LIQUID MOTION IN A ROTATING TANK EXPERIMENT (LME)

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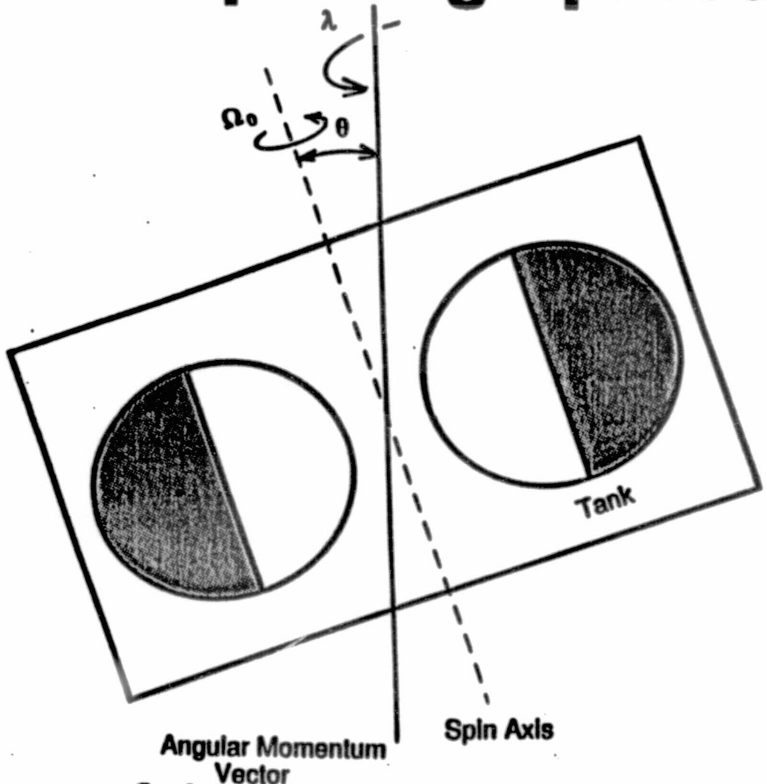
Problem Description

- Many spacecraft spin to obtain gyroscopic stability or to moderate solar heating effects
- A spinning spacecraft has a natural "wobbling" or nutational motion
- The nutation produces an oscillatory motion of the liquid in the spacecraft tanks
- The dynamic effects of the liquid motion can detrimentally affect the stability and control of the spacecraft
- These problems are aggravated by the lack of both knowledge and analytical models about liquid motions in spinning tanks

Generalized Spinning Spacecraft



Nutation frequency of the spacecraft is:

$$\lambda = \Omega_o \left| 1 - \left(I_{spin} / I_{transverse} \right) \right|$$

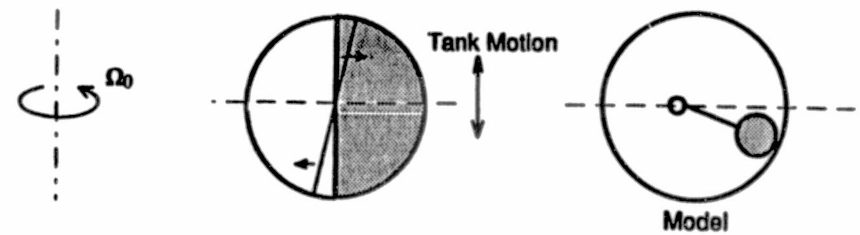
LME Objective

- There is a demonstrated need for improved under-standing of the dynamics of liquids in the tanks of spinning spacecraft.
- Objectives of LME are:
  - acquire representative data to improve ground-test scaling procedures for spacecraft design
  - obtain scientific understanding to formulate and validate better analytical models of liquid motions in spinning tanks

