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Technical Reference

Capstone Model C65 Performance

Introduction

This document presents performance information for the Capstone Turbine Corporation® Capstone (recuperated) Model C65 MicroTurbine™. The Capstone Model C65 MicroTurbine system is a compact, low emission, power generator providing up to 65 kW of electrical power.

ISO Full Load Performance

Performance is listed at full load power and ISO conditions for the Capstone Model C65 MicroTurbine. ISO conditions are defined as: 15 °C (59 °F), 60% relative humidity, and 101.325 kPa (14.696 psia) (standard sea level pressure), with no inlet or exhaust pressure losses. Other items are defined as: HHV: Higher Heating Value, LHV: Lower Heating Value, and HPNG: High Pressure Natural Gas.

Table 1 presents the (recuperated) Model C65 MicroTurbine performance for HPNG application.

Table 1. Capstone Model C65 MicroTurbine Performance (Grid Connect/Stand Alone)

Performance	Values
Rated Output	65.0 (+0/-2) kW
Net Thermal Efficiency	29.0 (±2)% LHV
Fuel Flow (LHV Based) (See Notes 1 and 2)	807,000 kJ/hr (765,000 Btu/hr)
Fuel Flow (HHV Based) (See Notes 1 and 2)	888,000 kJ/hr (842,000 Btu/hr)
Net Heat Rate (LHV Based) (See Notes 1 and 2)	12,400 kJ/kWhr (11,800 Btu/kWhr)
Generator Heat Rate (LHV Based)	11,600 kJ/kWhr (11,000 Btu/kWhr)
Exhaust Temperature	309 °C (588 °F)
Exhaust Heat Energy Rate	591,000 kJ/hr (561,000 Btu/hr)
Exhaust Mass Flow	0.49 kg/s (1.08 lbm/s)
Engine Air Inlet Flow	965 SCFM (27,300 SLPM)

NOTES	1. These parameters are fuel-type dependent. 2. Higher Heating Value (HHV) to Lower Heating Value (LHV) ratio is to be assumed 1:1.

Fuel Parameters

Refer to the Capstone MicroTurbine Fuel Requirements Technical Reference 410002 for detailed information regarding fuel parameters for the Model C65 MicroTurbine.

How to Use This Document

The following pages present several tables and graphs for determining the nominal net power output, efficiency, and other parameter values for various operating conditions.

To calculate the expected net power output, proceed as follows:

- ❑ Look up the estimated power and efficiency using Temperature Derating table.
- ❑ If the elevation is above sea level, use Figure 3 to estimate power output.
- ❑ Apply Back Pressure Derating.
- ❑ Apply Inlet Pressure Loss Derating.
- ❑ Subtract parasitic loads (Fuel Gas Booster, Battery charging).

Example

Conditions:

C65 Grid Connect, 4.5 kW loss from Fuel Gas Booster, ambient temperature of 75 °F, and 1000 ft above sea level.

Calculations:

Power based on temperature at sea level = 62.9 kW

Power based on elevation = 60 kW

Fuel Gas Booster Loss = 4.5 kW

Expected Power = 60.0 – 4.5 = 55.5 kW

Temperature Derating

Nominal net power output and efficiency versus ambient temperature at sea level for the Model C65 MicroTurbine is presented in Table 2. These values are estimated from nominal performance curves.

Table 2. Nominal Net Power Output and Efficiency versus Ambient Temperature at Standard Sea Level Pressure

