11th Australasian Fluid Mechanics Conference
University of Tasmania, Hobart, Australia
14-18 December 1992

7E-6

A REVIEW OF THE LAST ROUND TABLE ON WATER COLUMN SEPARATION - VALENCIA, SEPT 1991

B.B. SHARP

Burnell Research Laboratory
4 Hardidge Court, Doncaster, VIC 3108
AUSTRALIA

ABSTRACT

Various aspects relating to basics, theory, modelling and field studies are reviewed as reported in the last Round Table on Water Column Separation. Water hammer being an engineering interest tends to overshadow the rather complex fundamental fluid mechanic problems associated with transient flows. The conference revealed the nature of the velocity profile behaviour in the presence of transients which poses new problems of unsteady friction simulation. The shape of developing cavities and the complex two-phase shock interaction tend to expose the falacy of the assumptions made in the numerical modelling techniques in use. Advances, however have been made in the simple horizontal pipe solution where the reality of the larger pressures after the first cavity collapse were again well illustrated. Field studies supported the value of simple modelling of water column separation but research on this phenomenon has not reduced even with 20 years of activity by this group.

INTRODUCTION

A working group of IAHR on Transients with Water Column Separation ended its work with the 9th and final Round Table at Valencia in September 1991.

The activity began in 1971 and therefore 20 years have elapsed with many fine papers contributing to this topic. To a certain extent this meeting indicated the significant outstanding research areas still to be confronted and showed the state of the art, when new analytical methods are continuing to emerge and problems associated with the results of case studies abound.

The group was international in support but has seen a turnover of the participants and this requires a greater responsibility to ensure that new ideas are not ignoring much that has already been explored. The growing power of computational resource and technique has much to do with the direction of solutions and those able to contribute.

This review for the southern continent may help to indicate how far we have advanced, how well the table has been cleared and whether the last course has indeed been served to our satisfaction.

RANGE OF TOPICS

The Valencia meeting had papers dealing with the Basics, theoretical developments, numerical simulations and case studies and incidents.

BASICS

It appeared somewhat as a revelation that water hammer pressures greater than the Joukowsky value of $C_o v/g$ would be possible with valve closure in a simple system. In fact the development of better apparatus and measuring techniques merely have confirmed that which is well known during water column separation and due to the fact that the collapse of the first cavity does not occur exactly at a multiple of $2L/C_o$.

There was a valuable comparison by Anderson, for the simple valve closure level pipe case, of various northern hemisphere contributors, which only tended to emphasise the problems of modelling cavities that might be regarded as severe as opposed to mild.

The basic problem remains of establishing repeatability of experiments having regard for the effect that small amounts of gas have on cavity inception and the subsequent wave peaks.

The 'discrete free gas' model was tested and provided the initial void fraction is assumed to be a value of 10^{-7} the reproduction of the first phase features is good, and satisfactory to a degree, for subsequent pressures. These conclusions as yet do not encompass the pipe slope or length as parameters at this stage.

Two contributions highlight the continuing difficulties of modelling these transient phenomena.

Jonsson, showed in commendable detail the velocity profiles during transients. His most valuable contribution involved the results of measurements of transient velocity profiles where a laser doppler velocity meter with dual beam forward scattering was used. An interesting conclusion was the fact, that with the passage of the pressure wave, there was a general shift of the mean velocity profile, without a significant change in shape (except close to the wall). At times the mean of the velocity profile was zero, but near the wall there was a significant flow reversal, indicating a considerable wall shear stress. The velocity transients also decayed more rapidly than the pressure transients in the 49m long pipeline; negligible after about 5 cycles.

In Figure 1 is shown a sample of the velocity profiles observed.

The other contribution by Fuentes and Aguirre, described the nature of the cavity shape as it develops and becomes an elongated 2 phase separation.

Historical work by Sharp, was again cited and emphasised the need to understand the basics of growth and collapse of a single cavity.

THEORETICAL METHODS

A serious attempt was made by Anderson et al.,to develop new methods which do not require a total restructuring of the basic and powerful Method of Characteristic methods already widely in use.

To cope with the non-linear effects of differing signs for the V and the local acceleration $\partial V/\partial t$ at any instant and to comprehend the Coriolis effect of the velocity distributions in unsteady flow a somewhat empiric expression for the friction has been developed by Brunone et al.,

$$J = J_S + k_3/g\ (1 - C_o/w_V)\,\partial V/\partial t \quad \ldots(1)$$

where J_S is the steady state friction, k a coefficient, $w_V = \partial V/\partial t \div \partial V/\partial s$, (a propagation speed of a velocity V).

In this development, the concept of combining an effect of the difference in uniform flow and unsteady flow as a function of $\partial V/\partial t$ with the Coriolis effect as a constant term was abandoned. Nevertheless, the dilemma faced by these different considerations has been exposed.

