Some Scenarios for Transition on Turbomachinery Blading

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Abstract

Measurements on transition under different levels of adverse pressure gradient and free-stream turbulence level are described. This extensive series of investigations, which was predicated on intermittency measurement techniques, has resulted in correlations for transition length and turbulent spot formation rate. These correlations are intended to be used in conjunction with boundary layer prediction methods and examples are given of such predictions. More effective predictions of the transition region, especially under conditions of variable pressure gradient, are dependent on a more comprehensive understanding of transition and spot behavior. It is expected that this will result in improved transition modeling.

Measurements of natural and by-pass transition on a flat plate are described in which transition may occur by means of turbulent spots or alternatively by a subharmonic route having a low frequency cascading of discrete and periodic events. Breakdown mechanisms are discussed and evidence is presented on breakdown mechanisms within an incipient spot. Free-stream turbulence is presented as a by-pass inducing mechanism and work on spots resulting from such a by-pass is discussed. Insight on the structure of spots can be gleaned from such a study of these rather extensive by-pass spots. The work on spots extends to the adverse pressure gradient case and comparative information is provided on the growth and development of spots under zero and adverse pressure gradients.

SOME SCENARIOS FOR TRANSITION ON TURBOMACHINERY BLADING

J.P. GOSTELOW

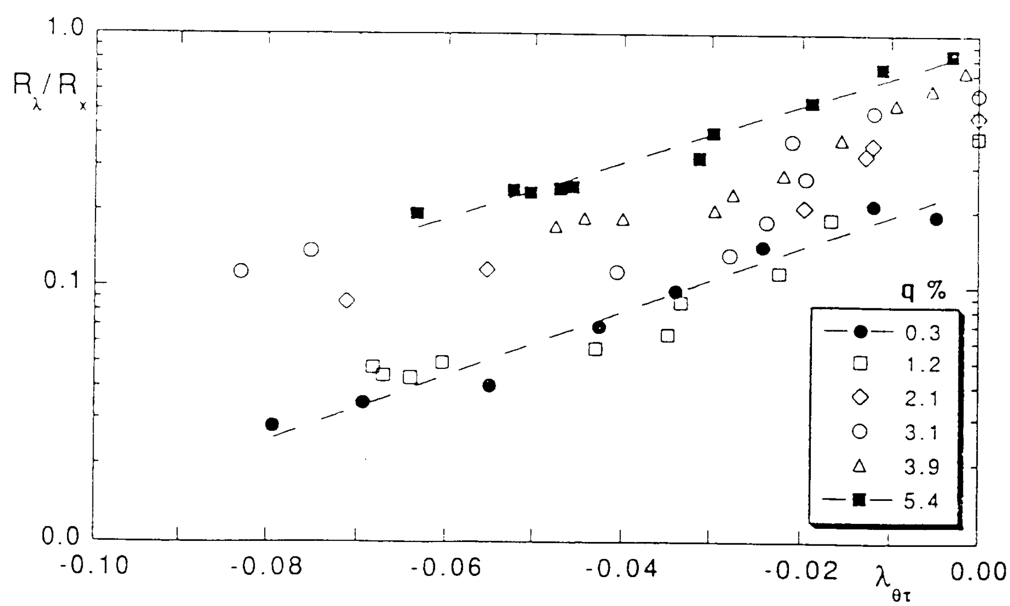
A rather broad and grandiose title for what I now propose to do, which is to outline some of the work we have been doing in Sydney on transition under adverse pressure gradients. There have been three main phases so far:-

(i) **Transition length experiments** under linear adverse pressure gradients and varying free-stream turbulence levels.

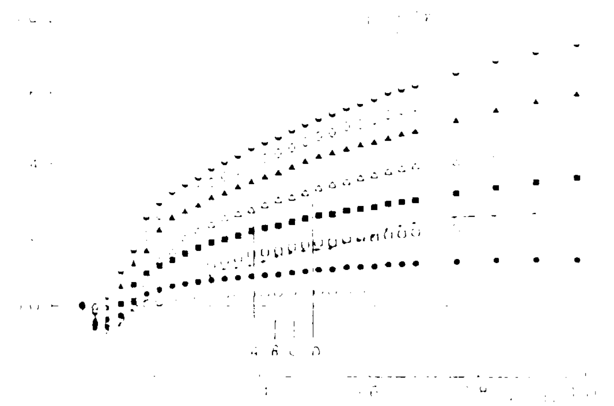
(ii) **Work on triggered spots under moderate linear** adverse **pressure gradient.** Free stream turbulence level of 0.3% and comparison with zero pressure gradient.