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (Btu/hr)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
-4	65.0	30.4	487	1.10	516000	729000	11200
-3	65.0	30.4	488	1.10	516000	729000	11200
-2	65.0	30.4	490	1.10	516000	729000	11200
-1	65.0	30.4	491	1.10	516000	729000	11200
0	65.0	30.4	493	1.10	516000	729000	11200
1	65.0	30.4	495	1.09	516000	729000	11200
2	65.0	30.4	496	1.09	516000	729000	11200
3	65.0	30.4	498	1.09	516000	729000	11200
4	65.0	30.4	500	1.09	516000	729000	11200
5	65.0	30.4	501	1.09	516000	729000	11200
6	65.0	30.4	503	1.09	516000	729000	11200
7	65.0	30.4	505	1.08	516000	729000	11200
8	65.0	30.4	506	1.08	516000	729000	11200
9	65.0	30.4	508	1.08	516000	730000	11200
10	65.0	30.4	509	1.08	516000	730000	11200
11	65.0	30.4	511	1.08	516000	730000	11200
12	65.0	30.4	513	1.08	516000	730000	11200
13	65.0	30.4	514	1.07	517000	730000	11200
14	65.0	30.4	516	1.07	517000	730000	11200
15	65.0	30.4	518	1.07	517000	730000	11200
16	65.0	30.4	519	1.07	517000	730000	11200
17	65.0	30.4	521	1.07	517000	730000	11200
18	65.0	30.4	523	1.06	517000	730000	11200
19	65.0	30.4	524	1.06	517000	730000	11200
20	65.0	30.4	526	1.06	517000	730000	11200
21	65.0	30.4	528	1.06	518000	730000	11200
22	65.0	30.4	529	1.06	518000	730000	11200
23	65.0	30.4	531	1.06	518000	730000	11200
24	65.0	30.4	533	1.06	518000	730000	11200
25	65.0	30.4	534	1.05	518000	730000	11200
26	65.0	30.4	536	1.05	518000	730000	11200
27	65.0	30.4	538	1.05	518000	730000	11200
28	65.0	30.4	539	1.05	519000	730000	11200
29	65.0	30.3	541	1.05	519000	731000	11200
30	65.0	30.3	542	1.05	520000	732000	11300

Table 2. Nominal Net Power Output and Efficiency versus Ambient Temperature at Standard Sea Level Pressure (Continued)

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (Btu/hr)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
32	65.0	30.2	545	1.05	522000	734000	11300
33	65.0	30.2	546	1.05	524000	735000	11300
34	65.0	30.2	548	1.05	525000	735000	11300
35	65.0	30.1	549	1.05	526000	736000	11300
36	65.0	30.1	551	1.05	527000	737000	11300
37	65.0	30.1	552	1.05	528000	738000	11400
38	65.0	30.0	554	1.06	529000	739000	11400
39	65.0	30.0	555	1.06	530000	740000	11400
40	65.0	29.9	557	1.06	531000	741000	11400
41	65.0	29.9	558	1.06	532000	742000	11400
42	65.0	29.9	560	1.06	534000	743000	11400
43	65.0	29.8	561	1.06	535000	744000	11400
44	65.0	29.8	563	1.06	536000	745000	11500
45	65.0	29.7	565	1.06	538000	746000	11500
46	65.0	29.7	566	1.06	539000	747000	11500
47	65.0	29.6	568	1.06	541000	749000	11500
48	65.0	29.6	569	1.06	542000	750000	11500
49	65.0	29.5	571	1.07	544000	751000	11600
50	65.0	29.5	573	1.07	546000	753000	11600
51	65.0	29.4	574	1.07	547000	754000	11600
52	65.0	29.4	576	1.07	549000	755000	11600
53	65.0	29.3	578	1.07	550000	757000	11600
54	65.0	29.3	579	1.07	552000	758000	11700
55	65.0	29.2	581	1.07	554000	759000	11700
56	65.0	29.2	583	1.07	556000	761000	11700
57	65.0	29.1	584	1.08	557000	762000	11700
58	65.0	29.1	586	1.08	559000	764000	11700
59	65.0	29.0	588	1.08	561000	765000	11800
60	65.0	28.9	589	1.08	562000	766000	11800
61	65.0	28.9	591	1.08	564000	768000	11800
62	65.0	28.8	593	1.08	566000	769000	11800
63	65.0	28.8	594	1.08	568000	771000	11900
64	65.0	28.7	596	1.08	570000	772000	11900
65	65.0	28.7	598	1.09	571000	774000	11900
66	65.0	28.6	599	1.09	573000	775000	11900
67	65.0	28.6	601	1.09	575000	777000	12000
68	65.0	28.5	603	1.09	577000	778000	12000
69	65.0	28.4	604	1.09	579000	780000	12000
70	64.9	28.4	606	1.09	580000	781000	12000
71	64.5	28.3	606	1.09	578000	777000	12000
72	64.1	28.3	607	1.09	577000	774000	12100
73	63.7	28.2	608	1.08	575000	771000	12100

Table 2. Nominal Net Power Output and Efficiency versus Ambient Temperature at Standard Sea Level Pressure (Continued)

