REON

SACRAMENTO PLANT

REPORT NO. RP-QR-0002
TO
SPACE NUCLEAR PROPULSION OFFICE - CLEVELAND EXTENSION

PHOEBUS-2 QUARTERLY REPORT
FOR THE PERIOD OF
1 SEPTEMBER THRU 30 NOVEMBER 1965

DECEMBER 1965

CONTRACT SNPC-35

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ROCKET ENGINE OPERATIONS - NUCLEAR

DECEMBER 1965

CONTRACT SNPC-35

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ABSTRACT

This quarterly report is published in response to and in partial fulfillment of Item 5, Task I, Article I - Statement of Work of Contract SNPC-35 and Item 4, Task N, Article I - Statement of Work of Modification No. 1, Supplemental Agreement to Contract SNPC-35.

This document is a report of work performed on Contract SNPC-35 during the period of 1 September thru 30 November 1965. It discusses progress within the active contractual tasks, namely, Task B - Heat Transfer and Coolant Pressure Drop, Task G - Reliability and Quality Assurance (STE), Task H - Special Test Equipment, Task I - Reports (CPFF), Task J - Design, Task K - Fabrication, Task L - Reliability and Quality Assurance (Nozzle Development), Task M - Testing, Task N - Reports (CPIF), and Task O - Procurement of Additional Materials.

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TABLE OF CONTENTS		Page No.
I	Summary	1
II	Detailed Discussion	3
	Task B - Heat Transfer Testing	3
	1. Gas-Side Experiments	3
	2. Liquid-Side Experiments	4
	Task G - Reliability and Quality Assurance (STE)	45
	Task H - STE and Facilities	47
	Task I - Reports (CPFF)	53
	Task J - Design	55
	1. Interface Task Force	55
	2. Nuclear Analysis	56
	3. Convectively Cooled Nozzle	60
	4. Fuel Film Cooled Nozzle	62
	5. Pressure Test Nozzle	66
	6. Multiorifice Injector	68
	7. Coaxial Injector	77
	8. Adapter, Nozzle-to-Injector	77
	9. Adapter Support	81
	10. Test Assembly	86
	11. Test Assembly Lines	86
	12. Materials Program	104
	Task K - Fabrication	131
	1. Convectively Cooled Nozzle	131
	2. Fuel Film Cooled Nozzle	132

3. Pressure Test Nozzle	132
4. Multi-orifice Injector	132
5. Coaxial Injector	133
6. Adapter, Nozzle-to-Injector	133
7. Adapter Support Assemblies	134
8. Test Assembly	134
9. Test Assembly Lines	135
10. Materials Program	135
a. Procurement	135
b. Welding Development Program	160
c. Brazing Development	166
Task L - Reliability and Quality Assurance (Nozzle Development)	169
Task M - Testing	175
Task N - Reports (CPIF)	177
Task O - Procurement of Additional Materials	179

FIGURE LIST

<u>Figure</u>		<u>Page</u>
1	Straight Tube Test Section	24
2	Straight Tube Test Section	25
3	Straight Tube Test Section	26
4	Straight Tube Test Section	27
5	Variation of Experimental Friction Factor With Bulk Reynolds Number	29
6	Comparison of Predictive Equations for LH_2 at 800 psia	32
7	Comparison of Predictive Equations for LH_2 at 1200 psia	33
8	Comparison of Predictive Equations for LH_2 at 1500 psia	34
9	1200 - 1400°R Wall Temperature Data Compared with Nusselt Equation	36
10	1000 - 1200°R Wall Temperature Data Compared with Nusselt Equation	37
11	1200 - 1400°R Wall Temperature Data Compared with Nusselt Equation	38
12	800 - 1000°R Wall Temperature Data Compared with Modified Hess & Kunz Equation	39
13	1000 - 1200°R Wall Temperature Data Compared with Modified Hess & Kunz Equation	40
14	1200 - 1400°F Wall Temperature Data Compared with Modified Hess & Kunz Equation	41
15	H/HC Ratio of Experimental to Calculated Heat Transfer Coefficient	42
16	Test Stand H-4B During Construction Effort	48
17	Burn Pond in Test Zone "H" (for Hydrogen Disposal)	49
18	Scale Burn Pond in Test Zone "A"	50
19	Close-Up View of Scale Burn Pond in Test Zone "A"	51
20	Nozzle Heating Rate Regions for Data Given in Table 4	59
21	Nozzle, Fuel Film Cooled	63
22	Torus - Nozzle Uncooled	65
23	Basic Parts List	67
24	Ring, Injector Baffle	69
25	Injector Assembly, Machined	70

FIGURE LIST (cont.)

<u>Figure</u>		<u>Page</u>
26	Injector Assembly, Brazed	73
27	Leg, Baffle - Injector	74
28	Injector Assembly	75
29	Phoebus-2 Co-Axial Injector Cylindrical Baffle Installation	78
30	Original Support-Adapter Assembly	82
31	Final Support-Adapter Assembly	84
32	Line Assembly Components	87
33	Line Assembly Components	88
34	Line Oxidizer - Injector Inlet P/N 1115645	89
35	Adapter Fuel Inlet Dwg No. 1115454-9	90
36	Line, Coolant-Nozzle Inlet P/N 1115456-9	91
37	Line, Coolant-Dump P/N 1115453-9	92
38	6-in. Adjustable Joint Assembly P/N 1115495	93
39	Fuel Film Supply Coolant Line	94
40	Line, Coolant Film P/N 1115748 Matl: CRES 304L	95
41	Basic Parts List	96
42	Basic Parts List	97
43	Basic Parts List	98
44	Basic Parts List	99
45	Basic Parts List	100
46	Basic Parts List	101
47	Basic Parts List	102
48	Basic Parts List	103
49	Design Properties - Hastelloy-X Forging	110
50	Round R-1 Tensile Specimen	111
51	Round R-3 Tensile Specimen	112
52	Tensile Specimen Round R-1-N and R-3-N	114
53	Ultimate Tensile Strength, Hastelloy X Forged Ring	117
54	% Elongation Values from Hastelloy X Forged Ring	118

FIGURE LIST (cont.)

<u>Figure</u>		<u>Page</u>
55	0.2% Yield Strength vs Temperature, Hastelloy X Forged Ring	119
56	Hastelloy X Grain Structure	124
57	Axial Tensile Specimen After Elongation	126
58	M ₆ C Prime Phase Etched Specimens	127
59	Elastic and Plastic Properties of Hastelloy-X	128
60	Tentative Channel Form Process	142
61	Large Porosity in Hastelloy X Ingot	144
62	Ingot Surface as Received for Forging	146
63	Ingot No. 1, Heat 2849, Depicting Crack Surfaces after Homogenization Treatment	147
64	Ingot No. 2, Heat 2849, Depicting OD Crack Machined to Depth of 1-3/4-in.	149
65	Inlet Cone Forging (with Flange Rough Machined), P/N 1114856-7	152
66	Upset Forging of Original 347 Stainless Steel Ingot	154
67	AISI 347 Stainless Steel Adapter Forging	155
68	Film Cooled Stainless Steel Nozzle Forging	158
69	Hastelloy-X Plate Weldment at Completion of 19 Passes Heat 261-5-4000, S/N 011	163
70	Hastelloy-X Ring Weldment Shown Near Completion Heat 261-5-4001, S/N 0000010	165

TABLE LIST

<u>Table</u>		<u>Page</u>
1	Calculated Test Parameters	6 thru 14
2	Calculated Test Parameters	15 thru 22
3	Data for High Heat Flux Series of Heat Transfer Test	28
4	Results of 2×10^6 Equivalent Histories for Nozzle Heating Rate Calculations	58
5	Design Data Determination	106
6	Material Design Properties - Thin Strip	108
7	Design Properties - Ring Forging Test Plan	109
8	Tensile Properties--Hastelloy X Forged Ring, Heat X5-2718EE	115
9	Effects of Various Heat Treatments on Hastelloy X (Heat X5-2718 EE)	121
10	Notched Tensile Data for Hastelloy X Heat X5-2718EE	122
11	Material Development Procurement	136
12	Forging History Summary of AISI 347 Stainless Steel Components	157
13	Schedule for Materials Development Welding Program	162
14	Material Development Procurement	180

I. SUMMARY

Gas-side heat transfer tests with heated hydrogen and nitrogen flows were completed with the 1/2-scale wedge motor and 1/9-scale axisymmetric nozzle. Data reduction and analysis of the test data was begun. Coolant-side heat transfer predictive equations were compared with test data to determine their accuracy at expected design conditions. Repair of the heat transfer test facility was begun and is scheduled to be completed by mid-December.

Implementation of the Phoebus-2 Nozzle Reliability and Quality Assurance program STE requirements continued.

A second iteration of the LASL/ACFI/AGC nozzle-pressure vessel interface analysis was begun.

The convection cooled nozzle top assembly drawing is 90% complete.

The design of the film cooled nozzle was completed and the final design review was held on 19 November.

Designs of the multi-orifice and coaxial injectors were completed and the final design review was held on 16 November.

The adapter top assembly drawing was released.

The Chemical Simulation Test Plan was completed and published.

Two of the three forgings required for the first convection cooled nozzle successfully completed the forging operation.

The nozzle welding cart was delivered and is undergoing checkout prior to welding.

The two film cooled nozzles successfully completed the forging operation.

Fabrication of the multi-orifice and coaxial injectors is proceeding on schedule.

Fabrication of the first and second adapter is proceeding on schedule.

Fabrication of the test assembly buildup cart was begun.

All Hastelloy X material requirements for the materials development program were received with the exception of the 0.75-in.-dia bar and one heat of 0.012-in.-thick strip stock.

A second welding boom and associated equipment was introduced into the development program for eventual use in fabricating deliverable hardware.

Straza Industries was awarded the contract to manufacture U-channels for the Phoebus-2 program.

The specification for weld wire, AGC 90058, Revision B, was released on 13 October and incorporated weldability performance tests and test methods of establishing the quality of the finished wire. The results achieved thus far in the application of weld wire from material heats procured to the revised specification indicates a definite improvement in the wire quality and in the deposited weld metal.

Semiautomatic welding of two Hastelloy X plates and two ring forgings from material Heats 261-5-4000 and 261-5-4001 was completed. Machining of sections from these weldments was initiated for chemical analysis, metallographic analysis, tensile testing, and hardness testing.

Implementation of the Phoebus-2 nozzle Reliability and Quality Assurance program requirements continued in the areas of design procurement and fabrication. The Test Assembly Inspection and Test Plan was published to formally define the inspection control points that are being and will be used in AGC and supplier fabrication.

The INOR-8 material requirements received include all the plate and bar stock on order. Ring forgings, sheet, and strip stock are scheduled for delivery in December.

Delivery of Allvac 625 materials is pending satisfactory completion of weldability tests.

II. DETAILED DISCUSSION

TASK B - HEAT TRANSFER TESTING

1. Gas-Side Experiments

a. Work Performed During the Quarter

Summary

The objective of the gas-side program is to better characterize gas-side heat transfer coefficients of the Phoebus-2 nozzle through scale-model experiments. Work accomplished during this quarter includes the following:

Completion of testing of the wedge motor with heated hydrogen as the test fluid.

Completion of testing of the 1/9-scale axisymmetric nozzle with heated hydrogen and nitrogen as the test fluid.

Initiation of data reduction and analysis of all heat transfer experiments.

Test Program

All scheduled heat transfer tests were completed using various core exit simulators*, hot nitrogen, and hydrogen as the test fluid on the wedge motor and 1/9-scale axisymmetric nozzle. Nineteen heat transfer tests (six nitrogen and thirteen hydrogen) were conducted on the wedge motor. Five heat transfer tests (one nitrogen and four hydrogen) were conducted on the 1/9-scale axisymmetric nozzle.

Data Analysis

A digital computer code was developed to facilitate detailed analyses of the great amount of data obtained in this program. The code treats experimental heat transfer data such as local heat flux, scale nozzle flow conditions of pressure, temperature and mass flux as input to the program and derives

*Description of simulators are given in Aerojet Phoebus-2 Quarterly Report No. RP-QR-0001.

effective values of C_g at each calorimeter station in the scale model nozzle. Analysis of the data is in process.

b. Work Planned for the Next Quarter

Wedge motor and axisymmetric nozzle data will be analyzed and a final topical report prepared.

