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Control-Structures Interaction Test of the LACE Satellite

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ABSTRACT

It is clear that additional experience and validation of Control-Structures Interaction (CSI) techniques are needed in controlling the structural dynamics of flexible spacecraft. It is also clear that the effects of the space environment such as weightlessness dictate that this be done in space. Unfortunately, orbital tests are difficult to achieve because of the high cost of the test article, the launch into orbit, the instrumentation and communication systems.

The LACE Satellite has provided an opportunity to achieve a CSI test in space for very little cost. First, the CSI test rode piggy-back and did not interfere with the primary objective of LACE. Second, the novel technique of using ground based measurements of vibration of the orbiting satellite was employed. The LACE has a heavy central body to which is attached booms with lengths as long as 150 feet. The ground measurements were obtained using a laser, Doppler radar at the MIT Lincoln Laboratory Firepond Facility.

The initial tests demonstrated the accuracy of the vibration measurements and obtained structural responses for enhancing the accuracy of the mathematical model of the structural dynamics. Germanium corner-cube retroreflectors attached to the central body and a boom deployed to 18 feet ensured a high strength return signal. Subsequent tests demonstrated the ability of an open-loop damper to attenuate the vibrations of the orbiting satellite. The LACE test results are important in (1) contributing to the validation of a CSI technique, and (2) demonstrating a novel ground measurement technique for orbital tests that is accurate but which has very low cost.

Flight Experiments Technical Interchange Meeting

Control - Structures Interaction Test of The LACE Satellite

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Outline of Presentation

- LACE satellite description.
- LACE dynamics experiment description.
- Firepond Laser Radar facility.
- Illumination and vibration measurement history.
- Dynamic excitations and on-orbit responses.
- Concluding remarks.

Objectives of the Dynamics Experiment

- Unique opportunity to measure effects of disturbances on spacecraft flexure; demonstrate ground-based sensing.

- Perform on-orbit system identification: vibration frequencies, damping and amplitude ratios.

- Demonstrate "open-loop" active damping.

  gravity-gradient boom used as actuator
  preprogram timed retractions/deployments
  induce and damp oscillations
  finite element models (FEM): NASTRAN
  dynamics simulation models

- Facilitate control of jitter and rapid slews in future spacecraft.

Piggyback/Secondary Experiment

- **Disadvantages:**
  - Play second fiddle to main experiments:
    - Orbit, power, telemetry, attitude control, environmental, thermal, radiation
  - Must meet stringent host interface requirements and launch schedule.
  - Publicity: Low profile
- **Advantages:**
  - Low-cost, rapid results
  - Main advantage: CSI flight experiments are possible

