Introduction to the Session on Structural Dynamics

by

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It is my privilege to act as chairman for this Session on Structural Dynamics. I wish to give a special welcome to the 15 professors who were at the Langley Research Center in the American Society for Engineering Education program. The full session topic could appropriately read, "The Role of Simulation in Structural Dynamics for Space Technology;" still more precisely, we could use the word "similitude" for the word "simulation." "Simulation" is a word with many connotations. It could mean pretending to be what you are not, for example, the protective coloration assumed by some animals in nature; or it could stand for the act of piloting a space vehicle without leaving the ground. In the use of the word in structural dynamics, we may mean to describe the role of a similar or dynamically scaled model, or even the parameters of governing equations of a mathematical model. A mathematical idealization of a physical situation always contains a degree of simulation. The art of a mathematical model lies in the simplest model that yet simulates. In fact, for Nature herself, the word "simulation" has the two distinct meanings: as, for example, protective color in animals or insects; or the meaning as given in D'Arcy Thompson's classic book, "On Growth and Form," in which famous scaling laws applying to large and small species in natural evolution are so clearly described.

All three of the talks for this morning's session are being given by my colleagues from Langley, and these talks, as well as the fourth talk to be given by Mr. Bozajian this afternoon, all deal with space vehicles, launch vehicles, and payloads, on the ground and in space. As you may know or realize on brief reflection, the major cost of our national space programs is in the hardware, in the vehicle itself, and its payload; thus, the major problems, moneywise, are in the engineering technology rather than in pure science. Space science, however, cannot be pursued without a suitable technological base. Distinguished scientists have frequently planned their scientific experiments well, but in many early space attempts have completely overlooked factors of the environments in which these experiments are placed. The role of simulation in space technology is thus very much like an insurance premium, and its main objectives are to reduce costs and ensure reliability of the final products. Many factors need to be considered in the realm of simulation of similitude: structural dynamics; physical phenomena; governing mathematical equations; parameters, dimensional and nondimensional; the natural environments as well as induced environments; material properties. Although very much remains to be done, progress has already been made, as our speakers will disclose.

	ENVIRONMENT		
	ACTUAL	APPROX.	SIMULATED
STRUCTURE			
FULL SCALE			
ACTUAL FLIGHT	X		
BOILER-PLATE FLIGHT		X	
GROUND TESTS			X
COMPONENTS			X
DYNAMIC MODEL			
REPLICA			X
DYNAMICALLY SIMILAR			X
COMPONENTS			X

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Figure 1.- Approaches to experimental analysis of space vehicles.

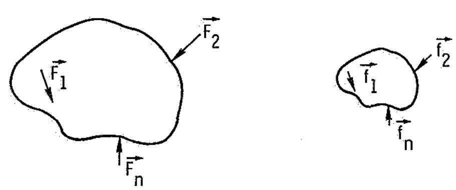
1. ON THE BASIS OF PAST EXPERIENCE WITH RELATED PROBLEMS

2. DERIVATION AND NONDIMENSIONALIZATION OF GOVERNING EQUATIONS

3. FORMATION OF RATIOS OF DIMENSIONALLY SIMILAR QUANTITIES WHICH GOVERN SYSTEM RESPONSE

4. APPLICATION OF THE PRINCIPLES OF DIMENSIONAL ANALYSIS

Figure 2.- Techniques for obtaining pertinent dimensionless ratios.



EQUATION: $\vec{F}_1 + \vec{F}_2 + \ldots + \vec{F}_n = 0;$ $\quad \vec{f}_1 + \vec{f}_2 + \ldots + \vec{f}_n = 0$

UNITS: TONS ; DYNES

$$\therefore \quad \frac{F_{1,i}}{F_{n,i}} = g\left(\frac{F_{2,i}}{F_{n,i}}, \ldots\right) \qquad \frac{f_{1,i}}{f_{n,i}} = g\left(\frac{f_{2,i}}{f_{n,i}}, \ldots\right)$$

SIMILARITY IS ACHIEVED IF

$$\frac{F_{1,i}}{F_{n,i}} = \frac{f_{1,i}}{f_{n,i}} \quad ; \quad \frac{F_{2,i}}{F_{n,i}} = \frac{f_{2,i}}{f_{n,i}}; \text{ etc.}$$

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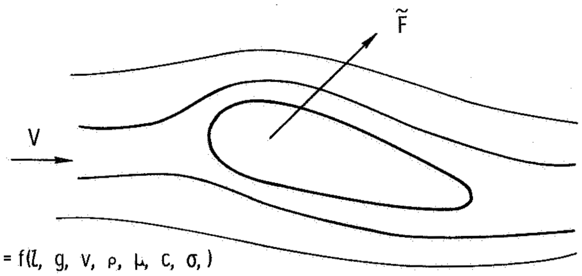
Figure 3.- Derivation of dimensionless ratios by nondimensionalization of governing equations.



