BOUNDARY LAYER TRANSITION ON AN AXIAL COMPRESSOR STATOR BLADE - WAKE PASSING AND FREESTREAM TURBULENCE EFFECTS

G.J. Walker and W.J.Solomon
Department of Civil & Mechanical Engineering
University of Tasmania
Hobart, Tasmania
Australia

ABSTRACT

Quantitative observations of transitional boundary layers in regions of strong flow deceleration on an axial compressor stator blade are reported. Measurements were obtained at a fixed chordwise position, and the blade incidence was varied by changing the compressor throughflow so as to move the transition region relative to the stationary probe. It was thus possible to observe typical boundary layer behavior at various stages of transition in the turbomachine environment. The range of observations covers separating laminar flow at transition onset, and reattachment of intermittently turbulent periodically separated shear layers.

Transition was characterised by the regular appearance of turbulent spots in association with disturbances from the passing wakes of upstream rotor blades. However, the initial breakdown did not coincide with the wake passage as has usually been observed by other workers. The spots rather evolved from the growth of instability wave packets which lagged the wake passage. This behavior is quite similar to that observed by other workers in the wind tunnel studies of artificially generated turbulent spots.

Data presented from the compressor blade measurements include : mean and ensemble-average velocity distributions and associated integral parameters; distributions of total, periodic and random disturbance components; typical individual velocity fluctuation records; contours of ensemble-average random disturbance level; and boundary layer intermittency distributions.

The transitional flow behavior is compared for two characteristically different types of freestream disturbance environment:

(a) isolated rotor wake disturbances interspersed with regions of relatively low freestream turbulence level; and

(b) isolated rotor wake disturbances with a continuous, relatively high freestream turbulence level superimposed.

In the latter case there is a noticeable increase in random velocity fluctuations within the boundary layer and a slight decrease in unsteadiness (i.e. amplitude of ensemble-average velocity variations with time). Transition onset is a little earlier, but the essential character of the turbulent breakdown (with spots appearing regularly in association with the rotor wake passage) remains unchanged. It is concluded that freestream turbulence is not the dominant factor promoting transition in this particular case.

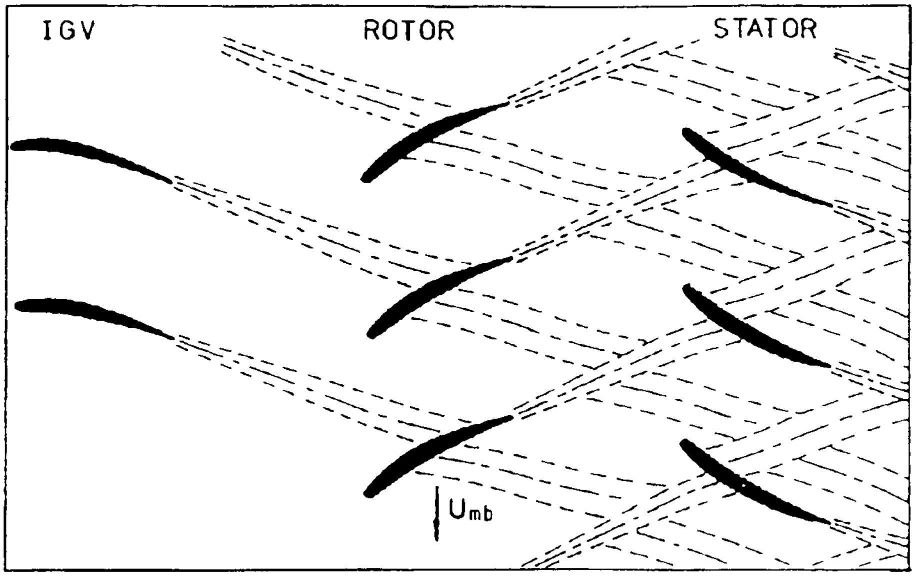


Fig. 1 Cross-section of compressor blading, showing typical instantaneous wake dispersion