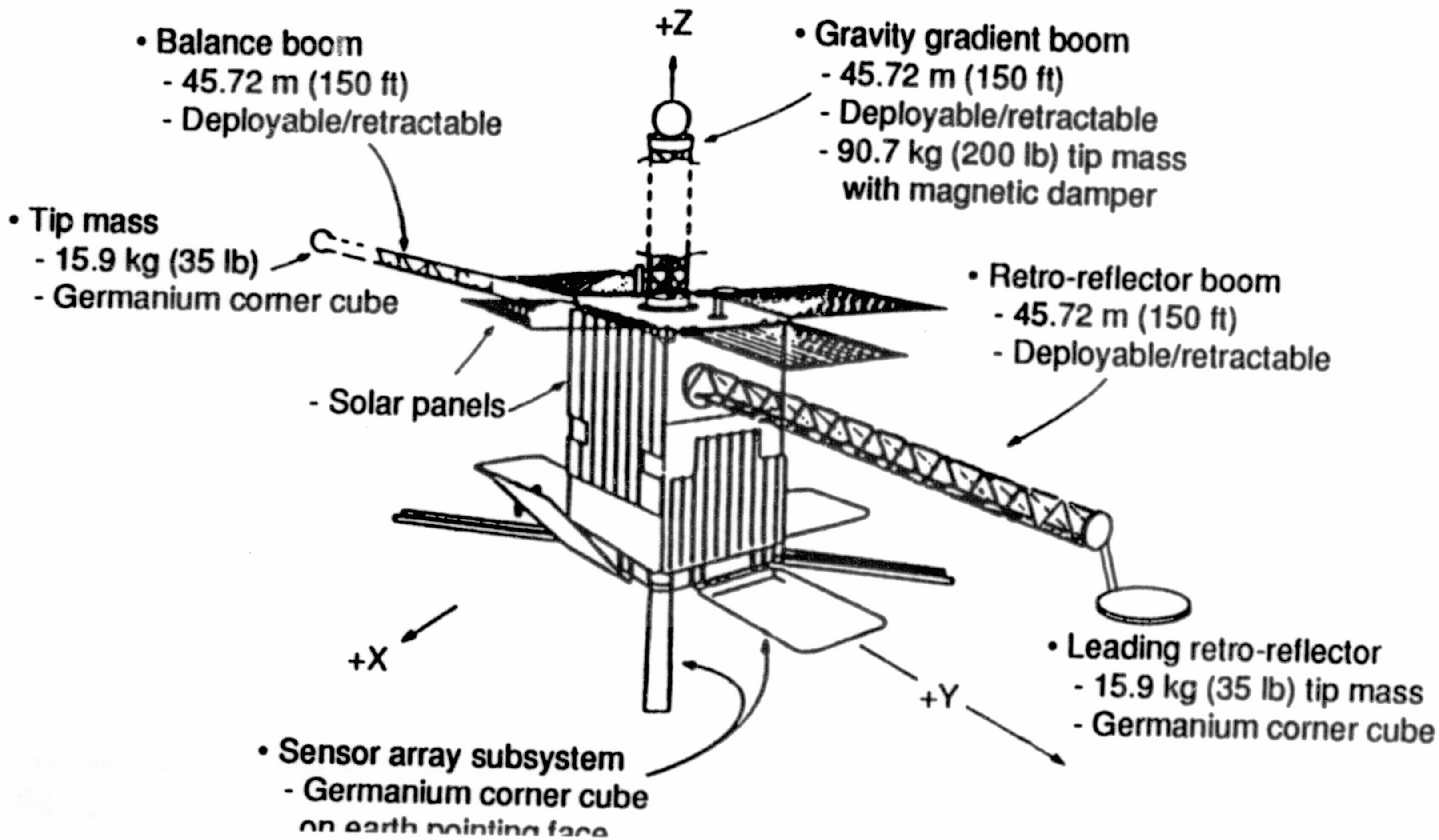
Key Points of the Experiment

- LACE spacecraft launched February 14, 1990

  Altitude at lauch 540 km, circular, 43° inclination

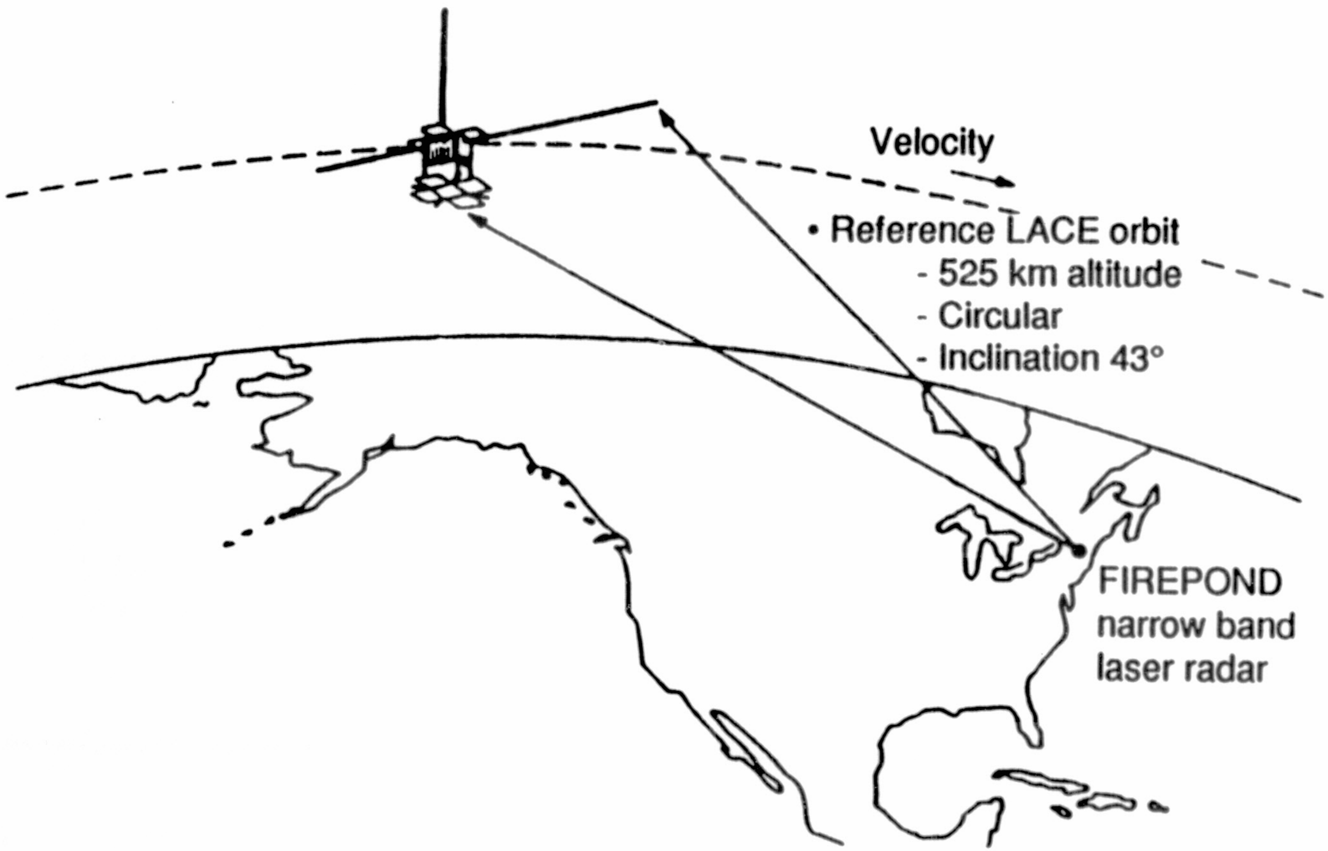
- Lace satellite built and launched by Naval Research Laboratory
- Dynamics experiment is a low - cost "piggyback" experiment.
- Germanium corner cubes (3) serve as targets for Firepond laser radar of MIT Lincoln Laboratory, Wastford, Massachusetts
- Laser Doppler data first collected January 1991 gave system id.
- Dynamic excitations observed and modelled August, September 1992

