

Heat transfer coefficient reconstruction in ribbed cooling channels using proper orthogonal decomposition

Supplementary Information

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Training design points

Table S1 lists the 50 Latin hypercube parameter combinations used to construct the POD training database for each geometry family. The same parameter combinations were evaluated independently for all six rib and guide-vane families. The designs provide broad coverage of the parameter space defined by aspect ratio, relative rib height, relative rib pitch, rib angle, and Reynolds number. Small extensions beyond the nominal parameter limits were retained in several dimensions to improve the space-filling characteristics of the sampling procedure.

Table S1: Latin hypercube parameter combinations used to construct the POD training database for each geometry family.

AR	e/D_h	P/e	α ($^\circ$)	Re
3.645	0.0497	4.772	25.42	16278
3.890	0.0466	4.985	28.75	19458
9.002	0.1897	6.423	74.30	33204
14.266	0.0941	11.940	54.09	171579
5.679	0.1520	12.386	73.45	164878
6.027	0.1857	8.921	59.03	121108
10.986	0.1017	8.444	41.87	24717
12.295	0.0789	5.449	35.03	196383
8.515	0.0699	8.862	36.31	76871
14.406	0.1597	8.679	65.17	189773
4.379	0.1408	8.115	37.30	112307
7.607	0.1222	14.112	40.93	35773
10.897	0.1648	11.726	46.08	48748
4.669	0.0835	9.197	44.46	95242
5.399	0.0973	11.521	51.21	124028
6.641	0.1563	11.270	34.83	101591
12.908	0.1254	14.940	38.44	21979
13.755	0.1211	12.540	61.05	153636
4.080	0.0861	12.019	65.94	87783
7.056	0.1484	13.789	45.19	143473
9.871	0.1684	5.105	43.60	61098
14.775	0.0615	10.961	69.07	140693
14.622	0.0732	14.564	63.44	107269
10.421	0.1316	10.358	47.54	148330
13.893	0.1966	5.969	40.47	64306
8.260	0.1060	10.632	31.19	183861
6.611	0.0902	7.549	71.62	56800
9.688	0.0681	9.437	48.67	44367
9.374	0.0644	6.303	59.79	158602
7.428	0.1452	6.950	56.97	185585
13.216	0.1784	12.962	67.76	80937
12.796	0.1094	8.007	39.72	132395

Table S1 continued

AR	e/D_h	P/e	α ($^\circ$)	Re
10.643	0.1150	9.933	33.21	39651
11.439	0.0585	10.159	32.23	82746
7.276	0.1171	5.368	30.25	177586
5.136	0.1913	13.569	61.61	150207
5.460	0.0545	9.666	53.22	115302
11.384	0.0797	14.611	70.10	94012
7.906	0.1719	10.789	48.24	68804
10.139	0.0513	13.315	66.30	71450
12.531	0.1287	7.684	62.53	163961
11.694	0.1747	6.619	70.80	102852
11.999	0.1976	6.989	55.25	175714
4.802	0.1377	5.777	50.38	127705
6.189	0.1830	7.266	56.34	54044
8.640	0.1442	13.094	57.94	30389
13.486	0.1614	12.709	52.23	192456
9.210	0.1042	14.134	72.81	137273
15.062	0.2020	15.166	77.85	204947
15.455	0.2046	15.075	75.51	202177

Section-wise heat-flux reconstruction results

Table S2 provides the complete section-wise non-dimensional heat-flux reconstruction results for the six geometry families and four validation designs. The table reports the CFD reference value, the value recovered directly from the POD-reconstructed temperature field, the corrected POD value, and the corresponding mean absolute normalized errors. The dataset comprises 24 validation cases and 120 individual channel sections.

The abbreviations V, W, and StV denote the V-rib, W-rib, and staggered-V-rib configurations, respectively. G180 $^\circ$ and G135 $^\circ$ denote the corresponding guide-vane configurations. The non-dimensional heat flux q^* and the corresponding error metric ϵ_q are defined in Eqs. (36) and (37) of the main manuscript, respectively.

