INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460892 - I

SMR/382- 22

WORKSHOP ON SPACE PHYSICS:
"Materials in Micorgravity"
27 February - 17 March 1989

"Microgravity Environment"

H. HAMACHER
DFVLR
Köln, Fed. Rep. of Germany

● Space Flight Conditions

Motivation to perform science in space. In many aspects different from conditions on Earth.

From the factors of space flight

e.g.

- Position above Earth
- space vacuum
- low column density

unique:

- Simulated state of weightlessness, in principle without time limitations.

However:

Weightlessness is an ideal state.
In reality: Residual accelerations
Microgravity

To optimize and to analyse experiments:

Need to understand the character of microgravity (magnitude, direction, frequency, etc.)

● Table of Content

- Principle for simulating weightlessness
- Effects causing residual accelerations.
- Characterization of the microgravity environment aboard an orbiting spacecraft
  - ▸ Case study: Spacelab D1 Mission
  - ▸ Outlook: EURECA, Space Station/COLUMBUS
- Other opportunities/programmes to perform microgravity experiments
  - ▸ Sounding rockets,
  - ▸ Aircrafts,
  - ▸ Drop tubes/towers

● The Earth's Gravitational Field

<u>Newton's second law</u> for central gravitational fields

$$-\vec{W} = m\underbrace{\frac{\gamma\, m_e}{r^2}\frac{\vec{r}}{r}} = m\,\vec{g}(r)$$

$\vec{g}$ field strength

$$g = \frac{\mu}{r^2}$$

$$g_0 = g(r_0) = 9.81\,\frac{m}{s^2}$$

$\mu = \gamma m_e$ gravitational parameter

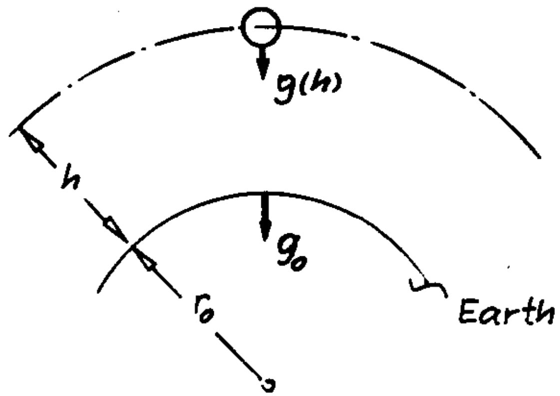
$r_0 = 6.371$ km mean radius

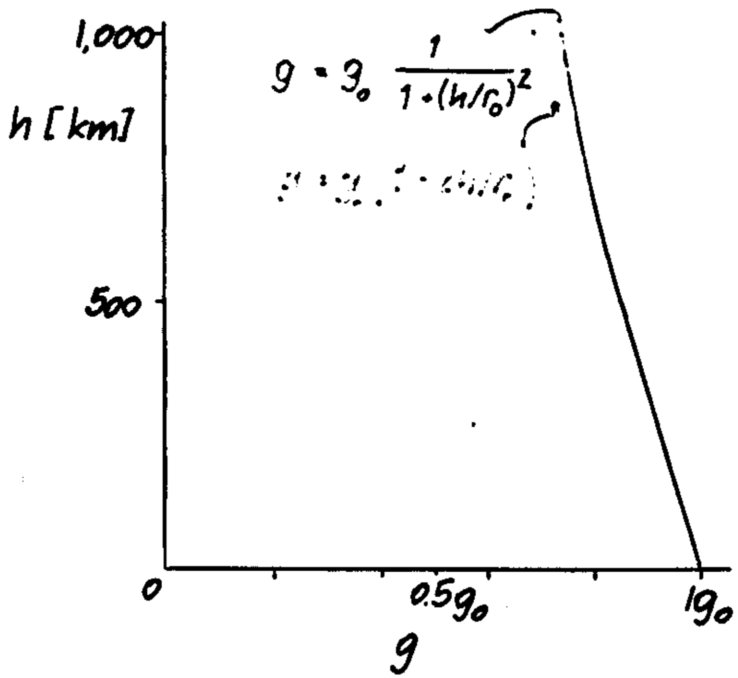
$$\left[\frac{g}{g_0} = \left(\frac{r_0}{r}\right)^2 = \frac{1}{(1+h/r_0)^2}\right]$$

$$\frac{g}{g_0} \simeq 1 - \frac{2h}{r_0}; \qquad \frac{h}{r_0} \ll 1$$

$\Delta g = 3\,\%$ for h=100 km

$= 3\cdot 10^{-7} g_0/m$





Simulation of Weightlessness
in [redacted]

1) Gravity can be compensated in orbital flight by centrifugal acceleration a_c due to the curvature of the orbit.

<u>Circular orbit:</u>

- $g = a_C$

  $\frac{\mu}{r_{CM}^2} = r_{CM}\,\omega_S^2$

  $\omega_S = 2\pi f_S = \sqrt{\frac{\mu}{r_{CM}^3}}$

  $v_S = \sqrt{\frac{\mu}{r_{CM}}}$

<u>h = 0:</u>

$\omega_{SO} = \sqrt{\frac{\mu}{r_0^2}} = 1.2 \cdot 10^{-3}\,s^{-1}$

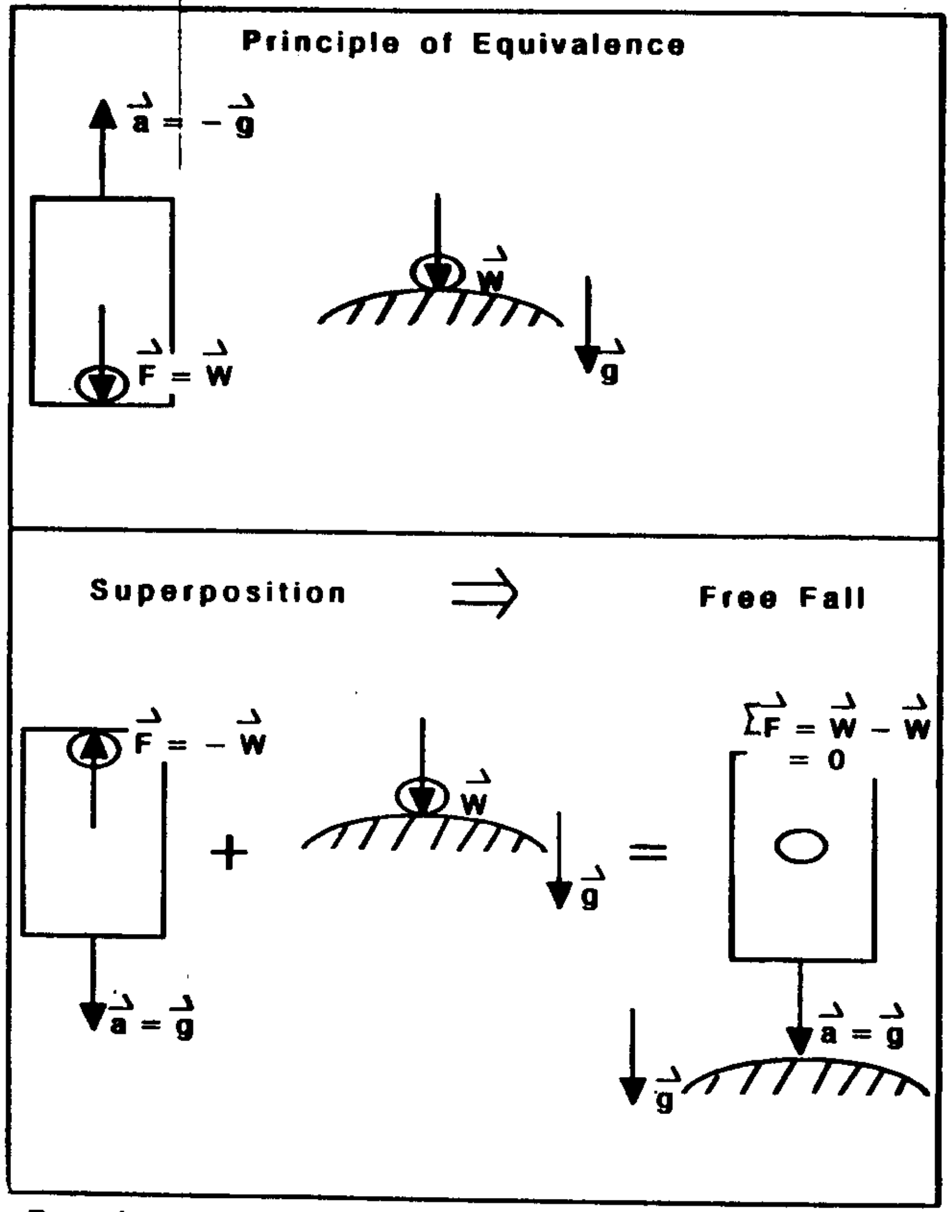
- $f_{SO} =$ $2 \cdot 10^{-4}$ Hz
- $v_{SO} =$ 8 km/s