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (Btu/hr)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
74	63.3	28.1	608	1.08	573000	768000	12100
75	62.9	28.1	609	1.08	572000	765000	12200
76	62.5	28.0	609	1.08	570000	762000	12200
78	61.7	27.9	610	1.07	567000	756000	12200
79	61.3	27.8	611	1.07	565000	753000	12300
80	60.9	27.7	611	1.06	563000	750000	12300
81	60.5	27.7	612	1.06	562000	747000	12300
82	60.2	27.6	612	1.06	560000	744000	12400
83	59.8	27.5	613	1.06	558000	741000	12400
84	59.4	27.5	613	1.05	557000	738000	12400
85	59.0	27.4	614	1.05	555000	735000	12400
86	58.6	27.4	614	1.05	554000	732000	12500
87	58.3	27.3	615	1.05	552000	729000	12500
88	57.9	27.2	615	1.04	550000	726000	12500
89	57.5	27.2	616	1.04	549000	723000	12600
90	57.2	27.1	616	1.04	547000	720000	12600
91	56.8	27.0	617	1.03	546000	717000	12600
92	56.4	27.0	617	1.03	544000	714000	12700
93	56.1	26.9	618	1.03	543000	712000	12700
94	55.7	26.8	618	1.03	541000	709000	12700
95	55.3	26.8	619	1.02	540000	706000	12800
96	55.0	26.7	619	1.02	538000	703000	12800
97	54.6	26.6	619	1.02	536000	700000	12800
98	54.3	26.6	620	1.02	535000	697000	12900
99	53.9	26.5	620	1.01	533000	695000	12900
100	53.5	26.4	621	1.01	532000	692000	12900
101	53.2	26.3	621	1.01	530000	689000	13000
102	52.8	26.3	622	1.00	529000	686000	13000
103	52.5	26.2	622	1.00	527000	683000	13000
104	52.1	26.1	623	1.00	526000	681000	13100
105	51.8	26.1	623	1.00	524000	678000	13100
106	51.4	26.0	623	0.99	523000	675000	13100
107	51.1	25.9	624	0.99	521000	672000	13200
108	50.8	25.9	624	0.99	520000	670000	13200
109	50.4	25.8	625	0.98	518000	667000	13200
110	50.0	25.7	625	0.98	517000	664000	13300
111	49.7	25.6	626	0.98	515000	661000	13300
112	49.3	25.5	626	0.98	514000	658000	13400
113	48.9	25.5	627	0.97	512000	656000	13400
114	48.6	25.4	627	0.97	511000	653000	13400
115	48.2	25.3	627	0.97	509000	650000	13500
116	47.9	25.2	628	0.96	508000	648000	13500

Table 2. Nominal Net Power Output and Efficiency versus Ambient Temperature at Standard Sea Level Pressure (Continued)

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (Btu/hr)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
117	47.5	25.1	628	0.96	507000	645000	13600
118	47.1	25.1	629	0.96	505000	642000	13600
119	46.8	25.0	629	0.96	504000	639000	13700
120	46.4	24.9	630	0.95	502000	637000	13700
121	46.1	24.8	630	0.95	501000	634000	13800
122	45.7	24.7	630	0.95	499000	631000	13800

Figure 1 presents a chart illustrating the nominal net power output versus ambient temperature at sea level for the Model C65 MicroTurbine.

