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REVIEWS

Flow Research on Blading. Edited by L. S. DZUNG. Elsevier, 1970. 400 pp. Df.180.00 or £9.50.

In March 1969 the Brown Boveri Company held a symposium on the fluid mechanics of turbomachinery. This book brings together the papers presented at that conference and records the discussion of them. On re-reading this book for the *Journal*, after taking part in the conference and using the book frequently since, I was struck once again by the enormous complexity of the flows in turbomachines. Such flows are unsteady, viscous, and three-dimensional, they may be subsonic, transonic, or supersonic, they may be attached or separated, laminar or turbulent; almost every conceivable complication is involved in the flow through a high-speed machine. This is illustrated vividly by the range of contributions to the volume which include: (i) an excellent review paper by Dzung (the editor) & Seippel illustrating how the turbomachinery designer has to range widely over fluid mechanics and thermodynamics; (ii) sound experimental papers by Traupel (deriving the "end-wall" or secondary losses in turbines) and by L. H. Smith (analysing data on annulus-wall boundary layers and showing how the variation of the forces exerted by the blades through the boundary layers is critical in their development); (iii) a discussion by Chauvin *et al.* of the complex shock patterns that occur in transonic flows through cascades of blades and a discussion by Carrière of the associated turbulent separations and re-attachments; (iv) description of the type of boundary layers that develop on blades and on the walls of turbomachines (Horlock) and the influence of the free-stream turbulence on the blade boundary layers (Schlichting & Das); (v) aerodynamic damping of vibrating blades (Legendre).

Is it perhaps too optimistic to hope that any rational fluid mechanical basis of design can be used in these complex situations? If the answer to that question were yes, then I myself would be out of business, so perhaps I cannot give an unbiased answer. However, there are several indications in the book which show how competent applied fluid mechanics is contributing to the understanding of flows in turbomachines and to improving design. Smith's annulus boundary layer work and his use of three-dimensional flow calculations (similar to those described by Renaudin & Somm in the book) have undoubtedly contributed to the successful design of the General Electric engines on the DC10 and of their enormous fans. Similarly, turbine firms will undoubtedly be using the data on end losses presented by Traupel in his paper. Also, the interest shown by all those attending the conference in Kline's films of turbulent structure and of the comparison of various methods for calculating turbulent boundary layers that he initiated at Stanford demonstrates how the good designer is ready to pick up useful fundamental work from universities, research laboratories and establishments.

There are still plenty of problems for the research worker in turbomachinery fluid mechanics to tackle. For example, the book has little material on unsteady flow in turbo-machines and the related problems of noise prediction, probably the problem which has increased most in importance since the conference was held in 1969.

Finally, one must refer to the far-sightedness of Brown Boveri in holding this symposium and to the technical competence of its engineers. The introductory review of turbomachinery fluid mechanics and thermodynamics by Dzung & Seippel includes many substantial contributions that they and their colleagues at Brown Boveri have made in this field. There is a distinction and sophistication in the work of these industrial engineers in applied fluid mechanics which has long inspired respect from research workers in many countries.

J. H. Horlock

Cavitation. By R. T. Knapp, J. W. Daily and F. G. Hammitt. McGraw-Hill, 1970. 578 pp. $25.00.

Cavitation was forced on the notice of engineers by the use at sea of the steam turbine. At first Parsons employed his invention to drive electric generators – an application for which it was particularly suitable, for the natural speed of both components is high. After ten years of development he turned his attention to ship propulsion, and displayed the Turbinia under memorable circumstances at the Diamond Jubilee Review in 1897. To help with the design of her nine propellers Parsons had built the first cavitation tunnel. It consisted of a closed circuit in a vertical plane; the onset of cavitation was promoted, not only by lowering the pressure by means of a pump, but also by heating the water. Subsequently propeller tunnels became standard equipment in experimental establishments. The most striking effect thus shown up is vortex cavitation produced at the blade tips; it is very persistent and extends a long way astern. (By those who enjoy observing things for themselves it may be seen without special apparatus provided the water is clear. Selecting a bright and windless day, the observer should stand on the quay close to the stern of a ferry boat; when its engine starts, he can obtain a glimpse of the tip vortex before the field of view is obliterated by disturbance at the surface.) After World War I, gearing was introduced, permitting the use of large slow-running propellers so that both components operated with high efficiency.