Table S2: Section-wise non-dimensional heat-flux reconstruction before and after distribution-based correction for all geometry families and validation designs.

Case	Section	CFD q^*	Uncorrected POD q^*	Corrected POD q^*	Uncorrected ϵ_q (%)	Corrected ϵ_q (%)
V-G180 $^\circ$ VD1	Passage 1	406.89	234.31	405.53	42.97	19.91
V-G180 $^\circ$ VD1	Passage 2	253.40	135.77	246.50	46.61	20.83
V-G180 $^\circ$ VD1	Passage 3	145.66	79.90	155.70	45.42	22.10
V-G180 $^\circ$ VD1	Top bend	222.05	161.49	259.65	28.38	27.83
V-G180 $^\circ$ VD1	Bottom bend	142.16	99.67	159.65	31.46	25.13
V-G180 $^\circ$ VD2	Passage 1	564.82	189.52	475.99	66.47	21.21
V-G180 $^\circ$ VD2	Passage 2	334.50	100.05	273.96	70.09	21.82
V-G180 $^\circ$ VD2	Passage 3	231.72	57.53	179.56	75.18	25.47

139	Table S2 continued						
140	Case	Section	CFD q^*	Uncorrected POD q^*	Corrected POD q^*	Uncorrected ϵ_q (%)	Corrected ϵ_q (%)
141							
142	V-G180° VD2	Top bend	301.84	126.23	221.93	58.22	31.01
143	V-G180° VD2	Bottom bend	196.31	74.11	133.15	62.26	34.39
144	V-G180° VD3	Passage 1	157.35	182.82	183.05	26.30	26.38
145	V-G180° VD3	Passage 2	93.71	102.46	102.60	24.37	24.42
146	V-G180° VD3	Passage 3	57.15	60.00	60.14	23.90	23.96
147	V-G180° VD3	Top bend	97.84	124.22	124.24	37.34	37.35
148	V-G180° VD3	Bottom bend	66.73	74.32	74.34	27.80	27.81
149	V-G180° VD4	Passage 1	379.26	184.62	322.80	51.34	21.38
150	V-G180° VD4	Passage 2	268.05	100.25	182.83	62.87	34.22
151	V-G180° VD4	Passage 3	178.22	56.97	112.44	68.13	38.11
152	V-G180° VD4	Top bend	279.22	124.02	214.48	55.58	28.30
153	V-G180° VD4	Bottom bend	186.84	73.64	124.74	60.59	33.97
154	V-G135° VD1	Passage 1	406.15	235.91	408.77	42.47	19.98
155	V-G135° VD1	Passage 2	250.41	135.35	246.13	46.09	20.41
156	V-G135° VD1	Passage 3	140.37	78.84	154.66	44.20	23.55
157	V-G135° VD1	Top bend	229.08	166.93	272.65	30.20	30.92
158	V-G135° VD1	Bottom bend	143.76	103.43	165.04	31.09	28.13
159	V-G135° VD2	Passage 1	564.74	190.24	476.37	66.33	21.14
160	V-G135° VD2	Passage 2	337.13	98.20	270.40	70.88	23.29
161	V-G135° VD2	Passage 3	228.03	56.23	177.10	75.35	25.89
162	V-G135° VD2	Top bend	328.70	130.51	245.95	60.30	29.71
163	V-G135° VD2	Bottom bend	210.41	76.11	144.83	63.83	33.07
164	V-G135° VD3	Passage 1	157.55	183.26	183.46	26.45	26.52
165	V-G135° VD3	Passage 2	90.74	100.85	100.98	25.43	25.48
166	V-G135° VD3	Passage 3	54.85	59.09	59.22	25.40	25.47
167	V-G135° VD3	Top bend	102.80	128.49	128.51	38.52	38.53
168	V-G135° VD3	Bottom bend	70.96	77.18	77.19	30.66	30.67
169	V-G135° VD4	Passage 1	379.58	184.62	321.65	51.38	21.49
170	V-G135° VD4	Passage 2	259.25	98.30	180.00	62.40	34.26
171	V-G135° VD4	Passage 3	169.17	55.43	110.37	67.54	37.52
172	V-G135° VD4	Top bend	282.80	127.15	220.90	55.11	29.57
173	V-G135° VD4	Bottom bend	193.92	75.29	126.36	61.20	36.25
174	W-G180° VD1	Passage 1	442.57	231.79	415.53	47.90	19.81
175	W-G180° VD1	Passage 2	234.21	116.71	220.61	51.57	26.26
176	W-G180° VD1	Passage 3	129.68	66.38	134.44	50.58	27.93
177	W-G180° VD1	Top bend	212.38	151.15	234.82	31.01	25.27
178	W-G180° VD1	Bottom bend	125.57	87.59	134.87	32.47	23.50
179	W-G180° VD2	Passage 1	600.87	192.68	464.97	67.95	27.67
180	W-G180° VD2	Passage 2	333.09	92.15	238.56	72.34	32.27
181	W-G180° VD2	Passage 3	218.93	52.10	149.48	76.21	34.97
182	W-G180° VD2	Top bend	307.21	122.73	216.64	60.07	33.58
183	W-G180° VD2	Bottom bend	188.73	69.38	122.57	63.24	37.39
184	W-G180° VD3	Passage 1	139.87	185.28	185.50	41.97	42.08
	W-G180° VD3	Passage 2	87.09	93.73	93.85	27.04	27.08
	W-G180° VD3	Passage 3	53.86	54.05	54.15	26.38	26.40
	W-G180° VD3	Top bend	101.55	118.69	118.72	32.32	32.33

