

NASA TECHNICAL  
MEMORANDUM

NASA TM X-53559

December 22, 1966

NASA TM X-53559

FACILITY FORM 602

NG 16542

(ACCESSION NUMBER)  
22  
(PAGES)  
TMX-53559  
(NASA CR OR TMX OR AD NUMBER)

(THRU)  
7  
(CODE)  
12  
(CATEGORY)

EFFECT OF REYNOLDS NUMBER ON SLOSH DAMPING  
BY FLAT RING BAFFLES

By Harry Buchanan and Larry Lott  
Aero-Astrodynamics Laboratory

NASA

*George C. Marshall  
Space Flight Center,  
Huntsville, Alabama*

GPO PRICE \$ \_\_\_\_\_

CFSTI PRICE(S) \$ \_\_\_\_\_

Hard copy (HC) 3.00

Microfiche (MF) .65

TECHNICAL MEMORANDUM X-53559

EFFECT OF REYNOLDS NUMBER ON SLOSH DAMPING  
BY FLAT RING BAFFLES

By

Harry Buchanan and Larry Lott

George C. Marshall Space Flight Center

Huntsville, Alabama

ABSTRACT

This paper examines the existing slosh data for flat ring baffles to define the effect of Reynolds number on damping. For this purpose, the drag coefficient of the baffle is presented in terms of Reynolds number. Results show that the drag coefficient increases sharply as the Reynolds number approaches zero. This implies that, for very low Reynolds numbers such as those encountered under low g, slosh damping by ring baffles will be significantly increased.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

---

Technical Memorandum X-53559

---

December 22, 1966

EFFECT OF REYNOLDS NUMBER ON SLOSH DAMPING  
BY FLAT RING BAFFLES

by

Harry Buchanan and Larry Lott

STRUCTURAL DYNAMICS SECTION  
DYNAMICS ANALYSIS BRANCH  
DYNAMICS AND FLIGHT MECHANICS DIVISION  
AERO-ASTRODYNAMICS LABORATORY  
RESEARCH AND DEVELOPMENT OPERATIONS

## DEFINITION OF SYMBOLS

<u>Symbol</u>	<u>Definition</u>
A	tank radius
$C_D$	baffle drag coefficient
d	baffle depth
g	acceleration level
$g_0$	acceleration due to gravity at earth's surface (9.8 m/sec <sup>2</sup> )
h	fluid depth
NDV	normalized damping value
$P_d$	nondimensional period parameter
r	radius
Re	Reynolds number suggested in this paper
Re <sub>Miles</sub>	Reynolds number suggested by Miles
W	baffle width
z	coordinate
$\zeta$	damping ratio
$\zeta_{exp}$	experimental damping ratio
$\eta_w$	maximum wave amplitude at wall
$\mu$	fluid viscosity
$\rho$	fluid density

TECHNICAL MEMORANDUM X-53559

EFFECT OF REYNOLDS NUMBER ON SLOSH DAMPING  
BY FLAT RING BAFFLES

SUMMARY

This paper examines the existing slosh data for flat ring baffles to define the effect of Reynolds number on damping. For this purpose, the drag coefficient of the baffle is presented in terms of Reynolds number. Results show that the drag coefficient increases sharply as the Reynolds number approaches zero. This implies that, for very low Reynolds numbers such as those encountered under low g, slosh damping by ring baffles will be significantly increased.

I. INTRODUCTION

The problem of predicting slosh damping values under low gravity conditions has become one of immediate concern to the designers of space vehicle attitude control systems. Intuitively, one might expect damping to be influenced by Reynolds number, especially in the extremely low Reynolds number range. Since the characteristic velocity is a function of gravity, propellant sloshing under low g is characterized by low Reynolds numbers. This paper defines the effect of Reynolds number upon damping, using currently available data. Once an adequate description of this effect has been obtained, it may be possible to develop from Miles' damping law a satisfactory low g damping law.

II. REVIEW OF PREVIOUS OBSERVATIONS

For ordinary rocket propellants under the influence of large gravity forces, slosh damping has generally been considered to be independent of Reynolds number. This conclusion was reached by a number of early investigators, and subsequently, no systematic review of damping data in terms of Reynolds number was ever conducted. Miles [1] concluded that the flow about baffles in large tanks was likely to be fully turbulent. He based this conclusion on the drag coefficients measured by Keulegan and Carpenter [2] for a flat plate in an oscillating fluid. Their results showed drag coefficient to be relatively independent of Reynolds number in the range  $5 \times 10^3 < Re < 14 \times 10^3$ . However, these

data did appear to be strongly dependent upon a nondimensional period parameter. For flow about ring baffles in cylindrical tanks, Miles developed the following expressions for Reynolds number and period parameters.

$$Re_{\text{Miles}} = 1.10W \left\{ \frac{\sinh [1.84 (\frac{h-d}{A})]}{\sinh (h/A)} \right\} \sqrt{g/A} \frac{\eta_w}{\mu} \rho \quad (1)$$

$$\text{Period Parameter} = \frac{\pi}{W/A} e^{-1.84d/A} (\eta_w/A). \quad (2)$$

In developing his damping equation, Miles ignored the effects of Reynolds number, but he did incorporate an empirical expression for drag coefficient in terms of this period parameter. When the resulting equations were checked against experimental results, they appeared to correlate very well [3]. As a result, this expression has been widely used to predict damping by flat ring baffles. For a single submerged baffle, this expression becomes

$$\zeta = 2.83e^{-4.60(d/a)} [2W/A - (W/A)^2]^{3/2} (\eta_w/A)^{1/2}. \quad (3)$$

Abramson and Ransleben [4] considered the problem of simulating Reynolds numbers using small model tanks and ordinary fluids. They concluded that damping was dependent upon Reynolds number and that Reynolds number must be simulated if tests in small tanks are to produce valid results.

### III. CURRENT INVESTIGATION

To establish the relationship between damping and Reynolds number, a considerable amount of data was reviewed. Figure 1 shows the tank configuration under discussion here. A thin, flat ring baffle is located at sufficient depth to remain submerged at all times (i.e.,  $\eta_w < d$ ). Also, it is assumed for all cases that  $h/A > 1.0$ . Since the previous comparisons had dealt with the drag coefficient

rather than damping, it was decided to represent these data in the same manner. According to Miles, the damping is given by

$$\zeta = \left[ .5e^{-5.52(d/A)} \right] \left[ \frac{\eta_w}{A} (2W/A - W^2/A^2) \right] C_D, \quad (4)$$

or, for our purpose,

$$C_D = \frac{\zeta_{\text{exp}}}{\left[ .5e^{-5.52(d/A)} \right] (W/A) (2 - W/A) \eta_w/A}. \quad (5)$$

Since the period parameter was found to be important in Reference 2, it seemed appropriate to consider it also. All experimental data used in these comparisons were taken from References 3, 5, and 6.

