INVESTIGATION OF A SHROUDED ROTOR-STATOR DISK CAVITY

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OBJECTIVES

TO UNDERSTAND:

1. TIME–AVERAGE AND UNSTEADY PRESSURE FIELDS IN THE MAIN–STREAM GAS PATH AND DISK CAVITY
2. VELOCITY FIELD IN THE MAIN GAS PATH AND DISK CAVITY
3. INGESTION OF MAIN GAS INTO THE DISK CAVITY
4. CONVECTIVE HEAT TRANSFER IN THE DISK CAVITY
5. EFFECTIVE RIM SEAL CONFIGURATIONS

APPROACH TAKEN:

EXPERIMENTS AND CFD SIMULATION

EXPERIMENTS PRESENTED

Re_ϕ	Re_m	β	c_w	$c_{w,\,fd}$
5.16×10^5	5.0×10^5	19.5°	0	8140
5.16×10^5	5.0×10^5	19.5°	1504	8140
5.16×10^5	5.0×10^5	19.5°	7520	8140

Re_m = main–stream flow Reynolds number, $= \rho V_m b/\mu$

Re_ϕ = disk rotationl Reynolds number, $= \rho \Omega b^2/\mu$

c_w = nondimensional mass flow rate of secondary air, $= \dot{m}/\mu b$

$c_{w,\,fd}$ = nondimensional free disk pumping mass flow rate, $= 0.219 Re_\phi^{0.8}$

CONVECTIVE HEAT TRANFER AT ROTOR DISK SURFACE

Local convective heat transfer coefficient:

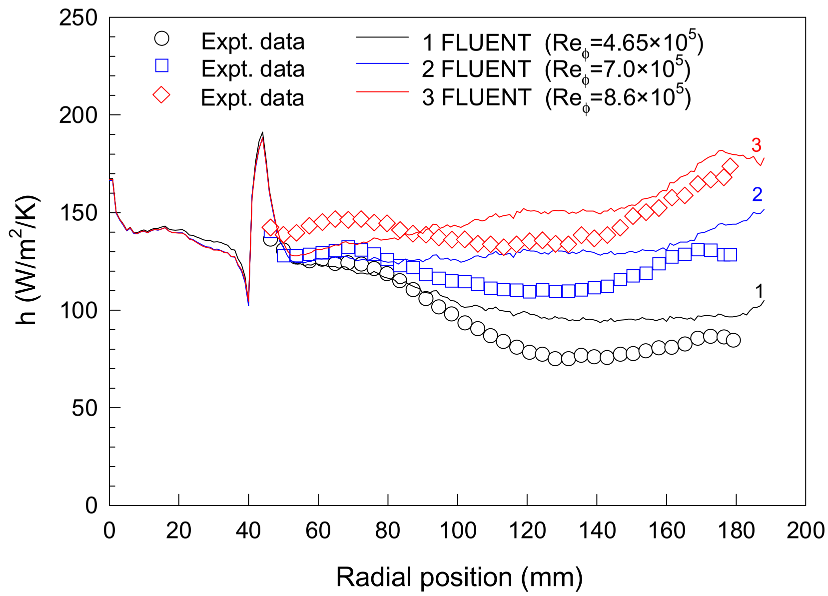
$$h(r) = \frac{q''_{w,ro,conv}(r)}{T_{w,ro} - T_{ref}(r)} = \frac{q''_{w,ro}(r) - q''_{w,ro,rad}}{T_{w,ro} - T_{ref}(r)}$$

Local Nusselt number:

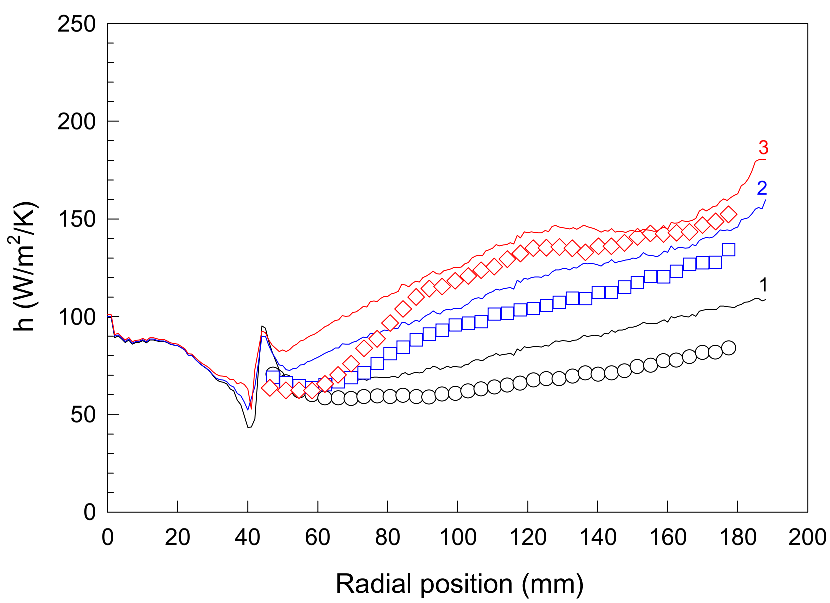
$$Nu_r \equiv \frac{h(r)r}{k_{air}}$$

Local rotational Reynolds number:

$$\mathrm{Re}_{\phi,r} \equiv \frac{\rho\Omega^2 r^2}{\mu} = (\frac{r}{b})^2 \,\mathrm{Re}_\phi$$

