Testing Large Structures in the Field

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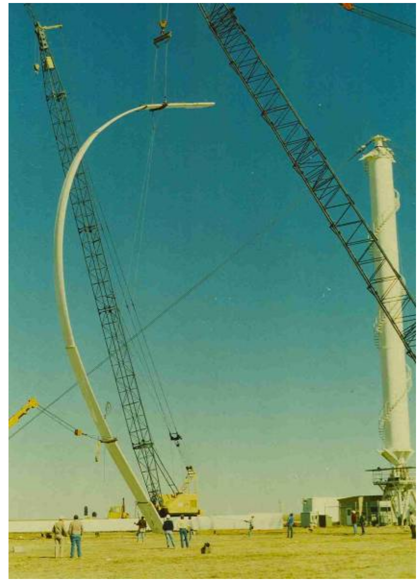
International Modal Analysis Conference – XXVII
Orlando, FL
February 9-12, 2009

Large Structure Test Issues

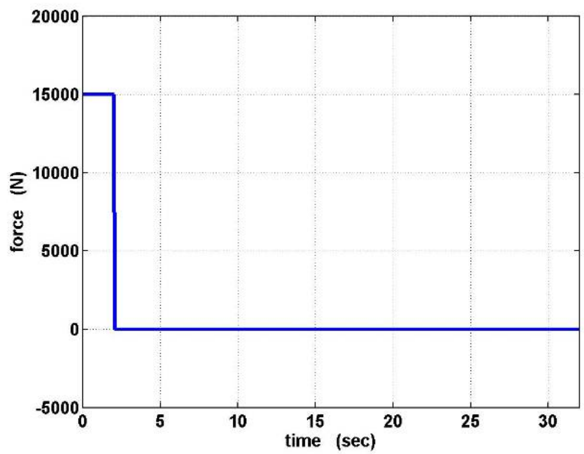


- **Need to test in the field**
- **Large input forces required**
- **Limited choices for boundary conditions**
- **Natural excitation sources cannot be removed**
- **May not be able to take out of service**

Purpose

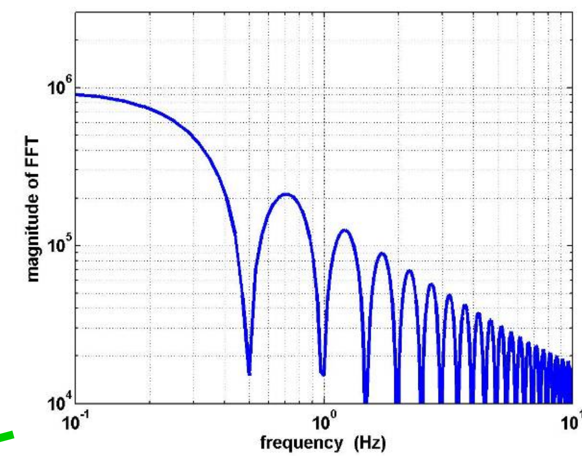
- To review a trajectory in the evolution of field testing of large structures as driven by Tom Carne and his colleagues.
  - Step relaxation testing – Can input large yet controlled forces
    - ✓ Vertical Axis Wind Turbine – non-rotating
    - ✓ Vertical Axis Wind Turbine - rotating
  - Support system modelling – Allows a wider range of support conditions
    - ✓ STARS launch system
  - Natural excitation analysis – Uses the natural environment for excitation
    - ✓ Vertical Axis Wind Turbines – non-rotating
    - ✓ Vertical Axis Wind Turbines – rotating
    - ✓ Other applications – HAWT’s, Trucks, STARS, Space Shuttle
  - Hybrid force reconstruction – Augments test data with analytical data
    - ✓ Space Shuttle Rollout Stack

