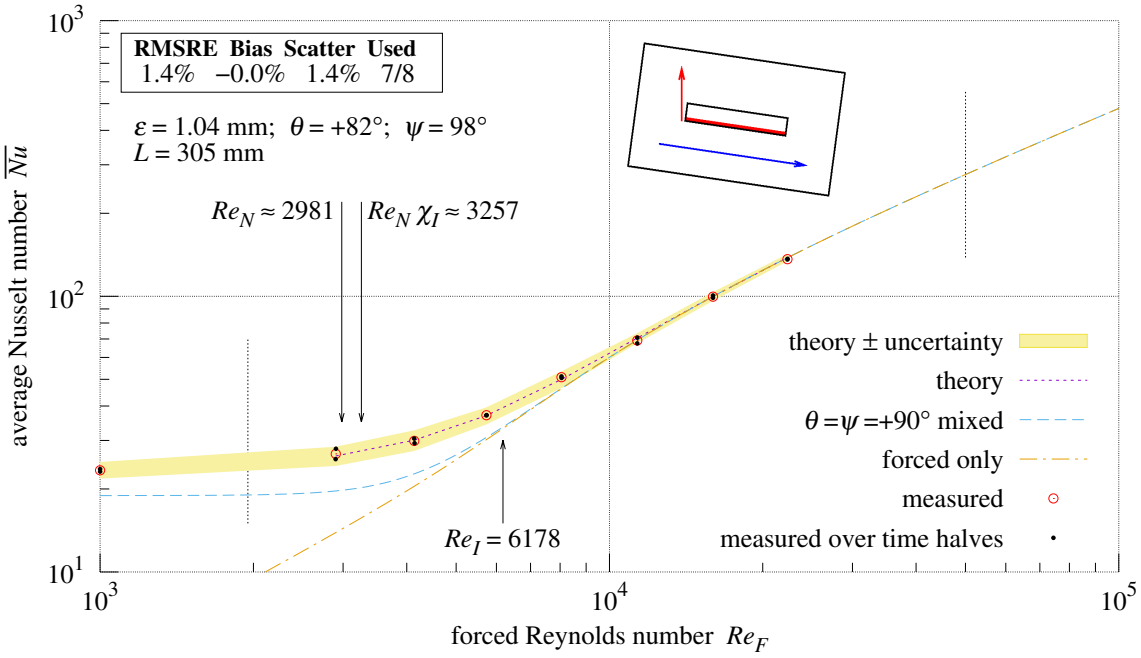
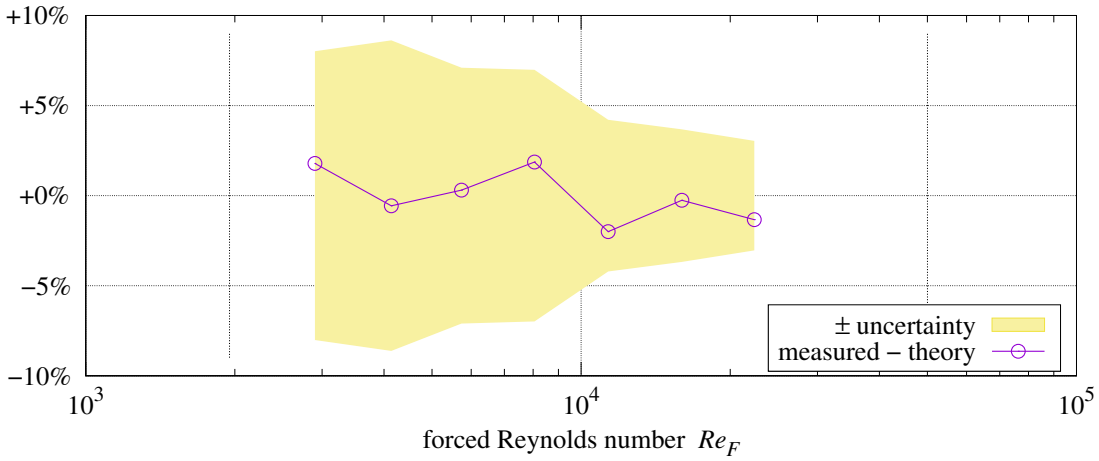
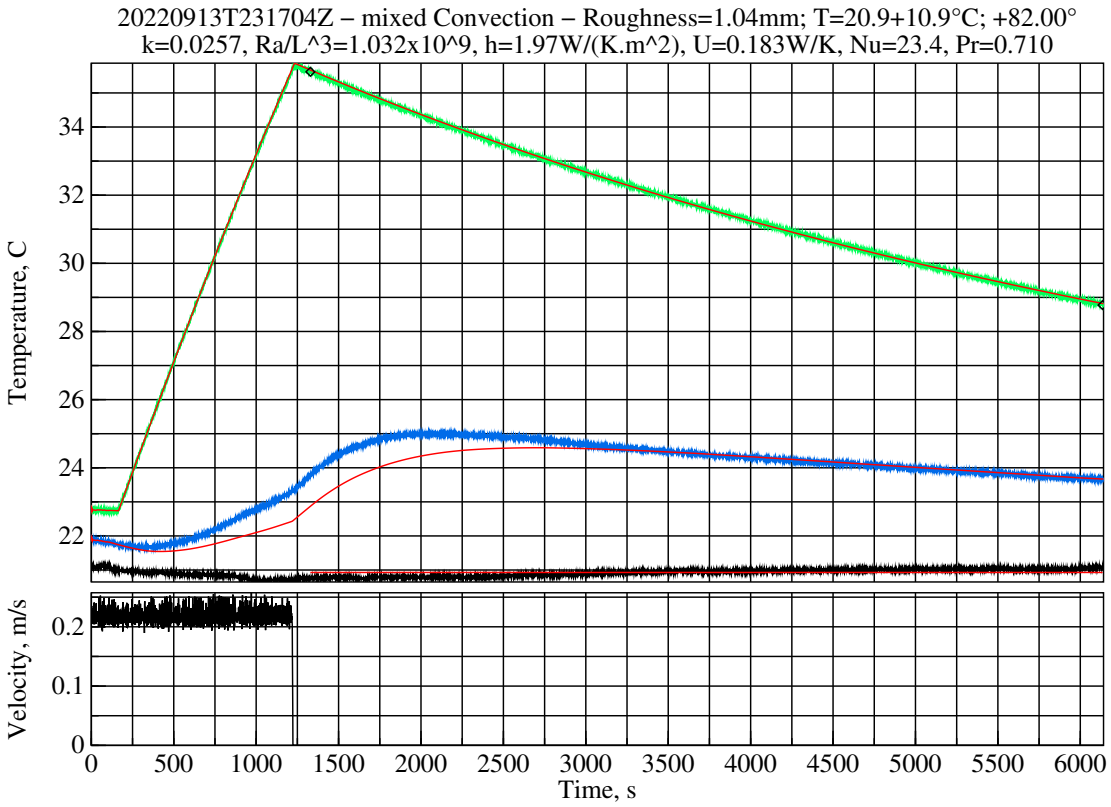
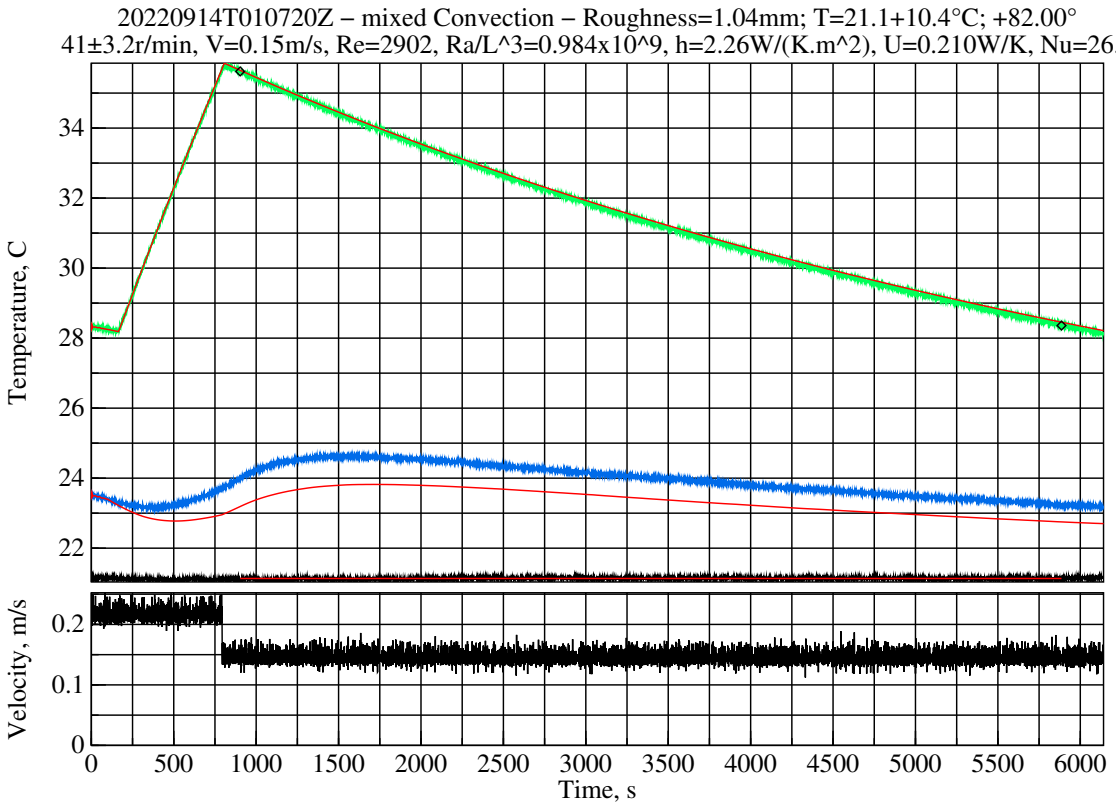

RMSRE Bias Scatter Used
1.4% −0.0% 1.4% 7/8
ε = 1.04 mm; θ = +82°; ψ = 98°
L = 305 mm
Re_N ≈ 2981
Re_N χ_I ≈ 3257
Re_I = 6178
theory ± uncertainty
theory
θ = ψ = +90° mixed
forced only
measured
measured over time halves
average Nusselt number Nu
forced Reynolds number Re_F
opposing inclined plate


+10%
+5%
+0%
−5%
−10%
± uncertainty
measured − theory
forced Reynolds number Re_F



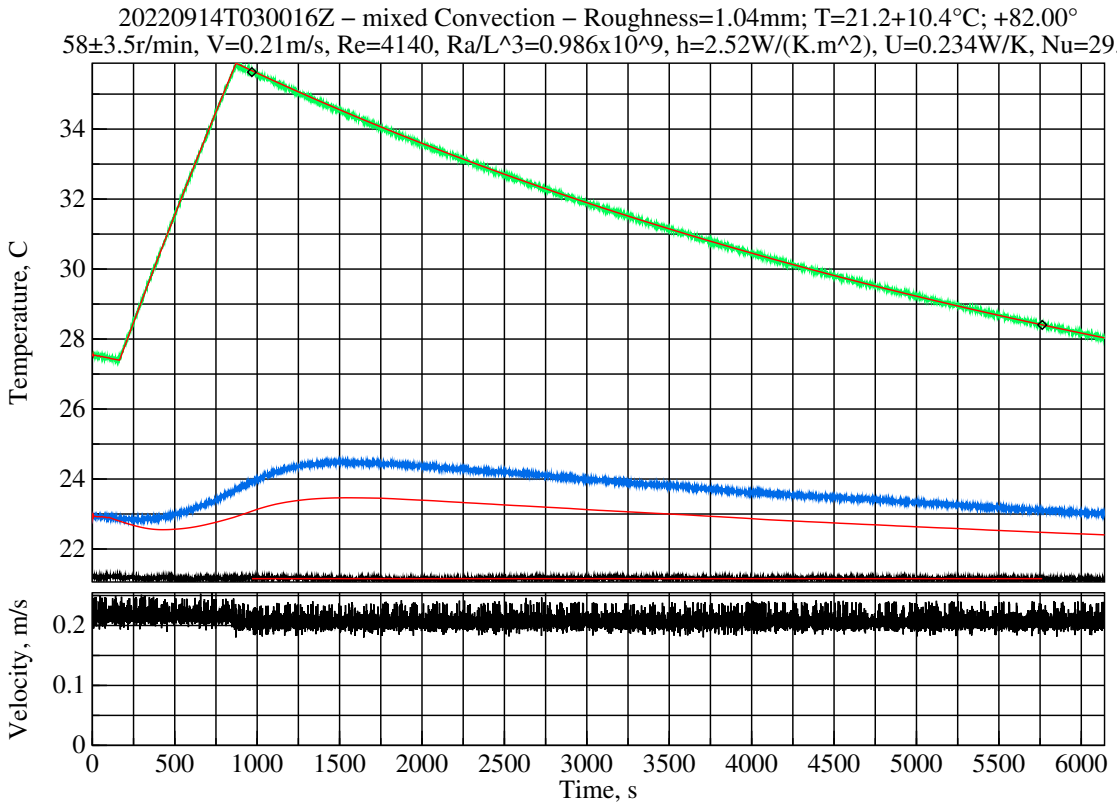
Estimated measurement uncertainties of natural convection at $\theta = 82.0$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
T	300K	+0.422%/K	0.50K	0.21%	LM35C temperature sensor
ΔT	10.9K	+32.2%/K	0.10K	3.22%	LM35C differential
T_{bb}	294K	+0.594%/K	0.50K	0.30%	radiative temperature
P	99.8kPa	+0.0008%/Pa	1.5kPa	1.27%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.072%/(J/K)	42J/K	3.07%	plate thermal capacity
L_c	0.305m	+940%/m	500um	0.47%	characteristic length
D_{PIR}	25.4mm	−752%/m	1.0mm	0.75%	insulation thickness
D_g	1.00mm	−763%/m	500um	0.38%	air gap
L_m	3.57mm	+2124%/m	500um	1.06%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.727\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.81%	PIR thermal conductivity
