R&D NOTES

Two-Phase Flow Regime Map Predictions Under Microgravity

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The power demands of future spacecraft are expected to grow as high as 1 MW in the next 20 years (Mahefkey, 1982), and this will require more efficient thermal transport techniques. According to Eastman et al. (1984), transport distances between the heat sources and the radiators could vary from 1 to 50 m, and transport capabilities of up to 5 million W · m may be needed. One concept proposed for obtaining more effective thermal transport would replace ordinary one-phase fluid circulating loops with two-phase-fluid loops (Eastman et al.). This would allow the use of the latent heat of vaporization in reducing flow rates, providing essentially isothermal operation, and improving heat transfer coefficients compared to single-phase fluid forced convection.

Research in two-phase flow has been in progress for over four decades owing to its application in the nuclear and chemical industries. Consequently, knowledge about two-phase flow and heat transfer has advanced greatly during recent times. Almost all the work in two-phase flow has been conducted for earth gravity applications, and very little has been done in the area of microgravity. Lack of knowledge of two-phase flow behavior in reduced gravities has prevented its use in space applications. However, some research programs (Lovell, 1985; Abdollahian and Levy, 1984) have been started to solve the problems associated with two-phase systems in microgravity. For this purpose it is essential to have flow regime transition maps under microgravity conditions.

In this paper, the widely used models of Taitel-Dukler and Weisman et al. are extrapolated to microgravity levels to compare predicted flow pattern boundaries for horizontal and vertical flows. Efforts have been made to analyze how the two-phase flow models available in the literature predict flow regime transitions in microgravity. The models of Taitel-Dukler and Weisman et al. have been found to be more suitable for extrapolation to a wide range of system parameters than the other two-phase flow regime maps available in the literature. The original criteria for all cases are used to predict the transition lines, except for the transition to dispersed flow regime in the case of the Weisman model for horizontal flow. The constant 0.97 on the right-hand side of this correlation should be two times that value, i.e., 1.94, in order to match this transition line in their original paper.

Microgravity Flow Regime Transitions

Horizontal flow

For horizontal flow, Taitel and Dukler (1976) were the first to propose correlations for various transitions based upon theoretical and empirical concepts. Weisman and his coworkers (1979) at the University of Cincinnati conducted numerous experiments to determine the effects of various fluid properties (such as viscosity, density, surface tension, and pipe diameter) on flow pattern transitions. They have proposed correlations for a set of mean transition curves based on their experimental results. For horizontal flow, the flow regimes considered are: stratified (smooth and wavy), intermittent (slug and plug), annular-mist, and dispersed bubble. These regimes have been used in both models considered here and therefore can easily be compared. The flow transition equations have been used to generate flow pattern boundaries at microgravity levels, as presented in Figures 1 through 3.

These figures show typical flow regimes for an air-water system (25°C, 1 atm, 2.54 cm ID horizontal pipe) for various values of g/g_n, namely, 1, 0.01, and 0.00001. Figure 1 shows the flow regime map predicted by Taitel-Dukler and Weisman models at $g/g_n = 1$. Transition predictions of the Weisman model are represented by solid lines, those of the Taitel-Dukler model by broken lines. A comparison of these two models reveals that the same flow regimes are identified in roughly the same regions of the plot. However, the slope of the transition line between intermittent and annular-mist is positive for the Taitel-Dukler model and is negative for the Weisman model. Figure 2 shows the flow regime map at $g/g_n = 0.01$. The boundaries between stratified and intermittent, intermittent and dispersed bubble, and strati-

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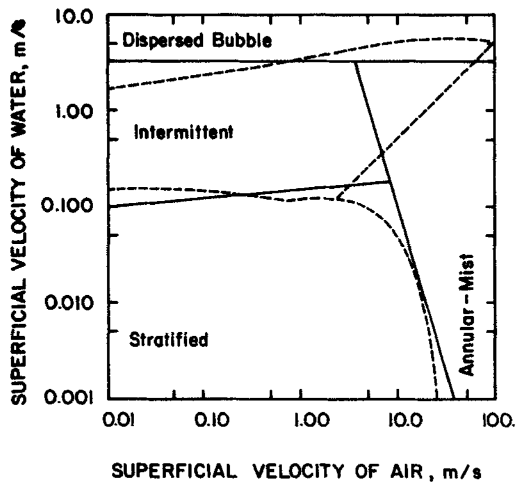

Figure 1. Horizontal flow regime transitions, $g/g_n = 1$.
Air-water system in 2.54 cm ID pipe at 1 atm, 25°C
--- Taitel-Dukler model; — Weisman et al. model

