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STEADY-STATE TEMPERATURE DISTRIBUTION WITHIN A BRAYTON ROTATING UNIT OPERATING IN A POWER CONVERSION SYSTEM USING HELIUM-XENON GAS

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SUMMARY

The Brayton Rotating Unit (BRU) -- consisting of a turbine, an alternator, and a compressor -- was tested as part of a Brayton cycle power conversion system over a wide range of steady-state operating conditions. The working fluid in the system was a mixture of helium-xenon gases. Turbine inlet temperature was varied from 1200 to 1600° F, compressor inlet temperature from 60 to 120° F, compressor discharge pressure from 20 to 45 psia, rotative speed from 32 400 to 39 600 rpm, and alternator liquid-coolant flow rate from 0.01 to 0.27 pound per second.

Test results indicated that the BRU internal temperatures were highly sensitive to alternator coolant flow rate below the design value of 0.12 pound per second but much less so at higher values. The armature winding temperature was not influenced significantly by turbine inlet temperature, but was sensitive, up to 20° F per kVA alternator output, to varying alternator output. When only the rotational speed was changed (± 10% of rated value), the BRU internal temperatures varied directly with the speed.

INTRODUCTION

The Brayton Rotating Unit (BRU) consists of a radial inflow turbine, a modified Lundell alternator, and a radial outflow compressor mounted on a single shaft supported by gas-lubricated bearings. The two journal bearings are located at each end of the alternator rotor. The thrust bearing is located on the compressor end.

Heat generated within the BRU is caused by several sources and must be controlled. The primary sources of heat are the losses within the alternator. These losses are directly related to the alternator output. Other sources of heat are bearing losses and compressor and turbine inefficiencies. To control heating effects on the internal temperature distribution within the BRU, several features were incorporated into the design. These features are discussed in detail in references 1 through 3. Probably the most important feature is the provision for liquid cooling the alternator. It is necessary to maintain the internal temperatures sufficiently low that the life expectancy of the alternator winding insulation and alternator-rotor shroud material be at least that of the Brayton system (five years). A maximum armature winding insulation temperature of about 425° F is considered compatible with the required life. For the rotor shroud, temperatures up to 600° F are considered acceptable.

Other authors (ref. 2 & 3) have reported testing the BRU and have presented BRU temperature data; however, the test from which the data for this report is taken is the most extensive thus far presented. For this test a Brayton power conversion system using helium-xenon as the working fluid was operated over a wide range of steady-state operating conditions. The turbine inlet temperature was varied from 1200 to 1600° F; the compressor inlet temperature was varied from 60 to 120° F; the compressor discharge pressure from 20 to 45 psia; Brayton Rotating Unit (BRU) rotative speed from 32 400 to 39 600 rpm; and BRU alternator liquid coolant flow rate from 0.01 to 0.27 pound per second. The resulting alternator output varied from 1 to 15 kVA. Curves are presented to show the effects of changing each of the operating parameters. Extensive data tables showing all of the BRU internal temperatures are included in an Appendix.

SYSTEM DESCRIPTION

The Brayton components tested in a closed gas power loop (ref. 4) were the Brayton Rotating Unit (BRU) and the Brayton Heat Exchanger Unit (BHXU). The working fluid used for all testing was a mixture of helium-xenon with a nominal molecular weight of 83.8. An electric heat source, gas management subsystem and liquid coolant subsystem were used as test support equipment. Also included in this system were duct heaters which were installed at the turbine inlet and outlet. These heaters minimized the errors associated with the gas temperature measurements.

The shaft speed of the BRU was controlled with a parasitic speed control (ref. 5). This speed control consists of three speed controllers which vary the current into the parasitic load resistor as a function of the line frequency. The parasitic load varies with changes in the useful load to maintain a constant total load on the alternator. This constant load balances the shaft power supplied by the turbine and holds the BRU speed constant. The speed controllers were modified for this test so that the BRU could be operated over a range of speeds. This permitted operation at 10 percent underspeed, 10 percent overspeed, plus the design speed of 36 000 rpm.

A digital data acquisition system (ref. 6) provided data acquisition and reduction. A total of 200 data channels representing temperatures, pressures, flows, etc., were processed for each data scan. Processing included the conversion of the raw data to engineering units and the performance of calculations. The processed data were then printed out on a teletype.

Brayton Rotating Unit

The Brayton Rotating Unit consists of a turbine, an alternator, and a compressor mounted on a single shaft designed to operate at 36 000 rpm. The shaft is supported by gas-lubricated journal and thrust bearings. The turbine is radial inflow whereas the compressor is radial outflow. The alternator, which is described in reference 7, is a modified Lundell alternator having a solid-bimetallic rotor, two stationary field coils, and a stationary armature winding. The alternator also includes an asbestos phenolic rotor shroud to reduce the rotor windage loss and heat transfer from the rotor to the armature end turns. The alternator has redundant coolant passages. The rated output is 14.3 kilovolt-amperes at 0.75 lagging power factor, 120/208 volts and 1200 hertz.

Figure 1 is a sectional view of the BRU. A total of 37 chromel-alumel thermocouples were installed within the BRU for temperature measurement. The locations of the internal thermocouples are shown on the diagram and described in Table I.

PROCEDURE

The Brayton power conversion system was operated over a wide range of steady-state operating conditions. The turbine inlet temperature range was from 1200 to 1600° F. The desired set-point temperature was preset on a proportional temperature controller. This unit controlled a power controller which regulated the input power to the electric heat source. The turbine inlet temperature was controlled to ± 3° F of the desired value.

The compressor inlet temperature range was from 60 to 120° F. Any specified temperature within this range was obtained by adjusting the coolant flow rate to the Brayton heat exchanger unit. Parallel coolant paths to the waste heat exchanger were employed to control the compressor inlet temperature to within ± 3° F of the desired value.

The coolant flow rate to the BRU was varied to investigate its effect on the internal temperatures of the BRU. The design flow rate to the BRU is 0.12 pound per second (approx. 1.0 gpm). The minimum flow rate was set to prevent one of the alternator end turn temperatures (thermocouple No. 5) from exceeding 425° F. In addition to the design flow rate a flow rate of 0.195 pound per second (approx. 1.6 gpm) and the maximum flow rate available were run. The maximum flow rate was the difference between the 4 gpm at the coolant loop pump and the flow rate required by the Brayton heat exchanger unit to obtain the desired compressor inlet temperature.

For compressor inlet temperatures of 80 to 120° F, the liquid coolant subsystem regulated the coolant temperature at 66 ± 3° F at the coolant pump outlet.

The rotative speed of the BRU was adjusted to 32 400; 36 000; or 39 600 rpm to study the aerodynamic characteristics of the BRU. This was accomplished by changing the frequency sense adjust pot on the speed controller. The parasitic load was set to 5 kW or less by varying the useful load. The minimum total alternator load was 1 kW.

The compressor discharge pressure range was 20 to 45 psia. By either adding or venting gas from the system it was possible to maintain this pressure to within ± 0.2 psi of the desired value.

For each data point, the steady-state condition was determined when thermocouple No. 23 (turbine-end journal bearing's flex-mounted shoe) reached a steady value. It had been determined that the bearing temperatures had the longest response time.

DISCUSSION

To show the effects of the changes in operating conditions upon the BRU internal temperature distribution, certain thermocouples were selected for close scrutiny. Where available, thermocouples located on parts where temperature limits were imposed because of concern over material life were selected. All of the available thermocouples on the armature winding were considered important. Of the eight armature winding thermocouples, two were defective and two were used for panel meters. Of the remaining four thermocouples, three (No. 2, 3, and 8 in figure 1) were selected for the data plots. The asbestos phenolic rotor shroud temperature was also considered important. Thermocouple No. 20 is mounted on the back of a copper button that penetrates through the shroud. Bearing temperatures were included to complete the list. The turbine journal bearing was chosen because it ran hotter than the compressor end journal bearing. The two shoe-mounted thermocouples were found to indicate about the same temperature and No. 23 was selected. The bearing carrier temperature was not included because the difference in temperature between the carrier and the shoes ranged from 65 to 85° F for the test. To complete the list the thrust bearing temperature was included, using thermocouple No. 31.

Almost all of the data presented in the figures in this report were extracted from Tables II through V of the appendix. Each table includes the complete list of BRU internal temperatures, the alternator output, and alternator liquid coolant flow rates and temperatures.