The existence of very non-uniform velocity distributions was highlighted by Nonoshita et al., in the case of large hydroelectric power plant draft tubes. There, the possibility of large swirling 'rope' type motions pose great problems of 3D modelling and the idea of localised water column separation or the suggestion of significant high pressure rejoin are difficult to visualise and quantify in theoretical models.

NUMERICAL SIMULATIONS

The clear message is that a good system designer must be familiar with numerical simulation techniques, but that an absolute trust in such models must not become habit and that often there is improper use of these facilities. In fact young engineers are being coached in the proper approach to hydraulic transient analysis in places such as Italy, Portugal, Mexico and Brazil.

The strongly non-linear phenomenon of water column separation is highly sensitive to initial conditions, leading to divergent results after a finite time from very similar starting conditions. Hence the predcitability of models may be limited.

There was a concensus that modelling is not universally successful for the extreme cases of severe cavitation and the modest or light cavitation (discrete small cavities).

Methods have been developed using variable wave speed, rigid column components and allowances for unsteady friction that increase the complexity of the algorithms.

In particular there is a dissatisfaction with the ability to predict the magnitude and timing of the excessive spikes of pressure for cavities occurring after the first, even for simple single pipe/valve systems.

Therefore, despite the prevailing need for engineering solutions for complex pipe systems, we are unable with precision to solve the simple type of system referred to above.

These problems suggest that the transition from the simple 1D modelling to the two and three dimensions to properly represent the transients with and without cavity separation is going to require more and more time consuming and complex history type algorithms which may be counter productive for most field problems. That is, one will always be plagued with the choice of approximate (near 1D) solutions or the more exact forms which are very demanding of computer resources.

It may be that we will always be forced to use the less detailed analysis for situations which involve the additional complexities of the many types of boundary conditions which are part of pipe systems, namely, pumps, valves, pipe junctions and transitions. It may be prudent not to abandon concepts and physics revealed by the use of the classical graphical analysis of Schnyder and Bergeron.

In the discussion of numerical techniques, some interesting comparisons were presented by Brunone et al., between the usual Method of Characteristics (steady state friction), a modified M. of C. (with a modified friction term) and an implicit method of solution. The study incorporated the new semi-empiric unsteady friction term indicated in equation (1) above.

Numerically, for the modified M. of C. solution, this is handled as previously, plus an explicit evaluation of the additional term at time t. The additional term is shown below in the modified differential equation.

$$dh + \frac{C_o}{g}dV + J_S\,ds + \frac{k_3}{g}(\partial V/\partial t - C_o\,\partial V/\partial s)\,ds = 0 \,..(2)$$

The results with and without cavitation were very successful and the case with cavitation is shown in Figure 2.

The implicit method was discarded as computationally complex - no significant improvement in accuracy.

Another perspective involved the study of a model incorporating an air pocket at a closed end. This problem of transient behaviour lent itself to rigid column theory analysis, but the object was to test the validity of such modelling in relation to an elastic model.

It was shown by Abreu et al., that the rigid column theory was adequate (and computationally much less demanding) for,

$$\rho\sigma > 10 \qquad \ldots.\ (3)$$

where ρ is a form of the dimensionless parameter expressing inertia time scale (VL/gH) / wave time scale (L/C_c), but in terms of the air bubble length relative to the liquid length and parameters for the air bubble behaviour, and σ is the ratio of the energy stored in the bubble to the kinetic energy of the liquid column.

As more sophisticated models of cavities are developed and the presence of air is allowed for, there is no doubt the time scales will be essential in defining the different phases and the above ideas would be relevant.

The use of varying wave speeds has been one method of handling the existence of cavities, and was raised in the proceedings. The motion of the cavity interface introduces differing time scales so that wave speeds reduced in proportion to cavity extent may be used with the standard Method of Characteristics solution.

In reality the times for transient passage between points which include some form of cavity will appear longer, but there is only ONE wave speed in a conduit full of liquid and although it may be expedient to vary the wave speed this should not be at the sacrifice of correct physical representation of cavity behaviour.

CASE STUDIES

The need to address real problems in enginering practice poses special problems for the study and evaluation of the effects of water column separation.

In one example by Wang and Locher, the presence of entrapped air was believed to play a role in the field tests of a pumping system involving about 48 km of pumping main, where there was fair agreement between the test results and the numerical simulation of events, see Figure 3.

The installation of air inlet valves along the pipeline and a two-step valve operation at the pump discharge provide factors which would require proper analytical treatment and the airvalves particularly introduce quantities of air as vacumm conditions occur which suggest a complex vapour/air cavity performance must be understood.

Further examples by Verhoeven and Van Pouche, discussed the problems of large air admissions during low pressures.

Given the difficulties of modelling simple (horizontal pipe) systems with water column separation, it is perhaps fortuitous when there is significant agreement between field tests and analysis. It must be presumed that the simulations involving discrete cavity modelling are reasonably productive for field design and analysis.

