

UNCLASSIFIED

AD 265 282

*Reproduced
by the*

**ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA**



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

**Best
Available
Copy**

265282

C. NO. 8-2879
PY NO. 2

①



AD No. _____
ASTIA FILE COPY

FC



XEROX
63-7-1

ASTIA
OCT 5 1961
TIFDR A

TECHNICAL LIBRARY
AIR FORCE BALLISTIC MISSILE DIVISION
HQ. ARDC
U.S.A.F.

1.10

8-2879
cy. RR

REG. NO. _____ THE RAMO-WOOLDRIDGE CORPORATION
LOG. NO. 21428
WDSOT _____

LOS ANGELES 45, CALIFORNIA
INTEROFFICE CORRESPONDENCE

GM45.3-327

TO: G. J. Gleghorn CC: those noted DATE: 2 July 1957

SUBJECT: Desirable Experiments on Slosh Damping

FROM: R. R. Berlot
G. Birkhoff
J. W. Miles

APPROVED
Technical Library
HQARDC

Preliminary Remarks

The available evidence indicates that slosh damping is influenced by laminar instability and other phenomena for which no adequate mathematical theory exists. Therefore, further purely theoretical hydrodynamical analysis seems unlikely to lead to accurate predictions.* A purely empirical approach also seems unpromising, because of the many parameters which must be specified. Indeed, existing experimental data cannot be correlated into a rational framework, because they are not accompanied by specifications of wall roughness, etc. Because of this fact, and because of the absence of full-scale data, there is no reliable information on which to base the design and evaluation of damping elements.

is
In general, the most promising line of attack ~~seems to us~~ to measure accurately the ratio Δ/Δ_{th} of actual to predicted logarithmic decrements (or their equivalents), under carefully controlled laboratory conditions. The hope is that observed values of this "variable constant" will vary gradually and according to recognizable trends. ~~In each case, a plausible Δ_{th} must be supplied by "theoretical" reasoning.~~

* Judicious adaptations of laminar flow models to new geometries may, however, give useful results. Also, a theoretical explanation of the build-up of circular waves from linear oscillations would be desirable.

** Theodore von Karman has defined engineering as, "the science of using variable constants". A reasonable goal should be to reduce our uncertainty from a factor of 3 to one of, say, 1.5.

Approaches to the problem of slosh damping are examined.

Spaced Baffles

Because of the prevailing belief that slosh control without baffles is inadequate, first priority should probably be given to experiments involving baffle arrangements simulating existing designs. In correlating such experiments, it seems reasonable to choose Δ_{th} as the damping predicted by Keulegan's excellent experimental data for the drag of a single plate in a sinusoidal current.*

For example, the effect of baffle spacing and the rounding of the baffle edge might be studied - also, that of roughening and perforating the baffle. The data obtained should be compared with existing formulae in books on hydraulics (e.g., on head loss through a perforated plate). To optimize such comparisons, close contact should be maintained continuously with specialists in hydrodynamics.

Scale Effects

Keulegan's data indicates that the baffle damping is not sensitive to changes in $Re = U_{max} D/\nu$, above $Re = 1,000$. (Here D is twice the baffle width, and U_{max} the maximum fluid oscillation velocity in the neighborhood of the baffle). Hence, full-scale experiments on baffle damping do not seem urgent, especially for large amplitude oscillations.

However, the effect of tank radius R on Δ/Δ_{th} may be large, for slosh damping without baffles. In this case, it seems reasonable to take Δ_{th} as the Stokes wall damping calculated by various persons at Ramo-Wooldridge. A change in R then increases Δ_{th} by a factor proportional to $R^{-3/4}$. However, full turbulent ** damping is effectively inertial in steady flow, which suggests that non-linear damping might well occur in full-scale sloshing. The effect on Δ/Δ_{th} might involve a factor as much as 5.

* See GM45.3-246 and GM61.4-9.

** As shown in GM-TN-12, similarity applies to turbulence and other instability effects, provided the relative wall roughness and slosh amplitude are preserved.

Amplitude Effects

In general, we may write

$$\Delta/\Delta_{th} = f(B, a, N, \dots), \quad (1)$$

where $B = \sqrt{gR^3/2}$, a is the relative amplitude, N the relative roughness, etc. In the laminar flow model without baffles, $\Delta_{th} = \Delta_{th}(B)$ for a given shape (e.g., for a given h/R with cylinders).

It is plausible that, as $a \rightarrow 0$, $\Delta/\Delta_{th} \rightarrow 1$; this has in fact been asserted. However, it must be confessed that this conjecture is not fully supported by experimental evidence.

Again, Keulegan's results suggest that, with baffles, Δ_{th} is proportional to \sqrt{a} . Rough checks of such dimensional dependence formulas would seem valuable for stability studies.

Roughness Effects, etc.

An attempt to correlate Δ/Δ_{th} with wall roughness should probably be made. Though accurate data are hard to come by (to judge by analogy with pipe friction), it should be checked whether (for example) coarse sandpaper doubles Δ/Δ_{th} .

Similarly, it should be checked whether surface roughness materially influences baffle damping; we doubt it.

Especially with small models, it would also be interesting to see whether surface tension or surface films affected Δ appreciably. Various writers have mentioned this possibility.

Hydroelastic Effects

Previous experiments have involved non-rigid (plastic) tanks and mountings. It may be that their flexure has led to additional damping; we recall that Jacobsen's measured Δ was about twice that measured here, under the same nominal conditions.

An experimental study of hydroplastic effects might clear up this question; it should be correlated with theoretical work on hydroelastic effects, which has been under-

taken here for other reasons*.

Design Specifications

If, at any time, guidance and control studies should have progressed to a point where damping requirements can be approximately specified, then experiments can be correspondingly directed to the most efficient achievement of these specifications. Because of the dependence of damping on amplitude, these specifications should be accompanied by statistical specification of probable variations in acceleration and attitude.

Similar remarks apply to strength requirements, which might affect the design of stiffening rings.

* GM61.4-11, GM-TR-87.

RRB }
GB } glc
JWM }

Distribution

M. V. Barton	106/5
R. R. Bennett/2	
J. R. Burnett	
C. Clauser	
A. F. Donevan	118/5
F. G. Ehler	
L. E. Freed	
P. E. Hakala	212/1
J. V. Howell	328/3
F. H. Kaufman	
D. C. Martin	
R. K. Whitford	
E. T. Wiggins	
C. J. Wang	740/5

31A
Vernon (Berlot)
TORONTO

R. R. Berlot
R. R. Berlot

R. R. Berlot for
H. Berlot
G. Berlot

J. W. Miles
J. W. Miles