Measurements in transonic steam turbine cascades

by

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We at G. E. C. Turbine Generators have for very many years been studying steam turbine transonic and supersonic blading flows using both experimental and theoretical methods. Our experimental development includes the use of both cascade rigs and single and multi-stage model turbines and our working fluids include air, freon and both dry and wet steam.

I wish to concentrate briefly this afternoon on supersonic cascade testing of long last L. P. blades. We see the main tasks here as: [1] the testing of optimum profiles for supersonic flows both for fixed and moving rows up to Mach Numbers of 2.0. [2] the testing of profiles for near root and tip in the transonic range at inlet, i.e. Mach Numbers of say 0.6 to 1.2.

I would like to show some results of cascade tests on a typical low reaction root section (Figs. 1 and 2). We also tested with a flared cascade (Figs. 3 and 4). These choking inlet Mach Numbers measured on test compare very well with theoretical values assuming one - dimensional area ratios and a flow coefficient, i.e. approx. 0.93 for parallel walls and 0.99 for flared walls where choking is at inlet to cascade.

Efficiencies are very low with the flared cascade due to divergence losses and the peak is in fact tending towards the value for the divergent arearatio, about M = 1.6. Flow streamlines near the root might be expected to be rather difficult to determine and affected by premature choking, and sophisticated 3-dimensional throughflow procedures allowing for streamline slope and curvature are being