In figure 2, the drag coefficient of the baffle is shown as a function of Reynolds number as given in equation (1). Although the data show some scatter, the overall trend indicates a higher drag coefficient for lower Reynolds numbers. Variation of drag coefficient with period parameter is shown in figure 3. It appears that  $C_D$  increases with a decreasing period parameter. The line indicated in figure 3 represents the empirical expression for  $C_D$  used by Miles. Several other combinations for Reynolds number were considered, one of which is shown in figure 4. For this one, the characteristic length was obtained by dividing the baffle area by the baffle width. The Reynolds number thus produced has the form:

$$Re = .55 \frac{[2WA - W^2]}{W} \left\{ \frac{\sinh \left[ 1.84 \left( \frac{h-d}{A} \right) \right]}{\sinh (h/A)} \right\} \sqrt{g/A} \frac{\eta_w}{\mu} \rho. \quad (6)$$

As indicated in figure 4, this improved considerably the correlation of the various data points. It appears that a peak of some sort occurs at  $Re = 1.5 \times 10^5$ . This region is shown in greater detail in figure 5. The lines shown are faired curves through the data. Notice that using this Reynolds number causes these peaks to line up very well. Figure 6 shows the same information as figure 4, but plotted on a log scale. The drag coefficient seems to remain constant with Reynolds number down to about  $2 \times 10^5$ . After this point, it increases sharply.

It is interesting to compare the data in figures 2, 3, and 4 with the results from reference 2, shown in figures 7 and 8. Figure 7, presenting drag coefficient as a function of period parameter, indicates the same trend as figure 3. Figure 8, showing the drag coefficient as a function of Reynolds number, according to this line of reasoning should be similar to figures 2 and 4. It is not, and the reason for this discrepancy is not obvious. Since the data in figure 8 seem to be dependent on Reynolds number when the plate width,  $W$ , is held constant, some geometric factor may have been ignored.

There is one weakness in the data so far presented. In these tests, no attempt was made to vary Reynolds number while holding the period parameter constant. To establish some means for evaluating the relative importance of these two parameters, another nondimensional quantity, the normalized damping value, was introduced. This was obtained by dividing the experimental damping value by the predicted value from equation (3). Thus,

$$NDV = \frac{\zeta_{exp}}{2.83e^{-4.60(d/A)} [2W/A - (W/A)^2]^{3/2} (\eta_w/A)^{1/2}} \quad (7)$$

Figure 9 shows NDV as a function of the Reynolds number. If Miles' expression for  $C_D$  in terms of period parameter is correct, NDV should be a function of only Reynolds number. The lines shown in figure 9 were obtained from a least squares curve fit of the data and apply in the regions indicated. Increased damping at low Reynolds numbers is at least suggested by these data.

As mentioned previously, low Reynolds numbers seem most likely to occur under low gravity conditions when fluid velocities are very small. Some typical Reynolds numbers for the liquid hydrogen tank of a Saturn S-IVB stage are shown in figure 10. Since the design value of  $g/g_0$  for this vehicle is approximately  $2 \times 10^{-5}$ , it appears to be in the region of very high damping. This is particularly true when the amplitude is very small.

#### IV. CONCLUSIONS

The data reviewed show that the drag coefficient of the baffle increases as Reynolds number decreases and decreases as period parameter increases. If the influence of Reynolds number is insignificant, as suggested by Miles, then baffle damping under low gravity will be



described by the expression used for high gravity. However, if the effect of Reynolds number is really considerable, baffle damping should increase with decreasing gravity level. A conclusion regarding the relative importance of these two effects cannot be reached using the data reviewed, since the two parameters, Reynolds number and period parameter, were not varied independently. Future experimental work is expected to yield this information.

