CONTROL OF LIQUID HELIUM MOTION BY CAPILLARY FORCES IN AEROGEL FOR THE SATELLITE TEST OF THE EQUIVALENCE PRINCIPLE (STEP)

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SPACE TEST OF EQUIVALENCE PRINCIPLE

● EINSTEIN'S EQUIVALENCE PRINCIPLE:

- GRAVITATIONAL MASS AND INERTIAL MASS ARE EQUAL

- IMPLIES THAT ALL MASSES FALL AT THE SAME VELOCITY IN A GRAVITATIONAL FIELD

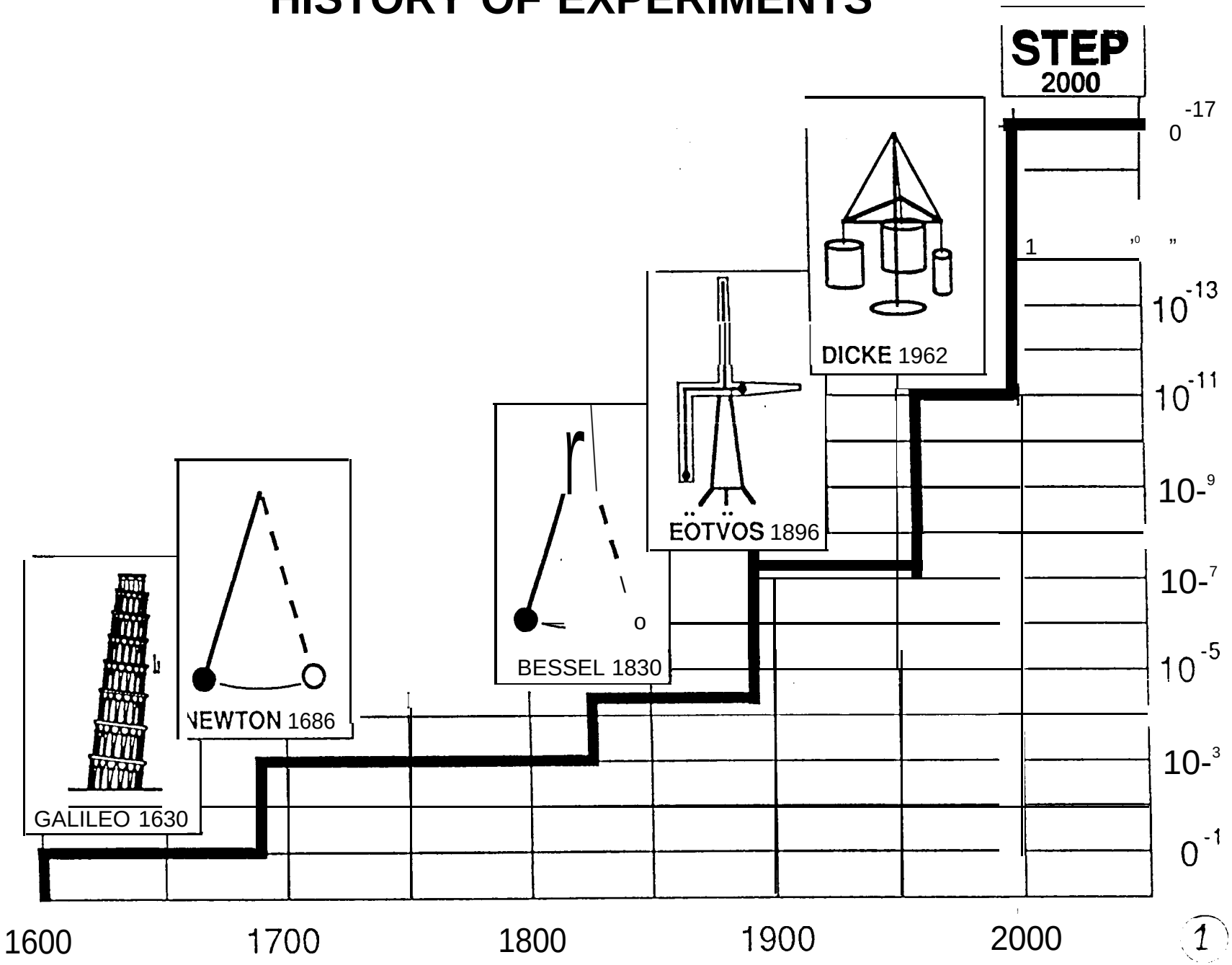
- POSTULATED, NOT DERIVED FROM MORE FUNDAMENTAL PRINCIPLES

- KEY POSTULATE OF GENERAL RELATIVITY

● NOW KNOWN TO BE TRUE TO 1 PART IN 10^{11}.

