AN INVESTIGATION OF METHODS FOR REDUCING BLADE AND SYSTEM LOADS FOR TWO-BLADED TEETERING-HUB HORIZONTAL-AXIS WIND TURBINES

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ABSTRACT

Designing low cost wind turbines having long fatigue lifetimes and low cyclic component and system loads is a major goal of the Federal Wind Energy Program and the wind industry. To achieve this goal, predictions derived from analytical models of complex and dynamically coupled systems are necessary. These models are necessary in order to capture the complex kinematic and dynamic couplings exhibited by the HAWT (Horizontal Axis Wind Turbine).

In this paper interactions between the rotor and tower for a two-bladed teetering hub wind turbine are examined. Several turbine design parameters including tip-brake mass, blade structural pre-twist, tower shadow intensity, and system natural frequencies directly affect the predicted blade and system loads. Figure 1 for example shows the effects blade-tip-brake mass might have on predicted blade-root edgewise-bending moments for a particuliar two-bladed teetering hub turbine under study.

We use the ADAMS (Automatic Dynamic Analysis of Mechanical Systems) software and the Oregon State University FAST (Fatigue, Aerodynamics, Structures, and Turbulence) codes to show these parameters on predicted rotor and system loads.

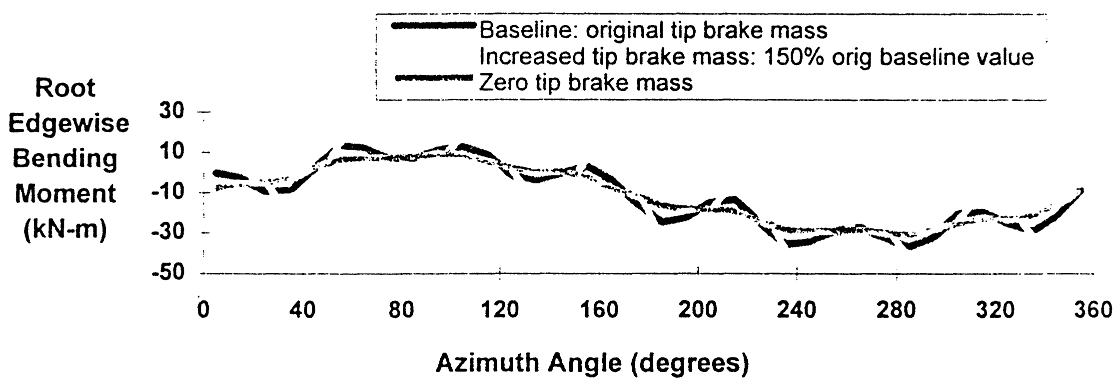

FIGURE 1. EFFECT OF BLADE-TIP-BRAKE MASS ON PREDICTED BLADE-ROOT EDGEWISE-BENDING MOMENT

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Objectives:

- Determine structural features which dictate the dynamic response of this machine type
- Determine methods of making these designs more stable: design guidelines

Dominant Responses

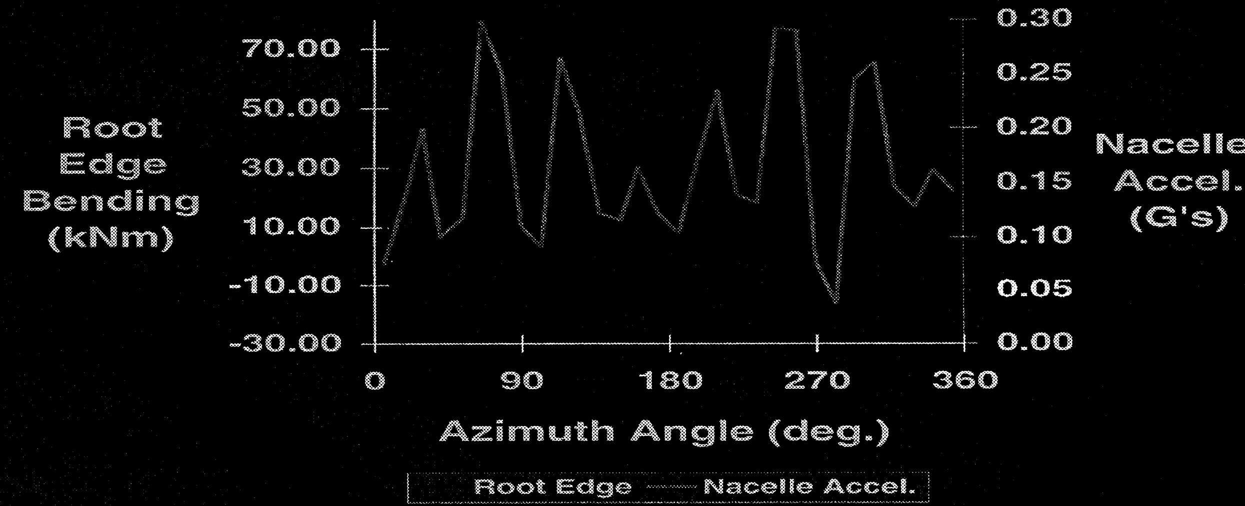
- Rotor Symmetric Lag Response
- Rotor Symmetric Flap Response

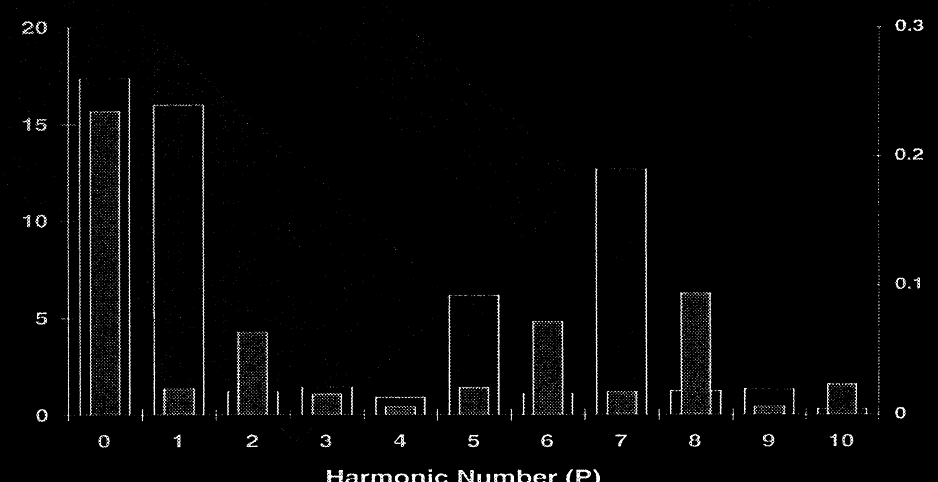
Procedure:

- Start with validated ADAMS model of particuliar 2-bladed downwind teetering hub machine
- Perform parameterization studies: analyze effect of parameter variations on predicted blade and system loads
  - Blade edgewise and flapwise stiffness
  - **Blade structural pre-twist**
  - Blade tip mass
  - Tower stiffness
  - Rotor speed