LACE Spacecraft



Dynamics Experiment

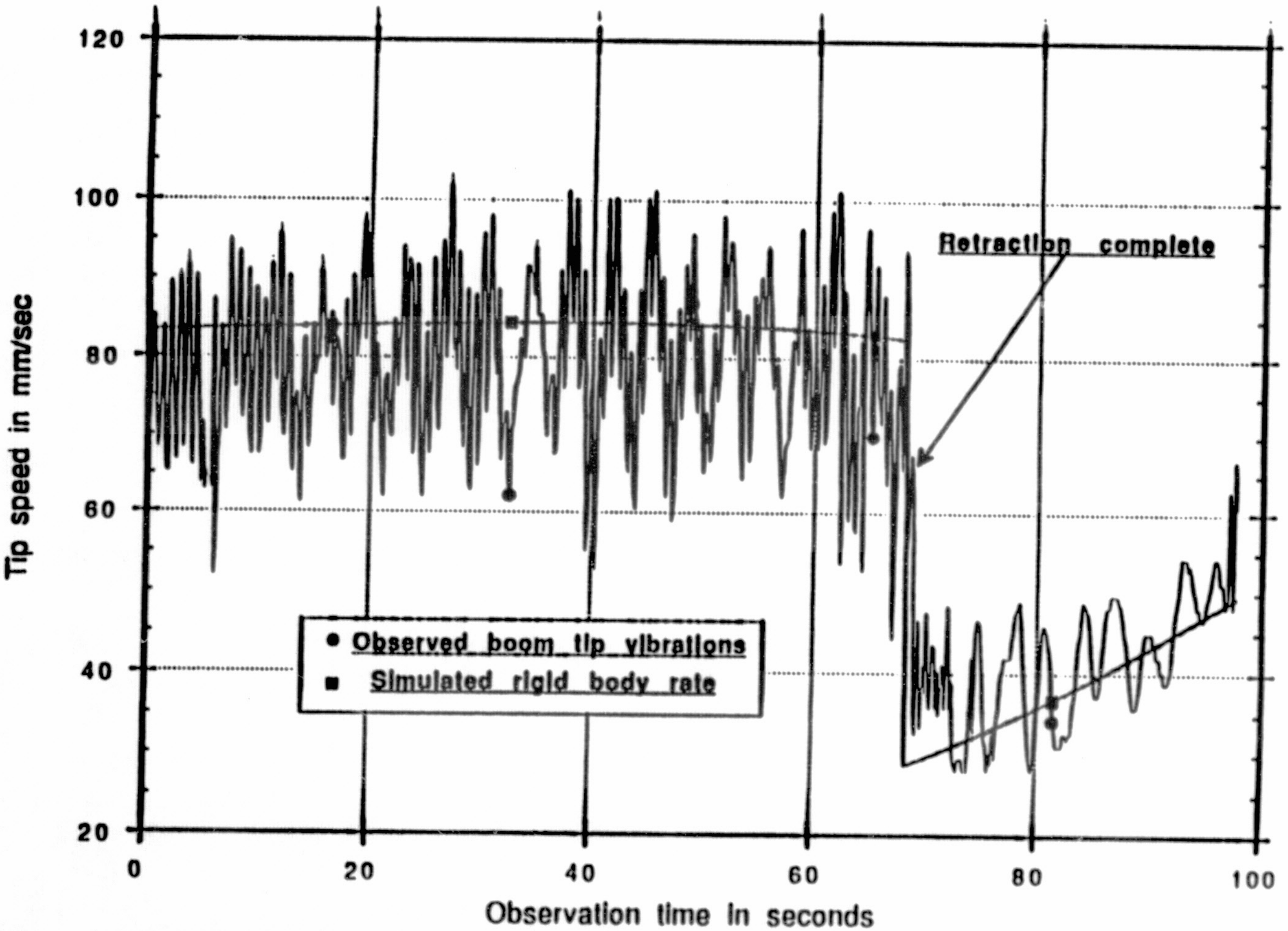
- Estimate satellite vibration modes from doppler resolved laser radar measurements



Boom Dynamics Experiment Observations

Date	Leading Boom (feet)	Trailing Boom (feet)	Tracking	Illumination
7 Jan 91	80 → 15	150	Active	Narrowband
8 Jan 91	80 → 15	150	Active	Narrowband
10 Jan 91	80 → 15	150	Active	Narrowband

VIBRATION OBSERVATIONS COMPARED WITH SIMULATED RIGID BODY RATES, DAY 91008



Comparison of observed with modes computed from FE modelling (stick model)

$EI = 1.55 * 10^4$ N - m^2 $GJ = 5.74 * 10^2$ N - m^2

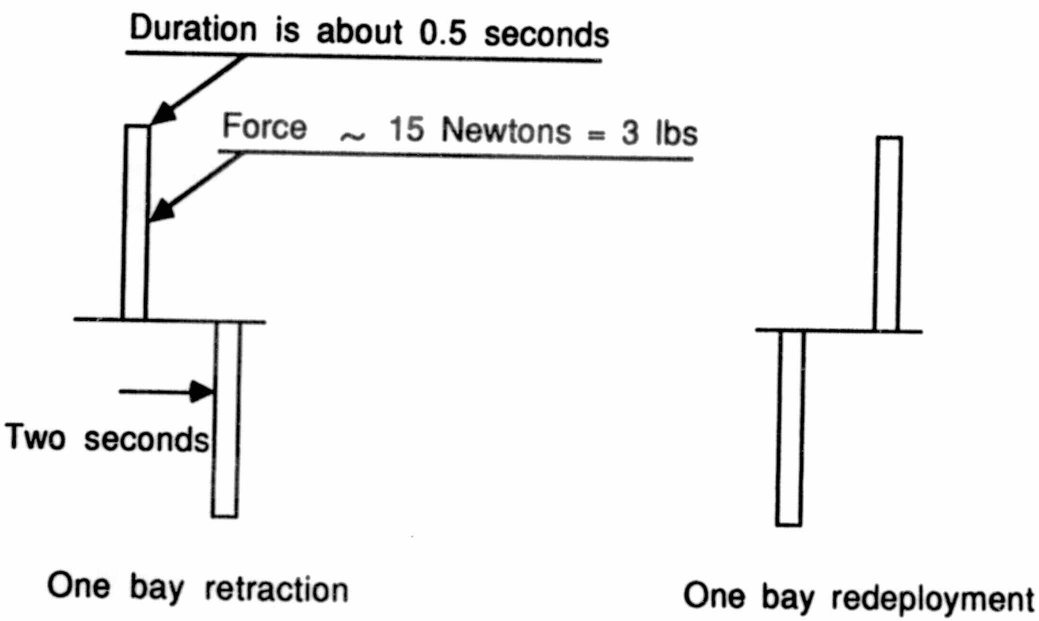
Obs freq	FEM freq	tip modal displacements	
		Δz	Δx
*0.019 Hz	0.019 Hz	.010	--
	0.110 Hz	.001	.05
	0.112 Hz	.002	.09
•0.124 Hz	**0.125 Hz**	**.09**	**.004**
	0.258 Hz	.009	--
	0.297 Hz	--	.08
•0.335 Hz	**0.316 Hz**	**.10**	**.006**
	0.320 Hz	.02	.02
•0.547 Hz	**0.577 Hz**	**.14**	**.124**
	0.646 Hz	.127	.135
	0.819 Hz	.004	--