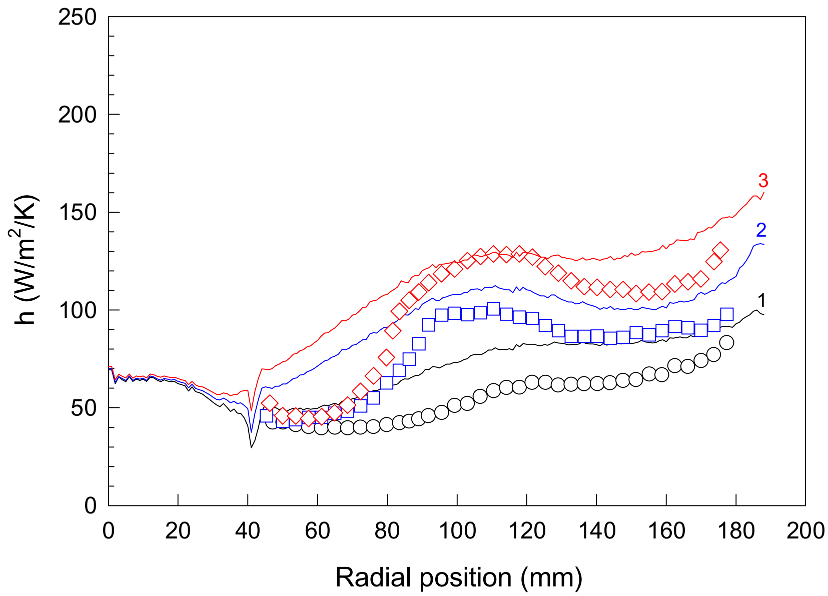


(a) c_w=7520

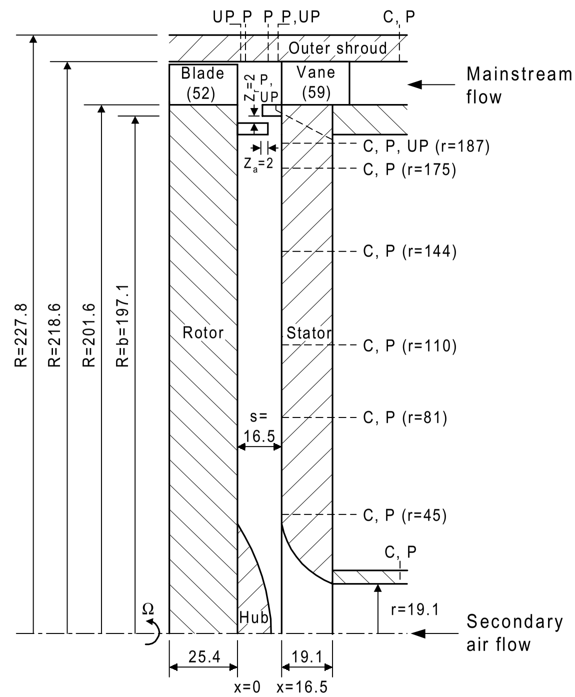


(b) c_w=3008

Effect of rotor disk speed on the convective heat transfer coefficient distribution

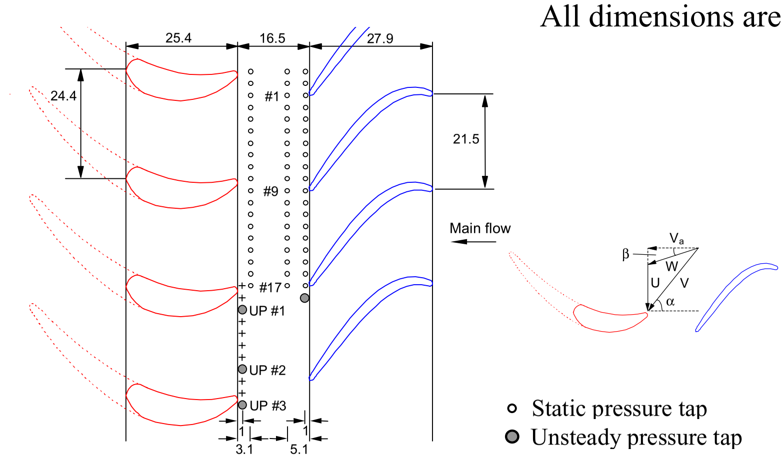

h (W/m²/K)
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
Radial position (mm)
1
2
3

(c) c_w=1504



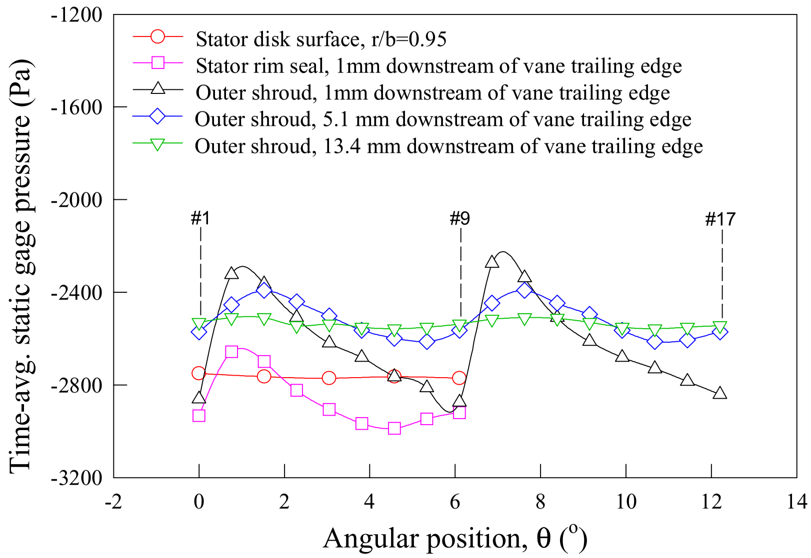
(a) The disk cavity

All dimensions are in mm

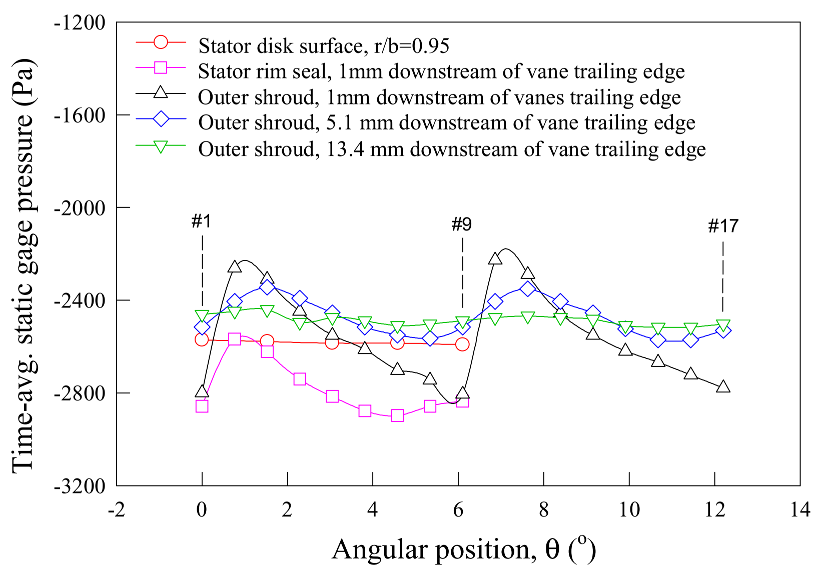


(b) Schematic of blades and vanes

The rotor-stator system (C: tracer gas concentration tap, P: static pressure tap, UP: unsteady pressure tap)