Making Step Relaxation Testing Viable



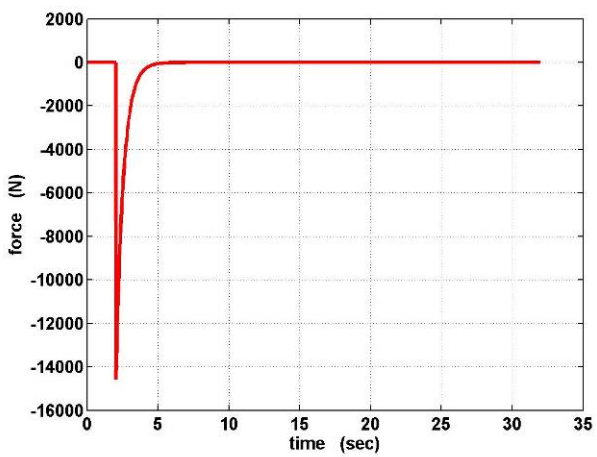
Step Relaxation Force - Time

Raw Step Relaxation Force does not convert to frequency domain in a usable form



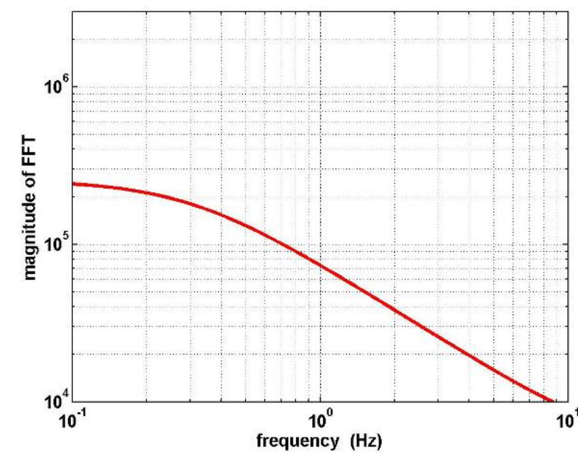
Step Relaxation Force - Frequency

Apply high pass filtering to both the input force and the responses



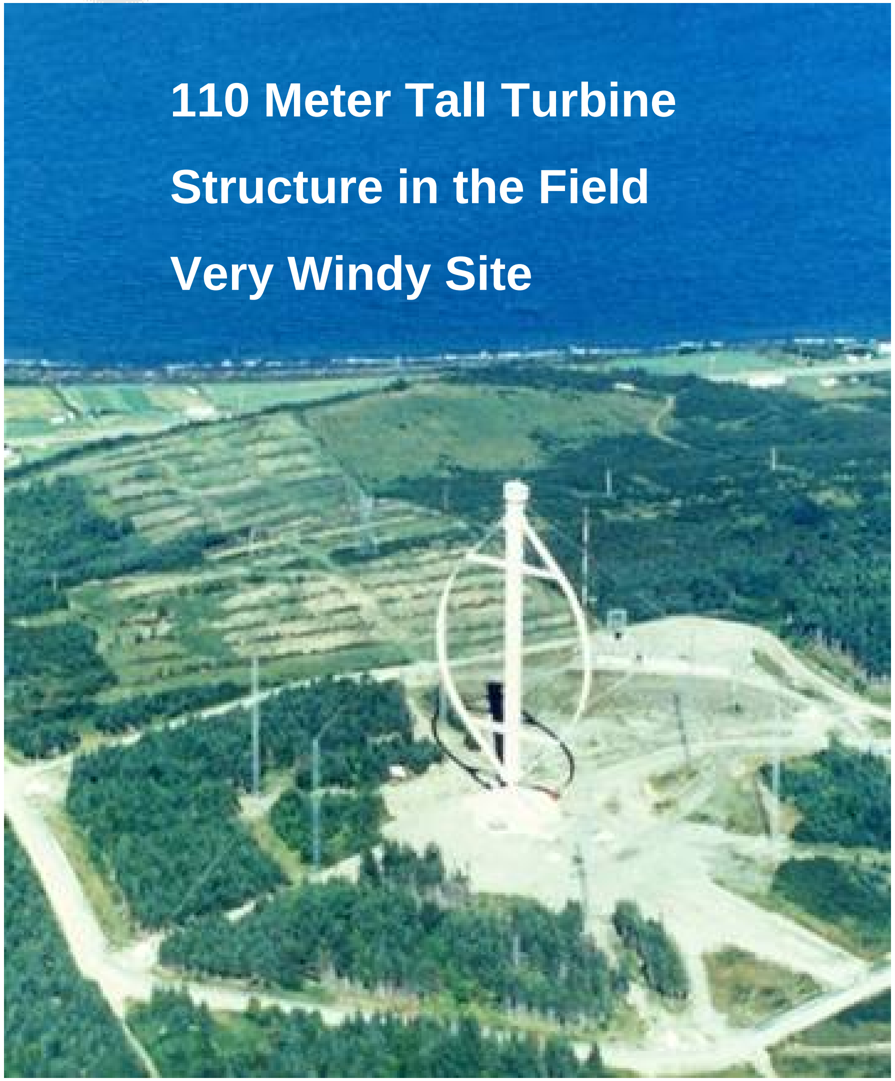
