Celebrations and challenges – waterhammer at the start of the 20th and 21st Centuries

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At the first specialist conference on waterhammer, pressure surges and unsteady flow in a new century, it is inevitable that we should feel the need to take stock of where we are now by looking back as well as looking forwards. To paraphrase the philosopher Santayana, if we forget our past we are condemned to re-live it. Indeed, in refereeing and reviewing the potential contributions to this Conference, the Technical Advisory Committee was struck by the fact that the very maturity of our field seems to be creating a situation where some of the established (or so we thought) lessons of the past appear to have been forgotten and are now being (sometimes painfully) rediscovered. It is partly for this reason that we have introduced at this Conference the Open Discussion Forum on a number of key issues. Half a century ago, Leliavsky (1951) noted fallacies in hydraulics that had been promulgated through failure to understand their historical perspective. The Committee hope that this Conference and its Proceedings will encourage the fluid transients community to avoid similar pitfalls.

Let us look back over the last quarter century and century (or so). Our series of Pressure Surge Conferences (1972-96) started in 1972, at a period which had seen the work of Paynter, Gray, Streeter, Evangelisti and others revolutionising unsteady flow analysis and modelling by exploiting the digital computer. At that time our Committee member (and former Chairman) David Thorley was promoting the new approaches to industry through short courses and our International Panel member Sam Martin (1973) was investigating the state-of-the-art in W Europe. Other major international conference series in related fields were being established in response to the increasing awareness of unsteady flow problems in industry, eg the IMechE series on Flow Induced Vibrations started in 1973 and the nine IAHR Working Group Round Tables on Hydraulic Transients with Water Column Separation ran from 1971 to 1991.

At the (First) International Conference on Pressure Surges in 1972, Prof V.L. Streeter presented a review of the work of his group and now, at the Eighth in the series, we have as Session Chairmen his long time collaborator Ben Wylie and one of his last PhD students, Angus Simpson. It is interesting, in retrospect, to see how that First Pressure Surge Conference differed from the slightly earlier IMechE and ASME Symposia in 1965. While at these Streeter was also demonstrating the new methods, many 'applications' papers were still using traditional graphical approaches. For the graphical methods of Schnyder and Bergeron, their equivalent to our First Pressure Surge Conference would have been the ASME Symposia of 1933 and 1937 (the latter including the last paper by Lorenzo Allievi). At these the then new graphical solutions were being used not just for hydro-electric plant but also for new applications such as diesel engine fuel injection systems.

These graphical methods, successful and valuable in their era, built on the theoretical foundations of our field put in place around the turn of the last century. It is perhaps instructive to consider four contrasting papers from then. An applications-driven paper by the great turbine engineer Rateau (1900) drew on work relating to hydroturbine governing established by Michaud, Leauté, Stodola and others, and contains many of the same misunderstandings and limitations as these, despite which it was widely quoted in European waterhammer studies for many years. In contrast, Lamb (1898) presented an entirely theoretical account which foreshadowed much future work on fluid-structure interaction (Tijsseling 1996) but which had no immediate practical application. This was very much a culmination of the great 19th Century continuum mechanics tradition.

The contributions with long-term impact, however, were those of N.E. Zhukovsky (more commonly written Joukowsky as in his own transliteration into German), presented in May 1898 to the Imperial Academy of Sciences in St Petersburg and published in both Russian (1899) and German (1900), and of L. Allievi (1902), subsequently translated into French (1904) and German (1909). Joukowsky, like Lamb, was very much a product of the 19th century European tradition in physics. In his own paper he takes no credit himself for waterhammer theory. He simply quotes and synthesises established equations*, in particular the work of Korteweg (1878) and Lamb (1898). These are part of an extensive scientific tradition in acoustics and physiological flows (Boulanger 1913, Lambossy 1950-51) but Joukowsky's remarkable achievement is to use these to explain a quite exceptional set of experimental investigations that he supervised at the Moscow Waterworks in 1897-98. Goupil (1907) gave a good summary of both theory and experiments in French, but the English version by Simin (1904), while translating the account of the experiments very faithfully, totally ignored the introductory theory as set out by Joukowsky and instead reviewed contemporary N American papers, many of which replicate the misunderstandings of Rateau (one, by Frizell, did not, but was overlooked by his contemporaries - see Wood (1970)). The earliest presentation of the theory in English was by Gibson (1908), who refers to Simin (1904) but notes in his Preface that there is no English translation of Joukowsky's theory.