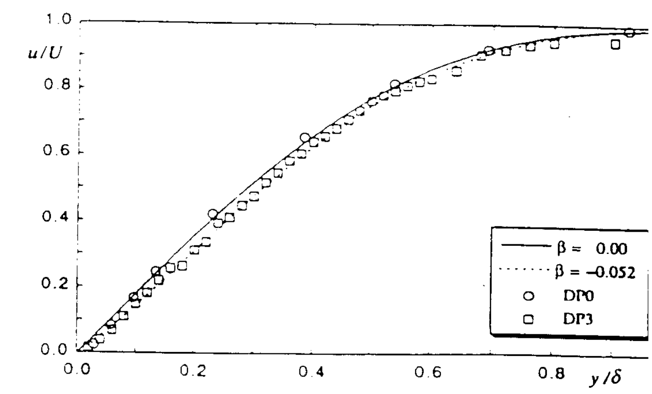
(iii) **Work on triggered spots under controlled diffusion adverse pressure gradient.** Carefully selected critical conditions allowing comparison between different transition scenarios.

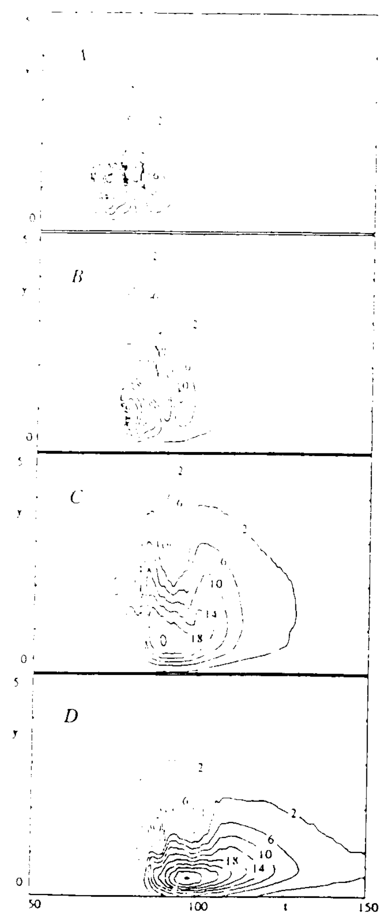
(i) **Transition Length Experiments.** Below is given the complete data set in one of the presentation formats we are using. Correlations of the data have been produced and published in ASME and other venues.



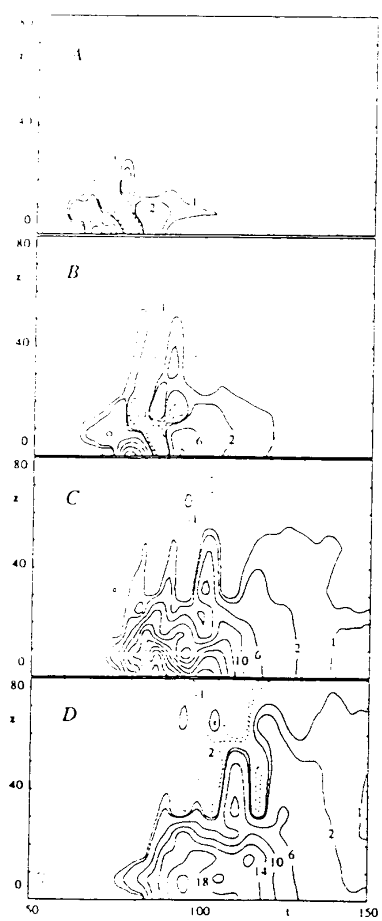
Transition length normalized by distance as a function of transition inception pressure gradient parameter.







CONTOURS OF VELOCITY PERTURBATION (u-u$_L$)/U ON THE CENTER-LINE IN THE y-t PLANE.