•Denotes modes observed.* Not positively identified

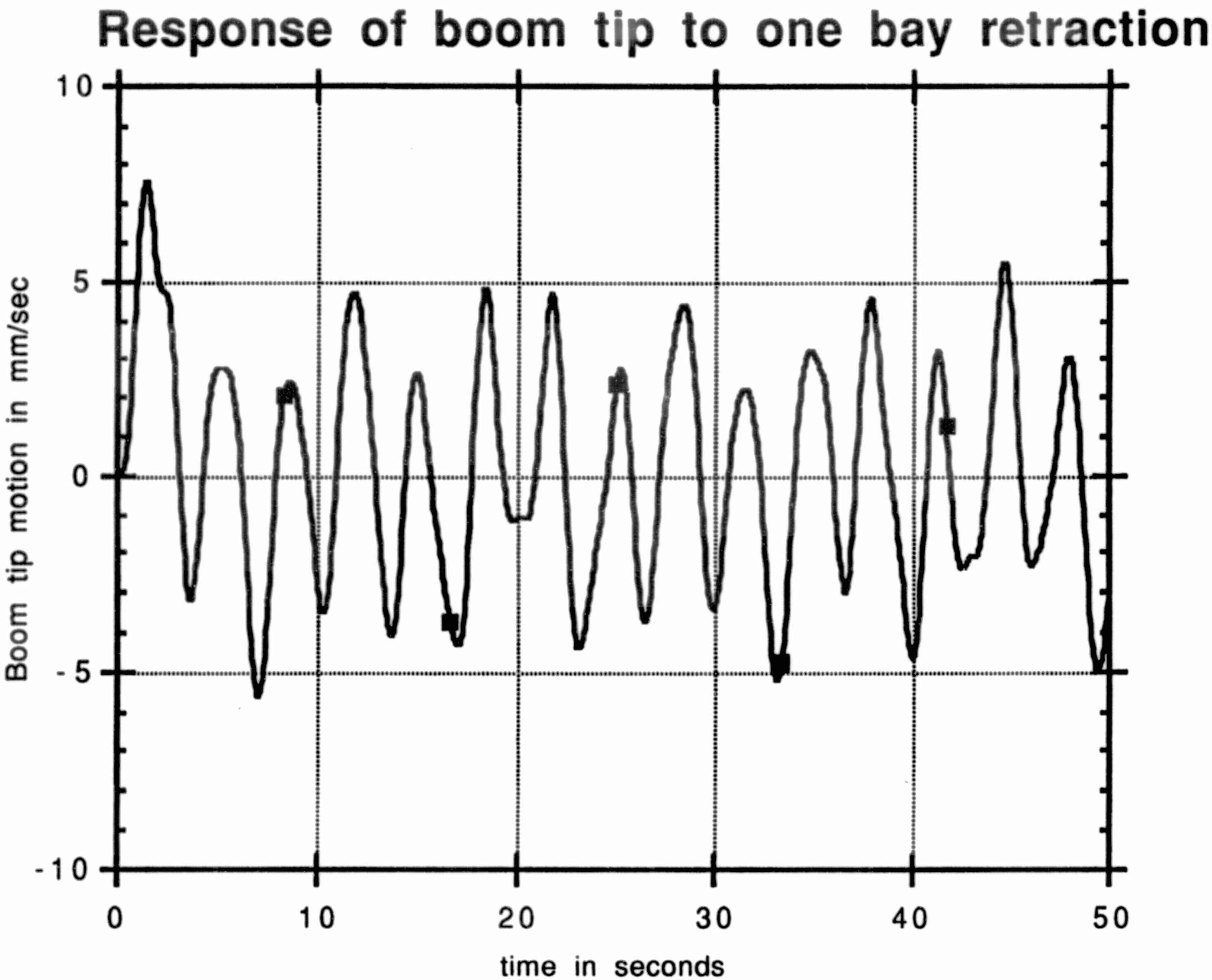
Use gravity-gradient boom for excitation

- Deploy or retract gravity-gradient boom 1 bay (6 inches)