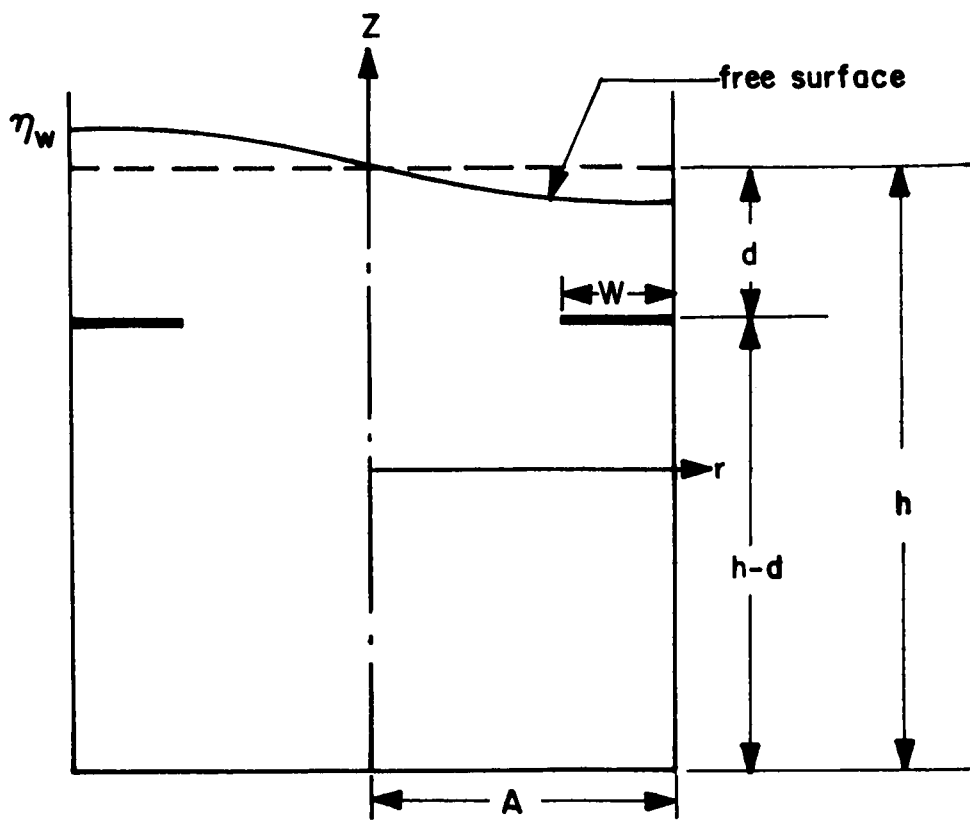


FIGURE 1

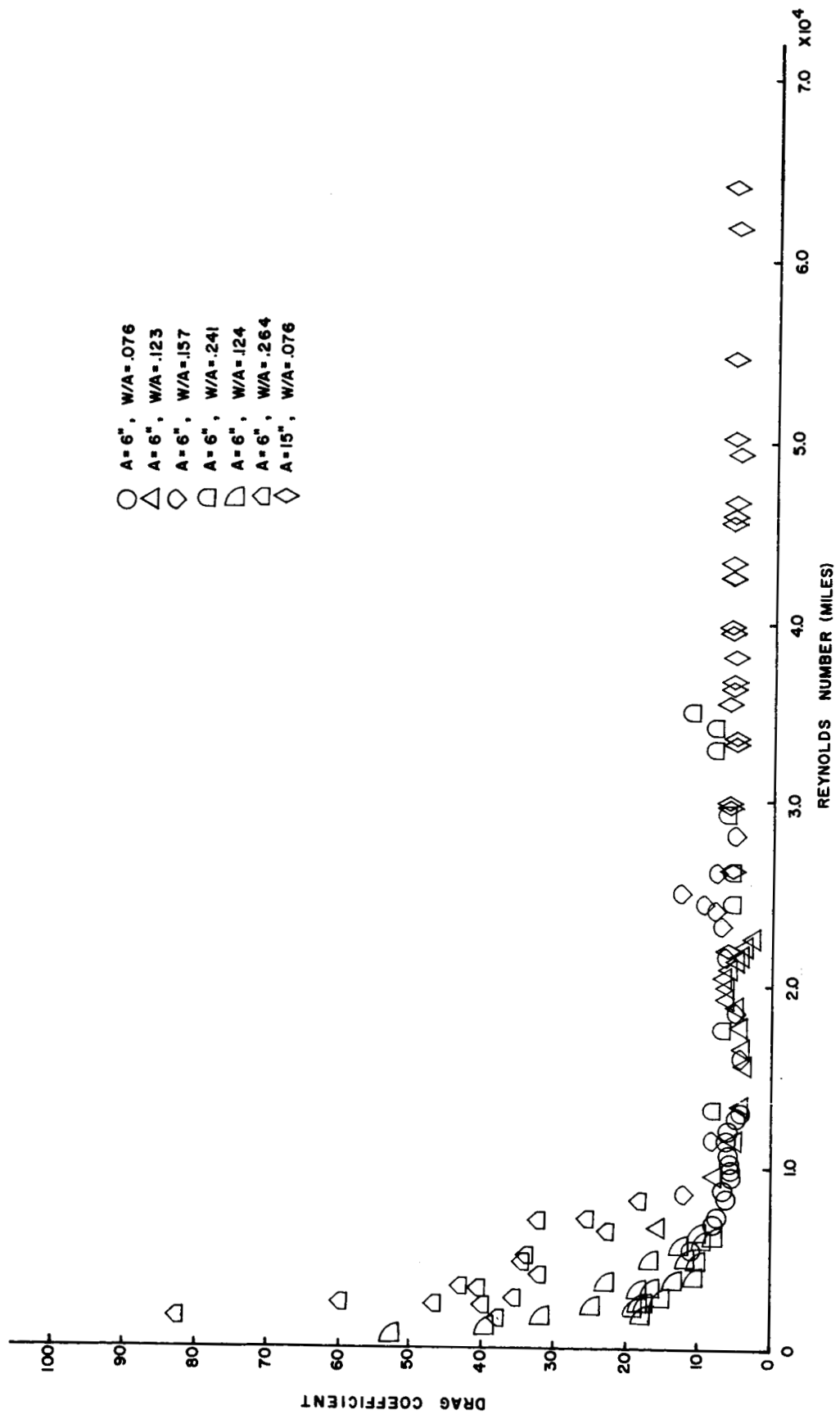


FIGURE 2

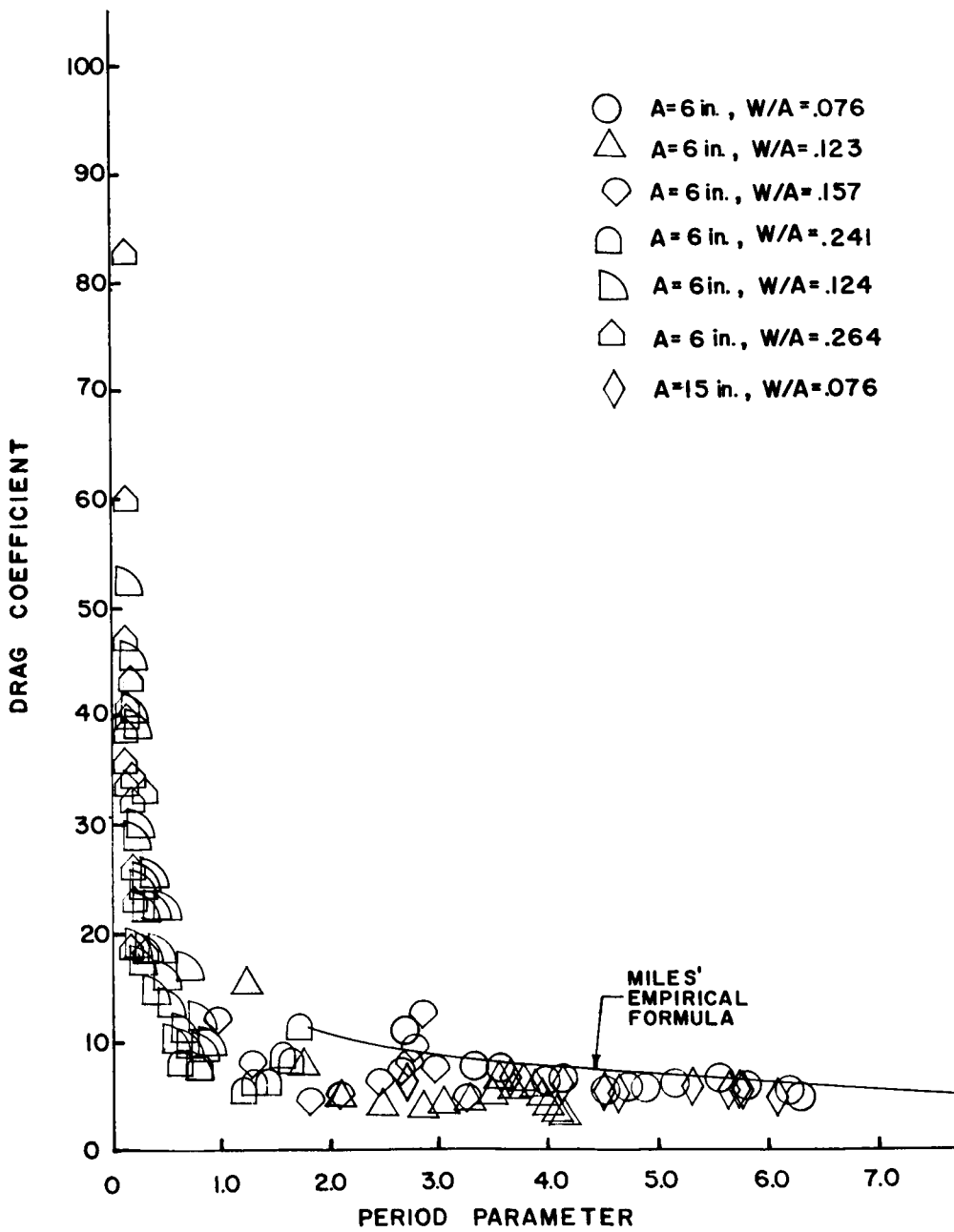


FIGURE 3

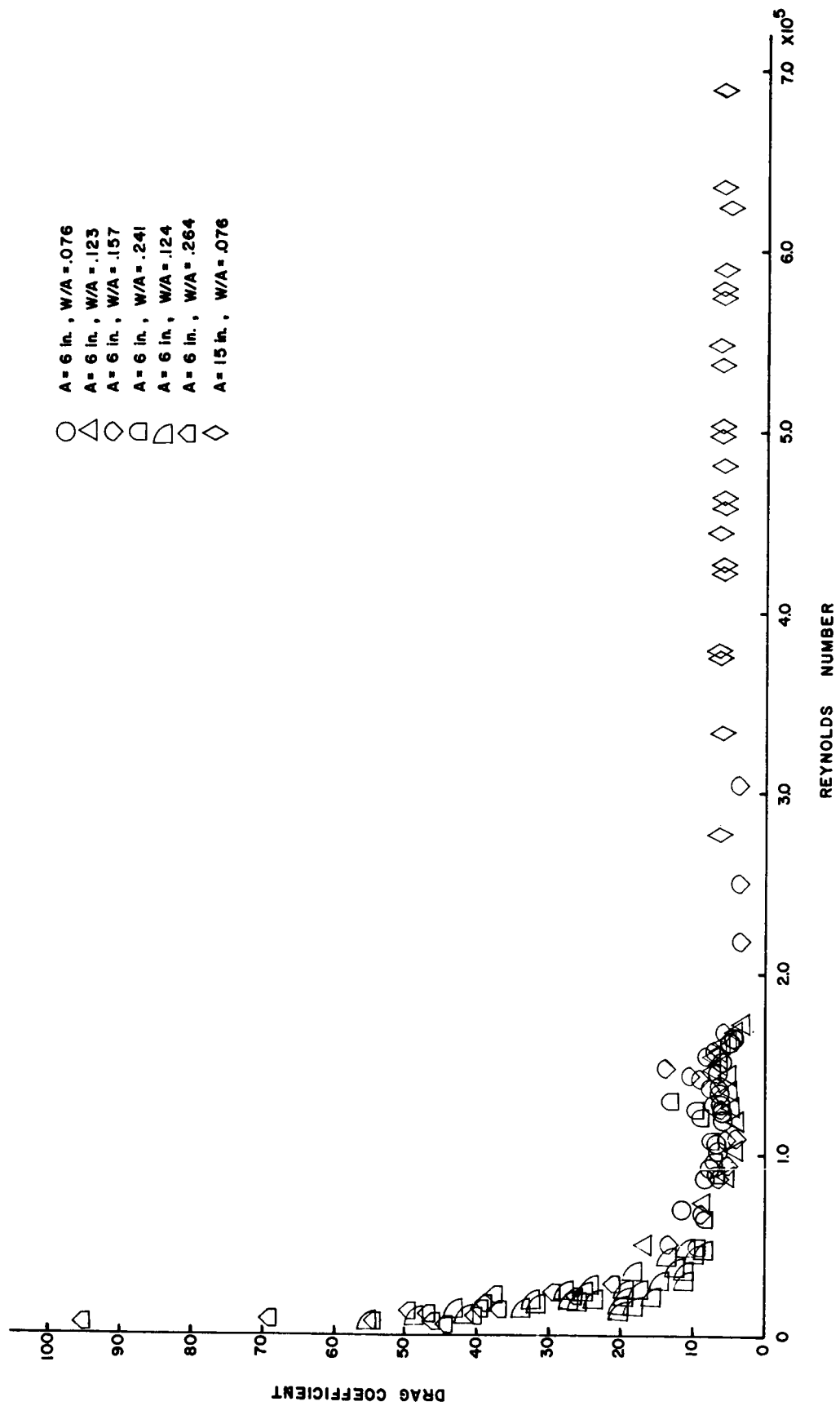


FIGURE 4

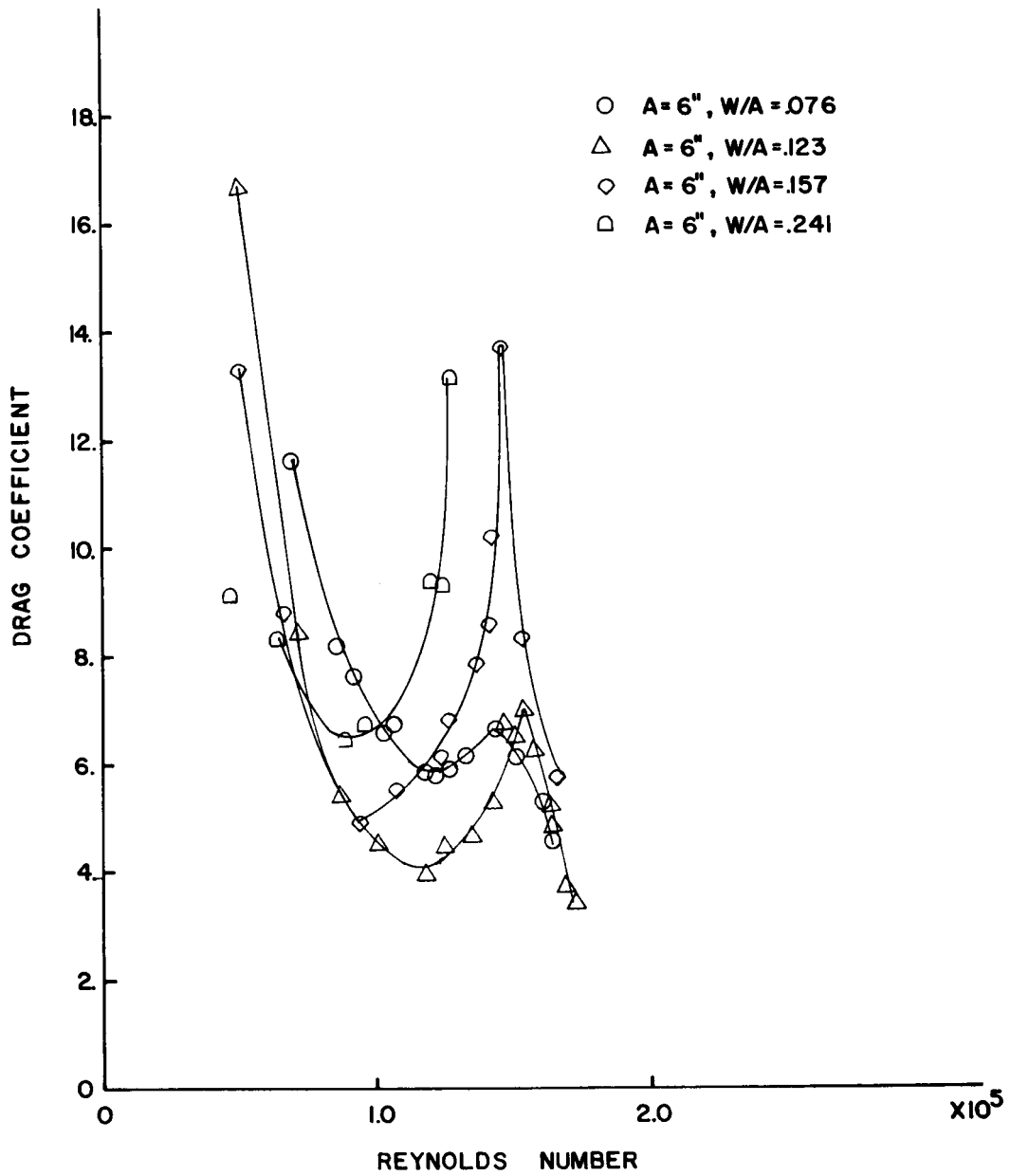


FIGURE 5

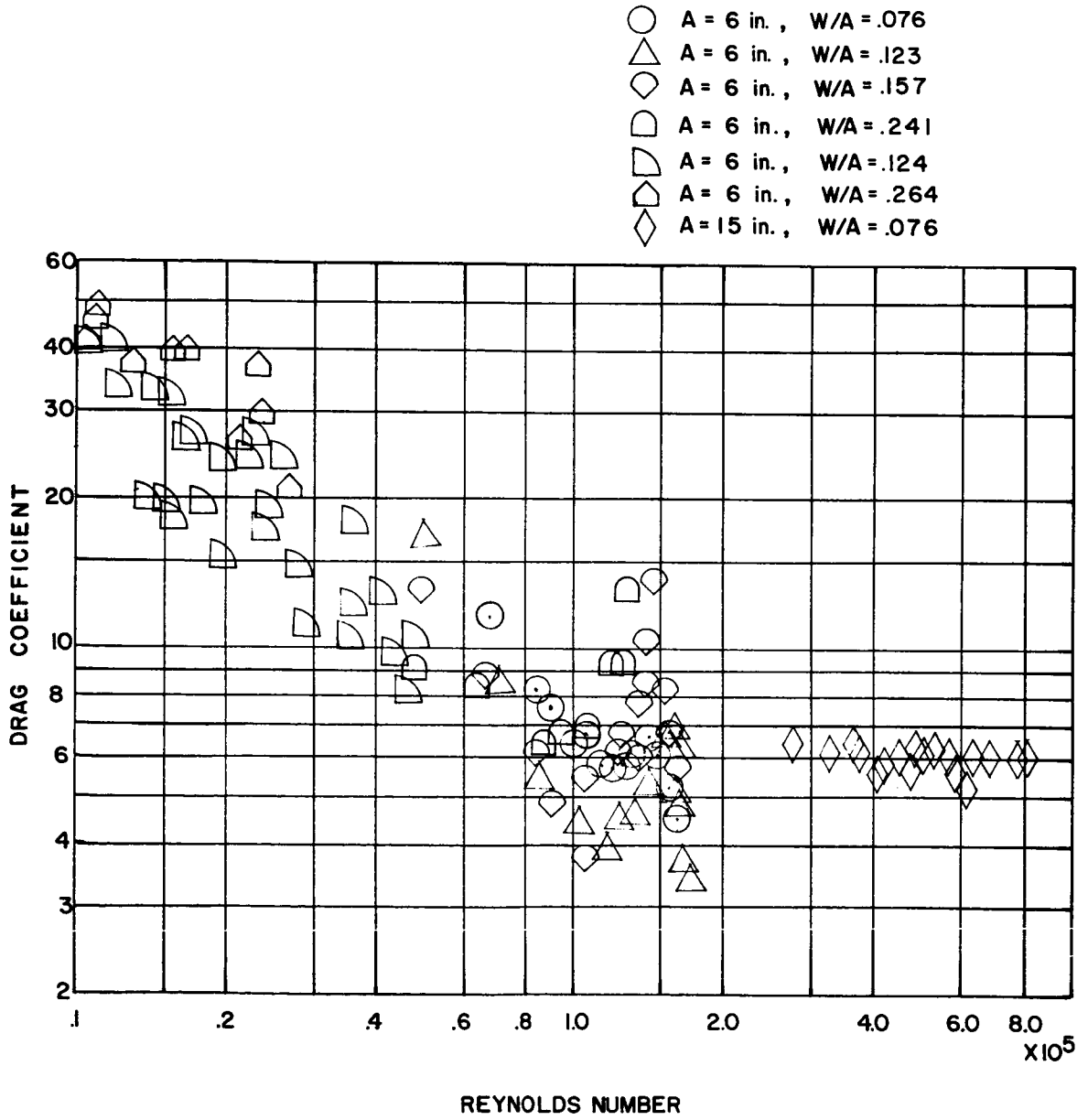


FIGURE 6

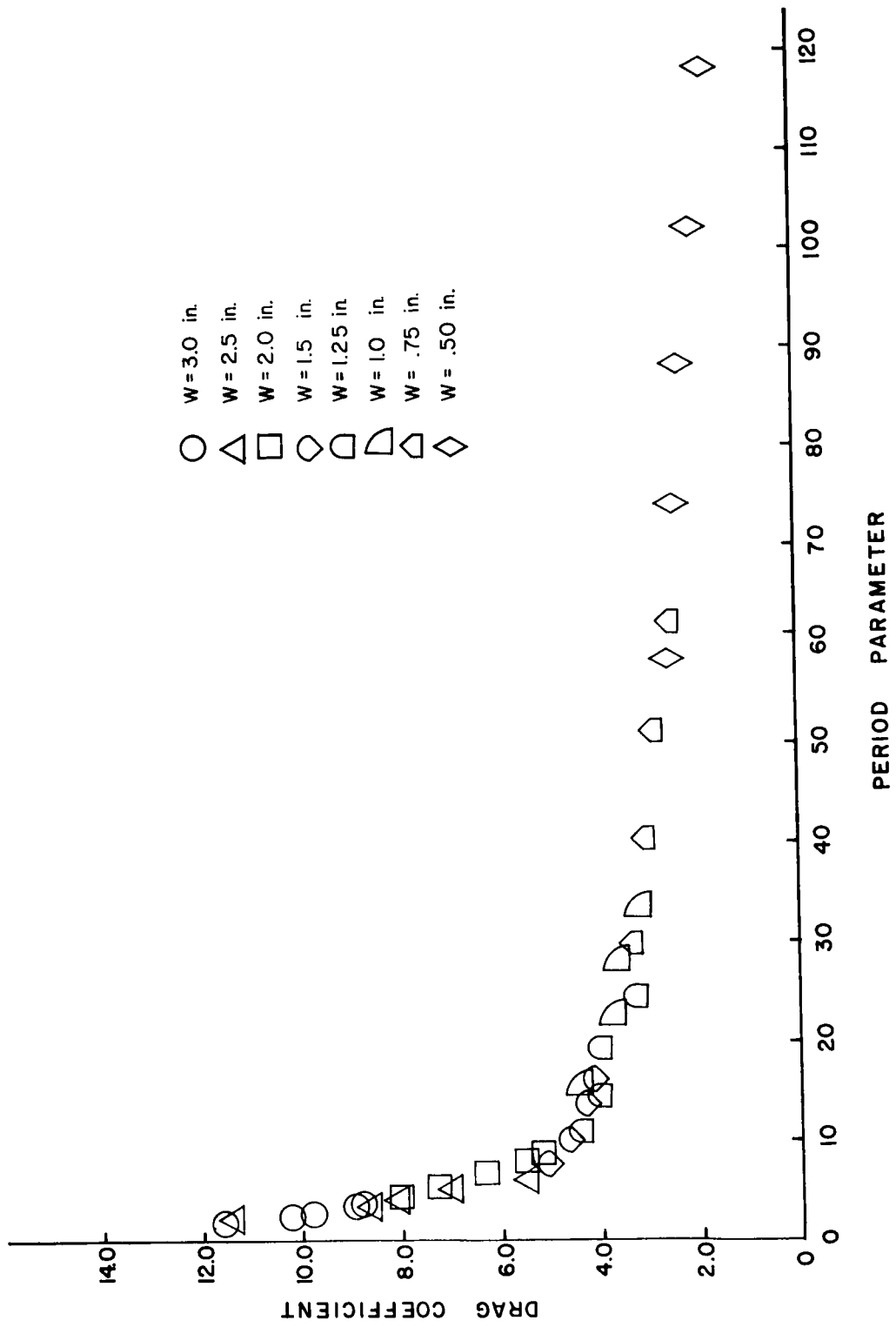


FIGURE 7



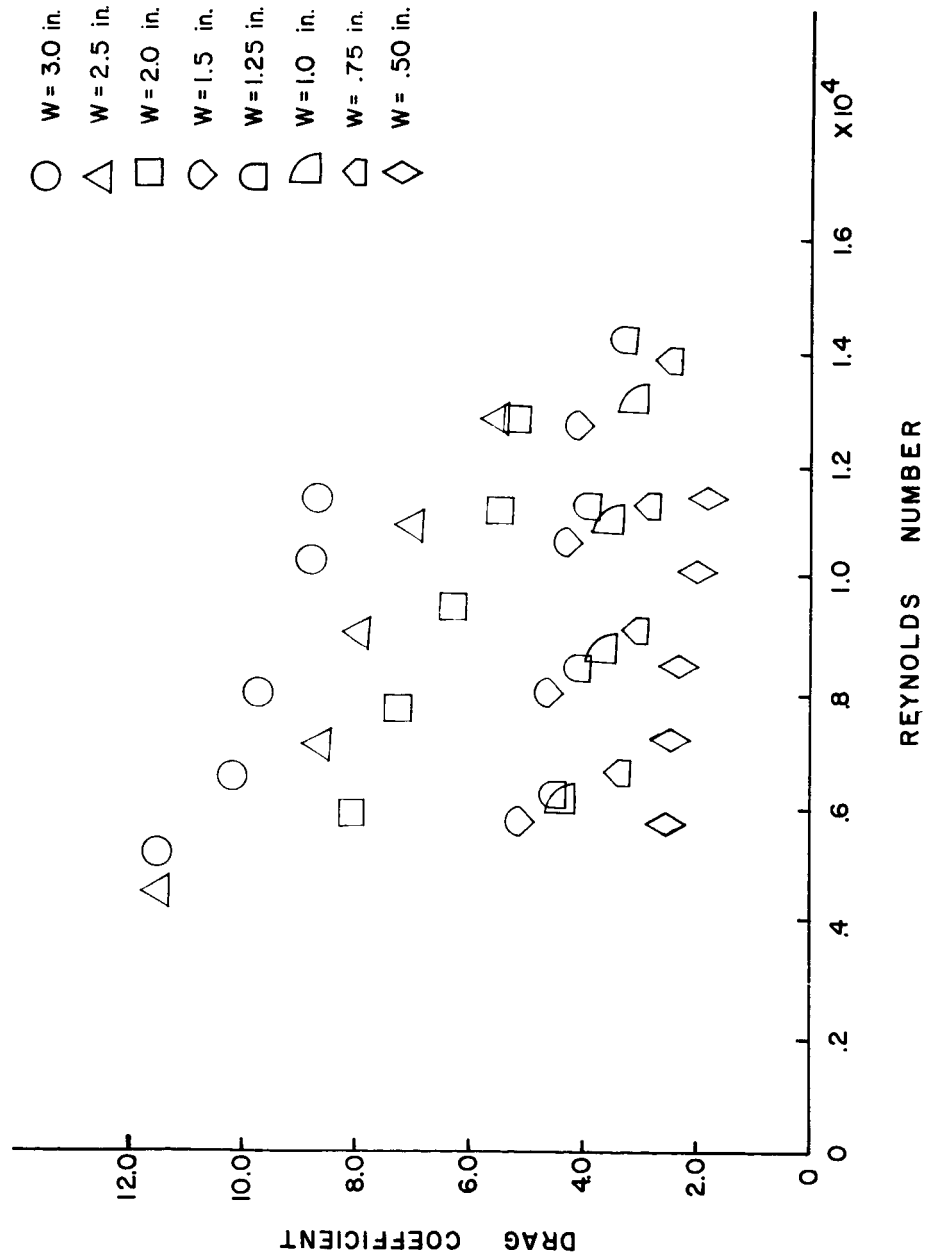


FIGURE 8

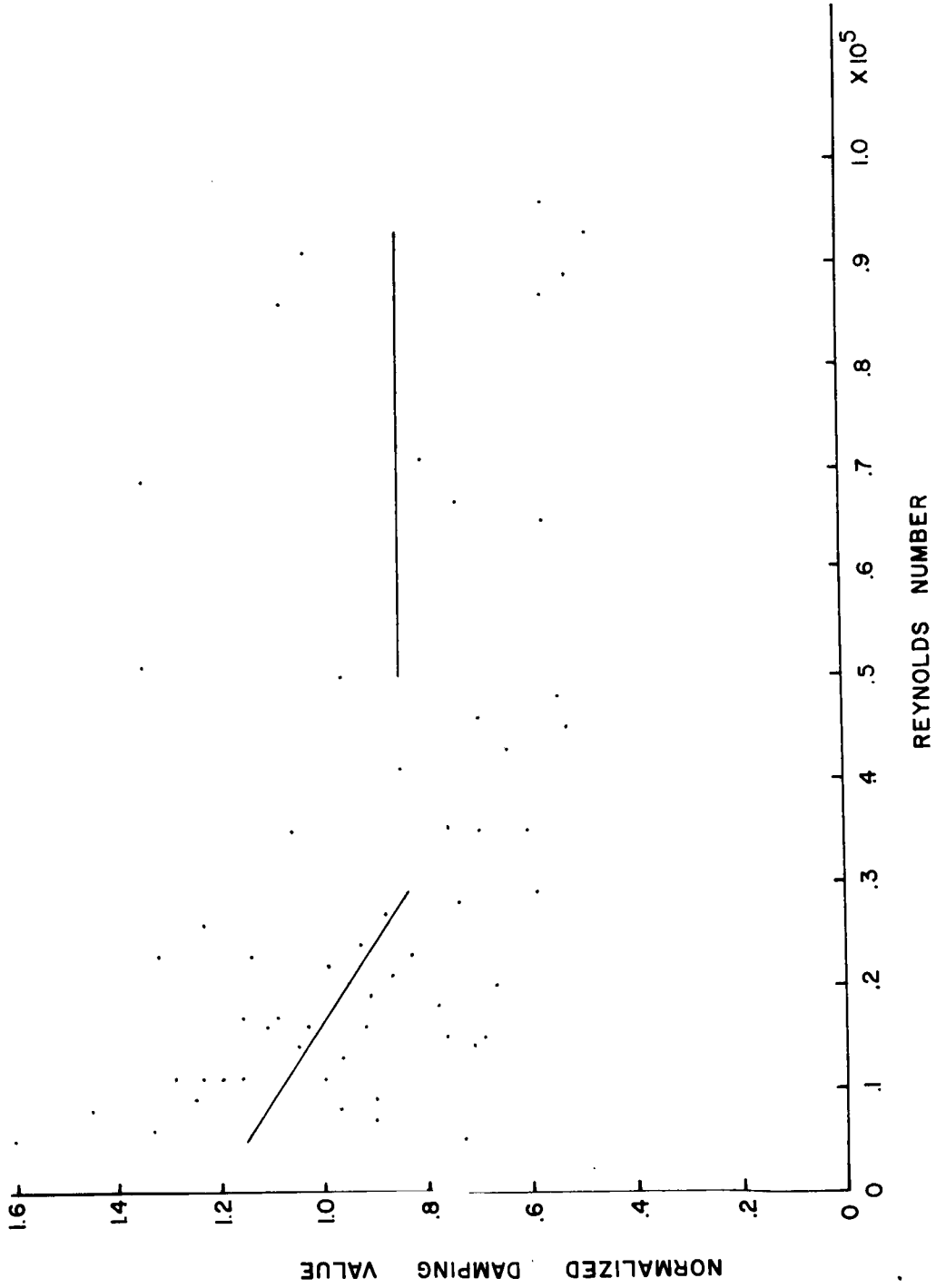


FIGURE 9

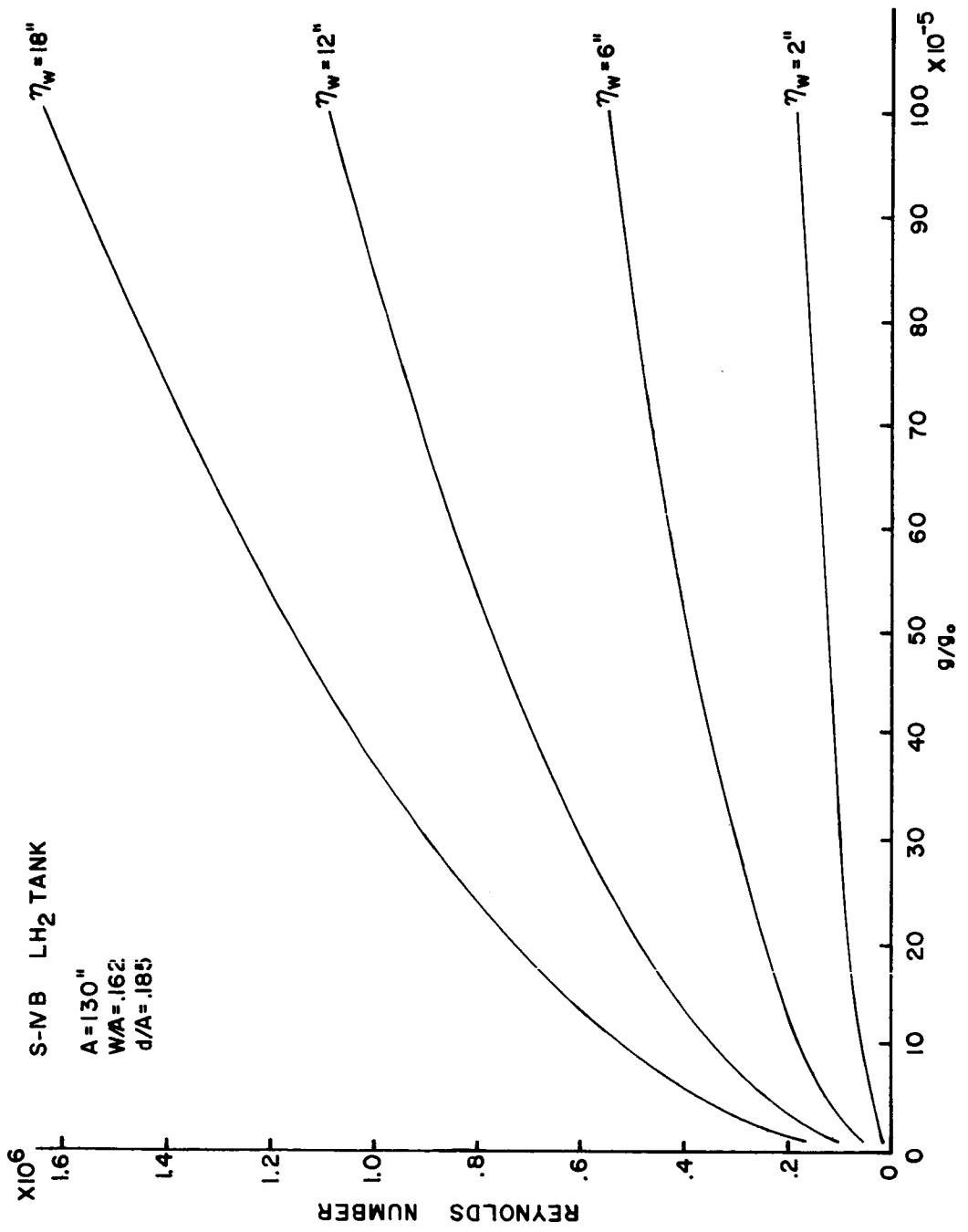


FIGURE 10

## REFERENCES

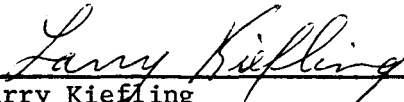