ϵ_{XPS}	0.515	+66.3%	0.010	0.66%	XPS emissivity
ϵ_{tp}	0.890	+79.8%	0.015	1.20%	tape emissivity
Ω_{tp}	0.540	+54.0%	0.020	1.08%	tape coverage
ϵ_{rs}	0.040	+283%	0.010	2.83%	test-surface emissivity
ϵ_b	0.190	+18.0%	0.020	0.36%	back emissivity
ϵ_{wt}	0.900	+133%	0.025	3.33%	wind-tunnel emissivity
θ	82.0°	−2.39%/°	0.50°	1.20%	plate angle
				6.93%	combined bias uncertainty



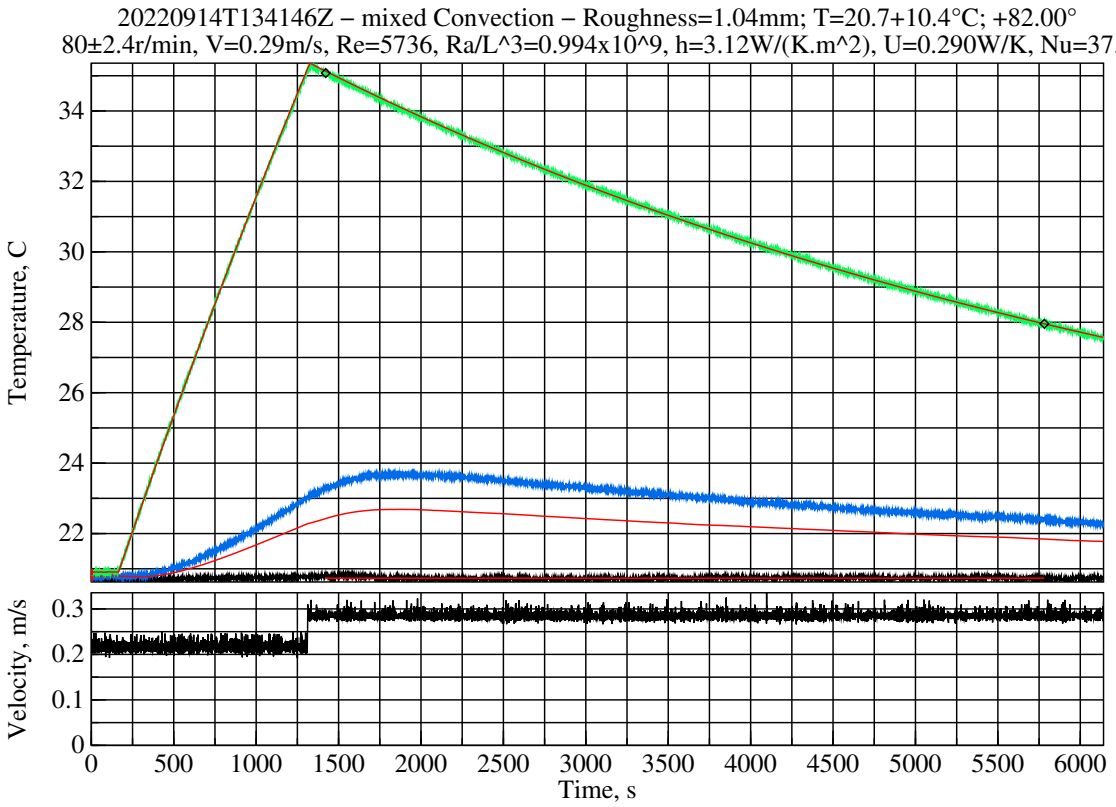
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 2902$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+30.7%/K	0.10K	3.07%	LM35C differential
T_{bb}	294K	+0.510%/K	0.50K	0.25%	radiative temperature
P	99.8kPa	+0.0010%/Pa	1.5kPa	1.44%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.067%/(J/K)	42J/K	2.85%	plate thermal capacity
η	0.402	+78.9%	0.004	0.32%	anemometer calibration
L_c	0.305m	+832%/m	500um	0.42%	characteristic length
ς	2.00mm	+2789%/m	100um	0.28%	post height
D_{PIR}	25.4mm	−818%/m	1.0mm	0.82%	insulation thickness
D_g	1.00mm	−830%/m	500um	0.42%	air gap
L_m	3.57mm	+1995%/m	500um	1.00%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.805\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.89%	PIR thermal conductivity