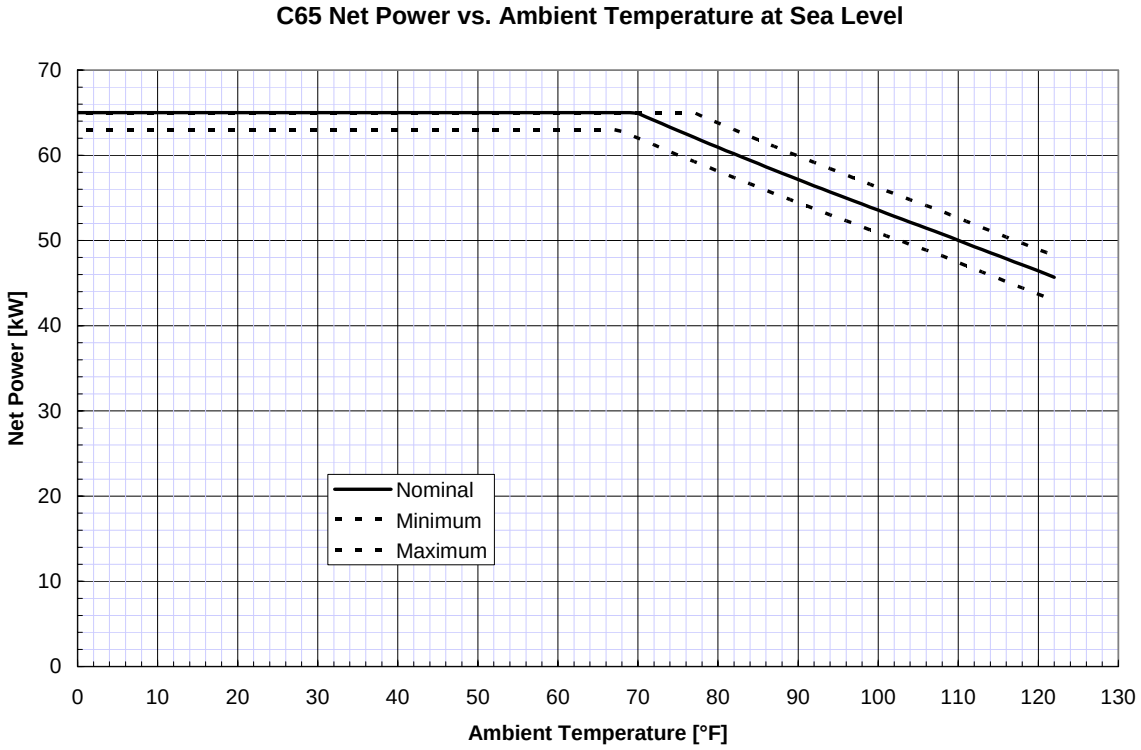

Figure 1. Nominal Net Power Output versus Ambient Temperature at Sea Level

Figure 2 presents a chart illustrating the net efficiency versus ambient temperature at sea level at for the Model C65 MicroTurbine.

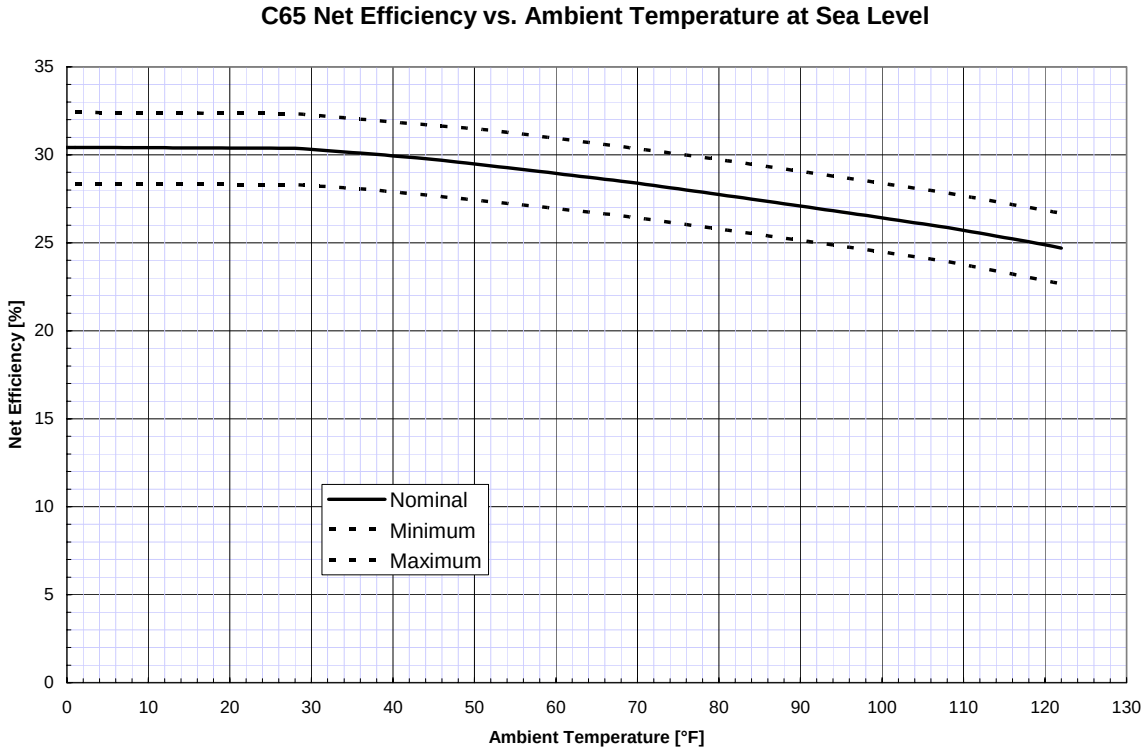

Figure 2. Nominal Net Efficiency versus Ambient Temperature at Sea Level

Elevation Derating

Elevation affects power output by changing the density of the air. Figure 3 provides expected maximum power output for several elevations versus ambient temperature. Values shown assume Nominal engine output, and are based on the 1976 US Standard Atmosphere model to correlate air density to elevation. Electrical efficiency is not strongly dependent on elevation, so the nominal efficiency values shown in Figure 2 can be used to estimate fuel consumption at any elevation for a given ambient temperature.