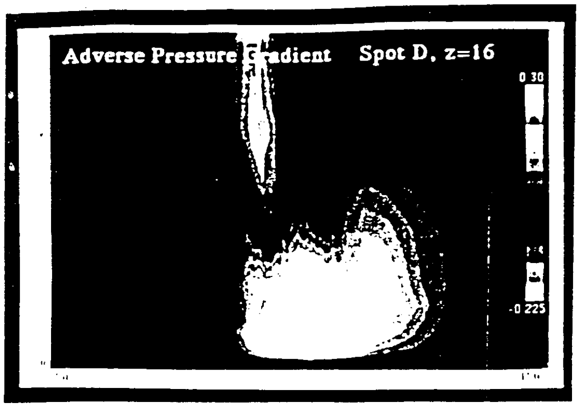


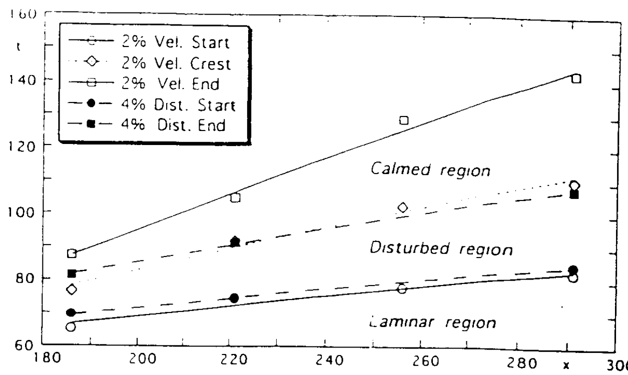
CONTOURS OF VELOCITY PERTURBATION (u-u$_L$)/U AT A HEIGHT OF 1.2mm IN THE z-t PLANE.

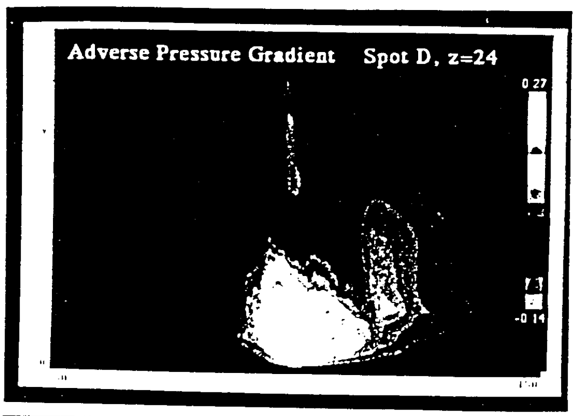
(ii) Triggered Spots under Moderate Linear Adverse Pressure Gradient.

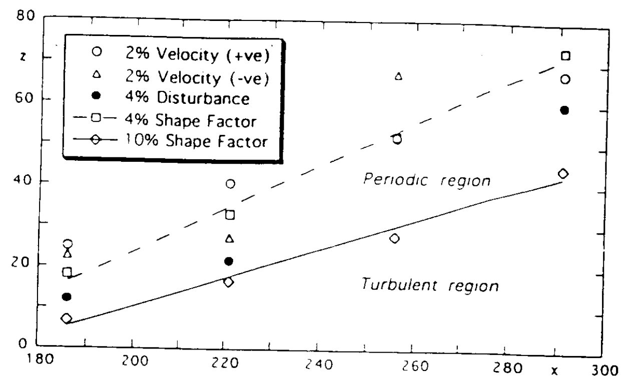
Above are given the pressure gradients used for phase (i), given as discrete points, and thatused for phase (ii), as a continuous line. Spots were measured at streamwise locations A,B,C,D. Also above is given the velocity profile comparison with appropriate Falkner -Skan parameters.

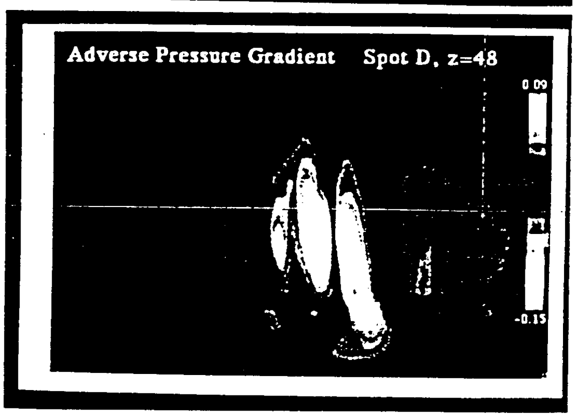
On the left are given the contours of velocity perurbation in the y-t and z-t planes.

