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LIQUID OSCILLATIONS AND DAMPING IN A ZERO GRAVITY ENVIRONMENT

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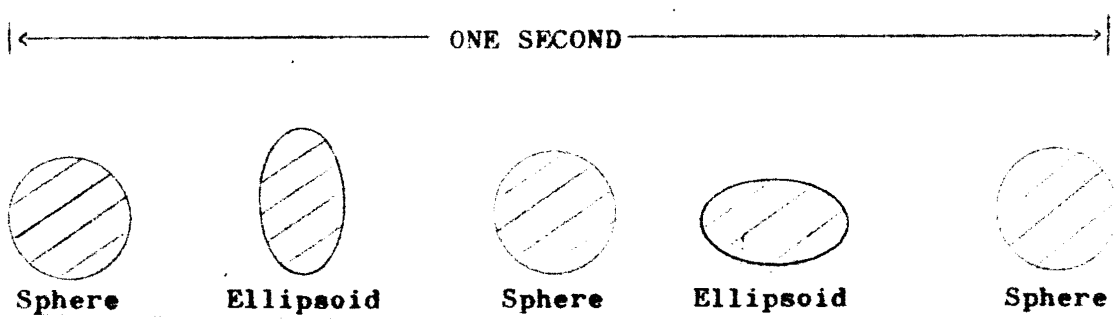
SUBJ: Liquid Oscillations and Damping

INTRODUCTION:

During the Centaur Zero-G flights in a KC-135 airplane early in 1961 it was observed that LN_2 often escaped from a cold trap on the LH_2 storage dewar. Most of the time the drops that formed (usually a jet would hit the ceiling and split up) were small, and they oscillated very rapidly and stabilized quickly to perfect spheres as they floated around in the cabin.

Once in awhile a bigger drop would form by chance without hitting the ceiling and could be observed in free floating condition somewhat better. It would have a rapidly fluctuating wrinkly appearance at first but would soon smooth out some and oscillate in a more regular way.

It was estimated on one occasion that a drop of approximately one inch diameter made a complete oscillation in the basic mode in roughly one second.



It was thought that those observations could be used for establishment of approximate scaling laws for liquid behavior.

ANALYSIS:

A preliminary approach using dimensional analysis gave the following results:

(1) $$T = C_1 \sqrt{f D^3}$$

and

(2) $$\tau = C_2 \phi D^2$$

Where:

C_1, C_2 = arbitrary constants

D = diameter of the drop

f = "Flexibility" of the liquid

= density (ρ)/surface tension (σ)

ϕ = "Fluidity" of the liquid

= density (ρ)/viscosity (μ)

T = period of oscillation

τ = time required to damp to a certain fraction of the amplitude of oscillation.

Figure 1 is a graph of these scaling equations.

ANALYSIS: (CONTINUED)

A bit of library research uncovered corroboration for the dimensional analysis in Sir Horace Lamb's "Hydrodynamics" — first published in 1879. Sections 275 and 355 of that work present analyses of and equations for the motion of oscillating fluid globules. The relations are shown below.

$$(3) \quad T = \pi \sqrt{\frac{(n+1) f_g + n f_s}{2n(n+1)(n-1)(n+2)} D^3}$$

Where, in addition to the previously defined variables, n = the harmonic order of the oscillation. ($n = 2$, for the simplest vibratory mode)

$$f_g = \rho_g / \sigma$$

$$f_s = \rho_s / \sigma$$

ρ_g = density of fluid in the globule

ρ_s = density of fluid surrounding the globule

σ = surface tension of the globule/surround interface.

Also, for a globule (surrounded by a fluid of negligible ρ and μ).

$$(4) \quad \tau = \frac{1}{4(n-1)(2n+1)} \phi_g D^2$$

And, for a bubble (filled with a fluid of negligible ρ and μ)

$$(5) \quad \tau = \frac{1}{4(n+2)(2n+1)} \phi_s D^2$$

Where τ is now elevated to the status of "Modulus of Decay", which is the time in which the amplitude of oscillation sinks to $1/e$ of its original value.

ANALYSIS: (CONTINUED)

For $\eta = 2$ the above equations readily reduce to:

$$(6) \quad \left.\begin{aligned} T &= \frac{\pi}{4}\sqrt{f D^3} \\ T &= \frac{1}{20}\phi D^2 \end{aligned}\right\} \quad \text{for a globule}$$

and,

$$(7) \quad \left.\begin{aligned} T &= \frac{\pi}{\sqrt{24}}\sqrt{f D^3} \\ T &= \frac{1}{80}\phi D^2 \end{aligned}\right\} \quad \text{for a bubble}$$

CONCLUSION:

The simple vibrating systems described by the above equations bear little direct relation to the complex shapes and surfaces which are usually seen in zero gravity, or to those which will probably exist in the Centaur fuel tank. The simple systems do, however, have the feature in common with the complex ones that their response to a disturbance is controlled by ρ, μ, and σ. The analytical expressions corroborate, for the simple system, the dimensional analysis which should also apply to the complex systems; the one data point lies remarkably close to the proper LN_2 line, and it appears therefore that the dimensional scaling laws presented here are very nearly the truth.