Filtered Step Relaxation Force - Time

Filtered Step Relaxation Force converts to frequency domain well



Filtered Step Relaxation Force - Frequency

Step Relaxation Testing – E'ole Wind Turbine



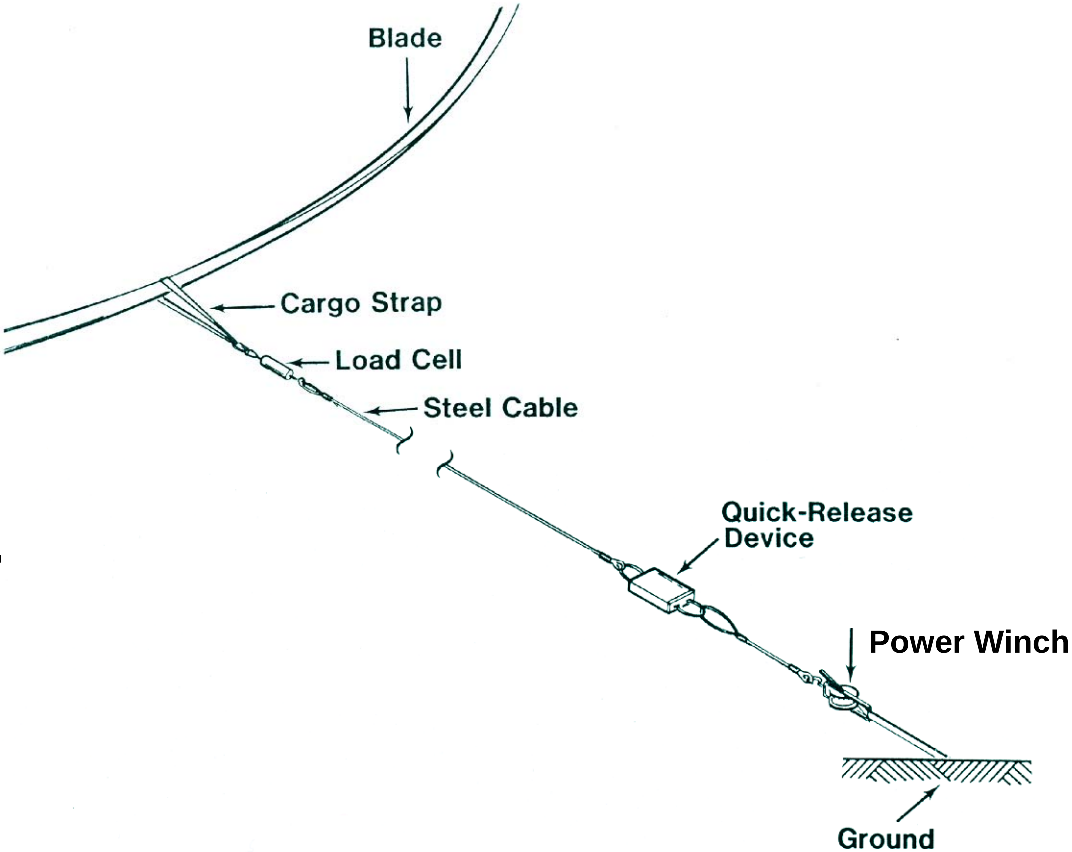
Step Relaxation Device - E'OLE

Step Relaxation

10,000 pounds on blade

30,000 pounds on tower

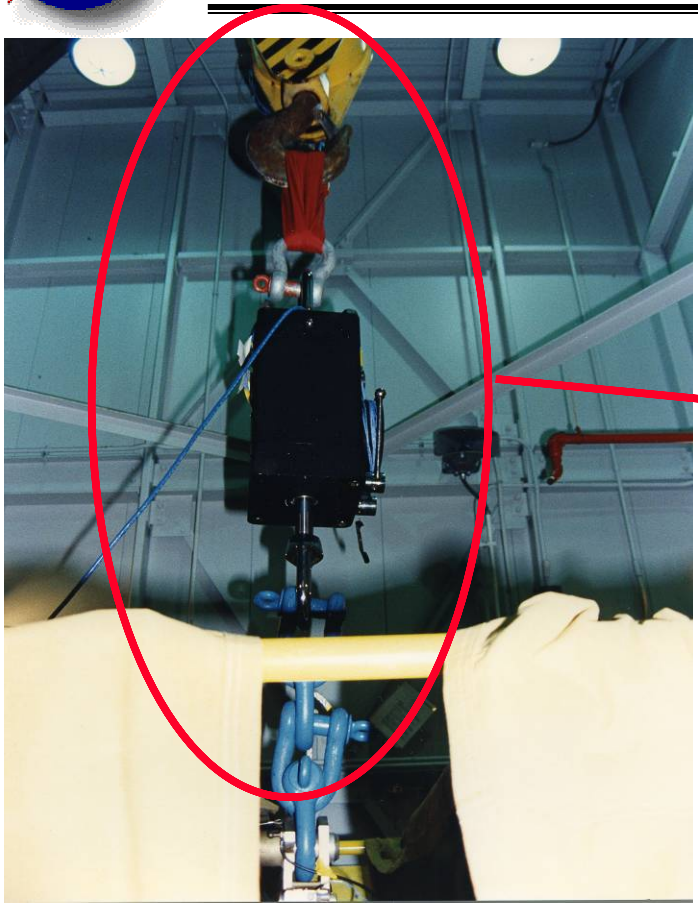