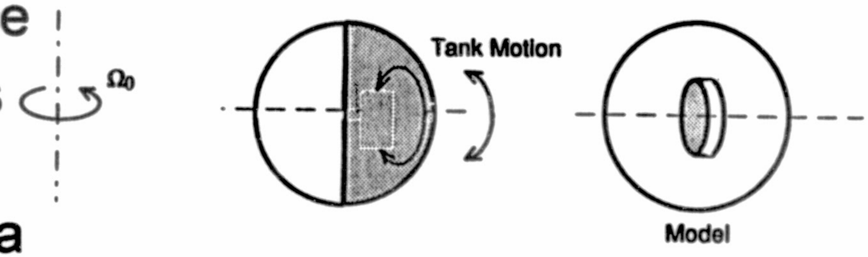
Liquid Oscillations in Spinning Tanks

Spinning-tank liquid motions are of two kinds:

- Free surface waves similar to liquid sloshing
  - need a free surface
  - mechanical analog is a pendulum
  - natural frequency is more than 2Ω



- Inertial (or internal) waves
  - no counterpart in a non-spinning tank
  - does not a free surface
  - natural frequency less than 2Ω
  - mechanical analog is a rotor

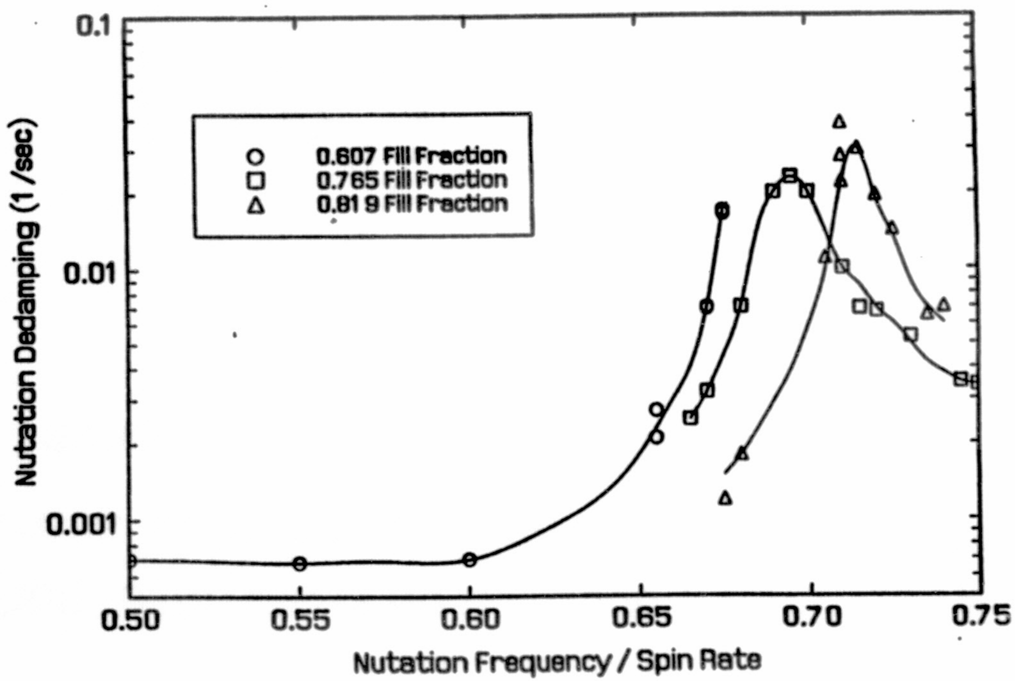


Importance of Problem

- The liquid inventory of spacecraft is a significant fraction of the total mass (over 50% for a spacecraft with a liquid apogee engine)
- Transient and oscillatory motions of such large amounts of liquid easily influence the spacecraft attitude control system when:
  - the liquid natural frequency is near the nutation frequency or control frequency of the spacecraft, or
  - the spacecraft is susceptible to a "flat" spin instability