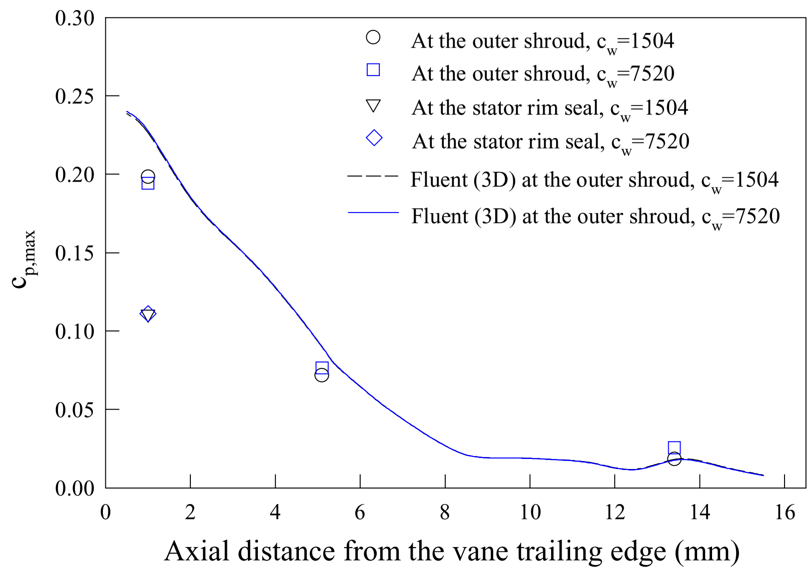


(a) c_w=1504

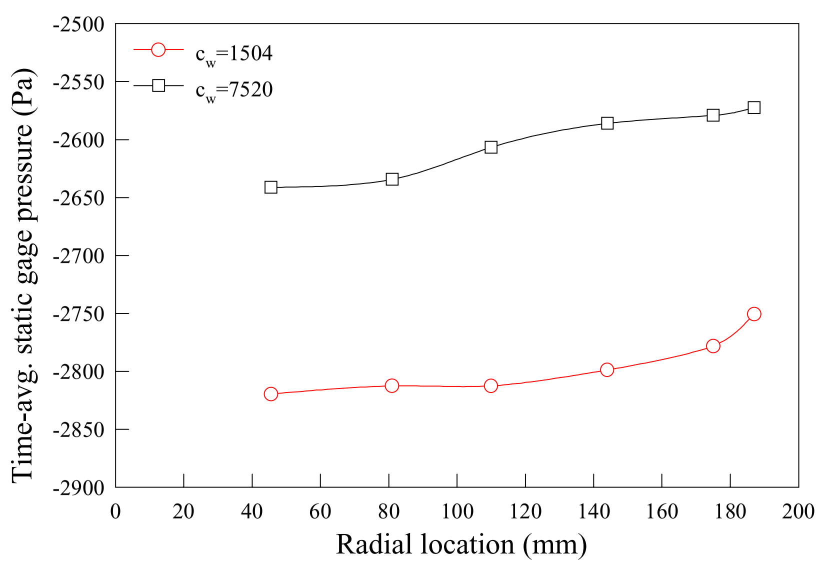


(b) c_w=7520

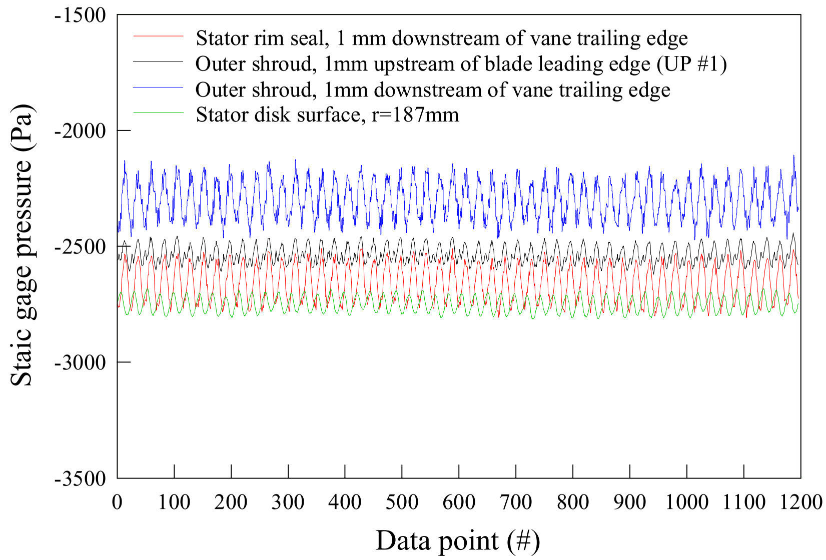
Measured circumferential distributions of time–average static pressure at the outer shroud, stator disk rim seal, and stator disk surface near its rim ($Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$)