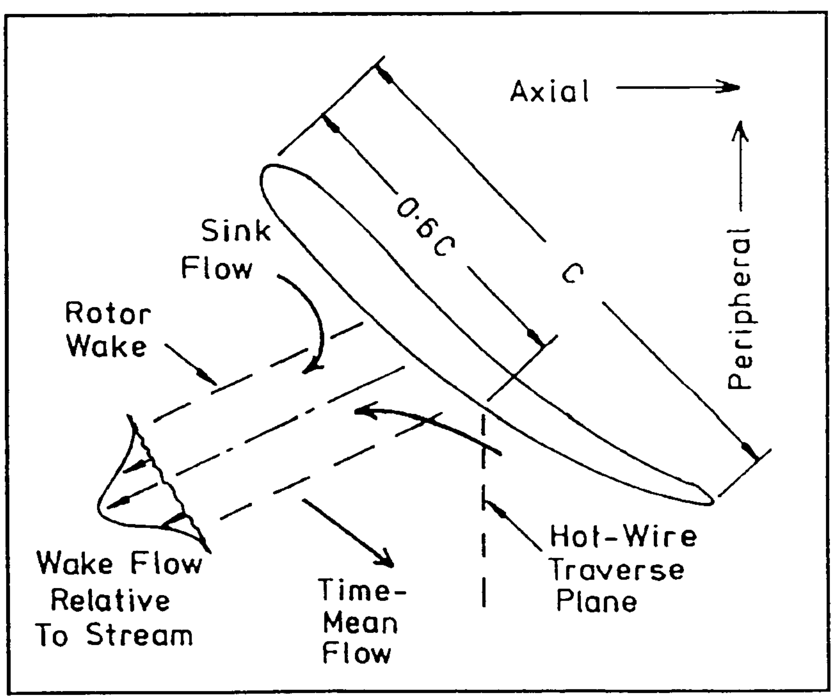
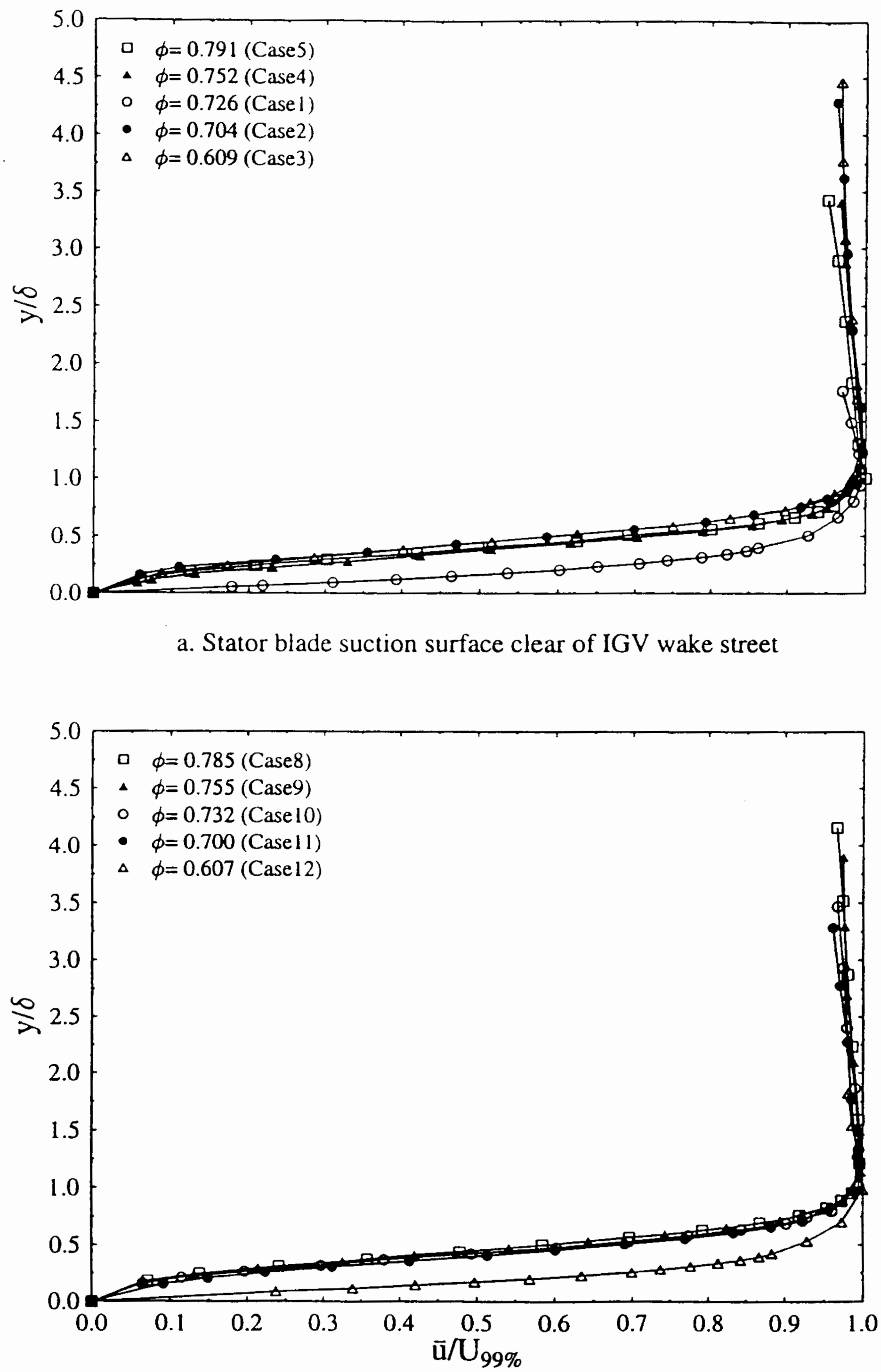


