIN DMI,DMINDX/FULLEIG,PHGF,,,,,,,,/ $
LAMX, ,LAMA/ASETEIG/-1$
ADD ASETEIG,FULLEIG/EIGDELTA/1./-1./0 $
ADD EIGDELTA,FULLEIG/PCNTDIFF/1./1./2 $
MATPRN PCNTDIFF,,,, // $
OUTPUT4 FULLEIG,,,,//0/15/0/ $ Full FEM eigenvalues
OUTPUT4 ASETEIG,,,,//0/15/0/ $ ASET FEM eigenvalues
OUTPUT4 PCNTDIFF,,,,//0/15/0/ $ Percent diff between
```

```
OUTPUT4 ASETEIG,,,,//0/16/0/ $ ASET FEM eigenvalues
ALTER 154
SMPYAD PHGF,MGG,PHG,,,/OCHK/3/1/1/1/1/0/0 $
MATPRN OCHK,,,, // $
OUTPUT4 OCHK,,,,//0/15/0/ $
OUTPUT4 PHA,,,,//0/16/0/ $
OUTPUT4 MAA,,,,//0/16/0/ $
```

Figure 6: 'Run Full FEM / ASET Job' DMAP

```
ASSIGN OUTPUT4 = `ASET_1st_try.f16', UNIT = 16, DELETE, FORM=FORMATTED
ASSIGN OUTPUT4 = `ASET_1st_try.f17', UNIT = 17, DELETE, FORM=FORMATTED
SOL 103
TIME 1000
REDUCED EIGS
COMPILE SEMODES SOUIN=MSCSOU NOREF NOLIST
ALTER 152
