Dan Joseph's response to Tom Hanratty's (10 Oct 2001) questions on definitions of scientific issues in multiphase flow science.

All project managers ask for innovation rather than incremental approaches to research. Usually if you have good ideas about innovation you do it rather than advocate it.

Our group does a lot of work on multiphase flow focussing on problems in the oil industry—mostly solid-liquid flow. What I don't think has worked well are two-fluid models and perturbations of Stokes flow. I think that in some sense these approaches have demonstrated failure.

The direction taken by multiphase science in the future ought to make maximum use of computers and storage. This points to direct simulations and to the processing of real data from experiments for correlations. I think curve fitting plus computers and storage gives rise to new and great opportunities for multiphase science. The secrets are in the data and with digital technology we can interrogate this data.

I made these points in a presentation at a panel at the recent meeting of ICMF given below.

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Dan Joseph's presentation at the Modeling Panel, *International Journal of Multiphase Flow* *

In my presentation and in the discussion that followed I took a too extreme position against modeling. I was motivated to do so by my general impression that many models fail to achieve their stated goals and by our recent success with the generation of correlations from direct numerical simulations of solid-liquid flow. (A list of papers is given in my paper "Power law correlations for lift from direct numerical simulation of solid-liquid flow" in the proceedings of this meeting.)

Generating correlations from experiments is an old method on which many industrial applications are based but it has come to have a bad name, viewed as empirical and not fundamental. The great example is the Richardson-Zaki correlation which is the cornerstone of fluidized bed practice. My enthusiasm for correlations has to do with the surprising emergence of correlations from the simplest kind of post-processing of our numerical experiments. We have done lift correlations for single particles and for the bed expansion of many particles in slurries. The procedure we follow is to plot the results of our simulations in log-log plots of the relevant variables. The surprise for us is that these plots frequently come up as straight lines giving rise to power laws. For example, a single particle will lift-off in a Poiseuille flow at a certain Reynolds number $R = Ud/v$ for a given settling Reynolds number $R_G = \rho_f(\rho_p - \rho_c)gd^3/\eta^2$. When we plotted the lift off criterion from about 20 points we found that

$$R = aR_G{}^n$$

with an intercept a and slop n in the log-log plot. The straight lines are impressively straight and we generated such correlations for lift to equilibrium, for the bed expansion of many particles and in non-Newtonian fluids. The existence of such power laws is an expression of self-similarity, which has not been predicted from analysis or physics. The flow of dispersed matter appears to obey those self-similar rules to a large degree.

We can get power laws when only two variables are at play; when there are three variables or more, it would appear that we get different power laws separated by transition regions. This is certainly the case for the Richardson-Zaki correlation; it has one power law relating the fluidization velocity to the solids fraction at low Reynolds number and another at high Reynolds with a Reynolds number-dependent transition between. We got such correlations between three variables for slurries, and from experiments (see "Power law correlations for sediment transport in pressure driven channel flow," by Patankar, Joseph, Wang, Barree, Conway and Asadi, submitted to *IJMF,* 2001.)

We have generated 3D calculations from simulation for a fluidized bed 1204 spheres (to appear in *JFM,* 2001), but it is very expensive. The direction of our work is to develop simulations to get efficient computation leading to 3D correlations. This will happen. Then we will get real engineering correlations from numerical experiments. I like this approach since it uses numerical simulations in a natural way evolving from their intrinsic properties rather than trying to fit them into a more familiar frame. I think that processing of data for correlations, from experiments, field data or simulations is a great new opportunity of the computer age and ought to be vigorously pursued.

The problem faced by models is how to get the various interaction terms right. Much of the time the guesses made for these interaction terms are poor and the predictive power of the model is not there. Better models must also make use of correlations for the interaction terms. For example, the Richardson-Zaki correlation gives an excellent correlation for bed expansion, but leaves the modeling of the drag force needed for a mechanist's model to imagination.

My position in the round table was too extreme; let it be said that the active pursuit of correlations is an excellent direction for future research using computers in a new way with direct applications to both engineering practice and model construction.

* May 28, 2001

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Specific questions

(1) I endorse the organization of a workshop.

(2) It should include liquid-gas, liquid-liquid and liquid-solid.

(3) The key scientific questions depend on your discipline. I am interested in hydrodynamic lift and migration of particles in slurries

(4) I advocate curve fitting and direct simulation as a *new* approach to multiphase flow science.