PROPOSED TEST WILL IMPROVE TO 1 PART IN 10^{18}

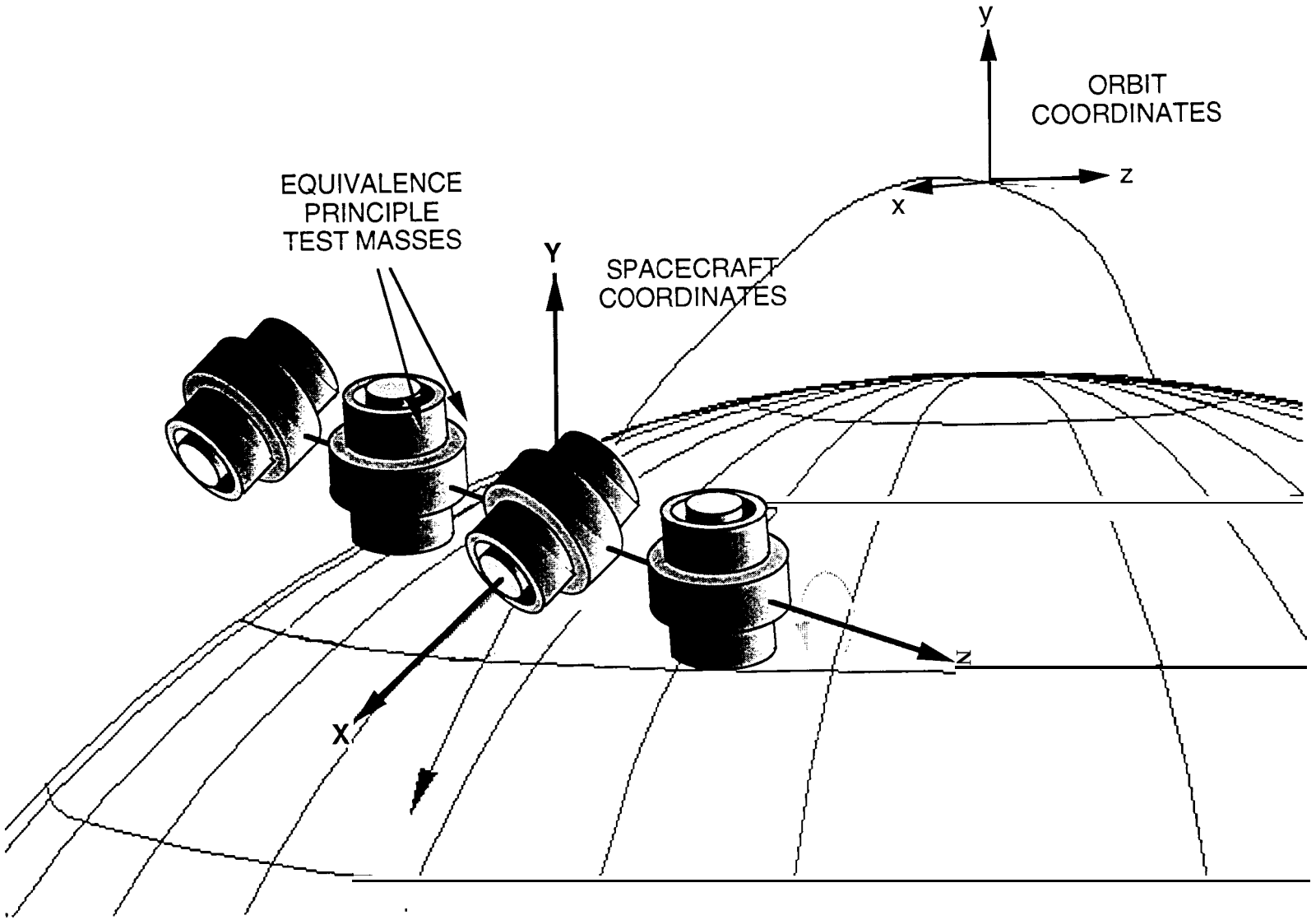
HISTORY OF EXPERIMENTS



STEP MISSION

- LAUNCH IN 200⊙
- 400 KM SUN SYNCHRONO S ORBIT, 4 MONTH MISSION
- SUPERFLUID HELIUM DEWAR, 18⊙L., 1.8 K
- ÷ SINGLE AXIS DIFFERENTIAL ACCELEROMETERS
- DRAG-FREE SATELLIT≤