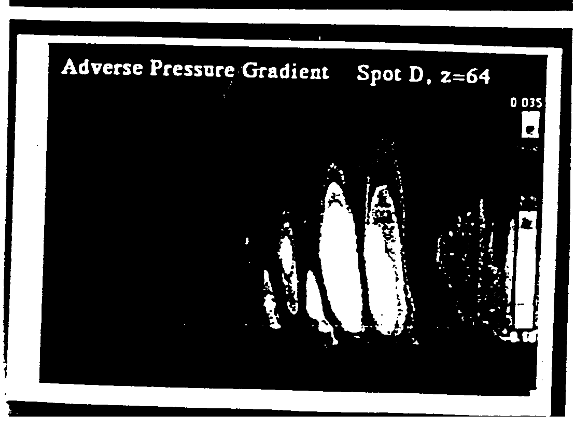






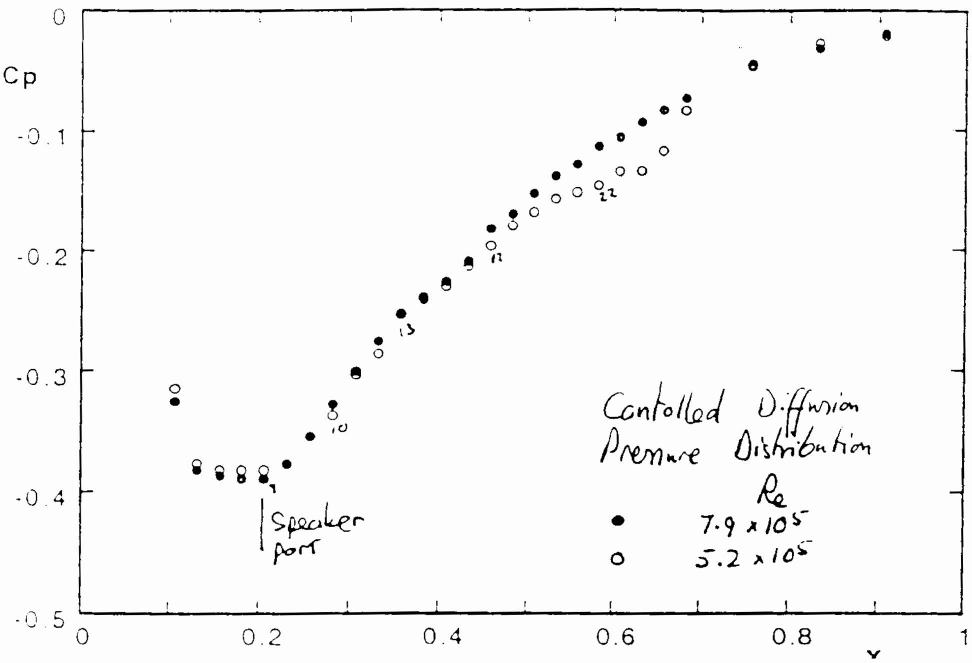




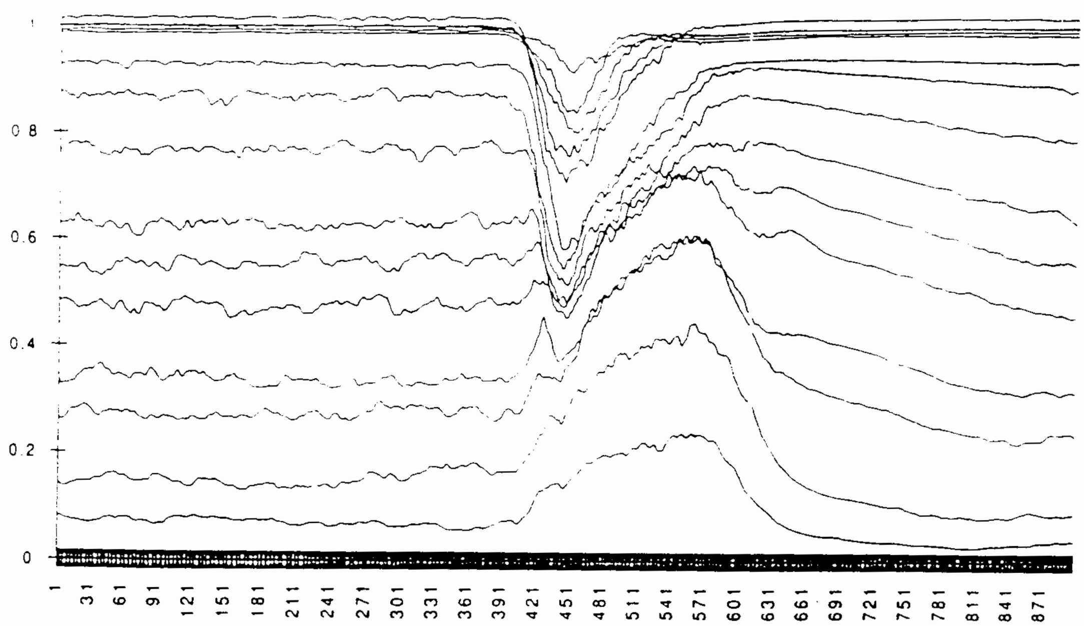


On the left hare are given velocity perturbation contours for the D spot at different z locations. Whilst near the center-line the differences from a zero pressure gradient spot are not profound, the outer region is not a turbulent spot. It is a highly amplified wave packet which has managed to keep abreast of the spot.

Above are given x-t and z-t plots. These enable celerity and spreading rate to be determined. On the basis of these results the leading edge of the adverse pressure gradient spot propagates at 80% of free stream velocity, the trailing edge of the turbulent region at 50% U and the