Release < 0.1 seconds

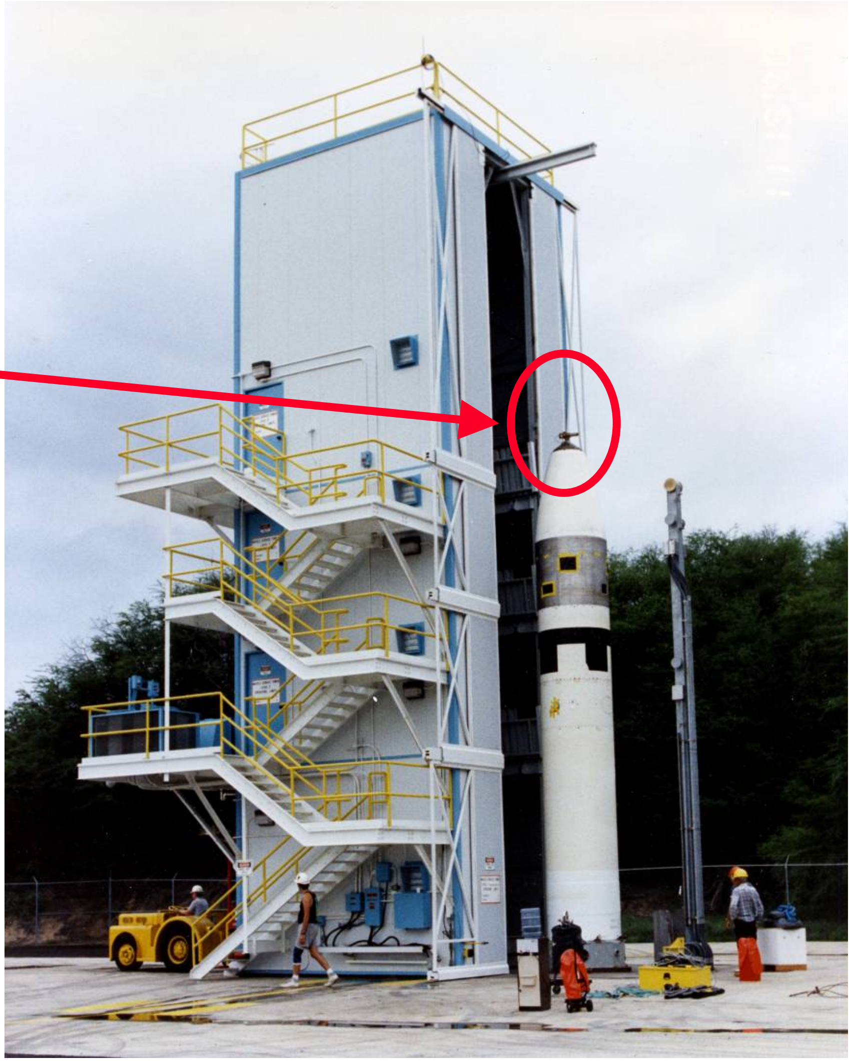


Attaching cable for Step Input

Free Support to Match Flight Conditions

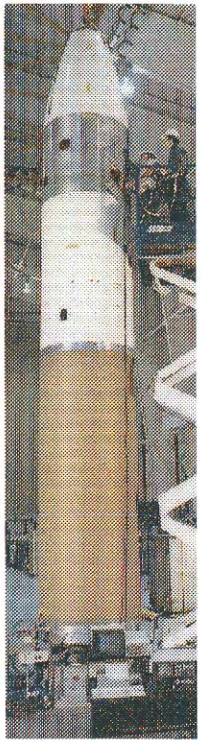
Increasing the Fidelity of Free B.C.'s

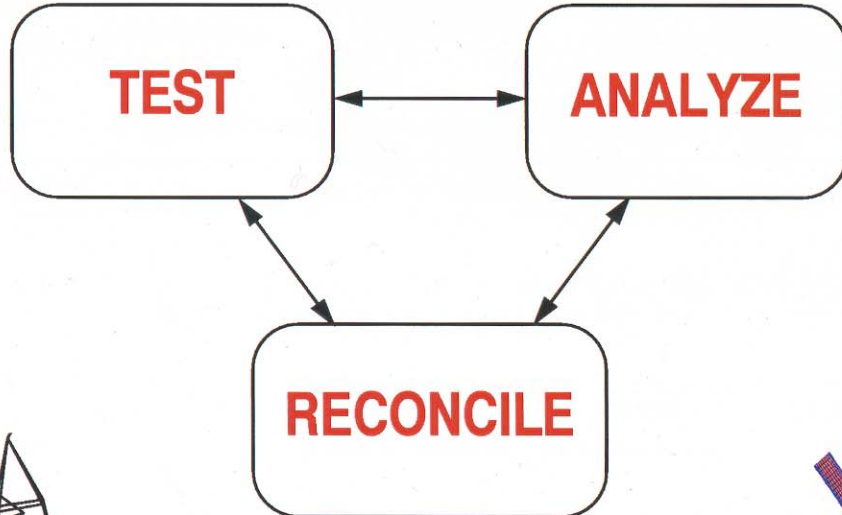




Hydroset and pulley block weighted several thousands pounds and were modeled as a double pendulum..