$\tilde{F} = f(l,\ g,\ V,\ \rho,\ \mu,\ c,\ \sigma,)$

FROM DIMENSIONAL ANALYSIS

$$\frac{\tilde{F}}{\rho V^2 L^2} = f_1\left(\frac{V^2}{lg},\quad \frac{\rho V l}{\mu},\quad \frac{V}{c},\quad \frac{\rho V^2 l}{\sigma}\right)$$

FORCE COEFFICIENT, P	FROUDE NO., F	REYNOLDS NO., R	MACH NO., M	WEBER NO., W

OR $\quad f_2\,(P,\ F,\ R,\ M,\ W) = 0$

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Figure 4.- Example of a complete set of dimensionless ratios for an assumed set of pertinent variables.

- GEOMETRIC:
  CORRESPONDING LENGTHS ARE PROPORTIONAL OR
  CORRESPONDING ANGLES ARE EQUAL
- KINEMATIC:
  CORRESPONDING CHANGES IN GEOMETRIC SHAPE
  OR POSITION OCCUR AT TIMES WHICH ARE
  PROPORTIONAL
- DYNAMIC:
  CORRESPONDING FORCES ON CORRESPONDING
  ELEMENTS OF MASS PRODUCE INTERNAL AND
  EXTERNAL MOTIONS WHICH ARE GEOMETRICALLY
  AND KINEMATICALLY SIMILAR

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Figure 5.- Definition of various types of similarity.

- SCALE FACTORS

  LENGTH: $l_f = \bar{\lambda} l_m$

  TIME: $t_f = \bar{\tau} t_m$

  MASS: $m_f = \bar{\mu} m_m$

  TEMPERATURE: $\theta_f = \bar{\phi} \theta_f$

- RELATIONSHIP OF SCALE FACTORS FOR SIMILARITY

  GEOMETRIC: $\dfrac{l_f}{l_m} = \bar{\lambda}$

  KINEMATIC: $\dfrac{l_f}{l_m} = c_1 \dfrac{t_f}{t_m}$ OR $\bar{\lambda} = c_1 \bar{\tau}$

  $\therefore \; v_f = (\bar{\lambda}/\bar{\tau})\, v_m$ and $a_f = \left(\bar{\lambda}/\bar{\tau}^2\right) a_m$

  DYNAMIC: $\dfrac{F_{1_f}}{F_{1_m}} = \dfrac{F_{2_f}}{F_{2_m}} = \dfrac{F_{i_f}}{F_{i_m}} = \ldots = \dfrac{m_f\, a_f}{m_m\, a_m} = \bar{\mu}\left(\bar{\lambda}/\bar{\tau}^2\right)$

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Figure 6.- Inherent relationships for various types of similarity.

PREFLIGHT
- SHOCK AND VIBRATION DURING HANDLING AND SHIPPING
- GROUND WIND LOADS
- ENGINE IGNITION SHOCKS

INFLIGHT
- PULSATIONS OF ENGINE THRUST
- TURBINE AND PUMP INPUTS
- ROCKET ENGINE ACOUSTIC PRESSURES
- FUEL SLOSHING FORCES
- CONTROL FORCES
- GUST, WIND SHEAR, AND FLOW SEPARATION PRESSURES
- BOUNDARY LAYER NOISE
- HIGH STEADY-STATE ACCELERATIONS
- STAGE SEPARATION SHOCKS

LANDING
- MANEUVER LOADS
- TOUCHDOWN SHOCKS

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Figure 7.- Sources of excitation of space vehicle structures.