Fig. 2 Stator blade boundary layer - hot wire traverse detail

Table 1 Test Parameters (time-mean values)

Case	1	2	3	4	5
ϕ	0.726	0.704	0.609	0.752	0.791
i (°)	-3.1	-2.0	2.3	-4.5	-6.3
U_{std} (ms^{-1})	20.3	19.8	17.6	20.8	21.4
$Tu_{D,\infty}$	0.029	0.033	0.050	0.034	0.026
δ (mm)	1.44	1.44	2.80	1.15	1.11
θ (mm)	0.157	0.167	0.287	0.136	0.137
Re_θ	186	197	339	160	161
H	3.77	3.37	2.17	3.92	3.70
$C_f \times 10^3$	0.39	0.70	1.73	0.42	0.59

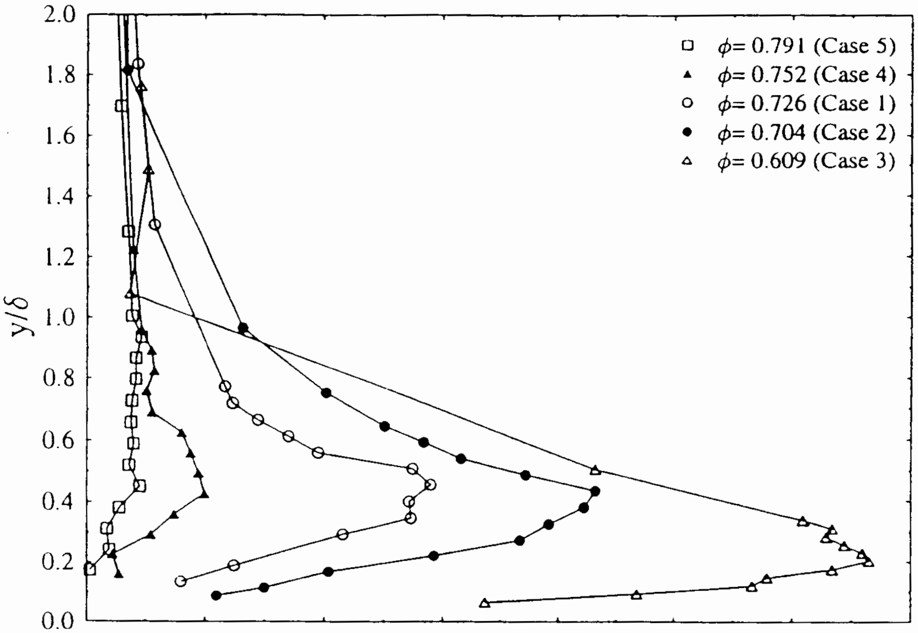
Case	8	9	10	11	12
ϕ	0.785	0.755	0.732	0.700	0.607
i (°)	-6.1	-4.6	-3.4	-1.9	2.3
U_{std} (ms^{-1})	21.8	20.7	20.2	19.6	17.6
δ (mm)	1.19	1.28	1.44	1.52	2.74
θ (mm)	0.138	0.148	0.158	0.175	0.266
Re_θ	163	175	187	207	314
H	4.04	4.04	3.98	3.61	2.29
$C_f \times 10^3$	0.42	0.37	0.37	0.52	1.47