Certain liquid data is shown in Table "A", and equations (6) and (7) are graphed in Figure 2.

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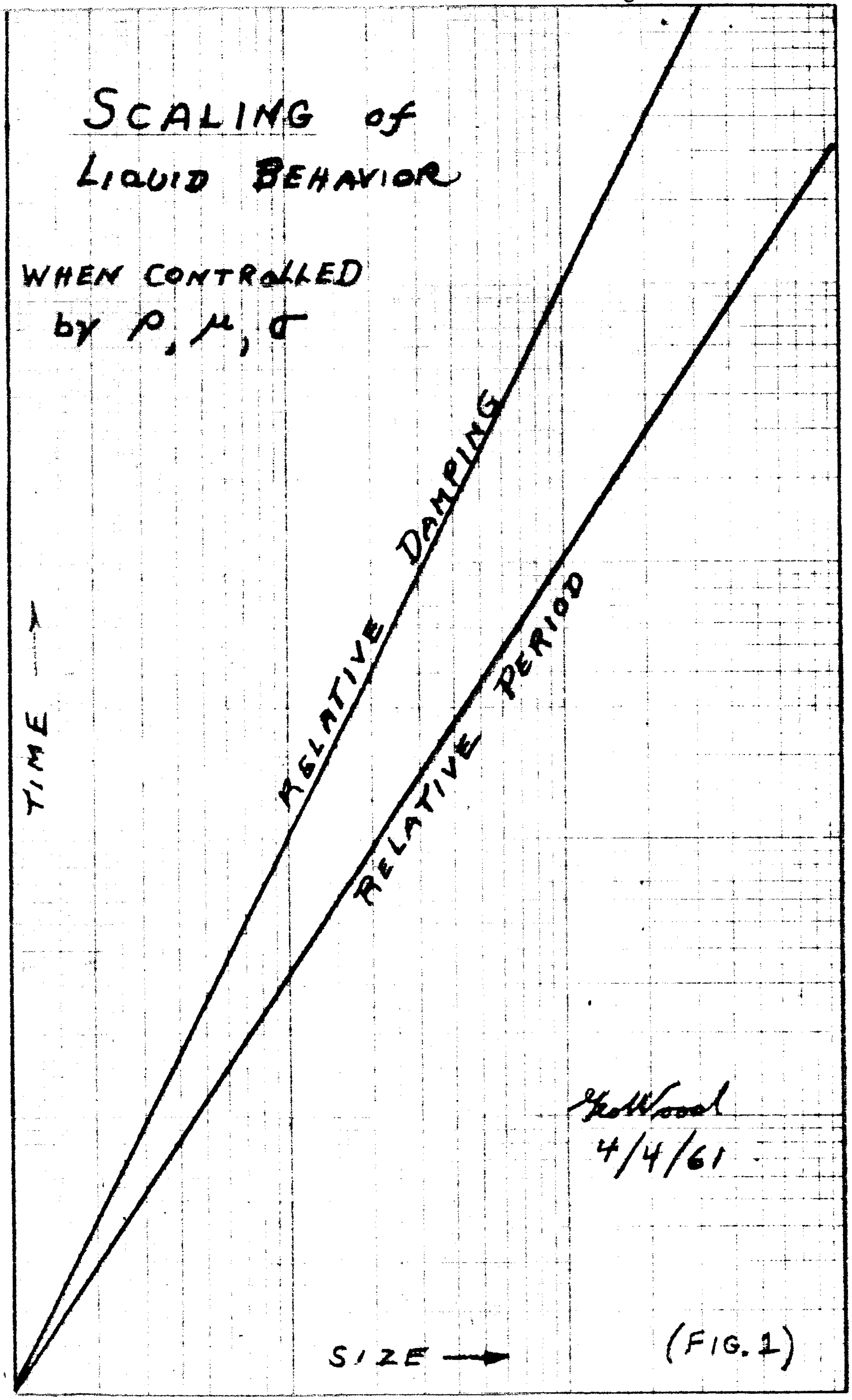
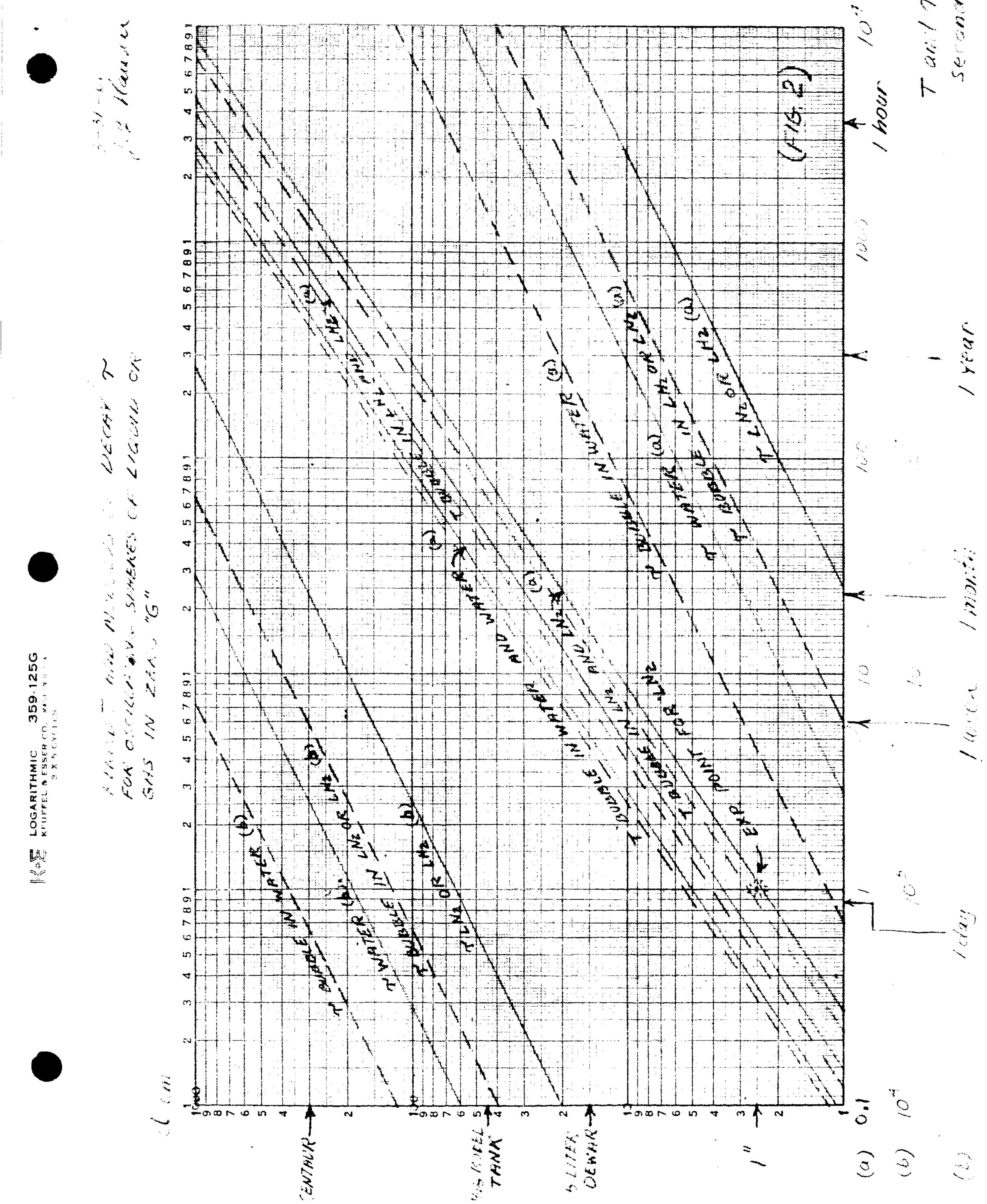
TABLE "A"