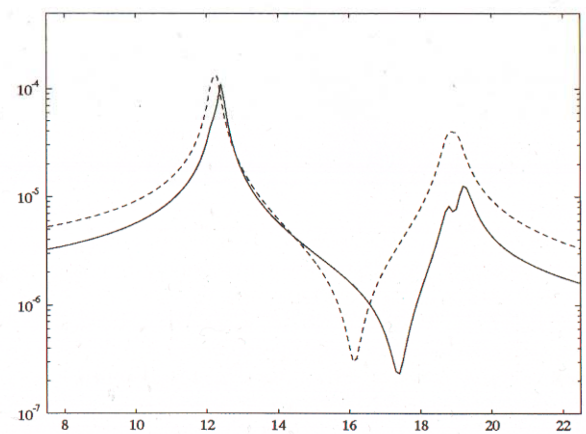
Reconciliation Performed with B.C. Model

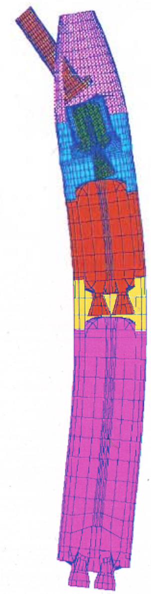


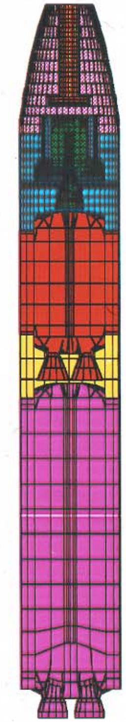


Test Mode Shape

Test/FEM Frequency Response Comparison





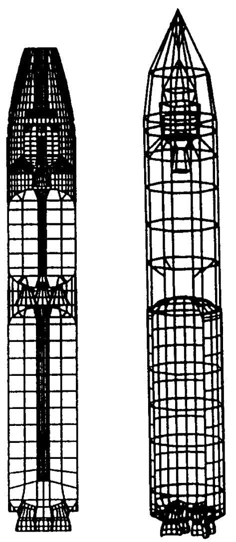


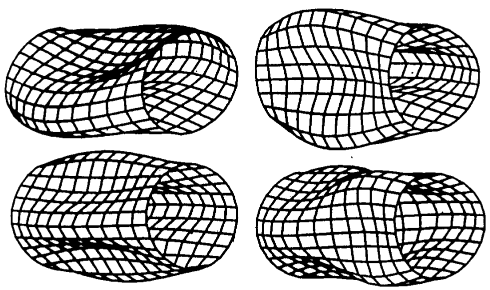
FEM Mode Shape

Model Match for STARS Shell Modes

Test/Analysis Correlation Using System Identification Techniques

STARS First Stage Shell Modes





FEM_o	FEM_f	Test	Δ_o %	Δ_f %	Mode
35.8	39.9	39.7	-9.8	+.50	3,0
41.5	48.1	49.3	-15.8	-2.4	4,0
50.0	54.4	54.8	-8.8	-.73	2,0
62.3	73.3	74.0	-15.8	-.95	5,0
71.1	79.5	78.1	-9.0	+1.8	4,1
76.5	88.0	86.6	-11.7	+1.6	5,1
88.2	96.3	97.1	-9.2	-.82	3,1