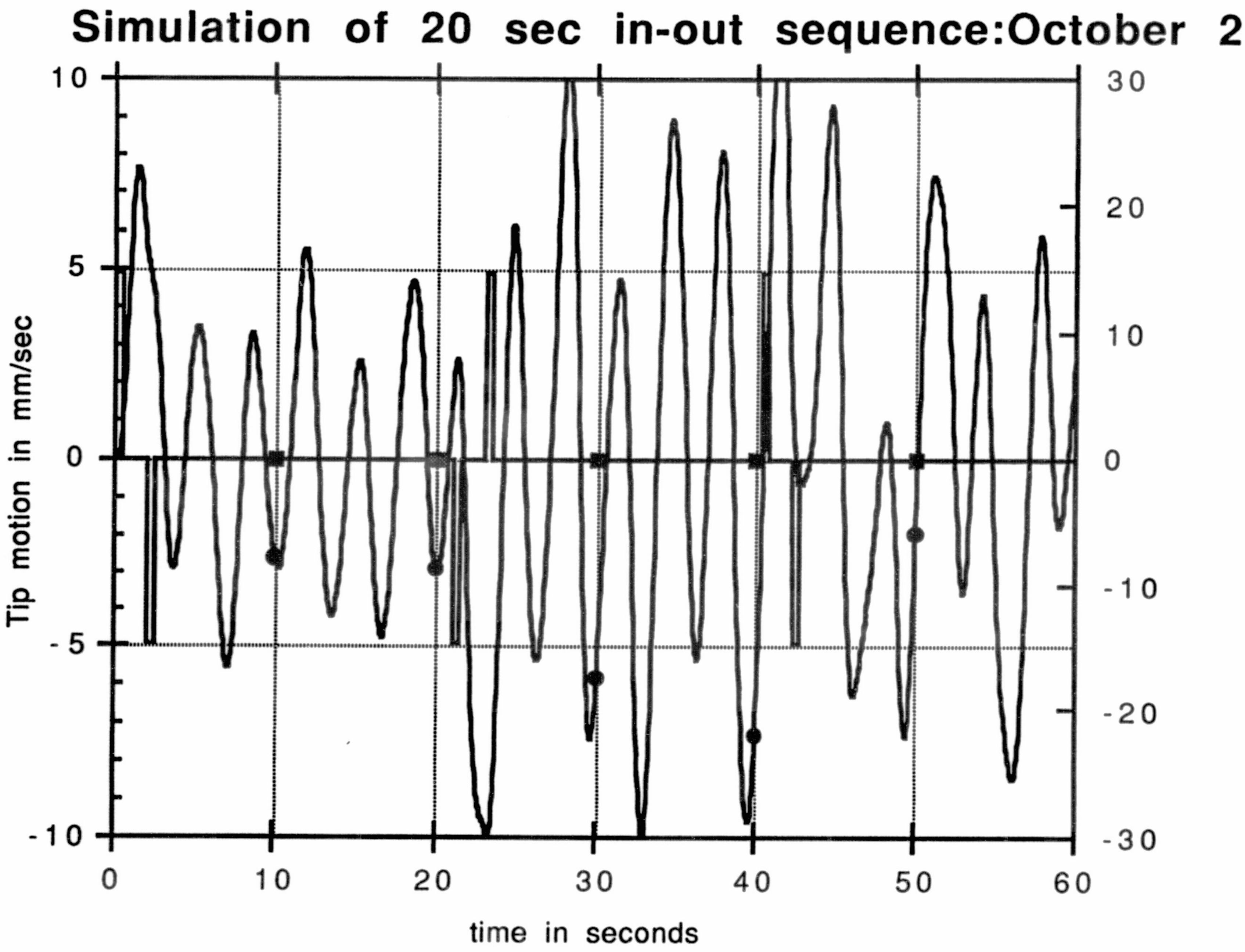
  Gives 2 impulses to spacecraft.

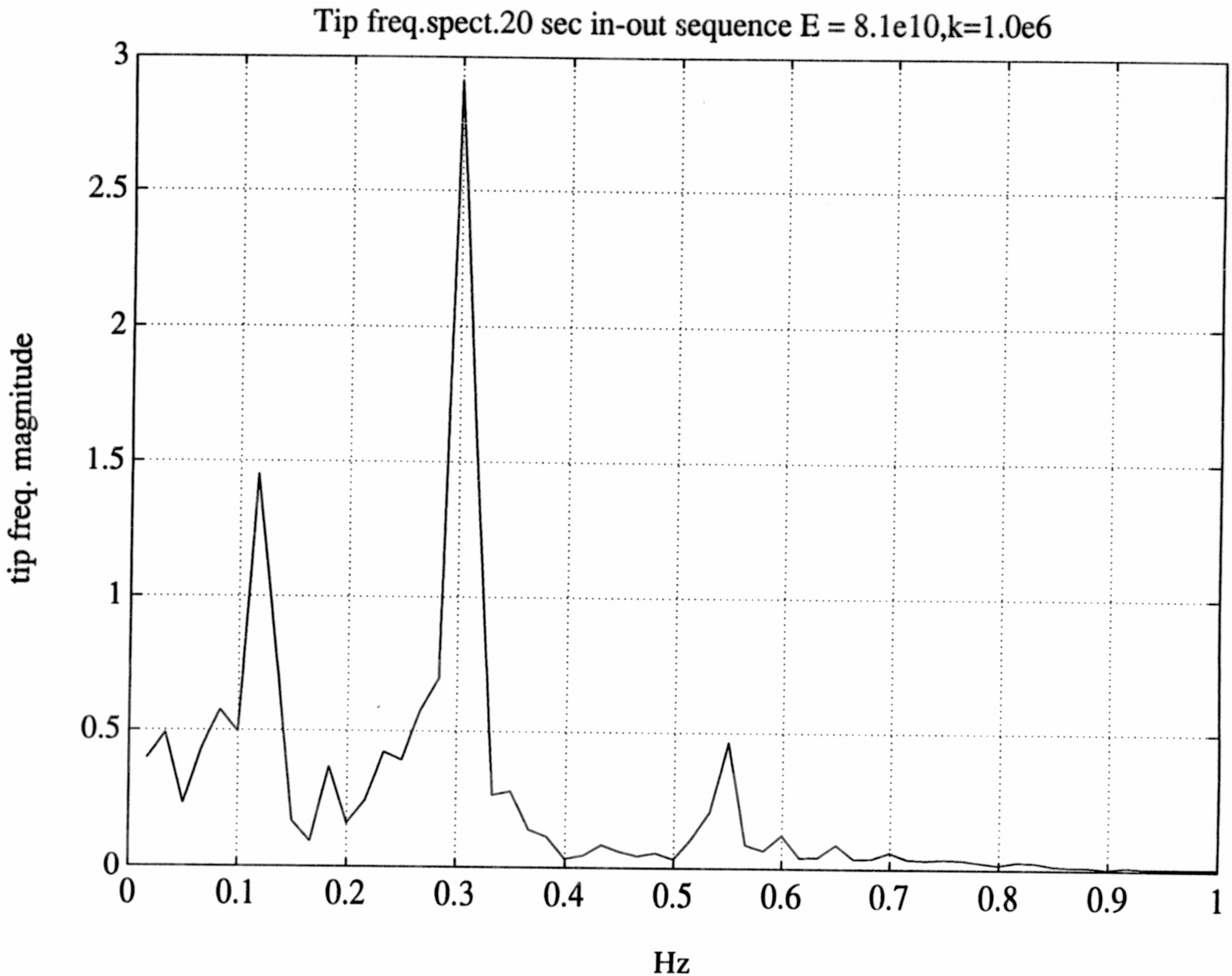


Boom starts up/stops in abt 0.5 sec
Retraction/deployment rate is abt 75 mm/sec = 3 in/sec