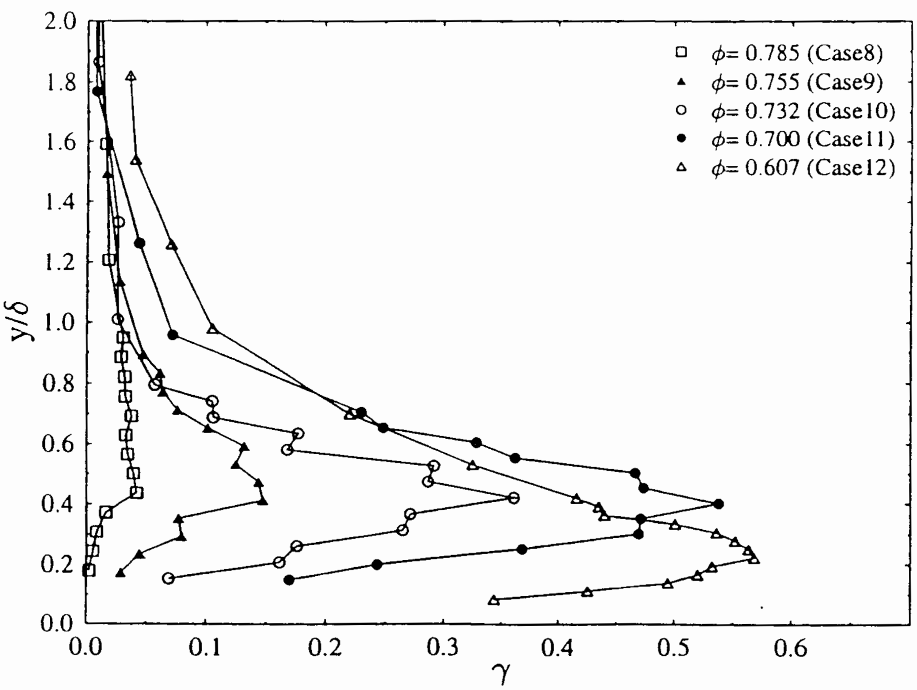
a. Stator blade suction surface clear of IGV wake street

