Description of the Joint Damping Experiment (JDX)

Flight Experiments Technical Interchange Meeting

Principal Investigators:
Steven L. Folkman
Frank J. Redd
Mechanical and Aerospace Engineering Department
Utah State University

Presented by:
Steven L. Folkman

October 5, 1992

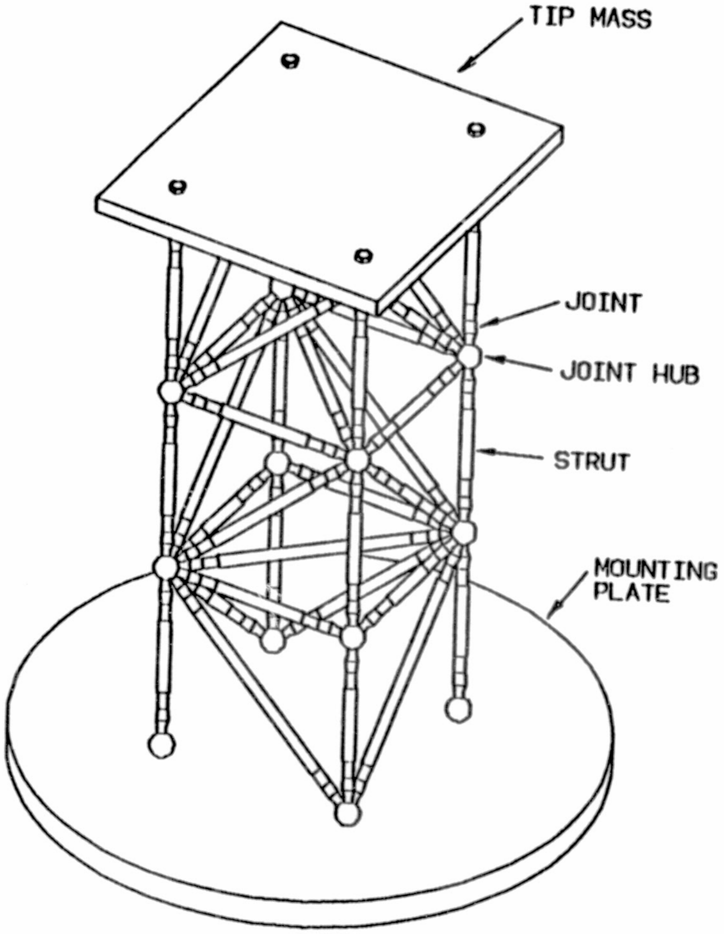
Overall Objective

Develop a small-scale shuttle flight experiment which allows researchers to: 1) characterize the influence of gravity and joint gaps on structural damping and dynamic behavior of a small-scale truss model, and 2) evaluate the applicability of low-g aircraft test results for predicting on-orbit behavior.

JDX Description

The experiment consists of a three-bay truss and associated hardware for truss excitation and measurement of oscillations.

- The experiment dimensions fit inside of a 5 cubic foot GAS canister.
- Cantilever truss with a tip mass to reduce the resonant frequency.
- Canister can be evacuated to eliminate air damping.
- Truss excitation in two bending modes and a torsional mode.
- Truss tip supported during launch and reentry.



Project Objectives

1. Student oriented project.

    - Graduate and undergraduate students will perform most of the design, analysis, and testing effort under the direction of the principle investigators.

    - JDX is to be relatively simple and inexpensive.

    - Fly as a Complex Autonomous Payload (CAP) in a sealed GAS canister to simplify integration problems and safety concerns and maximize flight opportunities.

    - JDX will provide a meaningful experience for students and an opportunity to extend the understanding of damping mechanisms in joints.

2. Construct a small truss with joints which provide gravity dependent damping.
    - Past tests show that a truss with pinned-joints can produce gravity dependent damping.
    - Damping from tight joints is generally not gravity dependent.

Project Objectives (continued)

3. Develop a database of damping behavior for various gravity environments and various joint pin gaps.

    - Ground-based testing to measure damping with 1-g loads.
        - A good characterization of the truss dynamics can be achieved.
        - Verification of gravity dependent damping achieved by testing the truss in different orientations.

    - Fly in aircraft tests for short duration low-g tests.
        - JDX must be cantilevered during testing - aircraft vibrations will be significant.
        - Short time period.
        - Space flight needed to verify low-g aircraft tests.

    - Fly as CAP Payload to measure damping in micro-gravity.
        - CAP Payload should provide relatively low cost and simple integration.
        - Test during orbiter free drift mode for a micro-gravity environment.

4. Correlating ground-based and low-g aircraft test results with on-orbit test results.

    - Can ground tests simulate zero-g tests.

    - Can low-g aircraft tests simulate zero-g tests.

Project Objectives (continued)

5. Refining analytical models of gravity-dependent damping mechanisms based on test results.

   - Relate measured damping with damping predicted from strut hysteresis tests, expected material damping, and simple friction and impact damping models.

   - Compare measured time histories with results of transient, non-linear finite element modeling techniques.

     - The recorded data should be a time history which can be readily be simulated using a transient computer model.
     - The transient decay of a single mode is desired.
     - A simple "twang" excitation method will produce the desired excitation.
     - The only motion recorded in flight would be the tip mass to reduce data storage.

Technology Need

Proposed space structures could often benefit from accurate prediction of structural damping and a better understanding of joint dynamics.

- Damping from the support structure is generally small.
- Passive damping sources generally are preferred.
- Joints will be a source of damping.
- Joints with gaps make dynamic behavior harder to predict.

Predicting damping in large space structures can be difficult.

- Difficult or impossible to test full scale structures on the ground.
- Ground test results of components may be affected by:
    - gravity
    - air
    - temperature
    - scale
- Analytical methods of predicting damping need improvement.
- Ground tests have shown that gravity effects joint damping.

A database of in-orbit and on-ground tests would be helpful:

- Providing qualitative information an important design variables.
- Assisting in improving analytical models of joint damping.

Current Understanding of Joint or Connection Damping

Pinned or bolted structures typically have more damping than welded structures.

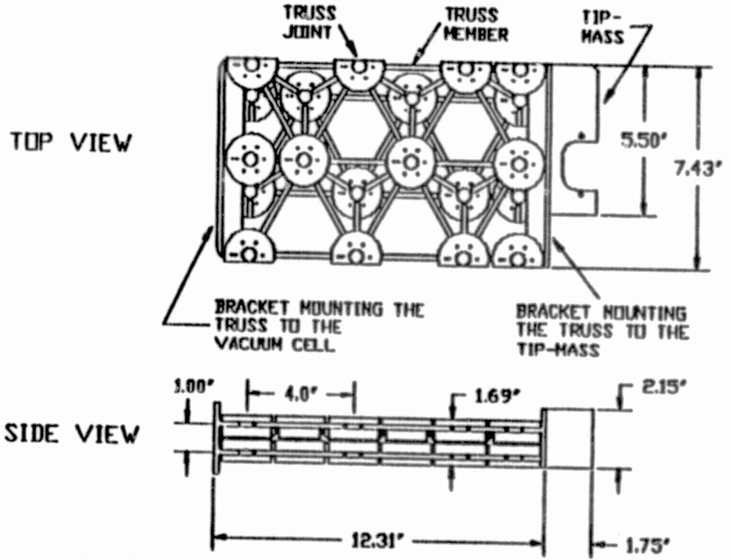
Damping is typically amplitude and frequency dependent.