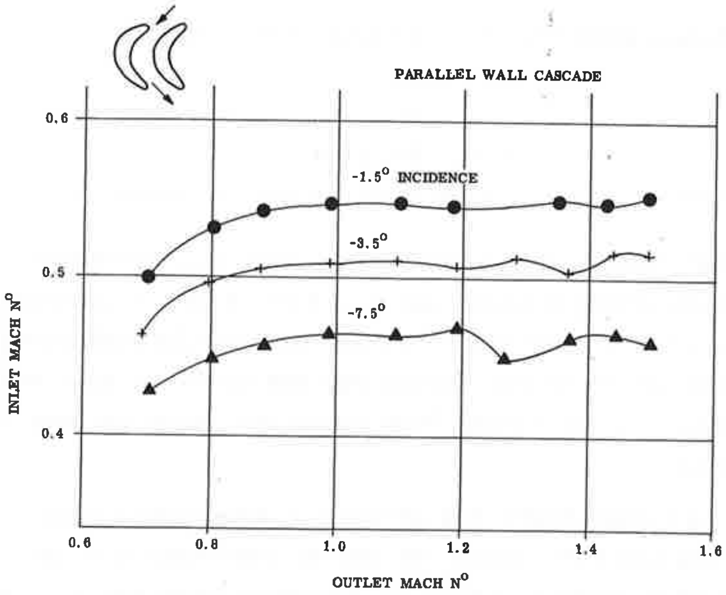


Fig. 1

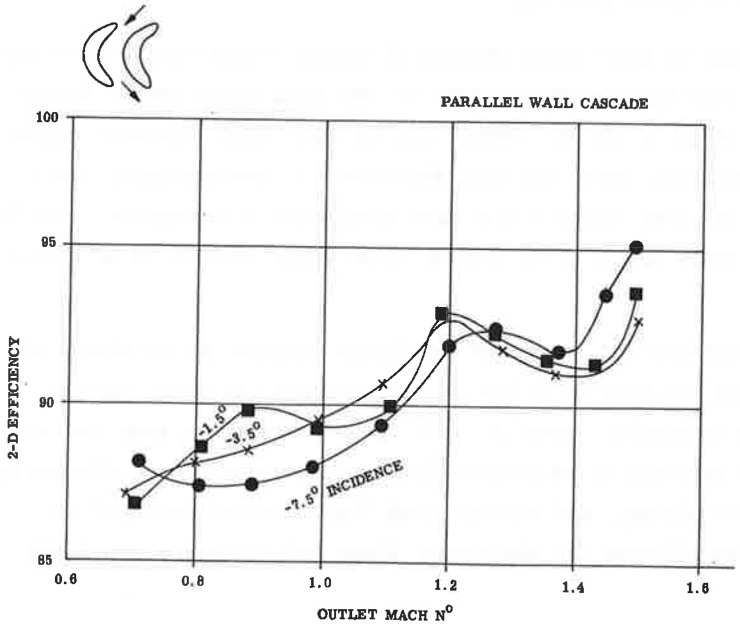


Fig. 2

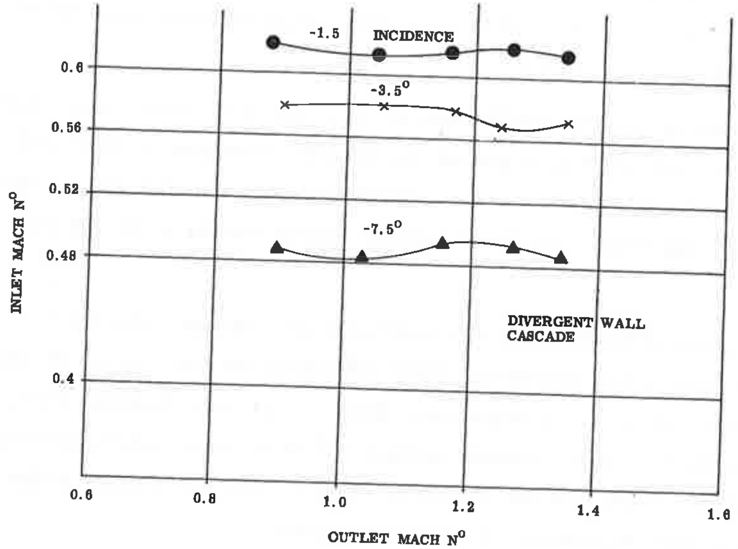


Fig. 3

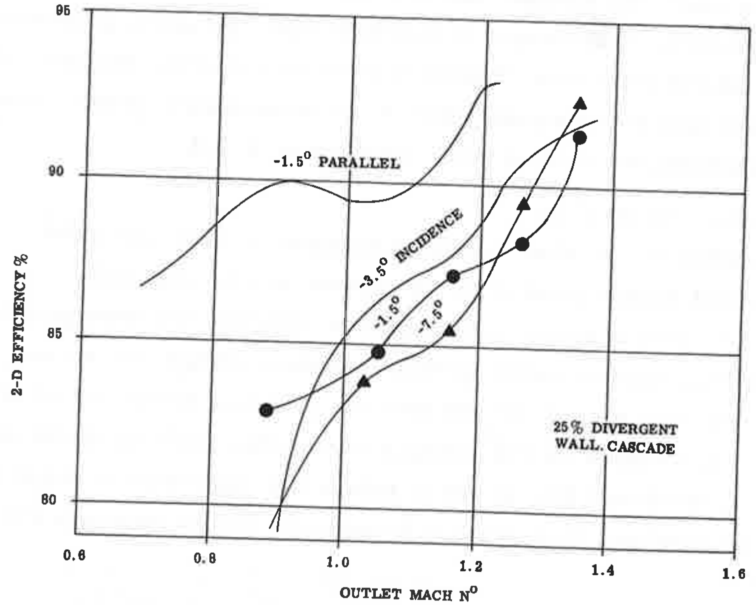


Fig. 4

applied to solve these problems. As blades get longer the designer in fact has a choice on how to play these increasing relative inlet Mach numbers both at root and tip.

This is shown up well by the Brown Boveri 1200 mm blade in Roeder's recent paper (Ref. 1) Fig. 5 shows the velocity triangles at root and tip which can be derived from the information given in the paper. As can be seen, the inlet root Mach number comes out at 1.13 and tip 1.03.

Foreseeing this difficulty, we are carrying out cascade tests on root and tip profiles using supersonic inlet velocities as well as outlet and this demands the use of a supersonic inlet tunnel with flexible walls. One has to strive for reasonably periodic flow at inlet and swallowing of the starting shock and we should be glad to hear of anyone at the meeting who has experience of such techniques.