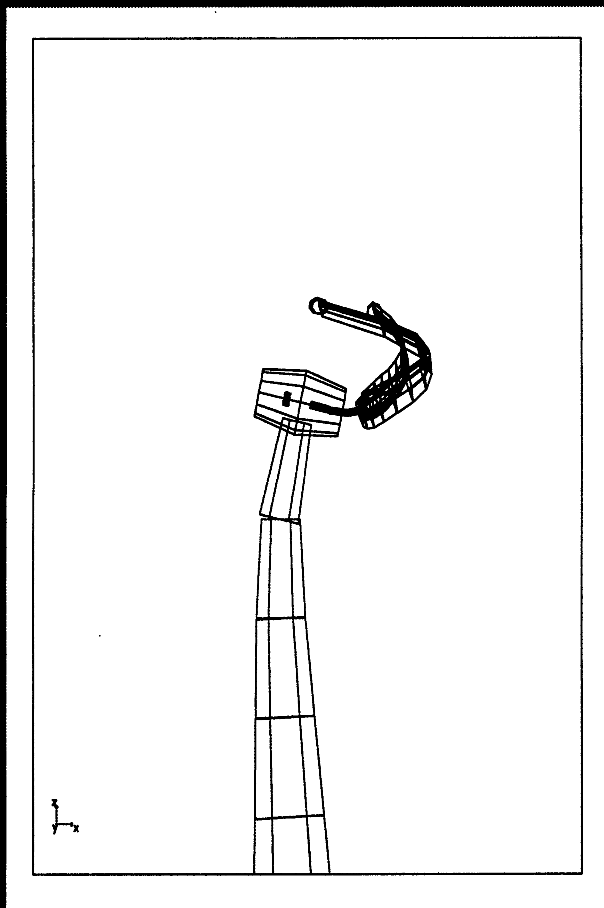
Rotor Lag Response

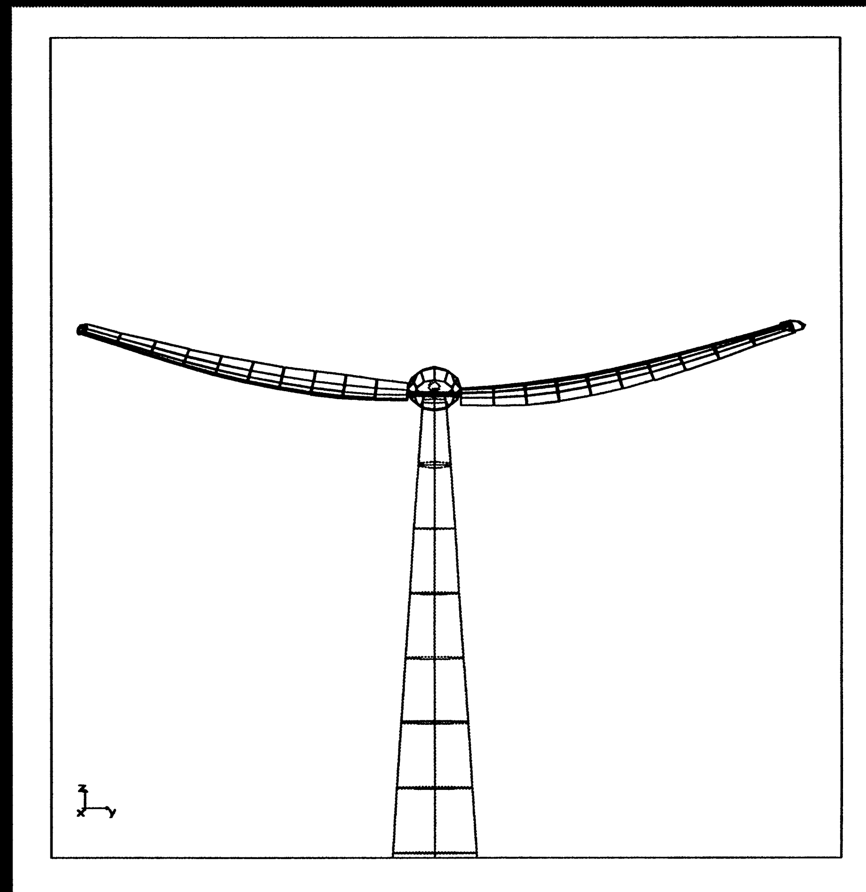
- Observed from data:
  - Root Edgewise Bending Moment 5&7P
  - Nacelle Vertical Acceleration 6 & 8P





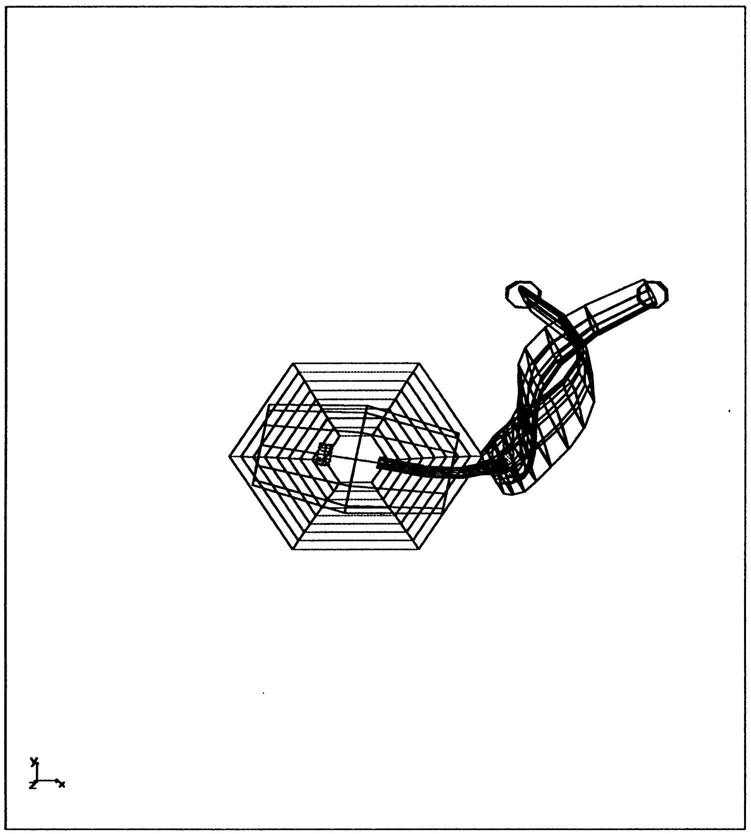
- **System Modes:**
  - Rotor Symmetric Lag (rotor horizontal)
    - » frequency equal to 7.1 Hz.

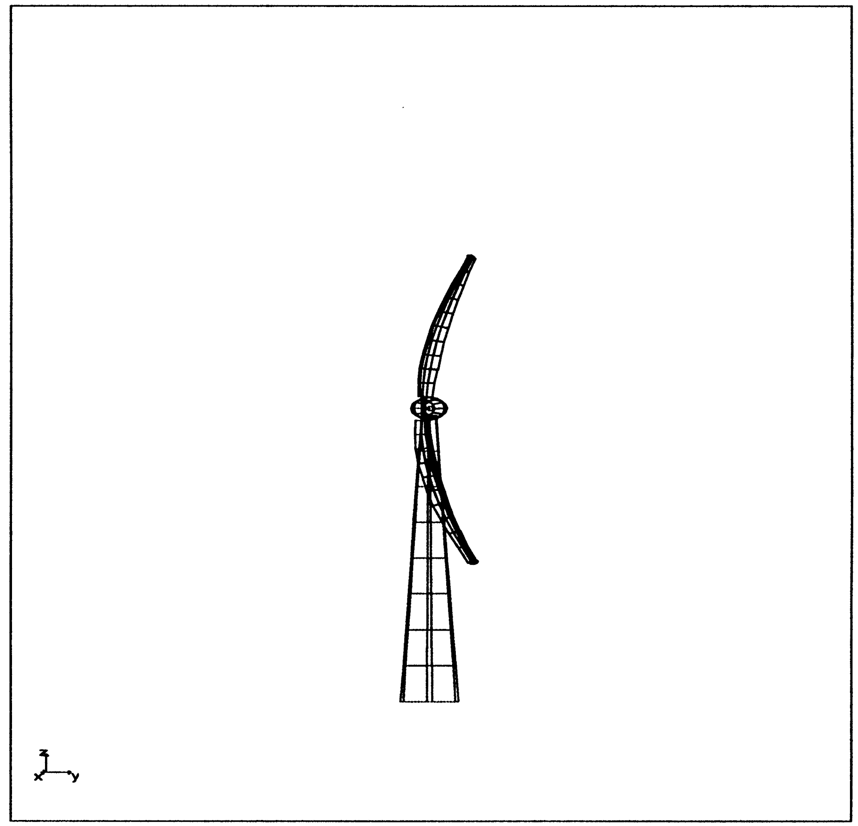




System Modes:

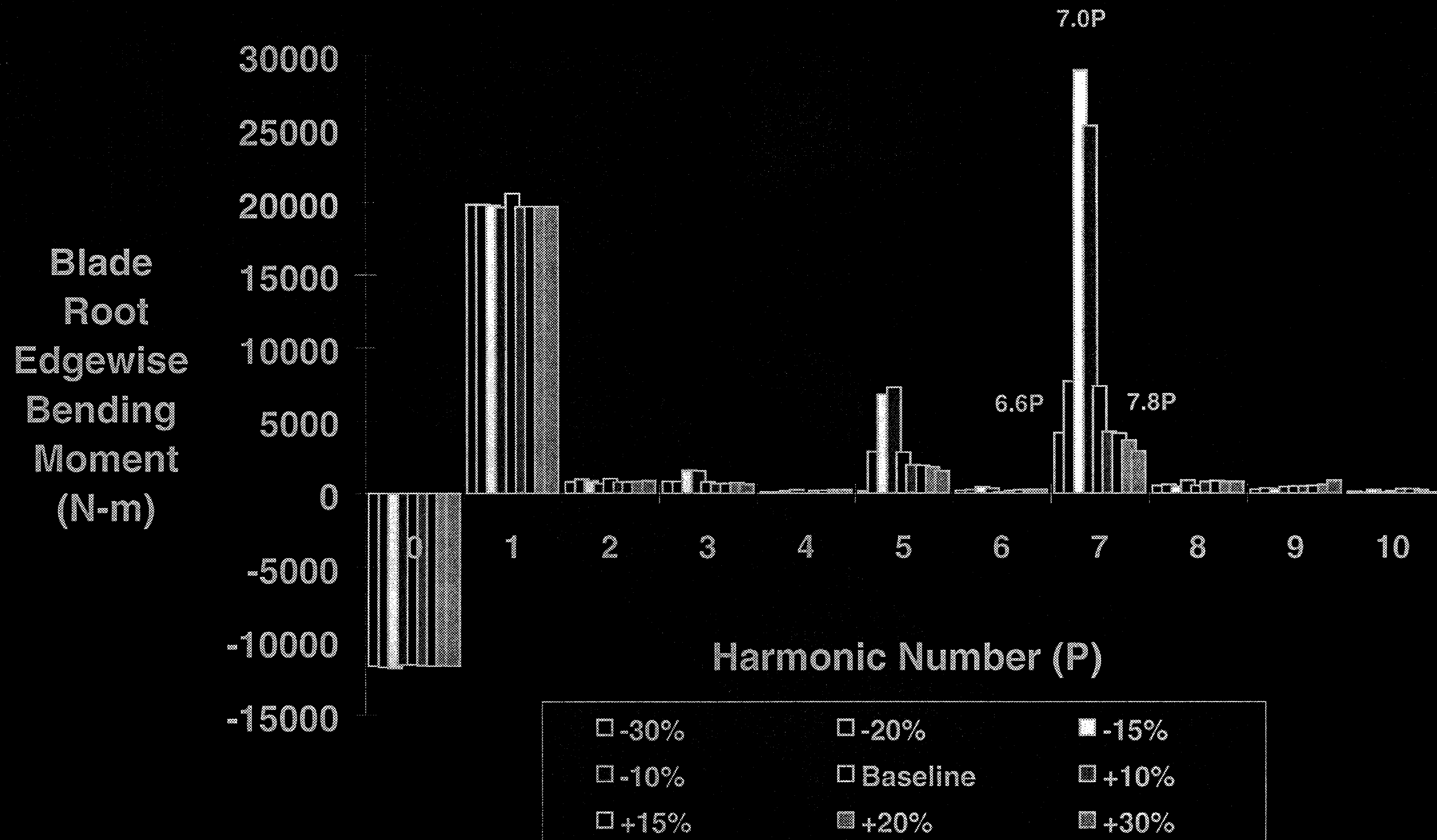
- Rotor Symmetric Lag (rotor vertical)
  - frequency equal to 6.8 Hz.