2. Liquid-Side Experiments

a. Work Performed During the Quarter

Summary

The coolant heat transfer and pressure drop study was restricted to data analysis and comparison of the test data with predictive equations. From this analysis it is suggested that the modified Hess and Kunz equation reasonably represents the high-heat flux, high-wall temperature test data generated in straight tube test sections.

The repair of the heat transfer test facility was initiated during this report period, and is scheduled to be completed by mid-December, permitting a continuation of the testing program at that time. In addition to the repair of the facility the test section enclosure is being modified by the inclusion of a burst diaphragm, and a water deluge system for fire fighting service is being installed at the test site.

Heat Transfer Test Data

The experimental heat transfer tests in straight tubes were conducted in two groups, one series of tests at mass velocities from 4 to 8.5 lb/in.²sec in three inch heated length tubes to generate high wall temperature test data at coolant temperatures ranging from 70 to 100°R, and a second series of tests in three and six inch heated length tubes at mass velocities of 10 to 25 lb/in.²-sec to generate test data at high heat fluxes.

The first series of tests were conducted at a heat flux range of from 6 to 13 Btu/in.²sec at coolant-side wall temperatures as high as 1600°R. In the second series of tests the local heat flux ranged from 11 to 27 Btu/in.²sec, at wall temperatures up to 1460°R. Certain of the pertinent calculated test parameters from these tests are tabulated in Tables 1 and 2.

Heat Transfer Analysis

The local test conditions tabulated in Table 1 are based on measurements made on the system. The data analysis consists of calculation of the coolant temperature and pressure at points in the system at axial location along the test section where wall temperatures are measured. From the calculated coolant temperature and the local coolant-side wall temperature and local heat flux a local heat transfer coefficient is computed

$$h_{\text{local}} = \left(\frac{(Q/A)_{\text{local}}}{T_w - T_b} \right) \quad (1)$$

To calculate the coolant temperature it is assumed that the electrical power is delivered to the fluid uniformly along the surface of the tube between the electrodes. It is assumed that the state of the fluid entering the test section is defined by the temperature at the inlet mixer and the static pressure at the inlet electrode. The coolant temperature is then determined by an iterative process balancing the energy picked up by the fluid in the heated area upstream of the wall temperature station and the increase in kinetic energy due to acceleration of the fluid. The resultant temperature is therefore based on a static enthalpy of the fluid. The coolant-side wall temperature and the local heat flux are computed from the measured outside wall temperature and local voltage drop along the heated length. The wall temperature thermocouples are fabricated from 40 gauge chromel-alumel thermocouple wire and insulated electrically from the test section by a thin layer of mica less than 0.001 in. thick. A finite differences solution of the differential equation describing the transfer of heat through a power generating solid with temperature dependent properties of resistivity and thermal conductivity was used to determine the temperature

Table 1
Calculated Test Parameters

TEST: D 123LC-1

Data Point	Station	Pressure P _b psi	Temperature		Unit Heat Flux Q/A ₂ Btu/in. ² sec	Heat Transfer Coefficient h ₂ Btu/in. ² sec ^{°R}	Velocity vs ft/sec
			Bulk T _b °R	Wall T _w °R			
2	3	990	71.2	776	7.37	.01047	266
	4	990	71.2	740	7.39	.01104	266
3	3	970	75.7	1363	9.66	.007501	301
	4	970	75.7	1321	9.66	.007757	301
4	3	971	75.6	1372	9.52	.00734	299
	4	971	75.6	1328	9.53	.00761	299
5	3	1041	77.1	1124	8.36	.007984	290
	4	1041	77.1	1096	8.37	.008213	290
6	3	901	70.8	913	8.06	.00957	286
	4	901	70.8	859	8.09	.01027	286
7	3	902	71.3	965	8.06	.00903	286
	4	902	71.3	941	8.08	.00928	286
8	3	894	77.1	1468	9.93	.00714	319
	4	894	77.1	1358	9.93	.00775	319
9	3	891	79.2	1440	10.14	.00744	330
	4	891	79.2	1373	10.14	.00783	330
10	3	1086	74.9	1058	8.67	.00882	288
	4	1086	74.9	1032	8.68	.00907	288
11	3	1080	78.5	1470	10.24	.00736	302
	4	1080	78.5	1418	10.23	.00764	302
12	3	1081	78.4	1480	10.18	.007257	303
	4	1081	78.4	1422	10.17	.007567	303
13	3	1084	78.1	1425	10	.007429	302
	4	1084	78.1	1383	10	.007665	302

Table 1
 Calculated Test Parameters

TEST: D123LC-1

Data Point	Station	Pressure	Temperature		Unit	Heat Transfer	Velocity
		P_b psi	Bulk T_b °R	Wall T_i °R	Heat Flux $Q/A_{.2}$ Btu/in. sec	Coefficient $h_{.2}$ Btu/in. sec °R	vs ft/sec
14	3	1098	77.7	1182	10.21	.00924	338
	4	1098	77.7	1146	10.22	.00957	338
15	3	1102	81.2	1274	10.47	.00878	341
	4	1102	81.2	1238	10.48	.00906	341

Table 1
 Calculated Test Parameters

TEST: D123LC-2

Data Point	Station	Pressure P_b psi	Temperature		Unit Heat Flux $Q/A.2$ Btu/in. sec	Heat Transfer Coefficient $h.2$ Btu/in. sec $^{\circ}R$	Velocity vs ft/sec
			Bulk T_b $^{\circ}R$	Wall T_f $^{\circ}R$			
1	3	1038	76.8	1549	11.25	.00764	350
	4	1038	76.6	1414	11.21	.00838	350
2	3	1039	77.1	1477	11.18	.00798	351
	4	1039	77.1	1428	11.17	.00827	351
3	3	1042	76.5	1300	10.43	.00852	344
	4	1042	76.5	1262	10.43	.0088	344
4	3	1042	76.6	1266	10.09	.00843	344
	4	1042	76.6	1216	10.10	.00887	344
5	3	1044	71.8	854	9.69	.01233	336
	4	1044	71.8	789	9.73	.01357	336
6	3	1049	73.5	1316	10.32	.00830	338
	4	1049	73.5	1249	10.33	.00879	338
7	3	1034	77.4	1649	12.69	.00808	366
	4	1034	77.4	1537	12.62	.00864	366
8	3	1033	78.4	1641	13.40	.008362	368
	4	1033	78.4	1528	13.26	.00916	368
9	3	1017	80.8	1622	13.42	.00871	389
	4	1017	80.8	1462	13.33	.00951	389

Table 1

TEST: D123LC-3 Calculated Test Parameters

Data Point	Station	Pressure	Temperature		Unit	Heat Transfer	Velocity
		P_b psi	Bulk T_b °R	Wall T_f °R	Heat Flux $Q/A_{.2}$ Btu/in. sec	Coefficient $h_{.2}$ Btu/in. sec °R	vs ft/sec
1	1	1086	75.5	802	7.18	.008695	220
	2	1086	75.5	883	7.19	.008907	220
	3	1079	75.3	886	7.45	.009303	254
	4	1079	75.3	958	7.41	.008496	254
2	1	1159	71.5	1046	8.44	.008616	228
	2	1159	71.5	929	8.50	.009919	226
	3	1151	82.6	1037	8.55	.008951	263
	4	1151	82.6	1033	8.55	.0090	263
3	1	1158	72.8	1151	9.15	.008485	227
	2	1158	72.8	1116	9.16	.008785	227
	3	1150	81.8	1187	9.30	.008436	267
	4	1150	81.8	1145	9.31	.008787	267
4	1	1137	70.2	991	9.16	.009952	259
	2	1137	70.2	842	9.24	.01137	259
	3	1128	80.8	979	9.32	.01048	297
	4	1128	80.8	971	9.32	.01047	297
5	1	1141	72.9	1222	10.87	.009458	258
	2	1141	72.9	1206	10.87	.009594	258
	3	1130	85	1300	10.93	.008994	305
	4	1130	85	1213	10.95	.009704	305
6	1	1125	72.6	1112	10.94	.01053	283
	2	1125	72.6	1059	10.97	.01112	283
	3	1113	84	1188	11.15	.0101	332
	4	1113	84	1136	11.17	.01062	332

Table 1
 Calculated Test Parameters

TEST: D123LC-3

Data Point	Station	Pressure	Temperature		Unit Heat Flux Q/A Btu/in. sec	Heat Transfer Coefficient h Btu/in. sec ^{°R}	Velocity vs ft/sec
			Bulk	Wall			
		P_b psi	T_b °R	T_i °R			
7	1	1129	75.2	1183	11.02	.009947	283
	2	1129	75.2	1138	11.04	.01038	283
	3	1117	86.8	1252	11.00	.009437	335
	4	1117	86.8	1150	11.02	.01008	335

Table 1
Calculated Test Parameters

TEST: D 123LC-4

Data Point	Station	Pressure P_b psi	Temperature		Unit Heat Flux $Q/A.2$ Btu/in. sec	Heat Transfer Coefficient $h.2$ Btu/in. sec ^{°R}	Velocity vs ft/sec
			Bulk T_b °R	Wall T_i °R			
1	1	1100	70.0	986	8.11	.00685	225
	2	1100	70.0	855	8.18	.01042	225
	3	1093	80.4	992	8.11	.006889	258
	4	1093	80.4	981	8.11	.009005	258
2	1	1099	71.8	1115	8.82	.008450	225
	2	1099	71.8	1062	8.84	.008933	225
	3	1091	83.2	1161	9.05	.008404	264
	4	1091	83.2	1107	9.08	.008863	264
3	1	1101	73.4	1210	10.01	.008808	234
	2	1101	73.4	1251	10.00	.008453	234
	3	1092	85.6	1364	10.07	.007879	279
	4	1092	85.6	1236	10.09	.008772	279
4	1	1076	72.5	1183	10.84	.009767	268
	2	1076	72.5	1175	10.85	.009835	268
	3	1065	84.2	1258	10.97	.009351	318
	4	1065	84.2	1191	10.99	.009932	318
5	1	1058	73.9	1265	12.19	.01023	300
	2	1058	73.9	1309	12.18	.009867	300
	3	1044	85.6	1315	12.39	.01007	357
	4	1044	85.6	1263	12.4	.01053	357

Table 1
 Calculated Test Parameters

TEST: D123LC-5

Data Point	Station	Pressure P_b psi	Temperature		Unit Heat Flux Q/A Btu/in. sec	Heat Transfer Coefficient h Btu/in. sec ^{°R}	Velocity vs ft/sec
			Bulk T_b °R	Wall T_1 °R			
1	1	1094	71.9	1109	13.21	.01274	329
	2	1094	71.9	1238	13.17	.0113	329
	3	1076	83.4	1254	13.33	.01139	388
	4	1076	83.4	1249	13.33	.01144	388
2	1	1090	74.6	1343	14.23	.01122	337
	2	1090	74.6	1383	14.24	.01089	337
	3	1071	86.7	1137	14.59	.01389	404
	4	1071	86.7	1430	14.61	.01087	404
3	1	1094	82.0	1356	14.44	.01133	359
	2	1094	82.0	1424	14.46	.01078	359
	3	1076	94.2	1540	15.33	.0106	438