DMIIN DMI,DMINDX/TESTEIG,PHT,,,,,,,,/ $
LAMX, ,LAMA/ASETEIG/-1$
ADD ASETEIG,TESTEIG/EIGDELTA/1./-1./0 $
ADD EIGDELTA,TESTEIG/PCNTDIFF/1./1./2 $
MATPRN PCNTDIFF,,,, // $
OUTPUT4 TESTEIG,,,,//0/17/0/ $ Test eigenvalues
OUTPUT4 ASETEIG,,,,//0/17/0/ $ ASET FEM eigenvalues
OUTPUT4 PCNTDIFF,,,,//0/17/0/ $ Percent diff between
OUTPUT4 ASETEIG,,,,//0/16/0/ $ ASET FEM eigenvalues
ALTER 154
SMPYAD PHT,MAA,PHT,,,/MSF2/3/1/1/1/1/0/0 $ CALCULATE MODAL SCALE FACTORS
DIAGONAL MSF2/MSF/'SQUARE'/0.5 $
TRNSP PHT/PHTT $
SOLVE MSF,PHTT/PTNT/0 $ FORM MASS NORMALIZED TEST EIGENVECTORS
TRNSP PTNT/PHTN $
SMPYAD PHTN,MAA,PHA,,,/OCHK/3/1/1/1/1/0/0
MATPRN OCHK,,,, // $
OUTPUT4 OCHK,,,,//0/17/0/ $
OUTPUT4 PHA,,,,//0/16/0/ $
OUTPUT4 MAA,,,,//0/16/0/ $
```

Figure 7: 'Run ASET/Test Job' DMAP

Results for: Test vs. ASET_rigidbdy

Action: Modify Mode Pairs | Print to File