TYPE	OBJECTIVE	DATA OBTAINED	USE OF DATA
STRUCTURAL DYNAMICS	STRUCTURAL CHARACTERISTICS	NATURAL FREQUENCIES MODE SHAPES DAMPING STRUCTURAL IMPEDANCE FORCED RESPONSE	STRUCTURAL INPUTS FOR SYSTEMS ANALYSIS
AERODYNAMIC	AERODYNAMIC FORCES AND MOMENTS	PRESSURE DISTRIBUTIONS FORCES AND MOMENTS STABILITY DERIVATIVES FLOW CHARACTERISTICS	AERODYNAMIC INPUTS FOR SYSTEMS ANALYSIS
AEROELASTIC	AEROELASTIC RESPONSE	BUFFETING PRESSURES DIVERGENCE FLUTTER AERODYNAMIC DERIVATIVES	INDICATE LOADS AND STABILITY BOUNDARIES OF FULL-SCALE VEHICLES
PROPELLANT-DYNAMICS	PROPELLANT CHARACTERISTICS	NATURAL FREQUENCES MODE SHAPES DAMPING FORCES ON TANKS	PROPELLANT INPUTS FOR SYSTEMS ANALYSIS
LANDING DYNAMICS	LOADS AND STABILITY DURING LANDING	LANDING LOADS STABILITY DURING LANDING ON VARIOUS SURFACES	INDICATE LOADS AND STABILITY BOUNDARIES OF FULL-SCALE VEHICLES

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Figure 8.- Various types of dynamic models used in space vehicle systems analyses.

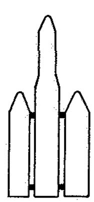
FULL SCALE

DYNAMIC MODELS

MONOCOQUE

VEHICLE	SCALE (PERCENT)	PURPOSE
SCOUT	15.0	GROUND WINDS
JUPITER	20.0	GROUND WINDS
TITAN-GEMINI	7.5	GROUND WINDS
TITAN III CORE	20.0	STRUCTURAL DYNAMICS
SATURN V	16.3	STRUCTURAL DYNAMICS
SATURN V	10.0	STRUCTURAL DYNAMICS
SATURN V	3.0	GROUND WINDS
SATURN V	2.5	STRUCURAL DYNAMICS

CLUSTER



VEHICLE	SCALE (PERCENT)	PURPOSE
TITAN III	7.5	GROUND WINDS
SAI BLOCK I	20	STRUCTURAL DYNAMICS
SAI BLOCK I	7.5	GROUND WINDS
SAI BLOCK II	7.0	GROUND WINDS
SAI BLOCK II	8.0	BUFFETING
SATURN IB	5.5	GROUND WINDS

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Figure 9.- Dynamic models of launch vehicle configurations under study at the Langley Research Center.

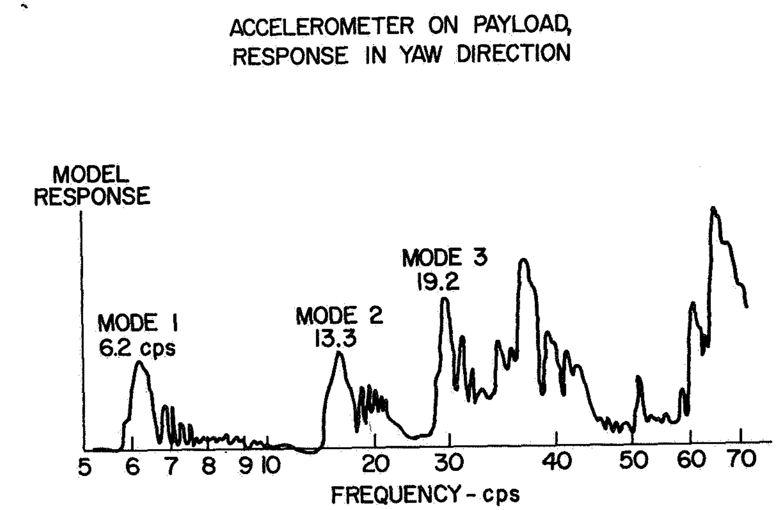

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Figure 10.- Typical sample of response data from 1/5-scale structural dynamics model of Titan III.