1. Miles, J. W., "Ring Damping of Free Surface Oscillations in a Circular Tank." *Journal of Applied Mechanics*, Vol. 25, No. 2, June 1958, pp. 274-276.
2. Keulegan, Garbis H. and Lloyd H. Carpenter, "Forces on Cylinders and Plates in an Oscillating Fluid," *Journal of Research of the National Bureau of Standards*, Vol. 60, No. 5, May 1958, pp. 423-440.
3. Silveria, M. A., D. G. Stephens, and H. W. Leonard, "An Experimental Investigation of the Damping of Liquid Oscillations in Cylindrical Tanks with Various Baffles," NASA TN D-715, Langley Research Center, May 1961.
4. Abramson, H. Norman and Guido E. Ransleben, Jr., "Simulation of Fuel Sloshing Characteristics in Missile Tanks by Use of Small Models," Southwest Research Institute Project 43-768-2, TR No. 7, Contract DA-23-072-ORD-1251, April 25, 1960.
5. Garza, L. R. and N. H. Abramson, "Measurements of Liquid Damping Provided by Ring Baffles in Cylindrical Tanks," Southwest Research Institute Project 6-1072-2, TR No. 5, Contract NAS8-1555, April 1, 1963.
6. O'Neill, J. P., "Final Report on an Experimental Investigation of Sloshing," Space Technology Laboratories, Inc., TR-59-0000-09960, March 4, 1960.