Table S2 continued							185
Case	Section	CFD q^*	Uncorrected POD q^*	Corrected POD q^*	Uncorrected ϵ_q (%)	Corrected ϵ_q (%)	186
W-G180° VD3	Bottom bend	68.75	68.34	68.37	26.55	26.56	187
W-G180° VD4	Passage 1	406.26	185.44	336.54	54.41	21.97	188
W-G180° VD4	Passage 2	247.34	91.18	173.02	63.76	34.91	189
W-G180° VD4	Passage 3	166.92	50.59	103.05	69.90	40.92	190
W-G180° VD4	Top bend	260.61	121.36	205.32	53.48	26.76	191
W-G180° VD4	Bottom bend	175.61	68.69	109.13	60.88	38.61	192
W-G135° VD1	Passage 1	443.13	229.56	410.39	48.45	20.09	193
W-G135° VD1	Passage 2	226.08	114.11	216.75	51.08	28.33	194
W-G135° VD1	Passage 3	134.38	63.95	135.09	53.54	24.29	195
W-G135° VD1	Top bend	218.48	148.64	237.77	33.26	24.16	196
W-G135° VD1	Bottom bend	128.41	86.25	139.07	34.34	23.83	197
W-G135° VD2	Passage 1	601.65	192.75	502.93	67.98	24.20	198
W-G135° VD2	Passage 2	333.74	91.95	261.57	72.45	28.08	199
W-G135° VD2	Passage 3	217.28	51.62	170.71	76.25	28.56	200
W-G135° VD2	Top bend	324.53	124.48	224.58	61.64	34.56	201
W-G135° VD2	Bottom bend	199.70	70.27	127.68	64.81	38.37	202
W-G135° VD3	Passage 1	140.68	185.96	186.18	41.71	41.82	203
W-G135° VD3	Passage 2	89.58	94.31	94.44	25.53	25.56	204
W-G135° VD3	Passage 3	53.91	53.62	53.73	25.77	25.78	205
W-G135° VD3	Top bend	105.48	119.68	119.72	29.38	29.39	206
W-G135° VD3	Bottom bend	71.84	69.48	69.51	27.03	27.03	207
W-G135° VD4	Passage 1	405.84	185.35	336.03	54.38	21.95	208
W-G135° VD4	Passage 2	250.07	90.30	171.85	64.15	34.87	209
W-G135° VD4	Passage 3	166.94	49.71	105.42	70.33	39.23	210
W-G135° VD4	Top bend	265.01	121.58	211.64	54.17	27.46	211
W-G135° VD4	Bottom bend	179.58	68.76	113.96	61.72	37.81	212
StV-G180° VD1	Passage 1	373.69	230.96	408.05	39.13	24.69	213
StV-G180° VD1	Passage 2	241.07	140.79	241.71	42.24	24.54	214
StV-G180° VD1	Passage 3	143.71	83.51	156.77	42.64	25.75	215
StV-G180° VD1	Top bend	225.98	172.14	293.18	25.44	38.48	216
StV-G180° VD1	Bottom bend	138.67	107.13	168.01	25.29	29.12	217
StV-G180° VD2	Passage 1	536.20	186.78	432.95	65.18	24.89	218
StV-G180° VD2	Passage 2	316.02	99.97	242.96	68.37	27.64	219
StV-G180° VD2	Passage 3	237.08	58.55	159.15	75.30	34.57	220
StV-G180° VD2	Top bend	311.55	128.45	251.60	58.81	27.49	221
StV-G180° VD2	Bottom bend	214.96	76.57	150.52	64.38	32.21	222
StV-G180° VD3	Passage 1	150.55	177.91	178.02	31.65	31.69	223
StV-G180° VD3	Passage 2	90.48	102.41	102.47	31.85	31.87	224
StV-G180° VD3	Passage 3	60.55	61.31	61.37	24.81	24.81	225
StV-G180° VD3	Top bend	97.77	125.43	121.69	39.34	36.82	226
StV-G180° VD3	Bottom bend	69.34	76.46	72.39	28.00	25.54	227
StV-G180° VD4	Passage 1	375.75	179.89	313.31	52.12	21.91	228
StV-G180° VD4	Passage 2	257.30	100.18	174.44	61.60	35.84	229
StV-G180° VD4	Passage 3	176.50	57.55	108.84	67.56	39.69	230
StV-G180° VD4	Top bend	281.46	125.96	254.26	55.28	22.66	230
StV-G180° VD4	Bottom bend	193.08	76.12	146.27	60.58	26.15	230