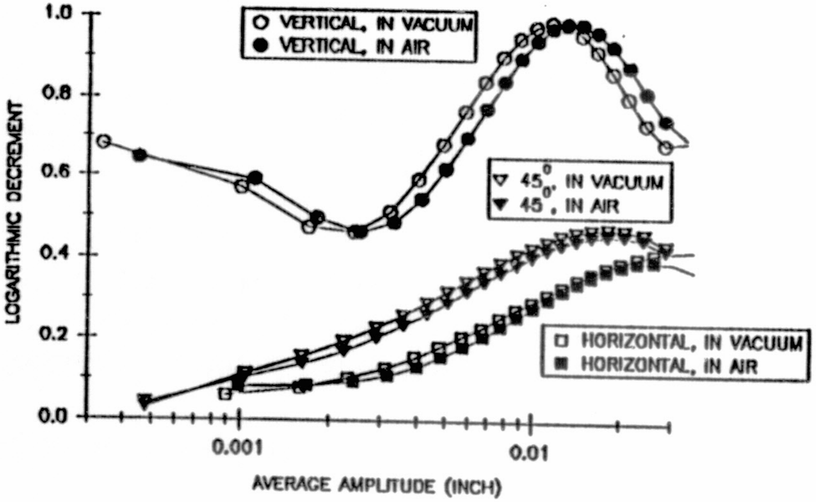
Common Mechanisms of Passive Damping in Joints or Connections:
- Air Damping (not present in space)
- Material Damping ($\zeta < 0.001$ for most metals at room temperature)
- Coulomb Friction:
  - Macroslip:
    - Can be a large source of damping.
    - Dependent on friction coefficients and joint loads.
    - Damping contributions can be inferred from joint pull tests.
    - Analytical models are available.
  - Microslip:
    - Damping is less than Macroslip damping.
    - Difficult to predict.
- Impact Damping:
  - Implies a gap is present.
  - Generally believed to be more important at higher frequencies (>1 Hz.).
  - Difficult to predict but characterized by the coefficient of restitution.
  - Difficult to separate from Coulomb Friction damping.

Previous Work Done at USU - Prior to Phase A

An experiment has been constructed to measure damping of a tetrahedral truss with pinned joints.

- **Developed on a very small budget.**
- **Demonstrated gravity dependent damping**





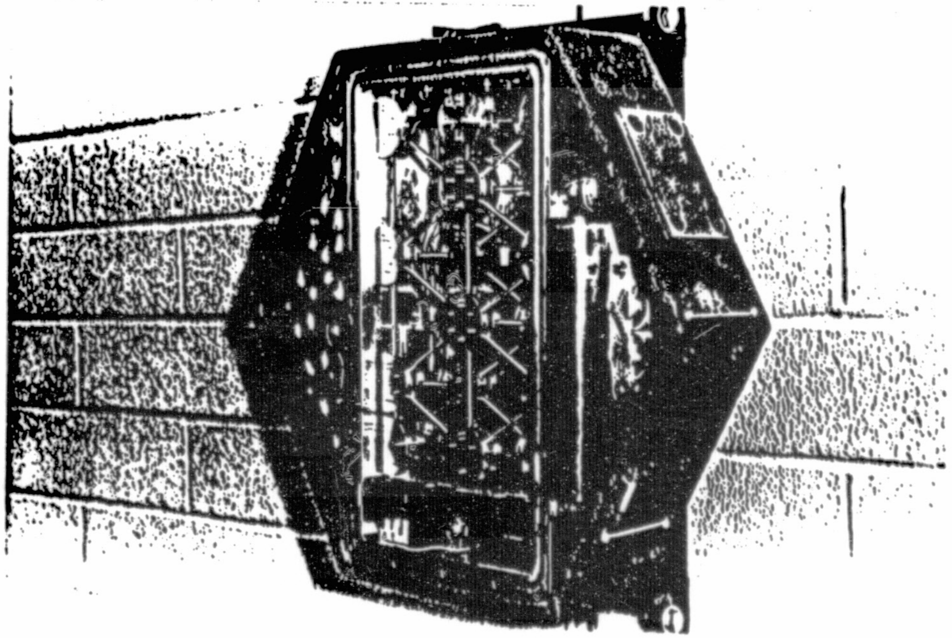
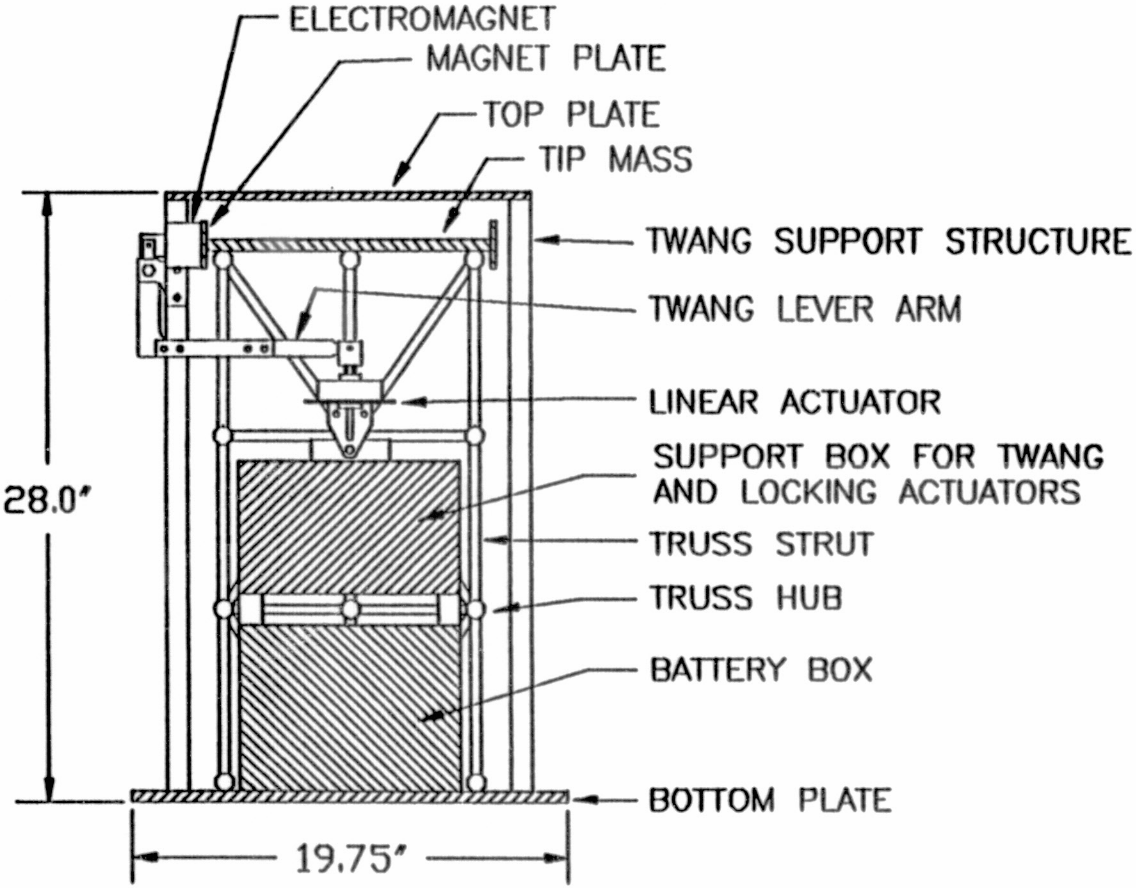
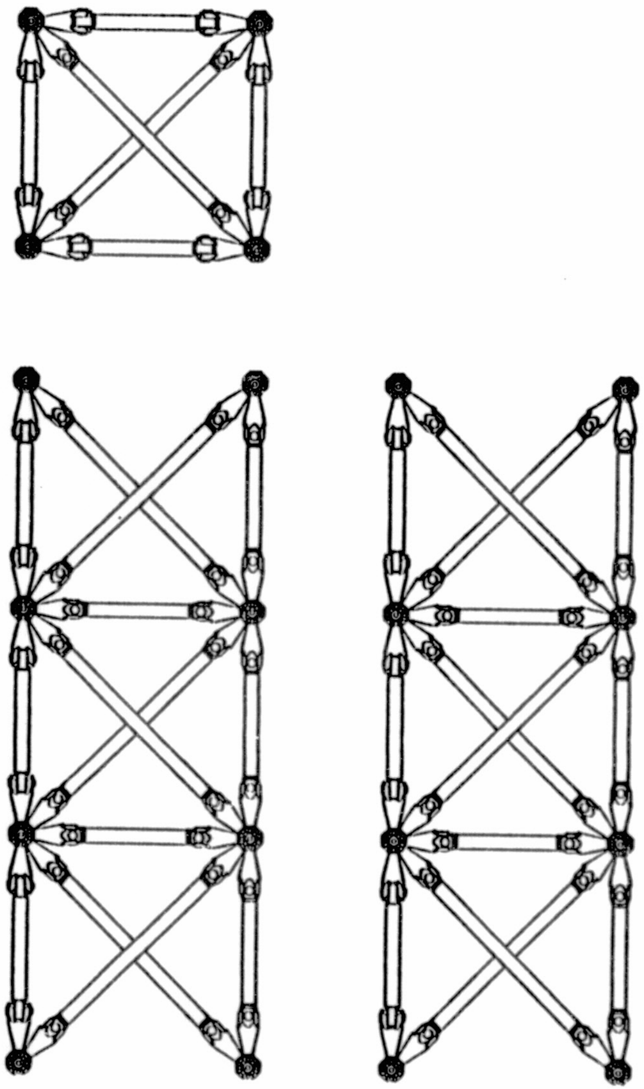