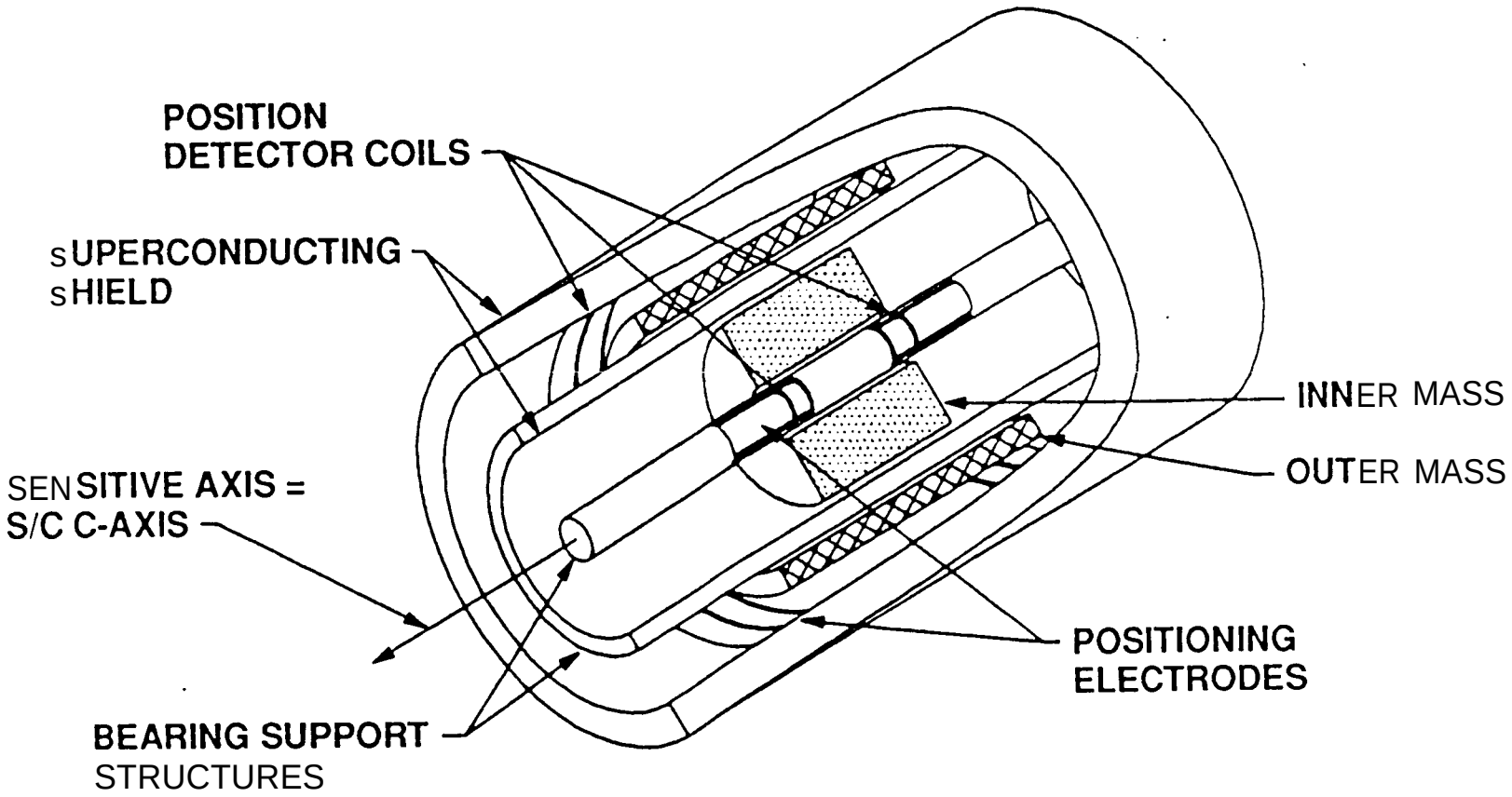
PAYLOAD GEOMETRY

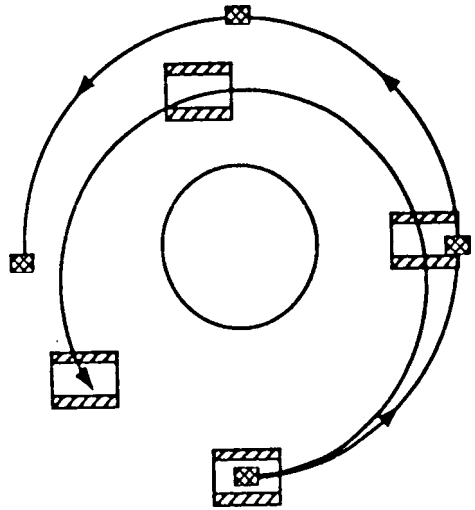


KEY TECHNOLOGICAL FEATURES

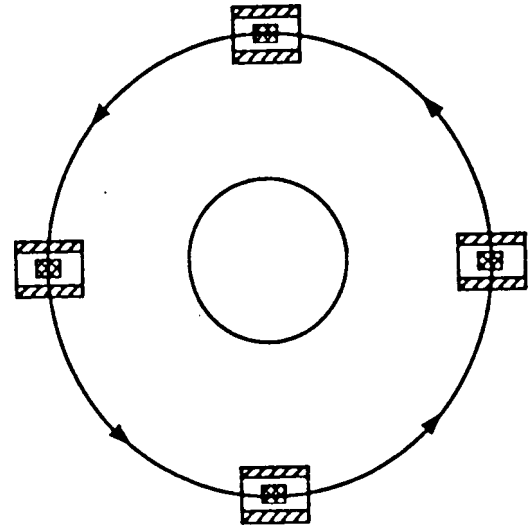
- DIFFERENTIAL ACCELEROMETER USING SUPERCONDUCTING QUANTUM INTERFERENCE DEVICES (SQUIDS) TO SENSE RELATIVE MOTION OF PROOF MASSES TO 10-13 CM
- ORBITING SPACECRAFT
  - GREATLY REDUCED SEISMIC NOISE AND GRAVITY GRADIENTS
  - GREATLY INCREASED FREE FALL TIME COMPARED TO DROP TOWER - 6000 SEC VS. 5 SEC
  - PERIODIC SIGNAL, FILTERING WILL ELIMINATE RANDOM NOISE -- DRAG FREE CONTROL SYSTEM USING HELIUM BOIL-OFF GAS