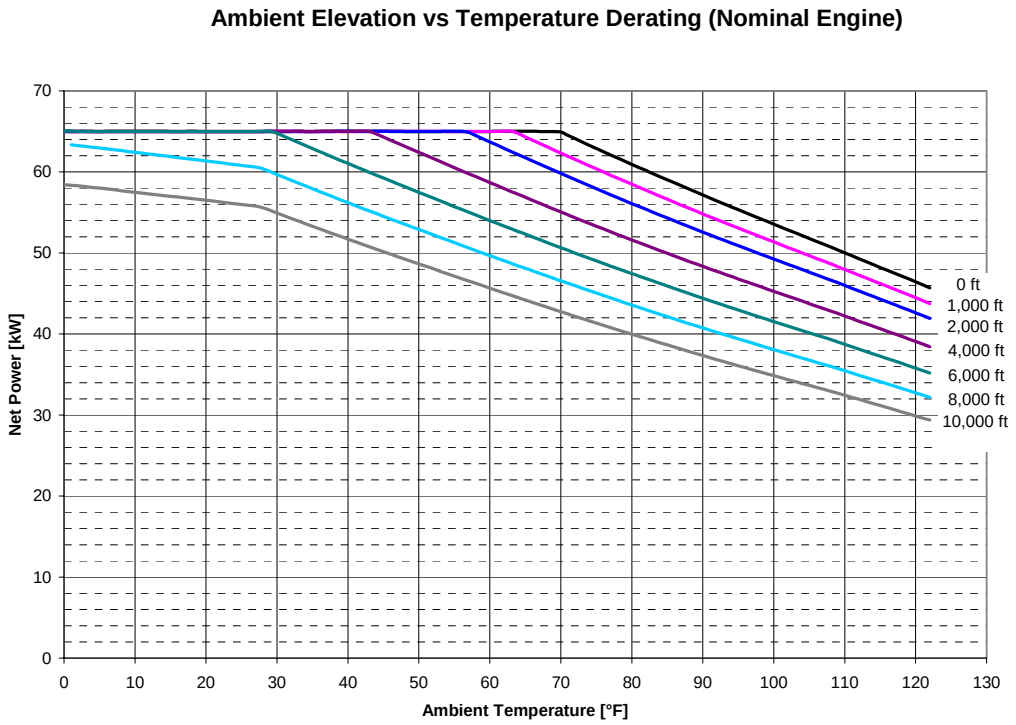

Figure 3. Ambient Elevation vs. Temperature Derating

Inlet Pressure Loss Derating

Air inlet design can affect engine performance. The amount of air inlet filter debris can also affect engine performance for all engine applications. The maximum allowable inlet pressure loss is 10 inches of water. Table 5 presents the nominal fraction of ISO zero inlet pressure loss power and efficiency versus inlet pressure loss at ISO ambient conditions for the Model C65 MicroTurbine. These values are estimated from nominal performance curves.

The inlet loss power and efficiency ratios are defined as follows:

$$\text{Power Ratio} = \frac{\text{Power Output}}{\text{Power Output at zero (0) Inlet Loss}}$$

$$\text{Efficiency Ratio} = \frac{\text{Efficiency}}{\text{Efficiency at zero (0) Inlet Loss}}$$

Table 5. Nominal Fraction of ISO Zero Inlet Pressure Loss Power and Efficiency versus Inlet Pressure Loss at ISO Ambient Conditions

Inlet Pressure Loss (Inches of Water)	Inlet Pressure Loss Power Ratio	Inlet Pressure Loss Efficiency Ratio
0.0	1.000	1.000
1.0	0.994	0.998
2.0	0.988	0.996
3.0	0.982	0.993
4.0	0.976	0.991
5.0	0.969	0.989
6.0	0.963	0.987
7.0	0.957	0.984
8.0	0.951	0.982
9.0	0.945	0.979
10.0	0.939	0.977

Nominal fraction of zero inlet pressure loss power and efficiency versus inlet pressure loss at sea level and ambient temperature of 59.4° F is presented in Figure 4.