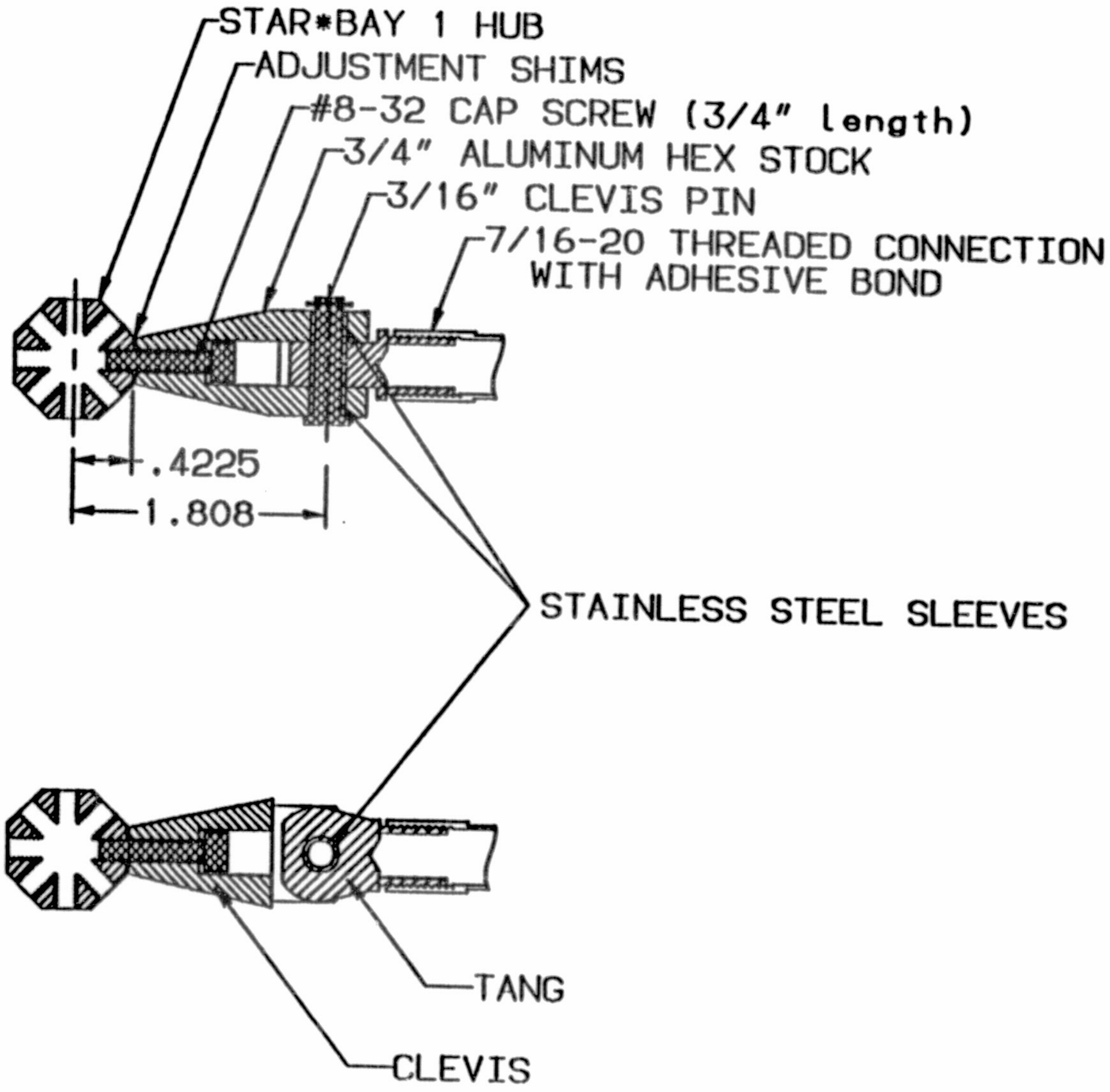
Illustration of the Experiment Layout



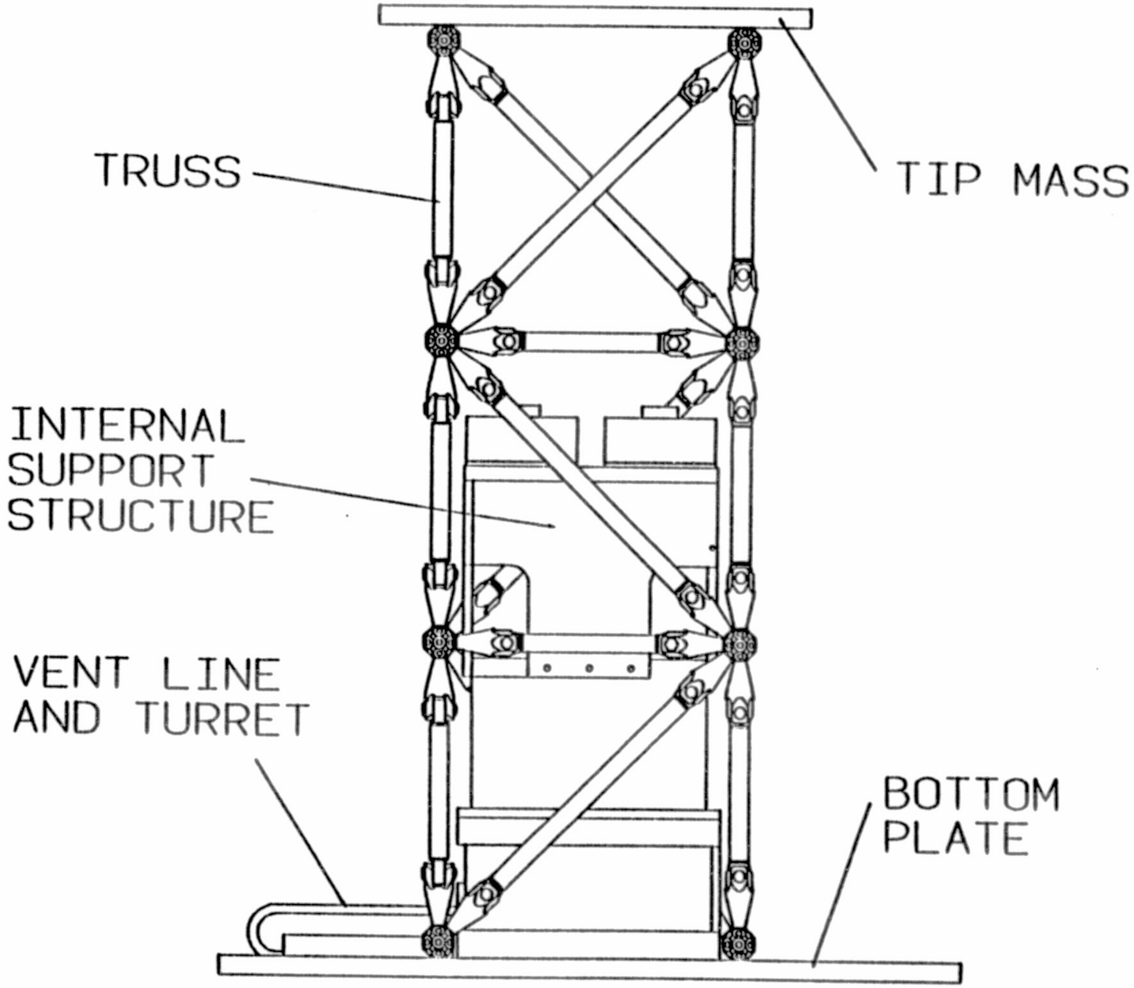
Strut Arrangement



Joint Design



Truss, Battery Box, and Bottom Plate

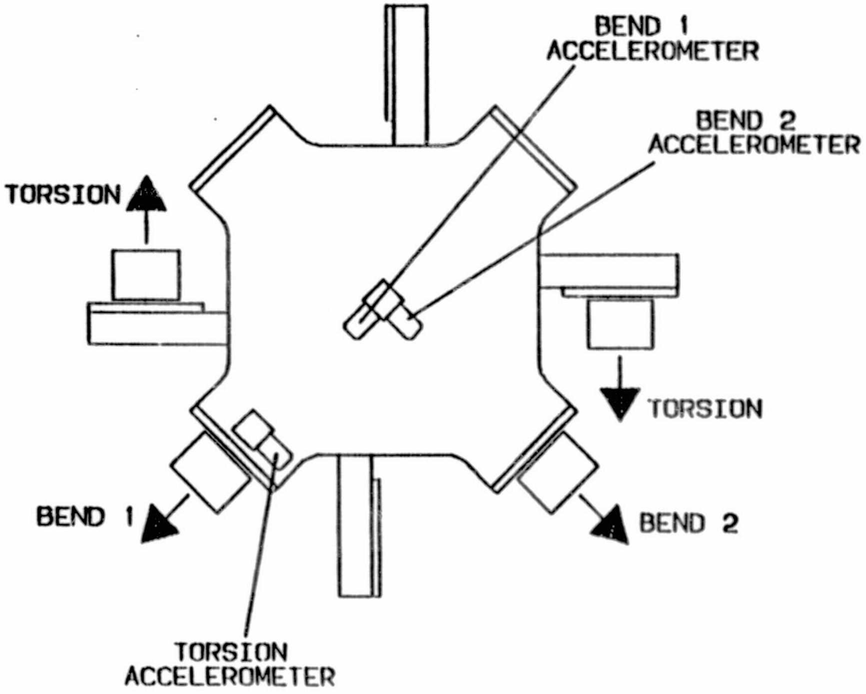


Twang Method of Excitation

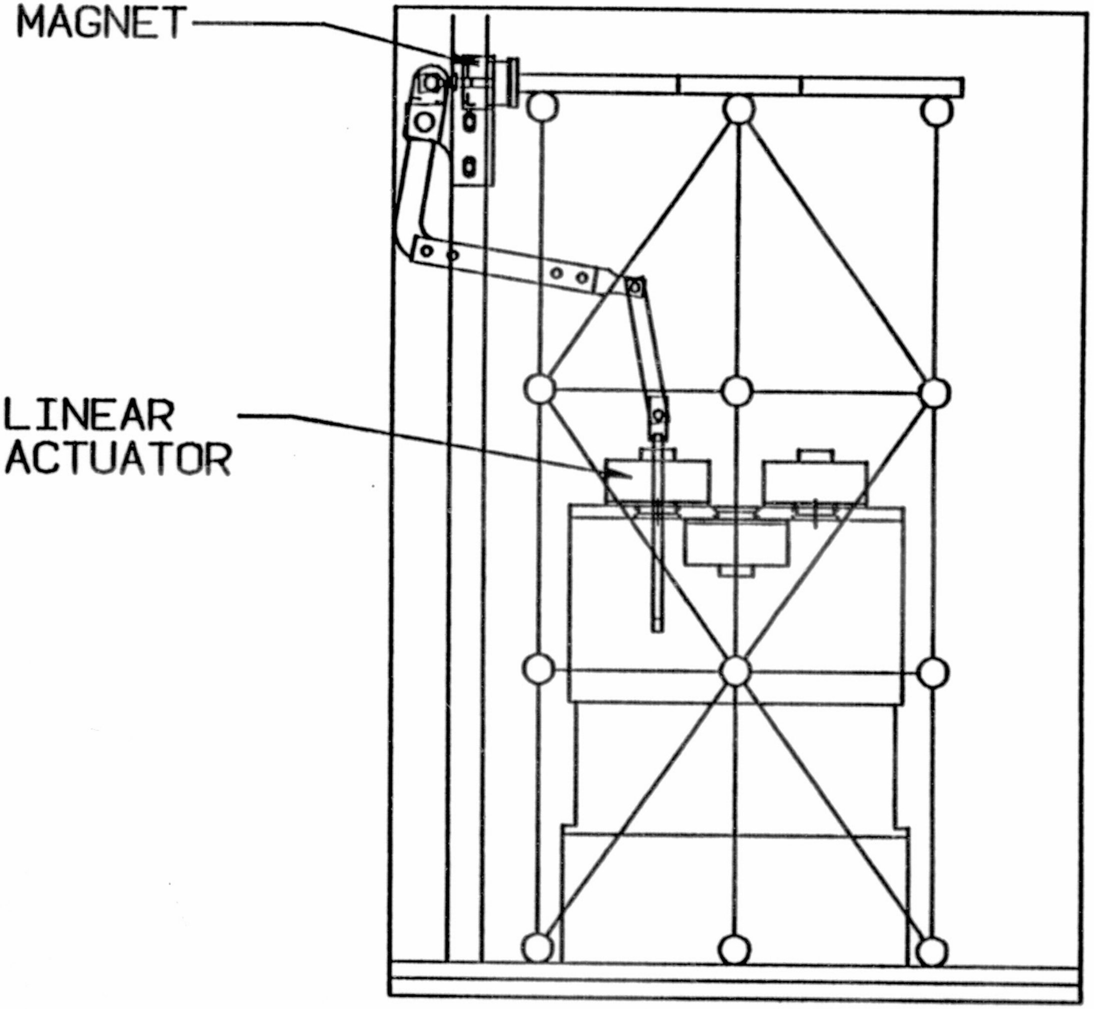
The twang excitation method is accomplished by a linear actuator/lever arm/electromagnet assembly.

- **A magnet is moved into contact with a magnet plate on the truss tip mass.**
- **The electromagnet is then energized and pulls the truss from its neutral position.**
- **The power is removed from the electromagnet, the truss is released, and the decay of oscillations is recorded.**
- **Two bending modes and a torsional mode excitation provided.**

