**Navcon
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Noise & Vibration Consultants

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Administrative Summary

Services For:	**National Renewable Energy Laboratory**
	1617 Cole Blvd., Golden, CO 80401, 303.275.3000
Subcontract Title:	**Modal Test of The Unsteady Aerodynamics Experiment**
	Navcon Engineering Project No. 00986, Spring 2000
Subcontract No:	TAT-0-30215-01, executed June, 2000
Prime Contract:	Department of Energy DE-AC36-99GO10337
Test Personnel:	James Steedman, Navcon Engineering Network
	Scott Larwood, National Renewable Energy Laboratory
Test Location:	NASA AMES, 80' by 120' Wind Tunnel
Test Item:	Unsteady Aerodynamics Experiment (UAE)
Test Setup:	UAE Tower Mounted to Wind Tunnel T-Frame
	(Simulated Fixed Boundary Condition)

Modal Test Configurations:

1. Test Designation – "**Y0A90**", Yaw = 0 deg. Azimuth = 90 deg.

Principal Components: Tower, Yaw Tube, Nacelle, Hub, Boom & Blades

Number of Modes Identified: 21 modes below 26 Hz.

2. Test Designation – "**NoBlades**"

Principal Components: Tower, Yaw Tube, Nacelle, Hub, & Boom

Number of Modes Identified: 15 modes below 25 Hz.

3. Test Designation – "**Tower**"

Principal Components: Tower

Number of Modes Identified: 17 modes below 25 Hz.

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Test Instrumentation

Impact Frequency Response Survey Test Instrumentation:

- Hewlett Packard 35670A Dynamic Signal Analyzer, 4 Channel Configuration

- PCB Piezotronics ICP Tri-axial Accelerometer Cluster, Model 356A18 (Qty. 1)

- PCB Piezotronics Sledge Hammer, Model 086B50

Shaker Frequency Response Survey Test Instrumentation:

- Hewlett Packard 35670A Dynamic Signal Analyzer, 4 Channel Configuration

- PCB Piezotronics ICP Tri-axial Accelerometer Cluster, Model 356A11 (Qty. 1)

- APS Dynamics Long Stroke Electrodynamic Exciter, Model 113

- APS Dynamics Power Amplifier, Model 124

Modal Test Instrumentation:

- APS Dynamics Long Stroke Electro-Dynamic Exciter, Model 113

- APS Dynamics Power Amplifier, Model 124

- Hewlett Packard 3566A Dynamic Signal Analyzer, 24 Channel Configuration

- PCB Piezotronics Triaxial ICP Accelerometer, Model 356A18 (Qty. 7)

- PCB Piezotronics Force Transducer Model 208B02

- Spectral Dynamics Star Modal Testing Software

- Vibrant Technology ME'scope Modal Testing Software

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Y0A90 Modal Survey

Task 1: **Impact Frequency Response Survey –** The Finite Element Model predicted the 1st set of orthogonal modes at 1.59 and 1.72 Hz. The principal objective of the impact survey was to verify the frequencies and determine whether the orthogonal modes could be excited using a single excitation position. The results indicated that a single excitation position would be adequate [See file, "*FRF_A_B.xls*" on the Compact Disk].

Task 2: **Fixture Shaker –** The APS Model 113 was mounted to a 6,325 lb. steel reaction mass. The mass was suspended from the main gantry crane. A load cell was screwed to aluminum block which was bolted to the top of the tower at –18 deg. from the –Y Axis (i.e., 252 deg. from the +X Axis). The shaker was attached to the load cell through a 12" steel threaded rod (called a stinger) and oriented at a 45 deg. angle to a straight line drawn between the center of the tower and the load cell block. [See the folder, "*Digital_Pics*" on the Compact Disk].

Task 4: **Shaker Frequency Response Survey –** Using the shaker to excite the UAE, a frequency response survey was conducted and the resonant frequencies compared with those identified from the impact measurements (*Task 1*). The measurements identified the same resonant peaks. [See file, "*FRF_A_B.xls*" on the Compact Disk].

Task 5: **Instrumentation System Calibration –** The HP3566A multi-channel analyzer was setup and an end-to-end system calibration performed using a hand held PCB Piezotronics vibration calibrator.