trailing edge of the calmed region at 23% U. The attendant wave packet propagates at a somewhat familiar 39% U. The turbulent region of the spot spreads at a half angle of 20° and the wave packet has a detectable spreading half angle of 29°.



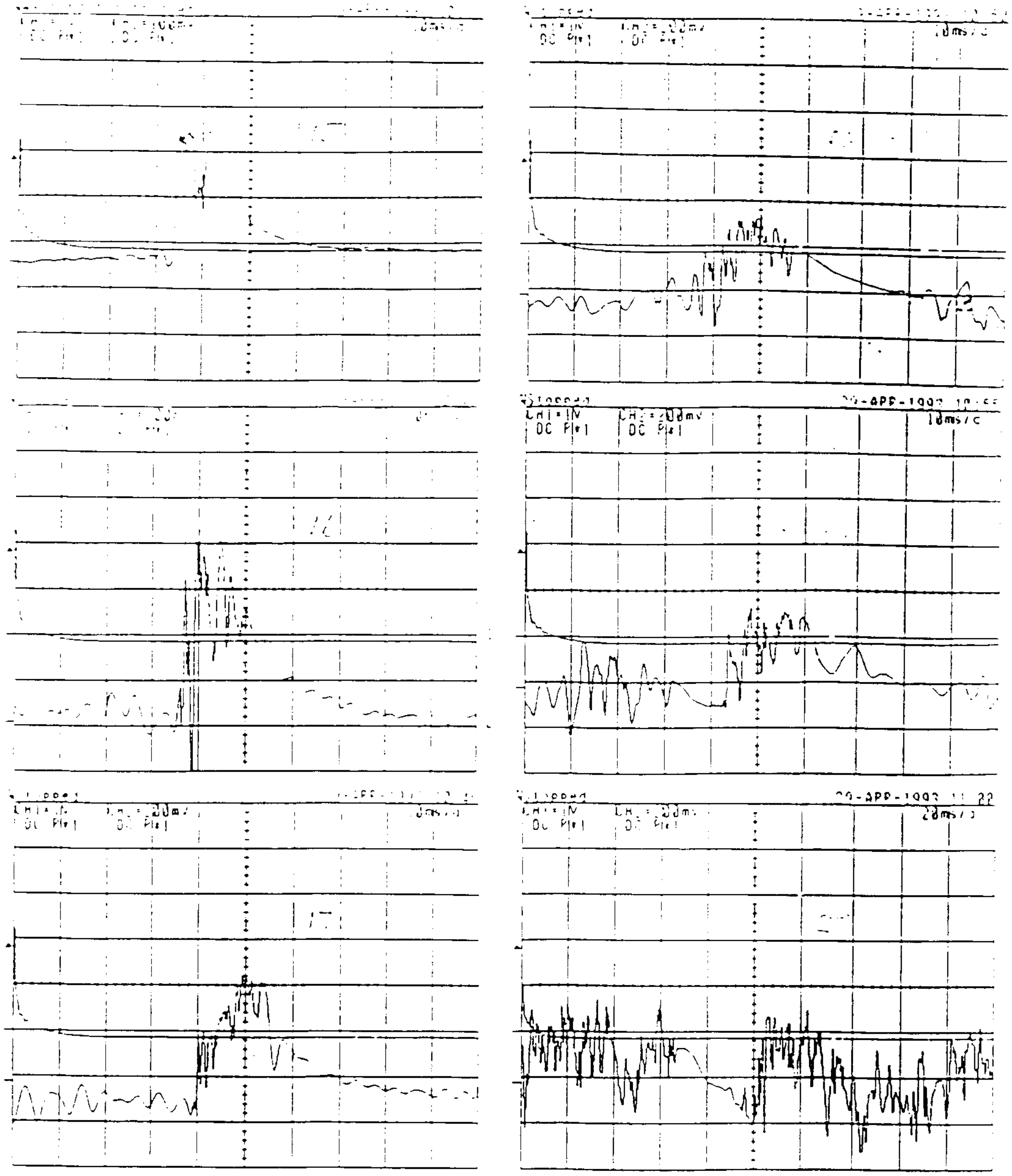
(iii) **Triggered Spots Under Controlled Diffusion Adverse Pressure Gradient.** Above is given the controlled diffusion pressure distribution being investigated; typical of a compressor stator. Initial tests reported here in preliminary form are for the higher Reynolds number (unseparated boundary layer). Triggering is such that the disturbance decays and then becomes amplified. The evolution from wave packet to spot is not by a by-pass mechanism.