2) A force-free state of the spacecraft requires:

$$\Sigma a_{tangential} = 0$$

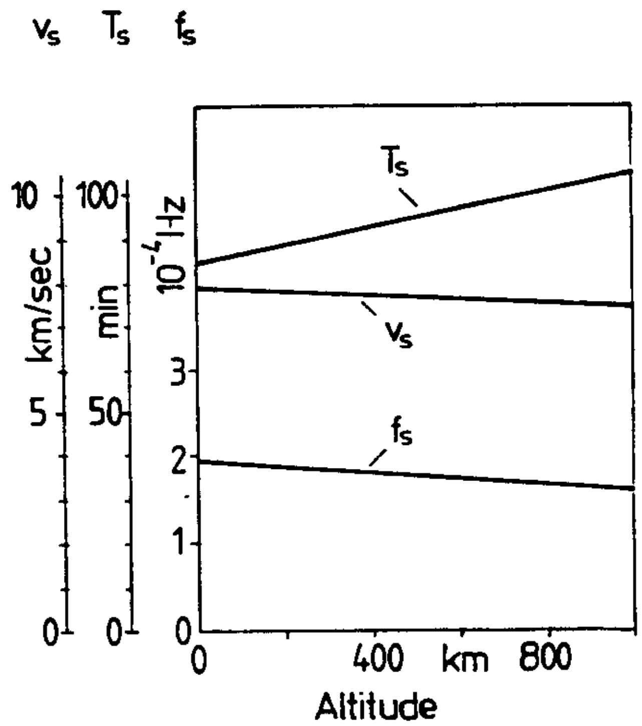
i.e. [redacted]

<u>Result:</u> A force-free state (weightlessness or 0g) is achieved in a free drifting spacecraft at the CM.
(A more general justification will be given later on)



Result: Weightlessness is simulated in a free fall system.

A freely drifting Spacecraft is a special case of free fall systems.



● The Real Spacecraft:
Residual accelerations

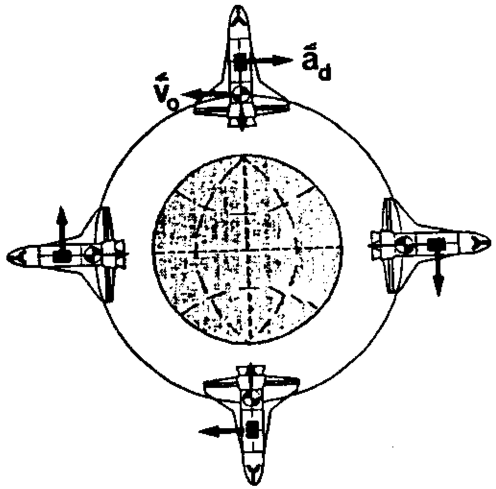
Weightlessness is an ideal state.
In reality: residual accelerations (Microgravity)
Effects:
1) ● Residual external forces
e.g. ● atmospheric drag
● solar radiation pressure
● thruster firings
Change momentum
Exerting a torque
2) ● The extended spacecraft.
For objects not located at CM
● $g \neq a_c$ (tidal effect)
● Rotation may cause additional centrifugal acceleration. Coriolis acceleration for moving ogjects.
● Internal forces
due to change of mass distribution.
(motion of mechanical parts, crew activities, etc.)
No change of momentum.

QUASI STEADY ACCELERATION

● ATMOSPHERIC DRAG

DIRECTED OPPOSITE TO THE ORBITAL VELOCITY VECTOR.

● GRAVITY GRADIENT MODE (GGM): CONSTANT DIRECTION OF THE DRAG VECTOR

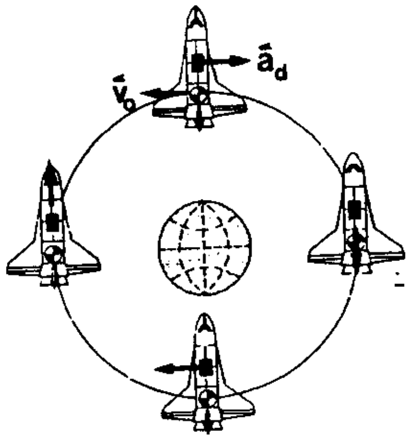


% OF SL ACTIVATED TIME

SL-1	D1
4	29

● INERTIAL MODE (IM): ROTATING DRAG VECTOR

SL-1	D1
43	28



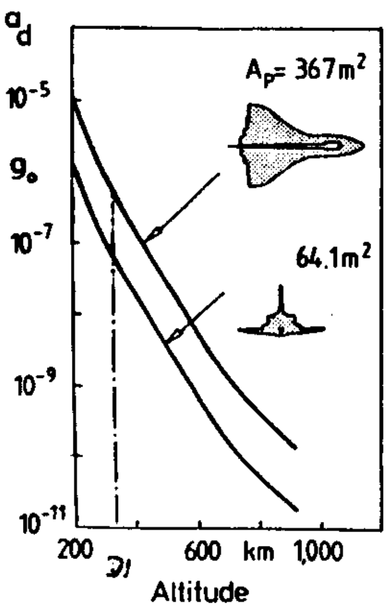
ATMOSPHERIC DRAG (CONT.)