Task 5: **Modal Data Acquisition –** The modal data was acquired using the following parameters:

-   Frequency Band: 0.5 Hz. to 25.5 Hz.
-   Spectral Lines: 800 Lines
-   Resolution: 0.3125 Hz.
-   Window: Hanning
-   Excitation: True Random (approximately 5.6 lbf)

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Task 6: **Modal Data Reduction –** The modal parameters were identified using a complex exponential curve fitting algorithm [See "*Y0A90_Results.xls*" on the Compact Disk]. A rational fraction algorithm was also used to verify the frequency, damping and mode shape estimates.

Task 7: **Modal Data Presentation –** The results of the *Y0A90* modal test are presented on the compact disk [See the folder "*Y0A90*" on the Compact Disk]. Following is a summary of the resonant frequencies and damping values. Digital movies of the mode shapes are presented on the CD in the folder, "Y0A90_Results/AVI's".

Mode No.	Frequency [Hz.]	Damping [Hz.]	Damping %Cr
1	**1.67**	0.1	4.8
2	**1.75**	0.1	3.5
3	**2.47**	0.1	5.5
4	**5.86**	0.1	1.9
5	**5.90**	0.0	0.5
6	**7.17**	0.2	2.6
7	**7.30**	0.1	1.0
8	**8.74**	0.1	0.7
9	**11.84**	0.1	0.6
10	**11.88**	0.1	0.6
11	**13.02**	0.2	1.4
12	**14.53**	0.1	0.9
13	**14.97**	0.2	1.5
14	**18.09**	0.2	1.1
15	**18.18**	0.2	1.0
16	**18.05**	0.3	1.5
17	**18.17**	0.2	1.2
18	**20.29**	0.3	1.5
19	**22.76**	0.2	0.8
20	**23.75**	0.3	1.1
21	**25.26**	0.4	1.5

Task 1: **UAE Configuration –** The blades were removed from the UAE.

Task 2: **Fixture Shaker –** The APS Model 113 was mounted to a 6,325 lb. steel reaction mass. The mass was suspended from the main gantry crane. A load cell was screwed to aluminum block which was bolted to the top of the tower at –18 deg. from the –Y Axis (i.e., 252 deg. from the +X Axis). The shaker was attached to the load cell through a 12" steel threaded rod (called a stinger) and oriented at a 45 deg. angle to a straight line drawn between the center of the tower and the load cell block. [See the folder, "*Digital_Pics*" on the Compact Disk].

Task 3: **Modal Data Acquisition –** The modal data was acquired using the following parameters:

- Frequency Band: 1.0 Hz. to 51.0 Hz.
- Spectral Lines: 1600 Lines
- Resolution: 0.3125 Hz.
- Window: Hanning
- Excitation: True Random (approximately 5.6 lbf)

Task 4: **Modal Data Reduction –** The modal parameters were identified using a both a complex exponential and a global rational fraction curve fitting algorithm [See the file, "*NoBlades_Results.xls*" on the Compact Disk].

Task 5: **Modal Data Presentation –** The results of the ***NoBlades*** modal test are presented on the compact disk [See the folder "*NoBlades*" on the Compact Disk]. The frequency and damping estimates are presented in the table on the following page. Digital movies of the mode shapes are presented on the CD in the folder, "NoBlades_Results/AVI's".

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NoBlades Frequency & Damping Table

Mode No.	Frequency [Hz.]	Damping [Hz.]	Damping %Cr
1	1.34	0.1	8.0
2	1.79	0.0	2.4
3	1.85	0.1	3.3
4	5.92	0.0	0.6
5	7.10	0.2	2.6
6	8.55	0.2	1.8
7	11.01	0.3	2.5
8	11.62	0.1	0.6
9	12.68	0.6	4.9
10	14.56	0.1	0.8
11	15.02	0.3	1.7
12	18.12	0.2	1.1
13	20.45	0.3	1.7
14	23.83	0.3	1.2
15	24.91	0.5	2.1

Tower Modal Survey

Task 1: **UAE Configuration –** The Nacelle & Yaw Tube were removed from the UAE so only the bare tower was remaining.