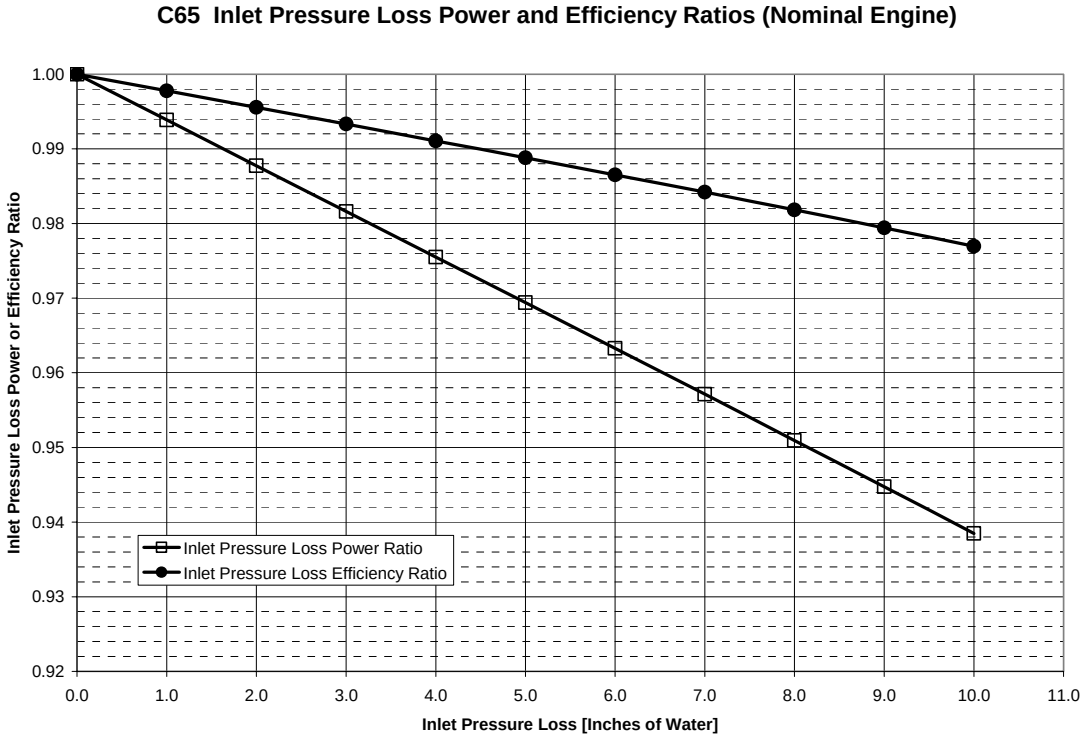

Figure 4. Nominal Fraction of ISO Zero Inlet Pressure Loss Power and Efficiency versus Inlet Pressure Loss at ISO Ambient Conditions

Back Pressure Derating

The maximum allowable exhaust back pressure is eight inches of water. Nominal fraction of ISO net power output and efficiency versus back pressure at sea level and ambient temperature of 59.4° F is presented in Table 6. These values are estimated from nominal performance curves.

The inlet loss power and efficiency ratios are defined as follows:

$$\text{Power Ratio} = \frac{\text{Power Output}}{\text{Power Output at zero (0) Exhaust Back Pressure}}$$

$$\text{Efficiency Ratio} = \frac{\text{Efficiency Output}}{\text{Efficiency Output at zero (0) Exhaust Back Pressure}}$$

Table 6. Nominal Fraction of ISO Net Power Output and Efficiency versus Exhaust Back Pressure at ISO Ambient Conditions

Back Pressure (Inches of Water)	Back Pressure Power Ratio	Back Pressure Efficiency Ratio
0.0	1.000	1.000
1.0	0.997	0.998
2.0	0.993	0.995
3.0	0.990	0.993
4.0	0.986	0.990
5.0	0.983	0.988
6.0	0.979	0.986
7.0	0.976	0.983
8.0	0.972	0.981

Nominal fraction of zero back pressure power output and efficiency versus back pressure at sea level and ambient temperature of 59.4° F (non-CHP) is presented in Figure 5.