For the next twenty years interest in cavitation was not great; as has often happened in the past, it was war that stimulated further developments. Attacks from the air were necessary on surface ships by torpedoes and on submarines by bombs. It became apparent that success was unlikely if the missile emerged from the sea a hundred yards beyond the point of entry and that an intense experimental programme was wanted. Full-scale work was carried out at Morris Dam, where a tube was constructed down the adjoining hillside to discharge missiles through the air into the lake. In addition, Knapp devised a launching tank in which models were projected through air at reduced pressure into stationary water, where their passage could be photographed. In this way the mysteries of surface seal and deep seal were elucidated.

However, evidently more was required, and this was provided by Knapp with his high-speed tunnel, in which cavitation round bodies fixed in space could be examined at leisure. This apparatus was the prototype of many that have been constructed in various parts of the world, and its construction earned him widespread recognition. It is relatively easy to induce cavitation by reducing the ambient pressure, but much harder to ensure the removal of the bubbles which otherwise would make a closed-circuit tunnel unusable after a brief spell of operation. In an early form of Knapp's tunnel the bubbles were released in an open tank on the roof, but consistent results were unobtainable. In spite of the cramped site the problem was solved by the addition of piping carried down many feet below the working section. In the resorber, as this arrangement is called, the bubbles are forced by hydrostatic pressure to disappear; as the circuit is completely closed, control over the air content and other properties of the working liquid is possible. With this tunnel Knapp obtained many striking and important results. He took the leading part in discussions on cavitation at the Lisbon meeting in July 1957 of the International Association for Hydraulic Research. It is noteworthy at the present time, when the contract system is under fire, that he had negotiated a research contract which, stripped of concealing verbiage, authorized him to continue his work in any way he thought fit. His sudden death in the following November was a great shock when all seemed set fair and he was at the height of his powers. He had begun to collect material for this book, and it is fitting that he should be cited as one of the authors.

Scientists are again indebted to the five principal engineering societies in the United States who aid the production of the series called the Engineering Societies Monographs. These are authoritative works on important topics which it would be impossible to publish without a subvention. This book has long been wanted. It covers the entire field, and gaps are hard to find. It has been brought up to about 1968, if one may judge from the reference lists at the ends of the twelve chapters. It presumes only a slight previous knowledge of fluid mechanics and the properties of materials. The treatment is lightened by innumerable photographs and diagrams, which are clearly reproduced. It is mostly descriptive, and the little analysis that exists is relevant and straightforward; cavitation is not a subject that has been spoilt by mathematicians.

The first two chapters are preliminary. The various types of cavitation are described, drawings are displayed of tunnels and cameras, and the possibility of serious damage to solid boundaries is explained. The cavitation parameter is introduced in an elementary way. The next chapter deals with more recondite matters, namely, the tensile strength of water and the effect of contaminants of many kinds. The scatter of results shows clearly that much remains to be discovered. Travelling and fixed cavities occupy chapters four and five, and here the full resources of high-speed photography must be brought to bear in studies of the collapse and re-formation of individual bubbles. Scaling problems are then dealt with, and flow in curved channels and around hydrofoils occupies chapter seven. The remainder of the book, nearly a third of the available space, is mostly devoted to damage. This proportion is correct, for damage in its varied forms is the aspect of cavitation that arouses most interest today.

The mechanics of attack on materials are discussed in chapter eight, chiefly with the aid of the long series of experiments on soft aluminium at the California Institute of Technology. It seems to be generally accepted that the damage is caused by shock waves radiating from the centre of a collapsed bubble. A subsidiary cause may be the deformation near the wall of a collapsing bubble, leading to the ejection of a microjet. In some circumstances chemical, electrical and temperature effects may be noticeable. Laboratory methods of estimating resistance to damage, which are fully described in the next chapter, fall into two classes. The more widely used method employs vibration, causing the relatively small volume of working liquid to go through the cycle at high frequency and so degassing it quickly to a steady level. In contrast, with systems using a tunnel or a Venturi tube each element of liquid cavitates only once as it traverses the circuit. No way of measuring the intensity of cavitation has yet been devised, and unfortunately the various test methods do not rate materials in the same order of resistance. The immense mass of experimental results given at the end of this chapter takes us far from fluid mechanics; it forms yet another branch of the art and science of testing materials by destructive methods.

More details of large tunnels and their equipment are given in chapter ten, and then a return is made to the problem of damage, which may be serious in fixed structures and even catastrophic in ship propellers as well as in the runners of pumps and turbines. In the design of these machines, which are now made in enormous sizes, cavitation is one of the limiting factors. The system of tendering for their construction is highly competitive, and the designer is under pressure to propose a machine cheap in first cost, regardless of the expense in time and money of repairs later on.

A. M. Binnie