Intermittency Models and Spot Measurements

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ABSTRACT

Experimental work at the University of Oxford Osney Laboratory has demonstrated characteristics of the late-stage transition process by the use of thin-film heat transfer gauges. The development of turbulent spots has been observed in a range of- environments, including flat plates, turbine blade cascade tests and wake-passing experiments.

These results were taken at Mach / Reynolds Numbers and gas-to-wall temperature ratios representative of gas turbines. Analyses of the spot characteristics are consistent with measurements taken in low speed experiments, and support the Schubauer and Klebanoff type of turbulent spots. The addition of simulated wakes from upstream stages has been observed to be primarily superpositional for these tests.

Intermittency models have been developed which can simulate the development of turbulent spots based on input of spot generation rates. As reliable methods become available to predict the streamwise distribution of spot generation rates, such models will provide a better separation of transitional influences, such as pressure gradient on spreading angle. These models can be used in a time-averaged form (by numerical integration) or in time-resolved methods.

It is possible to adapt such intermittency models to perform transitional boundary-layer calculations in conjunction with existing flowfield CFD techniques. There are many instances where the application of these models is appropriate to the analysis of fluid dynamic environments, such as during the design evaluation process or for simplified flowfield solvers. Time-resolved models are particularly useful in support of data analysis and interpretation. It is expected that further experimental work and analysis underway at the Osney Laboratory will help to develop practical applications for these techniques.

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Spot Measurements

- Measurements taken with Thin Film Heat Transfer Gauges are sensitive to laminar-turbulent transition and allow for high frequency resolution of turbulent spots

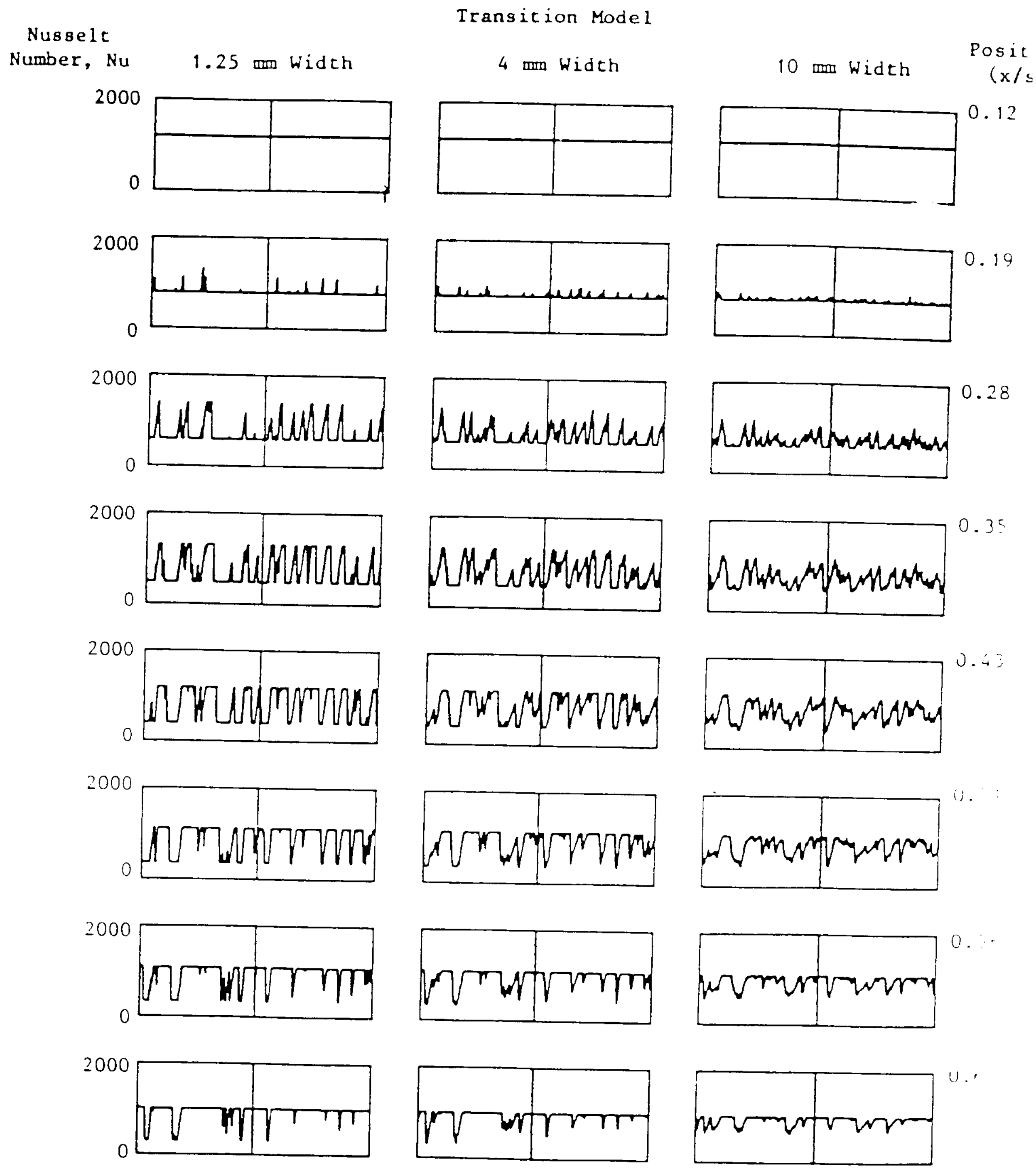
- Turbulent spots have been observed using TFGs on flat plates and a variety of 2D cascades. These have been taken at Mach numbers, Reynolds numbers and Tg/Tw consistent with gas turbine operating conditions.