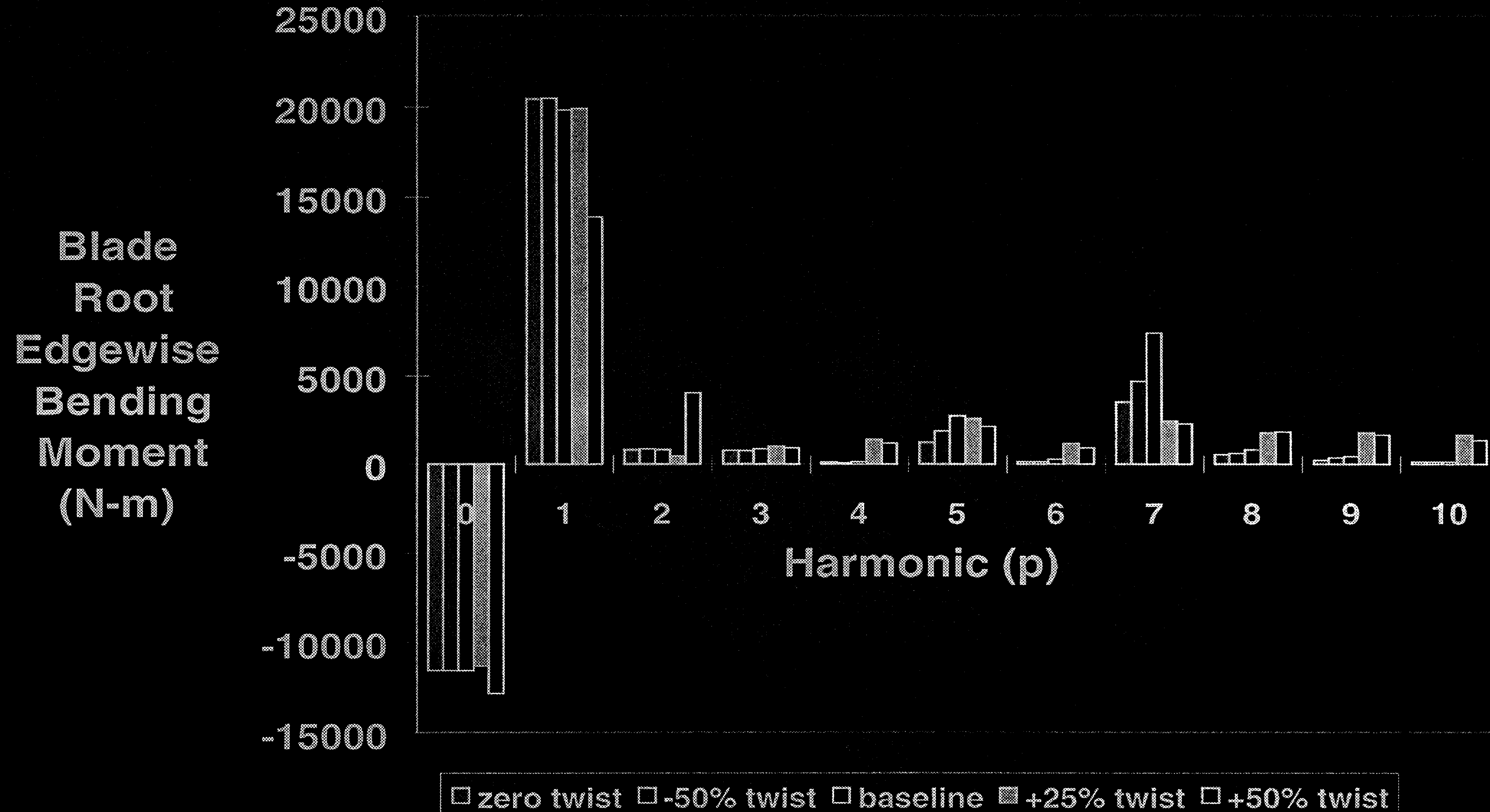


Parameterization Results

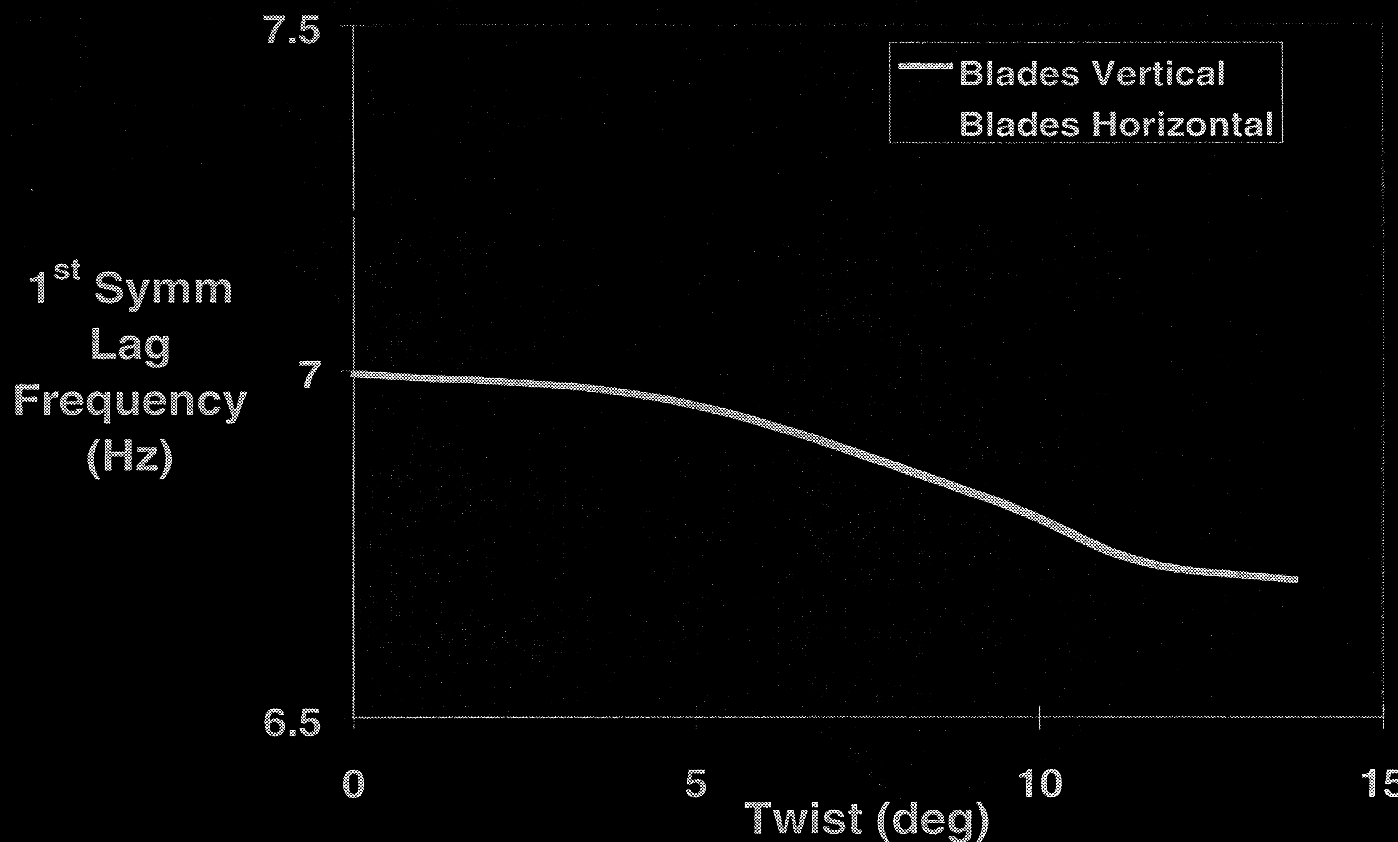
Effects of Blade Edgewise Stiffness



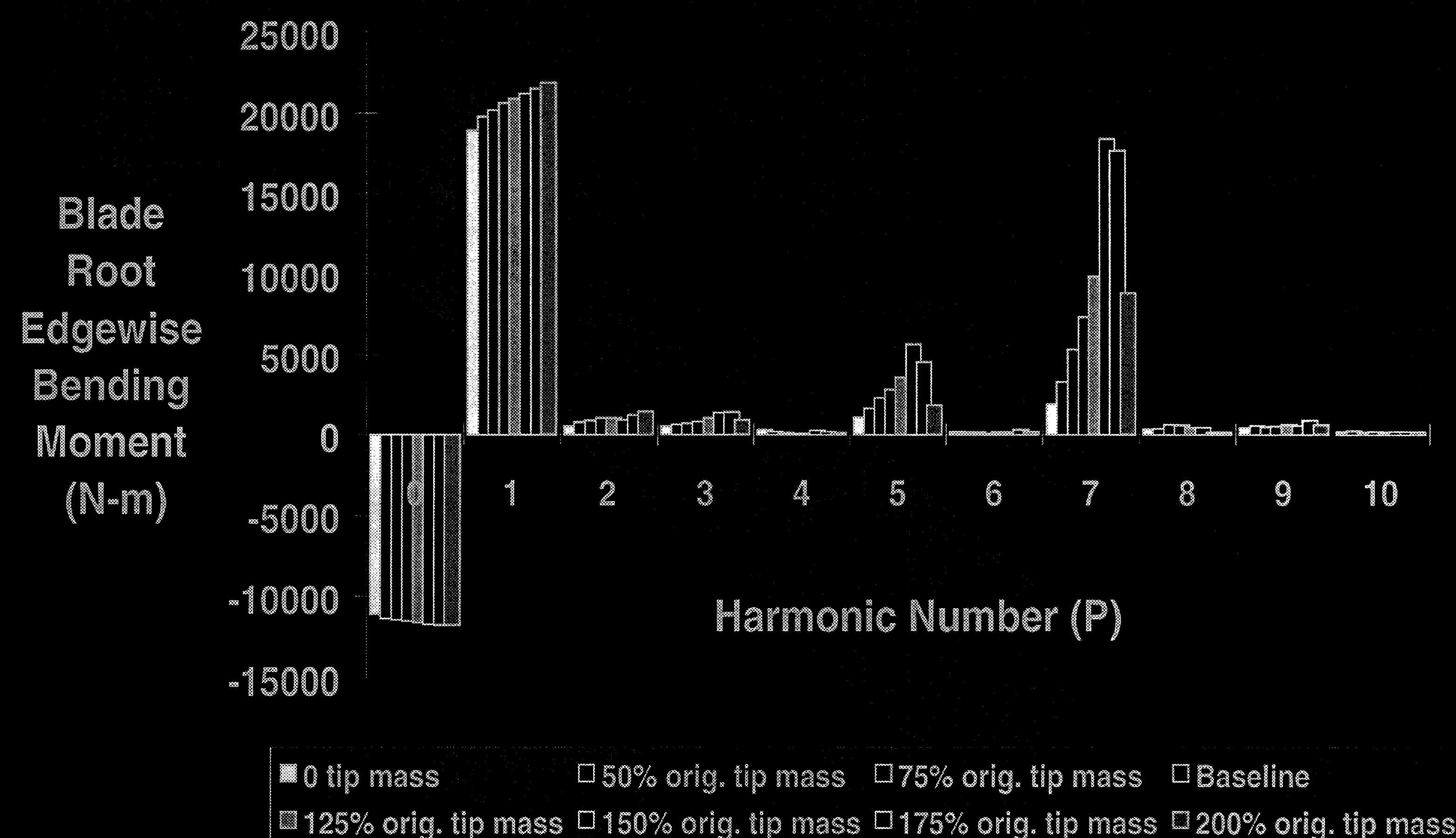
■ Effects of Structural Pre-twist



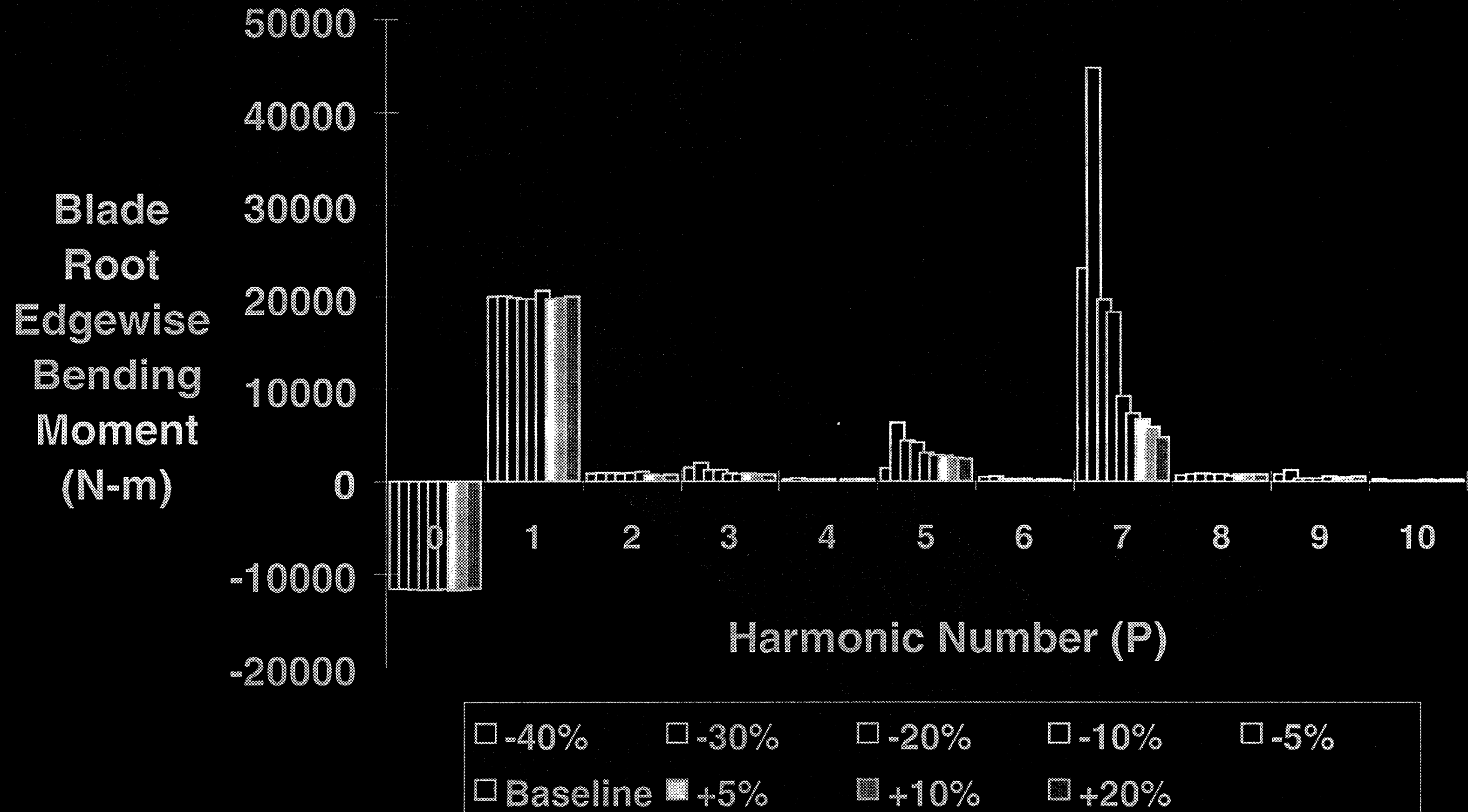
- Effects of Structural Pre-twist (Cont.)