RESULTS

Effect of Alternator Coolant Flow

The single most important design feature for maintaining acceptable temperatures within the BRU is the use of a liquid coolant for the alternator, Dow Corning 200 (2 cs). The coolant flow rate through this heat exchanger is a matter of user's choice. For the fixed coolant passage size, increasing flow rate would mean an increased pressure drop and pump power; therefore, the flow rate that maintains a satisfactory internal temperature distribution is the most desirable flow rate to maintain. The effect of varying coolant flow rate is shown in figure 2 for turbine inlet temperatures of 1600, 1400, and 1200° F at a shaft speed of 36 000 rpm, and compressor inlet temperature of 80° F. For each of these turbine inlet temperatures, the alternator output is essentially constant and the temperatures show the effect of coolant flow rate. A flow rate of 0.12 pound per second (approx. 1.0 gpm) is the design value. All three plots (fig. 2a, 2b, & 2c) show that flow rate greater than 0.12 pound per second does not bring large reductions in the BRU temperatures. For a flow rate less than 0.12 pound per second, the internal temperatures begin to increase rapidly as flow rate decreases. The slopes of all of the curves are approximately linear down to a flow rate of about 0.12 pound per second below which more rapid temperature increases occur. For the conditions of figures 2b and 2c though, it is possible to reduce the flow rate below 0.12 pound per second since the temperatures are less than the imposed winding and shroud temperature limits. The shroud temperature is shown in figure 2 by thermocouple No. 20. For the design alternator liquid coolant flow of 0.12 pound per second, this temperature is less than 500° F for an alternator output of approximately 13 kVA. Temperatures up to 600° F are considered acceptable for this material. The hottest of the three armature winding temperatures (thermocouple No. 3) is about 390° F at 0.12 pound per second coolant flow rate shown in figure 2a, dropping to 360° F in figure 2b, and 320° F in figure 2c.

The effect of different alternator output levels on BRU temperature is shown in figure 3 over a range of alternator coolant flow rates. The location (thermocouple No. 3) chosen for consideration is the armature winding where its insulation is temperature limited. The turbine and compressor inlet temperatures were held constant to eliminate their effects on BRU temperature. The alternator output change was effected by varying the compressor discharge pressure by adjusting gas inventory.

At the highest alternator output level, the temperature is seen to be in the 400° F region even at the higher coolant flow rates. At lower alternator output, the temperature levels are correspondingly lower. The difference in BRU temperature is approximately proportional to the difference in kVA output. Over the linear portion of the curves, a difference of 1 kVA results in a difference in the armature winding temperature of 20° F.

The curves depart from their linearity at coolant flow rates below 0.12 pound per second similar to the curves in figure 2. This characteristic of the curves suggests a close coupling of the BRU temperatures to the heat-transfer characteristics and temperature -- dependent properties of the alternator coolant. At a given alternator output level, decreasing coolant flow rates result in higher fluid operating temperatures, effecting a decrease in coolant viscosity. This change in fluid property aggravates the decreasing convective coefficient stemming from the lowered flow rates. It is the combined effect that would explain the higher rate of BRU temperature increase with the decreasing coolant flow rate. If the maximum allowable armature winding temperature would be increased, the upper two curves would be expected to rise similarly.

Effect of Turbine Inlet Temperature

The influence of the turbine inlet temperature on the BRU internal temperatures is shown in figure 4. Isolating the effect to the turbine inlet temperature along required cross-plotting to keep a constant alternator output (7 kVA). At first glance the temperature trend of the armature windings appears to be opposite to that anticipated. Instead, the armature winding temperatures follow the rotor cavity pressure. The pressure in the alternator rotor cavity is approximately equal to the bearing cavity pressure. The bearing cavity pressure is included at the top of figure 4. The rotor windage loss increases as the rotor cavity pressure increases and is shown in figure 4. The increased system pressure required to produce a constant 7 kVA, as turbine inlet temperature decreases, is responsible for increased rotor windage loss. The increased rotor windage loss would increase the gas temperature in the rotor cavity and probably explains why the winding temperatures increase even though turbine inlet temperature is reduced. The rotor shroud temperature, thermocouple No. 20, and bearing temperatures all increase as turbine inlet temperature is increased. The turbine end journal bearing shoe temperature, thermocouple No. 23, is affected the most -- about 70° F increase as turbine inlet temperature increases from 1200 to 1600° F. For this plot the compressor journal bearing shoe temperature, thermocouple No. 27, has been included. This temperature and the thrust bearing temperature, thermocouple No. 31, increased about 30° F for the 400° F increase in turbine inlet temperature. In effect, the trend of the armature winding temperature indicates that heat conduction from the turbine is insignificant.

Effect of Alternator Output

The manner in which the BRU internal temperatures are affected by alternator output is shown in figure 5. This figure shows that the armature winding temperatures (thermocouple No. 3, 8, and 2) increase rapidly as alternator output increases. Almost all of the increase in armature winding temperature is probably due to increased electromagnetic losses and increased rotor windage loss. The rotor shroud temperature, thermocouple No. 20, experiences the same increase with alternator output. The two bearing temperatures, thermocouple No. 23 and 31, show no change in temperature as alternator output is increased.

Effects of BRU Rotational Speed

The effects of changing rotational speed on the BRU internal temperatures is shown in figure 6 for the design speed of 36 000 rpm; for 10 percent underspeed (32 400 rpm); and 10 percent overspeed (39 600 rpm). From the underspeed to the overspeed condition, the alternator output increased from 10.5 to 13.1 kVA. Compressor discharge pressure was constant at 45 psia. The armature winding temperatures (thermocouples 3, 8, and 2) increased as speed increased. Again, this is due to increased electromagnetic and rotor windage losses. The bearing temperatures (thermocouples 23 and 31) also increased. The power dissipated in the bearings is proportional to the speed squared and this is reflected in an increase in the local gas temperature. This, in turn, resulted in higher bearing temperatures.

CONCLUDING REMARKS

1. In general, the BRU internal temperatures were highly sensitive to the alternator liquid coolant flow rate at values below 0.12 pound per second. Flow rates greater than 0.12 pound per second resulted in comparatively modest decrease in BRU internal temperatures.

2. Effect of the turbine inlet temperature on heating the alternator windings was insignificant. Of the BRU locations plotted, the turbine end journal bearing shoe temperature showed the maximum increase, 70° F, for the turbine inlet temperature increase from 1200 to 1600° F.

3. Varying alternator output by changing system inventory affected the alternator winding temperature at the rate of up to 20° F per kVA alternator output.

4. When rotational speed only was changed (from -10% to +10% of the design speed of 36 000 rpm), the internal temperatures varied directly with the speed.

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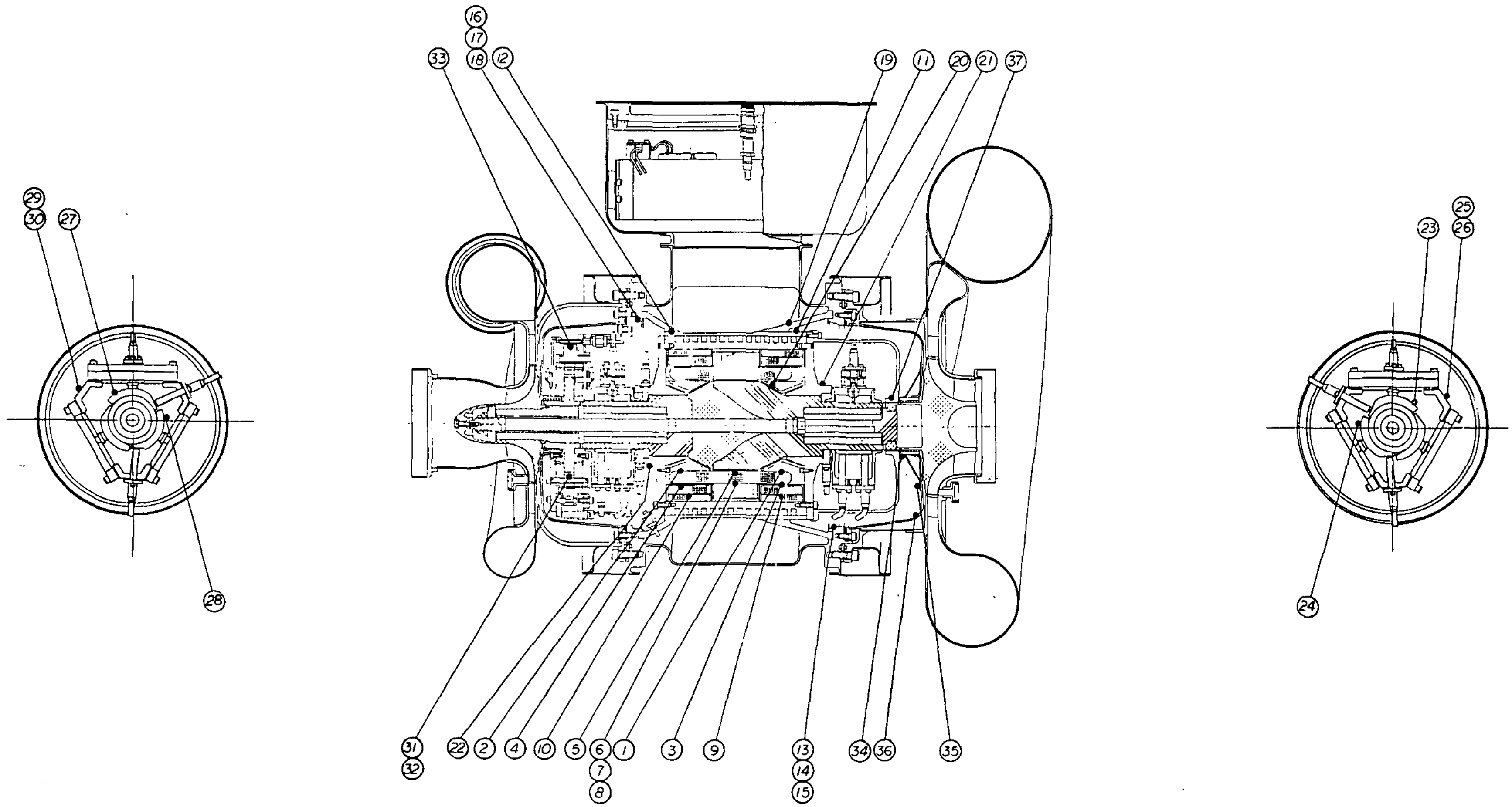