- Initial results allowed for tracking of individual spots, and led to calculations of trajectories and growth rates consistent with low-speed spot measurements

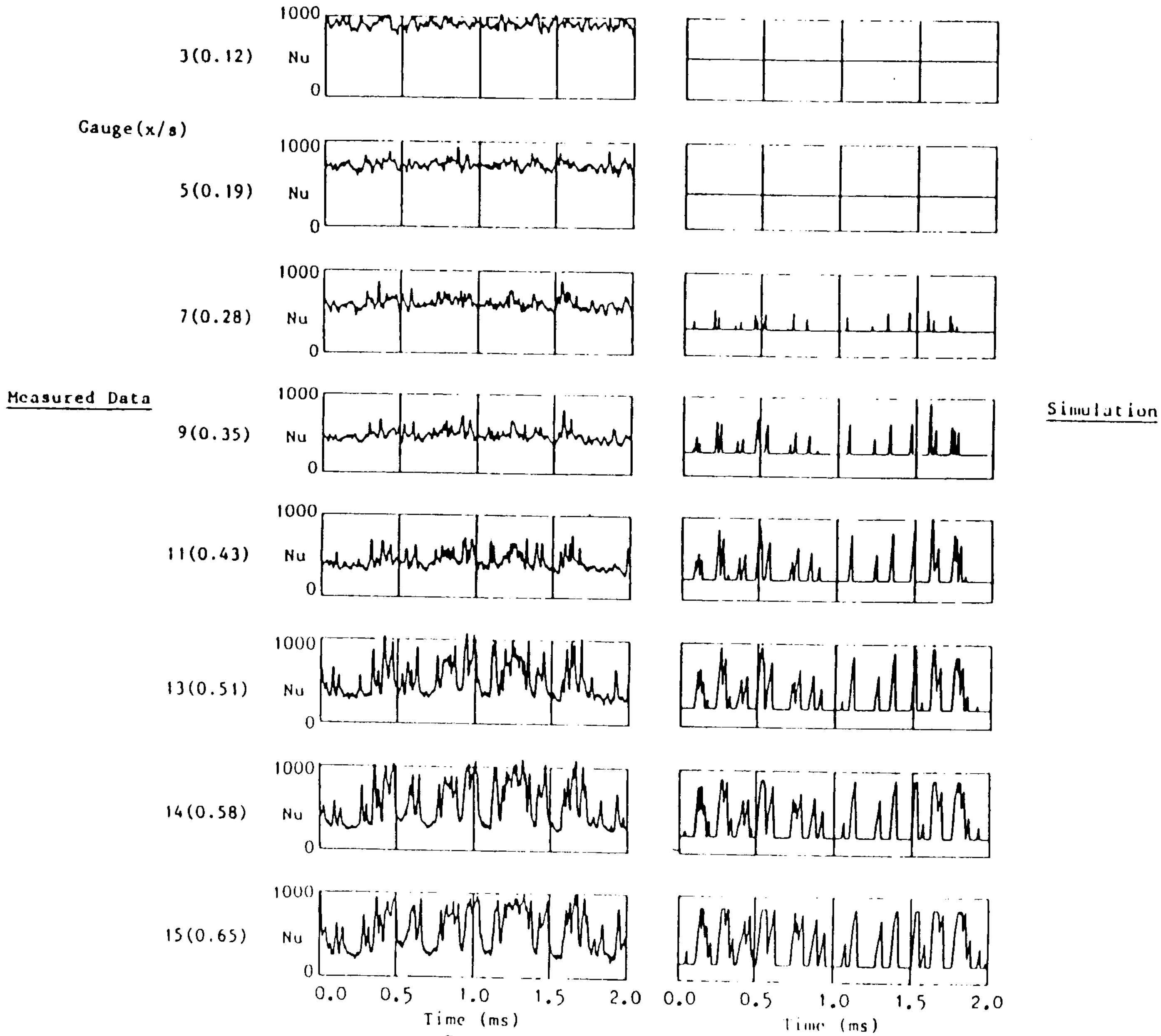
- Analysis of data suggested modelling techniques based on the Emmons' principles.