Table 1

Calculated Test Parameters

TEST: D123LC-6

Data Point	Station	Pressure P _b psi	Temperature		Unit Heat Flux Q/A ₂ Btu/in. sec	Heat Transfer Coefficient h ₂ Btu/in. sec ^o R	Velocity vs ft/sec
			Bulk T _b °R	Wall T _w °R			
1	1	1108	73.2	1041	6.48	.006697	166
	2	1108	73.2	975	6.51	.007215	166
	3	1104	84.7	1085	6.69	.006686	195
2	1	1105	78.0	1154	8.24	.007661	179
	2	1105	78.0	1213	8.22	.007243	179
	3	1099	92.0	1262	8.53	.007286	223
3	1	1105	80.0	1285	9.73	.008075	192
	2	1105	80.0	1327	9.72	.007795	192
	3	1098	95.2	1449	9.92	.007328	244
4	1	1105	80.4	1315	9.75	.0079	192
	2	1105	80.4	1312	9.76	.007923	192
	3	1098	95.8	1460	10.03	.007354	245
5	1	1098	79.1	1278	9.895	.008253	205
	2	1098	79.1	1332	9.885	.007889	205
	3	1090	93.4	1443	10.11	.007488	257
6	1	1086	79.2	1258	10.75	.009122	232
	2	1086	79.2	1449	10.74	.007840	232
	3	1077	93.1	1475	10.89	.007881	290
7	1	1064	75.9	1202	10.80	.009591	258
	2	1064	75.9	1280	10.78	.008959	258
	3	1053	88.3	1408	11.00	.008335	312
8	1	1068	78.9	1195	11.80	.01058	259
	2	1068	78.9	1519	11.81	.008199	259
	3	1057	92.4	1562	12.07	.008216	321

Table 1
 Calculated Test Parameters

TEST: D123LC-7

Data Point	Station	Pressure	Temperature		Unit	Heat Transfer	Velocity
		P_b	Bulk	Wall	Heat Flux	Coefficient	vs
		psi	T_b °R	T_f °R	Q/A Btu/in. sec	h Btu/in. sec °R	ft/sec
1	1	1096	72.8	973	11.68	.01297	286
	2	1096	72.8	1123	11.61	.01105	286
	3	1084	84.7	1381	11.56	.00892	340
2	1	1098	74.8	1085	12.87	.01275	288
	2	1098	74.8	1343	12.82	.01011	288
	3	1084	87.7	1571	13.06	.008809	349

Table 2
 Calculated Test Parameters

TEST: HT-3-104

Data Point	Station	Pressure P _b psi	Temperature Bulk Wall T _b T _i °R °R		Unit Heat Flux Q/A ₂ Btu/in. sec	Heat Transfer Coefficient h ₂ Btu/in. sec °R	Velocity vs ft/sec
1	1	880	61.6	474	11.05	.0268	460
	2	880	61.6	465	11.05	.02741	460
	4	851	68.3	646	11.38	.01969	504
3	1	1273	70.3	685	14.85	.02417	431
	2	1273	70.3	704	14.85	.02344	431
	4	1245	81.1	949	15.10	.0174	493
4	1	1256	71.5	875	15.38	.01914	418
	2	1256	71.5	865	15.39	.0194	418
	4	1228	83.0	1167	15.59	.01438	485
5	1	912	65.2	526	16.91	.0367	689
	2	912	65.2	534	16.92	.03611	689
	4	847	71.7	850	17.31	.02225	769
6	1	1081	70.0	952	14.41	.01634	409
	2	1081	70.0	893	14.43	.01754	409
	4	1053	80.7	1340	14.79	.01174	475
7	1	877	66.0	786	16.09	.02234	583
	2	877	66.0	725	16.10	.02442	583
	4	825	73.3	1159	16.57	.01526	662
8	1	939	69.2	1179	14.83	.01336	426
	2	939	69.2	1109	14.83	.01427	426
	4	906	79.1	1373	15.11	.01167	502
9	1	754	65.6	1066	16.40	.01639	586
	2	754	65.6	966	16.41	.01824	586
	4	696	72.4	1286	16.75	.01380	683

Table 2
 Calculated Test Parameters

TEST: HT-3-105

Data Point	Station	Pressure P_b psi	Temperature		Unit Heat Flux $Q/A_{.2}$ Btu/in. sec	Heat Transfer Coefficient $h_{.2}$ Btu/in. sec ^{OR}	Velocity vs ft/sec
			Bulk T_b °R	Wall T_i °R			
1	1	1213	71.5	782	14.44	.02031	414
	2	1213	71.5	746	14.45	.02141	414
	4	1186	82.5	1136	14.84	.01408	478
2	1	1186	72.4	952	14.71	.01674	398
	2	1186	72.4	905	14.73	.01769	398
	4	1159	83.9	1350	15.13	.01195	467
3	1	1144	71.2	635	19.02	.03374	636
	2	1144	71.2	581	18.99	.03724	636
	4	1087	80.2	1012	19.58	.02102	725
4	1	972	70.0	581	18.95	.03711	730
	2	972	70.0	552	18.92	.03924	730
	4	896	77.0	1032	19.62	.02054	836
5	1	954	71.0	665	18.98	.03198	714
	2	954	71.0	631	18.97	.0339	714
	4	879	78.1	1138	19.64	.01853	824

Table 2
 Calculated Test Parameters

TEST: HT-3-106

Data Point	Station	Pressure P_b psi	Temperature		Unit Heat Flux Q/A Btu/in. ² sec	Heat Transfer Coefficient h Btu/in. ² sec °R	Velocity vs ft/sec
			Bulk T_b °R	Wall T_i °R			
1	4	1064	73.9	540	18.7	.04009	918
2	2	1013	68.4	452	21.38	.05575	866
	4	916	74.8	1013	22.42	.02389	979
3	1	1118	70.6	430	24.07	.06686	900
	4	1012	78.0	817	25.12	.03402	1017

Table 2
 Calculated Test Parameters

TEST: HT-3-107

Data Point	Station	Pressure <u>P_b</u> <u>psi</u>	Temperature		Unit Heat Flux Q/A.2 <u>Btu/in. sec</u>	Heat Transfer Coefficient h.2 <u>Btu/in. sec^oR</u>	Velocity vs <u>ft/sec</u>
			Bulk	Wall			
			T _b <u>°R</u>	T _w <u>°R</u>			
1	1	1289	71.62	557.	24.3	.05015	745
	2	1289	71.62	587	24.4	.04735	745
	3	1212	81.54	1314	25.9	.02105	856
	4	1212	81.54	1028	25.5	.02699	856
2	1	1259	71.95	690.	24.6	.03987	730
	2	1259	71.95	692.	24.6	.03975	730
	3	1184	81.95	1427	26.3	.01957	842
	4	1184	81.95	1150	25.8	.02417	842
3	2	1097	76.69	570.	26.4	.05342	980
	3	967.5	83.41	1019	27.6	.02959	1138
	4	967.5	83.41	992.5	27.6	.03040	1138

Table 2
 Calculated Test Parameters

TEST: HT-3-109

Data Point	Station	Pressure P_b psi	Temperature		Unit Heat Flux Q/A_2 Btu/in. sec	Heat Transfer Coefficient h_2 Btu/in. sec ^{°R}	Velocity vs ft/sec
			Bulk T_b °R	Wall T_i °R			
1	1	1222	70.22	566.3	18.51	.03731	765.5
	2	1148	77.87	506.6	19.55	.0456	853.5
	3	1074	84.43	687.6	20.27	.03361	959.6
	4	1074	84.43	845.7	20.3	.02667	959.6
	5	999.7	90.06	1046	20.46	.0214	1080
	6	999.7	90.06	894	20.43	.02541	1080
	7	925.7	94.2	891.4	20.55	.02578	1244
2	1	1371	71.95	532.9	22.41	.04862	910.9
	3	1155	86.09	573.3	24.18	.04963	1154
	4	1155	86.09	862.6	24.48	.03152	1154
	5	1047	91.01	1240	24.97	.02173	1300
	6	1047	91.01	766.5	24.52	.0363	1300
	7	938.4	94.45	1134	25.14	.02418	1489

Table 2
 Calculated Test Parameters

TEST: HT-3-110

Data Point	Station	Pressure P _b psi	Temperature		Unit Heat Flux Q/A .2 Btu/in. sec	Heat Transfer Coefficient h .2 Btu/in. sec °R	Velocity vs ft/sec
			Bulk T _b °R	Wall T _w °R			
1	1	1173	69.99	500.6	19.57	.04463	858.3
	4	976.2	82.65	1030	21.62	.02283	1080
	5	878	86.55	1333	21.92	.01758	1243
	6	878	86.55	883.2	21.61	.02713	1243
	7	779.8	89.05	1039	21.79	.02295	1433
2	1	1276	72.17	442.2	21.0	.05675	922.8
	4	1066	84.82	974.8	22.97	.02581	1156
	5	961.1	89.04	1268	23.27	.01974	1310
	6	961.1	89.04	724.5	22.88	.03601	1310
	7	856.1	91.54	862	23.29	.02676	1500
3	1	1265	72.87	453.1	20.78	.05465	912.3
	4	1058	85.52	999	22.77	.02492	1146
	5	954.5	89.67	1345	23.14	.01843	1304
	6	954.5	89.67	749.7	22.67	.03435	1304
	7	851.0	92.24	1048	23.08	.02416	1495

Table 2
 Calculated Test Parameters

TEST: HT-3-111

Data Point	Station	Pressure P_b psi	Temperature Bulk Wall T_b T_i °R °R		Unit Heat Flux Q/A Btu/in. sec	Heat Transfer Coefficient h Btu/in. sec °R	Velocity vs ft/sec
1	1	1312	70.03	549.6	19.73	.04114	766.3
	4	1163	85.11	989.2	21.44	.02371	985.9
	5	1088	90.89	1266.0	22.02	.01874	1109.0
	6	1088	90.89	807.9	21.76	.03035	1109.0
	7	1014	95.97	1028.0	21.77	.02336	1243.0
2	1	1295	70.14	590.0	19.85	.03818	767.6
	2	1221	78.5	501.8	20.87	.04931	859.1
	3	1221	78.5	500.4	20.87	.04748	859.1
	4	1148	85.53	1054.0	21.63	.02234	969.1
	5	1074	91.47	1459.0	22.4	.01638	1094.0
	6	1074	91.47	889.9	21.88	.02741	1094.0
	7	1001	90.78	1070.0	21.84	.02243	1232.0
3	1	1172	69.4	552.4	19.44	.04025	819.5
	2	1080	76.67	481.3	20.6	.0509	913.8
	3	1080	76.67	478.1	20.61	.05134	913.8
	4	988.8	82.76	1007.0	21.23	.02298	1031.0
	5	897.3	87.14	1524.0	22.14	.01541	1191.0
	6	897.3	87.14	913.6	21.53	.02606	1191.0
	7	805.9	90.26	1044.0	21.42	.02246	1362.0
4	4	1121	84.41	889.2	22.86	.02841	1138.0
	5	1019	89.17	1252.0	23.58	.02027	1272.0
	6	1019	89.17	618.5	23.1	.04364	1272.0
	7	917.5	92.3	944.0	23.38	.02745	1457.0

Table 2
 Calculated Test Parameters

TEST: HT-3-111

Data Point	Station	Pressure <u>P_b psi</u>	Temperature		Unit Heat Flux <u>Q/A₂ Btu/in. sec</u>	Heat Transfer Coefficient <u>h₂ Btu/in. sec^oR</u>	Velocity vs <u>ft/sec</u>
			Bulk <u>T_b °R</u>	Wall <u>T₁ °R</u>			
5	4	1110	85.44	937.6	23.0	.02699	1132
	5	1009	90.28	1105.0	23.95	.01821	1270
	6	1009	90.28	688.3	23.28	.03893	1270
	7	909.1	93.41	1023.0	23.49	.02527	1463
6	4	1102	85.8	873.6	22.78	.02892	1191
	5	993.3	90.17	1132.0	23.37	.02243	1335
	6	993.3	90.17	563.8	22.94	.04843	1335
	7	884.6	92.52	913.7	23.33	.02841	1534
7	4	1108	87.4	928.8	23.18	.02755	1181
	5	1001	91.93	1393.0	24.08	.0185	1325
	6	1001	91.93	639.2	23.37	.0427	1325
	7	893.7	94.51	986.7	23.66	.02652	1532

drop through the wall and the local heat flux. In this computation the handbook properties of the Hastelloy X test section material were used. The fluid properties were based on density and enthalpy data.* The test section configurations tested are included as Figures 1, 2, 3, and 4.

Pressure Drop Data

The static pressure drop is measured across the heated length of the straight tube test sections, by means of pressure taps in the electrodes. This pressure measurement coupled with the measurement of temperatures and pressures in the inlet and outlet plenums on either side of the test section permits the calculation of the fluid state entering and leaving the test section proper.