k_{XPS}	$28.5\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.142\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.4\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.20%	XPS thermal conductivity
ϵ_{XPS}	0.515	+57.8%	0.010	0.58%	XPS emissivity
ϵ_{tp}	0.890	+69.7%	0.015	1.05%	tape emissivity
Ω_{tp}	0.540	+47.1%	0.020	0.94%	tape coverage
ϵ_{rs}	0.040	+247%	0.010	2.47%	test-surface emissivity
ϵ_{wt}	0.900	+114%	0.025	2.86%	wind-tunnel emissivity
θ	82.0°	−1.72%/°	0.50°	0.86%	plate angle
				6.34%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	40.9r/min	+0.775%/(r/min)	3.2r/min	2.45%	fan rotation rate
				8.01%	RSS combined uncertainty



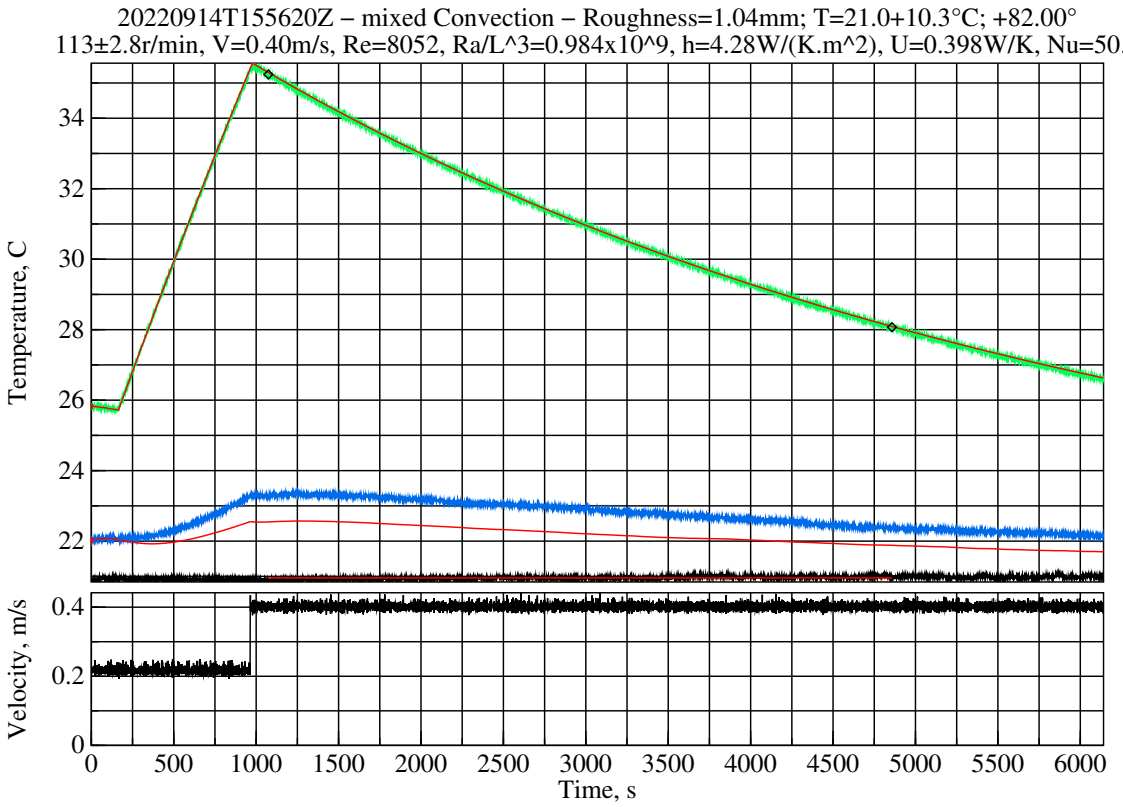
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 4139$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+28.0%/K	0.10K	2.80%	LM35C differential
T_{bb}	294K	+0.444%/K	0.50K	0.22%	radiative temperature
P	99.8kPa	+0.0011%/Pa	1.5kPa	1.58%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.062%/(J/K)	42J/K	2.63%	plate thermal capacity
η	0.402	+132%	0.004	0.53%	anemometer calibration
L_c	0.305m	+779%/m	500um	0.39%	characteristic length
D_{PIR}	25.4mm	−782%/m	1.0mm	0.78%	insulation thickness
D_g	1.00mm	−793%/m	500um	0.40%	air gap