Effects of Blade Tip Mass

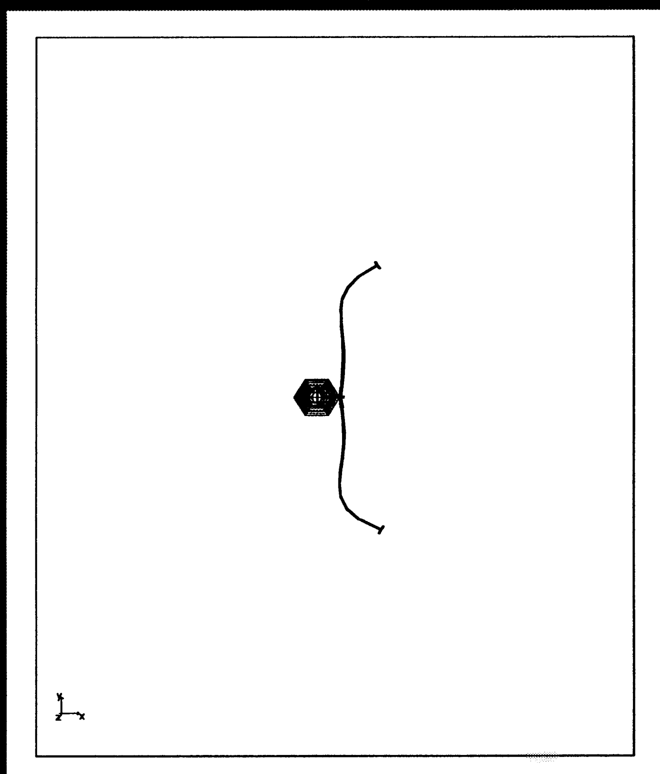


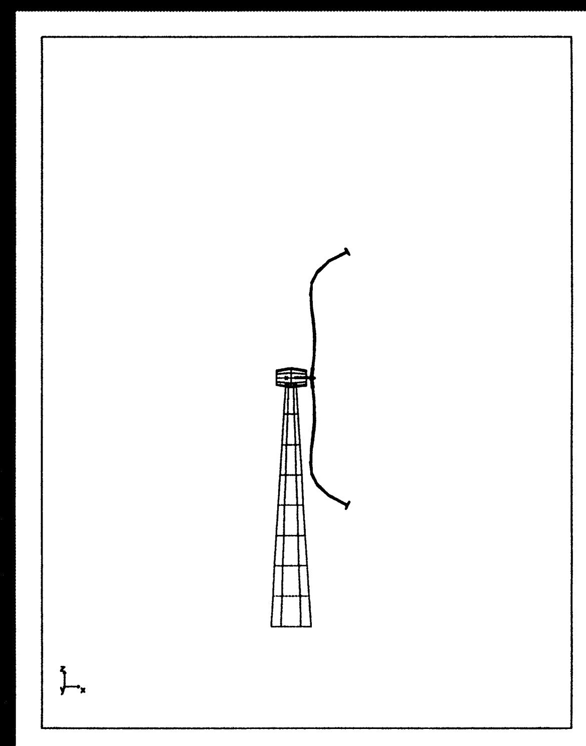
- Effects of Tower Top Stiffness



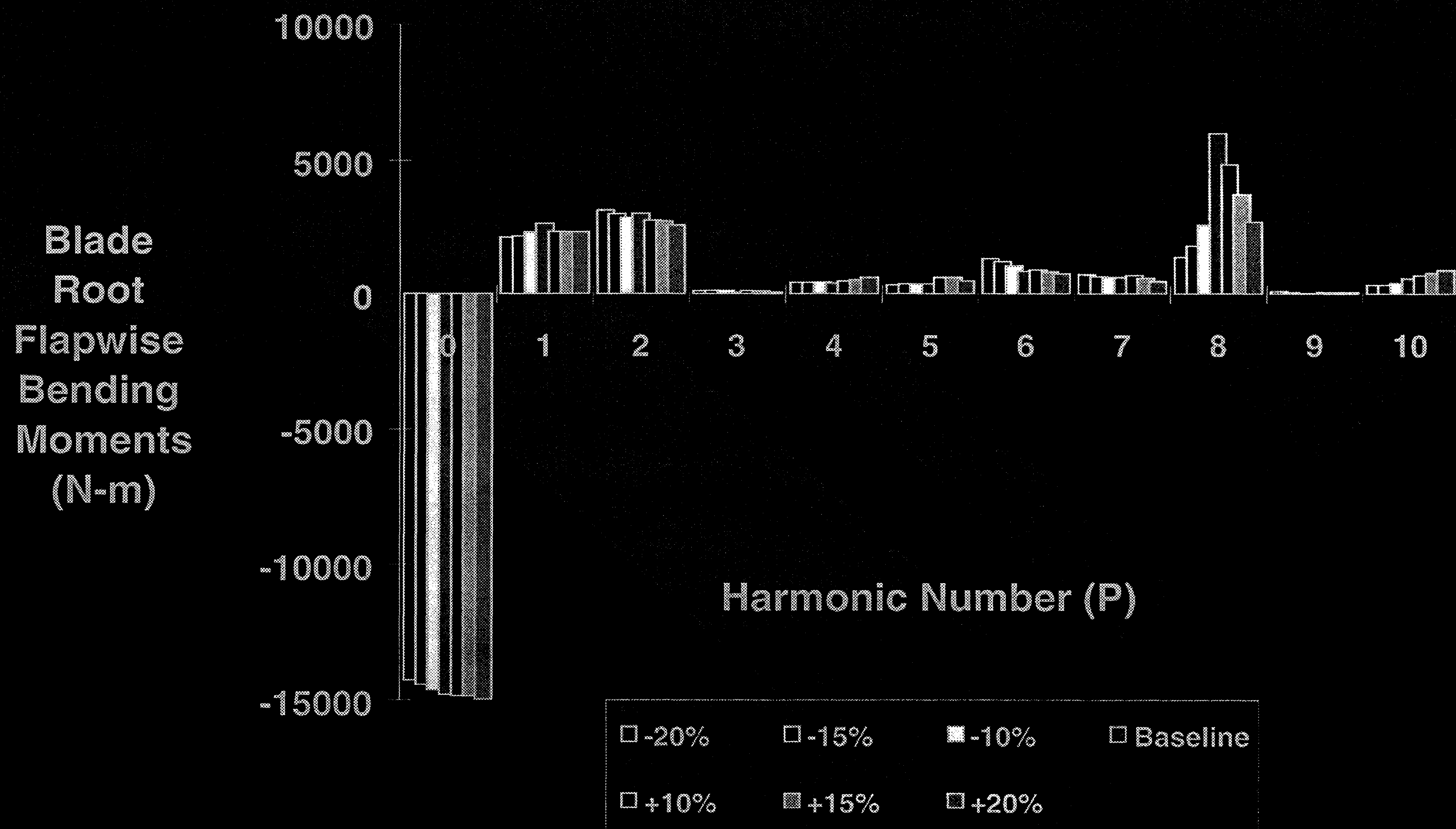
Rotor Flap Response

– Rotor 2nd symmetric flap mode

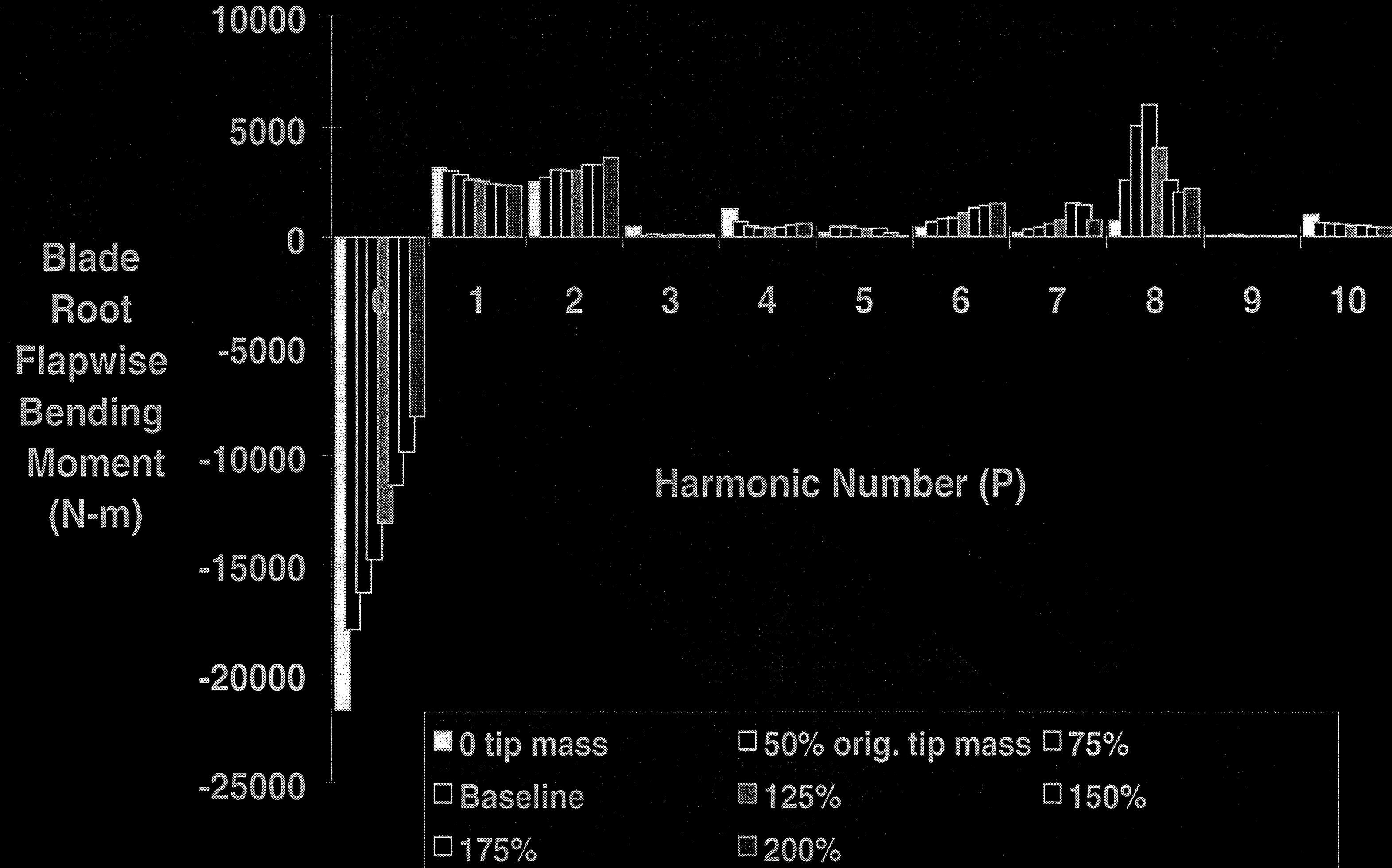


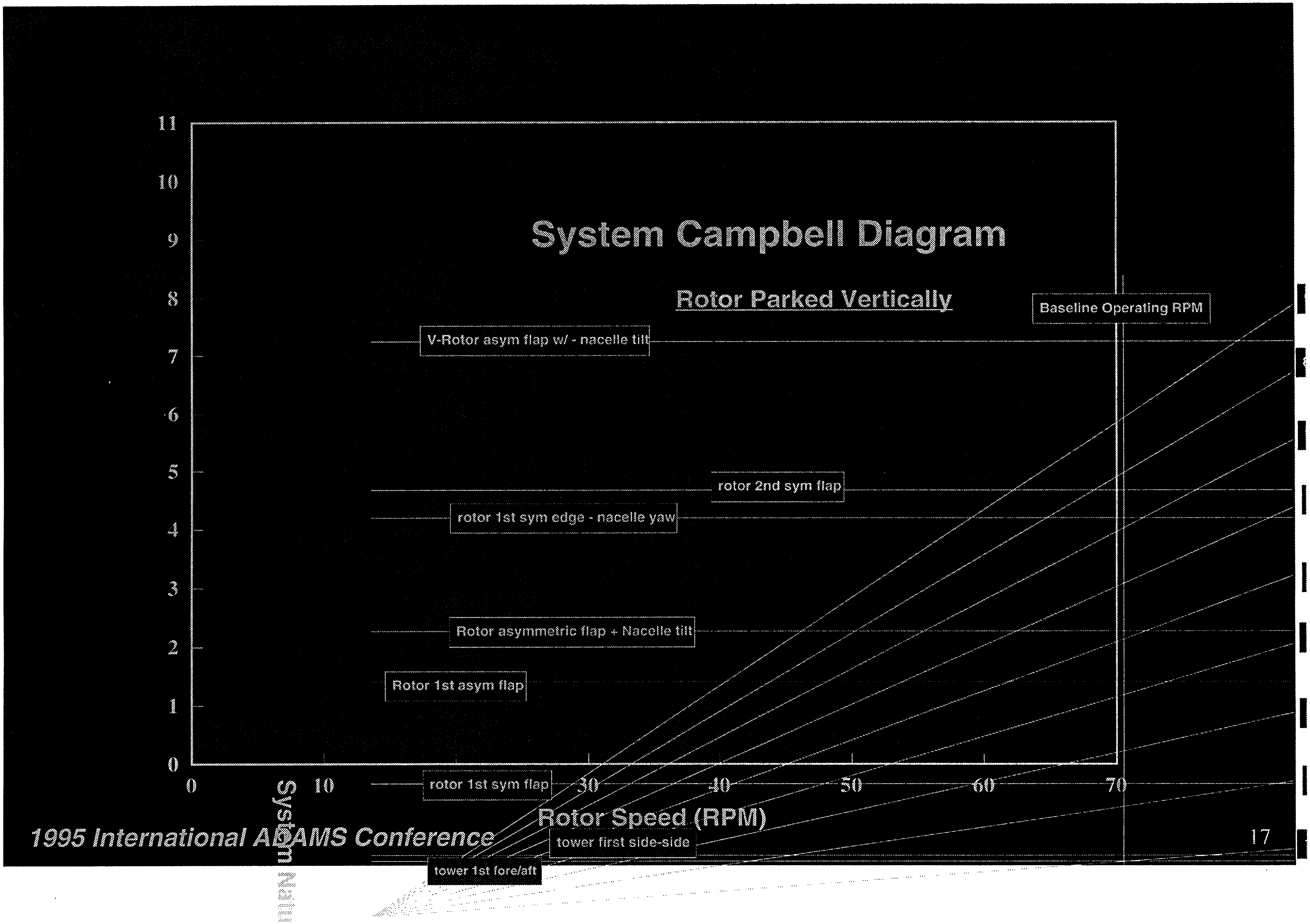