Turning now briefly to instrumentation, we cannot pretend that we are yet entirely happy with our techniques and frankly we have come to this meeting to learn and discuss. Mention can be made of the setting up of periodic flow, measurement of instream static pressure, problems of reflected shocks from free or solid boundaries and probe blockage. In fact we are still not completely free of the overpressure trouble, which subject promoted the first of these meetings at V.K.I.

Summarising, we employ:

(1) schlieren or shadowgraph photography at inlet and outlet.

(2) wall statics parallel to the cascade at inlet and outlet.

(3) at outlet a simple pitot-yawmeter with the yaw tubes parallel to the trailing edge to reduce pressure gradient effects and we can operate with cascades in air and also low pressure steam. As an alternative to wall statics we are trying a double-disc static as shown on Fig. 6 and we should like to ask if anyone has experience of the novel pitot probe developed by Goodyer at Southampton and also shown in Fig. 6 (Ref. 2).

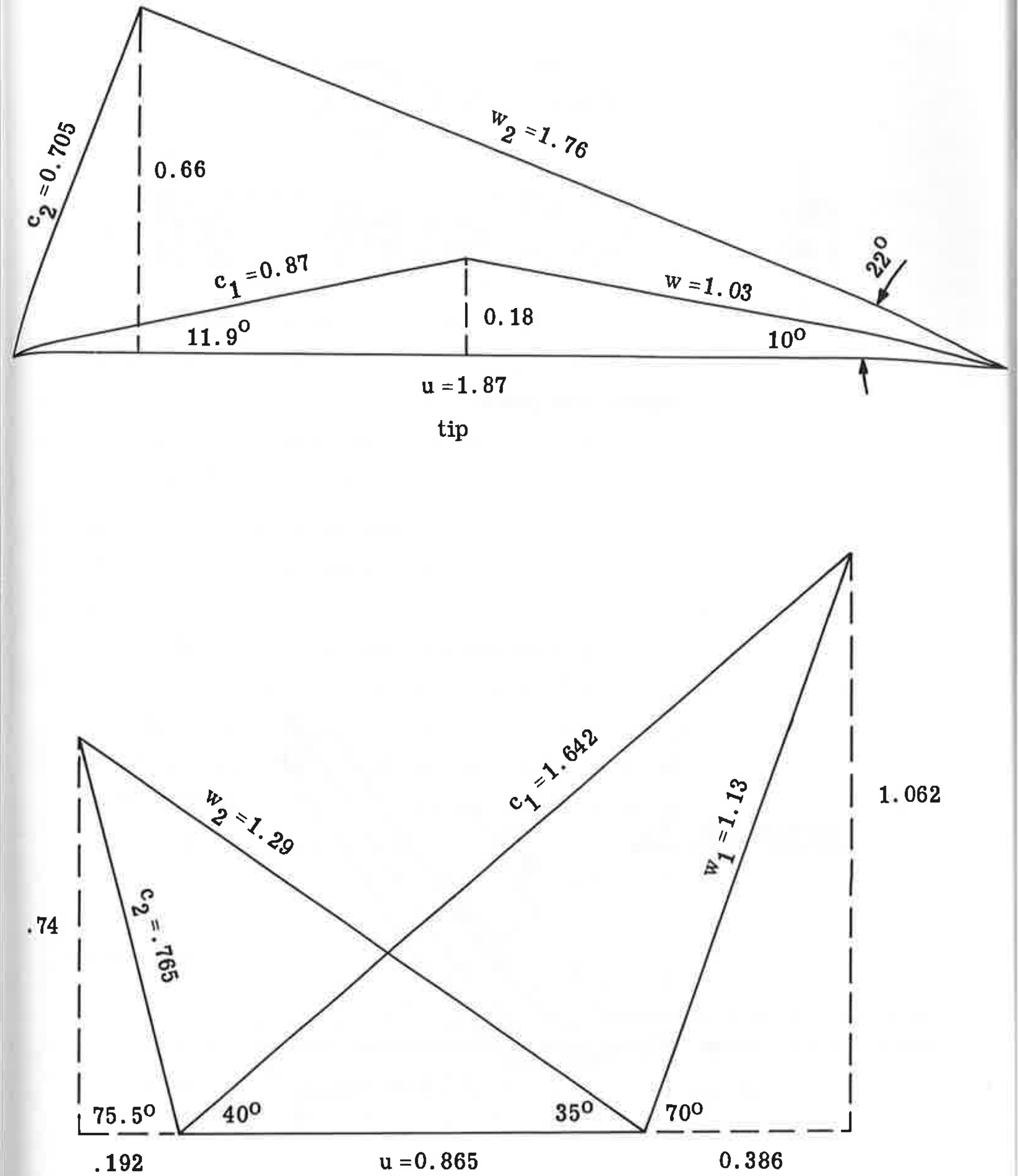
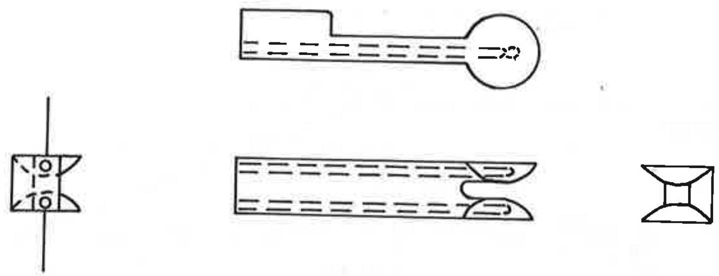