Applications and Future Work

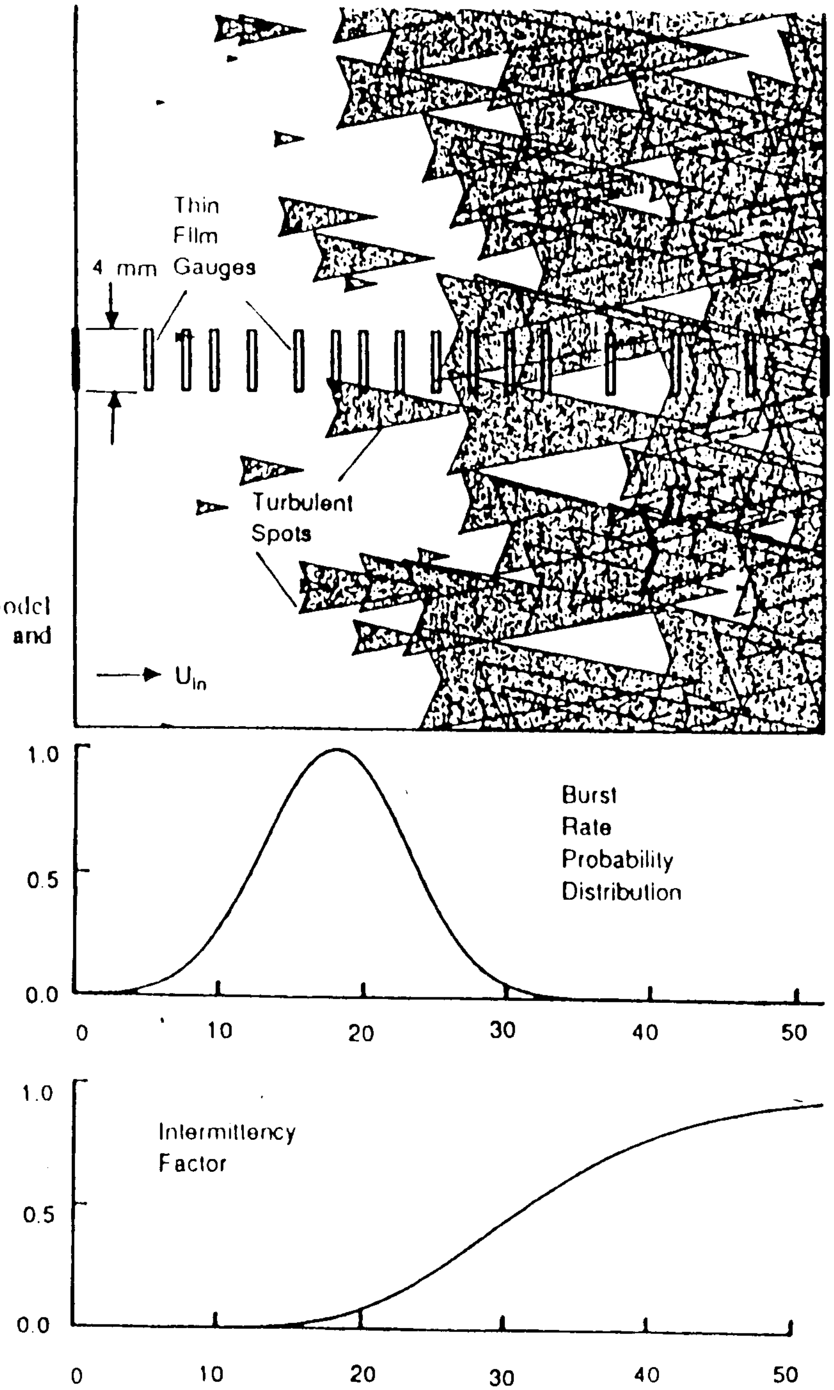
- Choice of model needs to suit application
- Process enables a better separation of variables
- Simulations provide a useful analysis tool
- Better predictions of inputs can feed common models
- Ability to apply to calculations involving time dependent phenomena, history effects, varying pressure gradients, 3-D flows, ...
- Better resolution of spots and effects of input parameters required for improved models



Effect of Variation in Spanwise Gauge Width on the Predicted Instantaneous Values of Nusselt Number through Transition. Even the 'noise-less' Intermittency Signals Become Difficult to Interpret as the Gauge Width Increases to 10 mm due to the Effects of Spanwise Averaging.



Comparison of transition simulation model predictions of instantaneous surface heat transfer rates with observed data.



Plan view of simulation of transition on model surface with assumed burst rate distribution and resulting intermittency.

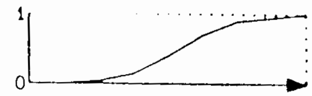
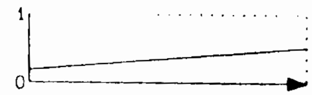
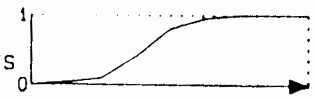
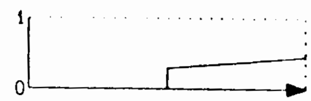
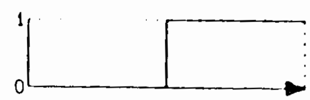
Modelling Principles

Several approaches can be made to the development of the Emmons model depending on the application:

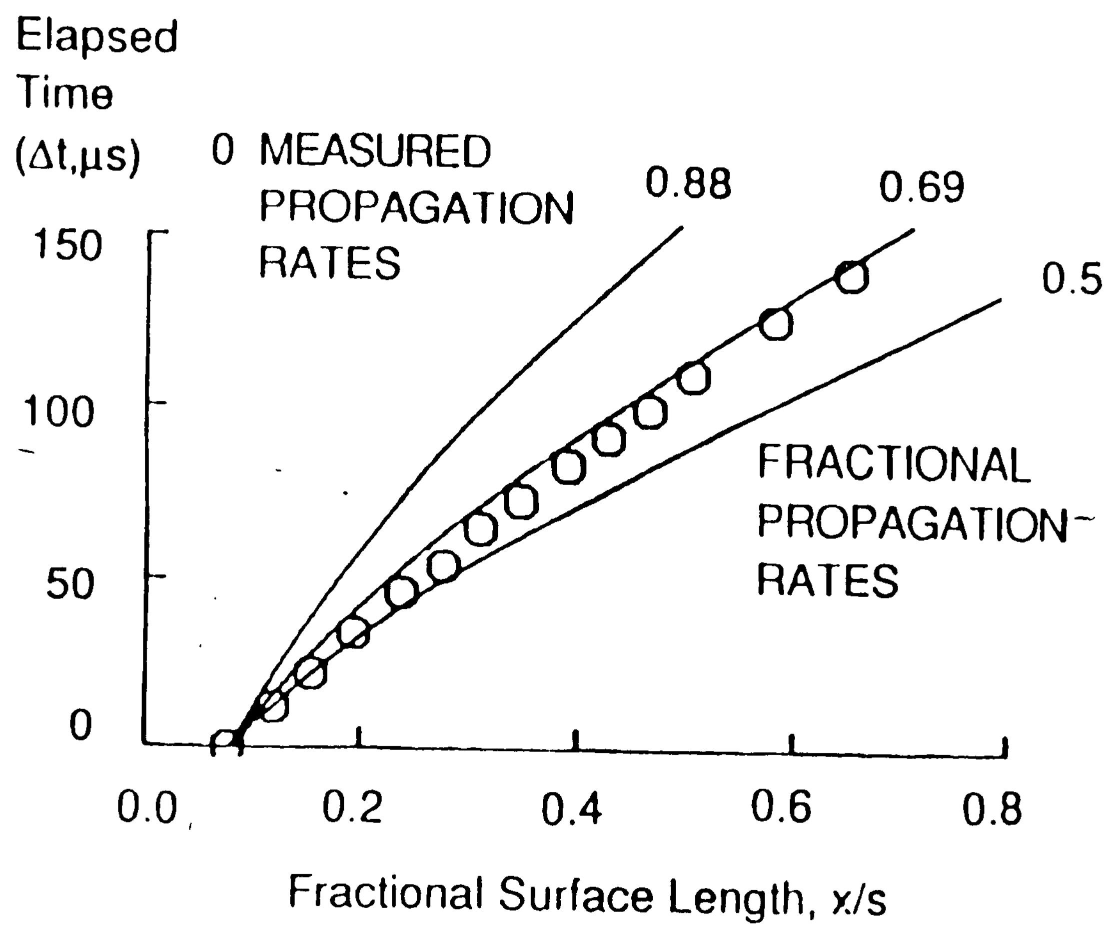
- Analytical solutions for straightforward spot sources
- Numerical integration for steady calculations
- Spot simulations for unsteady calculations and analysis