b. Stator blade suction surface in IGV wake street

Fig. 4 Mean velocity variation near stator suction surface, x/c = 0.60

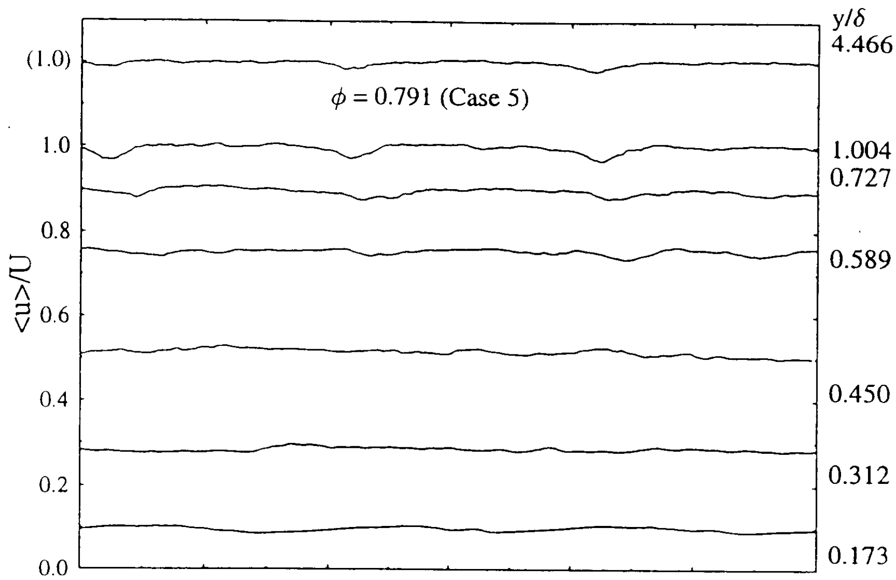


a. Stator blade suction surface clear of IGV wake street

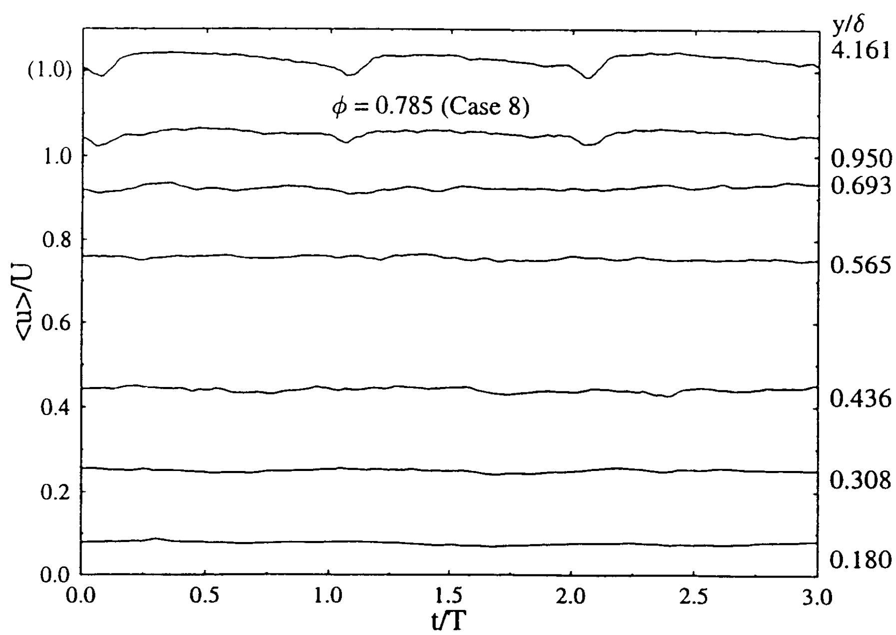


b. Stator blade suction surface in IGV wake street

Fig. 6 Intermittency distributions for boundary layers at different stages of transition, stator suction surface, x/c = 0.60