Effects of flap stiffness



Effects of Tip Mass




System Campbell Diagram
Rotor Parked Vertically
Baseline Operating RPM
V-Rotor asym flap w/ - nacelle tilt
rotor 2nd sym flap
rotor 1st sym edge - nacelle yaw
Rotor asymmetric flap + Nacelle tilt
Rotor 1st asym flap
rotor 1st sym flap
tower first side-side
tower 1st fore/aft
Rotor Speed (RPM)
0
1
2
3
4
5
6
7
8
9
10
11
0
10
30
40
50
60
70
1995 International ADAMS Conference
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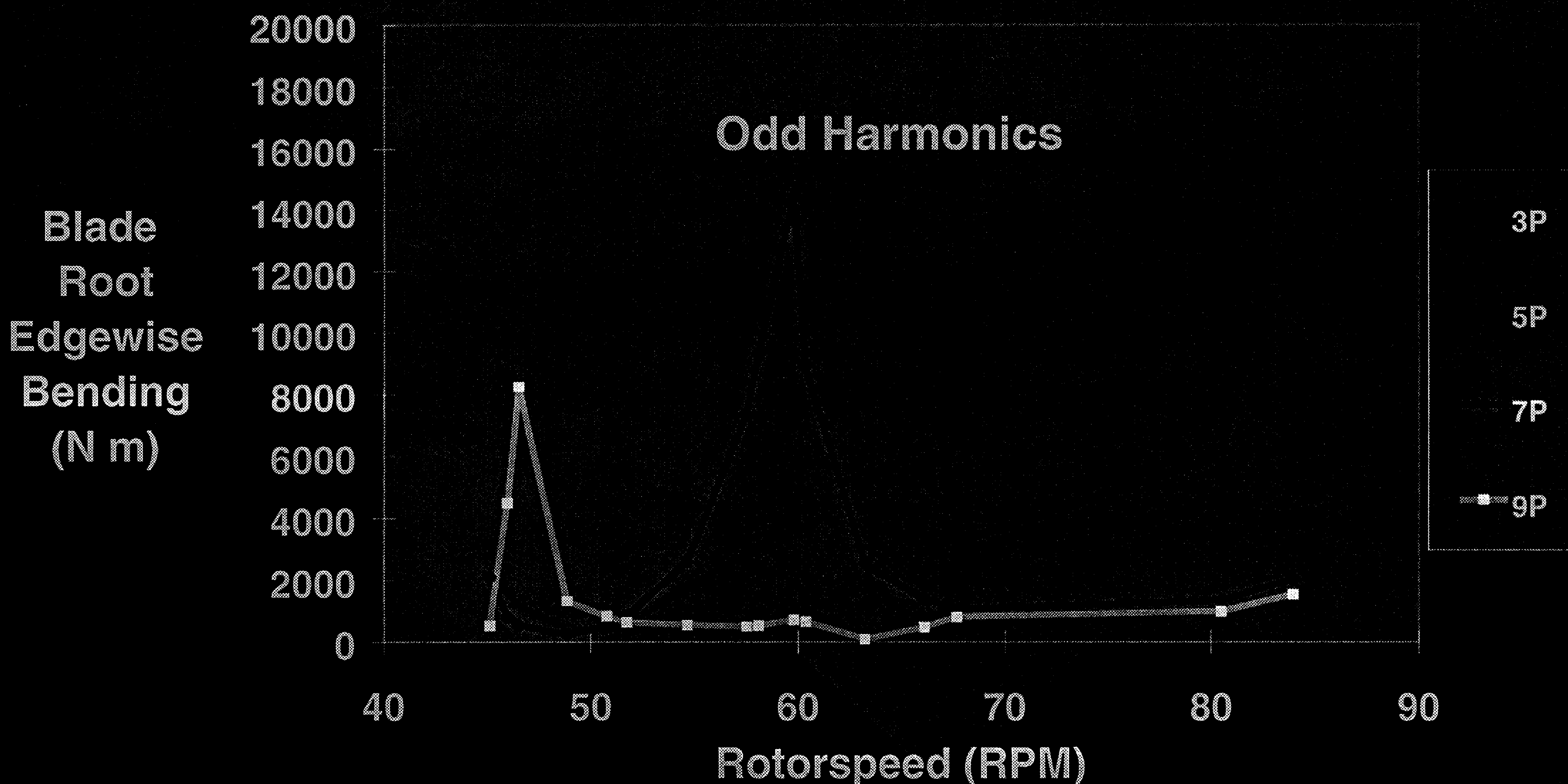
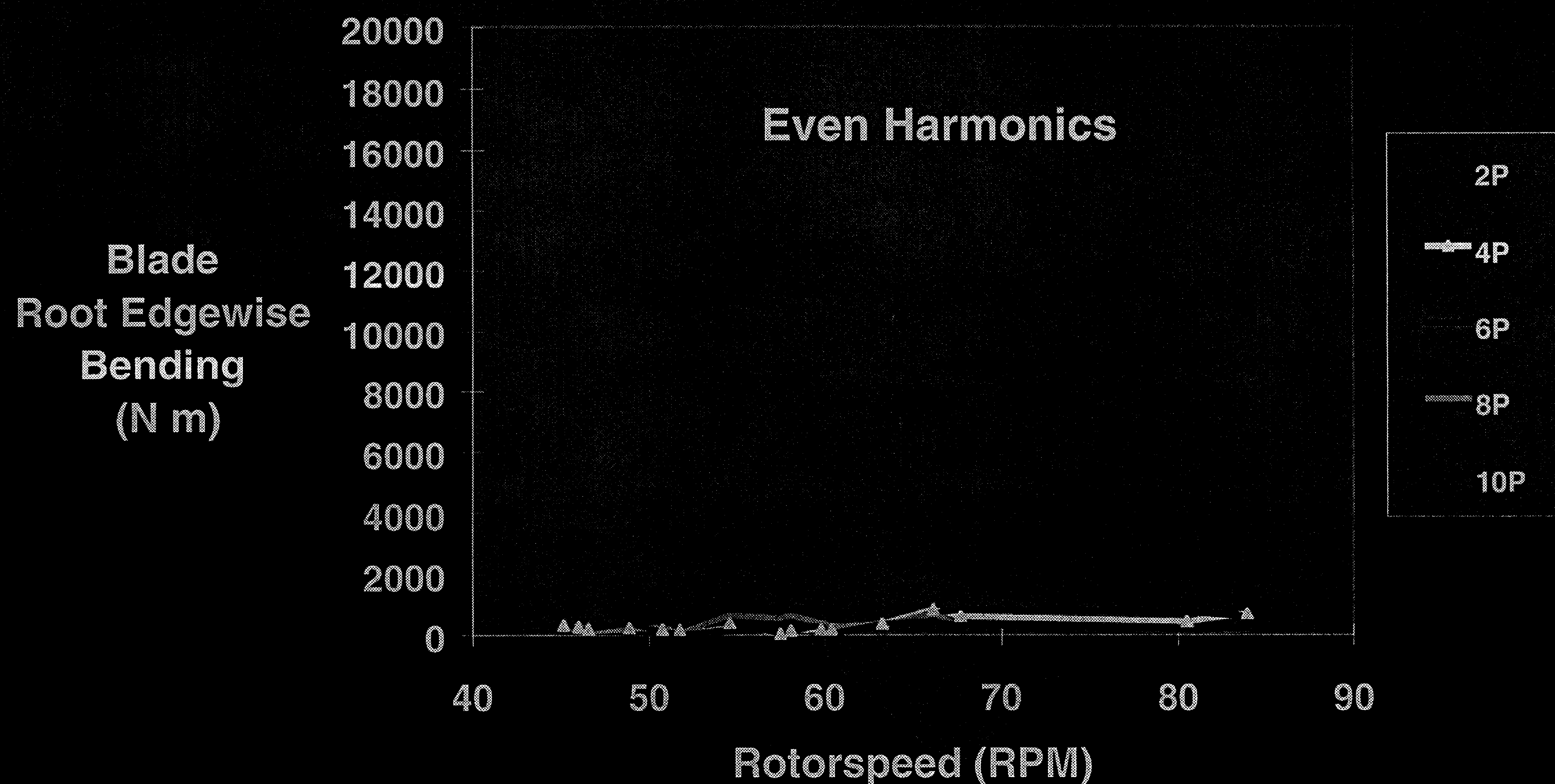
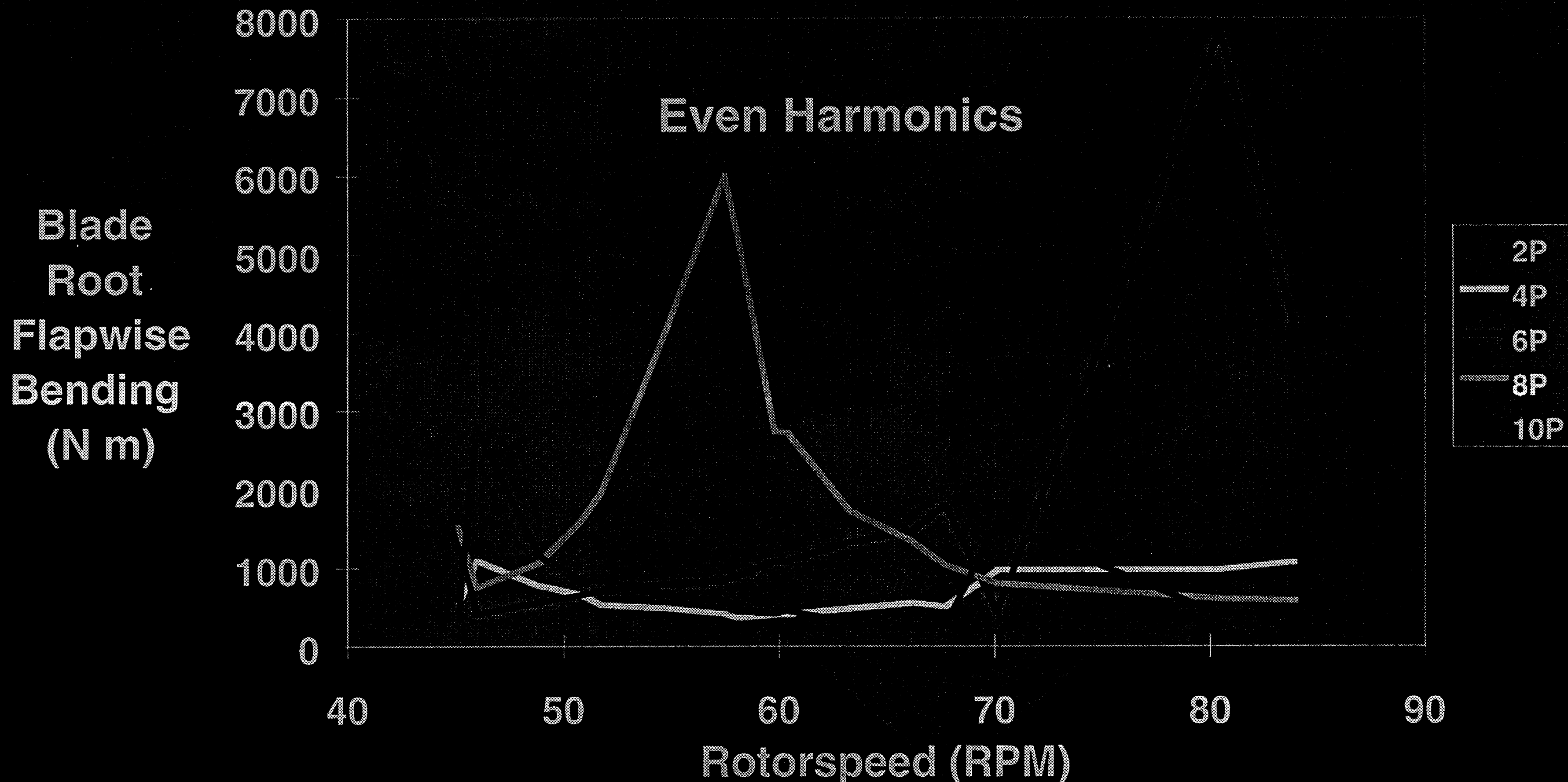
- **Effects of Rotorspeed:**
  - Edge



