THE UNIVERSITY OF MICHIGAN

College of Engineering

Department of Mechanical Engineering

Cavitation and Multiphase Flow Laboratory

Report No. ~~01077-2-I~~ 02643-1-I

A STATISTICALLY VERIFIED MODEL FOR CORRELATING VOLUME LOSS DUE TO CAVITATION OR LIQUID IMPINGEMENT

by

F. G. Hammitt
Y. C. Huang
C. L. Kling
T. M. Mitchell
L. P. Solomon

Financial Support Provided by:

U. S. Naval Air Development Center

Contract No. N62260-67-C-0631

April 1969

A STATISTICALLY VERIFIED MODEL FOR CORRELATING VOLUME LOSS DUE TO CAVITATION OR LIQUID IMPINGEMENT

This paper describes a simple relationship , verified statistically, between volume loss to materials due to cavitation and liquid impingement and the material mechanical properties. Much of the available pertinent data from various fields will be or have been used, although the study was motivated by the aircraft rain erosion application. We have assumed that droplet impingement and cavitation cause damage through a similar process. Thus our own data, obtained with an ultrasonic vibratory facility on materials whose mechanical properties we have measured, were used in this study. Comparison with tests performed elsewhere allows the construction of a normalization procedure to incorporate data from other facilities, both impact and cavitation. An overall correlation between damage and material properties in a rain erosion or other test is sought.

An exponential relationship has sometimes been assumed to exist between damage rate and the difference between the normal components of actual impact velocity and minimum velocity necessary to cause damage. If a further correction for projected area is made, then:

$$\text{MDPR} \sin \theta = \left[K(V - V_o) \sin \theta\right]^{a}, \tag{1}$$

which is a modified version of the form suggested by Baker et. al.[1] Data obtained with a rocket sled facility at Holloman AFB on rain erosion materials was analysed to obtain values of K, a, and V_o through a least-squares procedure. The analysis provided a confidence limit ranging from 0.1 to 10 times typical MDPR values. Dornier Systems GmbH[2] suggests a modified equation,

$$\text{MDPR} (\sin \theta)^{n} = \left[K(V - V_o) \sin \theta\right]^{a} \tag{2}$$

where n = 1.0, 1.5, 2.0, or 2.5. However, our curve fit with equation (2) is approximately as poor as that with equation (1). These experiences suggested more basic considerations of the phenomena were necessary in order to obtain a more acceptable relationship. Equations (1) and (2) were found to be insensitive to values of V_o; it could therefore be assumed to be zero without compromising the date. There is a rough correlation between K and α, leading, conceptually to an approximate single figure of merit for each material. It is then necessary to relate such a figure of merit with one obtained from material properties.

In agreement with Hoff et. al.[3] an equation, relating MDPR to kinetic energy striking the target, efficiency of energy transfer between drop and target (denoted by η), and a material parameter (denoted by ϵ) with dimensions of energy per unit volume, is obtained. This equation describes the impinging energy necessary to remove material:

$$MDPR = \frac{\eta}{\epsilon} \left(\frac{Ap}{Ae}\right)\left(\frac{\rho_{eff}}{2}\right)\left(\dot{V}^3\right) \qquad (3)$$

Our statistical analyses of a combined data group generated from various sources, including some of our own vibratory cavitation tests, indicate that ϵ is a material constant which depends upon ultimate resilience[4,5], and also upon strain energy to failure. Presumably η is a function of velocity and geometry only.

BIBLIOGRAPHY

1. Baker, W. C., Jolliffe, K. H., and Pierson, D., "The Resistance of Materials to Impact Erosion Damage," A Discussion on Deformation of Solids by the Impact of Liquids, Phil. Trans. Royal Society (London), Series A, Part No. 1110, Vol. 260, July, 1966, pp. 193-203.

2. "Investigation of the Angle-Time Dependence of Rain Erosion", (in German), Progress Report No. 62269-7-002050, Dornier System GmbH, March 1968.

3. Hoff, G., Langbein, G. and Rieger, H., "Material Destruction Due to Liquid Impact", ASTM, STP 408, 1966, pp. 42-69.

4. Garcia, R., and Hammitt, F. G., "Cavitation Damage and Correlations with Materials and Fluid Properties", Trans. ASME, J. Basic Engr., D, Vol. 89, No. 4, pp. 753-763, 1967.

5. Hobbs, J. M., "Experience with a 20-kc Cavitation Erosion Test", ASTM, STP 408, pp. 159-179, 1967.

NOMENCLATURE

MDPR	=	Mean depth of penetration rate (= volume loss rate/ exposed area).
K	=	Amplitude constant for equation (1).
a	=	Velocity exponent for equation (2).
V	=	Impact velocity.
V_o	=	Threshold velocity.
θ	=	Angle between tangent to surface and direction of impact
η	=	Efficiency of energy transfer between impacting drop or jet and surface.
ϵ	=	Removal energy (=energy/volume to remove given volum from surface).
Ap	=	Projected target area in flight direction.
Ae	=	Exposed target area.
ρ_{eff}	=	Effective liquid density, mass of liquid per unit volume of gas-liquid mixture.