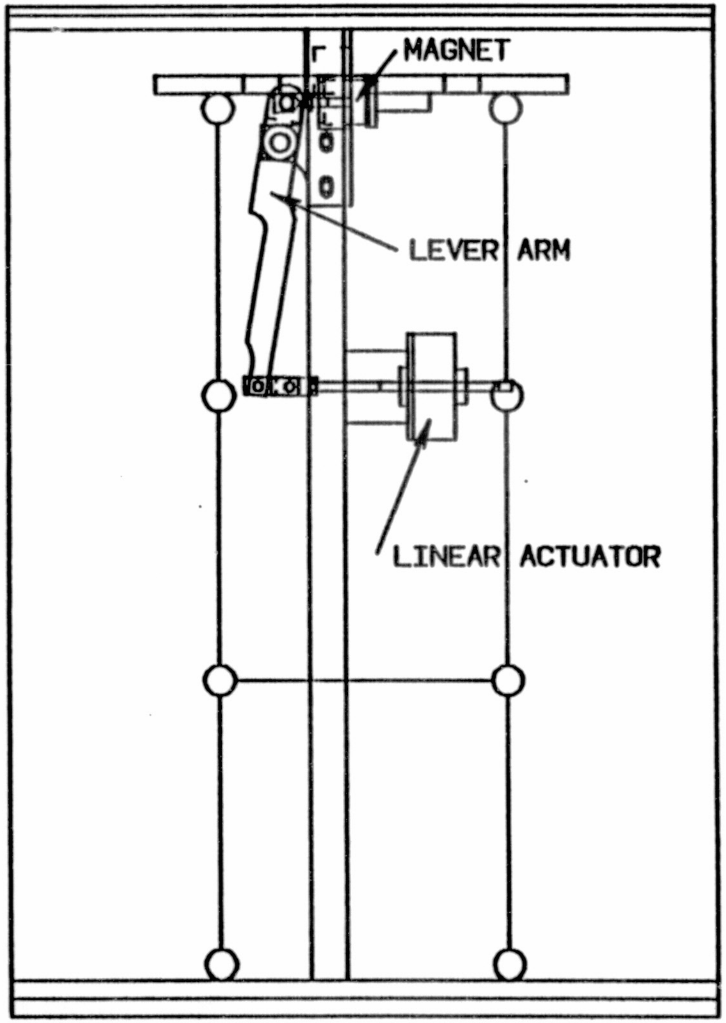
Top View of the Truss Tip Mass



Bend Excitation Side View

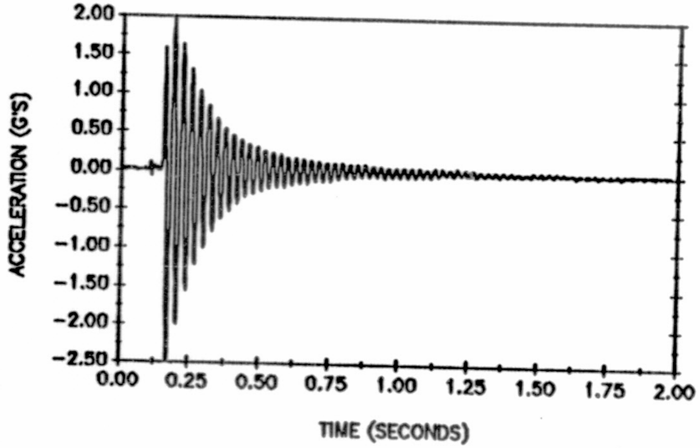


Torsion Excitation Assembly

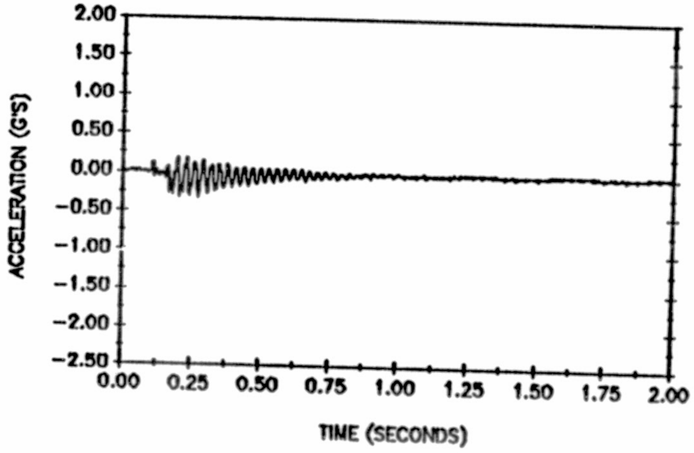


Ground testing of the Experiment Prototype

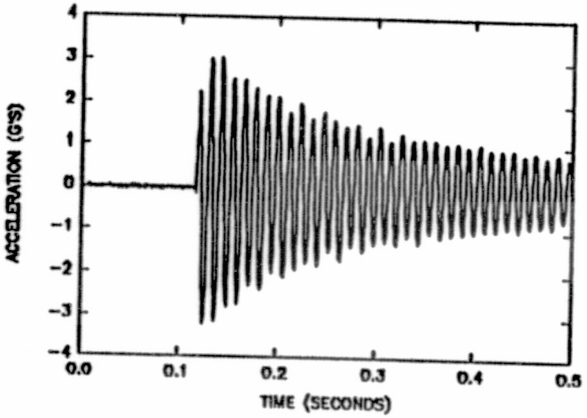
Twang tests of the truss were conducted.



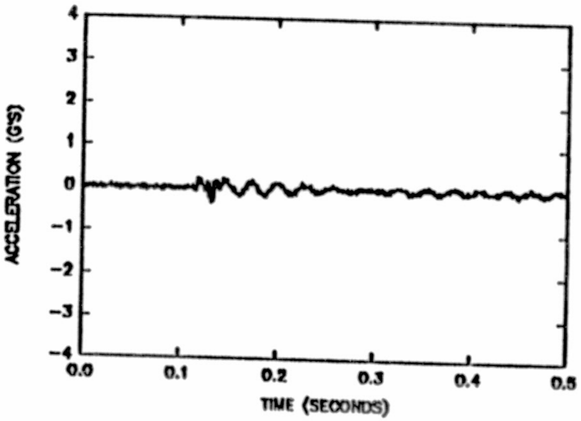
Acceleration in the direction of the first bending mode.



Acceleration in the opposite direction of the first bending mode.



Acceleration time history for a torsional mode twang test.



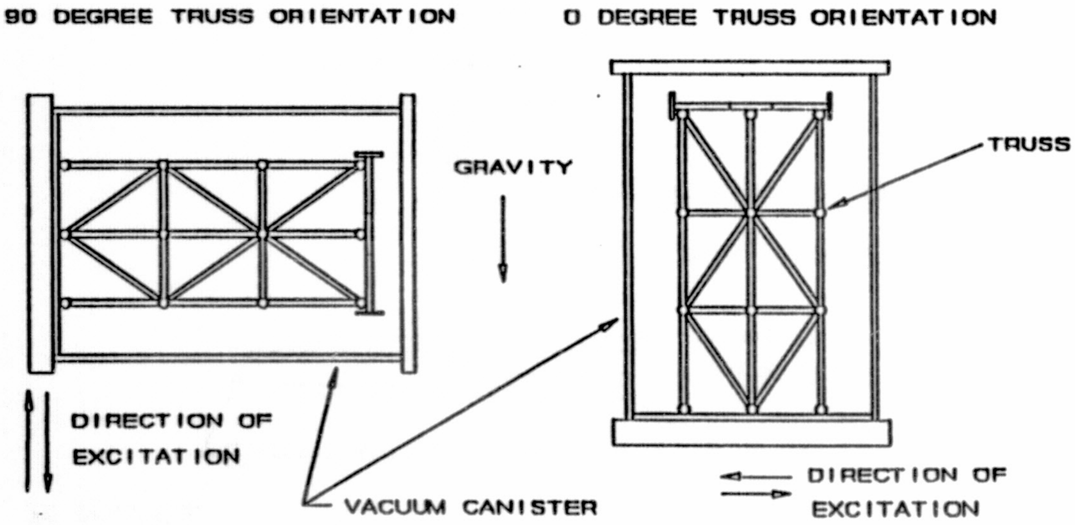
Acceleration at the tip-mass center during a torsional mode twang test.

Ground testing of the Experiment Prototype

Twang, Random Vibration, and Sine Sweep Tests of the truss.

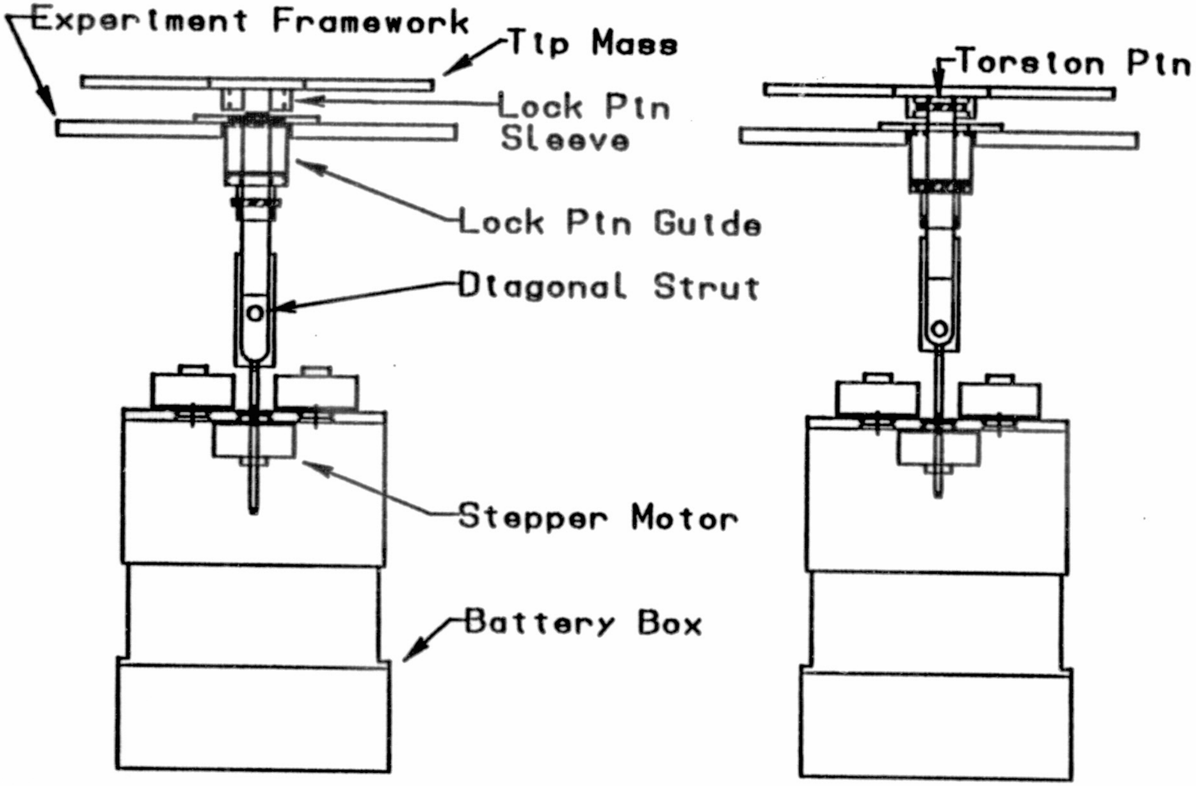
- **Experiment mounted inside a can:**
  - **Allows testing in vacuum.**
  - **Provides stiff mounting for base excitation.**

- **Tests conducted at different orientations to examine gravity dependence of damping.**



Tip Mass Locking Mechanism

- Lock mechanism provides support during launch and reentry to minimize joint wear.
- The truss design can withstand launch and reentry design loads in case the locking mechanism fails to operate.