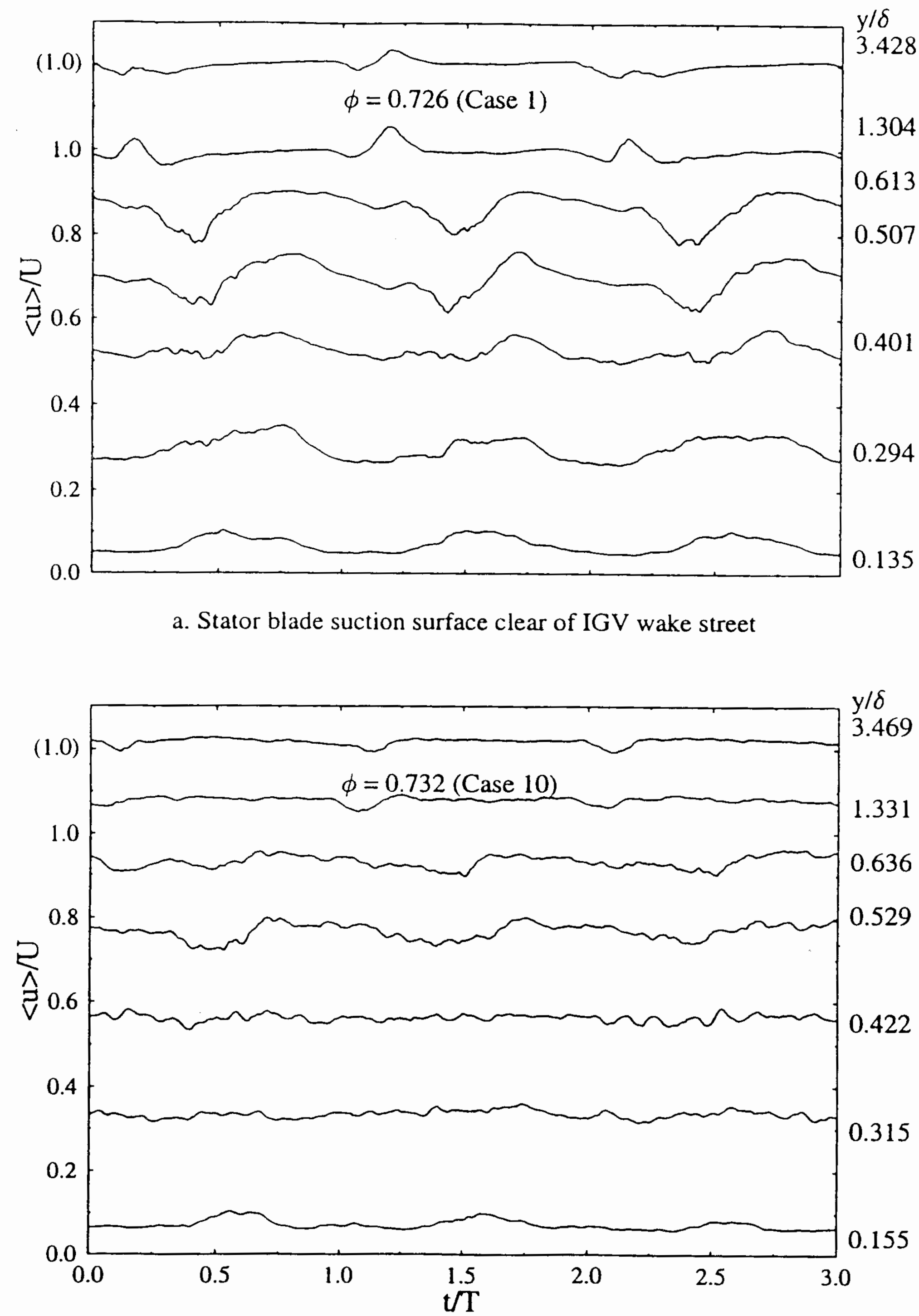


a. Stator blade suction surface clear of IGV wake street



b. Stator blade suction surface in IGV wake street

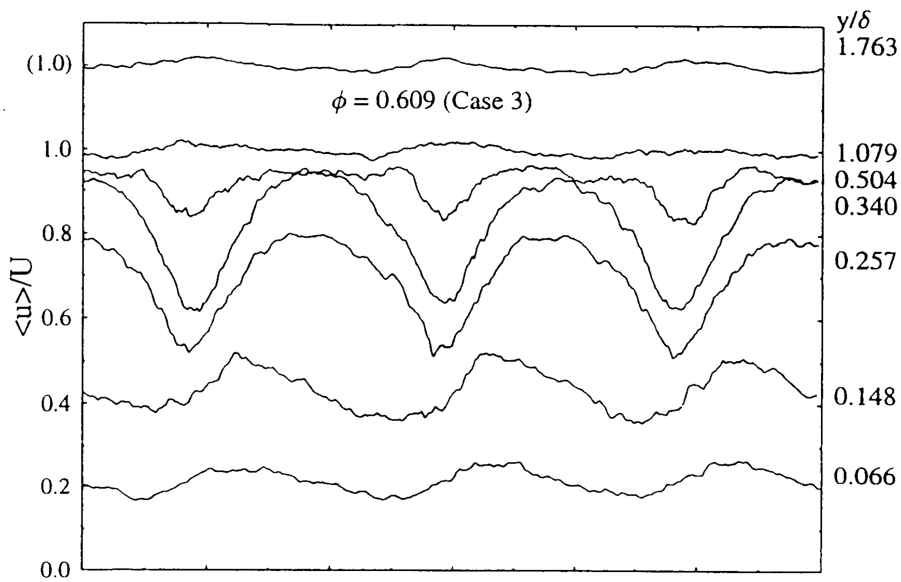
Fig. 8 Ensemble-averaged velocity variation with time, stator suction surface, x/c = 0.60