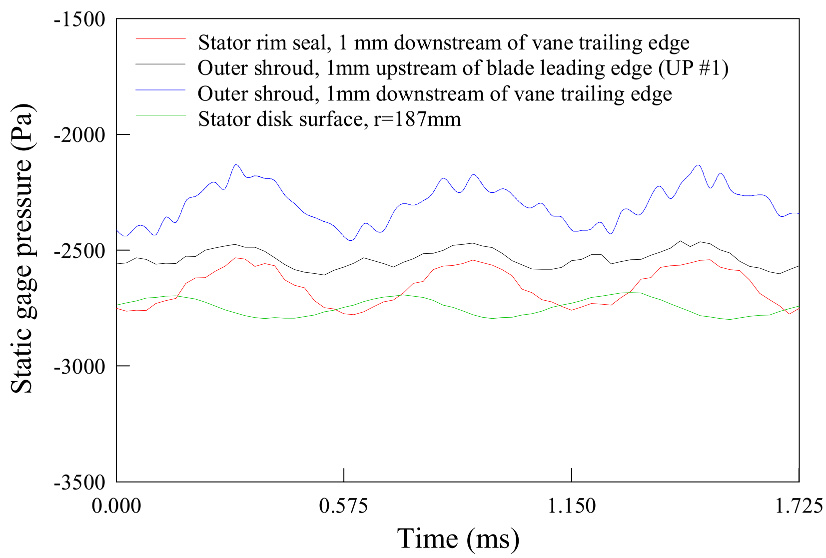
Time−average static pressure circumferential asymmetry coefficient at the main gas path outer shroud and stator rim seal (Re_ϕ=5.16×10^5, Re_m=5.0×10^5)



Radial distribution of static pressure at the stator disk surface for two secondary air flow rates (Re_ϕ=5.16×10^5, Re_m=5.0×10^5)

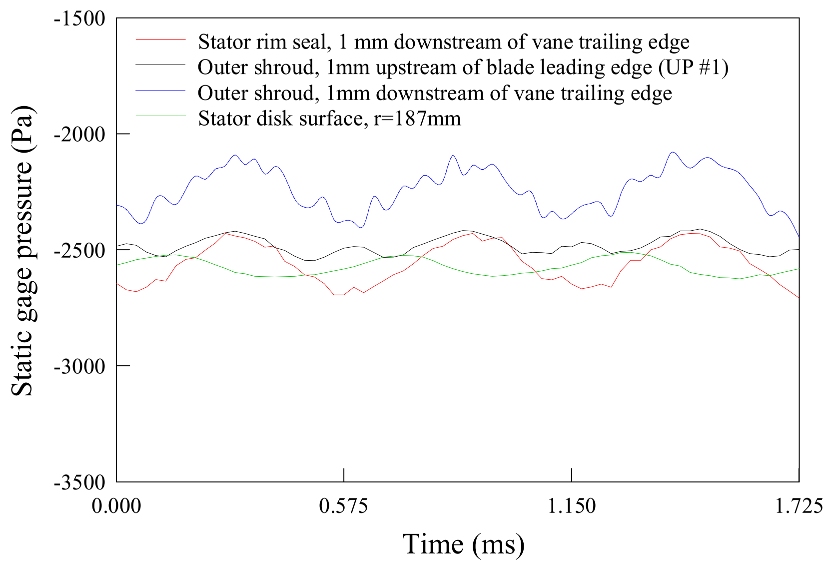


(a) c_w=1504 – one revolution of rotor disk

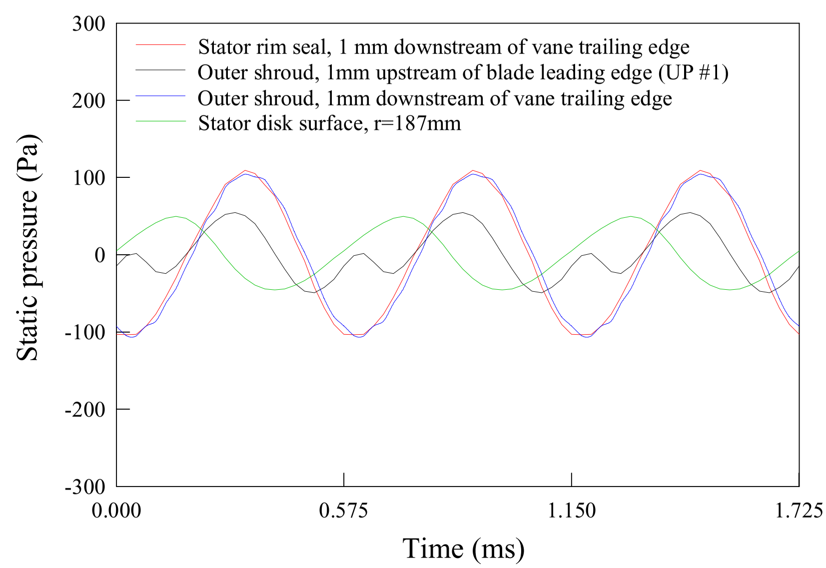


(b) c_w=1504 – three blade passages

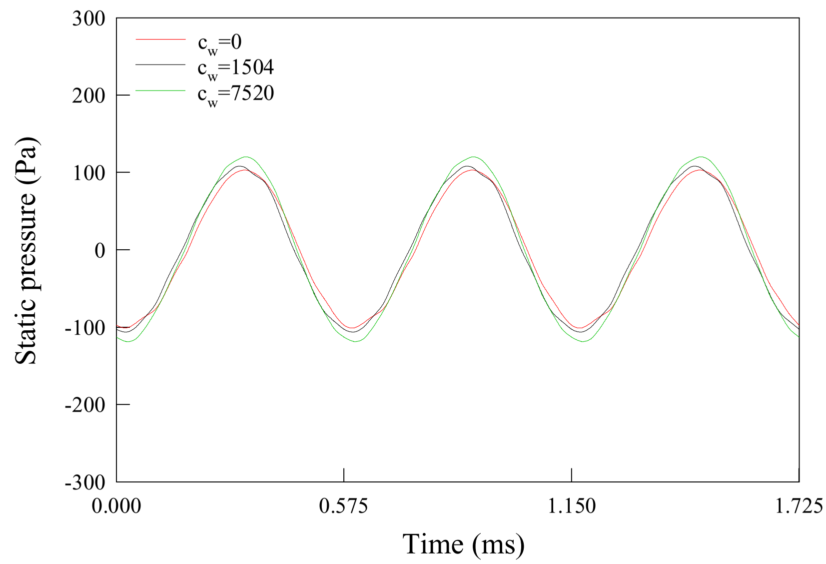
Ensemble–average unsteady static pressure at the outer shroud, rim seal of stator disk, and stator disk surface near the rim ($Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$)