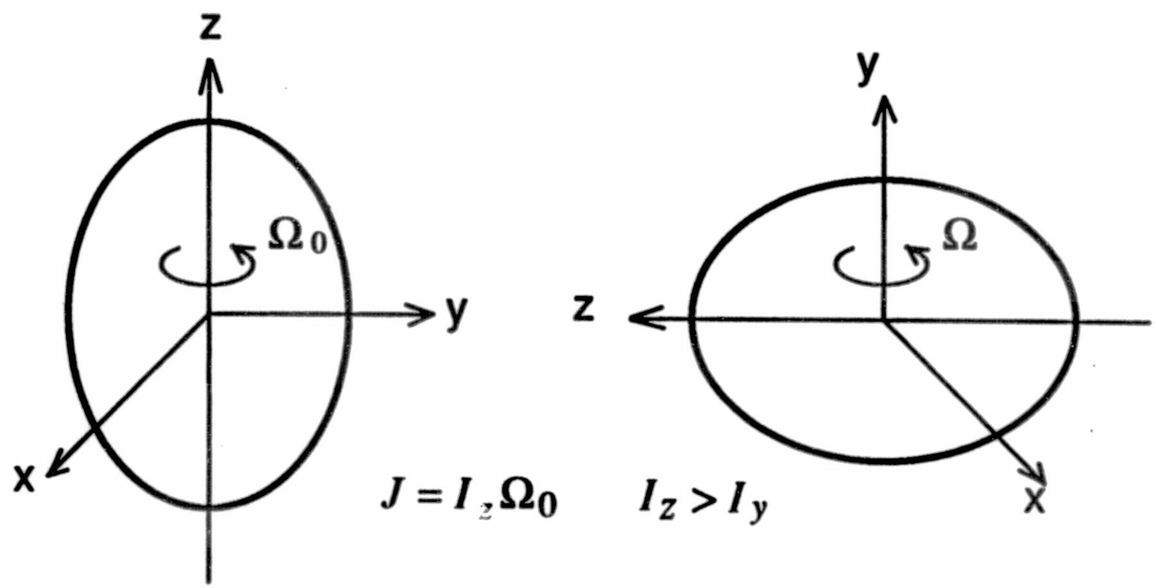
Importance of Problem (cont'd)

The graph shows liquid resonance effects obtained during in-space experimentation of INTELSAT IV. The resonance frequencies are near the nutation frequency. Ground testing could not and did not reveal the presence of these resonances.



Importance of Problem (cont'd)

- When resonances do not occur, energy dissipated by viscous liquid motions can cause serious problems
  - spacecraft kinetic energy is $J^2/2I_s$



- Since $I_z < I_y$, the spacecraft will eventually spin about the y axis - unless nutation is controlled

Limitations of Ground Testing

- Two general kinds of ground testing are in use
  - spin table (free-floating air bearing)
  - drop test
- Spin table tests must use unrealistically high spin rates to overcome gravitational acceleration
  - energy dissipation rates much greater than flight
  - inertial resonances are over-damped
  - any effect of surface tension cannot be studied
  - results must be scaled to flight conditions
    - correlations cannot be validated
- Drop tests must use small models
  - short test times (less than two seconds)