Fluid (Liquid)	ρ (g/cm^3)	σ (dy/cm)	μ $\left(\frac{dy\ sec.}{cm^2}\right)$	f $\left(\frac{sec^2}{cm^3}\right)$	ϕ $\left(\frac{sec}{cm^2}\right)$
H_2O	1	73.0	.0178	.0137	56.2
LN_2	.81	6.6	.0016	.123	506
LH_2	.070	2.0	.000135	.035	518
Freon TF $(CCl_2F-CClF_2)$	1.57	19.0	.00694	.083	226


SCALING of
LIQUID BEHAVIOR
WHEN CONTROLLED
by ρ, μ, σ
RELATIVE DAMPING
RELATIVE PERIOD
TIME →
SIZE →
G. W. Wood
4/4/61

(FIG. 1)


LOGARITHMIC 359-125G
KEUFFEL & ESSER CO.
3 X 5 CYCLES
FOR OSCILLATIONS OF SPHERES OF LIQUID OR
GAS IN ZERO "G"
DECAY τ
(FIG. 2)
T and τ
Seconds
1 hour
1 year
1 month
1 week
1 day
CENTAUR
5 LITER DEWAR
TANK
1"
τ BUBBLE IN WATER
τ WATER (b) IN LN2 OR LH2
τ BUBBLE IN LN2 OR LH2
τ BUBBLE IN WATER AND LN2
τ WATER IN LN2 OR LH2
τ BUBBLE IN LN2 OR LH2
EXP POINT
τ BUBBLE FOR LN2

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