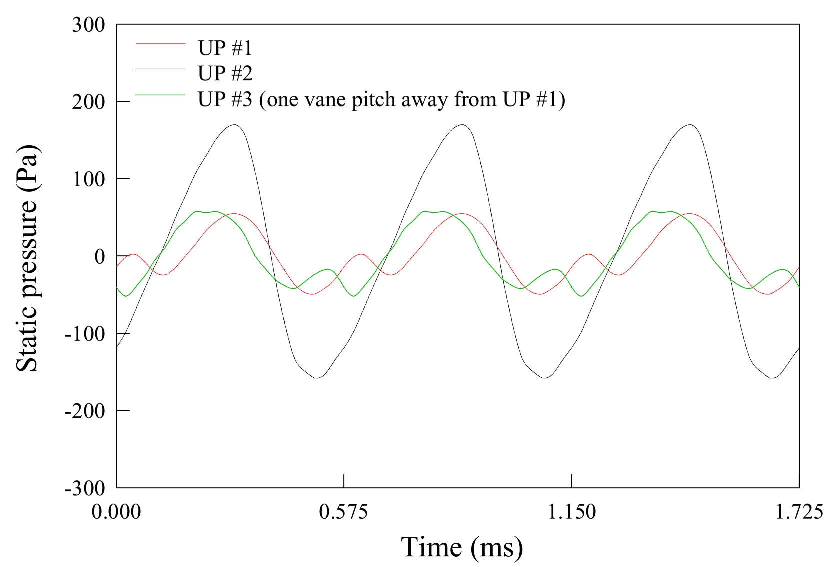
(c) c_w=7520 – three blade passages



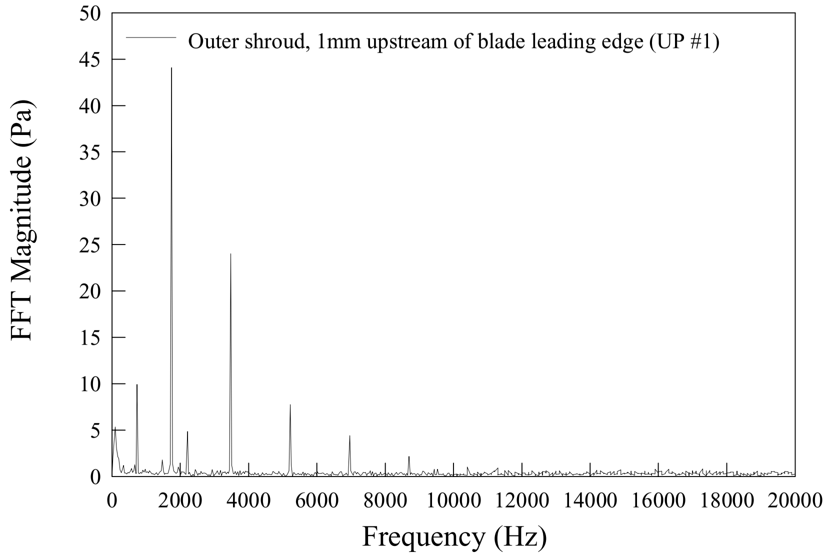
Blade–periodic static gage pressure at the outer shroud, stator disk rim seal, and stator disk surface near its rim ($Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$, $c_w=1504$) – three blade passages



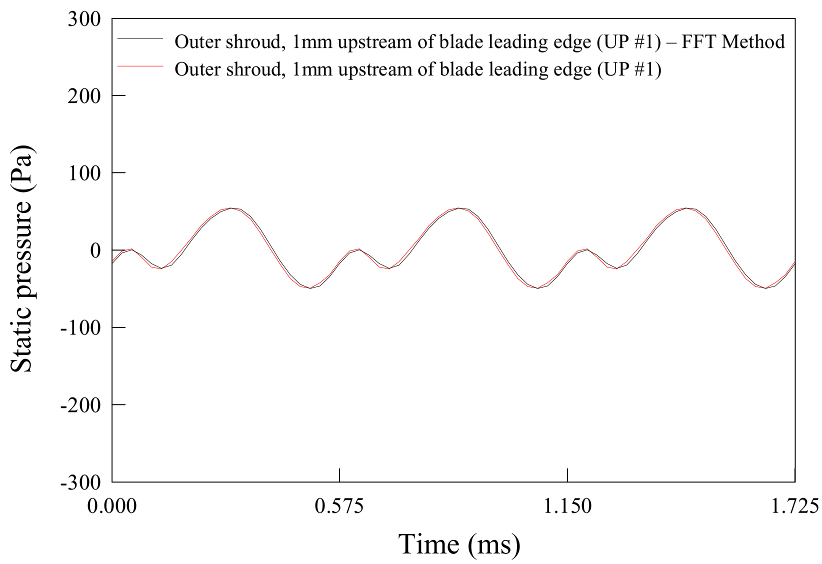
Effect of secondary air flow rate on blade–periodic static pressure at the stator disk rim seal 1 mm downstream of vane trailing edge ($Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$) – three blade passages