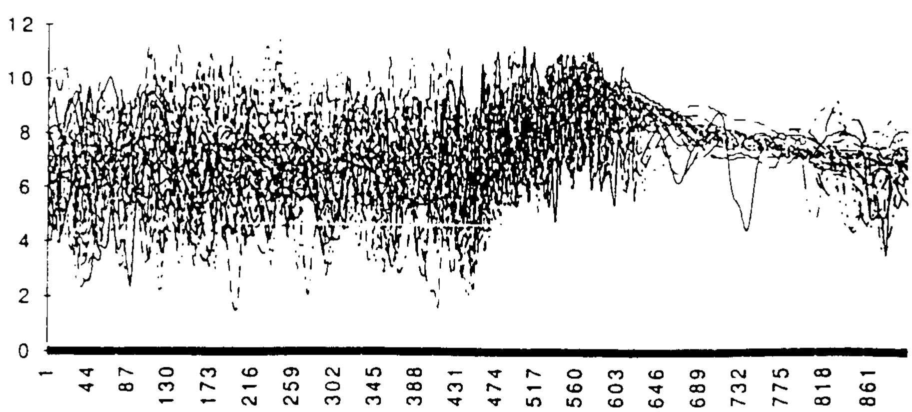


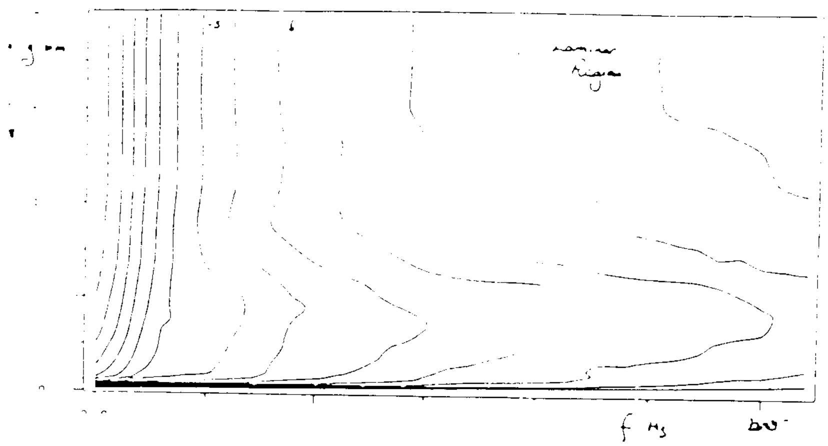
In these results it is possible to compare growth rates of the spot and the adjacent and competing natural transition of strongly amplified disturbances. Above are given some phase-averaged velocity traces for a situation where the surrounding boundary layer is in a transitional state.