Response of boom tip to one bay retraction
Boom tip motion in mm/sec
10
5
0
-5
-10
0
10
20
30
40
50
time in seconds


Simulation of 20 sec in-out sequence:October 2
Tip motion in mm/sec
time in seconds
10
5
0
- 5
- 10
30
20
10
0
- 10
- 20
- 30
0
10
20
30
40
50
60


Tip freq.spect.20 sec in-out sequence E = 8.1e10,k=1.0e6
tip freq. magnitude
Hz
0
0.5
1
1.5
2
2.5
3
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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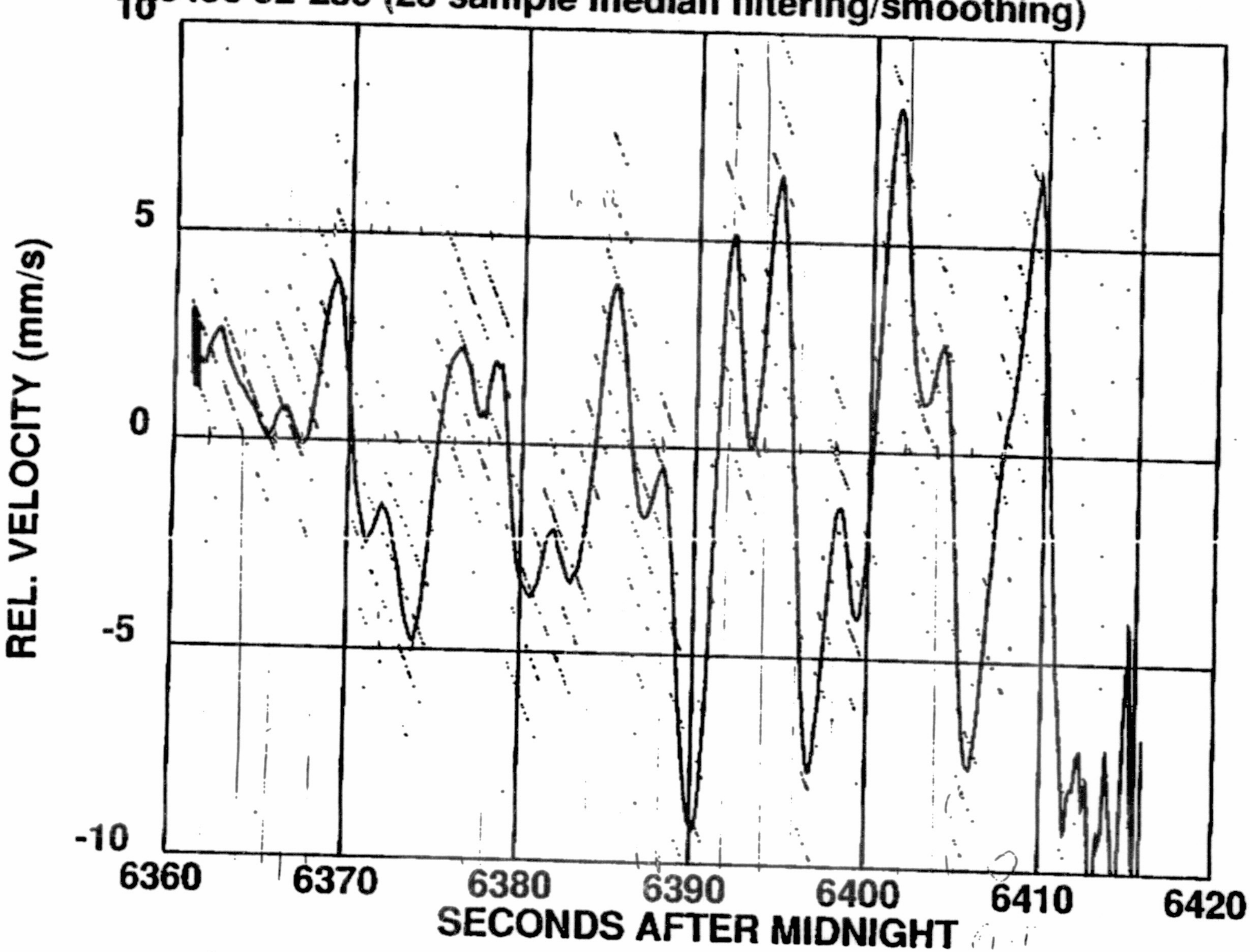
0 in
20 out
20 in
20 out

Tues..., Aug 25

20496 92-239 (28 sample median filtering/smoothing)