- **ATMOSPHERIC DECELERATION**

$$A_D = C_D \cdot (\rho/2) V_O^2 \cdot (A_P/M)$$

- (A_P/M) — F (TYPE OF S/C. ORIENTATION)
- V_O^2 — F (ALTITUDE)
- $(\rho/2)$ — F (ALTITUDE, DAY-NIGHT)

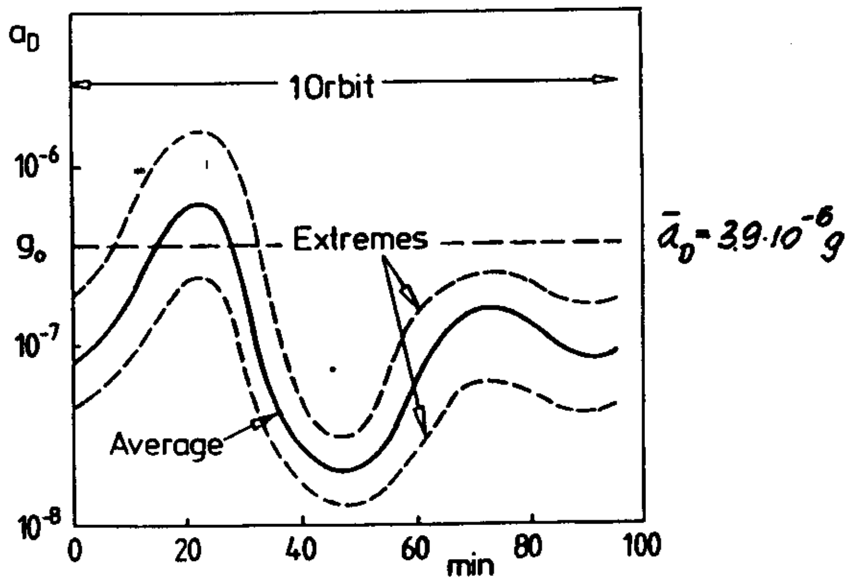
- **ORBITER/SPACELAB**



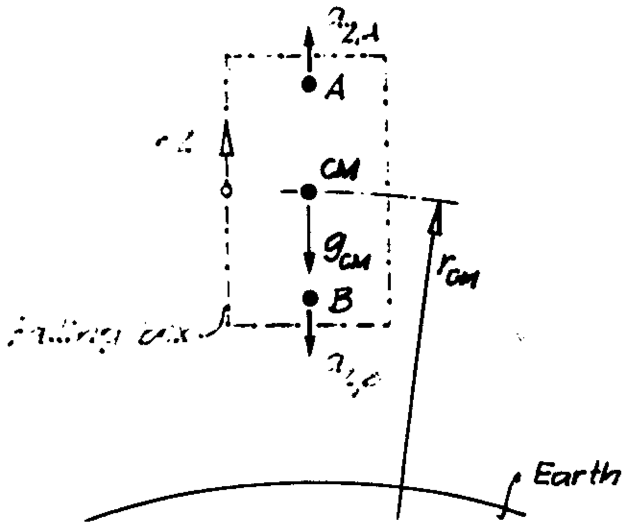
- **A_P/M FOR DIFFERENT CARRIERS**

EURECA I	$2.0 \cdot 10^{-2}$ M²/KG
US-MEM	$1.8 \cdot 10^{-2}$
ORBITER/SL	0.7 TO $4.0 \cdot 10^{-3}$
SPACE STATION	0.9 TO $1.2 \cdot 10^{-2}$

- **SPACE STATION**



The Tidal Effect



At point A : $g_A < g_{CM}$

Acceleration relative to the box :

$$a_{Z,A} = -g_A - (-g_{CM})$$
$$= g_{CM} - g_A > 0$$

$$a_{Z,B} < 0$$

Directed away from CM .