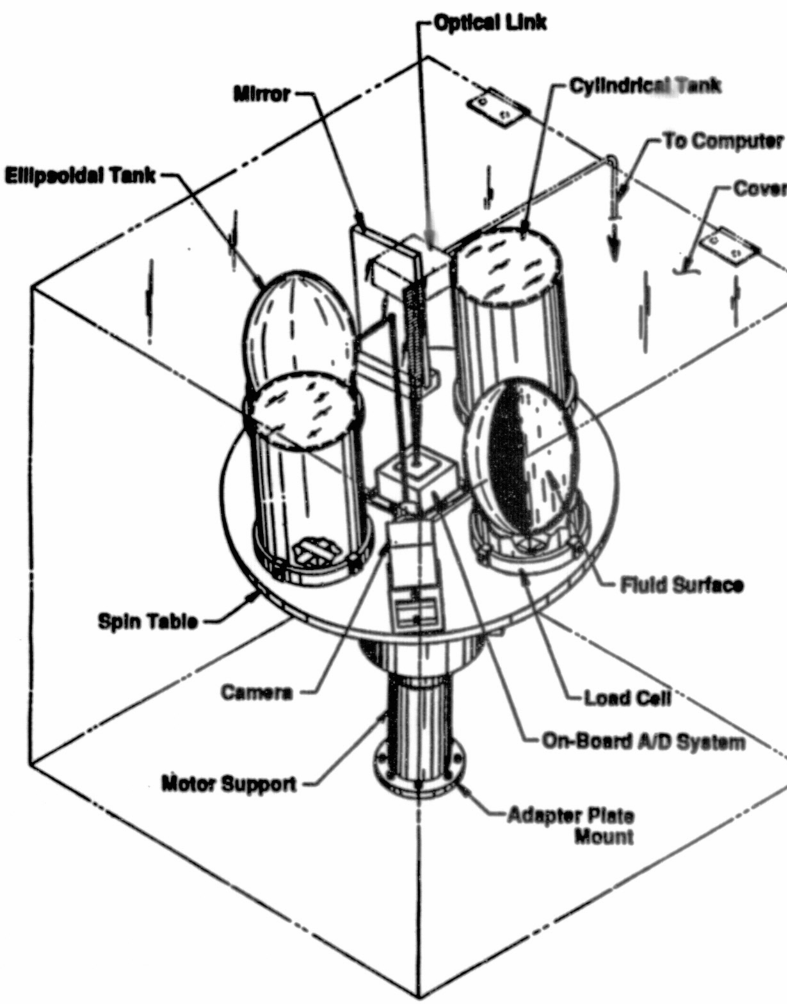
Need for LME Space Experiment

Space tests overcome **all** ground-test limitations

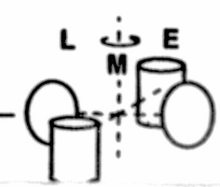
- eliminate unwanted and spurious effects of gravity
  - give correct geometric configuration
  - eliminate once-per-nutation cycle free surface excitation
- allow low spin rates to be used
  - reduce energy dissipation rate to flight-like values
  - eliminates over-damping of inertial oscillations
  - can investigate importance of surface tension
  - makes visual observations possible
- permits sufficiently long test times