L_m	3.57mm	+1816%/m	500um	0.91%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.772\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.86%	PIR thermal conductivity
k_{XPS}	$28.5\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.143\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.4\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.20%	XPS thermal conductivity
ϵ_{XPS}	0.515	+50.6%	0.010	0.51%	XPS emissivity
ϵ_{tp}	0.890	+61.0%	0.015	0.91%	tape emissivity
Ω_{tp}	0.540	+41.3%	0.020	0.83%	tape coverage
ϵ_{rs}	0.040	+217%	0.010	2.17%	test-surface emissivity
ϵ_{wt}	0.900	+99.7%	0.025	2.49%	wind-tunnel emissivity
θ	82.0°	−1.23%/°	0.50°	0.61%	plate angle
				5.77%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	58.3r/min	+0.911%/(r/min)	3.5r/min	3.20%	fan rotation rate
				8.62%	RSS combined uncertainty



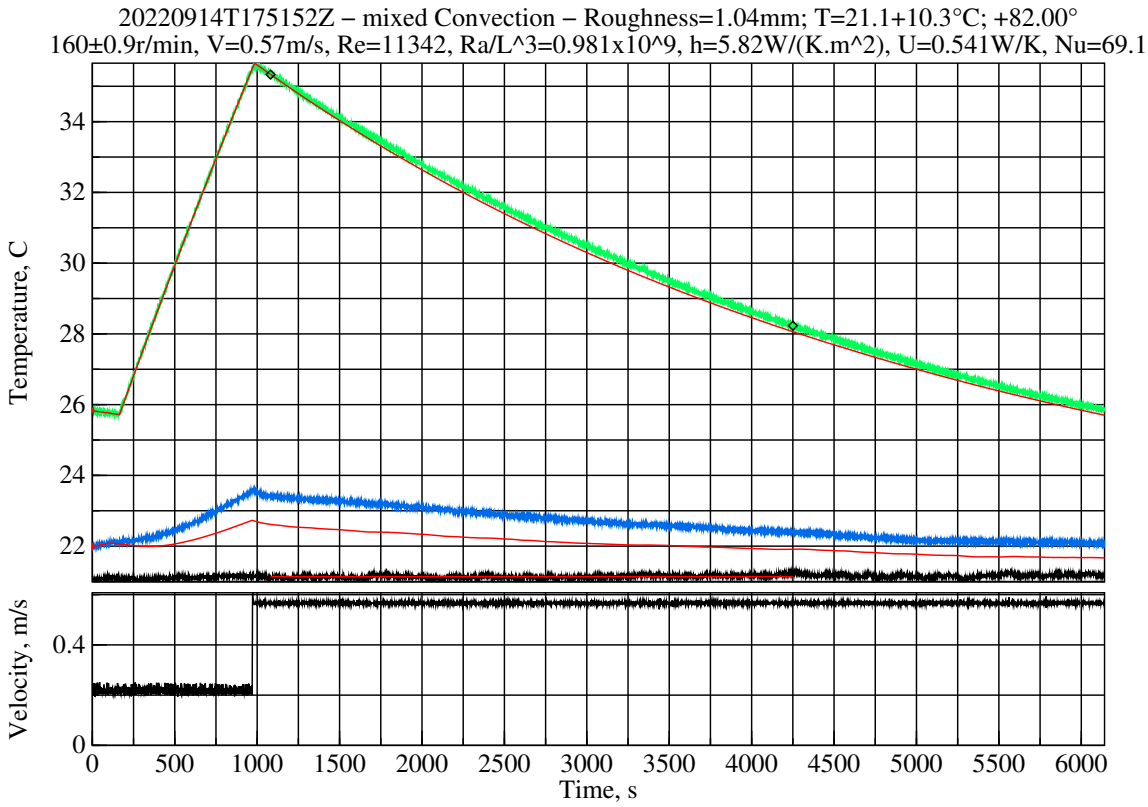
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 5735$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+24.6%/K	0.10K	2.46%	LM35C differential
P	100kPa	+0.0012%/Pa	1.5kPa	1.78%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.055%/(J/K)	42J/K	2.34%	plate thermal capacity
η	0.402	+204%	0.004	0.82%	anemometer calibration
L_c	0.305m	+735%/m	500um	0.37%	characteristic length