UNLOCKED POSITION

LOCKED POSITION

Experiment Controller/Data Acquisition System

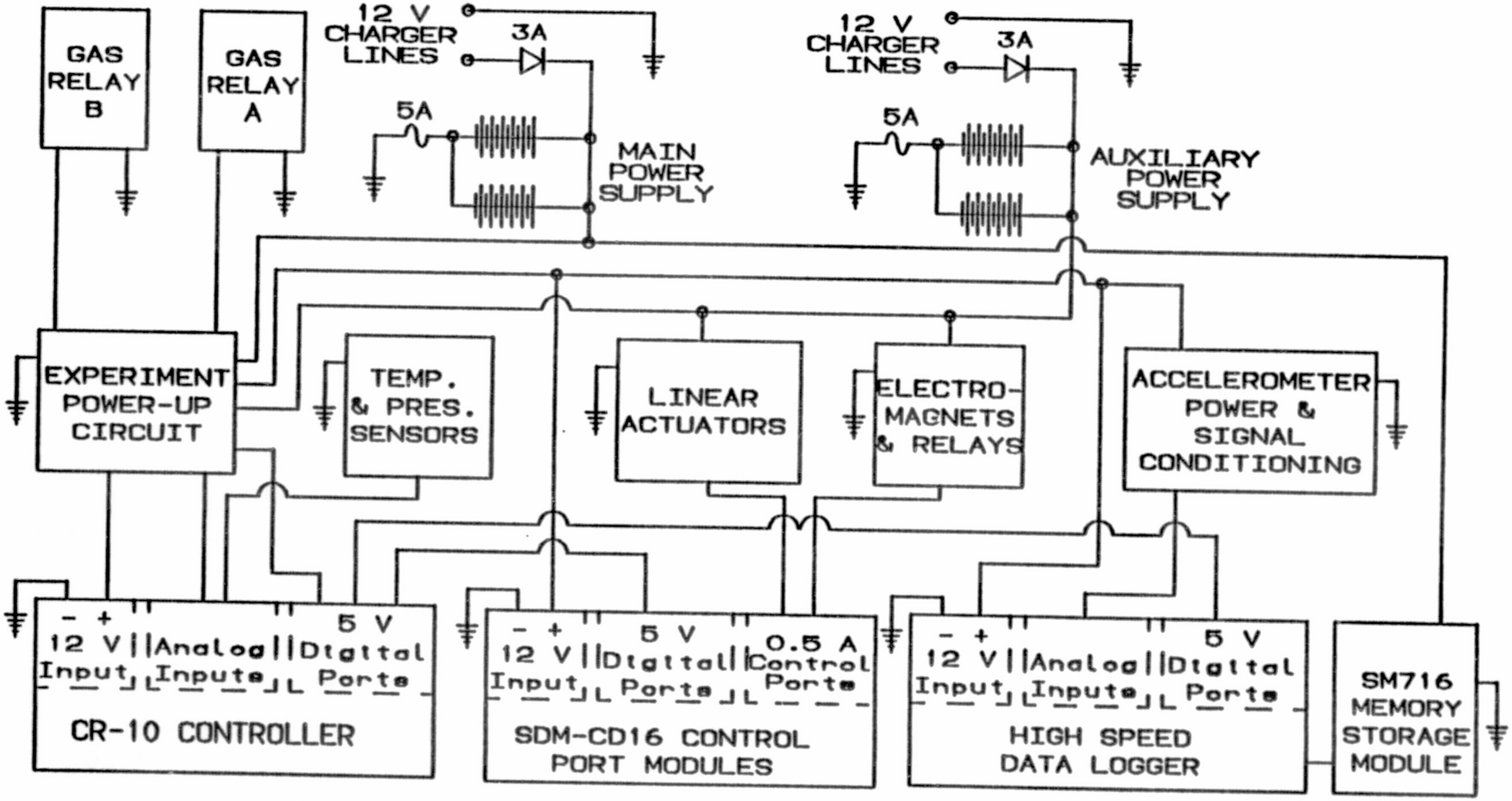
Campbell Scientific CR-10 controller/datalogger

- Will be used to control actuators and magnets and monitor temperature and pressure.
- Low power consumption (0.5 mA quiescent, 35 mA during measurements @ 12 V)
- 64K EEPROM for program and data.
- Loads program from EEPROM on Power-up.
- Easily programmed.
- Uses a Campbell Scientific Control Port Module (SDM-CD16) for control of 32, 0.5 A circuits.
- Powers-up a High Speed Data Logger for twang testing.

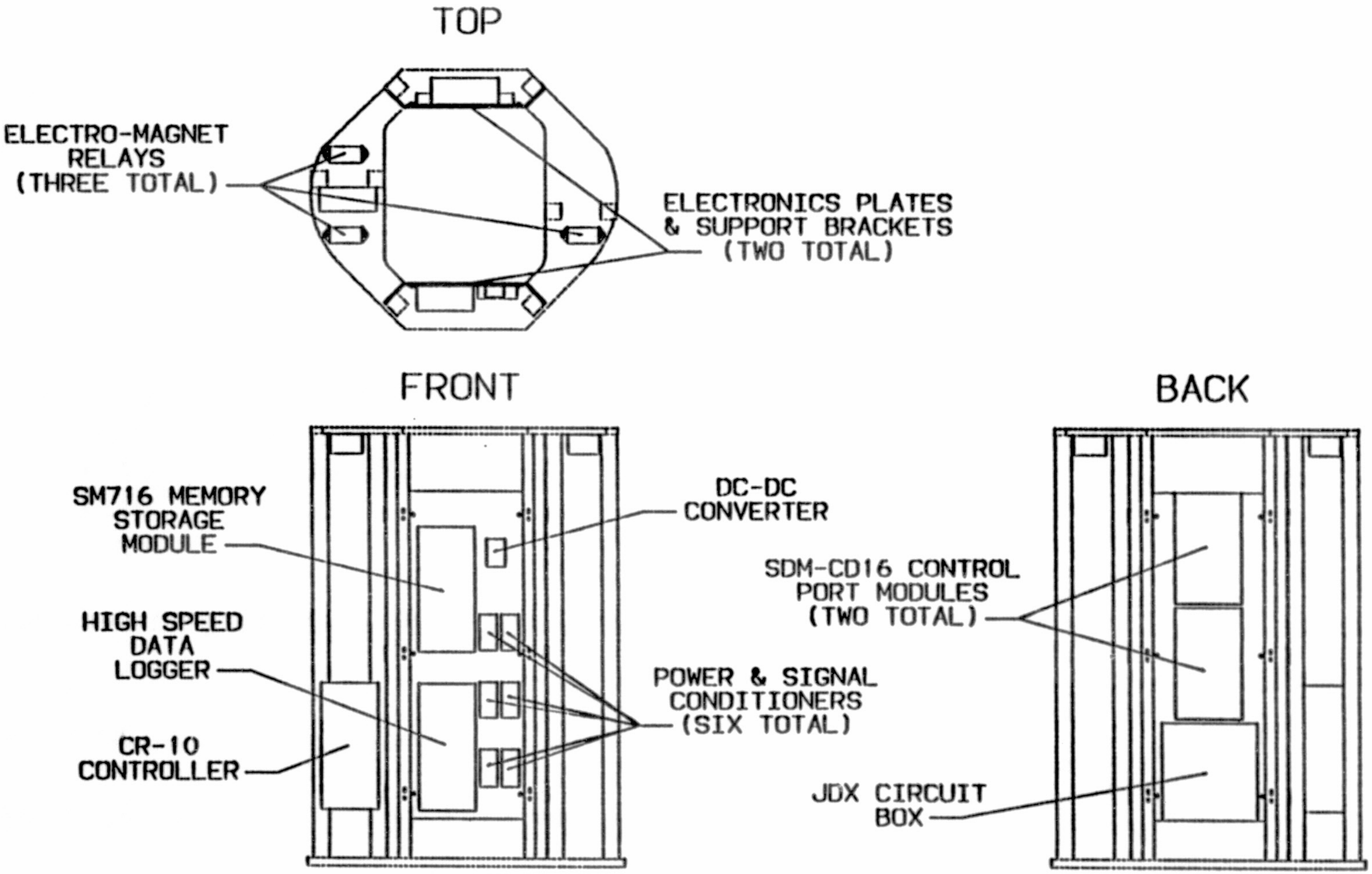
Campbell Scientific High Speed Data Logger