QUASI STEADY ACCELERATION

● TIDAL EFFECT

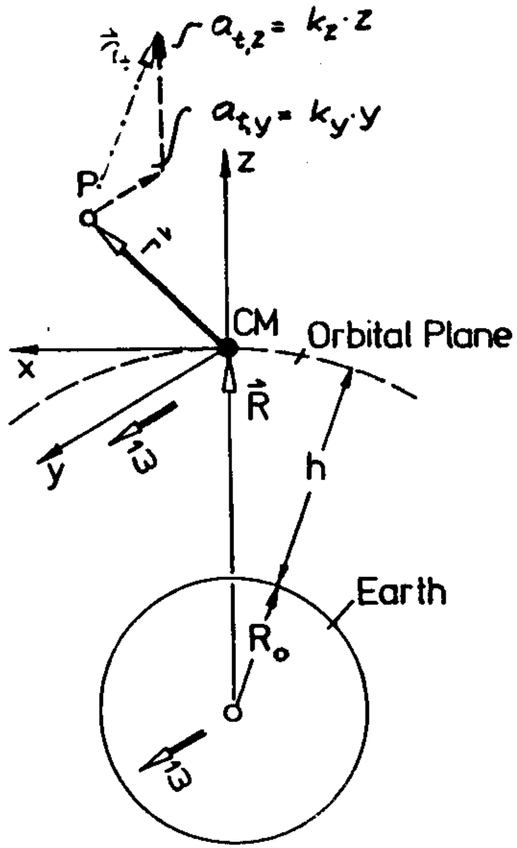
GRAVITY GRADIENT MODE

$h = 300$ km

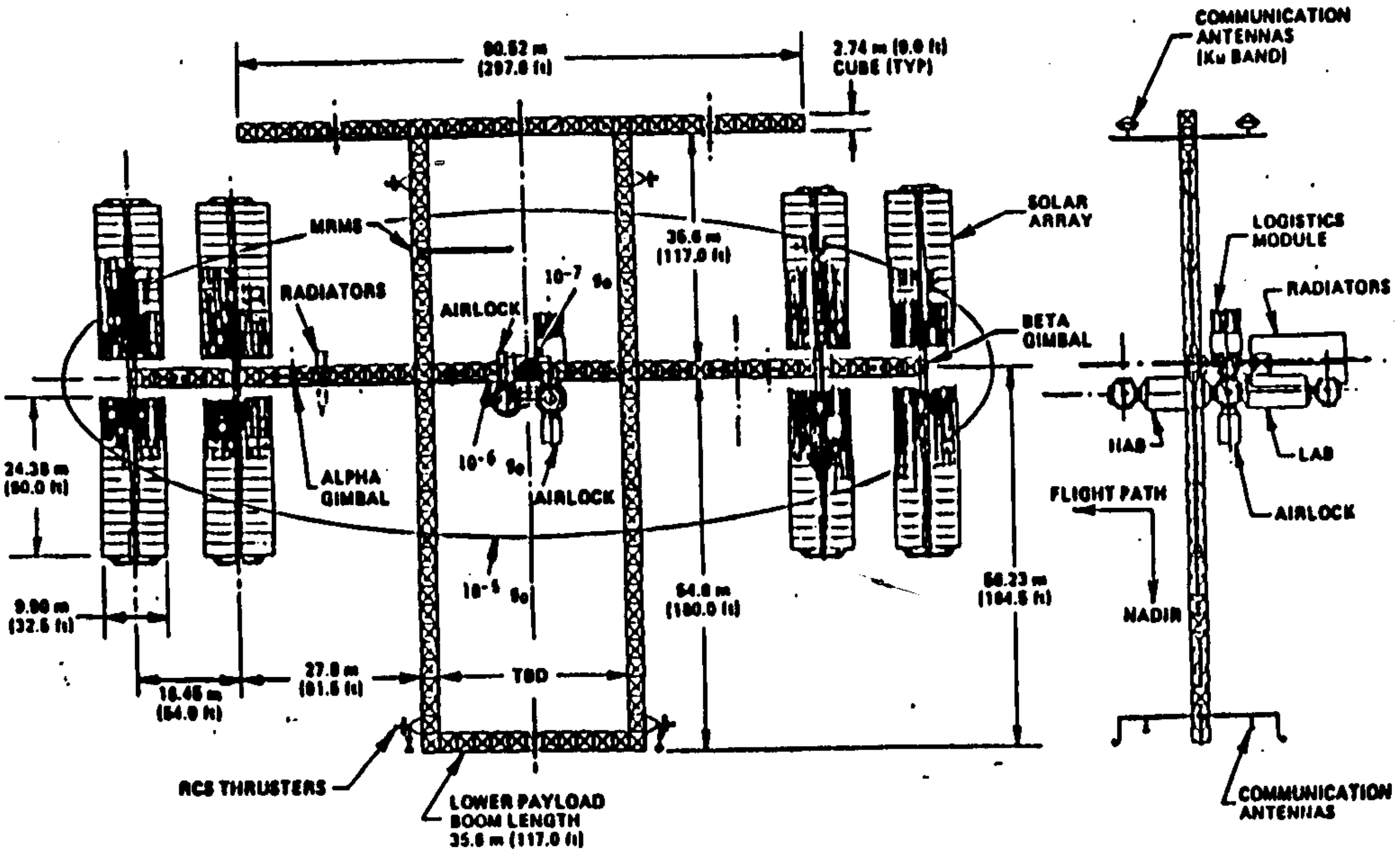
$k_z = 4 \cdot 10^{-7}\, g_o/m$

$k_y = -1.3 \cdot 10^{-7}\, g_o/m$

$k_x = 0$



MANNED CORE SPACE STATION



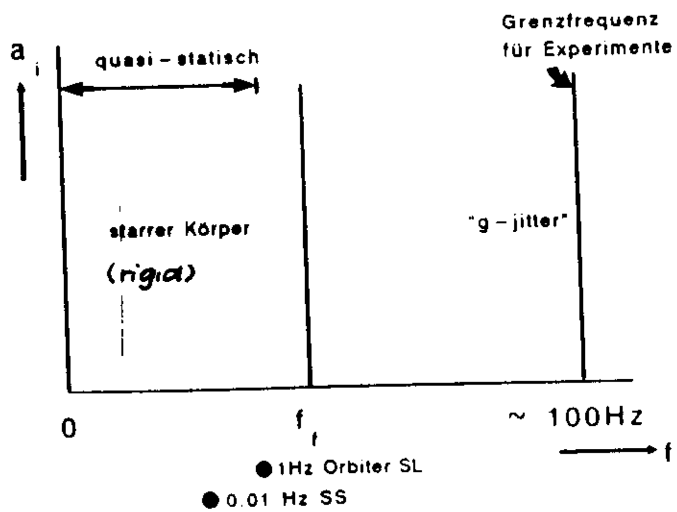
Antwort des Raumfahrzeugs

$$\underline{a}(\underline{r},t) = \sum \left(\underline{a}_{DC} + \underline{a}_{AC} \right)$$

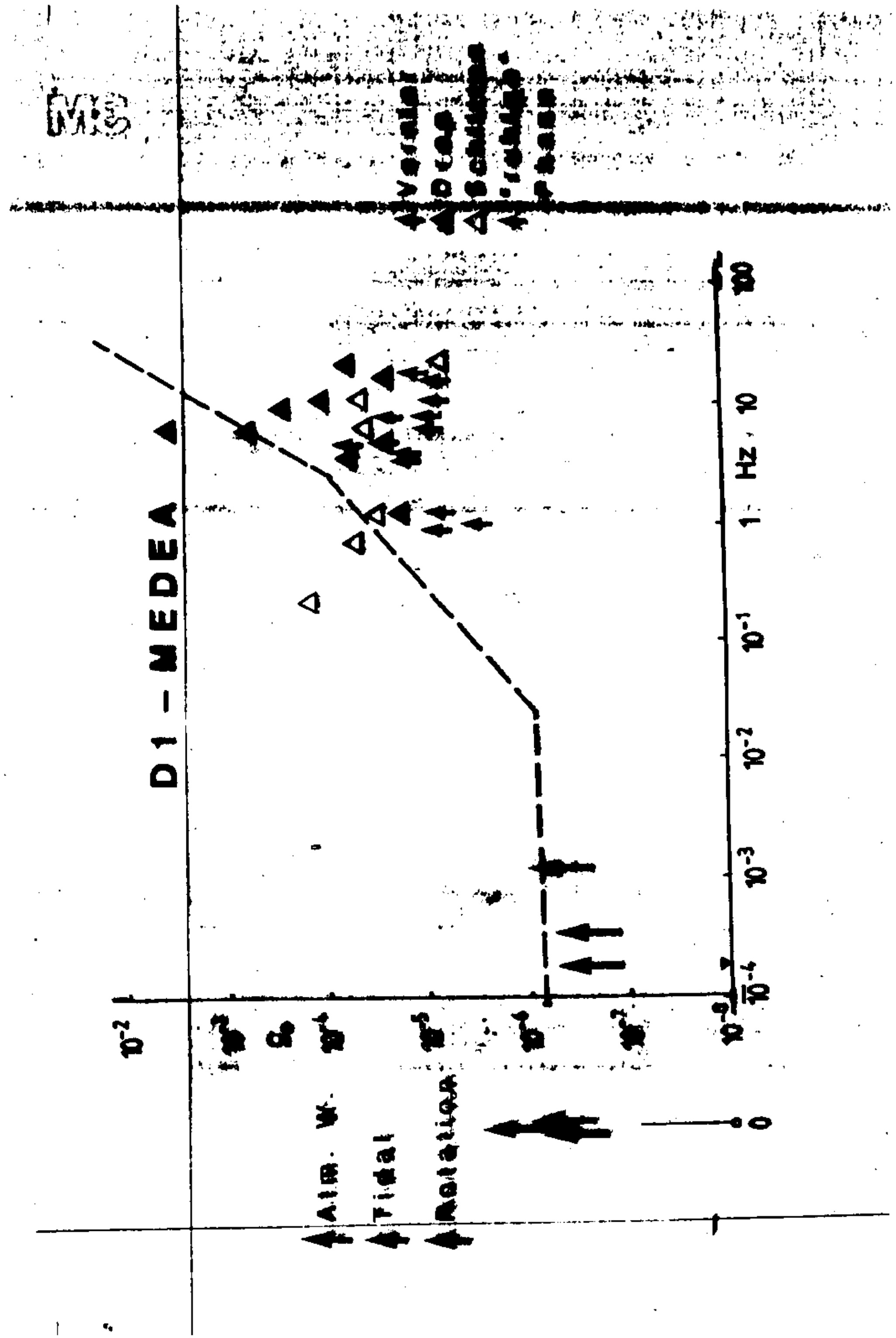
$\underline{a}_{DC}$: quasi-statisch

$\underline{a}_{AC}$: dynamisch

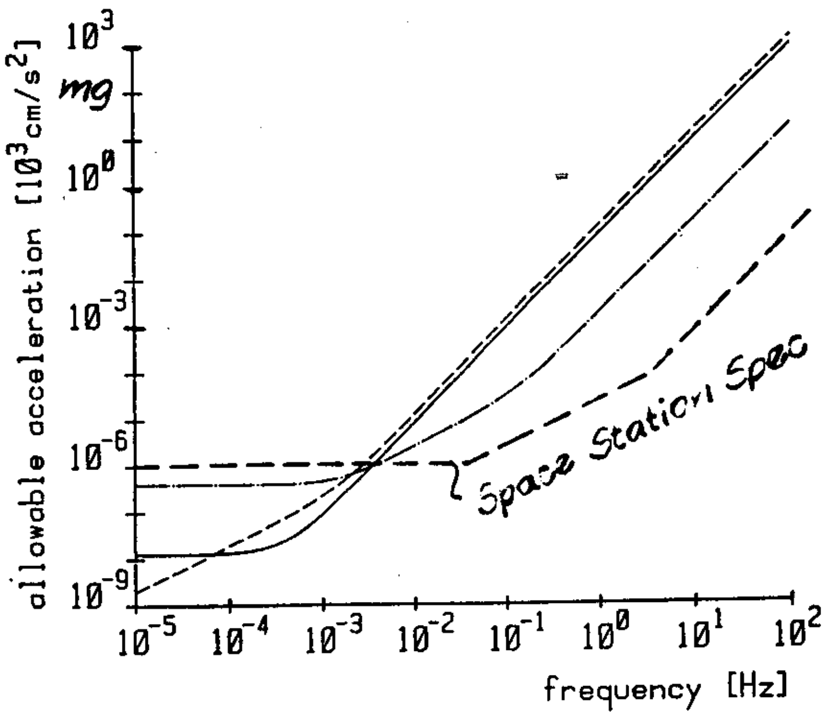
Frequenzspektrum: z.B. $|\underline{a}| = \emptyset(f)$