CONCLUSION

Some fundamental problems of fluid mechanics are associated with waterhammer. The transient fluid friction associated with complex unsteady flow profiles are challenging enough, quite apart from the two-phase interface (shock) effects which need to be defined as boundary conditions for wave reflections, so that we have still much to rationalise in the compromise between research and enginering need.

REFERENCES

International Meeting on Hydraulic Transients with Water Column Separation (9th Round Table of the IAHR Group), Valencia, Spain, Sept. 1991

AREU, J, CABRERA, E, GARCIA-SERRA, M and PEREZ, R, Boundary between Elastic and Inelastic Models in Hydraulic Transient Analysis with Entrapped Pockets, p198.
ANDERSON, A, SANDOVAL-PENA, R and ARFAIE, M, Column Separation behaviour Modes in a Simple Test Rig, p2.
ANDERSON, A and ARFAIE, M, Variable Waterhammer Wavespeed in Column Separation, p125.
BRUNONE, B, GOLIA, M and GRECO, M, Some Remarks on the Momentum Equation for Fast Transients, p140
BRUNONE, B, GOLIA, M and GRECO, M, Modelling of Fast Transients by Numerical Methods, p215.
JONSONN, L, Mean Velocity Profiles in Transient Flows, p59.
NONOSHITA, T, MATSUMOTO, Y, OHASHI, H and KUBOTA T, Model Analysis of Water Column Separation accompanied with Swirl Flow, p182.
SHARP, B B, Mechanics of Bubble Growth and Collapse, p105.
VERHOEVEN, R and VAN POUCHE, L, Waterhammer Protection Case Studies, p334.
WANG, J S and LOCHER, F A, Verification of Modelling Water Column Separation, p260.

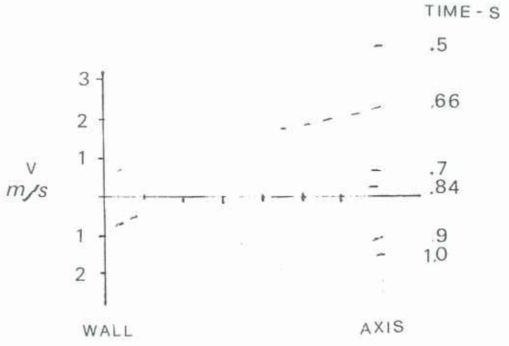

Fig. 1 Measured transient velocity profiles

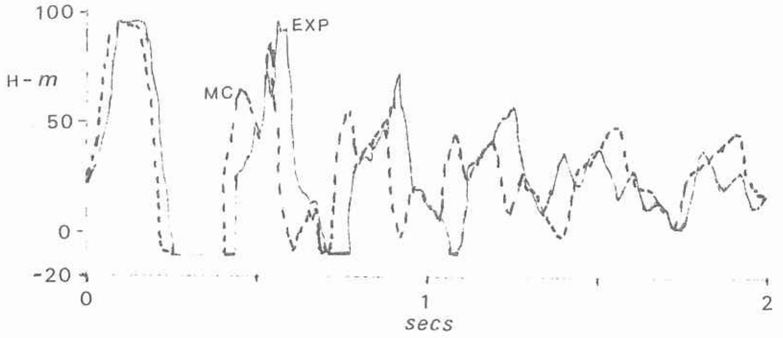

Fig. 2 Comparison of Experiment and M. of C.

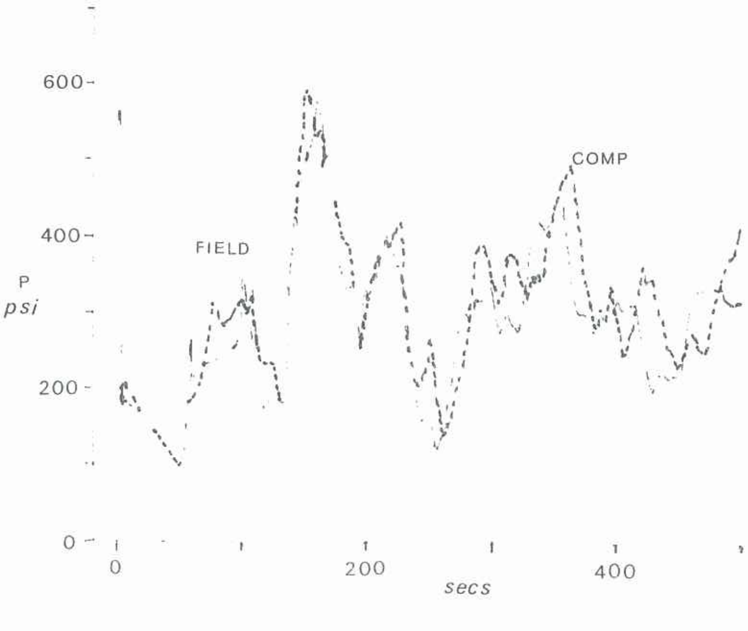

Fig. 3 Comparison of Field data and Computer