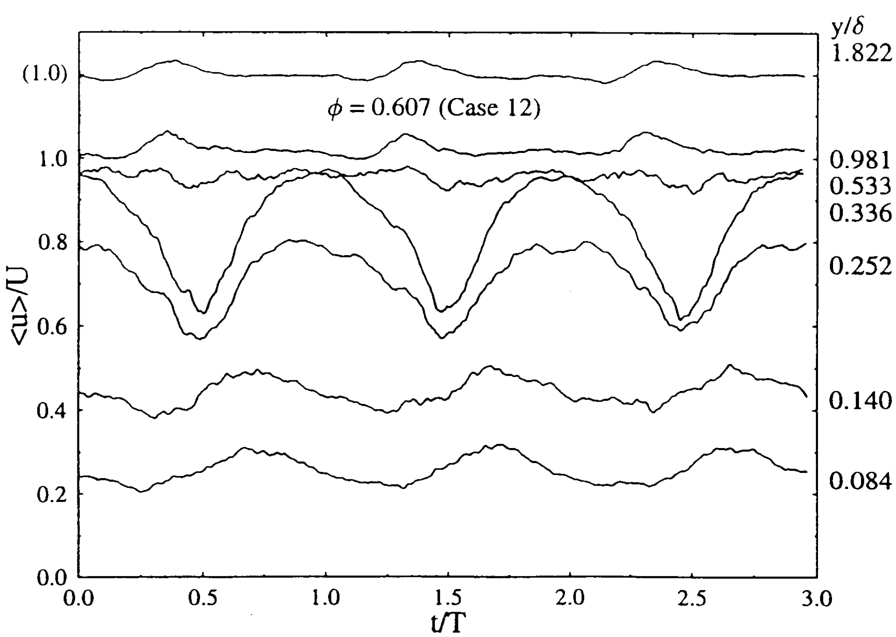
a. Stator blade suction surface clear of IGV wake street

b. Stator blade suction surface in IGV wake street

Fig. 10 Ensemble-averaged velocity variation with time, stator suction surface, x/c = 0.60