Fig. 5 Brown Boveri (1200 mm stage)
(Approx. from Röder paper [1])



Double disc static

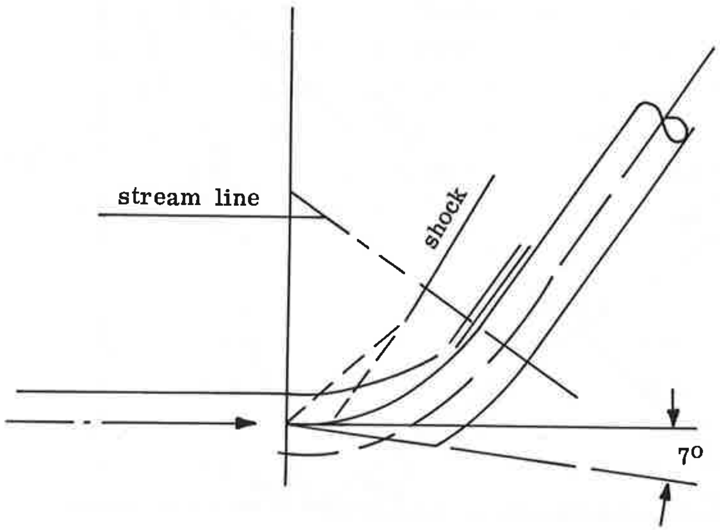


Fig. 6 Stagnation pressure probe for supersonic flows

This gets over the inherent difficulties of measuring free stream static pressure to arrive at the Mach number bow wave correction.

The principle is based on the use of a curved compression surface which decelerates the flow isentropically and a pitot tube which lies in the decelerated flow field and which, at its opening, measures very closely free stream stagnation pressure.

Measurements have shown that this probe is capable of measuring absolute stagnation pressure with an accuracy of 0.1% in the Mach number range 1.5 to 2.1 which is the area of most interest to us and is reasonably insensitive to pitch and yaw, at least to $\pm 5^{o}$. Difficulties would be in the transonic range and of making the probe small enough to obviate blockage troubles in some smaller cascade geometries.

We are also developing within the Company laser anemometry using both the real fringe and dual focus approaches which we have already used to explore Mach number variations along a classic 2D con-div. nozzle and pitchwise velocity measurements along a cascade. We see this as a powerful tool for examination of supersonic cascades thus eliminating the need for inflow probes and giving additional evidence on turbulence levels. We should be glad to hear of other experiences and difficulties in this field and the likely accuracy levels for velocity coefficients and efflux angles.

References

[1] "Final blades of the largest full-speed standard Low-pressure Turbine"- Roeder, Brown Boveri Review 2-16.

[2] "A Stagnation Pressure Probe for Supersonic and Subsonic Flows" - Goodyer, Aeronautical Quarterly May 1974.