In the pressure drop and average friction factor analysis the following assumptions were made:

- uniform pressure drop along the heated length
- uniform heat addition along the heated length
- adiabatic flow external to the resistance heated portion of the system

The electrical energy added to the test fluid is computed from measurements of the voltage drop across and total current flowing in the test section. The heated area is based on physical measurements of the test section.

The computation of the friction factor for the Hastelloy X test sections has been based on computed temperatures and pressures at thermocouple stations along the heated length. The experimental pressure drop, the momentum change, the frictional pressure drop and the friction factor for the second or high heat flux series of heat transfer tests are tabulated in Table 3. The relationship between the calculated adiabatic and non-adiabatic friction factor and the bulk Reynolds number is shown by Figure 5. The solid line is based on the equation:

$$\frac{1}{2f} = 2.54 \log_{10} [Re_b]^{-2.17} \quad (2)$$

* Roder, H. M., and Goodwin, R.D., Provisional Thermodynamic Functions for Para-Hydrogen, NBS Technical Note 130, Nos, Boulder Laboratories, Dec. 1961

Straight Tube Test Section

Figure 1

- ✓ Chromel-Alumel Thermocouple
- Voltage Taps

Test Section Hastelloy X Tube
Nom. Wall Thickness 0.015 in.
Inside Diameter 0.1475 in.

Test Section	L	Test No.
1	2.72	D 123 LC-1, -2
2	2.96	D 123 LC-3, -4, -5, -6, -7

Straight Tube Test Section

Figure 2

- ✓ Chromel-Alumel Thermocouples
- Voltage Taps

Hastelloy X Test Section
Inside Dia 0.1475 in.

TEST HT-3-104,-105,-106,-107

Figure 3
Straight Tube Test Section

Test HT-3-109

Test HT-3-110, -111

Figure 4
 Straight Tube Test Section

Table 3
 Data for High Heat Flux Series
 of Heat Transfer Test

T_1	P_1	T_2	P_2	ΔP_S	ΔP_V	ΔP_f	$f/2$	Re_b $\times 10^{-6}$
61.6	880.1	68.3	851.2	28.9	17.28	11.62	.0023	3.77
64.2	1176	69.9	1138	38	20.05	17.95	.0022	4.38
70.3	1273	81.1	1245	28	22.46	5.54	.0012	3.67
71.5	1256	83.0	1228	28	23.32	4.68	.0011	3.63
65.2	912.1	71.7	846.6	65.5	45.54	19.96	.0018	6.03
70.0	1081	80.6	1053	28	21.89	6.11	.0014	3.76
66.0	877.3	73.3	824.7	52.6	36.99	15.61	.0019	5.32
69.2	938.9	79.1	906.4	32.5	25.98	6.52	.0016	4.11
65.6	754	72.4	695.5	58.5	42.22	13.28	.0017	5.67
71.5	1213	82.5	1186	27	21.9	5.1	.0013	3.67
72.4	1186	83.9	1159	27	22.1	4.9	.0013	3.66
71.2	1144	80.2	1087	57	45.7	11.3	.0012	5.71
70.0	971.9	77.0	896	75.9	61.4	14.5	.0012	6.85
71.0	953.7	78.1	878.9	74.8	60.8	14.0	.0012	6.88
68.4	1013	74.9	915.7	97.3	79.2	18.1	.0010	7.70
70.6	1118	78.0	1012	106	85.3	20.7	.0011	8.08
71.6	1289	81.5	1212	77	68.9	8.1	.0006	6.46
71.9	1259	81.9	1184	75	68.0	6.9	.0005	6.45
76.7	1097	83.4	967.5	129.5	115.1	14.4	.0010	9.70
56.6	1299	57.5	1088.	211.	25.5	185.5	.00156	6.16
57.4	1262	58.8	1055.	207.	25.4	181.6	.00155	6.29
56.6	1299.3	58.0	1086.6	212.7	29.1	183.6	.00154	6.21

Figure 5
 Variation of Experimental Friction Factor
 With Bulk Reynolds Number

Pressure Drop Analysis

The pressure drop due to the increase in coolant velocity was computed from the following equation

$$\Delta P_v = \frac{\rho_{avg}}{288 \text{ gc}} \left[V_2^2 - V_1^2 \right] \quad (3)$$

where $\rho_{avg} = \frac{\rho_1 + \rho_2}{2}$

V_1 = Velocity at station 1 based on P_1 and T_1

V_2 = Velocity at station 2 based on P_2 and T_2

The frictional pressure drop is related to the static pressure drop by:

$$\Delta P_f = \Delta P_s - \Delta P_v \quad (4)$$

The friction factor is calculated using the relationship:

$$2f = \Delta P_f \left(\frac{\rho_{avg}}{G^2} \right) \left(\frac{144 \text{ d}}{\text{gc}^L} \right) \quad (5)$$

where d = test section diameter

L = test section length between Stations 1 and 2.

Prediction of Heat Transfer and Pressure Drop to Hydrogen in Straight Tubes at High Wall Temperatures

The ability of two of the proposed equations for predicting heat transfer to cryogenic hydrogen at pressures above 1000 psia have been compared with each other and with experimental data obtained in this program to determine which equation presented the better representation of the test data.

For purposes of identifying the effect of variations in the temperature and pressure on the computation of a heat transfer coefficient the two equations being compared were ratioed and this ratio was plotted as a function of the fluid temperature for lines of constant wall temperature. The effect of fluid pressure is illustrated by plotting the ratio at pressures of 800, 1200 and 1500 psia.

The equations compared in this analysis are a recommended Nusselt film temperature equation* and a modified form of the Hess and Kunz equation. Both of these equations are based on film temperature properties, or an arithmetic mean temperature between the wall and the fluid temperature. The comparison of these equations for the three pressures are shown by Figures 6, 7, and 8. In each figure the range of coolant temperatures is from 50 to 140°R and the wall temperature from 400 to 1500°R. The following conclusions can be drawn from this comparison:

The variation between the two equations is less than $\pm 20\%$ for the range of coolant temperatures and pressures considered at wall temperatures below 800°R.

Increasing pressure tends to decrease the difference between the prediction of the two equations until at 1500 psia the equations are essentially comparable up to 1200°R wall temperatures.

Increasing coolant temperature at higher wall temperatures tends to decrease the difference in the predicted heat transfer coefficient.

At pressures below 1200 psia the Nusselt film temperature equation predicts a comparatively smaller coefficient as the coolant temperature approaches 90°R and then an increasingly larger coefficient at coolant temperatures above 90°R.

Recognizing that the difference in predicting coefficients will be limited at low wall temperatures to a variation of less than $\pm 20\%$ the effect of extrapolating the equation to high wall temperatures at coolant temperatures ranging from 70 to 100°R is to be studied as being the region of distinct interest in the design of the Phoebus nozzle.

* Hendricks, R. C., R. J. Simoneau, and R. F. Friedman: Heat Transfer Characteristics of Cryogenic Hydrogen from 1000 to 2500 psia Flowing Upward in Uniformly Heated Straight Tubes, NASA TN D-2977, Sept. 1965

Figure 6
Comparison of Predictive Equations for LH_2 at 800 psia

H, PREDICTED BY HENDRICKS EQ.
 H, PREDICTED BY HESS & KUNZ (MODIFIED COEF.)

Figure 7
 Comparison of Predictive Equations for LH₂ at 1200 psia

Figure 8
 Comparison of Predictive Equations for LH_2 at 1500 psia

The comparison of the available experimental test data at wall temperatures above 800°R with the Nusselt film temperature equation is shown by Figures 9, 10, and 11. The same test data compared with the Hess and Kunz equation with a modified coefficient of 0.0176 rather than 0.0208 is shown by Figures 12, 13, and 14. An examination of these plots shows that in general the Nusselt film temperature equation understates the experimental coefficients by 20 to 25%, whereas the modified Hess and Kunz equation presents a less pessimistic representation of the data particularly for coolant temperatures in the 80 to 100°R region. Figure 15 is a plot of the test data from this test program and Reference (2) for the pressure range from 760 psia to 1500 psia compared with the Hess and Kunz equation. The line through an H/H_c value of 0.85 represents the design line. The $\pm 20\%$ lines indicate that the data are adequately represented by this equation. Only at low coolant temperatures does the equation fail to characterize the data, and at these temperatures the experimental coefficients are higher than predicted with the result that the wall temperatures predicted in this coolant temperature regime will probably be higher than actually experienced.

Based on this analysis it is suggested that the use of the Hess and Kunz equation with the modified coefficient be continued for predicting the coolant-side heat transfer coefficient in the Phoebus nozzle.

The pressure drop data without heat addition for the short test sections resulted in considerable variation and only the data for the six inch heated length test section are presented. The test data with heat addition, or the non-adiabatic tests, are for the three inch heated length test sections used in the high heat flux tests. In general the frictional pressure drop constituted less than 30% of the total static pressure drop, consequently the influence of the momentum drop tends to obscure the magnitude of the frictional drop. The conclusion drawn from the data on Figure 5 is that the equation currently used to predict the coefficient of friction f , represents approximately 50% of the test data from the high heat flux tests in circular straight tubes. There is insufficient evidence from these tests to substantiate a change in the design equation.

Figure 9
 1200 - 1400°R Wall Temperature Data Compared with Nusselt Equation

Figure 10
 1000 - 1200°R Wall Temperature Data Compared with Nusselt Equation

$$H_c = 0.021 Re_f^{0.8} Pr_f^{0.4} k_f/D$$

Pressure - 800 to 1500 psia

Coolant Side Wall Temperature - 1200 to 1400°R

Figure 11
 1200 - 1400°R Wall Temperature Data Compared with Nusselt Equation

Figure 12
 800 - 1000°R Wall Temperature Data Compared with
 Modified Hess & Kunz Equation

$$H_c = 0.0176 Re_f^{0.8} Pr_f^{0.4} (1 + 0.01457 \frac{u_w}{u_b}) k_f / D$$

Pressure - 800 to 1500 psia

Coolant Side Wall Temperature - 1000 to 1200°R

Figure 13
 1000 - 1200°R Wall Temperature Data Compared with
 Modified Hess & Kunz Equation

$$H_c = 0.0176 Re_f^{0.8} Pr_f^{0.4} \left(1 + 0.01457 \frac{v_w}{v_b} \right) k_f / D$$

Pressure - 800 to 1500 psia

Coolant Side Wall Temperature - 1200 to 1400°F

Figure 14
 1200 - 1400°F Wall Temperature Data Compared with
 Modified Hess & Kunz Equation

Figure 15
H/HC Ratio of Experimental to Calculated Heat Transfer Coefficient

b. Work Planned for the Next Quarter

The repair to the test facility will be completed in December and testing program will be continued. Tests to clarify the material compatibility or possible thermal cycling problem will be completed. Additional straight tube heat transfer tests have been proposed to clarify a possible tube oscillation or vibration problem and these tests would then follow the material compatibility tests. It is planned that the curved tube tests immediately follow these straight tube tests.

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TASK G - RELIABILITY AND QUALITY ASSURANCE (STE)

1. Work Performed During the Quarter

Special Test Equipment Design

The specifications and drawings for Amendment II to Specification AET-7900-0020 on the Test Stand H-4B installation were reviewed and approved. This provides for piping changes to accommodate the GH_2 and GN_2 filters, which are to be relocated from the M-1 facility, and incorporation of a 4000 psig rupture disc to limit pressure on the GN_2 filter.

Redesign of the Thrust Mount Assembly as set forth in Drawing ST-5515, Revision A, was reviewed and approved.

Purchase Requisition 496711, Specification SPE 65-1763 and associated drawings for rehabilitation of the fire damaged heat transfer facility in Area 30 were reviewed and approved.

The PMI Quality Control and Procedure Manual for the Test Stand H-4B installation was approved after revision.

Procurement Control

The following radiographic laboratories and film reading personnel were certified for radiographic examination of Test Stand H-4B components:

<u>Laboratory</u>	<u>Components</u>
North American Inspection Services	- Potter Flowmeters
Quaker Alloy Casting Company	- Hammel-Dahl Valves
Superior Testing Labs, Inc.	- Ladewig Valves

In-process surveillance of the Test Stand H-4B installation was conducted on a continuous basis, with particular emphasis on radiographic examination of piping elements and proper documentation of all phases of the shop and field inspections.