DFVLR



● TIME VARYING FORCES



The allowable acceleration in
a) a typical fluid physics experiment requiring a temperature gradient ————
b) a crystal growth experiment by the THM method —·—·—
c) an experiment on the Soret effect – – – –

● **PERIODIC**

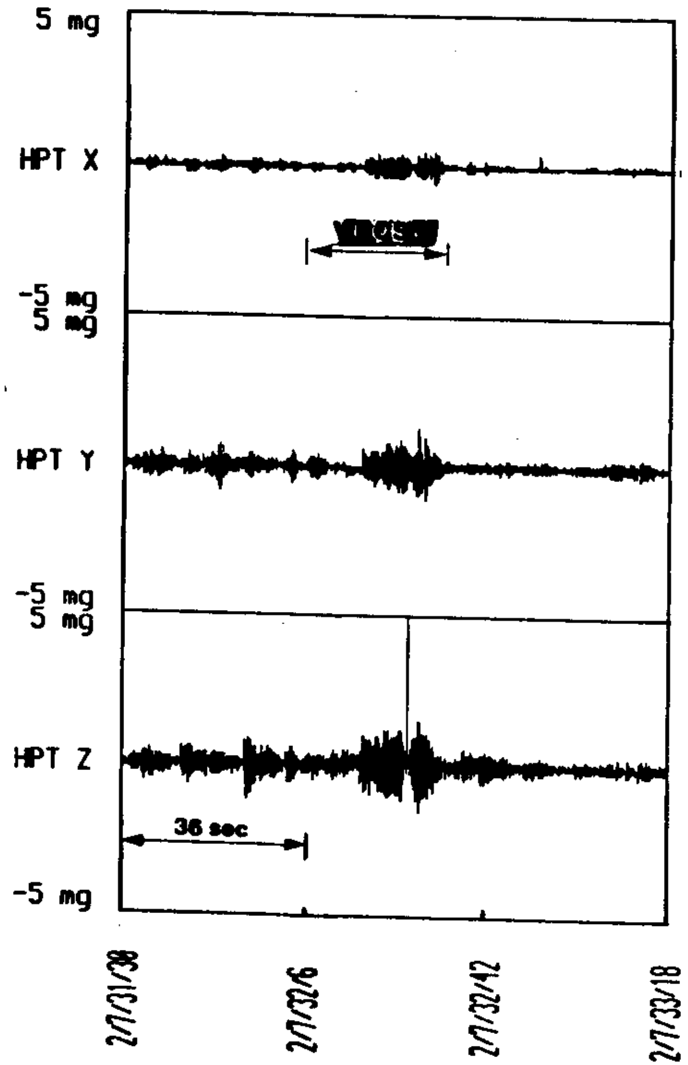
E.G. BY MOTORS
PUMPS
CENTRIFUGES
VESTIBULAR SLED (D1)