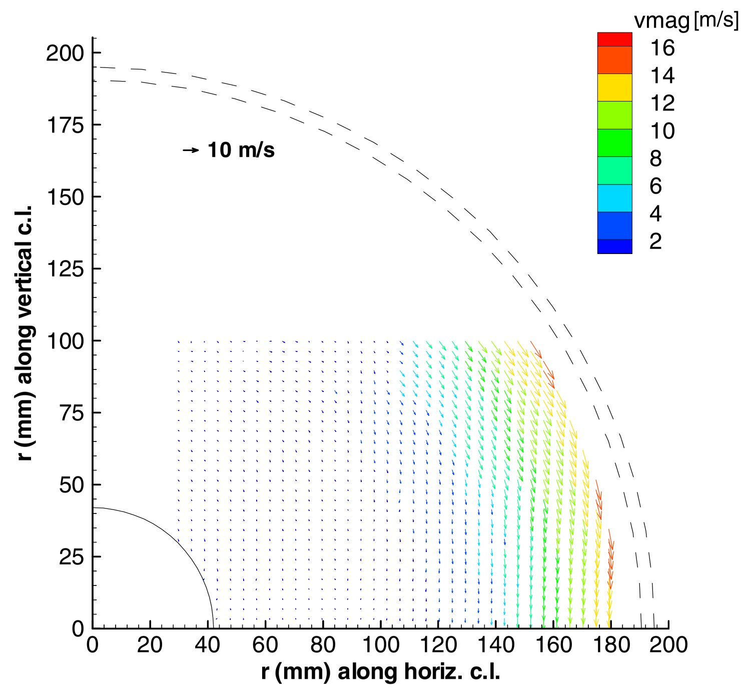
Circumferential variation of blade–periodic static pressure at the outer shroud 1 mm upstream of blade leading edge ($Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$, $c_w=1504$) – three blade passages



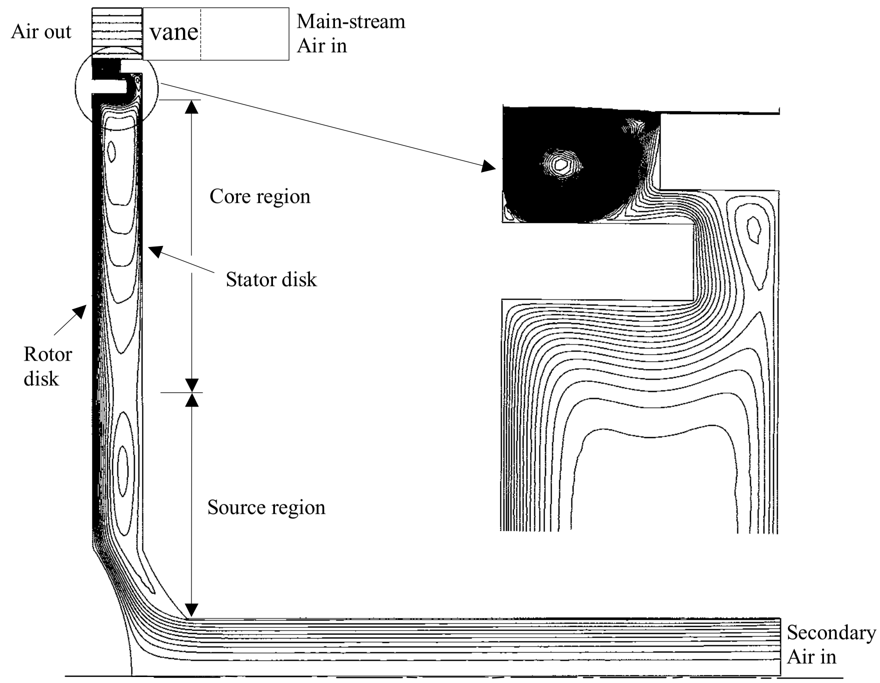
Frequency spectrum of the ensemble–average static pressure fluctuation at the outer shroud 1 mm upstream of blade leading edge ($Re_{\phi}=5.16\times10^5$, $Re_m=5.0\times10^5$, $c_w=1504$)



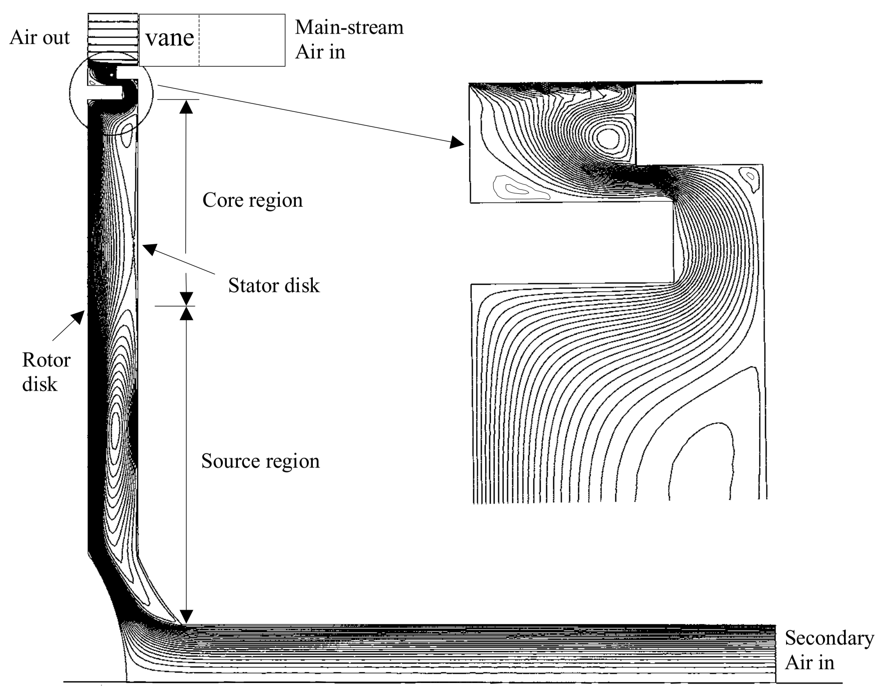
Comparison of FFT method with decomposition method: blade–periodic static pressure at the outer shroud 1 mm upstream of blade leading edge ($Re_{\phi}=5.16\times10^5$, $Re_m=5.0\times10^5$, $c_w=1504$) – three blade passages



r-ϕ plane map of the fluid time-average velocity in the cavity 3 mm from the stator disk for $Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$, $c_w=1504$