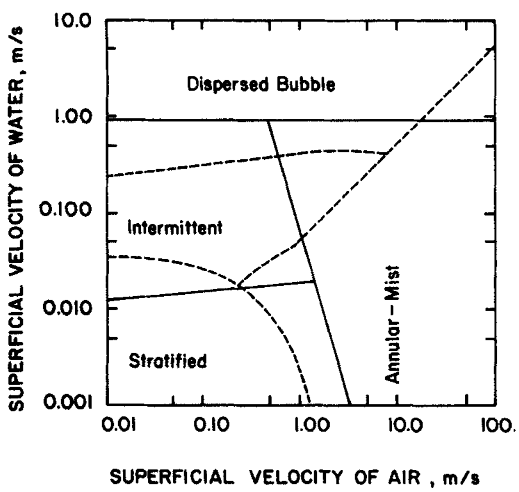

Figure 2. Horizontal flow regime transitions, $g/g_n = 0.01$.
Data and identification as in Figure 1

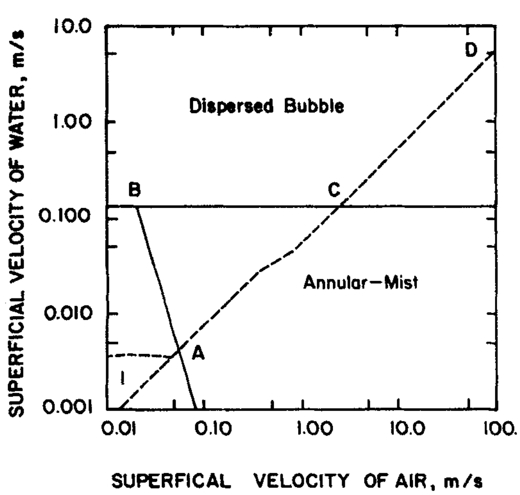

Figure 3. Horizontal flow regime transitions, $g/g_n = 0.00001$.
I, intermittent; data and other identification as in Figure 1

fied and annular-mist regimes all move toward lower superficial velocities of both phases as g/g_n is reduced. This trend is similar for both models. However, the region of the intermittent flow regime for the Taitel-Dukler model is much smaller than that predicted by the Weisman model.

At very low gravitational accelerations, i.e., $g/g_n = 0.00001$, Figure 3 shows that stratified flow will not exist, as predicted by both models. The Taitel-Dukler model predicts that essentially only dispersed bubble and annular-mist flows will occur, whereas the Weisman model predicts three flow regimes: intermittent, dispersed bubble, and annular-mist. For the Weisman model *AB* is the transition line between intermittent and annular-mist flow, and *BC* is the transition line between dispersed bubble and annular-mist flow. *ACD* is the transition line between dispersed bubble and annular-mist flow for the Taitel-Dukler model. From this map it is clear that predictions by these two models differ considerably in the type, size, shape, and extent of the flow regimes at low g/g_n values.

Vertical flow

For vertical flow, Taitel et al. (1980) and Weisman and Kang (1981) have proposed theoretical and/or empirical correlations for various flow regime transitions. Both these models have used the same set of flow regime definitions, namely, bubble, intermittent (slug and churn), annular-mist and dispersed bubble. These flow transition equations have been used to generate flow pattern boundaries at microgravity levels, as presented in Figures 4 through 6.

These figures show typical flow regimes for an air-water system (25°C, 1 atm, 2.54 cm ID vertical pipe) for various values of g/g_n, namely, 1, 0.01, 0.00001. Figure 4 shows the typical flow regime map predicted by the Taitel and Weisman-Kang models at $g/g_n = 1$. Weisman-Kang model transition predictions are represented by solid lines, those of the Taitel model by broken lines. A comparison of these models reveals that they agree reasonably well at $g/g_n = 1$. Figure 5 shows the flow regime map at $g/g_n = 0.01$. The boundaries between bubble and intermittent, bubble-intermittent and dispersed bubble, and intermittent and annular-mist flows all move toward lower superficial velocities of both phases as g/g_n is reduced. This trend is similar for both