As requested by SNPO-C, a 25-foot length of S/S pipe and two stainless steel reducers procured from Pacific Metals Company on P.O. LAE-051757 were subjected to dye penetrant inspection and accepted.

A 500-foot section of the 8-in.-dia C.S. Phoenix Steel Corporation pipe installed for high pressure GN_2 service successfully passed a 7500 psi hydro-test.

The installation of the Cryogenic Laboratory scale burn pond by Monterey Mechanical Company was inspected and given conditional acceptance subject to minor corrective actions which were subsequently made.

Field surveillance of the following procurements indicated satisfactory quality in planning and fabrication:

<u>P.O.</u>	<u>Component</u>
LAE-051943	One 6-in. Hammel-Dahl Valve
LAE-051844	Three 6 and 8-inch Hammel-Dahl Valves
LAE-051838	One 12-in. Annin Valve

2. Work Planned for the Next Quarter

Implementation of the Phoebus Reliability and Quality Assurance Program Requirements will continue to be conducted in accordance with the scope defined in the Phoebus-2 Nozzle Reliability and Quality Assurance Program Plans, Reports RP-TR-0003 and 0004. Procurement surveillance on special test equipment components and the in-process surveillance of the Test Stand H-4B installation will be completed.

In-process surveillance and acceptance of the heat transfer facility rehabilitation in Area 30 will be completed.

Modes of failure analysis of the Phoebus Test System and Nozzle Test Assembly will be coordinated.

TASK H - STE AND FACILITIES

1. Work Performed During the Quarter

The subcontracted effort for the construction of Test Stand H-4B under AETRON Specification AET 7900-0020 continues.

- 11 65 SP 1263 Figure 16 shows some of the progress being made by the subcontractor, P.M.I., in the construction of Test Stand H-4B.
- 12 65 SP 506 Figure 17 is a view of the hydrogen disposal pond in Test Zone H with manifold and distribution fingers in place.

AGC Components to be furnished to the subcontractor arrived throughout the quarter. Delivery of 8-in.-dia and 10-in.-dia carbon steel pipe was completed on 14 September. Also received were Grayloc flanges, electrostatic charge amplifiers, vacuum jacketed pipe, gimbal joints, and check and control valves of 1-1/2-in. to 3-in. sizes.

Construction of a scale burn pond in Test Zone "A" was completed on 5 November. The task was subcontracted to the Monterey Mechanical Company on 1 October under the conditions of AETRON Specification AET 7900-0026.

- 11 65 SP 947 Figure 18 shows the scale burn pond in Test Zone A as seen from the Cryogenics Laboratory. The small concrete blockhouse to the right of the pond is for housing instrumentation and controls STE.
- 11 65 SP 946 Figure 19 is a closeup view of the interior of the scale burn pond in Test Zone A. The manifold and gas distribution fingers are shown within the pond. The manifold and fingers will be covered with water when the pond is being used for gas disposal. The two rectangular metal boxes on the right edge of the pond are the propane igniters which will provide continuous ignition.

Figure 16
Test Stand H-4B During Construction Effort

Figure 17
Burn Pond in Test Zone "H" (for Hydrogen Disposal)

Figure 18
Scale Burn Pond in Test Zone "A"

Figure 19
Close-Up View of Scale Burn Pond in Test Zone "A"

Activation of the scale burn pond was completed on 11 November with the initiation of testing. The initial test utilized LN_2 at a flow of 45 lb/second to determine the surface conditions of the water in the pond, the freezing effect, and the flow distribution characteristics for 1-1/2-in.-dia nozzles.

Three tests were conducted on the scale burn pond (two on 24 November and one on 30 November) using a mixture of GN_2 and LN_2 at a total flow rate of 29 lb/second consisting of 13 lb/second of ambient gaseous nitrogen and 16 lb/second of liquid nitrogen. The objectives of these tests were the shakedown of the mixing system, determination of the effects of cold effluent gas and H_2O turbulence characteristics, determination of flow distribution with sonic nozzles, determination of freezing characteristics, and simulation of main pond momentum.

2. Work Planned for the Next Quarter

The construction of Test Stand H-4B under AETRON Specification AET 7900-0020 will be completed by the end of December. Although completion was anticipated by mid-December, the subcontractor was given additional time to complete the job because of time lost due to interference by NERVA testing and inclement weather.

Following the completion of subcontractor activity, stand activation will begin. Due to the extension to the subcontracted construction effort, the previously expected mid-February completion of activation was rescheduled to the first of March. The 1 March date is predicated upon receipt of test hardware three weeks prior to the start of testing.

Arrival of components will continue through December, with all long lead procurements expected to be completed during the first part of January.

The test program for the scale burn pond in Test Zone "A" will be completed during the first half of December. Experience gained during testing of the scale burn pond will then be used to establish operational procedures and determine any necessary modification to the current design for the full scale burn pond in Test Zone H.

TASK I - REPORTS (CPFF)

1. Work Performed During the Quarter

Weekly TWX reports to SNPO-C were compiled and transmitted each Friday of the quarter (RP-TWX-0023 through -0035).

Ten copies of the Financial Management Report, NASA Form 533, for the CPFF and CPIF portions of the Contract were submitted on 20 September, 15 October, and 9 November.

On 23 and 24 September an oral presentation was made on the technical status of the program per request of SNPO-C.

The Materials Report for the first six-month period of the Contract from 15 February through 15 August was submitted to the Contracting Officer in September (RP-DR-0001).

On 12 October lithographed copies of the Technical Status Report viewgraphs were distributed to the attendees of the 23 and 24 September presentation. (RP-TM-0001).

The first Quarterly Report (RP-QR-0001) for the period 18 May through 31 August 1965 was distributed in final form on 22 October according to the list furnished by the SNPO Technical Director.

Monthly Progress Reports for September and October were submitted on 22 October and 19 November, respectively (RP-MR-0005 and 0006).

The Phoebus-2 Nozzle Proof Test Method, Chemical Simulation Test Plan, was prepared in November for submittal (RP-TR-0005) to SNPO-C.

2. Work Planned for the Next Quarter

Reports required by the Work Statement plus other contractually required or customer required reports, will be submitted to SNPO-C. Included will be the revised and finalized edition of the second Quarterly Report and submittal of the Phoebus-2 Nozzle Proof Test Method, Chemical Simulation Test Plan.

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TASK J - DESIGN

1. Interface Task Force

a. Work Performed During the Quarter

Representatives from LASL/ACFI/AGC met in Albuquerque to perform an updated stress analysis of the nozzle-pressure vessel interface area. This analysis will be presented as an addendum to the report "Phoebus-2 Pressure Vessel Nozzle Interface Analysis Part IV-Stress Analysis."

The primary reason for this iteration was the development of new nuclear heating rates by AGC which resulted in a new temperature profile for the nozzle and pressure vessel. Also, the following changes in the nozzle, pressure vessel, and operating loads were included:

- Reduction of pressure vessel pressure from
940 psia to 855 psia
- Reduction of nozzle skirt length
- Increase in nozzle skirt thickness
- Incorporation of latest nozzle flange dimensions
- Incorporation of latest pressure vessel flange
dimensions

The new heating rates resulted in an increase in shell and flange temperatures. The maximum shell temperature increased from 957°R to 1130°R for nominal heating rates and to 1275°R for 1.25 x nominal heating rates. The maximum flange temperature increased from 934°R to 1191°R for nominal heating rates and to 1349°R for 1.25 x nominal heating rates.

Results of the analysis show that the interface loads were not changed significantly. The final stress computer runs were received and are being evaluated.

b. Work Planned For the Next Quarter

The second iteration of the nozzle-pressure vessel interface analysis will be completed.

2. Nuclear Analysis

a. Work Performed During the Quarter

Additional point kernel analyses were performed during the last quarter to provide nuclear heating data for the final iteration on temperature and stress calculations. These data differed from those presented in the Summary Report (RP-SR-0001, Vol. II) in three general ways:

Changes in the reference configuration required consideration of a 0.6-inch thick skirt; other changes were considered to have a negligible effect on nuclear heating of the nozzle.

Heating rates due to primary gammas were increased by 6% for compatibility with the source terms predicted by LASL in Memo N-27999, "Gamma Ray Source Power in Relation to Reactor Power", G. A. Graves, 16 August 1965.

Heating rates due to secondary gammas produced by neutron captures in the nozzle were reduced by 50%. This is a result of considering self-absorption of neutrons by a discrete representation of the nozzle in the TDC model.

In addition to updating the data contained in the Summary Report, new heating rate data were calculated for detector points specified by ACFI. These detector points differed from the AGC selection in that they were heavily concentrated in the pressure vessel regions of the interface. Both sets of data are compatible within 0% to 6% with the 6% differences existing near the outboard locations where total heating rates were lowest. These small differences result from the more complete treatment given to the source terms in past work for the AGC detector locations.

Monte Carlo analysis during the quarter consisted of a study of biasing techniques and the use of these techniques in predicting Monte Carlo heating rates

for the nozzle subassemblies. The biasing techniques selected resulted in a ten-fold reduction in computer running time for heating rate data with comparable statistics. The results are summarized in Table 4. Figure 20 identifies the regions for which heating rate data are provided in Table 4. The Monte Carlo heating rates are given along with the 90% confidence limits as calculated by the "T-test" of statistics.

Also given in the table are the volume-averaged point kernel heating rates. Considering the average values for the skirt, flange, and 3-region jacket, the point kernel heating rates are shown to be 3.88%, 31.02%, and 1.52% higher than the Monte Carlo heating rates, respectively. This would indicate that the point kernel method was good in the high heating rate regions but tended to over-estimate values for the low heating rate region.

b. Work Planned For the Next Quarter

Liaison activities with various project personnel and with LASL and ACF personnel will continue.

An addendum will be written for the interface nuclear heating analysis.

A report will be written describing the nuclear analysis activities during the nozzle development phase.

TABLE 4
RESULTS OF 2×10^6 EQUIVALENT HISTORIES FOR
NOZZLE HEATING RATE CALCULATIONS

<u>Subassembly</u>	<u>Region</u>	FMC-G Heating Rate (Btu/in ³ -sec)	90% Confidence Limits (Btu/in ³ -sec)		QAD Volume Averaged Heating Rate (Btu/in ³ -sec)	Percentage Difference (FMC-G)-(QAD) (FMC-G)
			Upper	Lower		
Skirt	62	0.4850±0.0372	0.5287	0.4412	0.4414	8.49
	63	0.3160±0.0225	0.3424	0.2896	0.3217	- 1.80
	64	0.2615±0.0239	0.2896	0.2334	0.3036	-16.10
	Ave	0.3401±0.0154	0.3583	0.3220	0.3533	- 3.88
Flange	79	0.0676±0.0313	0.1045	0.0307	0.0914	-35.21
	81	0.0927±0.0130	0.1080	0.0774	0.1046	-12.84
	82	0.1214±0.0206	0.1457	0.0972	0.1561	-28.58
	83	0.0450±0.0126	0.0599	0.0301	0.0636	-41.33
	84	0.0354±0.0113	0.0487	0.0222	0.0456	-28.81
	86	0.0608±0.0125	0.0755	0.0461	0.0829	-36.35
	Ave	0.0722±0.0109	0.0850	0.0594	0.0946	-31.02
Jacket	87	0.2386±0.0261	0.2693	0.2079	--	--
	88	0.3471±0.0125	0.3619	0.3326	0.3233	6.88
	89	0.3188±0.0208	0.3483	0.2942	0.3356	- 5.27
	90	0.2935±0.0287	0.3273	0.2598	0.3229	-10.02
	91	0.1082±0.0348	0.1491	0.0672	--	--
		0.2977±0.0157	0.3162	0.2793	--	--
3-Region Jacket Ave (88-89-90)		0.3227±0.0156	0.3411	0.3043	0.3276	- 1.52

Figure 20
Nozzle Heating Rate Regions for Data Given in Table 4

3. Convectively Cooled Nozzle

a. Work Performed During the Quarter

Nozzle Final Assembly drawing P/N 1114830 is 90% complete. The following drawings were released:

Venturi Meter	P/N 1115346
Adapter-Bolt Coolant Line	P/N 1115380
Bolt Coolant Line Assembly	P/N 1115344
Instrumentation Boss	P/N 1115347
Jacket Final Machining	P/N 1114831
Manifold-Bolt Coolant	P/N 1115205
Adapter-Bolt Coolant	P/N 1115805
Weld Cart	P/N T-1015200
Transportation Cart	P/N T-1015215
Flush and Flow Fixture	P/N E-1015240
I.D. Contour Template	P/N T-1015247
O.D. Contour Template	P/N T-1015248
I.D. Contour Check Template	P/N T-1015246
Access Platform	P/N T-1015222

The following drawings are being reviewed prior to release:

Coolant Inlet	P/N 1115349
Inlet Flange	P/N 1115350

Revision "B" was incorporated in the fabrication order of the nozzle tube drawing, P/N 1115058-B. This was made at the subcontractors' request to facilitate channel fabrication.