FIGURE 1 - Location of Thermocouples in the BRU

TABLE I. - THERMOCOUPLE LOCATIONS

T/C No.	
1	Alternator armature winding end turn I.D. turbine end
2	Alternator armature winding end turn I.D. compressor end
3	Alternator armature winding end turn O.D. turbine end
4	Defective
5	Alternator armature winding at I.D. of slot
6,8	Alternator armature winding at O.D. of slot
7	Defective
9	Alternator field coil, turbine end
10	Alternator field coil, compressor end
11	Alternator heat exchanger outer wall, turbine end
12	Alternator heat exchanger, outer wall, compressor end
13,14,15	Main housing flange, turbine end, 120° apart
16,17,18	Main housing flange, compressor end, 120° apart
19	Turbine end main housing flange support strut
20	Thermocouple spotted on copper button mounted on rotor shroud
21	Alternator secondary flux-gap shoe, turbine end
22	Defective
23	Journal bearing flex-mounted shoe, turbine end
24	Journal bearing fixed-mounted shoe, turbine end
25,26	Journal bearing carrier, turbine end
27	Journal bearing flex-mounted shoe, compressor end
28	Journal bearing fixed-mounted shoe, compressor end
29,30	Journal bearing carrier, compressor end
31,32	Thrust bearing
33	Thrust bearing gimbal
34	Turbine back shroud
35	Defective
36	Turbine back shroud
37	Not used

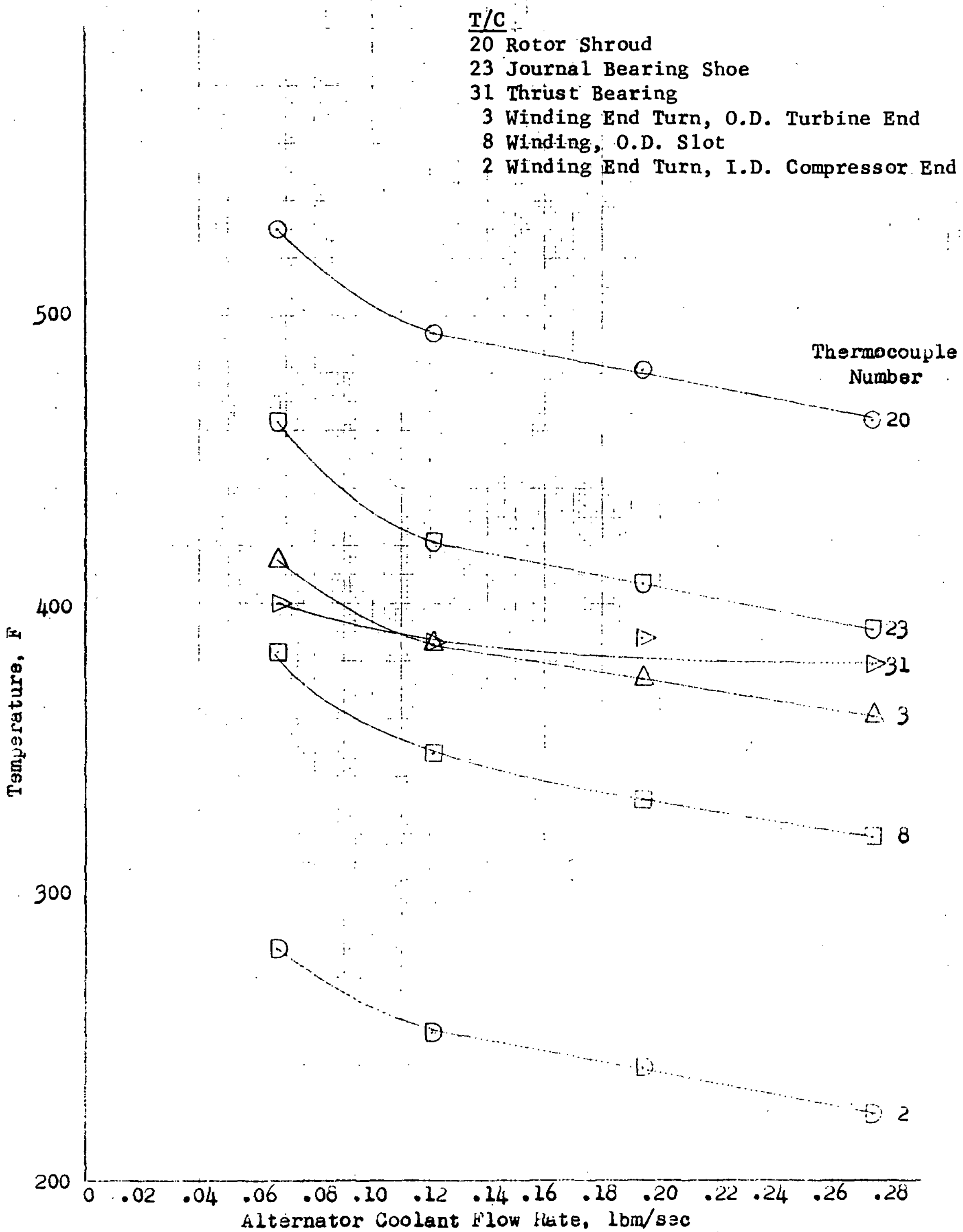

Figure 2-a Effect of alternator coolant flow upon BRU internal temperatures. Compressor inlet temperature 80F; compressor discharge pressure 45psia; coolant Dow Corning 200 (2cs); turbine inlet temperature 1600F output of alternator 13.0 to 13.2 KVA, Rotational speed 36000 RPM.

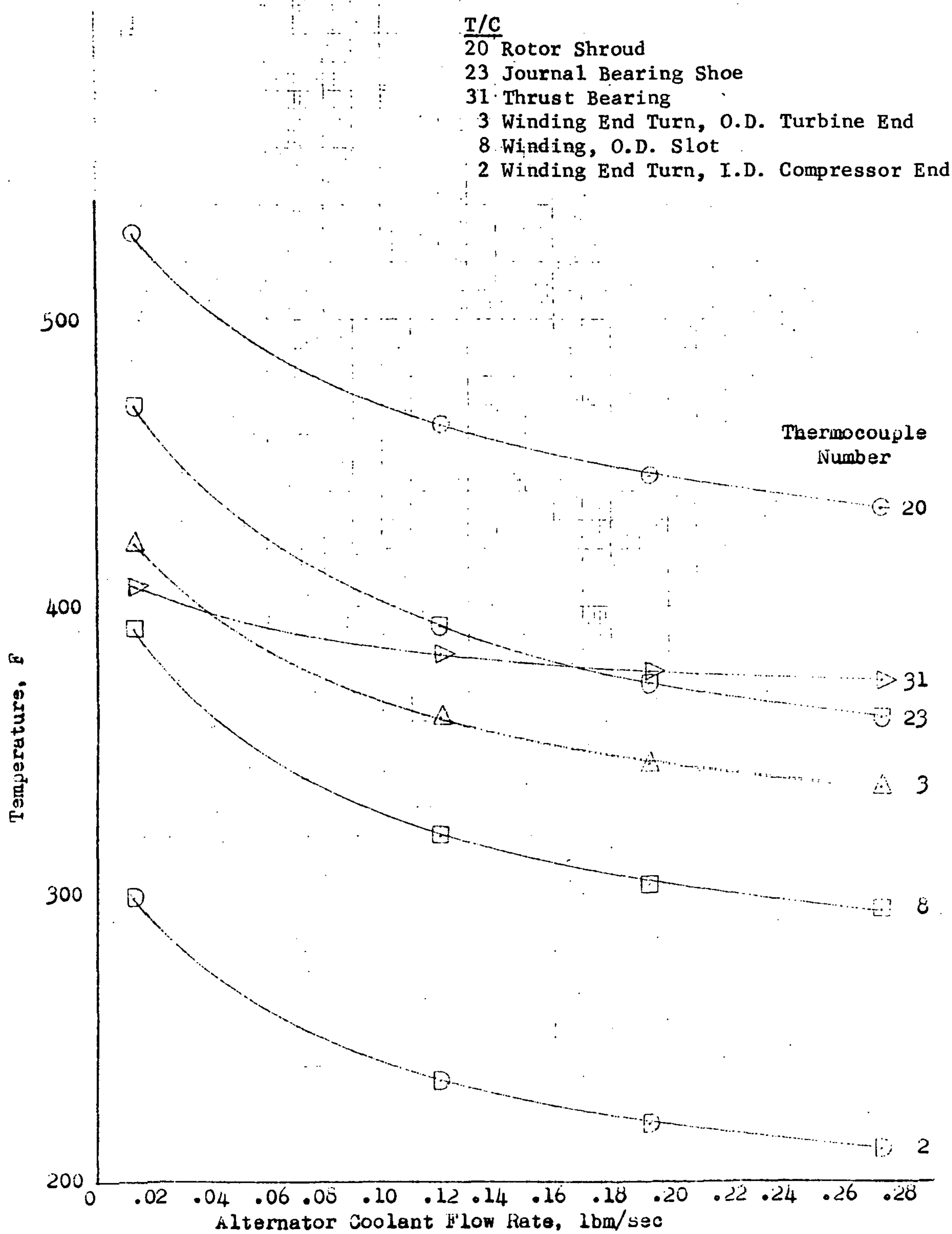

Figure 2-6 Turbine inlet temperature 1400F;
alternator output 10.3 to 10.5 KVA.