Task 2: **Fixture Shaker –** The APS Model 113 was mounted to a 6,325 lb. steel reaction mass. The mass was suspended from the main gantry crane. A load cell was screwed to aluminum block which was bolted to the top of the tower at –18 deg. from the –Y Axis (i.e., 252 deg. from the +X Axis). The shaker was attached to the load cell through a 12" steel threaded rod (called a stinger) and oriented at a 45 deg. angle to a straight line drawn between the center of the tower and the load cell block. [See the folder, "*Digital_Pics*" on the Compact Disk].

Task 3: **Modal Data Acquisition –** The modal data was acquired using the following parameters:

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- Frequency Band: 1.0 Hz. to 51.0 Hz.
- Spectral Lines: 1600 Lines
- Resolution: 0.3125 Hz.
- Window: Hanning
- Excitation: True Random (approximately 5.6 lbf)

Task 4:   Modal Data Reduction – The modal parameters were identified using a both a complex exponential and a global rational fraction curve fitting algorithm [See the file, "*NoBlades_Results.xls*" on the Compact Disk].

Task 5:   Modal Data Presentation – The results of the *Tower* modal test are presented on the compact disk [See the folder "*Tower*" on the Compact Disk]. The frequency and damping estimates are presented in the following table.   Digital movies of the mode shapes are presented on the CD in the folder, "Tower_Results/AVI's".

Mode No.	Frequency [Hz.]	Damping [Hz.]	Damping %Cr
1	1.74	0.1	6.3
2	2.36	0.2	6.5
3	2.73	0.1	3.2
4	3.91	0.0	0.5
5	4.03	0.0	0.6
6	8.14	0.1	1.2
7	10.38	0.2	2.0
8	10.66	0.2	1.6
9	11.93	0.1	0.5
10	14.01	0.3	2.2
11	14.75	0.1	0.6
12	18.07	0.3	1.8
13	19.50	0.2	0.9
14	19.91	0.1	0.7
15	21.03	0.1	0.3
16	22.04	0.3	1.3
17	24.80	0.2	1.0

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Compact Disk Summary

Y0A90 Modal Test Results Folder:

- **Y0A90_Results.xls**   Excel file which summarizes the modal parameter estimation process & results and the geometrical model.

Sheet	Title	Description
1	Read_Me	General Discussion
2	F&D_Summary	Table of Frequency & Damping Values
3	MPF_Chrt	Graphic - Modal Peak Functions
4	MPF_Data	Table - Modal Peak Functions computed as H[imaginary]^2
5	ADF_1	Did not use these fits. Initial fits Modes 1-8. Tables & Graphs.
6	ADF_2	Modes 1-8 Freq. & Damping Table, Stability Tables and Stability Graphs.
7	ADF_3	Modes 9-15 Freq. & Damping Table, Stability Tables and Stability Graphs.
8	ADF_4	Modes 16-21 Freq. & Damping Table, Stability Tables and Stability Graphs.
9	MAC	Modal Assurance Criteria For the 21 modes.
10	Coord	Coordinates for modal test points. Also refer to Cosines sheet.
11	Cosines	Cosines matricies for points on the blades.
12	Dsplq	Display sequence - I.e., display lines connecting the modal test points.
13	Geo_1	Graphic showing modal test point layout - Tower
14	Geo_2	Graphic showing modal test point layout - Yaw Tube, Nacelle, Hub & Boom
15	Geo_3	Graphic showing modal test point layout - Blades
9	MAC	Modal Assurance Criteria For the 21 modes.
10	Coord	Coordinates for modal test points. Also refer to Cosines sheet.
11	Cosines	Cosines matricies for points on the blades.
12	Dsplq	Display sequence - I.e., display lines connecting the modal test points.
13	Geo_1	Graphic showing modal test point layout - Tower
14	Geo_2	Graphic showing modal test point layout - Yaw Tube, Nacelle, Hub & Boom
15	Geo_3	Graphic showing modal test point layout - Blades

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- **Y0A90_FRFs.xls**   Excel file containing the frequency response measurements in a magnitude / phase format.

- **Coord_Dsplq.xls**   Excel file containing the modal model coordinates and display sequence.

- **Blade_Cosines.xls**   Excel file containing the direction cosines matrix used for the orientation of the accelerometers on the blades.