Table S2 continued

Case	Section	CFD q^*	Uncorrected POD q^*	Corrected POD q^*	Uncorrected ϵ_q (%)	Corrected ϵ_q (%)
StV-G135° VD1	Passage 1	378.51	229.71	360.34	41.11	23.29
StV-G135° VD1	Passage 2	240.24	128.62	221.31	46.79	24.24
StV-G135° VD1	Passage 3	139.77	72.10	139.99	48.70	22.81
StV-G135° VD1	Top bend	235.35	172.34	242.29	30.82	23.94
StV-G135° VD1	Bottom bend	144.00	101.56	145.73	32.07	21.68
StV-G135° VD2	Passage 1	535.77	190.85	384.11	64.41	31.51
StV-G135° VD2	Passage 2	318.33	102.26	225.97	67.88	32.52
StV-G135° VD2	Passage 3	233.09	57.26	152.94	75.43	36.38
StV-G135° VD2	Top bend	338.36	142.47	242.27	57.90	31.95
StV-G135° VD2	Bottom bend	226.52	82.31	142.86	63.67	37.73
StV-G135° VD3	Passage 1	150.85	202.24	202.31	42.91	42.93
StV-G135° VD3	Passage 2	88.03	114.16	114.14	40.75	40.70
StV-G135° VD3	Passage 3	59.18	61.00	60.92	27.02	26.81
StV-G135° VD3	Top bend	98.45	168.57	141.71	76.86	54.14
StV-G135° VD3	Bottom bend	70.82	94.34	68.03	44.24	24.72
StV-G135° VD4	Passage 1	375.20	186.73	309.55	50.24	23.81
StV-G135° VD4	Passage 2	256.73	101.92	172.33	60.50	35.80
StV-G135° VD4	Passage 3	174.03	56.33	110.35	67.74	38.06
StV-G135° VD4	Top bend	278.80	138.76	238.34	50.43	29.13
StV-G135° VD4	Bottom bend	193.74	80.46	135.19	58.54	31.92

Section-wise normalized Nusselt-number reconstruction results

Table S3 provides the complete section-wise normalized Nusselt-number reconstruction results for the six geometry families and four validation designs. The table reports the CFD reference value, the POD-predicted value, and the corresponding mean absolute normalized reconstruction error. The normalized Nusselt number Nu_{norm} and the corresponding error metric ϵ_{Nu} are defined in Eqs. (38) and (39) of the main manuscript, respectively.