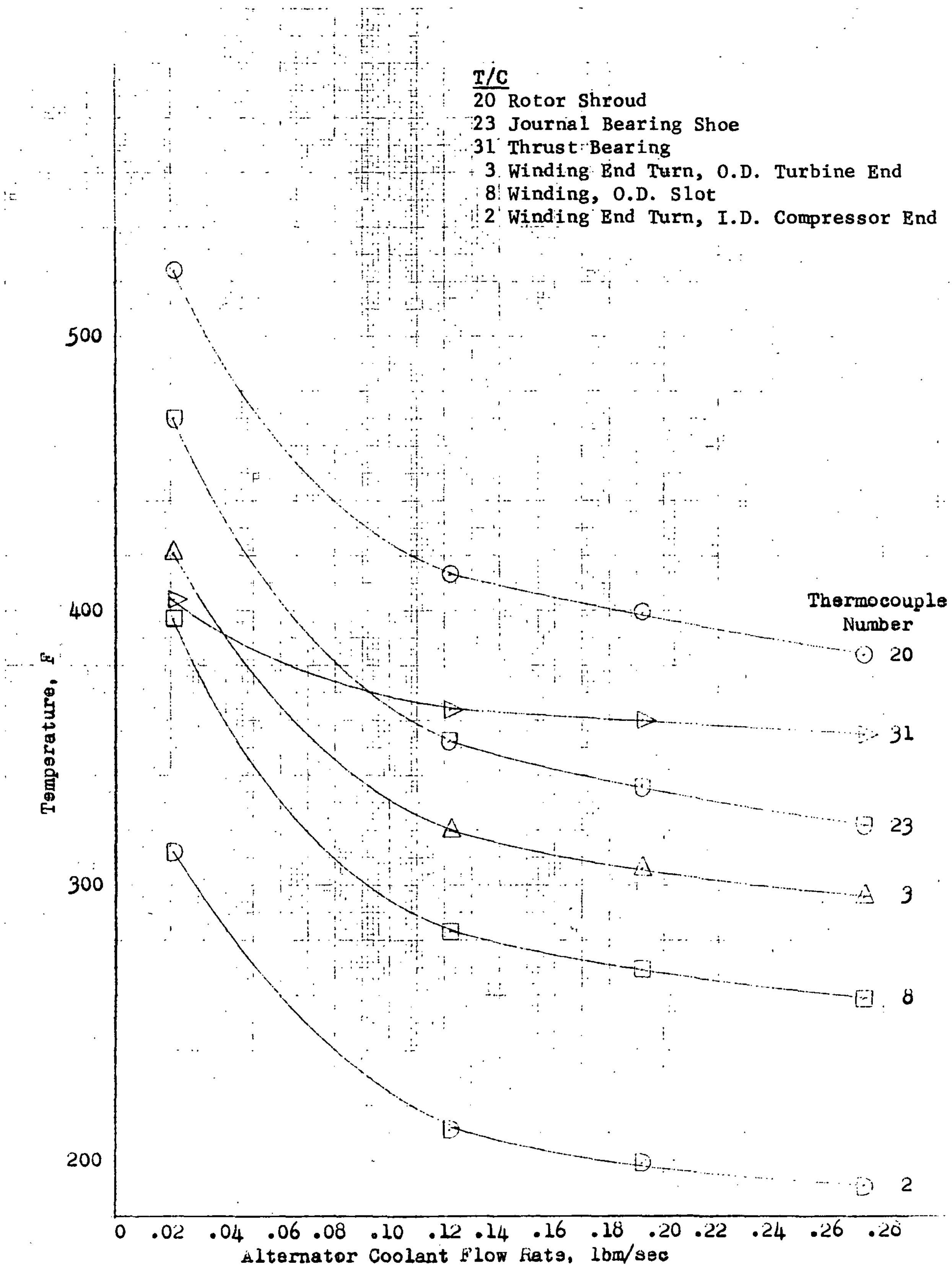

Figure 2-c Turbine inlet temperature 1200F; alternator output 7.3 to 7.5 KVA.

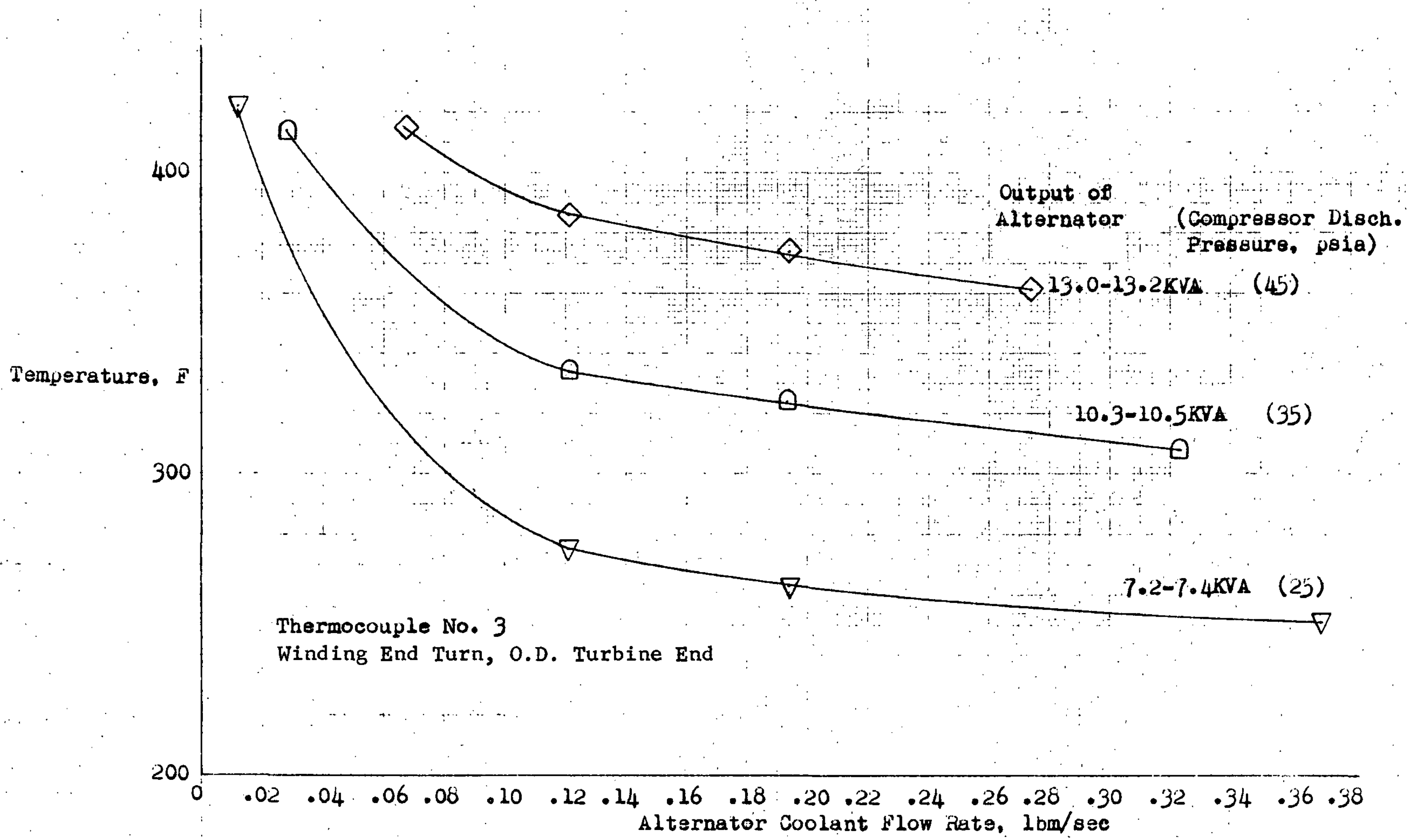

Figure 3 Influence of power level on characteristics of coolant flow versus BRU temperature curves.

Turbine inlet temperature 1600F; compressor inlet temperature 80F; Dow Corning 200 (2cs) coolant; Rotational speed 36000 RPM.