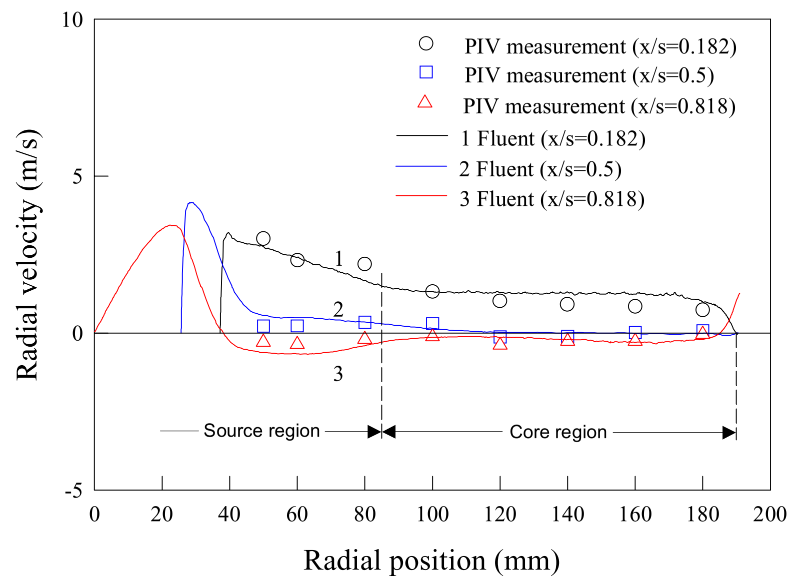


(a) $c_w = 1504$

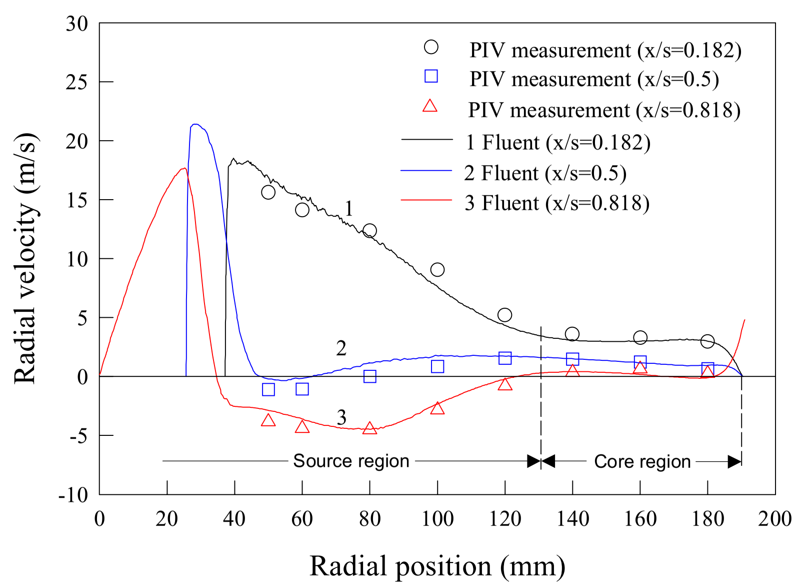


(b) $c_w = 7520$

Computed streamlines for $Re_\phi = 5.16\times10^5$, $Re_m = 5.0\times10^5$
(steady rotationally-symmetric simulation)