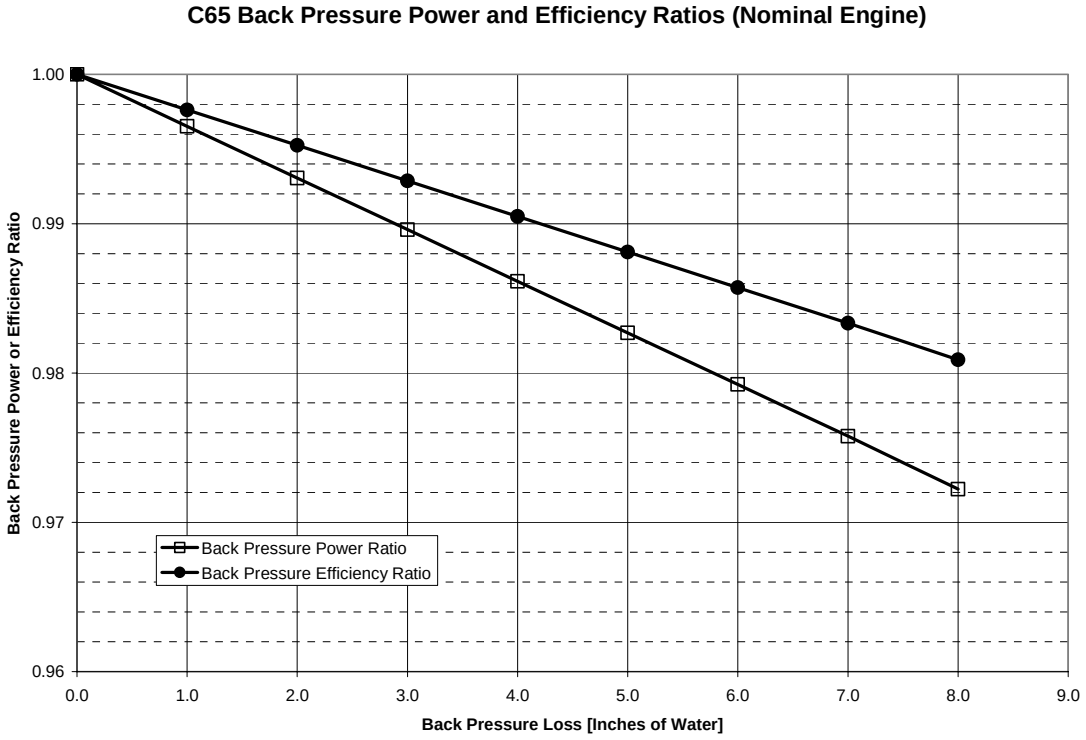

Figure 5. Nominal Fraction of ISO Zero Back Pressure Power Output and Efficiency versus Back Pressure at ISO Ambient Conditions

ISO Partial Load Performance

Performance at partial load and ISO conditions for the Capstone Model C65 is presented in Table 8. These values are estimated from nominal performance curves.

Table 8. Partial Load Performance at ISO Ambient Conditions

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (Btu/hr)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
2.0	6.7	358	0.32	89400	102000	51100
3.0	8.5	379	0.35	105200	121000	40400
4.0	9.9	397	0.38	119500	138000	34600
5.0	11.3	403	0.40	129000	151000	30200
6.0	12.6	408	0.42	138000	163000	27100
7.0	13.6	414	0.44	148000	176000	25100
8.0	14.6	418	0.46	156000	187000	23400
9.0	15.5	422	0.48	163000	198000	22000
10.0	16.4	426	0.49	170000	208000	20800
11.0	17.1	430	0.51	178000	219000	19900
12.0	17.8	435	0.52	186000	230000	19100
13.0	18.4	440	0.54	194000	241000	18600
14.0	18.9	445	0.55	202000	253000	18000
15.0	19.4	450	0.57	210000	264000	17600
16.0	19.9	454	0.58	217000	274000	17100
17.0	20.4	458	0.59	225000	285000	16700
18.0	20.8	462	0.61	233000	295000	16400
19.0	21.2	466	0.62	240000	306000	16100
20.0	21.5	470	0.63	248000	317000	15900
21.0	21.9	474	0.65	256000	328000	15600
22.0	22.2	478	0.66	263000	338000	15400
23.0	22.5	481	0.67	271000	349000	15200
24.0	22.8	485	0.68	279000	360000	15000
25.0	23.0	489	0.70	287000	371000	14800
26.0	23.2	493	0.71	295000	382000	14700
27.0	23.5	496	0.72	303000	393000	14500
28.0	23.7	500	0.73	311000	404000	14400
29.0	23.9	503	0.75	318000	415000	14300
30.0	24.1	506	0.76	325000	424000	14100
31.0	24.4	508	0.77	331000	434000	14000
32.0	24.6	511	0.78	338000	443000	13900
33.0	24.9	513	0.79	344000	453000	13700
34.0	25.1	515	0.80	351000	463000	13600
35.0	25.3	518	0.81	357000	472000	13500
36.0	25.5	520	0.82	364000	482000	13400
37.0	25.7	522	0.83	370000	491000	13300

Table 8. Partial Load Performance at ISO Ambient Conditions (Continued)