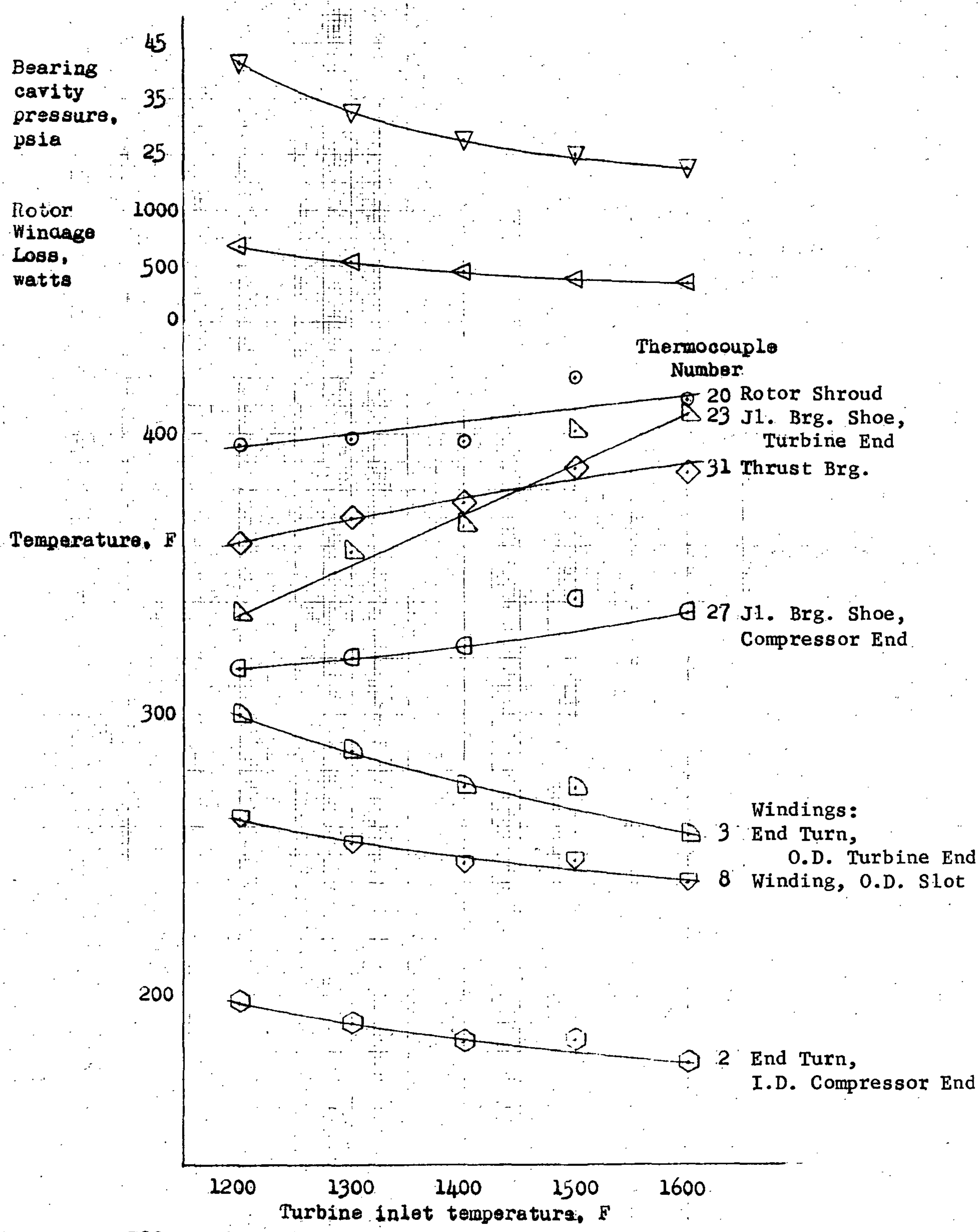

Figure 4 - Effect of Turbine Inlet Temperature on BRU Internal Temperatures. Compressor inlet temperature 80F; alternator output 7KVA; alternator coolant flow rate 1.6 GPM; rotational speed 36000 RPM

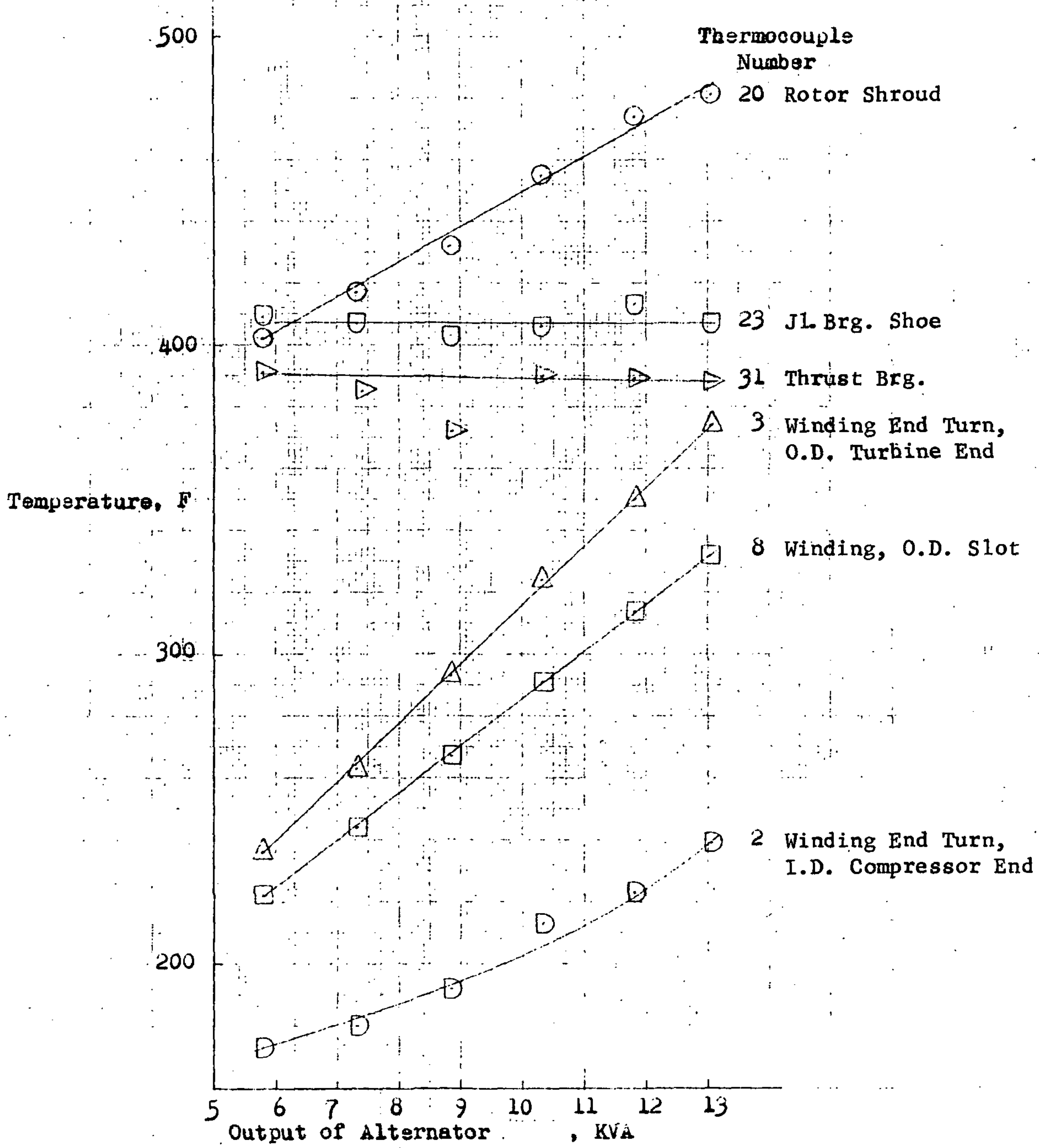

Figure 5 Effect of alternator output on BRU internal temperatures. Turbine inlet temperature 1600 F; alternator coolant flow 1.6 G.P.M.; compressor inlet temperature 80F.