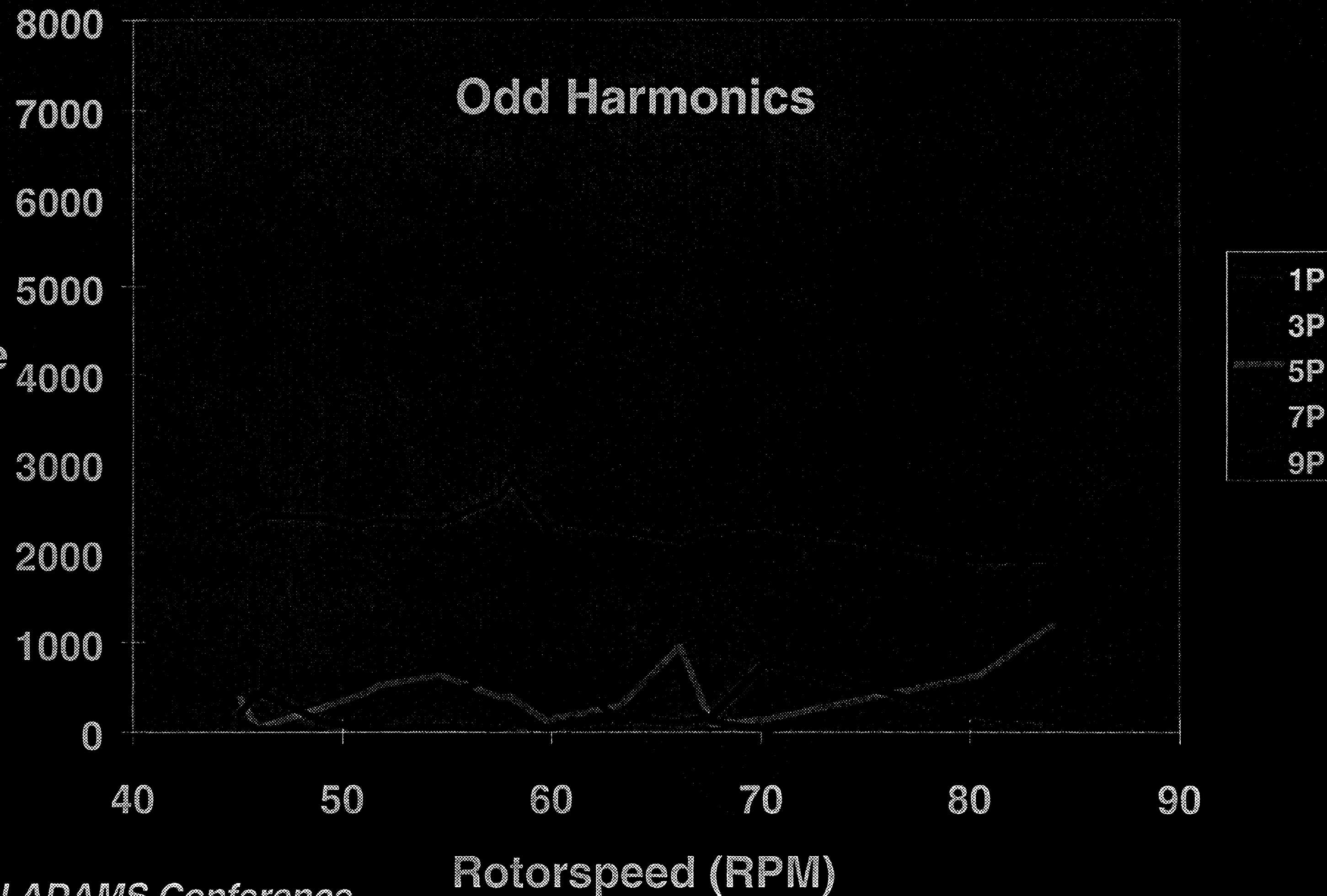
- Effects of Rotorspeed:
  - Edge



- **Effects of Rotor Speed**
  - flap



- Effects of Rotor Speed
  - flap



General Design Guidelines

- Symmetric Flap Modes: Try to design machine so that these modes are at ***Odd*** Harmonics
- Symmetric Lag Modes: Try to design machine so that these modes are at ***Even*** Harmonics

Design Guidelines (cont.)

- Do careful preliminary design
- Symmetric lag Modes: blade edge stiffness, tower top stiffness, tip mass, shaft stiffness, nacelle inertia
- Symmetric Flap Modes: blade flap stiffness, tip mass.

Future Work

- Perform similiar design guidelines study for 3-bladed rigid hub rotors
- Modify Oregon State University FAST codes to include edgewise bending-good preliminary design tools
- Modify wind industry codes to predict rotating blade modes and perform Floquet Analysis