JPL STEP DIFFERENTIAL ACCELEROMETER

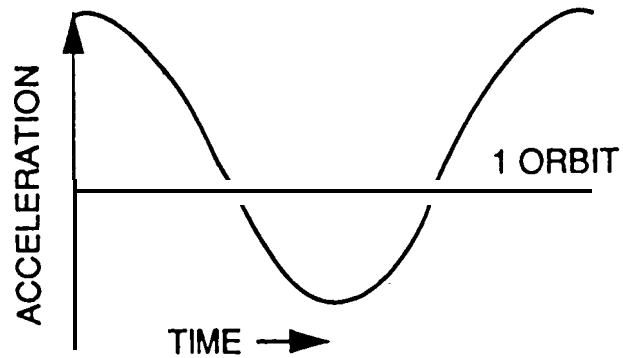




UNCONTROLLED MASSES



EFFECT OF SERVO

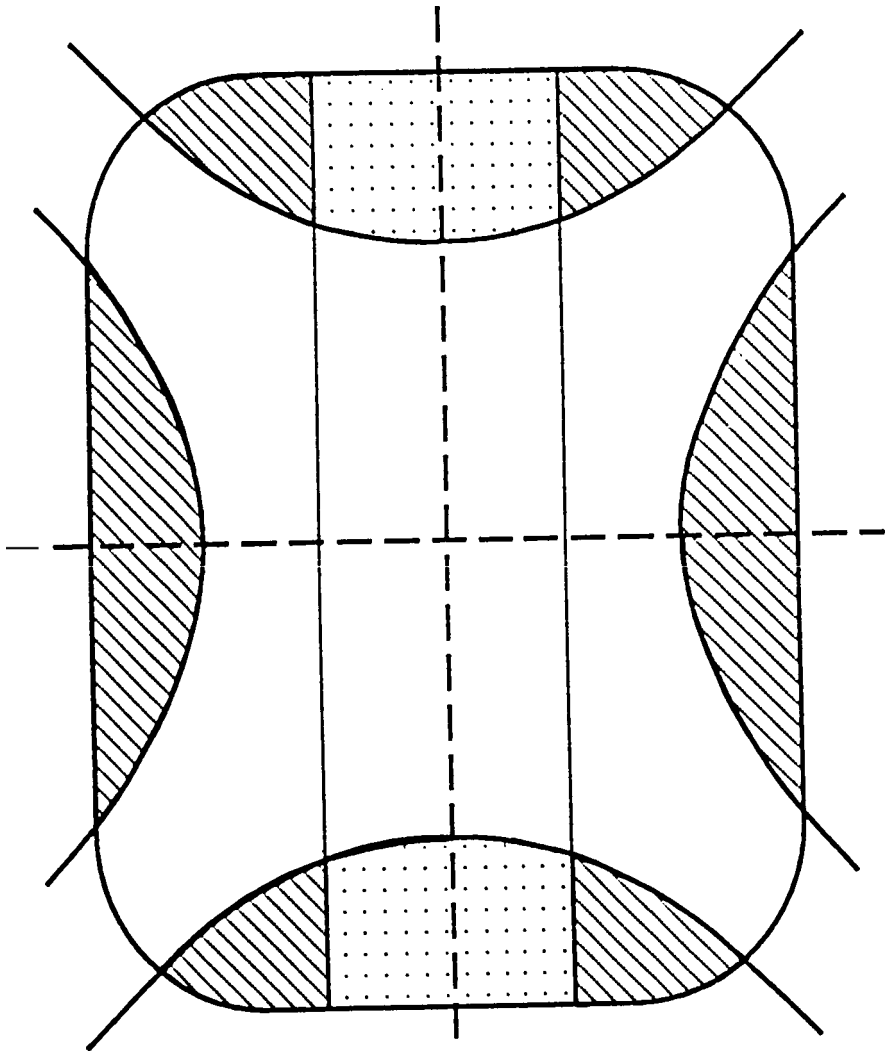


SIGNAL OF VIOLATION

SOURCES OF ERROR AT ORBITAL PERIOD

- HELIUM T DAL MOTIONS CAUSED BY GRAVITY GRADIENTS
- THERMAL DISTORTIONS CAUSED BY TERRESTRIAL HEATING
- EFFECTS OF EARTH'S MAGNETIC FIELDS ON SQU DS