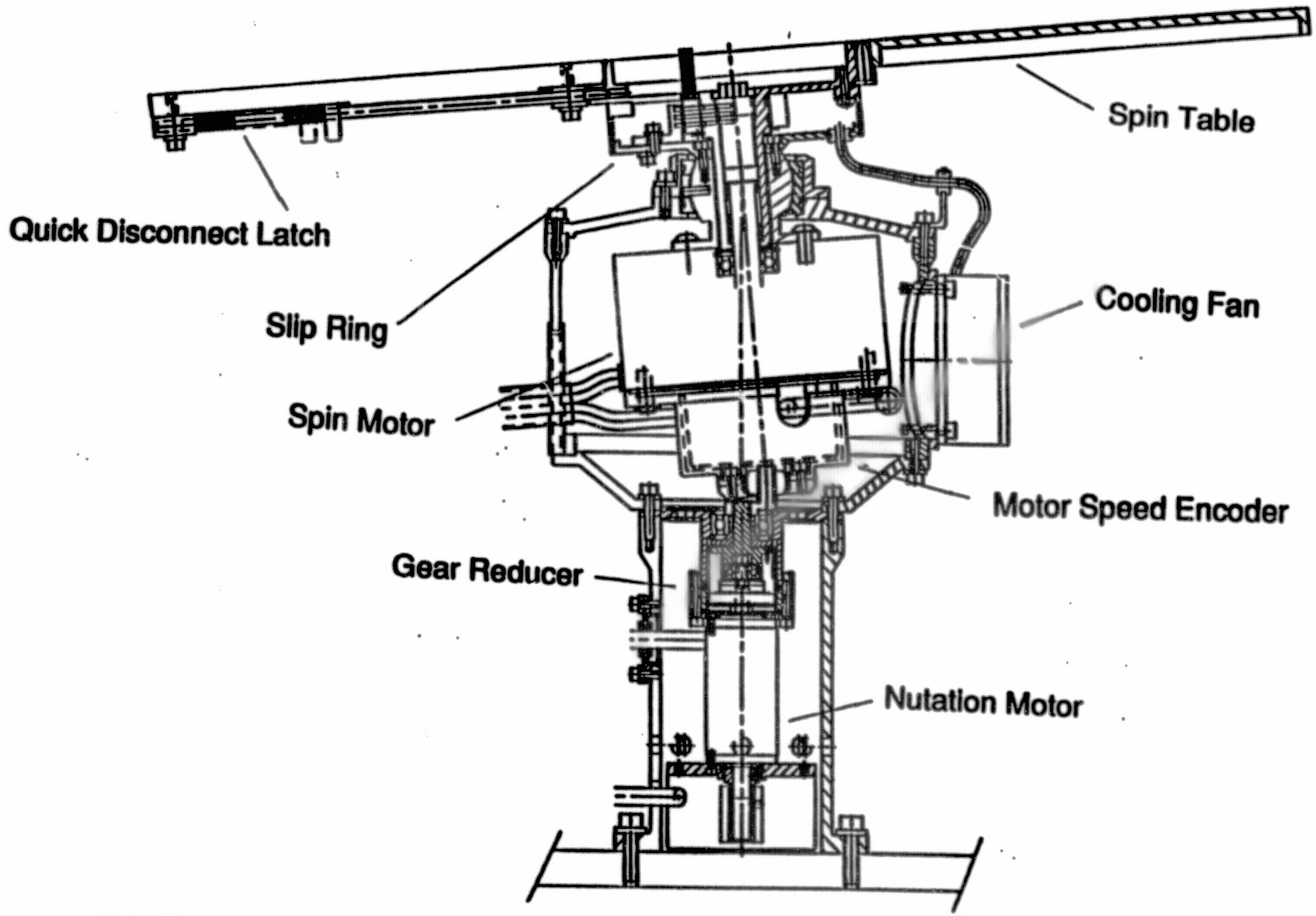
LME Description

- Basic experiment design is a spin table that will subject a set of 4 model tanks containing liquid to realistic nutation motion
  - hardware is mounted on a double adapter plate
  - experiment computer is located in an adjacent locker
- Nutation frequency is variable for any spin rate
  - spin table driven by two independently-controllable brushless DC motors
- Tank shape, liquid fill level, and liquid properties are the primary test variables
  - 2 sets of tanks are required (changed in flight)
  - all 4 tanks of a set are tested simultaneously