These can be patched into flowfield or boundary-layer models

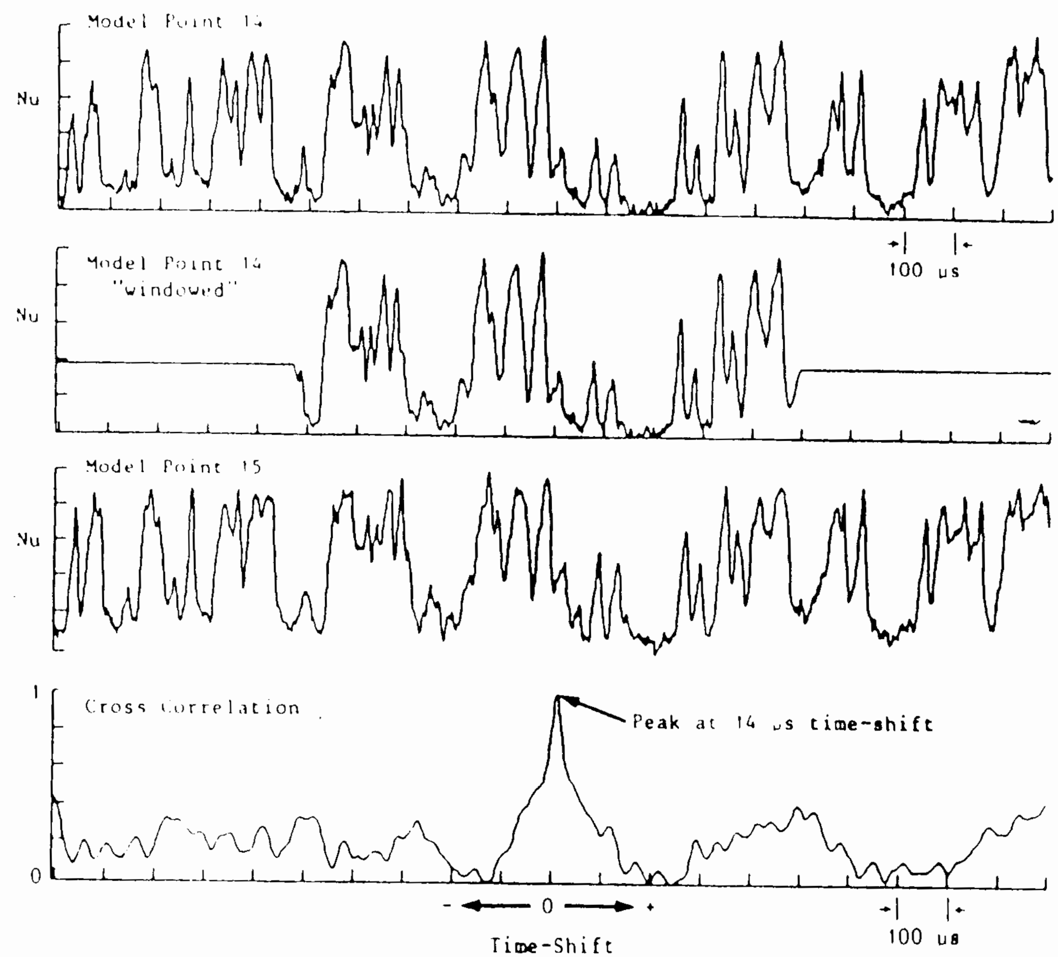
The models give an increasing amount of flexibility based on an input of spot generation rates, trajectories and spreading rates

	MODE	DESCRIPTION	TYPICAL γ	APPLICABILITY	PREDICTION TYPE
1.	NATURAL TRANSITION	T-S WAVE AMPLIFY. DEVELOP 3-D DIS-TURBANCES -> TUR-BULENT SPOTS		MILD ADVERSE -> FAVOURABLE dp/dx. CONVEX --> FLAT. ISOTROPIC DIS-TURBANCES	STABILITY CALC.-> ONSET Re. INTERMITTENCY MODEL
2.	WAKE PASSING	TURBULENT PATCHES DUE TO WAKE PRESENCE		TIME AND SPACE AVERAGED (~2-D). REAL TURBINES	STRIPED-AIR CALC. -> DURATION + LAG EFFECTS
3.	GOERTLER VORTICITY	LONGITUDINAL VORTICITY INDUCED BY CONCAVE SURFACES -> INSTABILITY		CONCAVE SURFACES. OR REGIONS WITH CONCAVE STREAMLINES	CORRELATIONS. TURBULENT VISCOSITY MODELS
4.	INTERMITTENT SEPARATION	MOMENTARY FLOW REVERSAL. DUE TO FLOW UNSTEADINESS		MILD ADVERSE dp/dx. PERIODIC EFFECTS. SHOCK/B.L. INTERACTIONS	CORRELATIONS BASED ON CRITICAL POHLHAUSEN PARAMETER
5.	STEADY SEPARATION	STRONG ADVERSE dp/dx. TURBULENT RE-ATTACHMENT	 SURFACE LENGTH	DIFFUSION REGIONS. NEAR CHANGE IN SIGN OF dp/dx -ve TO +ve	CORRELATION FOR CRITICAL POHLHAUSEN PARAMETER