Pair #	Test M# - Hz	ASET M# - Hz	% Diff	Diagonal	Max Off-Diag
1	1 - 9.66	2 - 10.43	7.94%	0.9867	0.0960
2	2 - 9.87	1 - 10.16	2.95%	0.9986	0.0494
3	3 - 20.55	4 - 25.20	22.61%	0.9696	0.1934
4	4 - 22.90	3 - 24.67	7.75%	0.9899	0.3483
5	5 - 31.28	6 - 39.27	25.55%	0.9324	0.1934
6	6 - 32.31	5 - 38.72	19.83%	0.9290	0.3483
7	Skip	Skip	N/A	N/A	N/A
8	Skip	Skip	N/A	N/A	N/A
9	Skip	Skip	N/A	N/A	N/A
10	Skip	Skip	N/A	N/A	N/A
11	Skip	Skip	N/A	N/A	N/A
12	Skip	Skip	N/A	N/A	N/A

Reset | Auto-Pair | Undo | Exit Form

Figure 8: Mode Pairs & Calculation Form

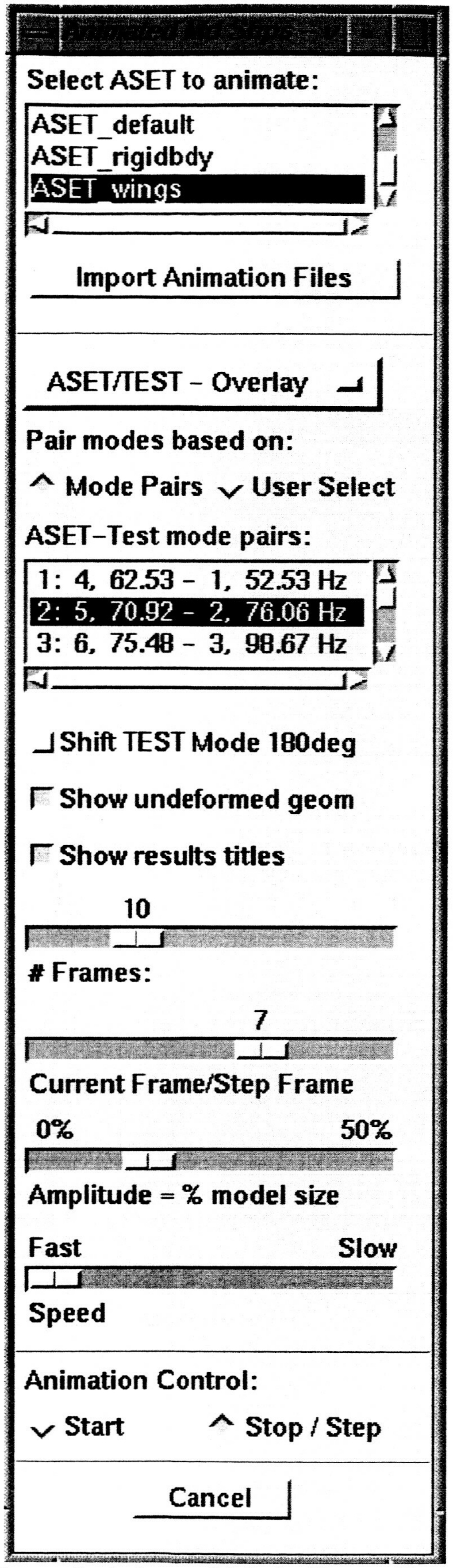

Figure 9: Animated Mode Shapes Form

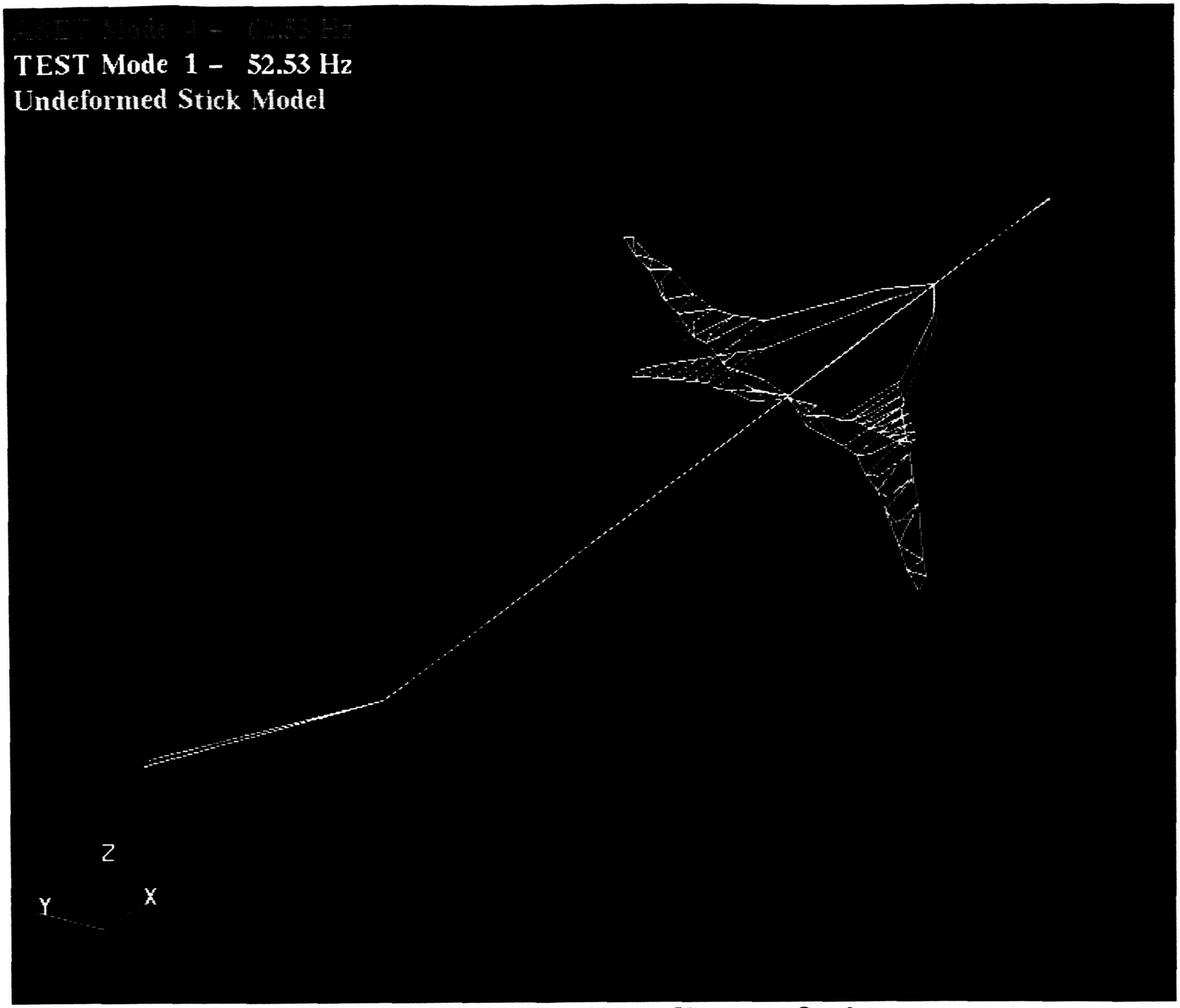

Figure 10: Stick Model Animation Viewport - Overlay

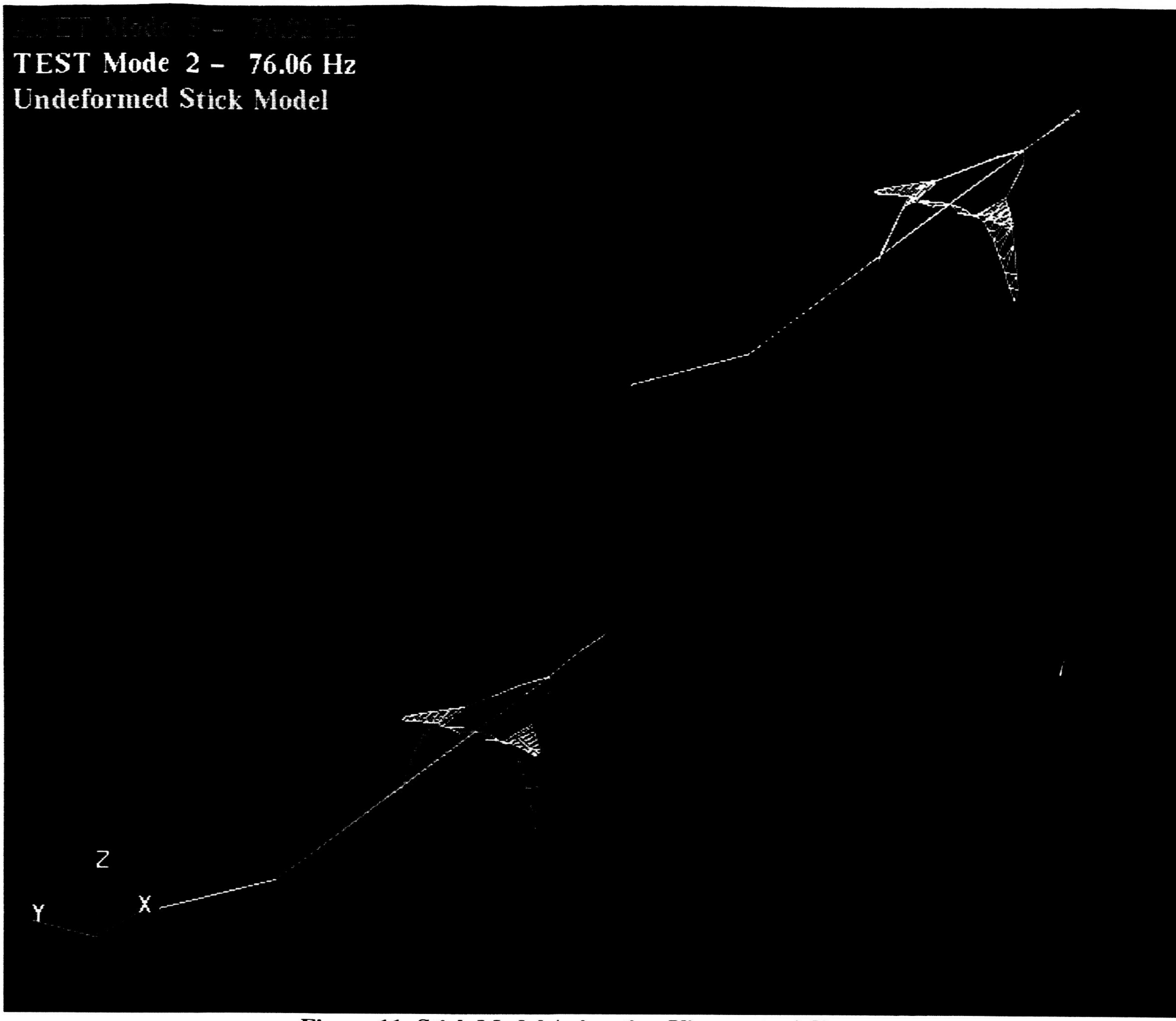

Figure 11: Stick Model Animation Viewport - Adjacent