Six additional lifting holes were added to the Jacket Aft Flange, P/N 1114831-A to more evenly distribute lifting loads on the aft end of the nozzle.

A list of all Hastelloy X raw material requirements for the convectively cooled nozzle was prepared and transmitted to the material supplier to ensure raw stock availability.

Analysis to determine the effects on "U"-tube gas side wall temperatures (TWG) with reduced coolant discharge pressures of 880 psig and 855 psig for the rated nuclear case showed no significant change in TWG.

A study was begun to determine the coolant discharge state from the nozzle and the corresponding operating map for the range of conditions specified by LASL. These maps will be produced for the case of zero peripheral cooling and for the peripheral cooling specified in Revision "A" to the hydrodynamic State Diagram. During the course of this study, difficulty was encountered on several computer runs in that the program iteration procedure was unable to converge to a solution. After verifying that the problem was not due to input errors, a study was made of the heat transfer and fluid flow parameters of the computer runs which failed to converge to a solution. It was found that the characteristic common to these runs was the high accelerations and corresponding rapid static pressure drop that the coolant was experiencing ahead of the minimum tube flow area located at the geometric throat of the nozzle. As a result of the large pressure gradients experienced in these regions, a fairly rapid change in the heat transfer parameters was occurring over the station intervals normally utilized, indicating that the usual approximation in finite difference form of the differential was not sufficiently accurate. The program was modified by incorporating a subroutine for an automatic computation of additional stations when convergence does not occur. A number of checkout cases were run with this program modification and they demonstrated its effectiveness. This program modification study also indicated that, where convergence problems arise, these particular combinations of nozzle operating conditions are marginal or meaningless when the coolant discharge pressure falls below chamber pressure or fluid velocity exceeds Mach -1.

About 70% of the operating map with zero peripheral cooling was completed prior to encountering convergence difficulties. Computations are being made to complete these maps.

Thermal analysis for the nozzle/pressure vessel interface region with the revised AGC nuclear heating rates at nominal values and at 25% above nominal values were completed for assumed conditions of intimate contact and infinite resistance at the nozzle-pressure vessel interface. Predicted temperatures on the flange with 25% above nominal heating rates indicated a marginal condition prompting an analysis which is in progress to establish the temperature distribution in the nozzle flange when a cooling manifold is incorporated into the outer periphery of the flange.

b. Work Planned For the Next Quarter

Computations will be completed for the steady-state operating maps for the case of zero peripheral cooling and for the peripheral cooling specified in the hydrodynamic State Diagram.

Computations will be initiated to establish nozzle behavior during "scram" shutdown conditions provided by LASL.

The following drawings will be released:

Nozzle Assembly, Convectively Cooled	P/N 1114830
Coolant Inlet	P/N 1115349
Inlet Flange	P/N 1115350
End Covers (Nozzle, Protective)	P/N T-1015214

4. Fuel Film Cooled Nozzle

a. Work Performed During the Quarter

Final assembly drawing P/N 1115279 (see Figure 21), and the component part drawing P/N 1115950 (see Figure 22) were released.

The final report of the stress analysis was completed. It concludes that the nozzle is adequate to test at 900 psia chamber pressure for a ten cycle life.

The Modes of Failure Analysis was completed.

On 19 November, the Final Design Review meeting was held. The Method of Coolant injection was reviewed for the primary and secondary points. At the primary

Figure 21
 Nozzle, Fuel Film Cooled
 Sheet 1 of 2

Figure 21
Nozzle, Fuel Film Cooled
Sheet 2 of 2

Torus - Nozzle Uncooled

point (at the support flange) a knurled type of injection system will be used. At the secondary point a slot type of injection will be used. The design criteria, component design, layout, component BPL, fluid analysis, thermal analysis, stress analysis, modes of failure analysis, and the fabrication plan were reviewed.

A Fabrication Order was initiated on 22 November for purchase order placement. Two nozzles will be fabricated with machining scheduled to start the first week in December.

Refinements of previous thermal analyses were made. Analyses were confined to details of the primary and secondary film coolant injector points.

b. Work Planned For the Next Quarter

Surveillance of hardware procurement will be maintained.

5. Pressure Test Nozzle

a. Work Performed During the Quarter

The following drawings were released:

Nozzle Assembly, Pressure Test	P/N 1115307
Weldment	P/N 1115304
Cover Plate	P/N 1115354"A"
Contour Template I.D.	P/N T-1015213
Contour Template O.D.	P/N T-1015206

A basic parts list is shown in Figure 23.

A revision to the pressure test nozzle aft closure is being considered. This revision would eliminate the need for welding the aft closure plate by retaining the as-forged closure and machining to the desired configuration. Layout drawings for this modification are being prepared and coordinated with the forging subcontractor.

AGC 2-327 CC 87540-00661

Figure 23

Basic Parts List

The jacket and cover plate stress analysis was completed. Results indicated positive margins of safety in all areas.

b. Work Planned for the Next Quarter

The final design review will be delayed pending definition of test conditions, methods of loading, and support.

6. Multiorifice Injector

a. Work Performed During the Quarter

The final assembly drawing and drawings for all components parts were released. The following drawings were released. (Extracts from some of these drawings are shown in figures in parentheses).

Adapter Instrumentation	1115379	
Ring, Injector Baffle	1115483	(Figure 24)
Leg, Injector Baffle	1115484	
Injector Assembly Mach'd & Weld	1115309	(Figure 25)
Injector Assembly Brazed	1115310	(Figure 26)
Face Plates	1115482	
Leg Injector Baffle	1115458	(Figure 27)
Patter Orifice PUMT-1-1	1115192	
Tube, Coolant	1115193	
Final, Injector Assembly	1115311	(Figure 28)

A heat transfer analysis was completed. It predicts high face temperatures at the center of the injector and at the inside diameter of the 17th fuel ring. A comparison analysis of the NERVA injector was performed and predicts a higher temperature for NERVA than for Phoebus. A visual inspection of a recent NERVA firing shows the injector face (copper face plates and baffles) without erosion or hot spots.

The final Design Review meeting of the multiorifice injector was held on November 16.

Figure 24
 Ring, Injector Baffle

Figure 25
 Injector Assembly, Machined
 Sheet 1 of 3

CHANNEL NO.	B DIA	C DIA	D DEPTH
1	.400	1.400	.25
2	1.600	2.600	.29
3	2.800	3.800	.36
4	4.000	5.000	.44
5	5.200	6.200	.63
6	6.400	7.400	.59
7	7.600	8.600	.77
8	8.800	9.800	.77
9	10.000	11.000	1.26
10	11.200	12.200	.94
11	12.400	13.400	1.35
12	13.600	14.600	1.06
13	14.800	15.800	1.49
14	16.000	17.000	1.21
15	17.200	18.200	1.68
16	18.400	19.400	1.40

Figure 25
 Injector Assembly, Machined
 Sheet 3 of 3

Figure 26
 Injector Assembly, Braze

Figure 27
 Leg, Baffle - Injector

Injector Assembly

Figure 28

The following action items resulted from the Review meeting:

1. Establish combustion stability monitor (CSM) transducer location. The pie manifold instrumentation bosses now being readily accessible, the transducer will be installed on one of the pie manifold bosses.
2. Resolve whether Pc6 instrumentation bosses will be used instead of Pc5 bosses. Pc6 monitors chamber pressure at the center of the injector. Pc5 monitors chamber pressure at the 17th channel fuel ring. There is no significant difference in pressure readings between the two locations. Chamber pressure will be monitored at the Pc5 location.
3. Complete adapter-to-injector interface stress analysis. Preliminary stress analysis indicates excessive flange separation. This question will be resolved prior to the final design review on the Test Assembly.
4. Investigate use of lower mixture ratio by NERVA. Design personnel in charge of TCA and testing have already taken action on this request. This will also be resolved prior to the final design review on the Test Assembly.

The following subjects were presented and discussed in detail:

1. design criteria
2. layout drawing
3. basic parts list
4. fluid flow analysis
5. thermal analysis
6. stability analysis
7. stress analysis
8. fabrication

A two-dimensional, transient-state thermal analysis of the multiorifice injector design was performed. The analytical model was made from an axial, two-dimensional section through an oxidizer pie section. A similar analysis was performed for the NERVA injector (which is of similar design, with varying combustion efficiency at the injector face) to determine a realistic value to use in the Phoebus analysis.

b. Work Planned For the Next Quarter

Surveillance of hardware procurement will be maintained.

7. Coaxial Injector

a. Work Performed During the Quarter

All design drawings for the coaxial injector were released.

The element was redesigned to ensure a velocity ratio V_f/V_o of 15 at a conservative nominal adapter fuel discharge temperature. The original design assumed a maximum predicted fuel temperature whereas the new design is based upon a predicted nominal fuel temperature.

The intermediate and final design reviews were held. All action items resulting from the reviews were resolved. The minutes from the design reviews will be published as part of the design report now in preparation.

Design of a cylindrical film cooled baffle was begun (see Figure 29). The baffle will be designed, fabricated, and incorporated in S/N 2 injector, P/N 1115314.

A conduction heat transfer analysis of the injector was completed for utilization in stress analysis. Previous stress analyses assumed ambient temperatures whereas the final analysis considered the effect of temperature. This initial analysis is conservative in that it does not take into account increased material strength at reduced temperature.

A two-dimensional transient-state thermal analysis was performed for the coaxial injector design. The analysis was similar to the one performed for the multiorifice design except that no analysis was made of the face region.

b. Work Planned For the Next Quarter

Design of the baffled injector will be completed.

8. Adapter, Nozzle-to-Injector

a. Work Performed During the Quarter

The following drawings were released:

Adapter Assembly (Brazed)	B/P 1115468
Adapter Leg (Final Machine Uncooled Nozzle)	B/P 1115493

Figure 29
Phoebus-2 Co-Axial Injector
Cylindrical Baffle Installation

Adapter Leg (Final Machine Cooled Nozzle)	B/P 1115202
Torus	B/P 1115629
Torus Inlet	B/P 1115601
Splitter, Adapter Inlet	B/P 1115477
Tube Leg Spacer	B/P 1115862 (Tool Sketch)
Detective Spacer	B/P 1115856 (Tool Sketch)
Drive Blank	B/P 1115602 (Tool Sketch)

Stress analyses of the adapter, adapter-support structure were performed using the finite element computer code. These analyses show that stresses due to pressure and thrust loads (mechanical stress) are all in the elastic stress range of the material, and that thermal stresses plus mechanical stresses are within the allowable stress range for 100 cycles of operation as defined in Figure N-415 (B) of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels.

The relative deflection between the adapter and the nozzle skirt due to mechanical and thermal deflections is shown to be 0.064-in. The sealing capability of the seal is 0.040-in. The difference between the seal capability and the pressure and thermal deflections will be eliminated by "preloading" the test assembly. The "preloading" will be accomplished by machining the adapter leg to provide a compressive load at the adapter-nozzle skirt interface at assembly.

Two methods of restricting the axial deflection were studied. The first method consisted of a series of ribs attached to the adapter at the outer flange and at the secondary injector boss. An analytical geometrical representation of a non-axisymmetrical problem is quite difficult, but a suitable model was developed and analyzed. It was found that although the deflections were limited and the stresses were in the elastic range, the gap developed at the nozzle skirt-adapter interface (hereafter called the "seal gap") was beyond the sealing capability of the seal. Different rib sizes were analyzed and this system was found to be unsuitable.