- **Y0A90.UNV**   Universal File Format (UFF) file containing the model geometry, frequencies, damping values and modal vectors.

- **Y0A90_Data.UNV**   Universal File Format (UFF) file containing the frequency response measurements

- **Folder – AVI's**   Folder containing digital movies of the mode shapes.

NoBlades Modal Test Results Folder:

- **NoBlades_Results.xls**   Excel file which summarizes the modal parameter estimation process & results and the geometrical model.

Sheet	Title	Description
1	Read_Me	General Discussion
2	F&D_Summary	Table of Frequency & Damping Values
3	MPF_Chrt	Graphic - Modal Peak Functions
4	MPF_Data	Table - Modal Peak Functions computed as H[imaginary]^2
5	ADF_1	Modes 1-3 Freq. & Damping Table, Stability Tables and Stability Graphs.
6	GFD_1-4	Modes 4-9 Freq. & Damping Table, Fit Table
7	ADF_2	Did not use in final analysis, for reference only.
8	GFD_5	Modes 10-15 Freq. & Damping Table, Fit Table
9	MAC	Modal Assurance Criteria For the 21 modes.
10	Coord	Coordinates for modal test points. Also refer to Cosines sheet.
11	Dsplq	Display sequence - I.e., display lines connecting the modal test points.
12	Geo_All	Graphic showing modal test point layout - All Points
13	Geo_Top	Graphic showing modal test point layout - Yaw Tube, Nacelle, Hub & Boom
14	Geo_Tower	Graphic showing modal test point layout - Tower

- **No_Blades_FRFs.xls**   Excel file containing the frequency response measurements in a magnitude / phase format.

- **Coord_Dsplq.xls**   Excel file containing the modal model coordinates and display sequence.

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- **No_Blades.UNV**   Universal File Format (UFF) file containing the model geometry, frequencies, damping values and modal vectors.

- **No_Blades _FRF's.UNV** Universal File Format (UFF) file containing the frequency response measurements

- **Folder – AVI's**   Folder containing digital movies of the mode shapes.

Tower_Modal Test Results Folder:

- **Tower_Results.xls**   Excel file which summarizes the modal parameter estimation process & results and the geometrical model.

Sheet	Title	Description
1	Read_Me	General Discussion
2	F&D_Summary	Table of Frequency & Damping Values - 17 Modes Identified Below 25 Hz.
3	MPF_Chrt	Graphic - Modal Peak Functions
4	MPF_Chrt Zoom	Graphic - Modal Peak Functions - Use this for visualization - Zoom X-Axis as needed
5	MPF_Data	Table - Modal Peak Functions computed as H[imaginary]^2
6	ADF_1	Modes 1-3 Freq. & Damping Table, Stability Tables and Stability Graphs.
7	ADF_2	Modes 4-8 Freq. & Damping Table, Stability Tables and Stability Graphs.
8	GFD_1	Modes 9-11 Freq. & Damping Table, Fit Table Parameters
9	ADF_3	Modes 12-17 Freq. & Damping Table, Stability Tables and Stability Graphs.
10	MAC	Modal Assurance Criteria For the 21 modes.
11	Coord	Coordinates for modal test points. Also refer to Cosines sheet.
12	Dsplq	Display sequence - I.e., display lines connecting the modal test points.
13	Geo_All	Graphic showing modal test point layout - All Points
14	Geo_Tower	Graphic showing modal test point layout - Tower Points
15	Geo_T-Frame	Graphic showing modal test point layout - T-Frame Points

- **Tower_FRFs.xls**   Excel file containing the frequency response measurements in a magnitude / phase format.

- **Coord_Dsplq.xls**   Excel file containing the modal model coordinates and display sequence.

- **Tower.UNV**   Universal File Format (UFF) file containing the model geometry, frequencies, damping values and modal vectors.

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- **Tower _FRF's.UNV**   Universal File Format (UFF) file containing the frequency response measurements

- **Folder – AVI's**   Folder containing digital movies of the mode shapes.

Other Files:

- **Folder – Digital_Pics** Folder containing 2 sets of digital photographs of the modal survey

- **Test_A_B_FRFs.xls**   Excel file Excel file containing the impact and initial shaker frequency response measurements in a magnitude format.