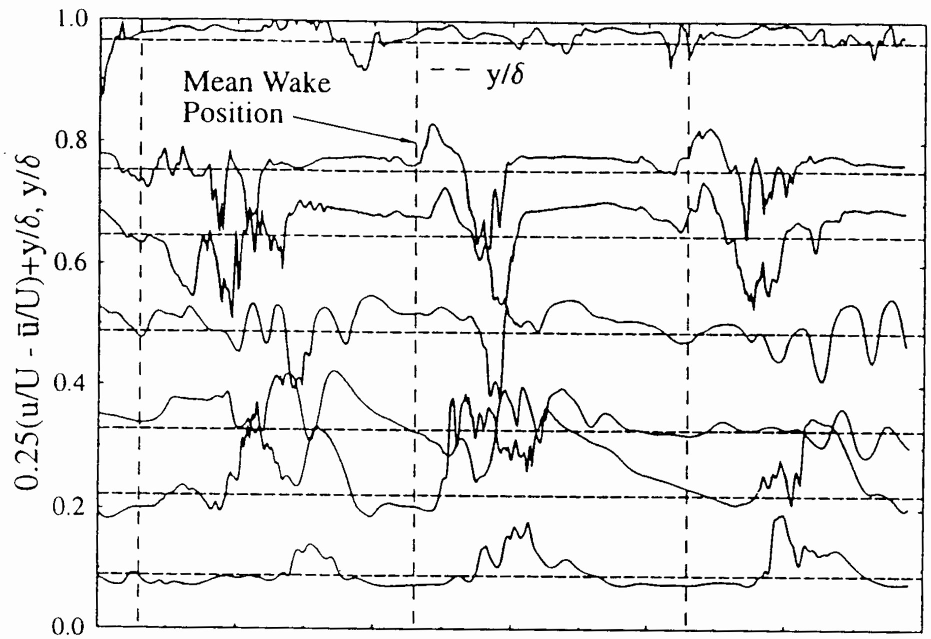


a. Stator blade suction surface clear of IGV wake street

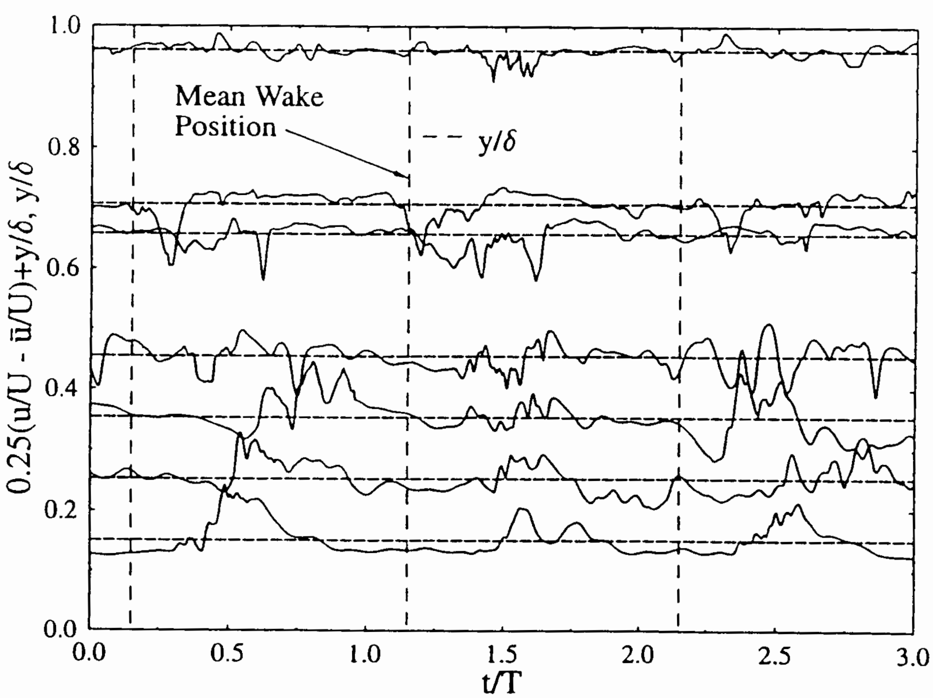


b. Stator blade suction surface in IGV wake street

Fig. 12 Ensemble-averaged velocity variation with time, stator suction surface,



a. Stator blade suction surface clear of IGV wake street (Case 2)



b. Stator blade suction surface in IGV wake street (Case 11)

Fig. 14 Set of typical individual u(t) records for different y, stator suction surface, x/c = 0.60

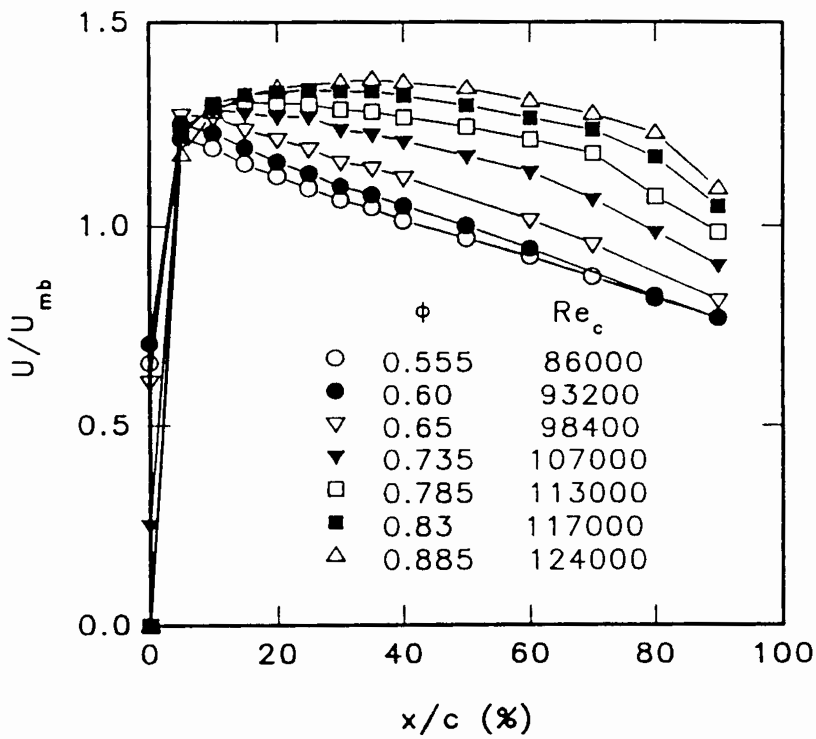


Fig. 16 Stator suction surface velocity distributions at mid-blade height (Compressor speed 500rpm, $Re_{ref} \approx 120000$)