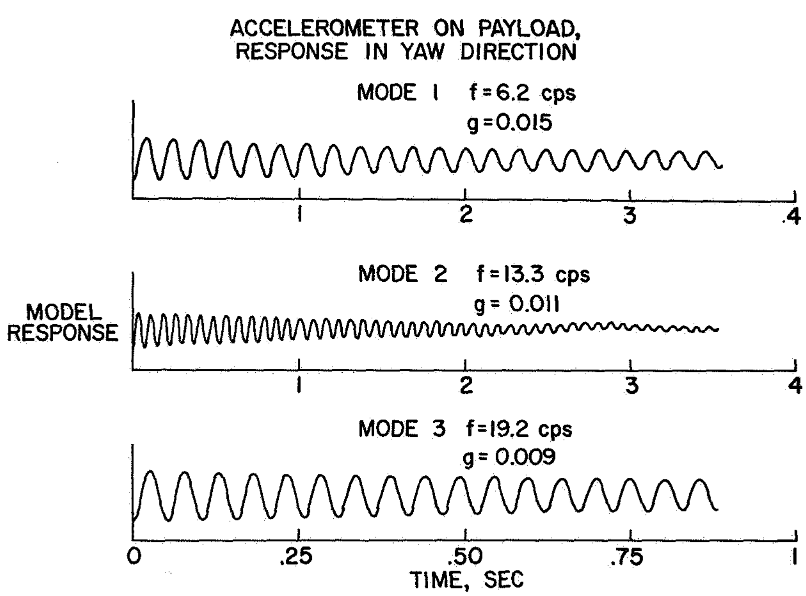

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Figure 11.- Damping of 1/5-scale structural dynamics model of Titan III.

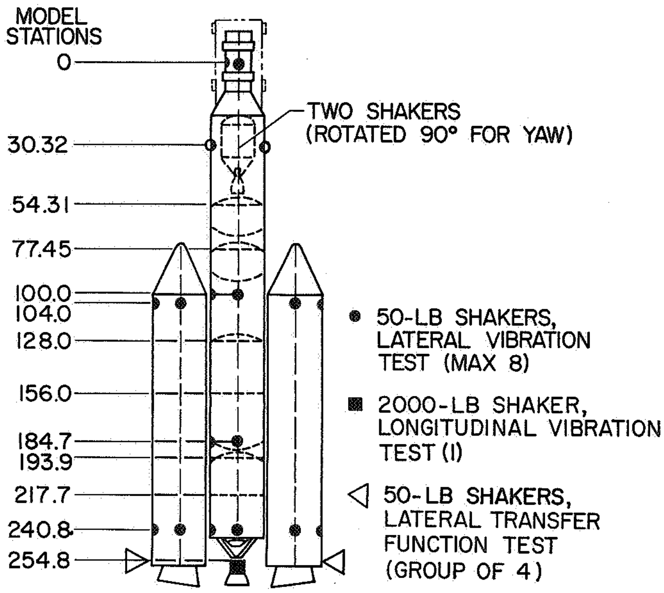

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Figure 12.- Sketch of 1/5-scale structural dynamics model of Titan III.

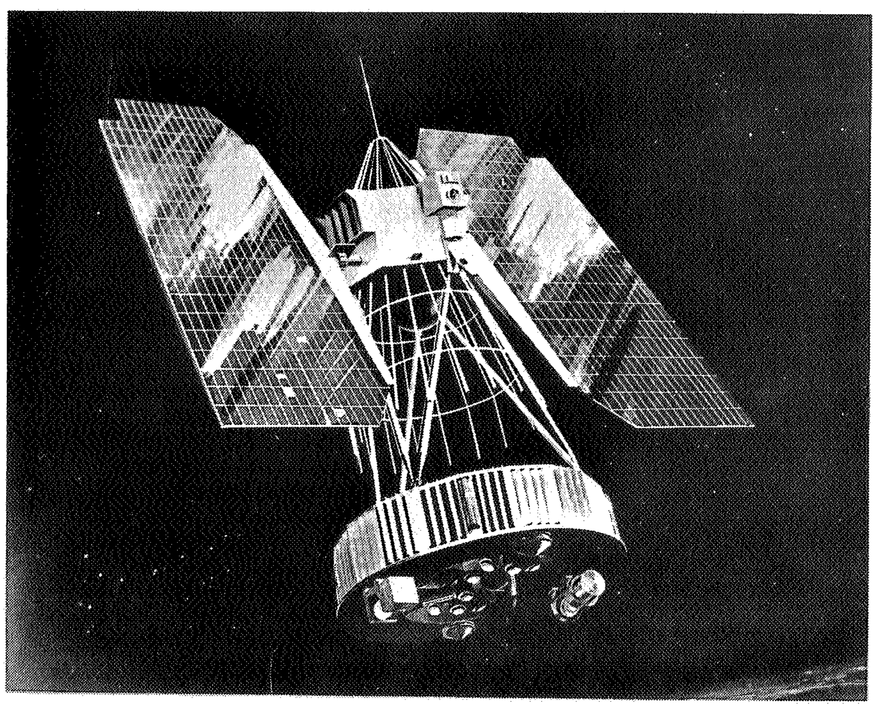

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Figure 13.- Nimbus - Polar Orbiting Weather Satellite.