- 16 bit A/D and 100,000 sample/sec capacity.
- Power consumption: 0.13 Amp @ 12 V
- 512 K EEPROM for program and memory and 512 K RAM
- Storage of 358K values using a Campbell Scientific Memory Module (SM716)

JDX Top Level Wiring Diagram



Mounting of Electrical Components



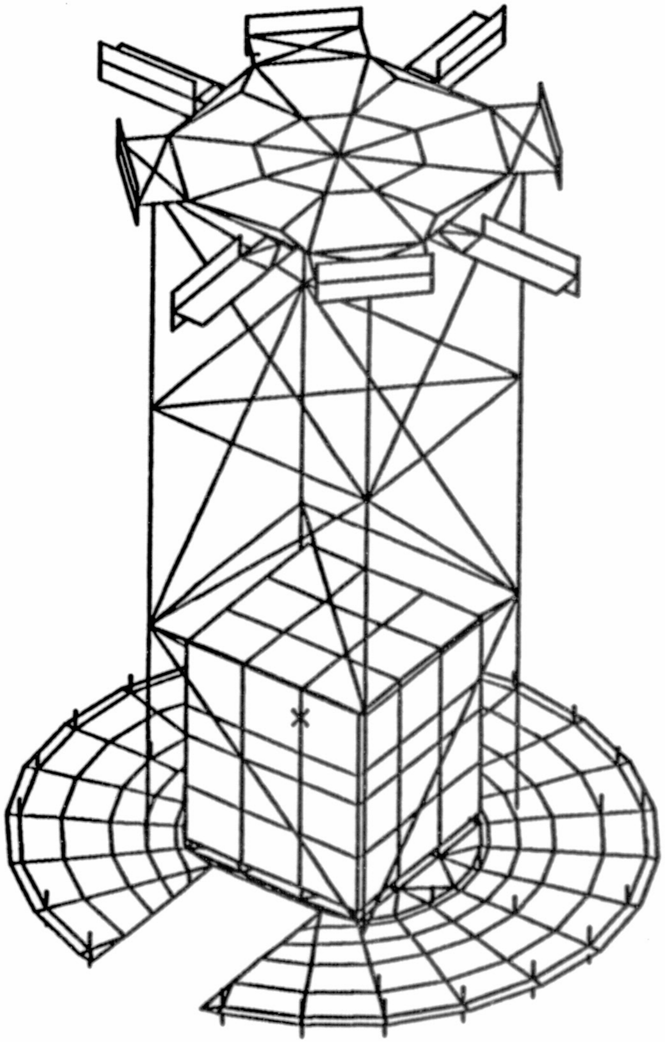
Structural Analyses of the Truss and Base Plate

Linear Static Analysis

- Design Accelerations: ±11.0 g's in X and Y and Z.
- Safety Factor against yield > 2

Predicted Resonant Frequencies (ignoring joint gaps)

Mode Number	Natural Freq. (Hz.)	Mode Description
1	46.8	Bending mode
2	51.3	Bending mode
3	110.1	Torsional mode



JDX Mission Operational Plan

Experiment Activation:

- Powered up at 50,000 feet by the baroswitch attached to APC relays.
- Unlock the truss during the first hour before significant cooling of the experiment occurs.
- The controller will monitor its built-in clock, the GAS relay switches A and B, and the battery box temperature.

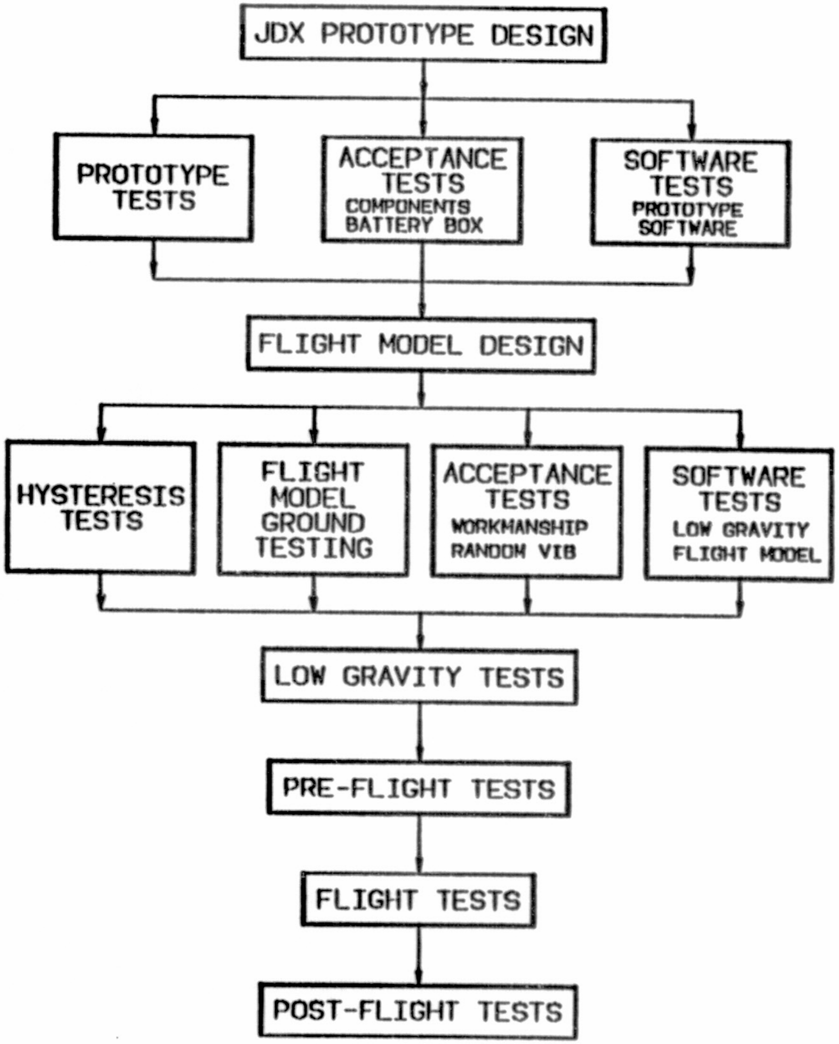
Experiment Execution:

- JDX will begin the twang test sequence when the first of the three following events occur:
  (1) Relay B is manually activated by the crew indicating a period of orbiter free drift,
  (2) the temperature of the experiment drops below a lower limit value (TBD), or
  (3) 18 hours has passed since closure of the APC baroswitch.
- Begin testing by:
  (1) Move all electromagnets to their preset stop positions,
  (2) Perform approximately 10 twang tests for each mode shape,
  (3) Record experiment temperature and air pressure during the tests, and
  (4) Lock the truss by activating a linear actuator.