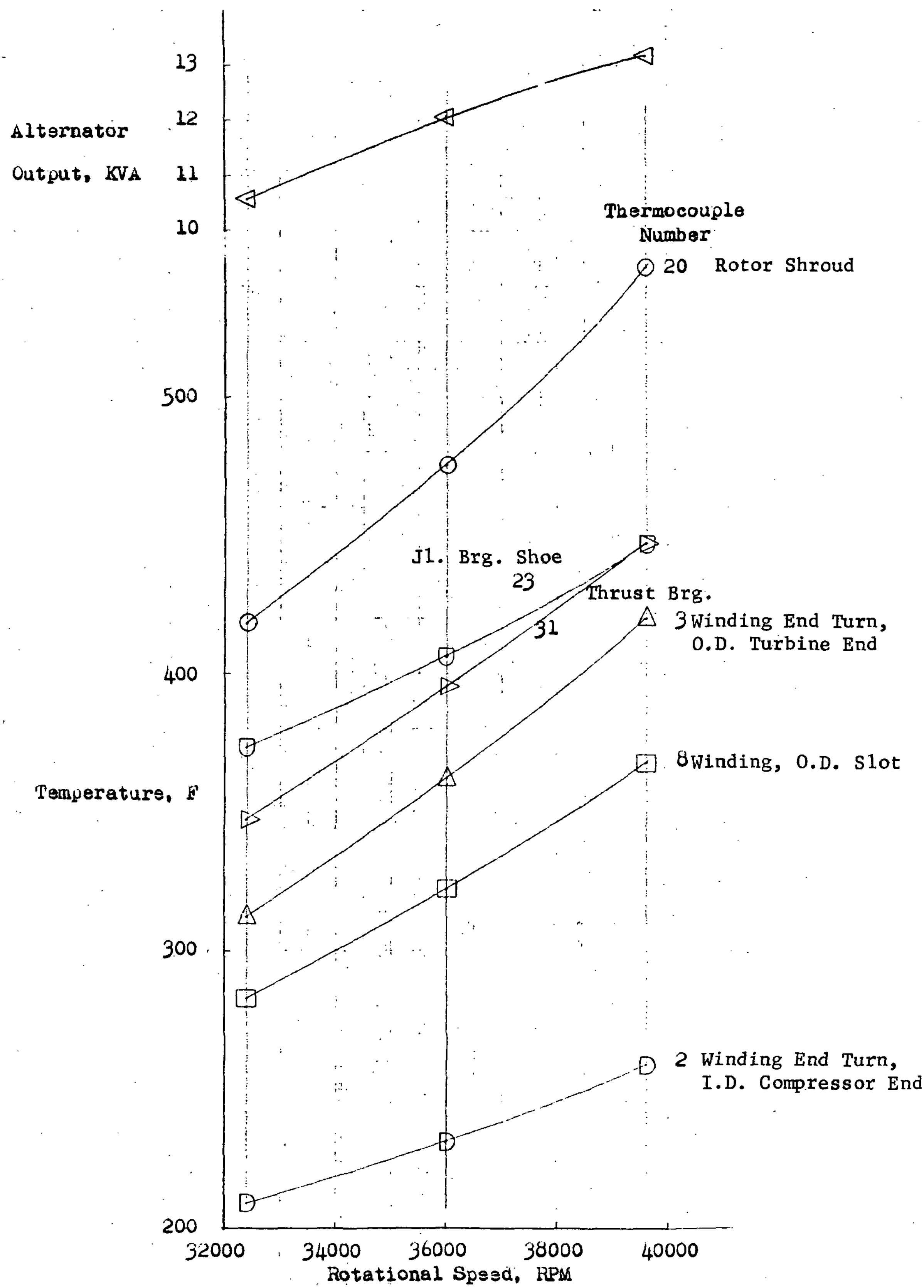

Figure 6 Speed effects on BRU internal temperatures. Turbine inlet temperature 1600F; compressor inlet temperature 100F; compressor discharge pressure 45 psia; alternator coolant flow rate 1.6 GPM.

APPENDIX

Table II-a Brayton Rotating Unit temperatures (F) with alternator coolant flow variations.

Comp. Disch. Pres., psia	45				35				25			
Flow	Max.	1.6 GPM	1.0 GPM	Min.	Max.	1.6 GPM	1.0 GPM	Min.	Max.	1.6 GPM	1.0 GPM	Min.
T/C No.												
* 1	306		332	361			285	368	216	227	238	388
2	223	239	251	280	193	213	220	302	169	180	191	343
3	361	374	386	415	308	324	334	414	251	263	275	422
*5	369		396	428			342	430	256	268	280	440
6	223	237	252	287	193	210	222	315	166	178	189	354
8	319	332	348	383	275	291	305	398	230	244	258	424
9	145	164	183	222	129	151	168	276	115	135	153	341
10	123	134	146	172	111	124	134	200	101	112	123	247
11	115	127	152	196	106	122	145	264	98	117	139	343
12	90	108	123	147	84	102	114	176	79	98	108	223
13	432	441	450	479	440	452	462	532	449	463	473	600
14	429	436	449	479	427	435	451	532	418	132	441	573
15	451	460	470	496	443	454	467	538	436	452	461	591
16	171	187	189	207	163	182	184	223	156	173	178	256
17	189	193	199	218	184	189	193	236	174	182	188	269
18	160	165	171	188	153	162	166	204	147	155	160	239
19	223	240	253	291	219	239	252	348	220	237	254	423
20	465	481	494	530	433	455	465	554	400	417	430	582
21	256	269	291	334	232	250	271	381	207	229	248	438
23	391	407	422	463	386	406	422	520	386	407	421	587
24	396	411	427	467	389	409	425	522	387	408	422	588
25	318	332	349	391	309	329	347	448	304	326	342	518
26	320	334	351	393	311	331	349	450	306	329	344	520
27	337	349	351	371	329	347	346	394	326	337	343	432
28	337	348	351	371	329	346	346	394	326	337	343	432
29	274	287	288	308	268	286	285	330	268	280	285	369
30	281	293	294	313	275	293	291	335	274	286	291	373
31	379	388	386	400	374	390	384	414	378	385	388	442
32	382	390	389	403	376	392	385	415	379	386	389	442
33	330	337	336	352	326	344	336	368	329	338	339	397
34	996	969	1004	1020	1023	1005	1035	1063	1049	1054	1057	1100
36	1177	1172	1182	1192	1178	1171	1185	1203	1170	1174	1176	1206
POWER KW	11.68	11.68	11.81	11.78	8.62	8.52	8.69	8.83	5.49	5.54	5.59	5.70
P.F.	0.896	0.895	0.896	0.900	0.834	0.826	0.835	0.840	0.758	0.758	0.761	0.768
KVA	13.04	13.05	13.19	13.09	10.34	10.32	10.41	10.55	7.24	7.31	7.34	7.42
COOLANT IN °F	70	70	72	76	69	69	70	76	68	72	72	85
COOLANT OUT, °F	70 96 93	146	176	212	69 89 86	130	148	246	68 84 82	172	152	315
COOLANT FLOW lbm/sec	0.274	0.194	0.121	0.067	0.323	0.193	0.121	0.028	0.370	0.194	0.121	0.012

Turbine inlet temperature 1600F; Compressor inlet temperature 80F; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table II-b Brayton Rotating Unit temperatures (F) with alternator coolant flow variations.

Comp. Disch. Pres., psia	45				35				25			
Flow	Max.	1.6 GPM	1.0 GPM	Min.	Max.	1.6 GPM	1.0 GPM	Min.	Max.	1.6 GPM	1.0 GPM	Min.
T/C No.												
* 1	288	296	311	373	241		272	380	207	216	230	367
2	211	220	235	299	188	193	209	316	164	176	187	319
3	337	345	361	422	283	297	315	422	237	248	264	399
* 5	337	349	388	427	277		316	427	230	293	261	405
6	214	223	240	313	188	194	213	331	162	174	188	332
8	294	303	320	392	249	265	282	403	213	226	242	395
9	139	152	173	259	122	137	159	293	111	128	149	313
10	120	127	141	195	107	115	130	219	99	108	119	231
11	108	120	145	243	100	114	138	286	93	110	130	314
12	92	105	121	174	82	100	114	194	78	95	106	211
13	371	380	392	451	375	384	401	489	383	394	407	521
14	371	379	392	451	360	372	389	478	360	371	384	501
15	391	399	411	466	376	387	406	494	373	384	398	513
16	172	182	188	224	160	169	185	236	153	166	175	244
17	189	189	198	235	179	180	192	249	171	177	185	257
18	157	161	169	201	148	151	165	217	143	149	157	227
19	203	214	233	315	195	206	230	352	193	208	225	379
20	434	445	463	530	392	412	435	550	366	381	401	542
21	236	249	271	358	208	227	251	387	189	207	228	400
23	361	373	393	470	346	364	389	512	348	368	386	529
24	365	377	397	474	349	368	392	513	350	367	387	536
25	288	302	321	402	272	292	316	442	271	289	310	466
26	290	303	323	403	273	294	317	443	273	291	311	466
27	329	336	345	380	315	320	338	400	311	320	331	468
28	328	334	344	380	314	320	337	400	311	320	331	413
29	271	278	286	322	259	263	282	340	259	268	277	413
30	278	284	292	326	265	269	287	345	265	273	283	352
31	374	377	383	407	365	361	380	418	368	374	380	357
32	376	379	385	410	366	362	382	420	369	375	381	428
33	325	328	334	361	315	310	333	373	320	327	331	384
34	834	840	847	876	865	889	880	924	905	910	916	964
36	1025	1027	1031	1048	1019	1026	1030	1055	1019	1022	1026	1057
POWER, KW	8.78	8.80	8.84	9.02	6.33	6.43	6.40	6.61	3.98	4.01	4.02	4.17
P. F.	0.832	0.832	0.834	0.874	0.796	0.787	0.780	0.788	0.701	0.702	0.691	0.697
KVA	10.55	10.57	10.60	10.32	7.95	8.17	8.19	8.39	5.69	5.70	5.82	5.99
COOLANT IN, F	66 66	67	70	75	66 65	72	72	79	67 67	71	72	81
COOLANT OUT, F	92 87	137	162	239	83 80	177	154	274	81 78	129	144	296
COOLANT FLOW lbm/sec	0.274	0.193	0.120	0.033	0.327	0.193	0.120	0.020	0.369	0.193	0.124	0.012

Turbine inlet temperature 1400F; compressor inlet pressure 80F; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table II-c Brayton Rotating Unit temperatures (F) with alternator coolant flow variations.