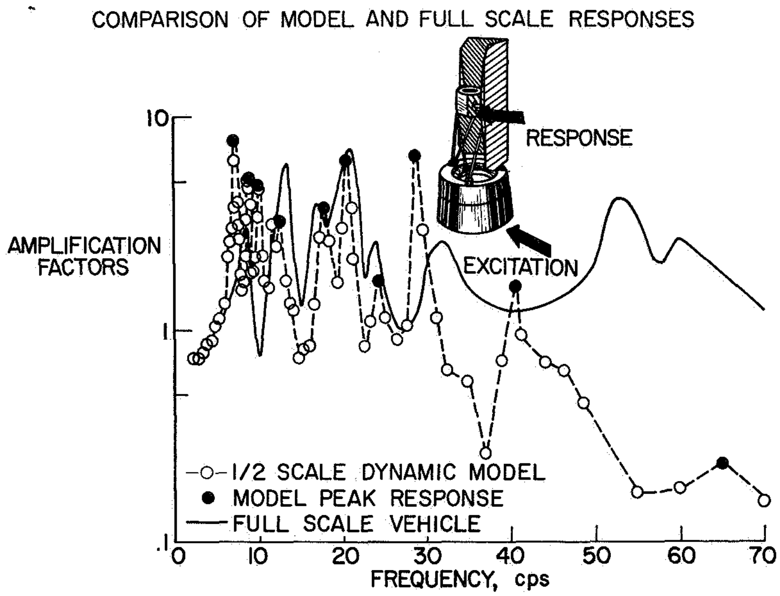

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Figure 14.- Comparison of responses at the base of control section on 1/2-scale model and full-scale spacecraft. Excitation along pitch axis. Model frequencies divided by 2.

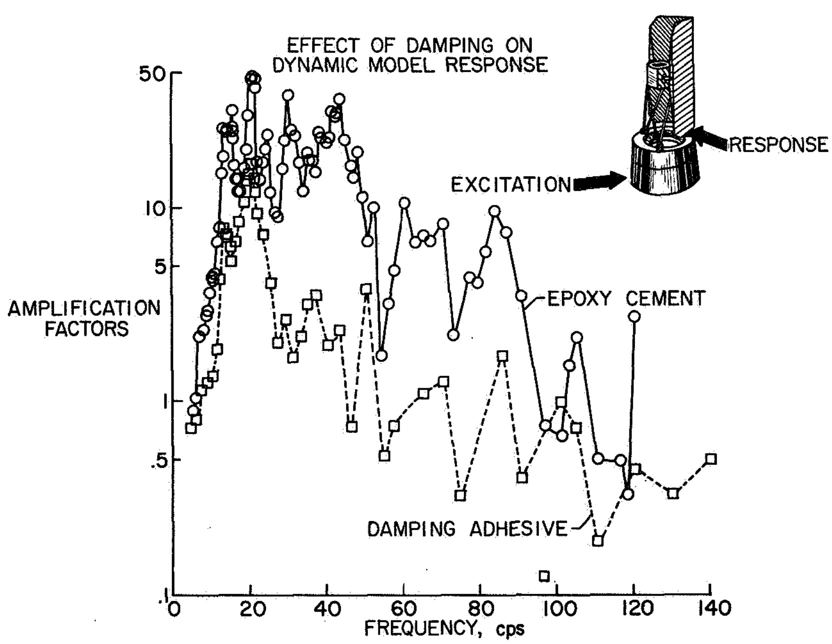

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Figure 15.- Effect of solar panel damping on dynamic amplification as a function of excitation frequency.