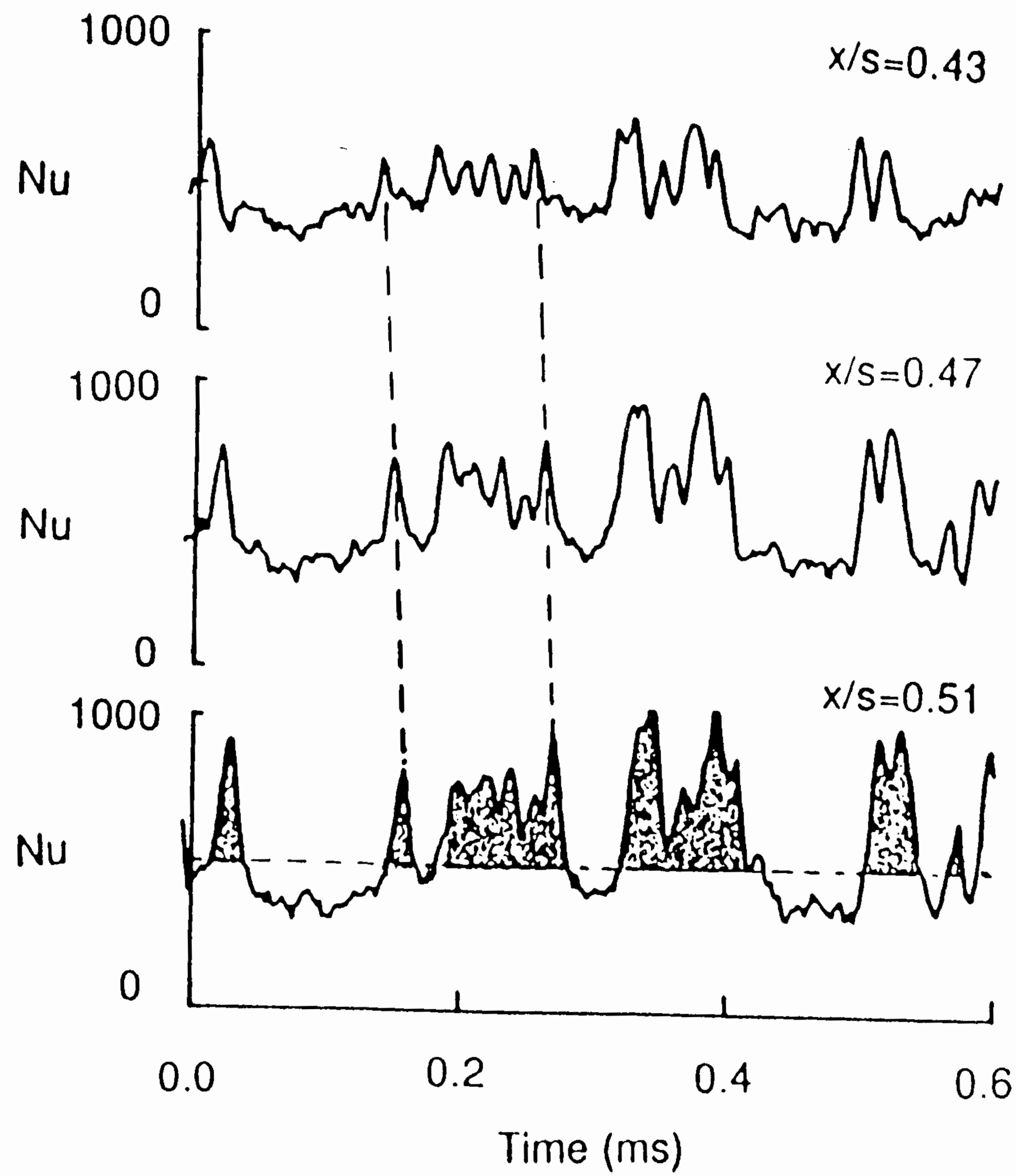
Description of Some of the Competing Modes of Transition from Laminar to Turbulent Flow.