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ELM:1545:ASME:8/22/91

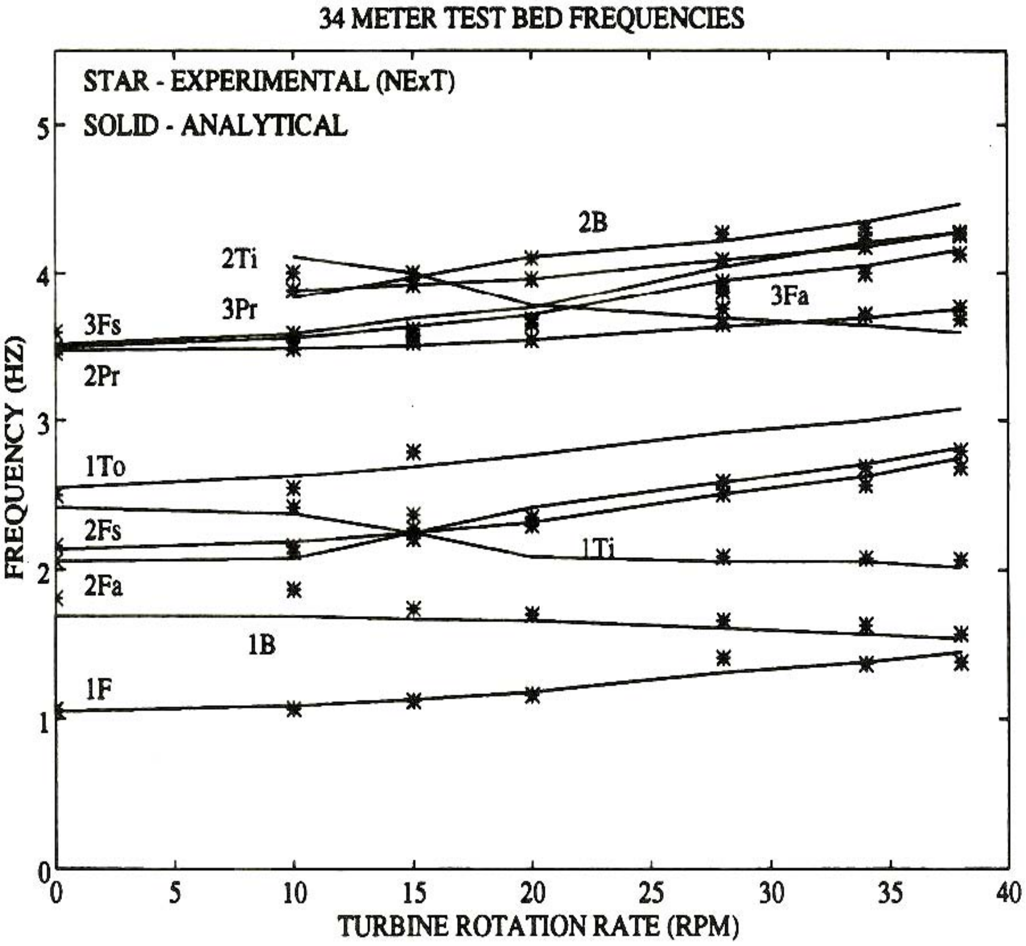
Early Assessment of Natural Excitation Input

MODE SHAPE DESCRIPTION	STEP RELAXATION (Hz)	WIND EXCITATION (Hz)	FINITE ELEMENT MODEL (Hz)
FIRST TOWER OUT-OF-PLANE	0.63	0.63	0.63
FIRST TOWER IN-PLANE	0.74	0.73	0.75
SECOND TOWER OUT-OF-PLANE	0.93	0.94	0.92
BLADE FLATWISE ANTI-SYMMETRIC	1.30	1.30	1.27
BLADE FLATWISE SYMMETRIC	1.32	1.34	1.29
SECOND TOWER IN-PLANE	1.38	1.39	1.42
BLADES BENDING OUT-OF-PLANE	1.55	1.55	1.61
THIRD TOWER OUT-OF-PLANE	1.79	---	1.76
ROTOR TWIST (DUMBBELL)	1.93	1.94	1.96
SECOND FLATWISE SYMMETRIC	2.24	2.25	2.20
SECOND BLADE OUT-OF-PLANE	2.33	2.33	2.34
SECOND BLADE ANTI-SYMMETRIC	2.40	2.39	2.38

Making Natural Excitation Work

- ❑ **Natural Excitation used on E'OLE and other turbines**
- ❑ **E'OLE test published '88 IMAC and M.A. journal**
- ❑ **Formalized approach in '92 IMAC & Oct.95 journal**
- ❑ **Called this NExT:**
  - 1. Acquire response data -- long time histories
  - 2. Calculate auto & cross- correlation functions
    - ✓ Showed that correlation fcns sum of decaying sinusoids
    - ✓ Reference dofs
  - 3. Time domain modal id algorithm to estimate
    - ✓ Poly-Reference and ERA
  - 4. Extract mode shapes
- ❑ **NExT used on rotating systems (VAWT & HAWT)**
- ❑ **Applied to flight systems (STARS and Space Shuttle)**

Rotating 34-Meter VAWT Using NExT



Space Shuttle Roll-Out Numbers

Space Shuttle Elements:

Orbiter (Orb) – 250,000 lbs

External Tank (ET) – 65,000 lbs

Solid Rocket Boosters (SRBs) – $3x10^6$ lbs

Mobile Launch Platform (MLP) – $8x10^6$ lbs

Crawler Transporter (CT) – $1x10^6$ lbs

Total – $12x10^6$ lbs

Historical Roll-out Speed - .9 mph

Constrained Roll-out Speed - .8 mph

Desired Roll-Out Speed – 1.0 mph

Max CT Speed – 2.0 mph

Roll-out found to possess narrow-band excitation which drives system dynamics

Hybrid Approach Developed for Shuttle Stack

- **Measured data at .8, .9, and 1.0 mph from STS-115:**
  - MLP, SRB, and Orbiter sensors used;
  - CT, SSME, and wireless sensors not used; and
  - Six bad channels removed (2 on HDP's, 3 on SRB, 1 on Orb.).
- **Model from Shuttle Modeling and Integration Group:**
  - CT, MLP, and SRB models used for past roll-out work;
  - ET shell model developed by DCI, Inc.;
  - Cargo Hi-Fi Orbiter model with Lo-Fi SSME models; and
  - Node at undeformed C.G. and RBE3's to MLP/CT interfaces;
- **SWAT Forces and Moments Calculated:**
  - Sum of Weighted Accelerations Technique (SWAT)
  - 29 modes (including 6 rigid body) to 6.17 Hz; and
  - 400 seconds of data at 64 samples/second used.