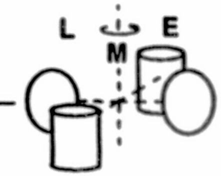


Isometric of LME Hardware Configuration



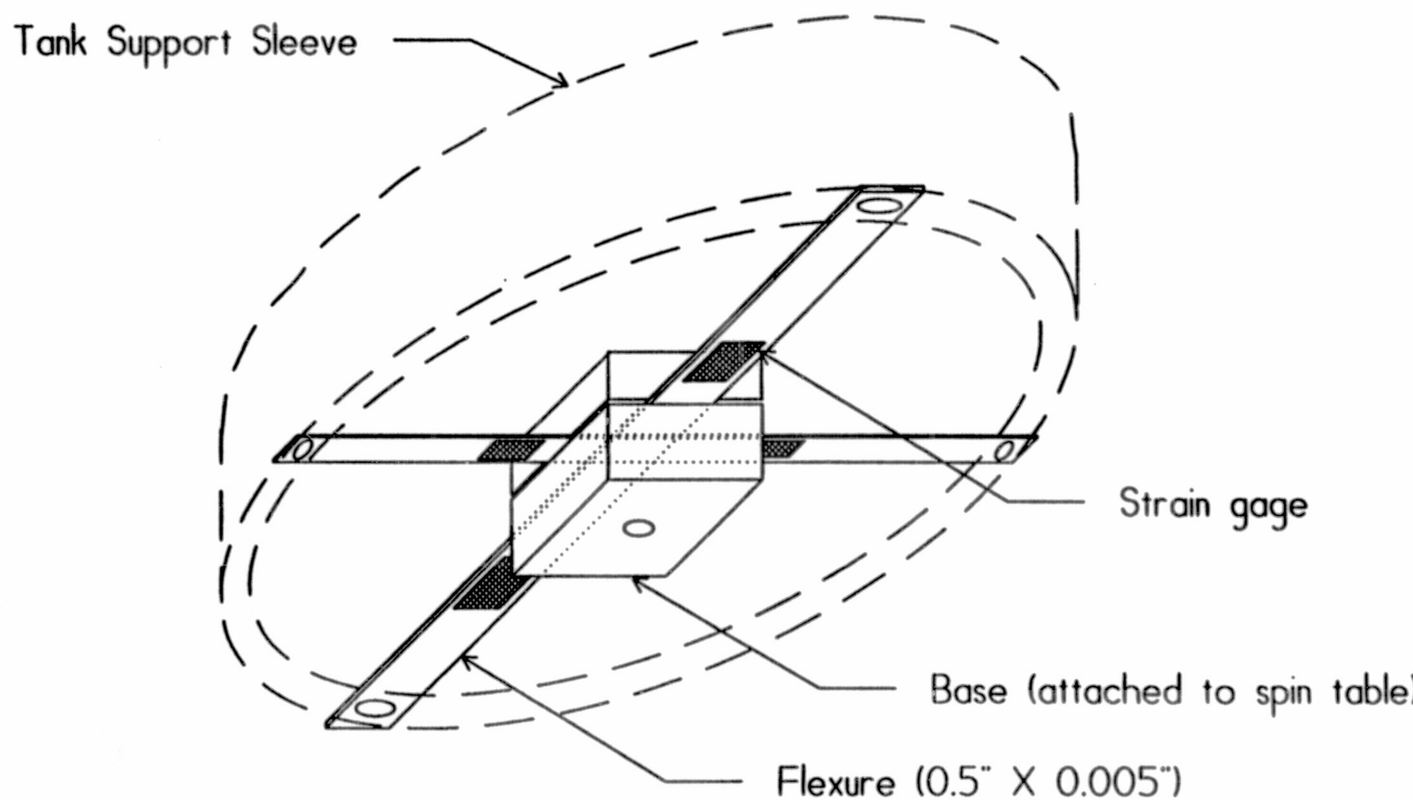


Schematic of LME Spin Table and Drive Motors



Load Cells

- Oscillatory torque magnitudes to be measured range from 1.7 X 10^{-4} in-lb to 0.025 in-lb