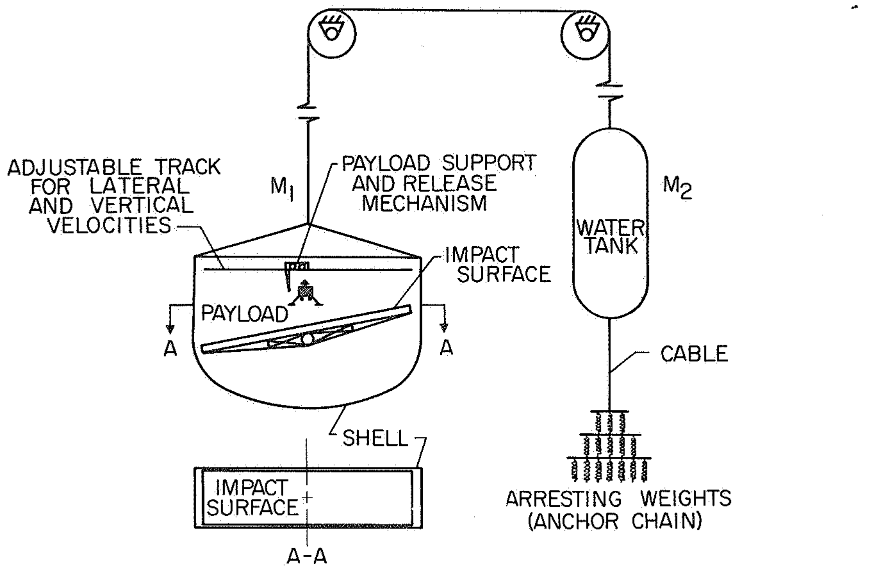

Figure 16.- Impact simulator for lunar and planetary gravitational fields.

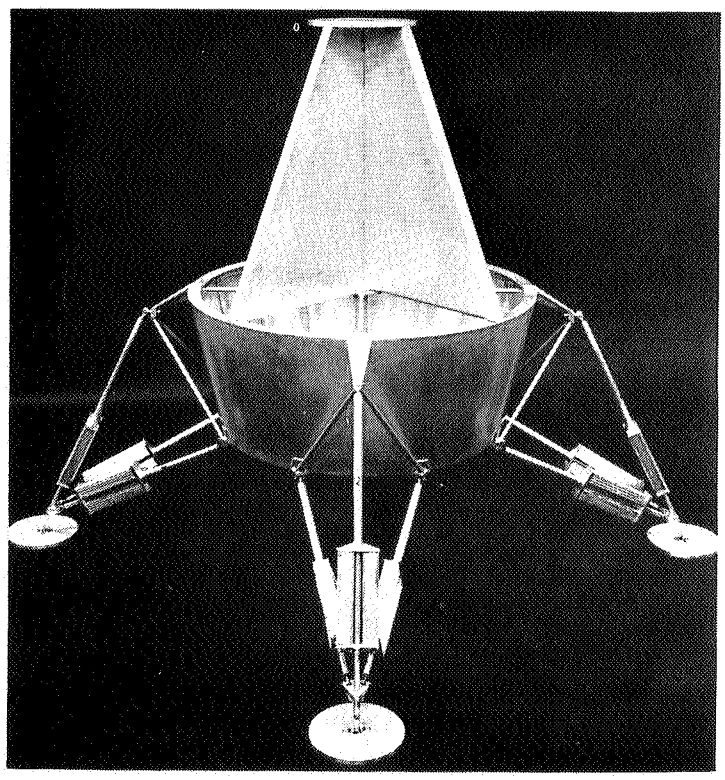

Figure 17.- 1/6-scale dynamic model of lunar landing spacecraft.

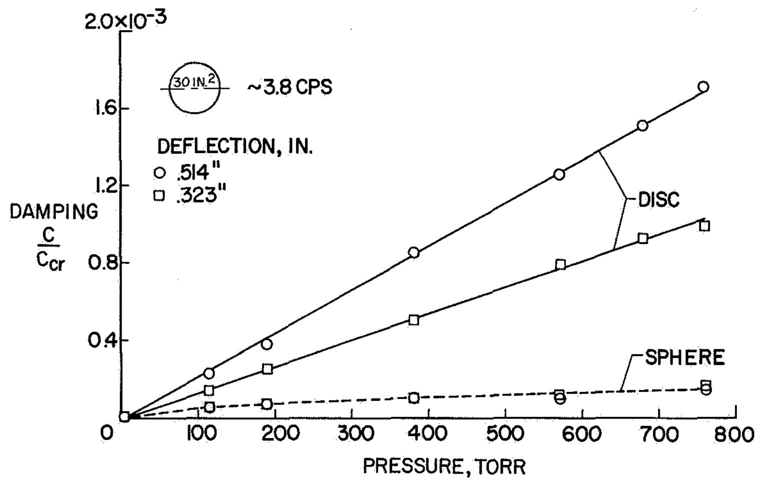

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Figure 18.- Effect of atmospheric pressure and amplitude of oscillation on aerodynamic damping of plates and spheres.