Table S3: Section-wise normalized Nusselt-number reconstruction results for all geometry families and validation designs.

Case	Section	CFD Nu_{norm}	POD Nu_{norm}	ϵ_{Nu} (%)
V-G180° VD1	Passage 1	2.281	2.472	20.21
V-G180° VD1	Passage 2	2.718	2.851	28.41
V-G180° VD1	Passage 3	2.791	2.990	20.23
V-G180° VD1	Top bend	1.697	2.289	43.53
V-G180° VD1	Bottom bend	1.819	2.350	36.71
V-G180° VD2	Passage 1	2.026	1.912	15.68
V-G180° VD2	Passage 2	2.392	2.249	29.61
V-G180° VD2	Passage 3	2.814	2.448	17.65

Table S3 continued

Case	Section	CFD Nu_{norm}	POD Nu_{norm}	ϵ_{Nu} (%)
V-G180° VD2	Top bend	1.410	1.281	24.76
V-G180° VD2	Bottom bend	1.521	1.349	24.35
V-G180° VD3	Passage 1	2.595	3.390	32.86
V-G180° VD3	Passage 2	2.726	3.745	41.22
V-G180° VD3	Passage 3	2.922	3.798	34.41
V-G180° VD3	Top bend	1.888	3.366	81.88
V-G180° VD3	Bottom bend	2.022	3.538	77.98
V-G180° VD4	Passage 1	1.573	1.508	16.62
V-G180° VD4	Passage 2	2.101	1.708	35.04
V-G180° VD4	Passage 3	2.324	1.800	25.93
V-G180° VD4	Top bend	1.569	1.488	23.14
V-G180° VD4	Bottom bend	1.722	1.504	21.67
V-G135° VD1	Passage 1	2.280	2.483	20.58
V-G135° VD1	Passage 2	2.724	2.843	30.70
V-G135° VD1	Passage 3	2.750	2.977	20.75
V-G135° VD1	Top bend	1.761	2.391	45.92
V-G135° VD1	Bottom bend	1.890	2.427	38.29
V-G135° VD2	Passage 1	2.024	1.910	15.60
V-G135° VD2	Passage 2	2.419	2.242	31.29
V-G135° VD2	Passage 3	2.827	2.454	17.77
V-G135° VD2	Top bend	1.522	1.443	23.82
V-G135° VD2	Bottom bend	1.657	1.496	21.16
V-G135° VD3	Passage 1	2.592	3.391	33.07
V-G135° VD3	Passage 2	2.686	3.720	43.54
V-G135° VD3	Passage 3	2.864	3.762	35.65
V-G135° VD3	Top bend	1.969	3.440	78.55
V-G135° VD3	Bottom bend	2.139	3.653	74.18
V-G135° VD4	Passage 1	1.574	1.503	16.60
V-G135° VD4	Passage 2	2.020	1.697	34.94
V-G135° VD4	Passage 3	2.201	1.794	25.18
V-G135° VD4	Top bend	1.584	1.534	27.69
V-G135° VD4	Bottom bend	1.788	1.539	24.52
W-G180° VD1	Passage 1	2.495	2.604	17.28
W-G180° VD1	Passage 2	2.524	2.858	25.79
W-G180° VD1	Passage 3	2.472	3.049	32.19
W-G180° VD1	Top bend	1.699	2.264	41.41
W-G180° VD1	Bottom bend	1.753	2.282	38.11
W-G180° VD2	Passage 1	2.131	1.877	20.35
W-G180° VD2	Passage 2	2.253	2.089	19.10
W-G180° VD2	Passage 3	2.590	2.270	21.47