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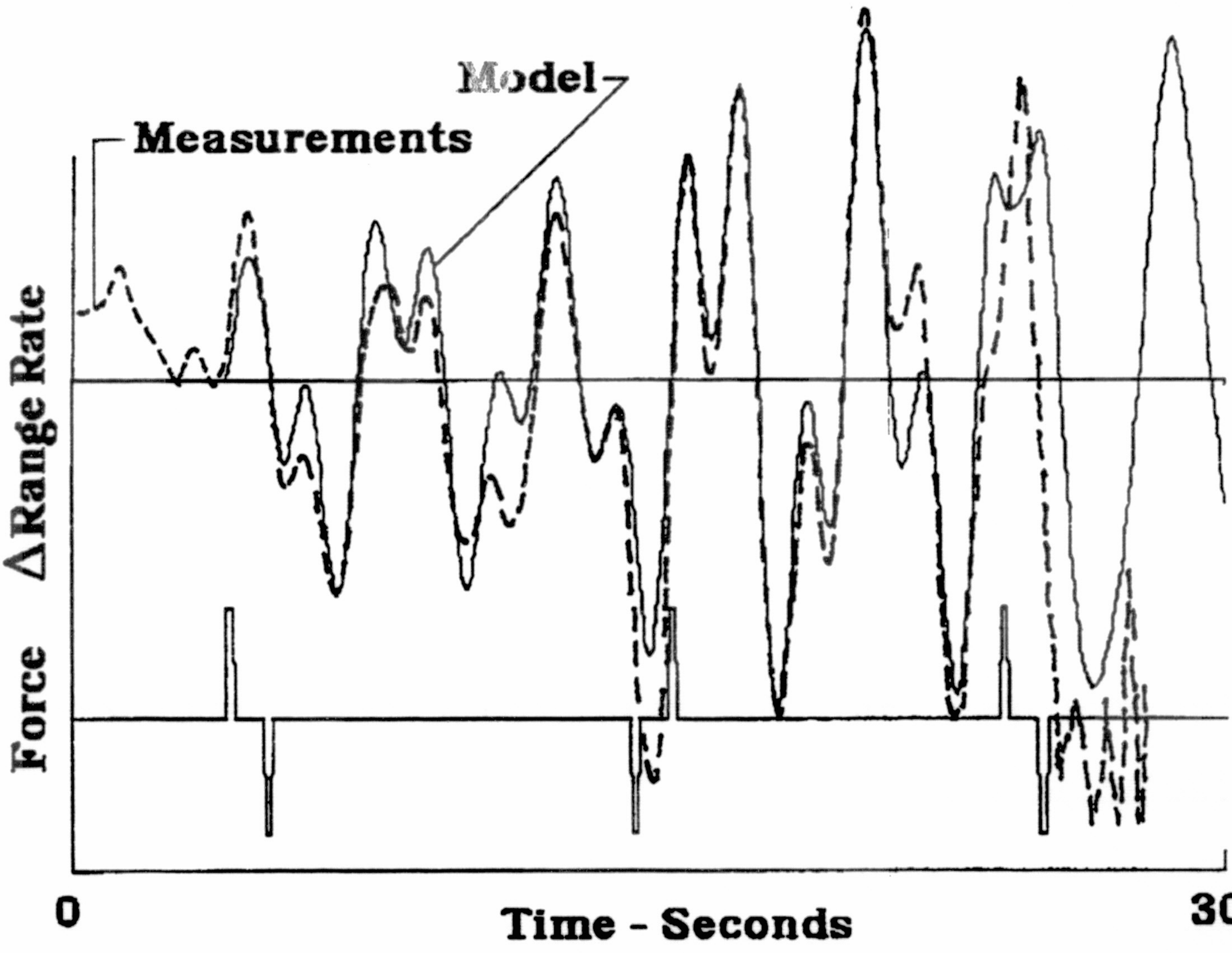
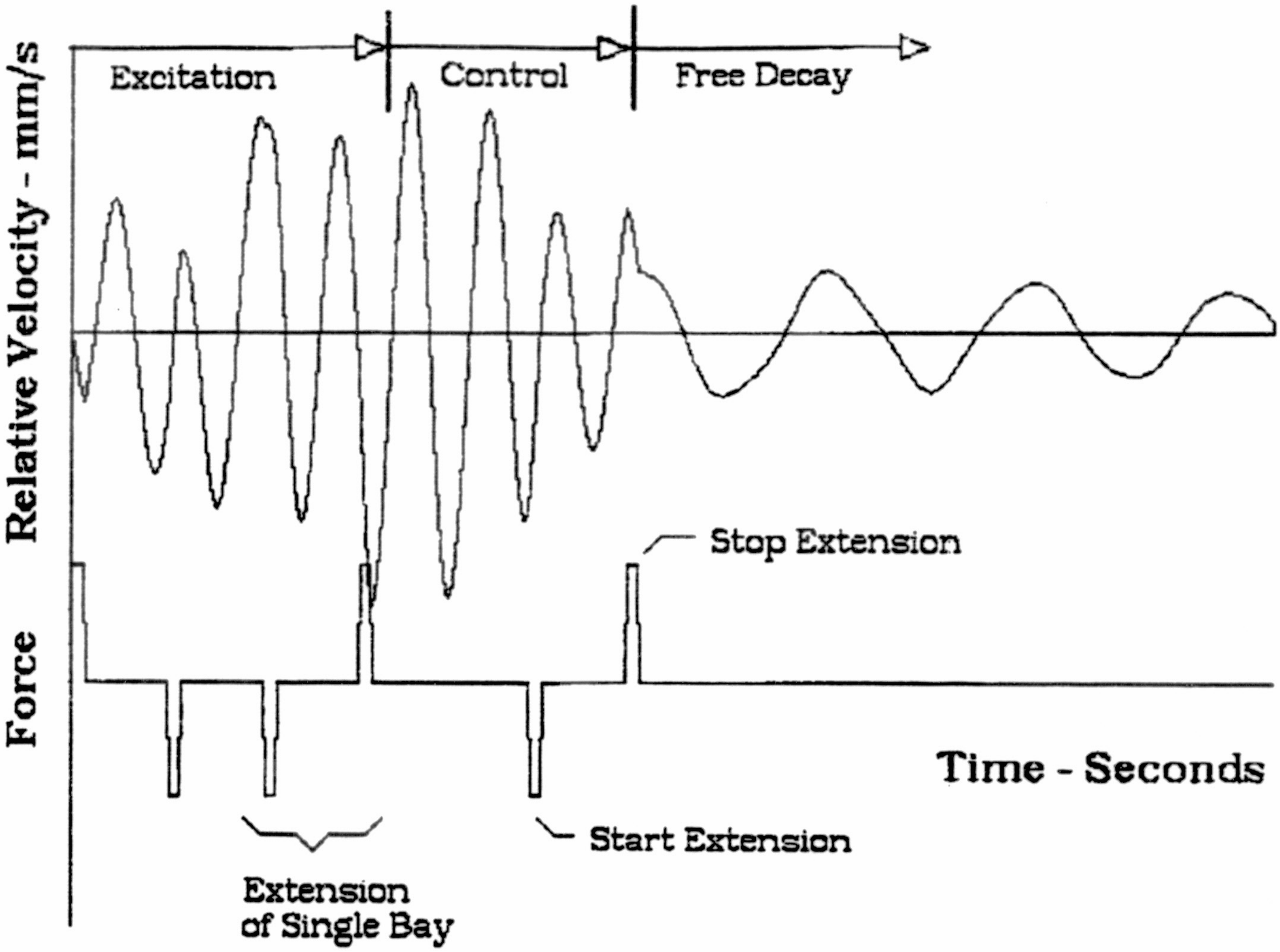
Comparison of Responses