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* The 'Joukowsky equation' for a pressure change Δp due to a change in velocity Δv in a fluid with density ρ and wave disturbance propagation velocity a:

$$\Delta p = -\rho a \Delta v \tag{1}$$

appears first in Rankine (1870). Though Joukowsky worked extensively in the field of gas dynamics and was familiar with Rankine's contributions, there is no evidence that he was aware of this particular paper. He seems to have been scrupulous about acknowledging all previous contributions to his new synthesis of waterhammer theory, including Menabrea's early ideas (Anderson 1976) but he does not mention this particular source. Rankine (1872) also published on the hydraulic ram, but he adopted rigid column theory for this work.

In contrast to Joukowsky, Allievi came from the engineering tradition, with Rateau (1900) amongst his references, but he independently arrived at a comprehensive theory, improving on the fluid acceleration equation of Korteweg and Joukowsky by including the convective acceleration term (but explaining that it usually has only minor significance). Like Joukowsky he stated the familiar functional form of the solution in terms of Riemann invariants but went much further in explaining its significance in terms of the waterhammer cycle and using it to develop solutions for slow as well as rapid valve operations. Unlike Joukowsky, who is principally remembered elsewhere for his contributions to aerodynamics and who does not seem to have returned to waterhammer investigations other than to investigate the hydraulic ram in 1899 (Strizhevsky 1957), Allievi continued to work and publish in the field. A very detailed history of the development of ideas up to Joukowsky and Allievi was set out by Boulanger (1913).

There are many lessons to be learned from these papers, not least of which is that classic work still springs from a combination of a sound theoretical basis, a good awareness of the literature and state-of-the-art as well as well-designed experiments or a clear understanding of the industrial process being modelled. It is difficult to see these papers by Joukowsky and Allievi and fail to be both impressed by their theoretical and practical skills, as well as depressed by how little we might seem to have added to them over a century. In my opinion, there is little doubt that if Allievi had access to the digital computer he would have been able to do much that we do today. With the aid of that tool, though, our generation has made significant advances in modelling phenomena like:

- cavitation and column separation/collapse,
- two-phase flow and gas release,
- fluid-structure interaction, and
- interactions with complex systems such as turbomachines and governors and the electrical systems within which these are embedded.

A noteworthy feature of this Eighth Conference may well prove to be the progress that is now being made towards practical modelling of unsteady friction.

However, much remains to be done in all these and other areas, and one major issue that has not really been addressed in fluid transients is that of how successful our models are, eg:

- How do we define ‘good’ (or even ‘acceptable’) agreement between model and measurement?
- When making such comparisons, do we systematically identify the sources of uncertainty? (see, eg, Gill & Anderson 1987)
- Does one ‘good’ comparison (or even a set of them) fully justify a model for all its potential application cases, ie how general are our ‘validations’?
- How robust are our models, eg to uncertainties in data values?

These issues are being addressed within other areas of Computational Fluid Dynamics (eg Douglass & Ramshaw 1994, Roache 1994, Karniadakis 1995, Fisher & Rhodes 1996) and we in the fluid transients community must also begin to do so.

One significant difference between the situation at the First Conference and that at this Eighth, is the availability now of commercially available fluid transients software. At the time of the First Conference, those undertaking transient analysis had either developed the code they were using or were working very closely with those who had. In contrast, now it is possible for someone with no background in the field to be undertaking transient analysis after only a short software familiarisation period. It is no use saying that this should not happen – it inevitably will. Our responsibility is to find ways to raise awareness of this situation and to make general practice professionally, environmentally, economically and socially acceptable. It is only by gathering together at Conferences like this that we can start to exchange and develop ideas about how our community can meet these new challenges.

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