Table S3 continued

Case	Section	CFD Nu_{norm}	POD Nu_{norm}	ϵ_{Nu} (%)
W-G180° VD2	Top bend	1.506	1.387	25.69
W-G180° VD2	Bottom bend	1.623	1.371	26.91
W-G180° VD3	Passage 1	2.237	3.436	55.91
W-G180° VD3	Passage 2	2.310	3.641	59.93
W-G180° VD3	Passage 3	2.346	3.730	60.89
W-G180° VD3	Top bend	2.158	3.493	64.96
W-G180° VD3	Bottom bend	2.334	3.608	57.90
W-G180° VD4	Passage 1	1.704	1.600	16.40
W-G180° VD4	Passage 2	1.858	1.742	22.71
W-G180° VD4	Passage 3	2.151	1.843	23.88
W-G180° VD4	Top bend	1.510	1.514	25.91
W-G180° VD4	Bottom bend	1.716	1.439	24.46
W-G135° VD1	Passage 1	2.496	2.578	17.03
W-G135° VD1	Passage 2	2.463	2.862	28.73
W-G135° VD1	Passage 3	2.618	3.169	28.11
W-G135° VD1	Top bend	1.756	2.325	40.95
W-G135° VD1	Bottom bend	1.811	2.425	41.08
W-G135° VD2	Passage 1	2.127	2.027	18.32
W-G135° VD2	Passage 2	2.266	2.283	18.18
W-G135° VD2	Passage 3	2.599	2.618	19.06
W-G135° VD2	Top bend	1.553	1.419	25.53
W-G135° VD2	Bottom bend	1.687	1.446	25.66
W-G135° VD3	Passage 1	2.238	3.434	55.71
W-G135° VD3	Passage 2	2.335	3.644	58.27
W-G135° VD3	Passage 3	2.352	3.731	60.25
W-G135° VD3	Top bend	2.153	3.494	65.68
W-G135° VD3	Bottom bend	2.348	3.670	59.46
W-G135° VD4	Passage 1	1.704	1.598	16.40
W-G135° VD4	Passage 2	1.892	1.746	21.67
W-G135° VD4	Passage 3	2.180	1.917	22.26
W-G135° VD4	Top bend	1.533	1.564	27.05
W-G135° VD4	Bottom bend	1.765	1.531	25.67
StV-G180° VD1	Passage 1	2.083	2.432	27.33
StV-G180° VD1	Passage 2	2.548	2.660	32.58
StV-G180° VD1	Passage 3	2.654	2.778	22.81
StV-G180° VD1	Top bend	1.714	2.497	53.61
StV-G180° VD1	Bottom bend	1.750	2.311	38.46
StV-G180° VD2	Passage 1	1.907	1.733	18.60
StV-G180° VD2	Passage 2	2.107	1.975	25.88
StV-G180° VD2	Passage 3	2.686	2.112	24.51