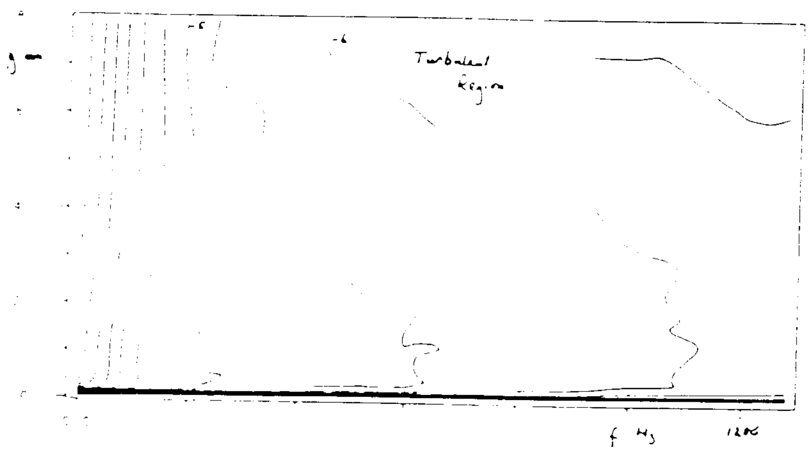
These results are raw data for the spot as it develops in the streamwise direction. The station numbers are identified and stations are 50 mm apart in a streamwise direction.

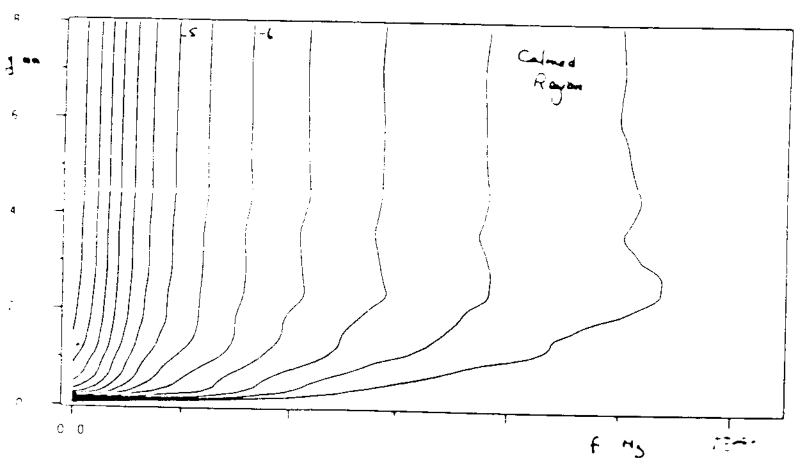
Stations 19 and 20 are essentially "don't even think about it" territory. The ensemble of 30 raw traces in the lower figure was taken at station 19. The most recognisable feature of the spot remaining is the calmed region. This feature remains visible well into the turbulent layer. Phase averaging also reveals spot structure which remains well into the turbulent layer.

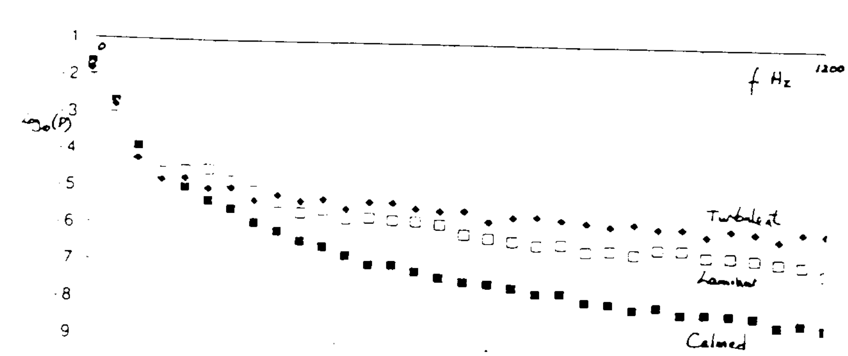












These power spectra have been presented in the form of y-f plots. The contours are of constant power density on a log basis. The lower of the four figures is a more conventional spectrum for the laminar, turbulent and calmed regions of a spot. The calmed region is obviously the most quiescent, the surrounding laminar layer shows the effects of strong disturbances at the fundamental frequency and higher, especially around a height of one displacement thickness. The turbulent region shows a filling in of the spectrum and a spreading of the higher turbulence components throughout the boundary layer.

These are only preliminary results and any suggestions for data analysis would be appreciated.

The important point is that this is an experiment which will permit a side-by-side comparison of most of the known transition scenarios which are relevant to turbomachinery blading. The value and importance of the adverse pressure gradient situation is that it presents a sounding board which enables us to probe and compa these different scenarios.