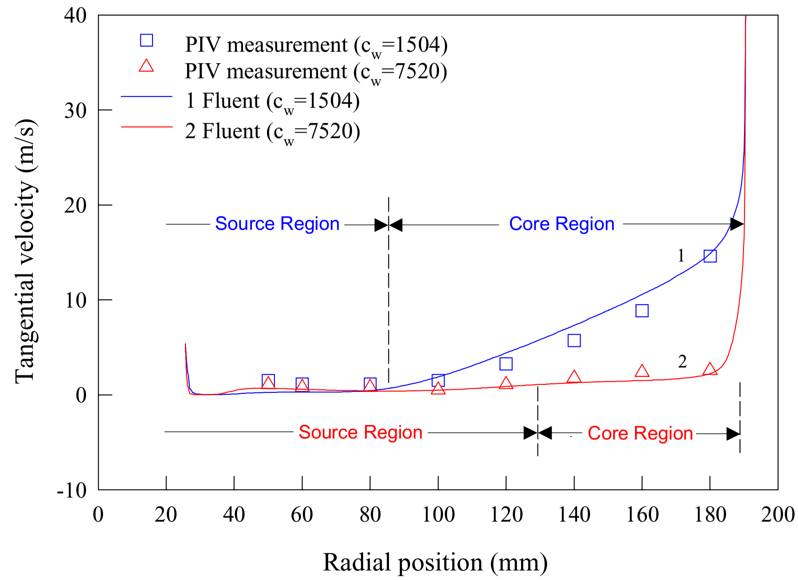


(a) c_w=1504

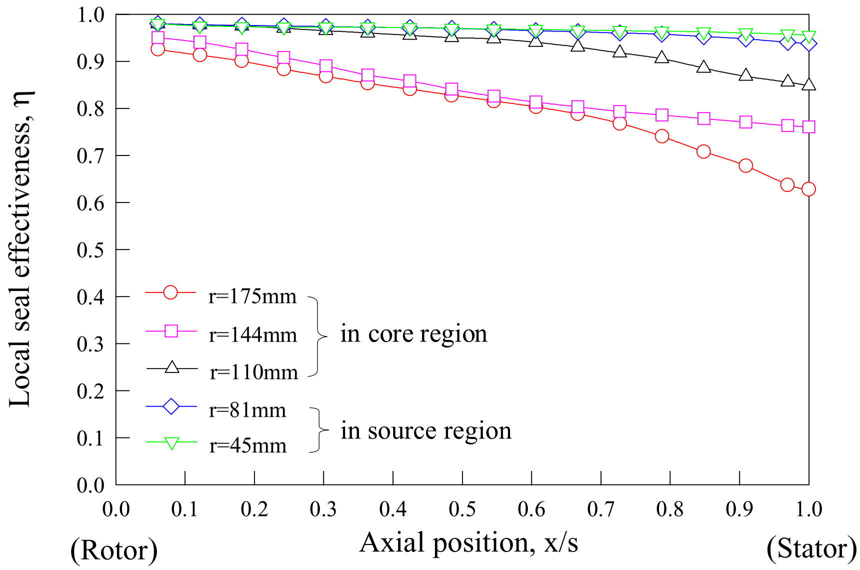


(b) c_w=7520

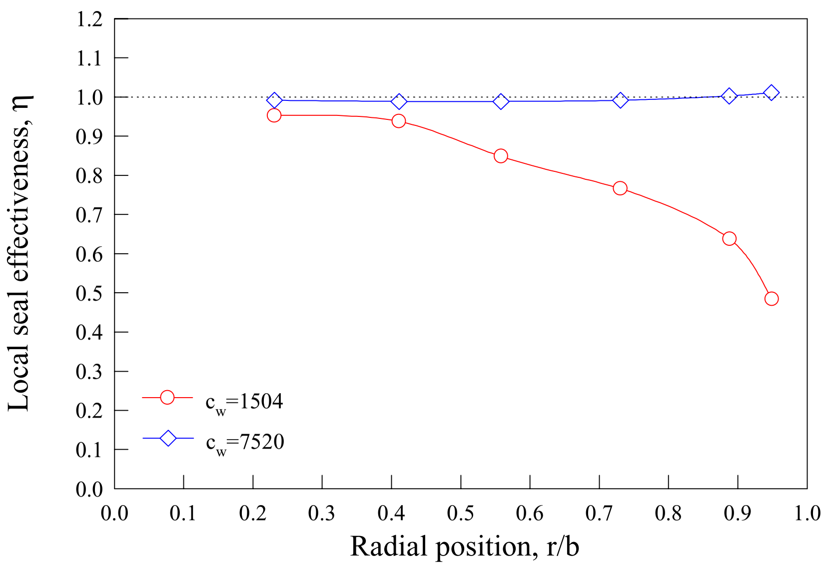
Radial distribution of fluid radial velocities at $Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$



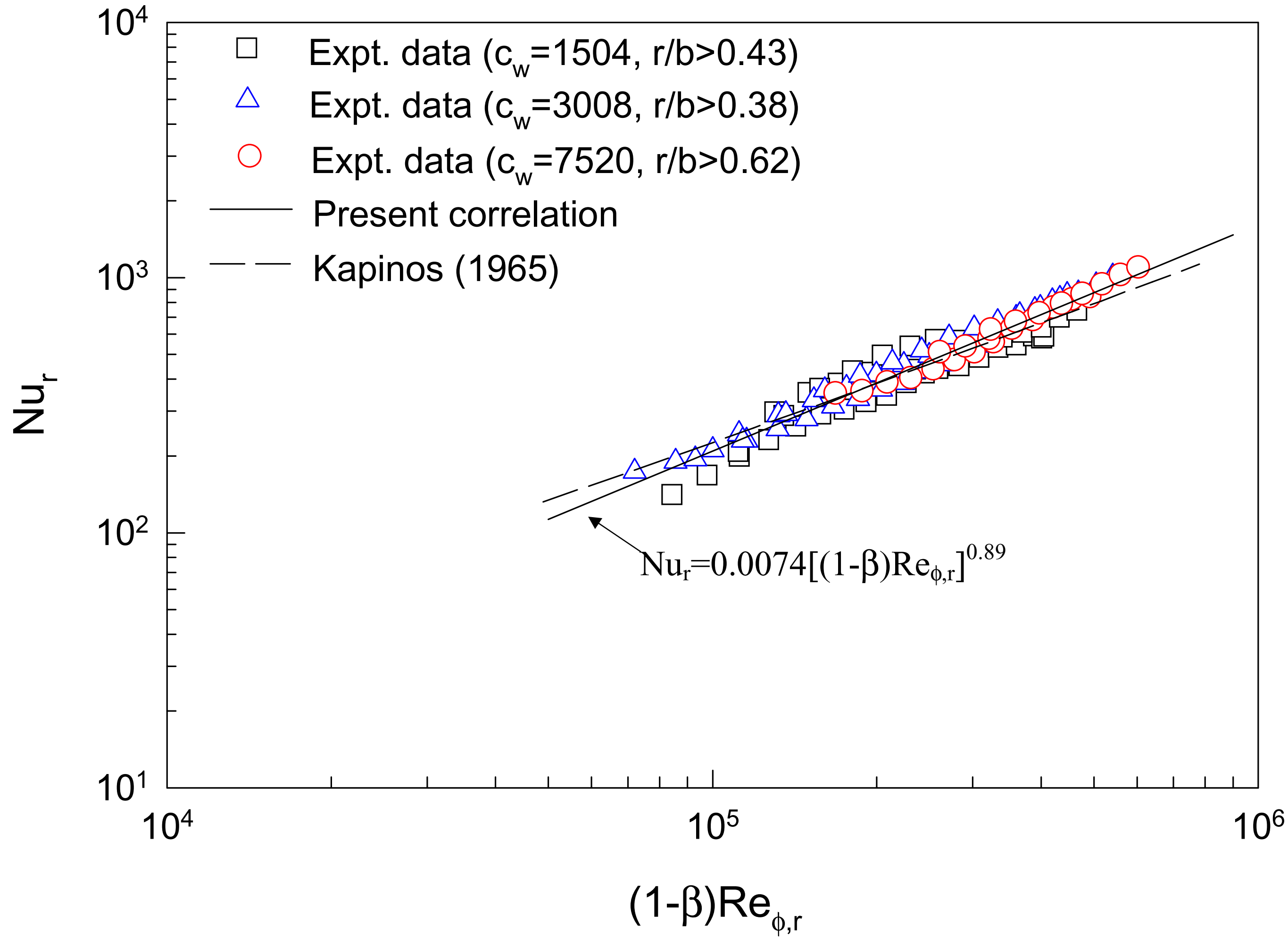
Effect of c_w on the fluid tangential velocity at the cavity mid–axial gap (x/s=0.5) for $Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$



Seal effectiveness distribution in the disk cavity for $Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$, c_w = 1504



Seal effectiveness distributions at the stator disk surface for $Re_\phi=5.16\times10^5$, $Re_m=5.0\times10^5$



Local Nusselt number versus local relative rotational Reynolds number (expt. data and correlation are for the core region and radially outermost part of the source region) – β, core fluid rotation ratio, = $V_\phi/\Omega r$