L_T	8.34mm	+3411%/m	100um	0.34%	post length
ς	2.00mm	−7948%/m	100um	0.79%	post height
D_{PIR}	25.4mm	−679%/m	1.0mm	0.68%	insulation thickness
D_g	1.00mm	−689%/m	500um	0.34%	air gap
L_m	3.57mm	+1542%/m	500um	0.77%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.673\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.75%	PIR thermal conductivity
ϵ_{XPS}	0.515	+40.8%	0.010	0.41%	XPS emissivity
ϵ_{tp}	0.890	+49.2%	0.015	0.74%	tape emissivity
Ω_{tp}	0.540	+33.3%	0.020	0.67%	tape coverage
ϵ_{rs}	0.040	+175%	0.010	1.75%	test-surface emissivity
ϵ_{wt}	0.900	+80.3%	0.025	2.01%	wind-tunnel emissivity
θ	82.0°	−0.659%/°	0.50°	0.33%	plate angle
				5.14%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	80.4r/min	+1.02%/(r/min)	2.4r/min	2.45%	fan rotation rate
				7.10%	RSS combined uncertainty



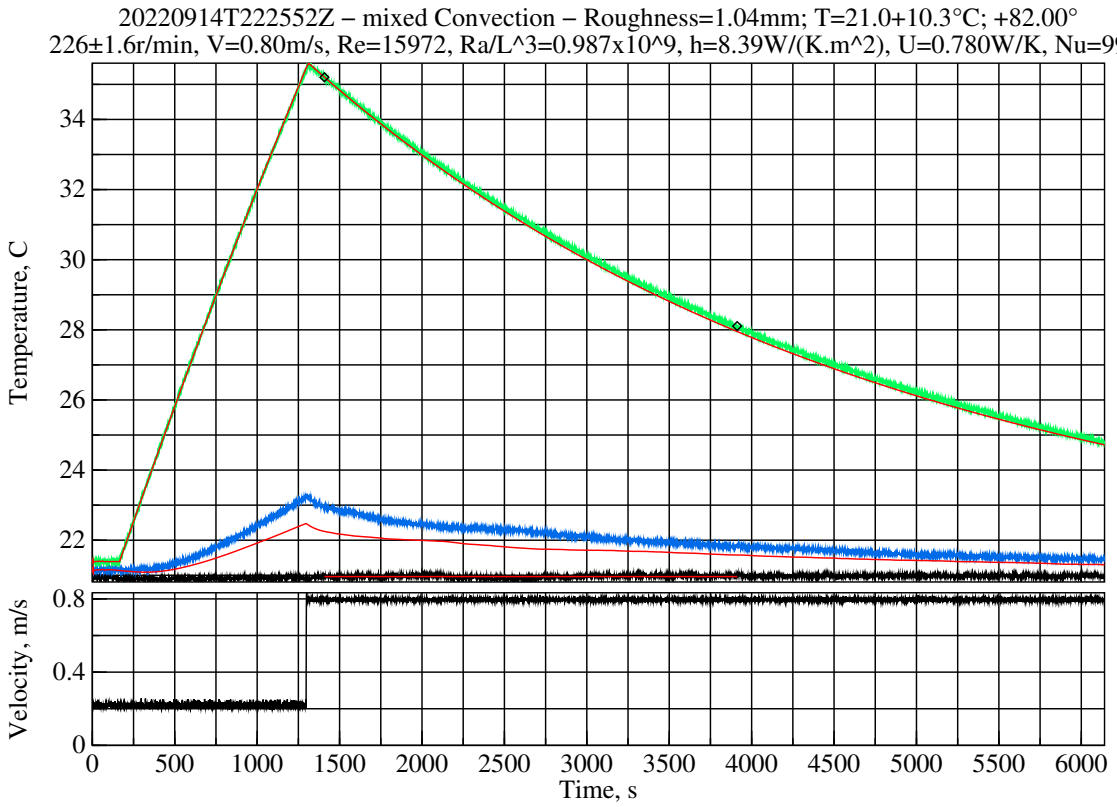
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 8052$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+20.6%/K	0.10K	2.06%	LM35C differential
P	100kPa	+0.0013%/Pa	1.5kPa	1.90%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.047%/(J/K)	42J/K	1.98%	plate thermal capacity
η	0.402	+263%	0.004	1.06%	anemometer calibration
L_c	0.305m	+640%/m	500um	0.32%	characteristic length
L_T	8.34mm	+6536%/m	100um	0.65%	post length