GRAVITY GRADIENT EQUIPOTENTIALS



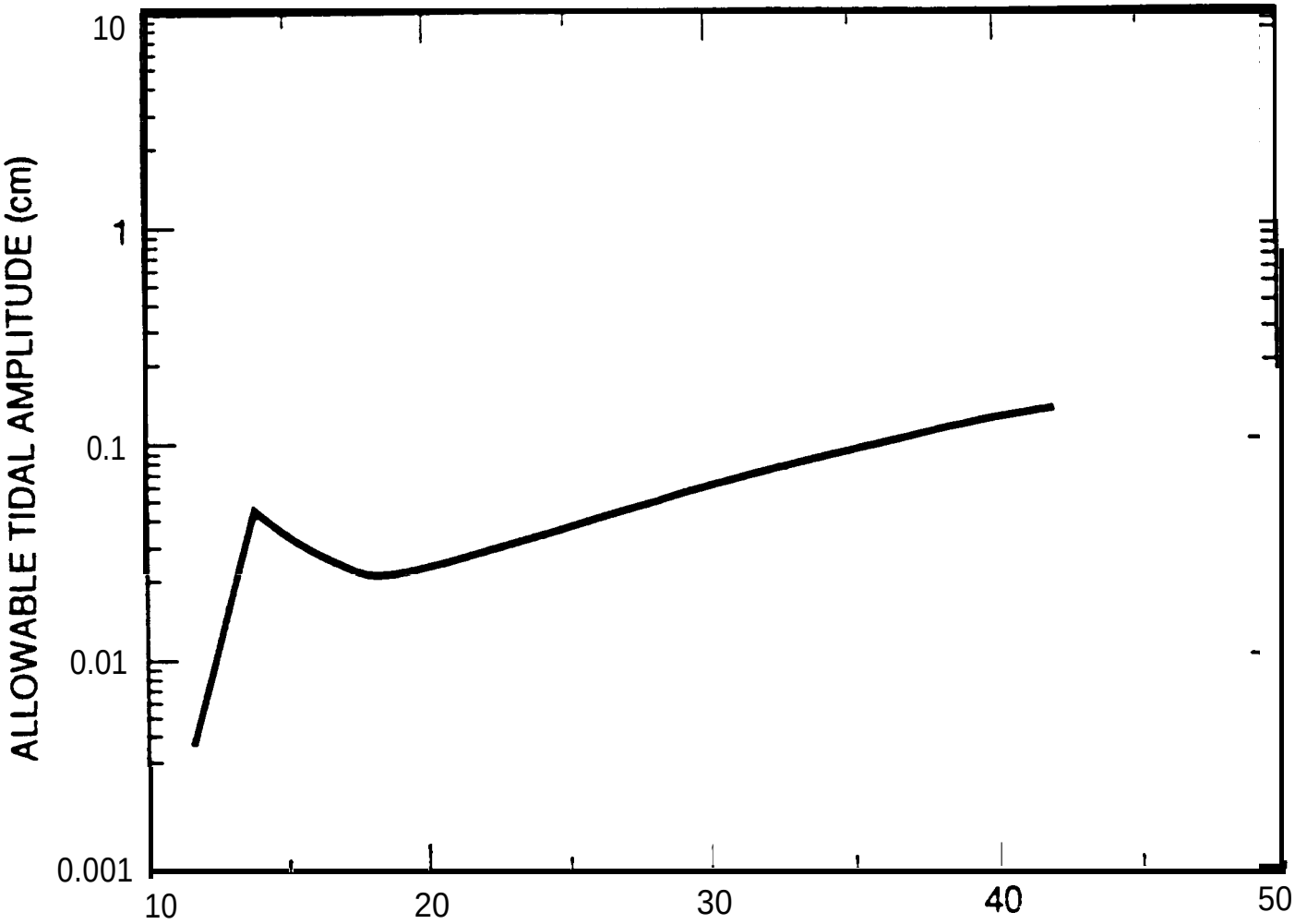
EFFECTS OF MASS MOTION

- LIQUID HELIUM ROTATES IN GRAVITY-GRADIENT FIELD

  (IF COMPLETELY SYMMETRIC, THESE IS NO EFFECT ON MASSES)

- LIMITS ON HELIUM PERMISSIBLE HELIUM MOTION

  GOAL IS TO ACHIEVE 90% REDUCTION OF MOTION



Allowed Helium Motion
Figure *4-23*

RETENTION FORCES

- CAPILLARY FORCE $F_c = 2\,\frac{\sigma}{R}$
- GRAVITATIONAL FORCE $F_g = \rho\, a\, R$
- EQUATING THESE GIVES A CHARACTERISTIC LENGTH. R

$$R = \sqrt{\frac{2\,\sigma}{\rho\, a}}$$

- IF R << DIMENSIONS OF THE INTERNAL STRUCTURE, SURFACE TENSION FORCES DOMINATE

RETENTION FORCE (CONT)

- FOR a = 10^{-7}g, σ = 3.5 X 10^{-4} N/M, and p = 125 KGM/M^3 (Lhe AT 1.6 K)