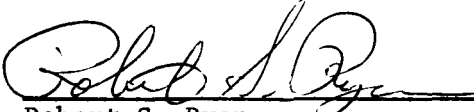
EFFECT OF REYNOLDS NUMBER ON SLOSH DAMPING  
BY FLAT RING BAFFLES

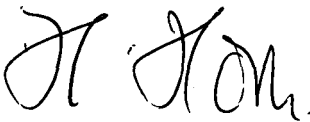
by Harry Buchanan and Larry Lott

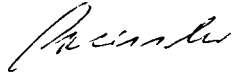
The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

  
\_\_\_\_\_  
Larry Kiefling  
Chief, Structural Dynamics Section

  
\_\_\_\_\_  
Robert S. Ryan  
Chief, Dynamics Analysis Branch

  
\_\_\_\_\_  
H. J. Horn  
Chief, Dynamics and Flight Mechanics Division

  
\_\_\_\_\_  
E. D. Geissler  
Director, Aero-Astroynamics Laboratory

DISTRIBUTION

DIR

DEP-T

R-ASTR

Dr. Haeussermann  
Mr. Hosenthien  
Mr. B. Moore  
Mr. Blackstone  
Mr. Mink  
Mr. Clark  
Mr. Seltzer  
Mr. Fisher  
Mr. Nicaise

R-P&VE

Dr. Lucas  
Mr. Hellebrand  
Mr. Showers  
Mr. Paul  
Mr. C. Wood  
Mr. Platt  
Mr. Hastings  
Mr. Swalley  
Mr. Lifer

MS-IP

MS-IL (8)

I-RM-M

CC-P

HME-P

MS-H

MS-T (6)

R-AERO

Dr. Geissler  
Mr. Jean  
Mr. Horn  
Mr. Dahm  
Mr. Lindberg  
Mr. Baker  
Mr. W. Vaughan  
Dr. McDonough  
Mr. Ryan  
Mr. Thomae  
Mr. Rheinfurth

R-AERO (Cont'd)

Mr. T. Deaton  
Mr. Hagood  
Mr. Townsend  
Mr. Kiefling  
Mr. Swift  
Mr. Buchanan (10)  
Mr. Milner  
Mr. Hays  
Mr. Worley  
Mr. Pack  
Mr. Bugg (10)  
Mr. Muller  
Mr. Papadopoulos  
Mr. Billups  
Mrs. King  
Mr. Stone  
Dr. H. Krause

Tech. & Sci. Info. Facility (25)  
Box 33  
College Park, Md.  
Attn: NASA Rep. (S-AK/RKT)

The Boeing Co.  
304 Oakwood Ave. N. E.  
Huntsville, Ala. 35801  
Attn: G. Riley

Douglas Aircraft Co.  
DAC-MSFC  
Bldg. 4481, Rm. 41  
Attn: Mr. Paul Dixon

Langley Research Center  
Langley Sta.  
Hampton, Va.  
Mail Stop 244  
Attn: Mr. Stephens

Chrysler Corp.  
HIC Bldg.  
Huntsville  
Dept 4812  
Attn: Mr. Kavanaugh