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Computational Methods in Turbomachinery

This was a very timely meeting organized by the UK Institution of Mechanical Engineers which brought together many people working on the application of computational methods to the prediction of flows in turbomachines. Within the UK there has been a lack of a suitable forum for such discussions and Professor Railly and the Conference Planning Panel should be congratulated on the organization of a successful international meeting.

It was particularly pleasing to see the strong representation from China, led by Chung Hua Wu, who had written the classic paper on the subject in 1952, a paper which remains an essential reference. It is interesting to look back at that early work which set out a new way of looking at the problem; it provided a new approach, but it could not be implemented at that time because of the lack of suitable computers. By 1965, two separate methods of solution had emerged, streamline curvature and matrix throughflow, both requiring fast computers with what was then regarded as a large store, 32K. In 1970, it was realised that these two methods were based on the solution of the same governing equations and hence they were no more than two different methods of solution which should lead to the same results.

The period from 1965 to 1975 was one in which experience was gained in the application of these new techniques and the various routines for curvature, losses, etc, were gradually improved. There remained, however, the problem of transonic and supersonic flows and this led to the development of the time-marching method, first for two dimensions and later for three dimensions. The early time-marching programs were very slow and not economic, but Denton's work led to a major improvement in the time taken to calculate flow and it then became a practical method of solution. In his keynote address, Dr Horlock surveyed these developments and emphasized the need for a balance between theoretical, computational and experimental work in turbomachinery fluid dynamics.

The technical sessions were opened with a paper by Freeman[1] which outlined the way in which Rolls-Royce had used computational methods for analysing and predicting turbomachinery flows. Perhaps the main point of his presentation was that when a firm has invested a great deal of time and effort in a particular numerical approach, then it will not change to a new scheme unless it can offer a significant improvement or solve important problems which were previously unable to be solved. He emphasized the use of the streamline curvature technique in a test–analyse–modify loop and asked that more attention should be given to hybrid methods where the data can be mixed, partly geometric and partly defined by flow.

Dr Casey[2] was complimented on the pseudo-Swiss accent which he used to describe his work at Sulzer on the application of the streamline curvature technique to a radial flow machine. For the through-flow method, Haslam-Jones[3] reported on the use of point relaxation rather than the matrix method. This led to discussion as to whether the point relaxation approach offers any advantage now that more powerful computers are available, but perhaps this point had already been covered by Freeman's comments on the investment of time and effort. Haslam-Jones showed that it was possible to analyse certain types of transonic flow, those with a supersonic patch between the grid lines and those with a supersonic flow at the leading edge, where the calculation is done in a fixed (subsonic) reference frame.

Dr Ginder[4] also examined transonic flow in a blade row, using a streamline curvature method with calculating planes placed within the blade rows, an approach which was advocated in the mid 1960s. He investigated the effect of introducing these calculating planes and reached the conclusion that while there was some effect on the thickness of the streamtubes within the blade row, nevertheless there was little different in the overall performance. This is consistent with earlier papers on flow models for turbomachines. The solutions presented in the paper were seen as a step towards obtaining a full S_1/S_2 solution for the flow.

The paper by Kumar[5] moved the meeting away from calculating the flow in blade rows to the more fundamental problem of swirling flow in an annular diffuser. The flow model was based on the work of Spalding and Patankar. A mixing length approach was used to introduce turbulence effects into the governing equations and by suitable choice of the empirical constant it was possible to obtain good agreement with experiments. The author's results suggest that the mixing length is reduced by swirl, but good agreement with the work of Hoadley was obtained on the basis that swirl did not affect the mixing length.

The inclusion of viscous effects in the flow calculation procedure was described by Ahmed[6], Bosman[7] and Roscoe[8]. Ahmed considered three-dimensional flows in duct geometries such as a 'swan-neck'. The approach used was to match the boundary layer and core flows using a surface displacement method. Bosman reported on the calculation of viscous flow in a centrifugal impeller tested by Eckardt. The comparisons with experiments showed inviscid flow calculations and the effect of including the turbulence model. There was good agreement for the general flow pattern when the turbulent flow effects were included. Roscoe described a solution for the time-dependent Navier-Stokes equations and this was applied successfully to a radial diffuser.

Two papers on the application of time marching methods to wet steam flows were presented by Bakhtar[9] and Young[10]. Dr Bakhtar reviewed the field, explaining clearly the difficulty of extending the time-marching method to wet steam and he presented results for the blade-to-blade flow in a supersonic tip section. Dr Young, in a very good presentation, described his work on linking time-marching with models for nucleation and droplet growth. This led to close agreement with experimental results obtained for wet steam flow in a gradually varying nozzle, showing the Wilson point and predicting well the average drop radius.

One of the major problems with the use of time-marching methods is the rate of convergence. Dick[11] described the use of over-relaxation to help convergence and he applied this in the calculation of a blade-to-blade flow. The initial calculation is based on a coarse grid which is then refined and the final solution showed good agreement with test results from VKI.

For cascade flows, Napolitano[12] described the implicit lambda scheme which is very fast. On Hobson's impulse cascade it gives a good prediction of the Mach number distribution. The method is, however, restricted to homentropic flows, or flows with weak shocks, and it cannot deal with choked flow.

Professor Wu[13] presented a paper describing flow calculations for a transonic cascade. The method is based on using experimental data to define the shock configuration when analysing experimental results, but it can also be used in design by prescribing the shock geometry required. The supersonic region is calculated by using the method of characteristics, while the matrix method is used for the downstream sub-sonic region. Later, Zhao[14] reported on the use of artificial compressibility, to extend a stream function method to transonic flow on S_1 stream surfaces.

In a second paper, Freeman[15] described the use of a time-marching method coupled with the calculation of blade boundary layers and the possibility of transpiration through the blade surface. The Mach number contours for a transonic fan show good agreement with measurements obtained by laser anemometry. Continuing with the extensions to time-marching, Dawes[16] reported on the development of a time-marching method with turbulent viscous effects. A low accuracy representation of the governing equation is used with appropriate correction terms which ensure that as the iteration proceeds, the solution has higher order accuracy. The low accuracy discretisation can be chosen to give stability. The comparisons with experimental results for Hobson's impulse cascade and a NACA nozzle row are very encouraging. Birch[17] showed that when skew is present in the end wall region, then it is important to include viscous effects in the flow calculations.

Railly[18] and Bosman[19] presented papers describing flow calculations for radial flow machines. Railly applied thin aerofoil theory with an additional source distribution to represent the boundary layer displacement thickness. In applying this technique to a radial impeller, it is necessary to specify the variation in the thickness of the stream surface. There was some discussion on the performance of the test machine since the level of agreement with the flow calculations appeared to be less satisfactory at high flow when there should be no separation. Bosman's approach was to develop a three-dimensional inviscid time-dependent flow calculation and to use this to predict the flow pattern at design and off design. The paper received a great deal of discussion, much of this being about the interpretation of the numerical results and whether an inviscid calculation method could predict a separation zone with recirculation, as proposed by the author. The issue was not resolved!

Overall, this was a very useful meeting allowing for an exchange of information with lively discussion and an opportunity for informal discussions. Perhaps it is useful to end by referring to Dr Horlock's theme, that there are three sources of information on turbomachinery flows—analytical, computational and experimental and that 'the turbomachinery designer must educate himself in all three areas—none of them can be excluded'.

H. Marsh

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