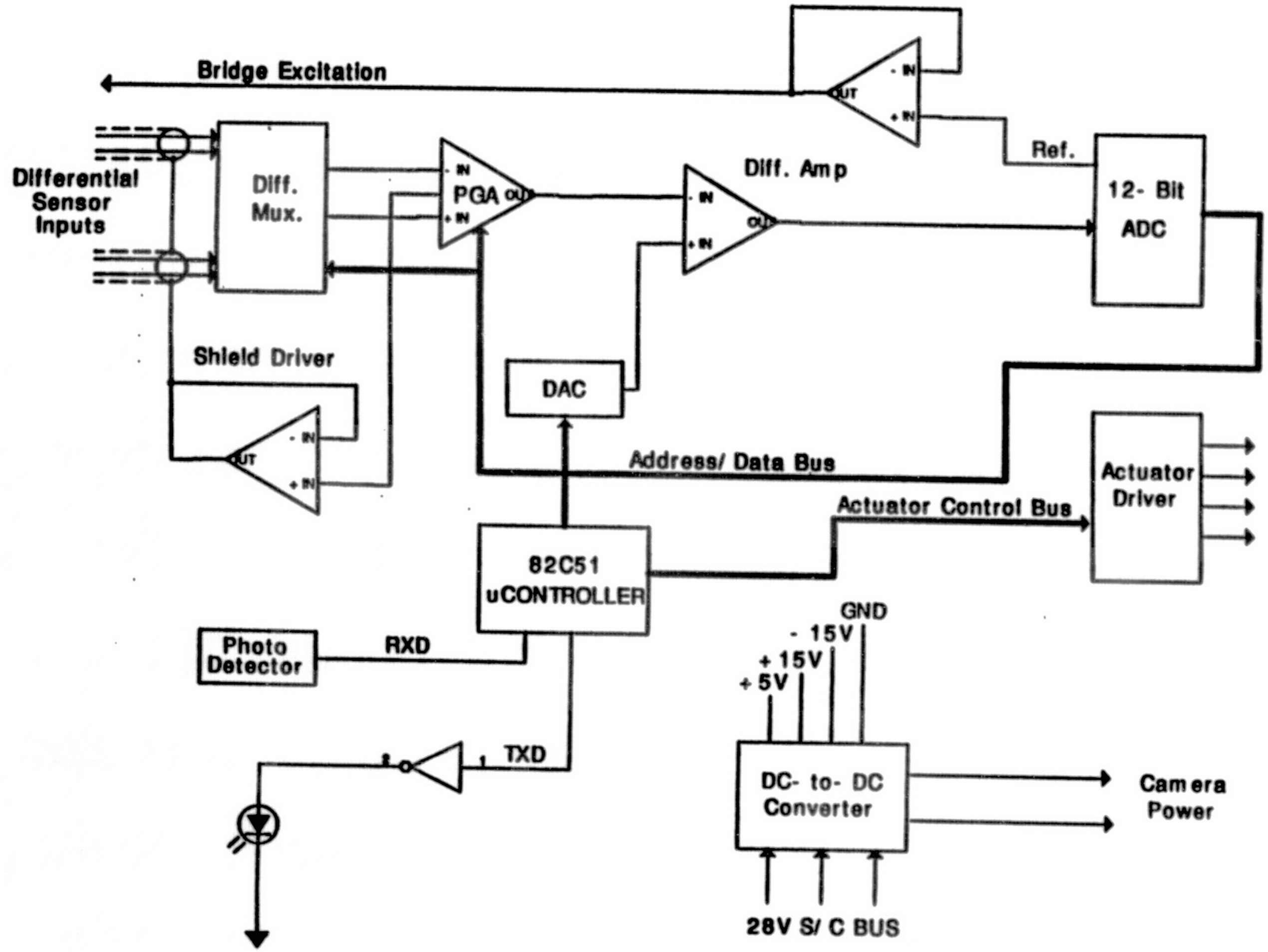


Schematic of Load Cell

Experiment Control and Data Acquisition

LME electronic subsystem consists of:

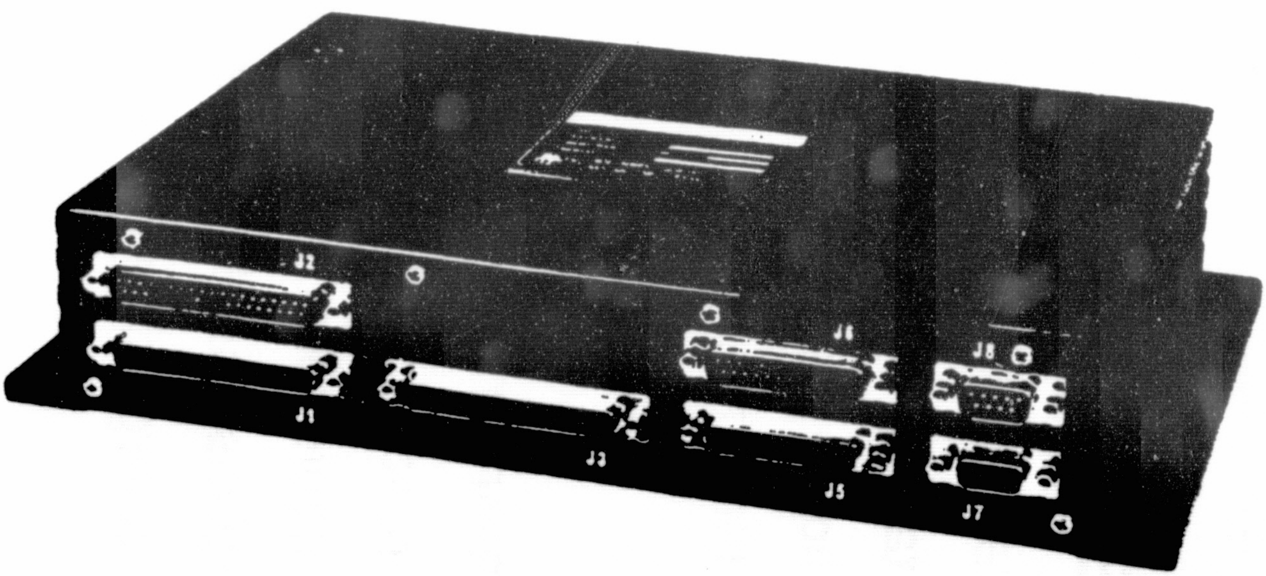
- 2 motor speed controllers
- Data acqusition system
  - printed wiring board mounted on spin table
  - signals transmitted optically to expmnt. computer
- Dedicated experiment processor (SC-4)
  - located in 3rd locker
- Data mass storage device (WORM optical disk)
- Operator interface computer
  - GRID computer supplied by NASA



LME Spin Table Electronics

SPECIFICATION
FOR THE
SC-4 SINGLE-BOARD SPACECRAFT COMPUTER

Central Processor	80C186/80C187 16 Bit
Clock Frequency	10 MHz
Operating System	MS-DOS and VRTX Compatible
Onboard Memory	
RAM	*512K Bytes w/EDC*
EEPROM	*256K Bytes w/EDC*
UVPROM	*64K Bytes w/EDC*
Hardware Vectored Interrupts	16 User Configurable
Timer/Event Counters	8, Software Configurable
Input/Output Capability	
Parallel I/O	*16 Input, 16 Output*
Analog Input	*32 Channels, 12-bit Resolution*
Analog Output	*4 Channels, 12-bit Resolution*
RS-422 Serial I/O	*2 Channels*
SCSI Interface	*1 Port*
Software Controlled Power Switch	*4 Each*
Mass Storage	24M Bytes, Read/Write Battery-Backed
Expansion	Internal Daughterboard Connector
Size	9.25 x 12 x 2.25 in.
Weight	5 Lb. (Approximate)
Power	28V @ 5W (Approximate)



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LME Variable and Response Parameters

- Parameters to be varied in LME tests:
  - tank shape and liquid fill level
  - liquid viscosity and surface tension
  - tank motion
    - nutation frequency swept from 1 rpm to twice the spin rate for each test
- Primary measured response parameters
  - resonant conditions (natural frequencies)
  - liquid torque as function of spin rate and nutation
  - phase angle between torque and nutation
  - energy dissipation rate (computed from torque)

Proposed Test Matrix

Spin Rate, rpm	Nutation Freq., rpm	Liquid Visc., cp	Centrifugal Accel., g's	Bond No.
4	1 - 8	1	0.0027	1.2
16	1 - 32	1	0.033	15
20	1 - 40	1	0.067	30
4	1 - 8	10	0.0027	1.2
16	1 - 32	10	0.033	15
20	1 - 40	10	0.067	30

- Total test time, including calibration runs and repeats, is estimated to be 6 to 8 hours
- Mission specialist will verify test setups and initiate each test

Summary

- The "Liquid Motion in Rotating Tank Experiment" (LME) will investigate and quantify liquid motions occurring in spin-stabilized spacecraft:
  - acquire representative data to validate ground-test scaling procedures
  - obtain scientific understanding to formulate better analytical models
- LME eliminates the limitations of ground testing
- LME design is nearing the end of Phase B
  - breadboard hardware model has been completed
  - load cells have been fabricated and tested
  - experiment computer has been flight qualified
  - other electronics have been breadboarded