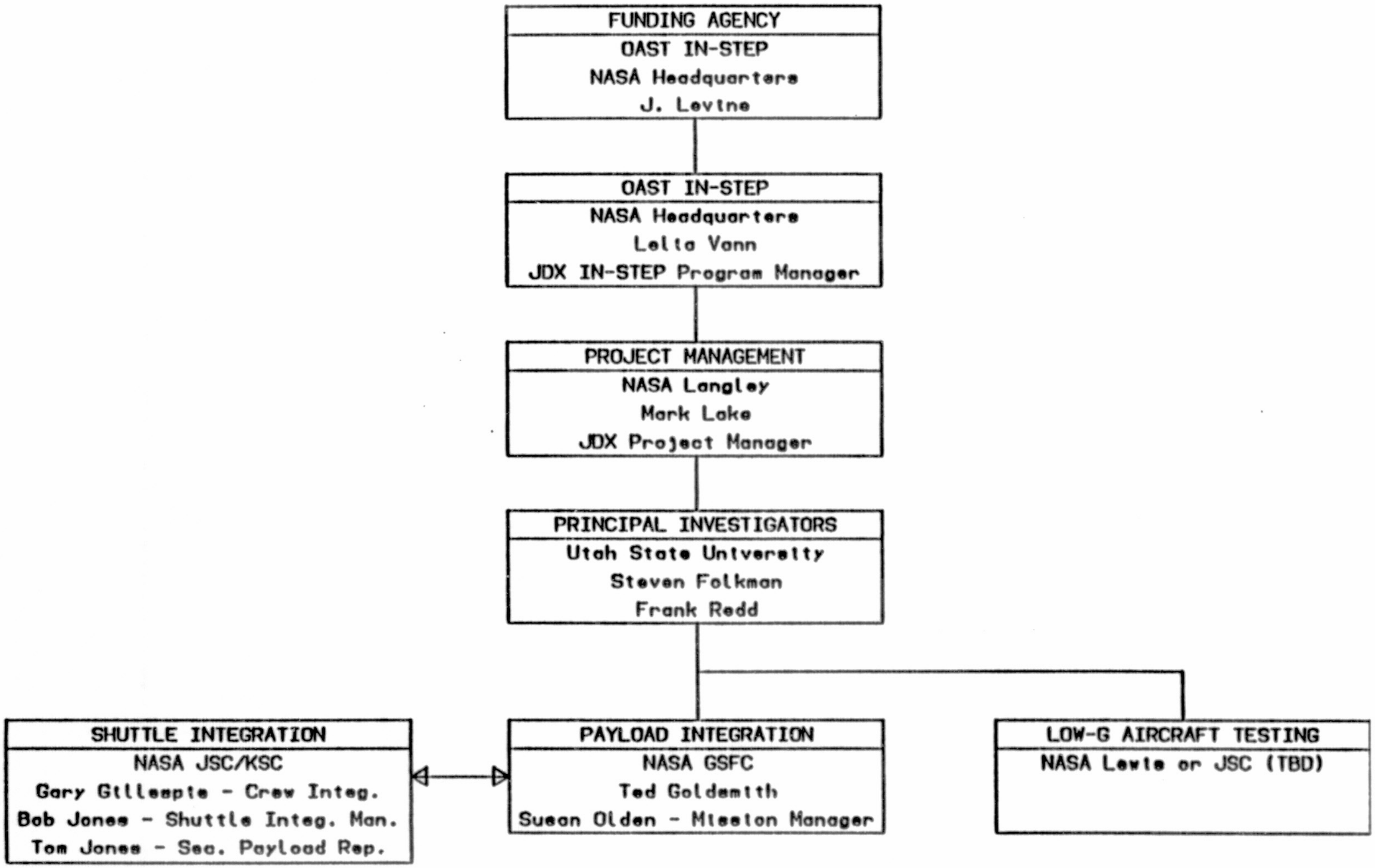
Experiment Deactivation:

- One hour after crew activation of Relay B, the crew will set Relay B to latent.
- Lock the truss (if it is not already locked).
- Shut down all experiment activities except the monitoring of experiment temperatures.
- Prior to the end of the mission, the crew will set Relay A to latent, thus powering down JDX.
- In the event of unsuccessful deactivation of Relay A, baroswitch opening at 50,000 feet during orbiter entry will power down the controller.

JDX Testing Flow Chart for Phase C/D



JDX Phase C/D Organization



FUNDING AGENCY
OAST IN-STEP
NASA Headquarters
J. Levine

OAST IN-STEP
NASA Headquarters
Leila Vann
JDX IN-STEP Program Manager

PROJECT MANAGEMENT
NASA Langley
Mark Lake
JDX Project Manager

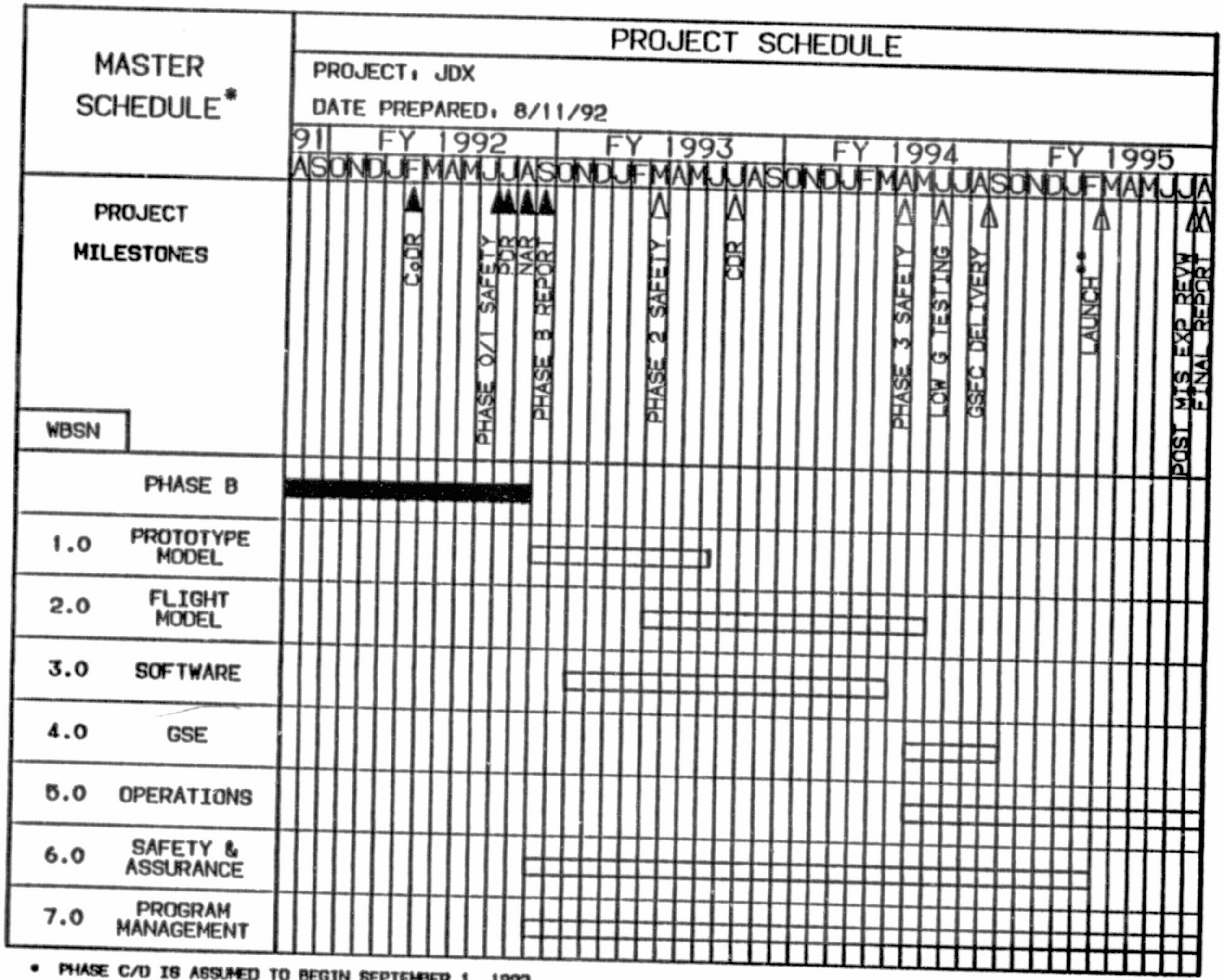
PRINCIPAL INVESTIGATORS
Utah State University
Steven Folkman
Frank Redd

SHUTTLE INTEGRATION
NASA JSC/KSC
Gary Gillespie - Crew Integ.
Bob Jones - Shuttle Integ. Man.
Tom Jones - Sec. Payload Rep.

PAYLOAD INTEGRATION
NASA GSFC
Ted Goldsmith
Susan Olden - Mission Manager

LOW-G AIRCRAFT TESTING
NASA Lewis or JSC (TBD)

JDX Schedule



* PHASE C/D IS ASSUMED TO BEGIN SEPTEMBER 1, 1992

** PER CONTRACT SPECIFICATION, A SIX MONTH TIME PERIOD BETWEEN HARDWARE DELIVERY TO GSFC AND LAUNCH ASSUMED. NORMAL PAYLOAD PROCESSING WOULD GIVE A LAUNCH DATE OF JANUARY 1, 1996