  THEN R = 150 CM, I.E. HELIUM LOCATION COMPLETELY CONTROLLED BY CAPILLARY FORCES IF SCALE IS << 150 CM

- VAN DER WAALS FORCES

  - RANGE IS ABOUT 300A

  $$F = \frac{k}{d^3}$$

  - FAR STRONGER THAN GRAVITY

AEROGEL

- OPEN-CELL SILICA GEL, FORMED BY PRECIPITATION FROM SOLVENT
- DENSITY RANGES FROM 0.2% TO 5% OF BASE MATERIAL

  4 mg/CC TO 200 mg/CC
- PORE SIZES 100A TO 1000A, DEPENDING ON PREPARATION
- BASICALLY GLASS-LIKE, STRONG BUT BRITTLE

ISSUES AND CONCERNS

- HOW MUCH DOES AEROGEL REDUCE MOTION?
- CAN WE USE OTHER MATERIALS WHICH ARE EASIER TO USE

  E.G. LARGER CELLS? EASIER INSTALLATION, STURDIER
- WHAT IS SPLIT BETWEEN FREE HELIUM, CAPILLARY-CAPTURED AND

  VAN DER WAALS-CAPTURED?
- HELIUM UPTAKE AND RELEASE
- MECHANICAL PROPERTIES: SHAPING, INSTALLATION AND

  DURABILITY

EXPERIMENT