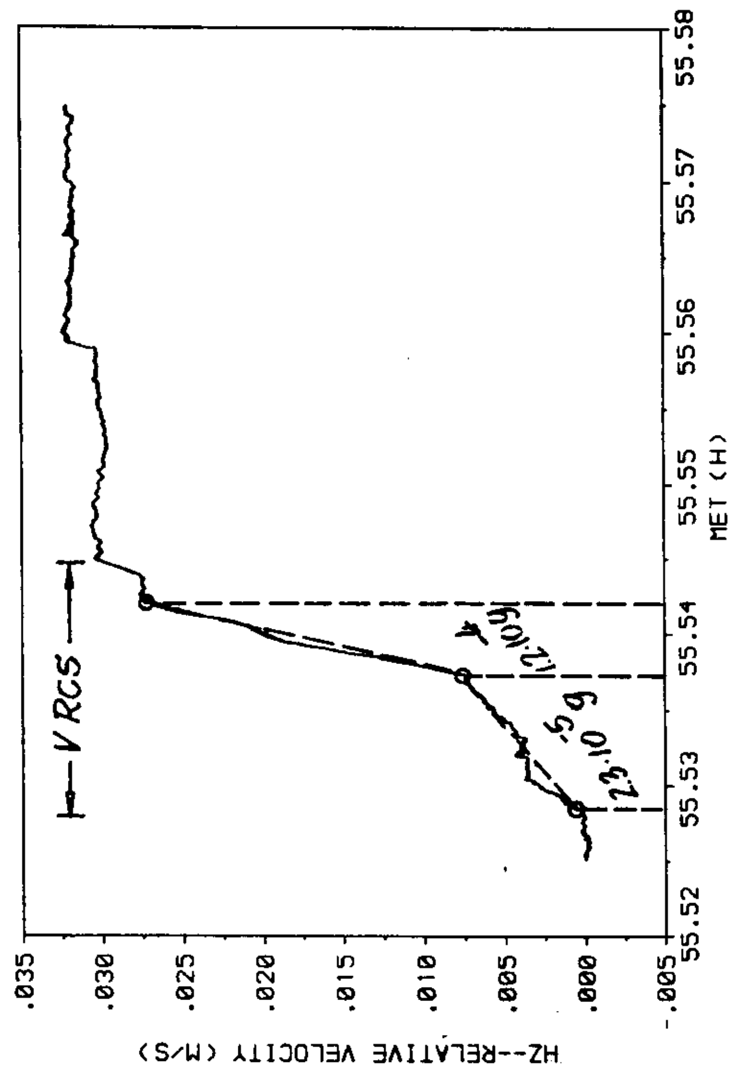
● **TRANSIENT**

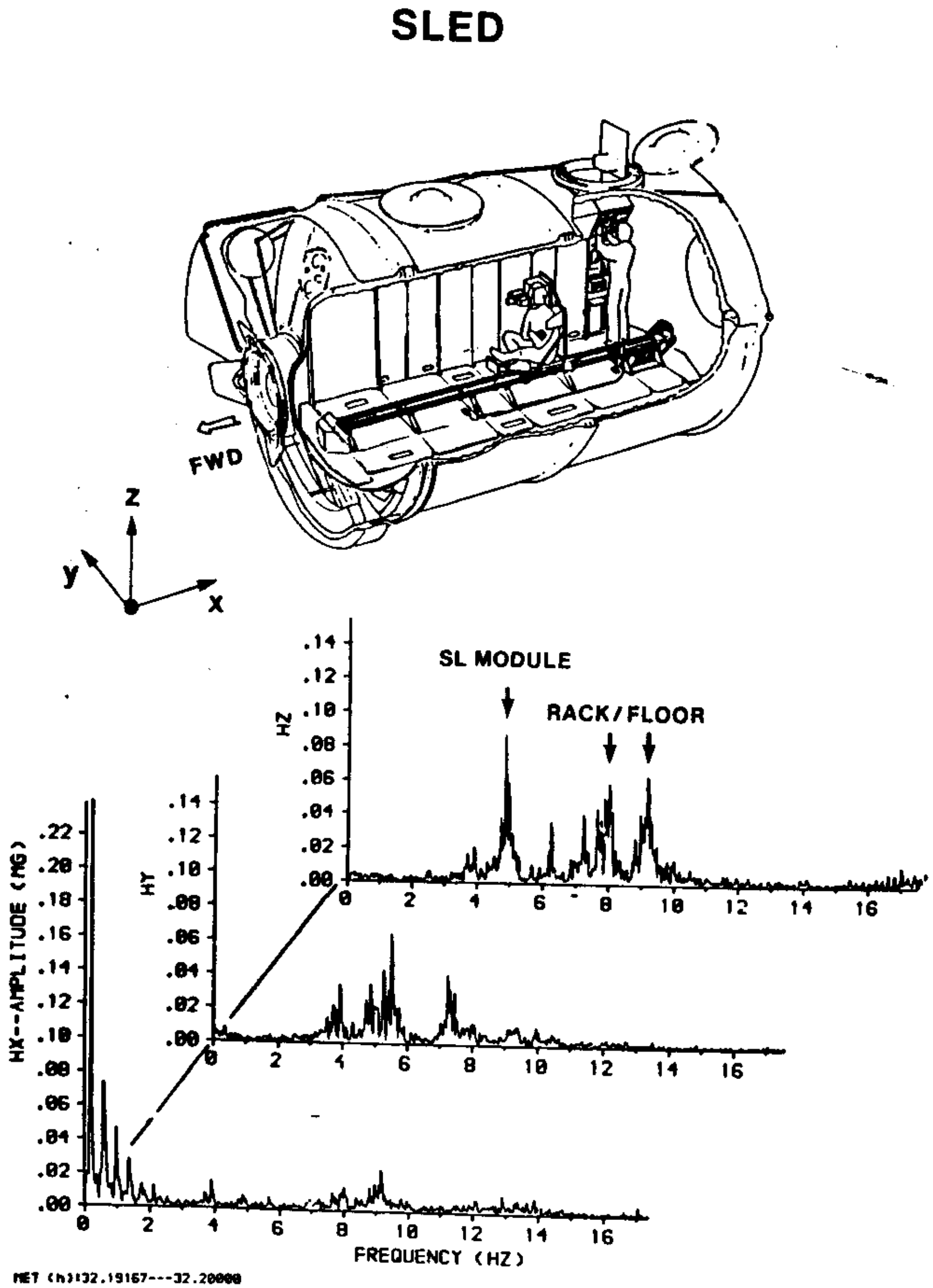
E.G. BY THRUSTERS
VALVES
DOORS
DRAWERS
ASTRONAUTS

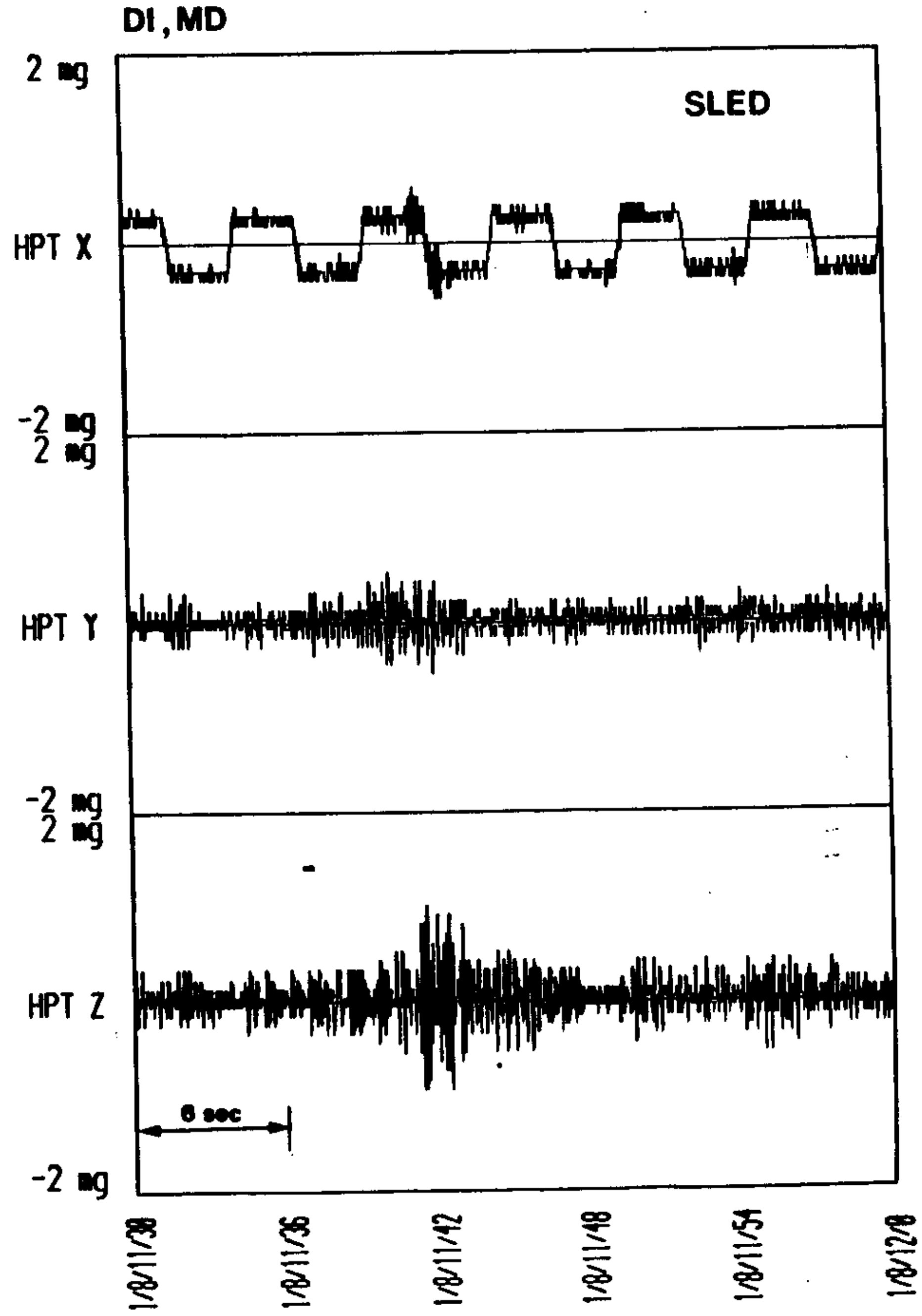
● **STOCHASTIC**