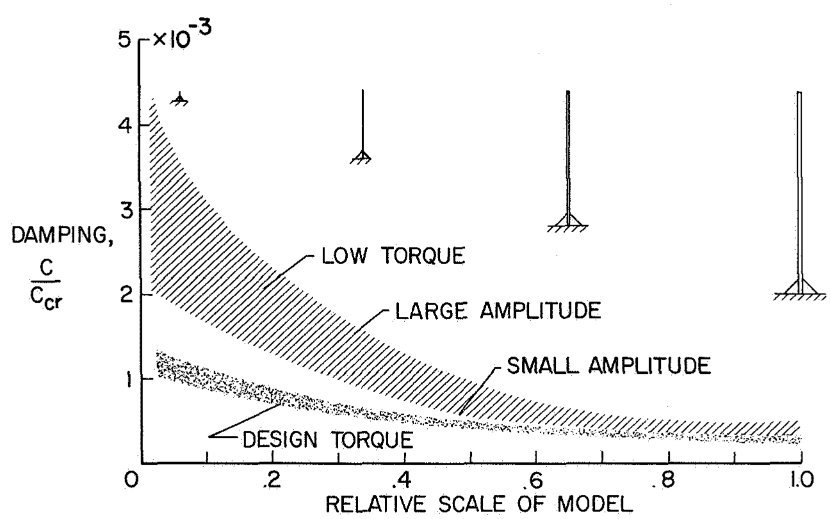

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Figure 19.- Effect of model scale on damping.

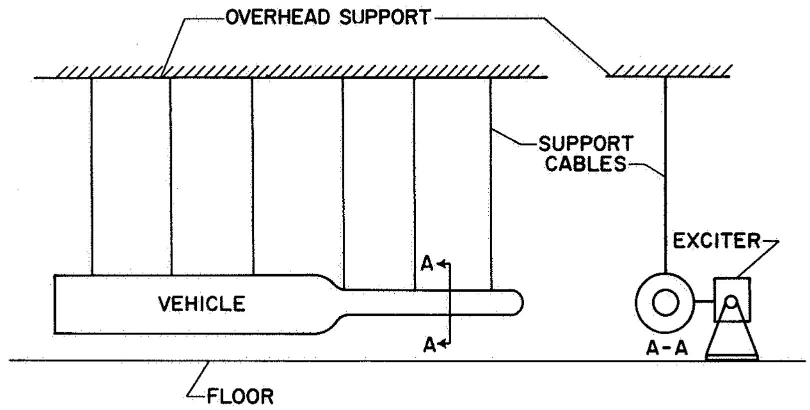

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Figure 20.- Horizontal support systems for launch vehicles.

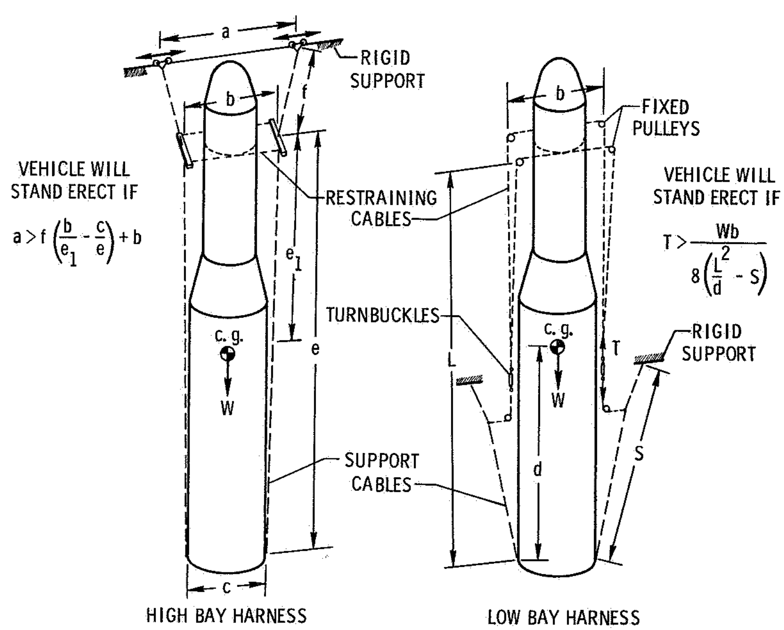

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Figure 21.- Vertical support systems for launch vehicles.