Comp. Disch. Pres., psia	45				35				25			
Flow	Max.	1.6 GPM	1.0 GPM	Min.	Max.	1.6 GPM	1.0 GPM	Min.	Max.	1.6 GPM	1.0 GPM	Min.
T/C No.												
* 1	252	260	273	375	222	230	245	379	197	207	217	387
2	191	199	211	312	174	184	192	329	156	167	177	318
3	296	306	320	421	259	268	284	418	227	237	248	396
* 5												
6	195	202	217	329	176	186	196	349	157	168	180	334
8	259	269	283	397	227	237	253	405	201	212	224	387
9	127	139	156	284	115	129	146	311	106	121	136	311
10	111	118	130	218	102	111	122	239	96	105	114	240
11	103	112	133	275	95	107	128	307	90	103	122	312
12	86	102	114	197	81	97	109	219	77	92	103	229
13	316	325	335	427	320	327	341	455	323	331	345	462
14	314	325	335	427	310	317	332	447	304	312	326	442
15	331	342	351	440	324	332	346	460	317	324	339	455
16	162	175	182	236	156	168	177	249	149	160	169	253
17	182	187	191	247	176	180	189	261	168	172	181	259
18	149	154	160	215	145	149	157	230	140	144	152	236
19	181	189	205	326	175	187	201	355	171	184	197	358
20	384	399	413	524	360	371	390	531	343	315	369	519
21	212	225	244	373	192	206	228	393	179	191	210	387
23	322	336	352	470	316	329	348	499	320	334	351	508
24	325	340	355	473	319	332	352	501	322	336	353	509
25	253	268	285	406	245	260	280	435	245	261	279	441
26	254	269	286	407	246	261	282	436	246	262	280	442
27	308	317	324	383	301	308	318	398	300	308	316	406
28	306	315	322	382	300	307	318	398	300	308	316	405
29	257	266	272	327	251	258	263	344	250	258	266	349
30	263	271	277	331	257	264	273	347	256	264	271	353
31	355	360	364	404	353	357	364	415	357	363	367	418
32	357	362	366	407	355	358	366	416	358	364	368	418
33	306	312	317	361	306	309	318	373	311	317	322	374
34	720	726	733	775	749	752	760	815	777	781	787	838
36	880	884	887	916	876	879	883	920	870	873	879	913
POWER, kW	5.54	5.56	5.53	5.74	3.90	3.91	3.89	4.09	2.32	2.27	2.36	2.33
P. F.	0.755	0.752	0.754	0.768	0.721	0.724	0.677	0.701	0.573	0.566	0.575	0.565
KVA	7.33	7.39	7.33	7.47	5.40	5.41	5.75	5.83	4.06	4.01	4.10	4.12
COOLANT IN, F	68 68	70	68	77	67 66	70	71	82	66 66	68	71	86
COOLANT OUT, F	89 86	144	154	268	82 80	134	148	298	79 77	123	137	237
COOLANT FLOW lbm/sec	0.273	0.192	0.122	0.021	0.324	0.193	0.120	0.013	0.367	0.194	0.120	0.012

Turbine inlet temperature 1200F; compressor inlet temperature 80F; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table III-a Brayton Rotating Unit temperatures (F) with turbine inlet temperature variations.

Turbine inlet Temperature, F	1600	1500	1400	1300	1200
T/C No.					
* 1		320	296	281	260
2	239	234	220	210	199
3	374	373	345	328	306
* 5		370	344	306	
6	237	236	223	213	202
8	332	328	303	288	269
9	164	162	152	145	139
10	134	135	127	123	118
11	127	126	120	117	112
12	108	110	105	104	102
13	441	413	380	353	325
14	436	419	379	353	325
15	460	436	399	371	342
16	187	192	182	180	175
17	193	204	189	191	187
18	165	173	161	159	154
19	240	230	214	202	189
20	481	485	445	426	399
21	269	271	249	239	225
23	407	408	373	357	336
24	411	413	377	361	340
25	332	332	302	290	268
26	334	334	303	288	269
27	349	362	336	329	317
28	348	360	334	327	315
29	287	301	278	273	266
30	293	307	284	279	271
31	388	405	377	371	360
32	390	408	379	373	362
33	337	362	328	323	312
34	969	904	840	784	726
36	1172	1100	1027	956	884
POWER, KW	11.68	10.43	8.80	7.34	5.56
P.F.	0.895	0.865	0.832	0.804	0.752
KVA	13.05	12.05	10.57	9.14	7.39
COOLANT IN, F	70	71	67	71	70
COOLANT OUT, F	147	152	83	141	144
COOLANT FLOW lbm/sec	0.194	0.195	0.194	0.194	0.192

Compressor inlet temperature 80F; compressor discharge pressure 45 psia; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table III-b Brayton Rotating Unit temperatures (F) with turbine inlet temperature variations.

Turbine Inlet Temperature, F	1600	1500	1400	1300	1200
T/C No.					
1*				247	230
2	213	200	193	189	184
3	324	315	297	287	268
* 5					
6	210	202	194	190	186
8	291	280	265	254	237
9	151	143	137	135	129
10	124	119	115	115	111
11	122	118	114	112	107
12	102	102	100	99	97
13	452	416	384	359	327
14	435	411	372	347	317
15	454	425	387	363	332
16	182	177	169	172	168
17	189	189	180	184	180
18	162	158	151	154	149
19	239	218	206	198	187
20	455	440	412	398	371
21	250	242	227	220	206
23	406	391	364	352	329
24	409	394	368	355	332
25	329	315	292	280	260
26	331	317	294	281	261
27	347	336	320	320	308
28	346	336	320	320	307
29	286	277	263	267	258
30	293	283	269	273	264
31	390	375	361	367	357
32	392	377	362	368	358
33	344	329	310	319	309
34	1005	954	889	813	752
36	1171	1099	1026	952	879
POWER, KW	8.52	7.50	6.43	5.20	3.91
P. F.	0.826	0.825	0.787	0.741	0.724
KVA	10.32	9.09	8.17	7.02	5.91
COOLANT IN, F	69	70	72	72	70
COOLANT OUT, F	130	171	177	134	134
COOLANT FLOW lbm/sec	0.193	0.195	0.193	0.192	0.193

Compressor inlet temperature 80F; compressor discharge pressure 35 psia; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table III-c Brayton Rotating Unit temperatures (F) with turbine inlet temperature variations.

Turbine Inlet Temperature, F	1600	1500	1400	1300	1200
T/C No.					
*1	227	230	216	212	207
2	180	183	176	171	167
3	263	266	248	243	237
*5	268	257	243		
6	178	181	174	170	168
8	244	243	226	219	212
9	135	135	128	124	121
10	112	113	108	106	105
11	117	115	110	107	103
12	98	97	95	93	92
13	463	430	394	364	331
14	432	409	371	342	312
15	452	425	384	356	324
16	173	175	166	164	160
17	182	185	177	175	172
18	155	158	149	147	144
19	237	225	208	195	184
20	417	417	381	368	315
21	229	225	207	199	191
23	407	400	365	350	334
24	408	401	367	352	336
25	326	318	289	276	261
26	329	320	291	277	262
27	337	340	320	314	308
28	337	340	320	314	308
29	280	283	268	263	258
30	286	290	273	269	264
31	385	387	374	368	363
32	386	388	375	369	364
33	338	341	327	321	317
34	1054	984	910	846	781
36	1174	1101	1022	947	873
POWER, KW	5.54	4.86	4.00	3.24	2.27
P.F.	0.758	0.737	0.702	0.640	0.566
KVA	7.31	6.60	5.70	5.06	4.01
COOLANT IN, F	72	72	71	70	68
COOLANT OUT, F	172	133	129	123	123
COOLANT FLOW lbm/sec	0.194	0.193	0.193	0.192	0.194

Compressor inlet temperature 80F; compressor discharge pressure 25 psia; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table IV Brayton Rotating Unit temperatures (F) with speed changes.

BRU Rotational Speed, RPM	32,4000	36,000	39,600
T/C No.			
* 1	268	310	361
2	209	231	259
3	312	362	420
* 5	315	367	432
6	207	230	259
8	283	322	365
9	153	161	172
10	126	132	141
11	122	126	133
12	102	108	115
13	442	446	449
14	433	439	447
15	454	463	469
16	174	188	208
17	182	199	221
18	155	169	186
19	226	241	248
20	418	475	547
21	243	268	298
23	373	406	447
24	376	410	452
25	311	333	360
26	313	335	362
27	312	353	397
28	311	351	396
29	260	291	325
30	265	298	332
31	347	395	447
32	349	398	451
33	304	343	386
34	986	981	978
36	1174	1177	1180
POWER, KW	9.01	10.38	11.51
P.F.	0.851	0.860	0.874
KVA	10.58	12.07	13.17
COOLANT IN, F	73	69	70
COOLANT OUT, F	141	148	159
COOLANT FLOW lbm/sec	0.192	0.194	0.194

Turbine inlet temperature 1600F; compressor inlet temperature 100F; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table V-a Brayton Rotating Unit temperatures (F) with compressor inlet temperature variations.