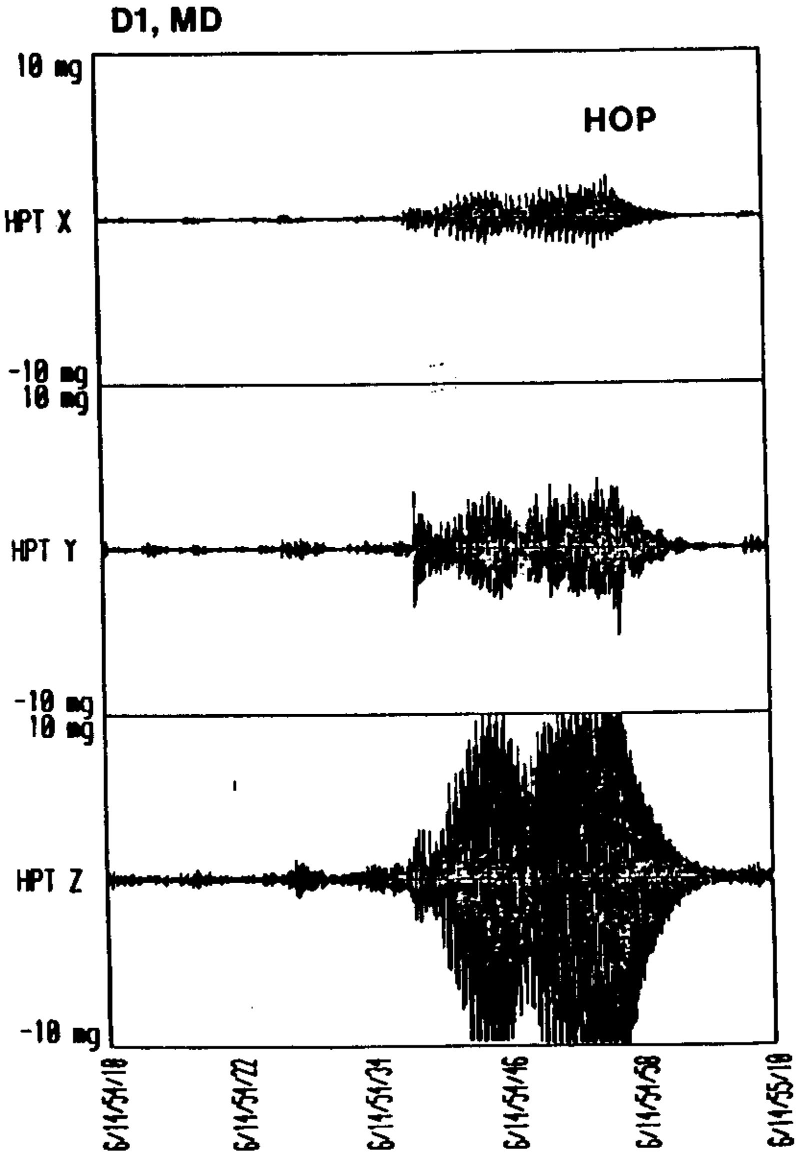
E.G. BY TURBULENT FLOW
CLEARANCE IN BEARINGS, LOCKERS, ETC.

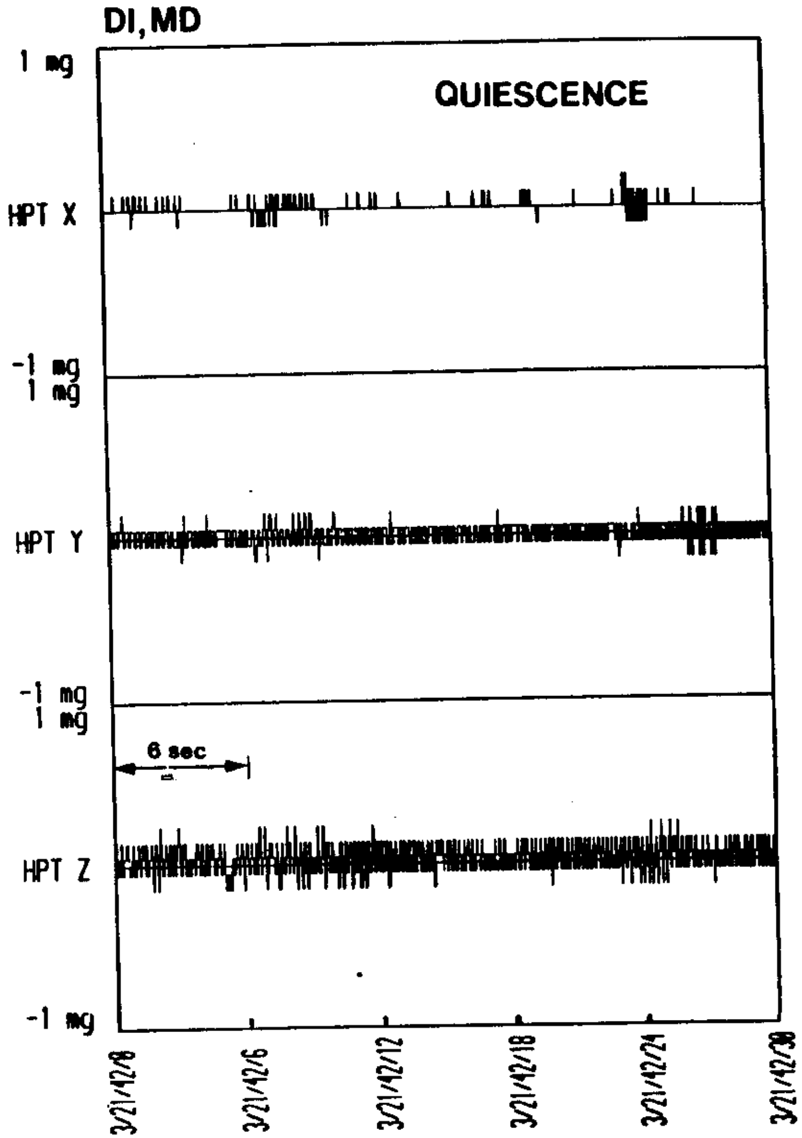

5 mg
HPT X
-5 mg
5 mg
HPT Y
-5 mg
5 mg
HPT Z
36 sec
-5 mg
2/7/31/38
2/7/32/6
2/7/32/42
2/7/33/18