Table S3 continued

Case	Section	CFD Nu_{norm}	POD Nu_{norm}	ϵ_{Nu} (%)
StV-G180° VD2	Top bend	1.416	1.456	26.17
StV-G180° VD2	Bottom bend	1.567	1.503	22.30
StV-G180° VD3	Passage 1	2.503	3.290	35.68
StV-G180° VD3	Passage 2	2.560	3.696	46.23
StV-G180° VD3	Passage 3	2.979	3.733	31.70
StV-G180° VD3	Top bend	1.923	3.262	74.59
StV-G180° VD3	Bottom bend	2.049	3.334	67.18
StV-G180° VD4	Passage 1	1.554	1.449	17.33
StV-G180° VD4	Passage 2	1.958	1.604	32.48
StV-G180° VD4	Passage 3	2.270	1.682	28.85
StV-G180° VD4	Top bend	1.571	1.752	29.76
StV-G180° VD4	Bottom bend	1.759	1.715	20.40
StV-G135° VD1	Passage 1	2.083	2.211	22.39
StV-G135° VD1	Passage 2	2.524	2.682	33.60
StV-G135° VD1	Passage 3	2.605	2.847	22.81
StV-G135° VD1	Top bend	1.773	2.237	37.14
StV-G135° VD1	Bottom bend	1.827	2.278	33.76
StV-G135° VD2	Passage 1	1.904	1.536	24.52
StV-G135° VD2	Passage 2	2.144	1.823	27.98
StV-G135° VD2	Passage 3	2.699	2.043	27.15
StV-G135° VD2	Top bend	1.532	1.430	23.33
StV-G135° VD2	Bottom bend	1.690	1.447	23.18
StV-G135° VD3	Passage 1	2.501	3.737	51.61
StV-G135° VD3	Passage 2	2.513	4.112	64.20
StV-G135° VD3	Passage 3	2.932	3.740	33.62
StV-G135° VD3	Top bend	1.949	3.831	100.84
StV-G135° VD3	Bottom bend	2.127	3.152	55.93
StV-G135° VD4	Passage 1	1.553	1.433	19.67
StV-G135° VD4	Passage 2	1.971	1.608	34.08
StV-G135° VD4	Passage 3	2.247	1.745	26.17
StV-G135° VD4	Top bend	1.558	1.661	31.15
StV-G135° VD4	Bottom bend	1.770	1.625	23.49

Computational performance

Table S4 provides the complete online computational timing results for all six geometry families and four validation designs. The reported reduced-order-model timings include modal-coefficient prediction, temperature reconstruction, wall heat-flux recovery and correction, bulk-temperature evaluation, and heat-transfer coefficient calculation. The offline costs associated with CFD database generation and model construction are excluded.

Table S4: Online computational performance of the POD-based workflow across all geometry families and validation designs. Speedup values were calculated from the unrounded timing measurements; the displayed wall and CPU times are rounded.

Geometry family	VD	CFD wall time (s)	CFD CPU time (s)	ROM wall time (s)	ROM CPU time (s)	Wall-time speedup	CPU-time speedup
V-G180°	VD1	186.3	52900	16.99	19.92	10.96	2656
V-G180°	VD2	120.4	34200	15.20	18.35	7.92	1864
V-G180°	VD3	61.12	17300	11.16	14.58	5.48	1187
V-G180°	VD4	270.9	77300	11.98	15.13	22.61	5111
V-G135°	VD1	183.4	52200	11.85	15.38	15.48	3394
V-G135°	VD2	119.9	33900	12.83	15.83	9.35	2141
V-G135°	VD3	54.92	15600	14.51	17.83	3.79	875
V-G135°	VD4	268.2	76500	15.07	18.18	17.80	4208
W-G180°	VD1	184.5	52600	17.36	21.09	10.63	2494
W-G180°	VD2	119.9	34100	17.26	20.95	6.95	1627
W-G180°	VD3	57.68	16400	13.73	16.70	4.20	982
W-G180°	VD4	272.0	77700	12.66	15.70	21.48	4948
W-G135°	VD1	185.5	52800	15.19	19.03	12.21	2774
W-G135°	VD2	120.0	34100	18.32	21.87	6.55	1560
W-G135°	VD3	62.25	17500	12.11	17.02	5.14	1028
W-G135°	VD4	273.0	78000	19.14	22.17	14.26	3518
StV-G180°	VD1	189.8	53900	9.77	12.68	19.42	4251
StV-G180°	VD2	134.5	38200	14.08	17.52	9.55	2181
StV-G180°	VD3	62.23	17700	9.94	13.14	6.26	1347
StV-G180°	VD4	285.9	81500	11.37	14.30	25.14	5698
StV-G135°	VD1	184.3	52500	13.90	16.84	13.26	3118
StV-G135°	VD2	116.3	33200	11.49	14.63	10.12	2269
StV-G135°	VD3	62.13	17600	9.41	12.63	6.60	1393
StV-G135°	VD4	287.2	81800	14.24	17.55	20.16	4662