ς	2.00mm	−16665%/m	100um	1.67%	post height
D_{PIR}	25.4mm	−525%/m	1.0mm	0.53%	insulation thickness
D_g	1.00mm	−533%/m	500um	0.27%	air gap
L_m	3.57mm	+1201%/m	500um	0.60%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.523\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.58%	PIR thermal conductivity
ϵ_{XPS}	0.515	+29.8%	0.010	0.30%	XPS emissivity
ϵ_{tp}	0.890	+35.9%	0.015	0.54%	tape emissivity
Ω_{tp}	0.540	+24.3%	0.020	0.49%	tape coverage
ϵ_{rs}	0.040	+128%	0.010	1.28%	test-surface emissivity
ϵ_{wt}	0.900	+58.4%	0.025	1.46%	wind-tunnel emissivity
				4.66%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	113r/min	+0.934%/(r/min)	2.8r/min	2.60%	fan rotation rate
				6.98%	RSS combined uncertainty



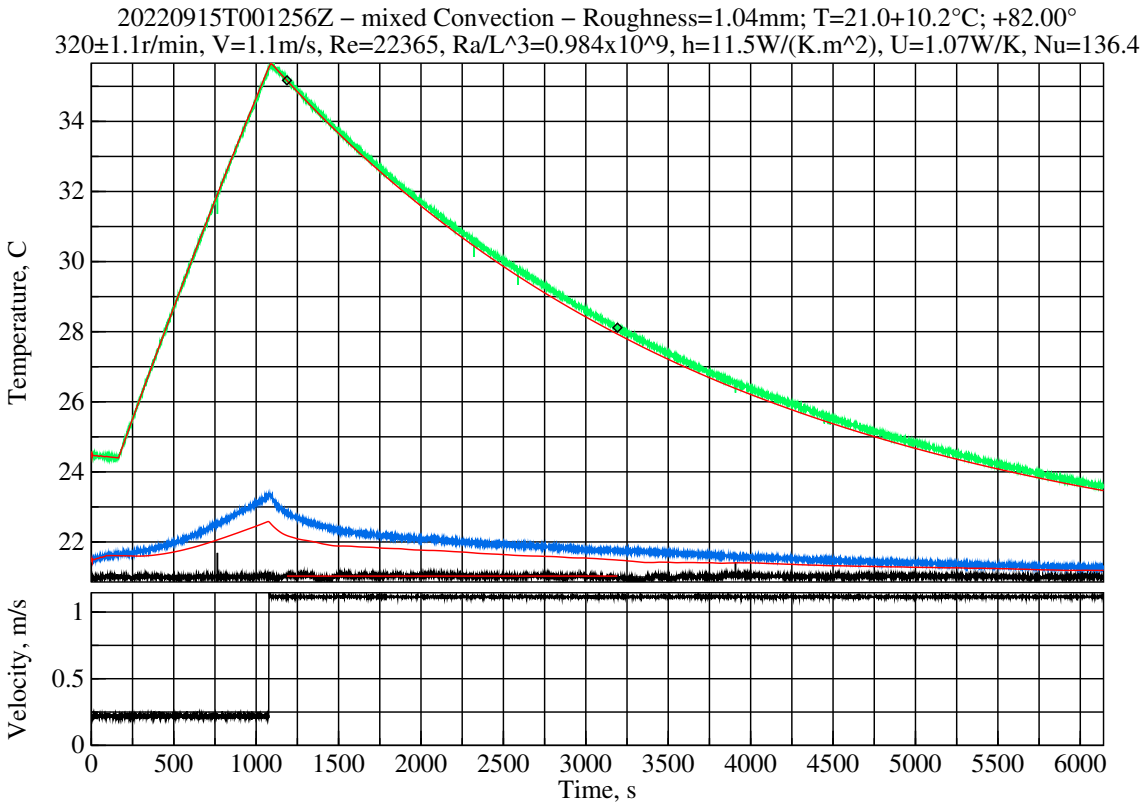
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 11342$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+17.3%/K	0.10K	1.73%	LM35C differential
P	100kPa	+0.0012%/Pa	1.5kPa	1.78%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.040%/(J/K)	42J/K	1.69%	plate thermal capacity
η	0.402	+264%	0.004	1.06%	anemometer calibration
L_c	0.305m	+475%/m	500um	0.24%	characteristic length
L_T	8.34mm	+8282%/m	100um	0.83%	post length
ς	2.00mm	−16089%/m	100um	1.61%	post height