Comp. Inlet Temp., F	60			80			100			120		
Comp. Disch. Pres., psia	45	35	25	45	35	25	45	35	25	45	35	25
T/C No.												
* 1	321	280	225			227	310	265	233	292	258	220
2	234	208	175	239	213	180	231	204	182	220	179	180
3	376	328	266	374	324	263	362	311	258	342	302	253
* 5	389	334	260			268	367	313	261	343	307	257
6	233	208	173	237	210	178	230	201	176	218	197	173
8	333	292	243	332	291	244	322	280	239	305	273	235
9	153	144	126	164	151	135	161	147	135	156	145	134
10	124	116	103	134	124	112	132	121	111	129	120	111
11	115	114	105	127	122	117	126	121	116	126	122	117
12	98	95	87	108	102	98	108	102	97	108	104	98
13	428	444	449	441	452	463	446	460	465	451	463	469
14	429	427	428	436	435	432	439	442	438	443	441	441
15	450	451	444	460	454	452	463	462	453	467	461	456
16	172	171	162	187	182	173	188	185	177	196	190	183
17	182	179	172	193	189	182	199	192	187	207	198	191
18	151	151	144	165	162	155	169	165	159	175	168	163
19	223	231	224	240	239	237	241	241	239	243	242	240
20	478	459	422	481	455	417	475	446	413	459	439	409
21	261	246	223	269	250	229	268	250	227	265	248	227
23	398	407	404	407	406	407	406	405	405	401	403	405
24	403	409	406	411	409	408	410	408	406	405	406	406
25	323	326	322	332	329	326	332	330	326	331	329	327
26	324	328	324	334	331	329	335	335	328	333	331	329
27	336	339	331	349	347	337	353	345	340	353	348	345
28	336	338	332	348	346	337	351	344	340	351	347	344
29	271	275	273	287	286	280	291	286	284	297	291	290
30	277	281	279	293	293	286	298	293	290	304	297	297
31	370	375	377	388	390	385	395	392	394	405	400	404
32	373	377	378	390	392	386	398	394	395	408	401	405
33	320	325	335	337	344	338	343	342	344	355	347	353
34	987	1001	1055	969	1005	1054	980	1019	1058	992	1031	1071
36	1172	1170	1177	1172	1171	1174	1176	1178	1176	1180	1181	1182
POWER, KW	12.92	9.52	6.23	11.68	8.52	5.54	10.38	7.51	4.84	9.31	6.62	4.19
P. F.	0.911	0.850	0.777	0.895	0.826	0.758	0.860	0.810	0.734	0.883	0.785	0.698
KVA	14.19	11.20	8.02	13.05	10.32	7.31	12.07	9.28	6.59	10.51	8.40	6.00
COOLANT IN, F	58	62	57	70	69	72	69	71	68	68	72	72
COOLANT OUT, F	154	146	135	146	130	—	148	142	130	149	152	142
COOLANT FLOW lbm/sec	0.195	0.192	0.195	0.194	0.193	0.194	0.194	0.194	0.195	0.192	0.194	0.193

Turbine inlet temperature 1600F; alternator coolant flow rate 1.6 GPM; Dow Corning 200 (2cs) coolant.

* Panel meter reading

Table V-b Brayton Rotating Unit temperatures (F) with compressor inlet temperature variations.

Comp. Inlet Temp., F	60			80			100			120		
Comp. Disch. Pres., psia	45	35	25	45	35	25	45	35	25	45	35	30*
T/C No.												
**1	290	255	210	296		216	282	248	212	268	235	223
2	214	191	165	220	193	176	214	192	172	205	188	180
3	345	302	246	345	297	248	331	289	242	315	275	259
**5	350	305	245	344		243	335	287	225	303	255	243
6	216	193	164	223	194	174	215	192	168	205	187	178
8	303	267	221	303	265	226	292	258	221	279	247	234
9	143	131	117	152	137	128	149	138	126	145	135	131
10	118	108	97	127	115	108	125	116	107	123	114	111
11	112	107	98	120	114	110	119	114	109	118	114	112
12	98	92	83	105	100	95	105	100	94	105	100	98
13	374	377	380	380	384	394	383	390	397	387	395	399
14	373	363	361	379	372	371	379	375	372	382	378	377
15	394	380	376	399	387	384	399	391	386	401	393	392
16	174	158	156	182	169	166	186	179	171	191	184	183
17	186	168	166	189	180	177	194	191	183	200	194	194
18	152	140	138	161	151	149	164	159	153	168	163	162
19	201	197	194	214	206	208	214	211	208	215	211	211
20	445	417	379	445	412	381	434	408	377	420	395	387
21	245	223	199	249	227	207	246	227	206	242	224	217
23	370	362	360	373	364	365	369	364	364	363	359	364
24	374	366	362	377	368	367	372	368	366	366	363	366
25	297	286	283	302	292	289	299	292	289	296	290	292
26	298	288	284	303	294	291	300	294	291	297	292	293
27	329	313	312	336	320	320	337	330	324	337	330	333
28	328	313	313	334	320	320	335	329	324	335	329	332
29	270	252	260	278	263	268	282	276	273	285	280	286
30	276	258	266	284	269	273	288	282	279	291	286	292
31	368	348	363	377	361	374	383	379	382	388	387	394
32	370	349	364	379	362	375	385	381	383	391	389	395
33	324	297	322	328	310	327	332	329	334	337	337	347
34	855	876	908	840	889	910	850	883	919	860	895	912
36	1021	1018	1016	1027	1026	1022	1032	1028	1025	1036	1034	1032
POWER, KW	10.15	7.36	4.70	8.80	6.93	4.00	7.63	5.47	3.38	6.60	4.54	3.73
P.F.	0.940	0.844	0.738	0.832	0.787	0.702	0.812	0.758	0.650	0.800	0.722	0.670
KVA	10.80	8.72	6.38	10.57	8.17	5.70	9.40	7.21	5.20	8.25	6.29	5.56
COOLANT IN, F	63	63	58	67	72	71	67	67	67	67	67	68
COOLANT OUT, F	178	168	163	137	177	129	141	133	124	139	130	128
COOLANT FLOW lbm/sec	0.192	0.192	0.195	0.194	0.193	0.193	0.193	0.193	0.194	0.194	0.194	0.194

Turbine inlet temperature 1400F; alternator coolant flow rate 1.6 GPM; Dow Corning 200 (2cs) coolant.

*The 25 psia case was not run. The 30 psia case is included instead.

**Panel meter reading

Table V-c Brayton Rotating Unit temperatures (F) with compressor inlet temperature variations.

Comp. Inlet Temp., F	60			80			100			120		
Comp. Disch. Presl, psia	45	35	25	45	35	25	45	35	25	45	35	30*
** 1	263	230	239	260	230	207	250	210	208	240	223	215
2	199	180	160	179	184	167	194	181	166	191	179	174
3	313	272	233	306	268	237	294	262	240	282	261	251
** 5	312	283					312	275		300	274	261
6	202	182	160	202	186	168	195	181	167	192	179	173
8	273	239	207	269	237	212	260	233	215	250	232	223
9	134	123	113	139	129	121	137	128	121	134	128	125
10	113	104	96	118	111	105	117	110	105	115	110	108
11	104	99	93	112	107	103	111	107	104	111	107	106
12	95	89	83	102	97	92	101	97	93	102	98	96
13	327	326	327	325	327	331	332	334	338	335	340	341
14	322	310	301	325	317	312	325	316	321	327	333	320
15	344	330	321	342	332	324	245	335	333	346	341	336
16	168	159	150	175	168	160	180	173	168	184	179	176
17	178	170	160	187	180	172	188	185	181	193	189	190
18	146	140	134	154	149	144	158	153	151	161	159	156
19	187	141	175	189	187	184	189	188	186	190	190	188
20	407	378	353	399	371	315	390	366	366	379	371	368
21	222	202	187	225	206	191	223	205	195	220	208	202
23	337	329	329	336	329	324	333	327	342	329	332	336
24	340	333	331	340	332	336	336	331	344	332	335	339
25	266	257	254	268	260	261	266	259	267	265	264	265
26	267	258	255	269	261	262	267	260	268	266	265	266
27	314	304	298	317	308	308	319	312	319	319	318	321
28	313	303	299	315	307	308	317	311	319	317	318	320
29	261	251	247	266	258	258	270	264	269	273	271	274
30	266	257	253	271	264	264	276	270	275	279	277	280
31	355	348	348	360	357	363	366	365	375	371	373	377
32	356	349	349	362	358	364	368	366	377	373	375	378
33	308	302	302	312	309	317	318	316	330	321	324	328
34	719	744	771	726	752	781	741	766	794	750	777	789
36	880	875	870	884	879	873	890	885	881	894	891	888
POWER, kW	6.73	4.89	2.98	5.56	3.91	2.27	4.42	2.97	1.65	3.37	2.20	1.57
P.F.	0.795	0.748	0.624	0.752	0.724	0.566	0.720	0.620	0.490	0.655	0.552	0.485
KVA	8.46	6.54	4.78	7.39	5.40	4.01	6.15	4.79	3.36	5.15	3.99	3.24
COOLANT IN, F	59	59	56	70	70	68	70	70	67	69	69	68
COOLANT OUT, F	146	134	121	144	134	123	143	134	116	141	134	129
COOLANT FLOW lbm/sec	0.195	0.195	0.195	0.192	0.193	0.194	0.194	0.194	0.194	0.194	0.194	0.194

Turbine inlet temperature 1200F; alternator coolant flow rate 1.6 GPM; Dow Corning 200 (2cs) coolant.

*The 25 psia case was not run. The 30 psia case is included instead.

**Panel meter reading