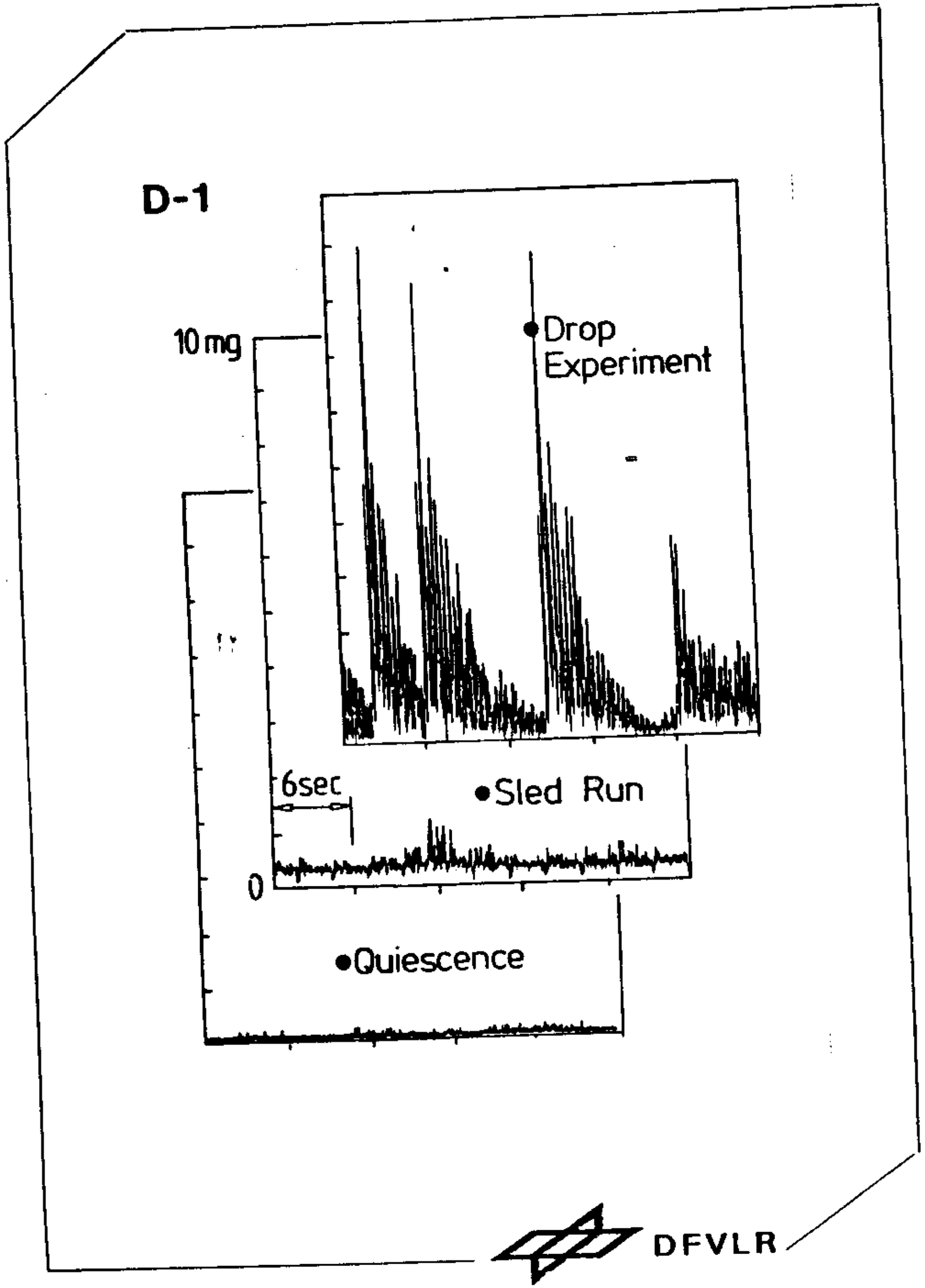

V RCS
55.52
55.53
55.54
55.55
55.56
55.57
55.58
MET (H)
.035
.030
.025
.020
.015
.010
.005
.000
-.005
HZ--RELATIVE VELOCITY (M/S)

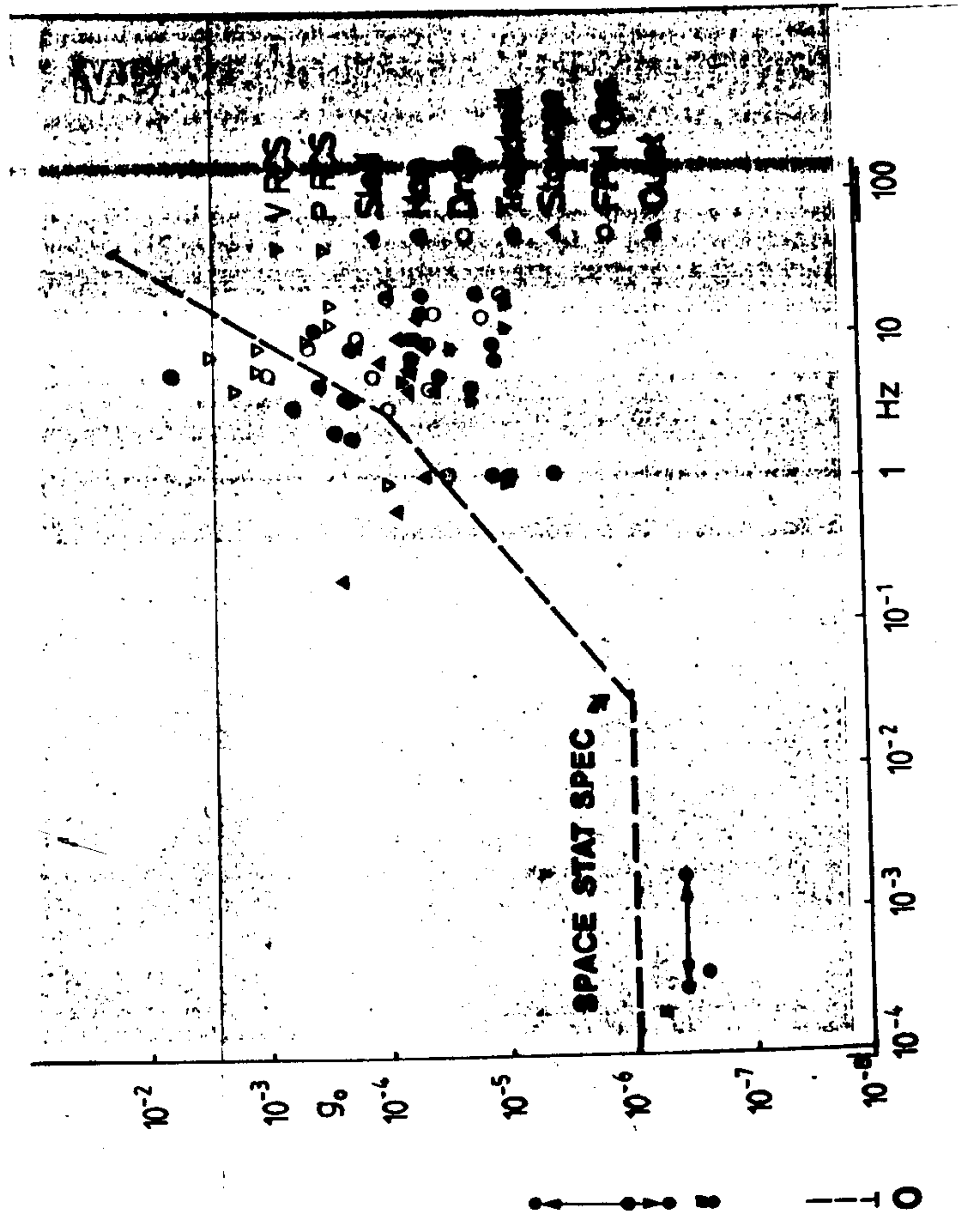

SLED
FWD
z
y
x
SL MODULE
RACK/FLOOR
HZ
HY
HX--AMPLITUDE (MG)
FREQUENCY (HZ)
MET (h):32.19167---32.20000


DI,MD
SLED
2 mg
HPT X
-2 mg
2 mg
HPT Y
-2 mg
2 mg
HPT Z
6 sec
-2 mg
1/8/11/30
1/8/11/36
1/8/11/42
1/8/11/48
1/8/11/54
1/8/12/0


D1, MD
HOP
10 mg
HPT X
-10 mg
10 mg
HPT Y
-10 mg
10 mg
HPT Z
-10 mg
6/14/54/10
6/14/54/22
6/14/54/34
6/14/54/46
6/14/54/58
6/14/55/10


DI, MD
QUIESCENCE
1 mg
HPT X
-1 mg
1 mg
HPT Y
-1 mg
1 mg
6 sec
HPT Z
-1 mg
3/21/42/0
3/21/42/6
3/21/42/12
3/21/42/18
3/21/42/24
3/21/42/30


D-1
10 mg
0
6sec
Drop
Experiment
Sled Run
Quiescence
DFVLR


SPACE STAT SPEC
Hz
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
100
10^{-2}
10^{-3}
g_o
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
VRCS
PRCS
Sled
Drop