The second method of support was a self-support type of system consisting of two conical shells and three rings. The outer shell is loaded in tension and the inner shell in compression as the system tends to deflect in the axial direction. The rings react the radial component of the shell loads. The original system utilized the inner support ring mounted to the secondary injector boss. A comparison of the ribbed support system analysis with the conical support system analysis showed that the latter system resulted in a smaller seal gap.

At this time the deflections from the computer runs were studied and plotted. Results showed that when the assembly was mounted to the test stand at the injector, the outer (and relatively massive) section of the adapter tended to rotate as a ring and that the rotation was a contributor to the seal gap. If the assembly could be mounted at the outer edge of the adapter, the seal gap would be minimized. The assembly was mounted at the forward support ring. The required load to restrain the system at this point is the thrust load developed.

Since the objective of the support structure is to restrain the relative axial motion between the adapter leg and the nozzle skirt-adapter interface, the final design has the inner support ring located as close as possible to the radial location of the nozzle skirt-adapter interface.

The final stress analysis will be performed by utilizing the PETS computer code. The resulting analysis is expected to verify the present analysis and will include the interface shear and moment loads at the adapter-injector, adapter-adapter leg, and adapter leg-nozzle flange interfaces. Since the adapter and adapter support are relatively massive, these interface loads will have little influence on the adapter stresses, but must be calculated in order to determine bolt torque requirements.

The stresses in the mechanical loading condition are in the elastic range for the 900 P_c case. The seal gaps for both the mechanical and thermal loading conditions are:

<u>Case</u>	<u>LOAD</u>		<u>DEFLECTION</u>		
	<u>Press</u>	<u>Thermal</u>	<u>Bolt</u>	<u>Seal</u>	<u>Net</u>
1	900 P _c	--	0.0187	-.00404	0.02274
1A	900 P _c	20 sec	0.0462	-.0178	0.0640

The net deflection in the combined loading case is still over the design limitation for the seal gap by .024-in. but this can be corrected by preloading the adapter leg.

The mounting block connecting the inner cone to the conical section of the adapter is under a high shear load which will be reacted by 140 shear pins and 22 bolts.

b. Work Planned For the Next Quarter

The final design review is scheduled. Completion of the stress and heat transfer analysis is scheduled. Stress analysis will be performed to determine the amount of preload required to seal at the seal gap.

9. Adapter Support

a. Work Performed During the Quarter

An intermediate design review was held on 8 September 1965. AISI 304L or 347 stainless steel were selected as acceptable materials of fabrication for the adapter support. Two conical adapter support configurations were analysed and are shown in Figures 30 and 31, respectively. The configuration shown in Figure 31 was selected. The adapter support will be used as the thrust structure in that the test assembly will be mounted to the test stand structure by attachment at the center ring of the adapter support.

Stress analysis of the adapter-support is discussed in the preceeding test under the topic Adapter, Nozzle-to-Injector.

b. Work Planned for the Next Quarter

Surveillance of hardware procurement will continue.

Figure 30
 Original
 Support-Adapter Assembly
 Sheet 1 of 2

SECTION 13-13
2 PLACES

SECTION A-A

DETAIL C

Figure 30
Original
Support-Adapter Assembly
Sheet 2 of 2

Figure 31
 Final
 Support-Adapter Assembly
 Sheet 1 of 2

SECTION A-A

SECTION B-B
 2 PLACES
 180° APART

VIEW D

VIEW E
 4 PLACES

Figure 31
 Final
 Support-Adaptor Assembly
 Sheet 2 of 2

10. Test Assembly

a. Work Performed During the Quarter

Chemical Simulation Test Plan, Report No. RP-TR-0005 is released.

The first draft of the Chemical Test Specification was prepared.

Drawing 1114175, Propellant Line Strainer, is released.

b. Work Planned for the Next Quarter

Test assembly drawings for both film-cooled and convection cooled nozzles will be released.

A chemical test specification and a test request for the film-cooled nozzle test series will be published.

Stress analysis of all test assembly interfaces and fasteners will be completed and a final design review will be held.

11. Test Assembly Lines

a. Work Performed During the Quarter

All test assembly line drawings were completed. The materials selected for the lines are Hastelloy C for the 6 and 8-in.-nominal size pipe lines and 304L for the 1.5-in.-nominal size pipe lines. Rod restrained bellows were selected for use in the 6 and 8-in.-nominal size pipe lines to obtain the maximum degree of movement in the minimum space. Figures 32 through 40 depict line component relationships and configurations.

The flange design and seal selection was developed to permit the use of E-ring seals (prime) and Flexitallic (back-up). The drawings required were released.

The preliminary basic parts lists appear as Figures 41 through 48.

b. Work Planned for the Next Quarter

The tolerance study of both fuel systems (film and convectively cooled) will continue. Data resulting from this study will be used in the preparation of assembly instructions and stress analysis. Fluid analysis will continue to determine the ullage affects on the convectively cooled nozzle. Pressure drop calculations will be upgraded and specifically related to the current nozzle test parameters. A final design review will be held.

Figure 32
 Line Assembly Components

Figure 33
 Line Assembly Components

7

Figure 34
 Line Oxidizer - Injector Inlet
 P/N 1115645

Figure 35
 Adapter Fuel Inlet
 Dwg No. 1115454-9

Figure 36
 Line, Coolant-Nozzle Inlet
 P/N 1115456-9

Figure 37
 Line, Coolant-Dump
 P/N 1115453-9

Figure 38
 6-in. Adjustable Joint Assembly
 P/N 1115495

Figure 39
 Fuel Film Supply Coolant Line

Figure 40

Line, Coolant Film
P/N 1115748
Matl: CRES 304L

BASIC PARTS LIST											DRAWING NO. 1115454		
											SHEET 1 OF 1		
LET.	DATE	REVISION	BY	CHKD	TITLE								
					LINE, FUEL - INLET ADAPTER
					AEROJET-GENERAL CORPORATION <small>TORRANCE, CALIFORNIA</small>				DRAWN		DATE		
									CHECKED				
									APPROVED				
SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME		NO. REQ'D	SYM	IDENT CODE
E	1115454		x						Line, Fuel - Inlet Adapter		1		
	-1		x						Flange - 6.00 IPS 900# Small Groove Face, 6.000 Bore CRES304L		1		
	-3		x						Pipe - 6.00 IPS Sch 40S Hastelloy "C"		1		
	-5		x						Pipe - 6.00 IPS Sch 40S Hastelloy C		1		
	-7		x						Elbow - 6.00 IPS 90° Long, R .313 Wall Hastelloy C		1		
	-11		x						Elbow - 6.00 IPS 90° Long, R .313 Wall Hastelloy C		1		
	-13		x						Pipe - 2.00 IPS Sch 40S CRES 304L		1		
	-15		x						Elbow - 2.00 IPS 90° Long, R Sch 40S CRES 304L		1		
E	1115495-19		x						Bellows		1	SCD	
E	1115499-27		x						Flange		1		
	2-GR-20		x						Hub - 2.067 Bore - CRES 304L		1	V	14713
	EC 1252		x						Anti - Tamper Sealer		AR	V	04633
			x						Weld Rod - ERN-7C		AR		
			x						Weld Rod - Hastelloy W		AR		
			x						Weld Rod AISI 308 etc		AR		

Figure 41

Basic Parts List

Figure 42

Basic Parts List

BASIC PARTS LIST											DRAWING NO. 1115453-9		
											SHEET 1 OF 1		
LET.	DATE	REVISION	BY	CHKD	TITLE								
					LINE - COOLANT DUMP
					AEROJET-GENERAL CORPORATION <small>10000 WILSON AVENUE, TORRANCE, CALIF. 90503</small>							DRAWN	DATE
												CHECKED	
												APPROVED	
SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D			
E	1115453-0	x							Line - Coolant Dump	1			
	-1		x						Pipe - 8.00, Sch 10S NPS Hastelloy "C"	1			
	-3		x						Pipe " " "	1			
	-5		x						Pipe " " "	1			
	-7		x						Pipe " " "	1			
	-11		x						Elbow - 8.00, Sch 10S, NPS, 90° L.R., Hastelloy "C"	2			
	-13		x						Boss - .875 Dia. Bar Hastelloy "C"	3			
	-15		x						Hub - Alter from 8-GR-82	1		14713	
D	1013605-3	x							Flange	1			
E	1115495-29	x							Bellows	1	SCD		
	AN806-S4	x							Plug	3			
	AS1119J1-4	x							Gasket	3			
	EC1252	x							Anti-Tamper Sealer	AR	V	04633	
		x							Weld Rod - ERN-7C	AR	B		
		x							Weld Rod, Hastelloy "W"	AR	B		

Figure 43

Basic Parts List

BASIC PARTS LIST										DRAWING NO. 1115645-9	
										SHEET	OF
LET.	DATE	REVISION	BY	CKD	TITLE						
					LINE, OXIDIZER - INLET INJECTOR
					AEROJET-GENERAL CORPORATION					DRAWN	DATE
										CHECKED	
										APPROVED	
SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D.	
E	1115645-9	1							Line, Oxidizer - Inlet Injector	1	
	-1		x						Flange - 6.00, 900# WNF- 6.065 Bore, CRES 304L	1	
	-3		x						Pipe - 6.00 Sch 40 NPS Hastelloy "C"	1	
	-5		x						Elbow - 6.00, 90°, L.R. Sch 40 NPS, Hastelloy "C"	1	
	-7 & -11		x						Elbow - 6.00, 90°, LT, LR Sch 40 NPS, Hast. C, (-7 & -11 made 1 from 1 elbow)	1	
	-13		x						Pipe - 2.00 Sch 40 NPS, CRES 304L	1	
E	1115495-19		x						Bellows	1	SCD
E	1115499-27		x						Flange	1	
	2-GR-20		x						Hub - CRES 304L	1	V 14713
	EC 1252		x						Anti-Tamper Sealer	AR	V 04633
			x						Weld Rod ERN-7C	AR	
			x						Weld Rod Hastelloy W	AR	
			x						Weld Rod AISI 308 B1C	AR	

Figure 44

Basic Parts List

AGC 2-327 CC 87540-00661

Basic Parts List

BASIC PARTS LIST											DRAWING NO. 1115748	
											SHEET 1	OF 1
LET.	DATE	REVISION	BY	CK'D	TITLE LINE, COOLANT - FILM
					AEROJET-GENERAL CORPORATION						DRAWN	DATE
											CHECKED	
											APPROVED	
SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D		
E	1115748-9		x						Line, Coolant Film	1		
D	1115749-1		x						Venturi	1		
	1115749-3			x					Body 2.00 dia Bar CRES 304L	1		
	1115749-5			x					Boss .875 dia Bar CRES 304L	3		
				x					Weld Rod AISI 308 Elc	AR		
	1115748-1		x						Reducer 2.000 O.D. Bar CRES 304L	1		
	1115748-3		x						Tube 1.500 O.D. x .120 Wall CRES/ 304L	1		
	1115748-5		x						Pipe 1.50 Sch 10S NPS CRES 304L	1		
	1115748-7		x						Pipe " " " " " "	1		
	1115748-11		x						Pipe " " " " " "	1		
	1115748-13		x						Pipe " " " " " "	1		
	1115748-15		x						Elbow CRES 304L Elbow 1.50-90° Sch 10S NPS Long R/	2		
	AN806-S4		x						Plug	3		
	AN818-24C		x						Nut	1		
	AN818-32C		x						Nut	1		
	MS20819-24C		x						Sleeve	1		
	MS20819-32C		x						Sleeve	1		
	AS1119J1-4		x						Gasket	3		
			x						Weld Rod AISI 308 Elc	AR		