Hybrid Approach Developed for Shuttle Stack

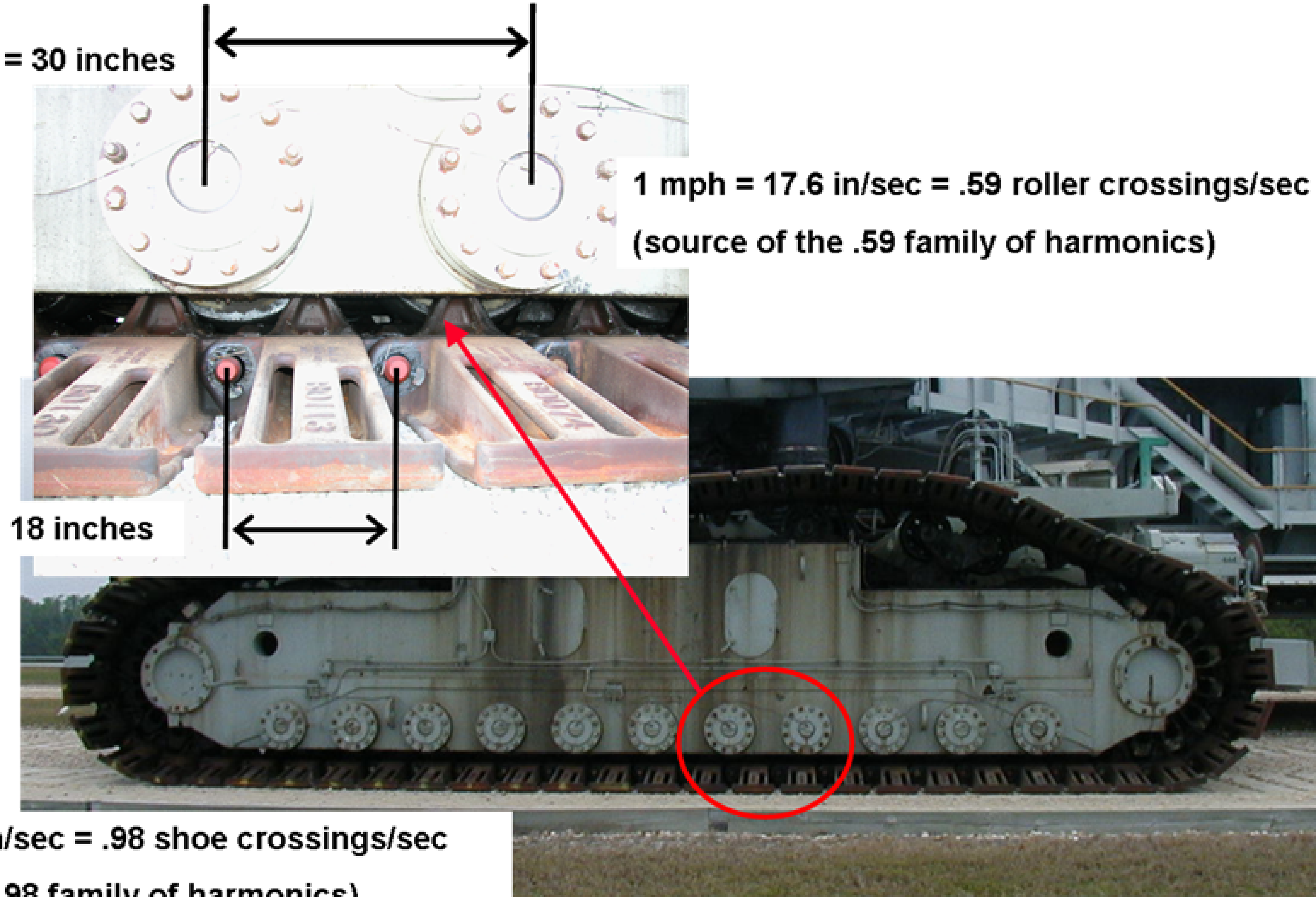
- **SWAT forces time-shifted to estimate other speeds:**
  - Assumes that the frequency content changes slowly with speed;
  - Assumes that the magnitude changes slowly with speed; and

***New Time Vector = (Original CT Speed / New CT Speed) * Original Time Vector*.**

- **.8 mph SWAT forces generated .76, .78, .82, and .84 mph forces.**
- **.9 mph SWAT forces generated .86, .88, .92, and .94 mph forces.**
- **1.0 mph SWAT forces generated .96, .98, 1.02, and 1.04 mph forces.**
- **Forces used to drive the vehicle model at the C.G.**
- **15 NASTRAN transient solutions produced.**
- **RMS and PSD data plotted as a function of CT speed.**