- OBJECTIVE

  MEASUREMENT OF HELIUM RETENTION AND MOTION IN 1 G

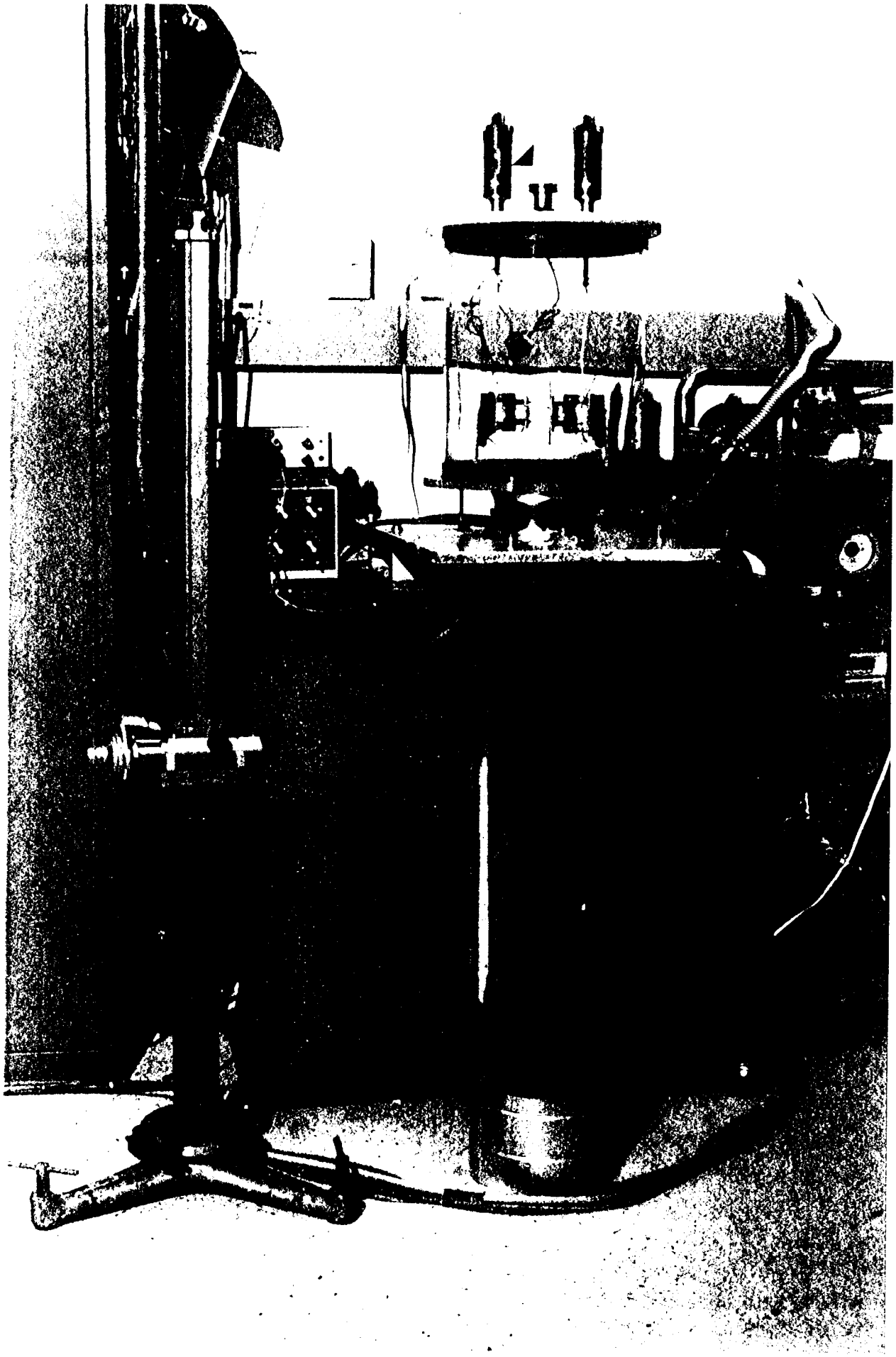
  1. MEASUREMENT OF TOTAL He MASS IN A KNOWN VOLUME OF AEROGEL

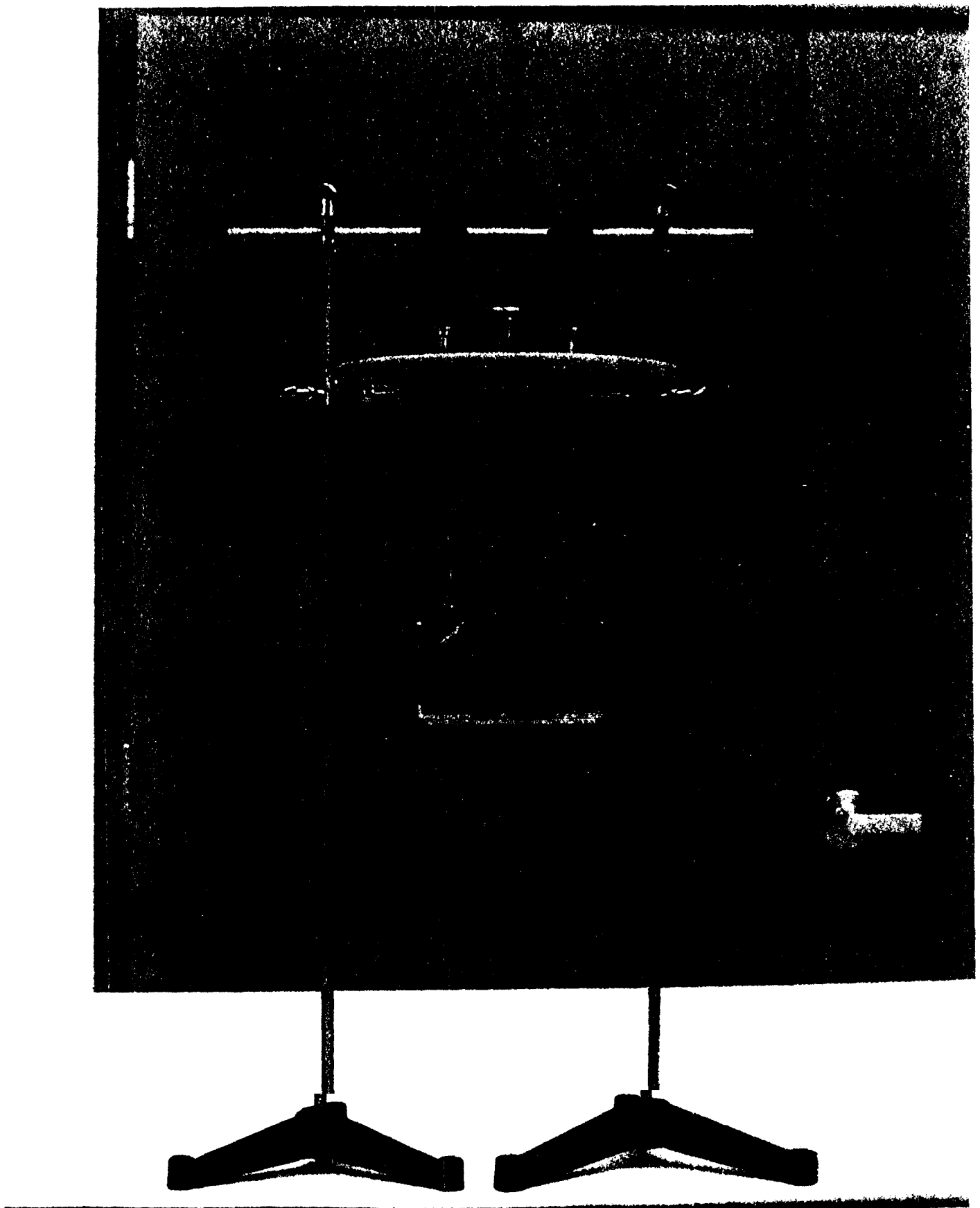
  2. MEASUREMENT OF MOTION OF CG

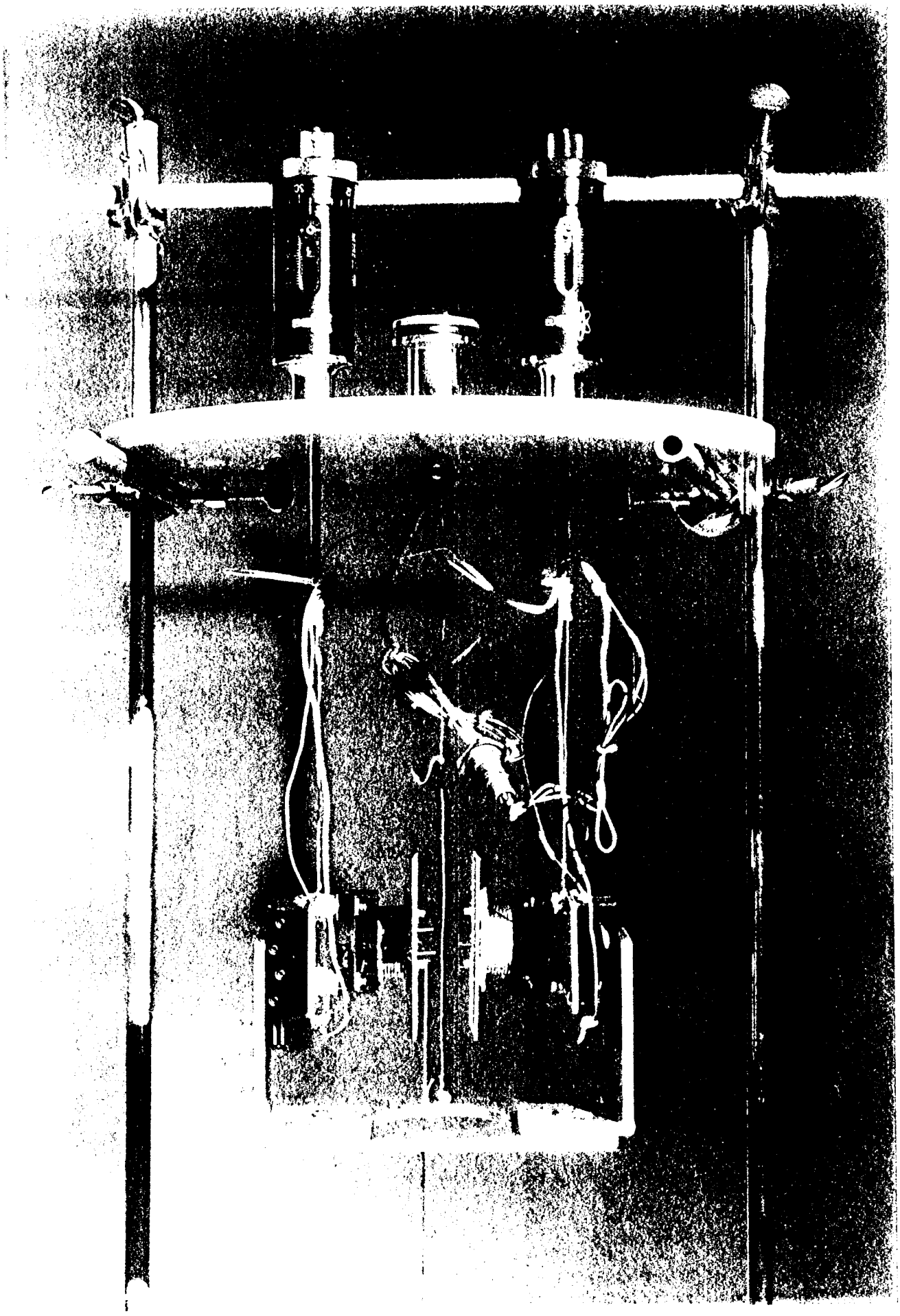
  3. MEASUREMENT OF HELIUM DIFFUSION FROM AEROGEL

- EXPERIMENTAL APPARATUS

  DUAL FORCE-BALANCE ELECTRONIC SCALE







- OBSERVATIONS

  . HELIUM UP-TAKE 70 to 90% OF AVAILABLE VOLUME

  2. HELIUM EVAPORATES COMPLETELY FROM AEROGEL IN A RADIATIVELY HEATED ENVIRONMENT

FURTHER TESTS

CENTER OF MASS MOTION

THERMAL CONDUCTIVITY

PLANNED WORK

	MOTIVATION	WORK DESCRIPTION	PLACE	TIME
1	Fundamental Properties	Superfluid Static Behavior with Assessment with Tilt Cell	JPL	96-97
2	"	Superfluid Dynamics Assessment with Torsional Oscillator and Optical Inspection	Trento	1996-97
5	"	Large Scale Fluid Dynamic test	Lockheed/Trento	
3	"	Helium Heat Conductance	Trento/JPL	1997
3a	Aerogel Properties	Aerogel Fabrication and Supply to Investigators	Lockheed	1996-8
3b	"	Aerogel shaping and contamination issues	Lockheed/JPL/ Trento	1996-97
4	Application to STEP Cryostat	Test Dewar Concept Design	All	End 1997
6	"	Dewar Mechanical Behavior assessment	Lockheed / JPL	
7.	"	Dewar Thermal Behavior Assessment	Lockheed/Trento	
8	"	Evaporation, Thruster Feeding	Lockheed / JPL	
9	"	Fabrication Procedure	Lockheed	
10	Flight Qualification	Test Dewar #1 -51	Lockheed	1998
11	"	Test Dewar # 2 Helium Filling and Handling Test	Trento/Torino	1998
12	"	Final Helium Confinement Device Design (Deliverable)	Lockheed/Trento	End 1998