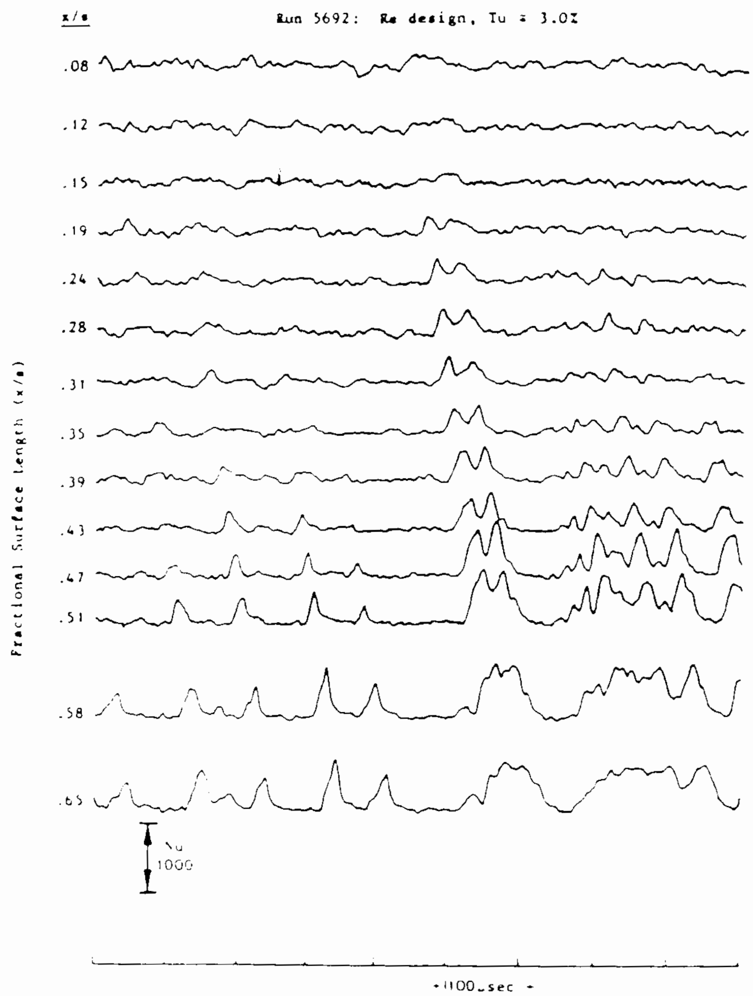
Turbulent spot trajectories along model surface.



Example of Cross-Correlation Analysis of Adjacent Heat Transfer Signals in a Transitional Boundary Layer.



Time resolved surface heat transfer rates on successive gauge positions showing convection rate and intermittency estimation procedure



Heat Transfer Measurements (as defined in Fig. 5.1) Drawn to an Expanded Time-Scale. By Closely Spacing Adjacent Traces the Degree of Similarity between Neighbouring Gauge Measurements is Evident. A Pair of Disturbances Occurring at about x/s 0.15 – 0.19 can be Tracked Along the Surface until they Merge by x/s = 0.65.