DAY 239



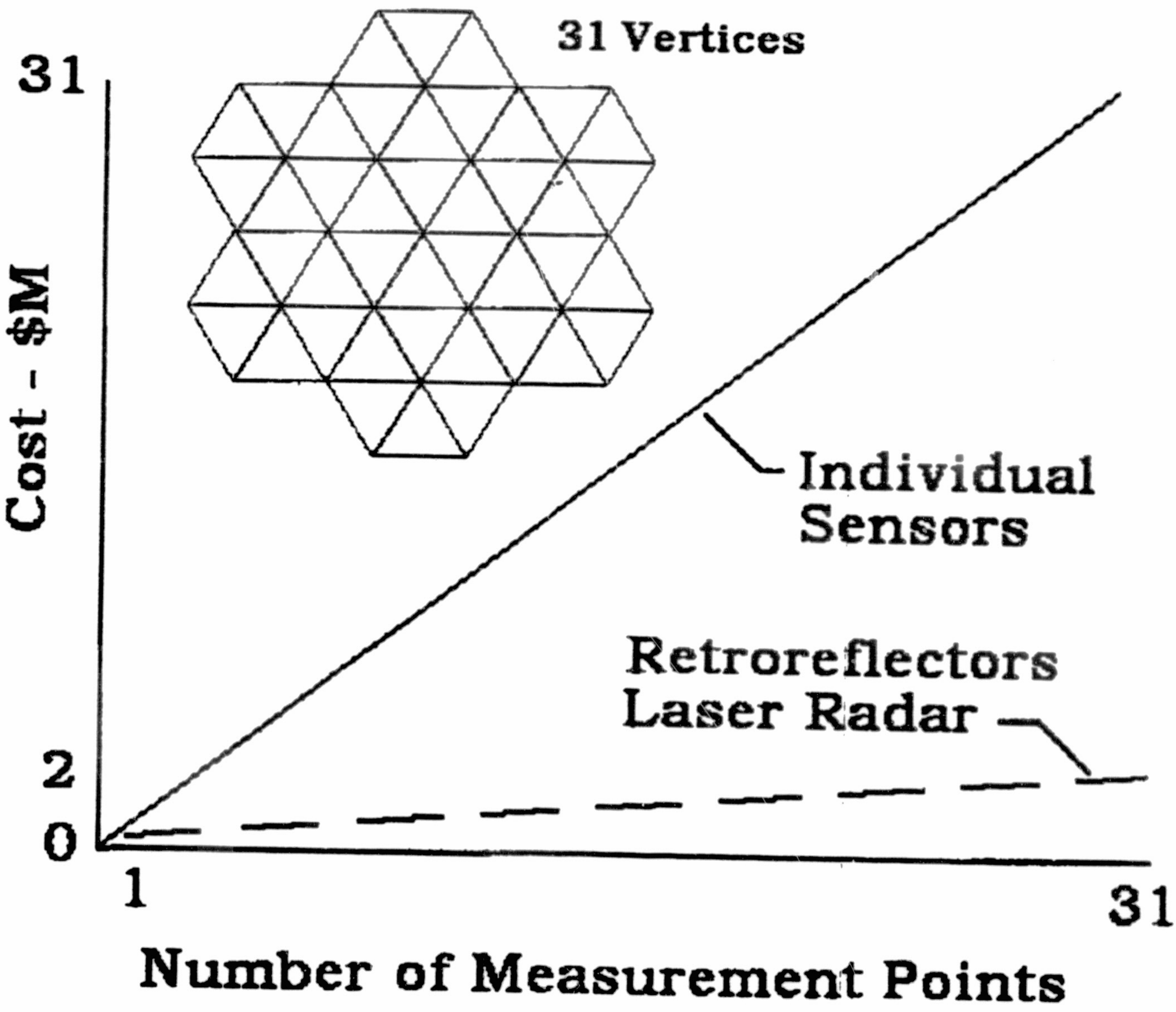
Targeted Open Loop Damping of .319 Hz Mode. Response of .125 Hz Mode Included.

Discussion of measurements and simulations

- Modes excited by the boom movements were quite observable by the Firepond ground-based system.
- Observations enabled refinements of models: FEM, PDE and modal models.
- Dynamics model gave good qualitative estimates of vibratior amplitudes (abt 10 %) and good prediction of which modes would be excited by the boom movements.
- Still refining our models: TREETOPS, DISCOS.
- Open-loop damping is difficult due to extreme sensitivity to system parameters and timing of boom movements.
- Method gives low-cost vibration measurements.

 [redacted]

Cost Comparison



ACCOMPLISHMENTS OF LACE EXPERIMENT

- First ever ground-based laser measurements of vibrations of an orbiting satellite.
- Established feasibility of remote health monitoring & inspection of orbiting structures.
- Validated system modeling – but also found errors in model; showed need for flight experiments to validate modeling parameters.