D_{PIR}	25.4mm	−383%/m	1.0mm	0.38%	insulation thickness
L_m	3.57mm	+910%/m	500um	0.45%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.383\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.43%	PIR thermal conductivity
ϵ_{XPS}	0.515	+20.7%	0.010	0.21%	XPS emissivity
ϵ_{tp}	0.890	+24.9%	0.015	0.37%	tape emissivity
Ω_{tp}	0.540	+16.9%	0.020	0.34%	tape coverage
ϵ_{rs}	0.040	+89.0%	0.010	0.89%	test-surface emissivity
ϵ_{wt}	0.900	+40.5%	0.025	1.01%	wind-tunnel emissivity
				4.02%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	160r/min	+0.664%/(r/min)	0.93r/min	0.62%	fan rotation rate
				4.21%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 15972$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+15.1%/K	0.10K	1.51%	LM35C differential
P	100kPa	+0.0011%/Pa	1.5kPa	1.59%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.035%/(J/K)	42J/K	1.49%	plate thermal capacity
η	0.402	+242%	0.004	0.97%	anemometer calibration
L_T	8.34mm	+8893%/m	100um	0.89%	post length
ς	2.00mm	−11744%/m	100um	1.17%	post height
D_{PIR}	25.4mm	−281%/m	1.0mm	0.28%	insulation thickness
L_m	3.57mm	+715%/m	500um	0.36%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.283\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.31%	PIR thermal conductivity