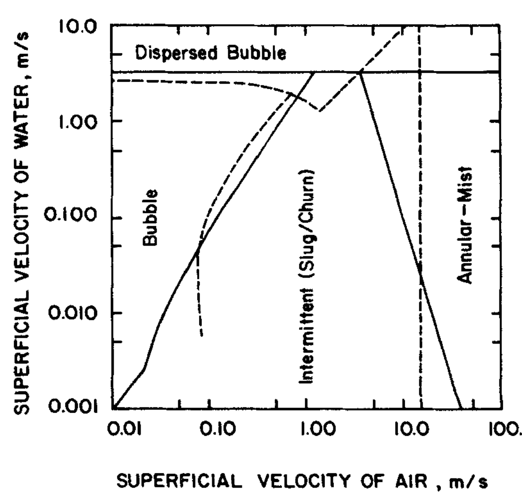

Figure 4. Vertical flow regime transitions $g/g_n = 1$.
Air-water system in 2.54 cm ID pipe at 1 atm, 25°C
--- Taitel et al. model; — Weisman-Kang model

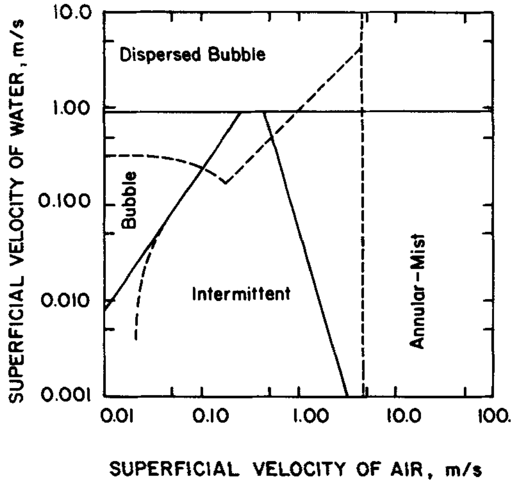

Figure 5. Vertical flow regime transitions, $g/g_n = 0.01$.
Data and identification as in Figure 4

models. However, the region of the intermittent flow regime for the Taitel model is much larger than that predicted by the Weisman-Kang model.

At low gravitational values, i.e., $g/g_n = 0.00001$, Figure 6 shows that bubble flow will not exist, as predicted by both models. The three flow regimes predicted by both models are intermittent, annular-mist, and dispersed bubble. The Taitel model predicts that annular-mist flow would predominate for all values of large air flow. The Weisman-Kang model predicts that dispersed bubble flow would occur for all values of large water

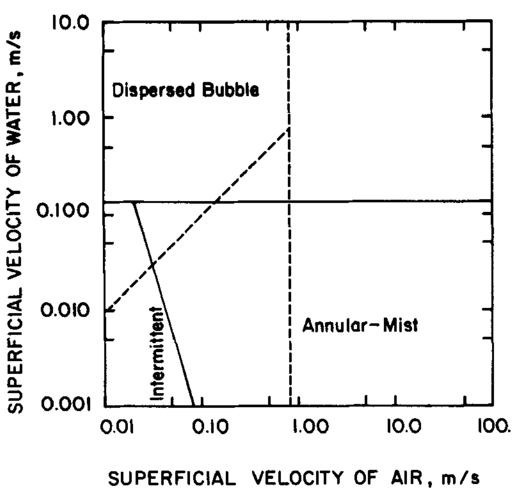

Figure 6. Vertical flow regime transitions, $g/g_n = 0.00001$.
Data and identification as in Figure 4

flow. In the case of vertical flow, these two models differ considerably at low g/g_n values.

Comparison of Horizontal and Vertical Models

A comparison of the Taitel-Dukler model for horizontal flow and the Taitel et al. model for vertical flow at $g/g_n = 0.00001$, Figures 3 and 6, respectively, reveals that two flow regimes (dispersed bubble and annular-mist) are predicted for horizontal flow and three regimes (intermittent, dispersed bubble, and annular) for vertical flow. It is also observed that the orientation of the transition line between dispersed bubble and annular-mist flow is different; this line has a positive slope in the case of horizontal flow and infinite slope in the case of vertical flow.

Weisman et al. and Weisman and Kang have not proposed different flow regime transition correlations for horizontal and vertical flow, except for stratified to intermittent in the case of horizontal flow and bubble to intermittent for vertical flow. A comparison of flow regime maps at $g/g_n = 1$, Figures 1 and 4, shows that the horizontal stratified and intermittent flow regimes are replaced by the bubble and intermittent regimes in the case of vertical flow. The other transitions are the same. At the reduced gravity of $g/g_n = 0.00001$ the flow regime maps, Figures 3 and 6, are almost identical. The stratified and bubble flow regimes for horizontal and vertical flow, respectively, move toward the region of very low phase velocities whereas the positions of other flow regime transitions remain unchanged.

Notation

g = acceleration due to gravity, m/s^2
g_n = acceleration due to gravity on normal earth conditions, m/s^2

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