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (Btu/hr)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
38.0	25.9	525	0.84	377000	501000	13200
39.0	26.1	527	0.85	383000	510000	13100
40.0	26.3	529	0.85	389000	519000	13000
41.0	26.5	532	0.86	395000	529000	12900
42.0	26.7	534	0.87	401000	538000	12800
43.0	26.8	536	0.88	408000	547000	12700
44.0	27.0	538	0.89	414000	556000	12600
45.0	27.2	540	0.90	420000	565000	12600
46.0	27.3	542	0.91	426000	575000	12500
47.0	27.5	545	0.92	432000	584000	12400
48.0	27.6	547	0.92	439000	593000	12400
49.0	27.8	549	0.93	445000	603000	12300
50.0	27.9	551	0.94	452000	612000	12200
51.0	28.0	554	0.95	459000	622000	12200
52.0	28.1	556	0.96	465000	632000	12200
53.0	28.2	558	0.97	472000	642000	12100
54.0	28.3	561	0.98	479000	652000	12100
55.0	28.4	563	0.99	486000	661000	12000
56.0	28.5	565	1.00	493000	671000	12000
57.0	28.6	568	1.00	500000	681000	12000
58.0	28.6	570	1.01	507000	691000	11900
59.0	28.7	572	1.02	514000	701000	11900
60.0	28.8	574	1.03	521000	711000	11800
61.0	28.9	577	1.04	528000	721000	11800
62.0	28.9	579	1.05	536000	732000	11800
63.0	28.9	582	1.06	544000	743000	11800
64.0	29.0	585	1.07	552000	754000	11800
65.0	29.0	588	1.08	561000	765000	11800

ISO partial load efficiency vs. net power is shown in Figure 6. These engine values are estimated from nominal performance values at ISO conditions.

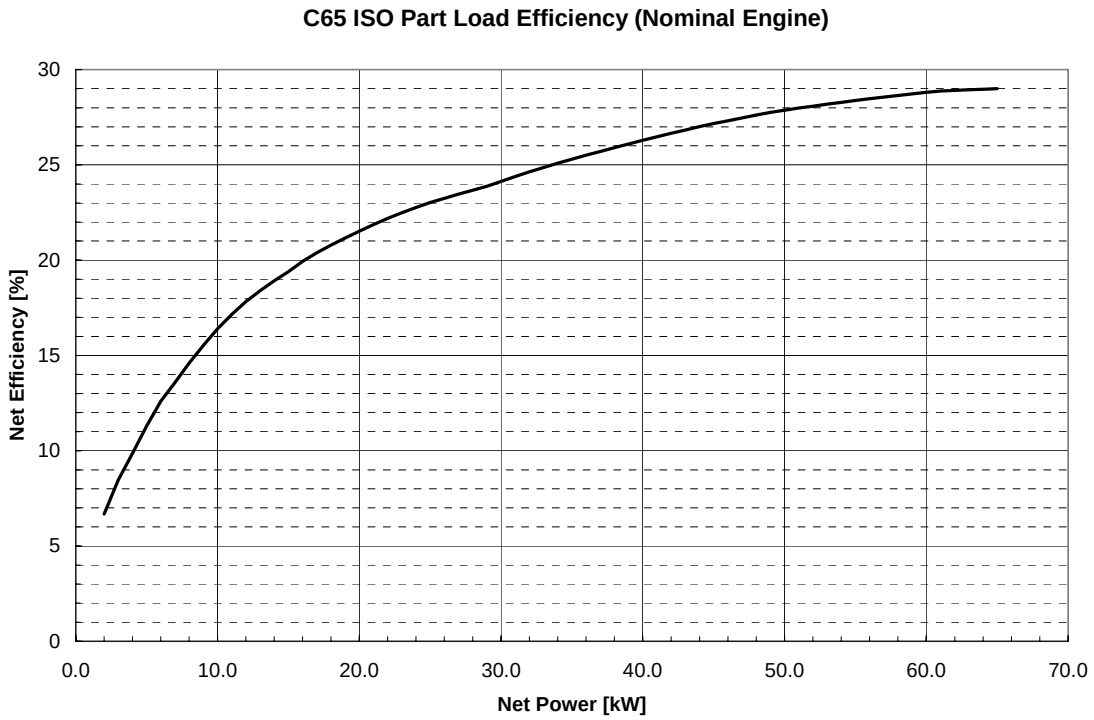

Figure 6. ISO Partial Load Efficiency vs Net Power (Nominal)