ϵ_{tp}	0.890	+17.5%	0.015	0.26%	tape emissivity
Ω_{tp}	0.540	+11.8%	0.020	0.24%	tape coverage
ϵ_{rs}	0.040	+62.7%	0.010	0.63%	test-surface emissivity
ϵ_{wt}	0.900	+28.4%	0.025	0.71%	wind-tunnel emissivity
				3.40%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	226r/min	+0.430%/(r/min)	1.6r/min	0.70%	fan rotation rate
				3.68%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 22365$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.2K	+13.7%/K	0.10K	1.37%	LM35C differential
P	100kPa	+0.0010%/Pa	1.5kPa	1.45%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.032%/(J/K)	42J/K	1.36%	plate thermal capacity
η	0.402	+220%	0.004	0.88%	anemometer calibration
L_T	8.34mm	+9128%/m	100um	0.91%	post length
ς	2.00mm	−7921%/m	100um	0.79%	post height
D_{PIR}	25.4mm	−211%/m	1.0mm	0.21%	insulation thickness
L_m	3.57mm	+593%/m	500um	0.30%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.213\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.24%	PIR thermal conductivity
ϵ_{rs}	0.040	+45.6%	0.010	0.46%	test-surface emissivity
ϵ_{wt}	0.900	+20.6%	0.025	0.52%	wind-tunnel emissivity
				2.98%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	320r/min	+0.276%/(r/min)	1.1r/min	0.30%	fan rotation rate
				3.04%	RSS combined uncertainty