Source of Roll-Out Harmonic Forces

Roller Spacing = 30 inches



1 mph = 17.6 in/sec = .59 roller crossings/sec

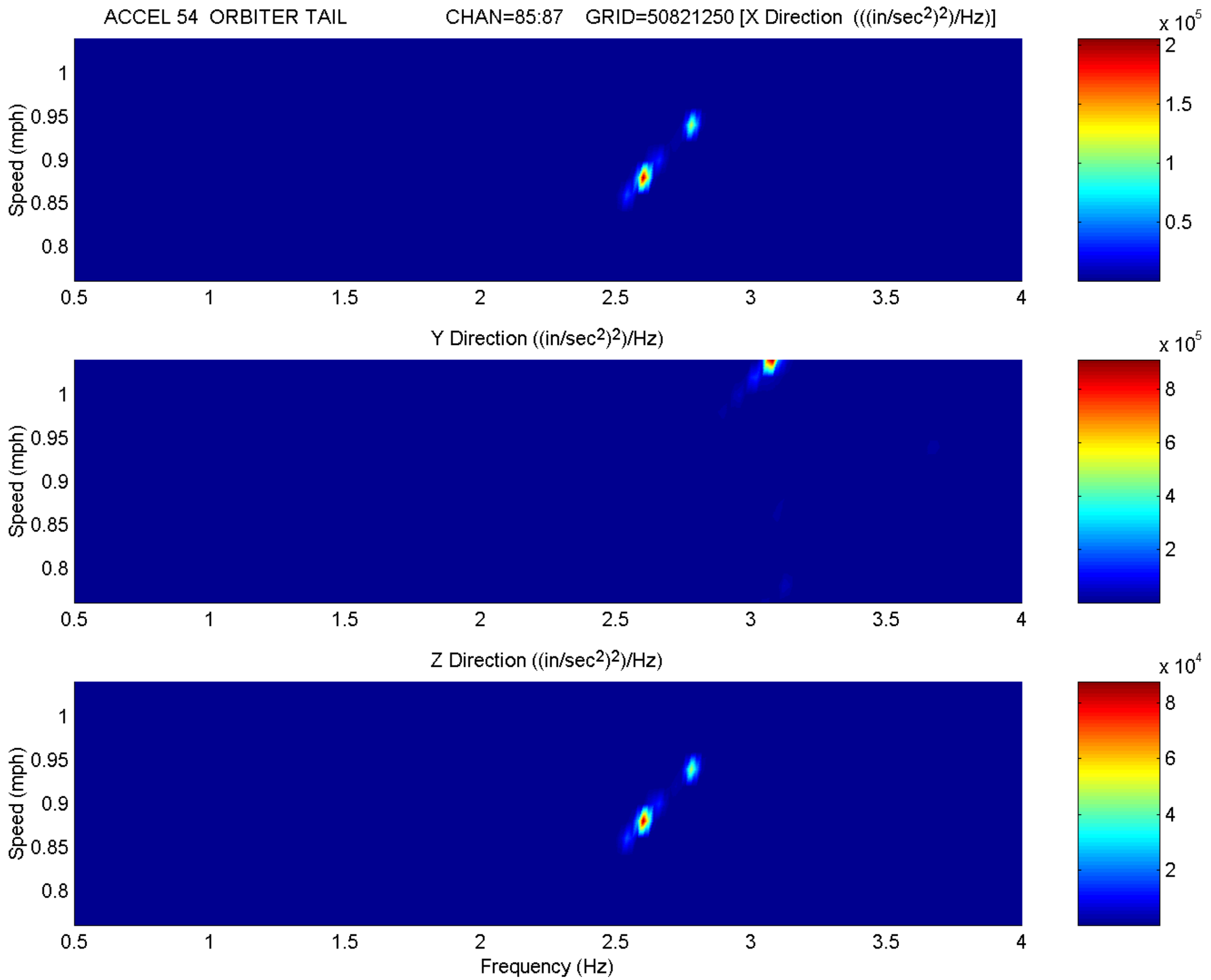
(source of the .59 family of harmonics)

Shoe Spacing = 18 inches

1 mph = 17.6 in/sec = .98 shoe crossings/sec

(source of the .98 family of harmonics)

Frequency Sensitivity for Orbiter Tail



Conclusions

- ❑ **Testing large structures in the field creates unique challenges.**
- ❑ **Several critical developments have been covered:**
  - Step Relaxation Testing has been developed into a useful technique to apply large forces to operational systems by appropriate windowing;
  - Capability for large structures testing with free support conditions has been expanded by implementing modeling of the support structure;
  - Natural excitation has been developed as a viable approach to testing large structures in the field; and
  - A hybrid approach as been developed to allow forces to be estimated in operating structures.
- ❑ **These developments have greatly increased the ability to extract information from large structures.**

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