Figure 46

Basic Parts List

AGC 2-327 CC 87540-00661

Basic Parts List

BASIC PARTS LIST										DRAWING NO. 1115752-9		SHEET 1 OF 1			
LET.	DATE	REVISION	BY	CKD	TITLE										
					LINE, COOLANT - FUEL FILM SUPPLY
					AEROJET-GENERAL CORPORATION					DRAWN		DATE			
										CHECKED					
										APPROVED					
SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME				NO. REQ'D.		
E	1115752-9		x						Line, Coolant - Fuel Film Supply				1		
	-1		x						Pipe, 1.50 Nom Pipe Size Sch 10S GRES 304L				1		
	-3		x						Pipe - 1.50 Nom. Pipe Size - Sch 10S GRES 304L				1		
	-5		x						Pipe - 1.50 Nom. Pipe Size - Sch 10S GRES 304L				1		
	-7		x						Elbow - 90° Sch 10S Long Radius 1.50 GRES 304L				2		
E	1115499-37		x						Flange				1		
D	1115749-1		x						Venturi				1		
	-3			x					Body, 2.00 dia Bar GRES 304L				1		
	-5			x					Boss, .875 dia Bar GRES 304L				3		
				x					Weld Rod AISI 308 F1a				AR		
	AN806-84		x						Plug				3		
AN	AN818-32C		x						Nut				1		
	MS20819-32C		x						Sleeve				1		
	AS1119J1-4		x						Gasket				3		
			x						Weld Rod AISI 308 E1c				AR		

12. Materials Program

a. Material Design Properties of Hastelloy X

(1) Work Performed During the Quarter

(a) Summary

All data obtained during this quarter were representative of the first forged rings, Heat X5-2718EE, which were procured to AMS 5754. Only the tensile properties (i.e., ultimate tensile, yield strength, % elongation, % RA, and stress-strain curves) were obtained as a result of the deficiencies observed in the properties of the ring forgings. It was concluded that the total integrated hot work reduction experienced during the process of fabrication of the rings was approximately one half that of the nozzle forgings, and was insufficient to provide microstructural homogeneity comparable with wrought Hastelloy X. On the basis of the first results, a request was made of the forging vendor (Viking Forge) to increase the forging reduction during the early stages of hot working, to reduce the anisotropy problem, and to provide a more representative forged ring. The vendor agreed and added another stage of cross-forging prior to ring rolling. The improved forgings, Heats No. 261-5-4000 and 261-5-4001, were completed and delivered in November.

The data developed from the first heat (X5-2718), as listed below, were not considered representative and therefore were not recommended for use for design values as originally planned. The observed effects of heat treatment prior to the braze cycles appear useful but must be confirmed on more representative heats. The two heats received

in November, No. 261-5-4000 and 261-5-4001, are preferred for determination of the design values. The latter forgings are believed to be metallurgically more representative of the actual nozzle forgings within the limitations of the ring-roll forgings as simulation of the nozzle parts.

No data were obtained on the 0.012-in. thick Hastelloy X strip. This material was received in late November and passed the receiving inspection requirements at the end of November.

(b) Test Plan

The materials design data task was planned to provide the Phoebus-2 project with representative data for Hastelloy X forgings for the entire temperature range to be experienced in service. Despite the many years of experience with this alloy, only limited data were available on the tensile properties of heavy forgings such as those required by Phoebus-2. There was also a deficiency of data on the effects of heat treatment as generated by the brazing cycle, which must be the last thermal treatment on the nozzle prior to service. These factors, in addition to the consumable electrode vacuum melting required for the Phoebus material, introduced substantial process changes that were not defined by available data. A list of the required types of data and the available data are shown on Table 5.

The manufacturing process for the 0.012-in. strip should closely resemble that of thin sheet used widely in the past 10 years. However, the properties of the same material after the three braze cycles were not defineable by available data. The braze heat treatment results

Table 5
Design Data Determination

DATA REQUIRED BY PHOEBUS - 2

1. TENSILE YIELD-RA, % E (UNIFORM & TOTAL), SHEAR & COMPRESSIVE STRENGTH
2. TEMPERATURE RANGE - 423 TO 1200°F (JACKET FORGINGS)
3. TEMPERATURE RANGE - 423 TO 1800°F (CHANNEL STRIP)
4. LOW CYCLE THERMAL FATIGUE
5. BI-AXIAL PLASTIC STRAIN ENDURANCE DATA
6. PHYSICAL PROPERTIES RELATIVE TO THERMAL STRESS
7. EFFECTS OF THERMAL CYCLING (BRAZING) THRU TEMPERATURE RANGE
OF 1200°F TO 1800°F

DATA AVAILABLE

1. COMMERCIAL DATA ON SHEET, BAR, WIRE AND PLATE FROM ROOM TEMPERATURE
TO 1800°F
2. NO CRYOGENIC DATA EXCEPT A FEW UTS VALUES AT -320°F
3. NO DATA ON HEAVY FORGING, STRIP OR SHEET AFTER SLOW COOLING FROM 1800°F
4. ONLY AIR MELTED, AS SOLUTION HEAT TREATED DATA

in partial hardening (precipitation) effects which reduces the elongation and reduction of area values, as well as increase the yield values to a lesser degree. The design properties task shown in Table 6 was planned to evaluate the effects of the process variables (brazing) and provide representative and design values for thin strip.

The test plan for all the mechanical tests for forgings is summarized in Table 7. Only the tests indicated for all three heats on Table 7 were performed on the first heat, X5-2718EE. The sampling plan for evaluating the ring forgings is illustrated in Figure 49. Round tensile specimen were cut in the tangential, axial, and short transverse directions. The R-1 specimens (see Figure 50) were required at all temperatures except -423°F; namely -320, -110, RT, 400, and 1200°F, while the R-3 specimens (see Figure 51) were planned for at -423, -320, RT, and 1200°F. The R-3 tensiles are the only specimens that can be tested with existing equipment at -423°F, and this size will also be taken from the actual nozzle forgings. The R-3 specimens were taken from the axial and short transverse directions of the rolled rings.

In the first forging (Heat X5-2718EE), smaller R-4 specimens were used in the short transverse direction in place of R-3, since the thickness of the ring was under 3 in. In the new heats of Hastelloy X plans call for R-3 specimens in both the tangential and short transverse direction in addition to the axial direction. The tangential direction is regarded as most significant to the design requirements and will be more completely evaluated in the future forgings.

Table 6
Material Design Properties - Thin Strip

<u>CONDITIONS</u>		<u>PROPERTIES</u>	<u>ALLOY HEATS</u>	<u>SPECIMENS</u>
<u>HEAT TREAT</u>	<u>TEMPERATURES</u>	<u>MECHANICAL</u>		
SIMULATE	- 423°F	TENSILE ⁽¹⁾	3. HEATS	63
BRAZE	- 320°F	NOTCH TENSILE		30
CYCLES	- 100°F			
	R. T.	SHEAR	1 HEAT	40
	1200°F	COMPRESSIVE		
	1600°F			
	1800°F			
			TOTAL	133

(1) TENSILE PROPERTIES:

$F_{tw}, F_{ty}, e, RA, e_{uniform}, E_{static}, \text{HARDNESS } R_c, \text{ STRESS/STRAIN DIAGRAM}$

(2) COMPRESSIVE - F_{cy}, F_{bru} (USE 0.050" SHEET)

<u>Conditions</u> ⁽³⁾		<u>Properties</u>	<u>Alloy Heats</u>	<u>Specimens</u>
<u>Direction</u>	<u>Temperature</u>	<u>Mechanical</u>		
Axial	-423°F	Tensile ⁽¹⁾	3 Heats	90
	-320°			
	-100°	Notch Tensile		81
	R.T.		1 Heat	
	400°	Shear		30
	1200°	Compressive ⁽²⁾		
Tangential	R.T.	Tensile	3 Heats	54
	-320°	Notch Tensile		
	1200°			
Short	R.T.	Tensile		12
Transverse				
Selected	R.T.	Tensile		12
Locations				
Welded Specimens	-423°	Tensile	2 Filler Wires	45
	-320°			
	-100°			
	R.T.	Notch Tensile	2 Heats	30
	1200°			
Brazed	R.T.	Shear		18
Specimens				
Total				372

(1) Tensile Properties include:

F_{tu} , F_{ty} , e , RA , $e_{uniform}$, E_{static} , HARDNESS Rc, STRESS/STRAIN DIAGRAM

(2) Compressive = F_{cy} , and F_{bru}

(3) Heat Treat to Simulate Braze Cycles (All Specimens)

Table 7
Design Properties - Ring Forging Test Plan

HASTELLOY X RING FORGING
 23" OD, 3" WALL, 6" LONG

SECTION A-A

TANGENTIAL R-1 TENSILE
 SPECIMENS

9 - DWG 1114843
 9 - DWG 1114845

SEGMENT #2

AXIAL R-1 TENSILE
 SPECIMENS

15 - DWG 1114843

SECTION B-B

AXIAL R-3 TENSILE.
 SPECIMENS

20 - DWG 1114844

SECTION C-C

SHORT TRANSVERSE -
 R-4 SPECIMENS

4 - DWG 1114842

Figure 49

Design Properties - Hastelloy X Forging

Figure 50
Round R-1 Tensile Specimen

Figure 51
Round R-3 Tensile Specimen

The notch tensiles, see Figure 52, were made from each orientation and location as the comparable smooth tensiles. Both the R-1-N and R-3-N specimens were designed for a stress concentration factor of $K_t = 6.3$.

(c) Test Results

The tensile tests were performed on the ring forged by Viking Forge and Steel Company (Heat X5-2718EN). The ring was received in the solution heat treated condition, (2150°F/one hour/water quenched) and was then re-heat treated by exposure to three braze cycles.

The reference Braze Cycles used on the first forging were as follows:

- 1st Cycle - Heat up to 1825°F - 7 $\frac{1}{2}$ hours
Hold at 1825°F $\pm$ 20°F - 1 hour
Furnace cool 58°F per hour to 950°F - 14 $\frac{1}{2}$ hours
- 2nd Cycle - Heat from 950°F to 1800°F - 7 hours
Hold at 1800°F $\pm$ 20°F - 1 hour
Furnace cool 56°F/hour to 950°F - 15 $\frac{1}{2}$ hours
- 3rd Cycle - Heat up 1775°F - 7 hours
Hold at 1775°F $\pm$ 20°F - 1 hour
Furnace cool 58°F/hour to 950°F - 14 hours
Air cool to room temperature - 2 hours

The tensile test data obtained from the first ring forging (Heat X5-2718EN) are summarized in Table 8. The observed anisotropy is evident primarily with the ultimate tensile strength, elongation,

Figure 52
 Tensile Specimen
 Round R-1-N and R-3-N

Table 8

TENSILE PROPERTIES--HASTELLOY X FORGED RING, HEAT X5-2718EE*
(ALL STRESS VALUES IN ksi)
(HEAT TREATED THROUGH THREE BRAZE CYCLES)

TYPE OF SPECIMEN		TEST TEMP	ID OF RING				CENTER OF RING				OD OF RING			
ORIENTATION	SIZE	F	UTS	YS	%E	%RA	UTS	YS	%E	%RA	UTS	YS	%E	%RA
AXIAL	R 3	-423	140	92	5.2	6.0	124	88	6.4	10.0	128	89	7.1	6.0
AXIAL	R 3	-320	120	72	8.0	10.1	116	74	7.5	10.9	—	—	—	—
AXIAL	R-1	-320	118	75	8.8	8.2	126	77	9.6	8.4	149	78	18.6	16.0
TANGENTIAL	R-1	-320	146	74	19	17	150	74	21.6	19.0	148	73	18.7	16.4
AXIAL	R 1	-110	99	54	*	9.9	129	55	10.5*	10.6	106	57	26	23
AXIAL	R 1	RT	89	46	11.0	11.6	92	46	11.1	*	112	46	27.8	23.8
AXIAL	R-1	RT	88	45	10.8	11.2	93	45	13.4	15.7	113	47	26.0	22.8
TANGENTIAL	R-1	RT	109	46	22.0	23.0	109	45	26.5	24.2	112	46	29	25.6
AXIAL	R 3	RT	94	49	12.3	14.0	96	49	13.5	13.8	—	—	—	—
SHORT TRANSVERSE	R-4	RT	—	—	—	—	114	47	27	30	—	—	—	—
SHORT TRANSVERSE	R-4	RT	—	—	—	—	107	47	21	19	—	—	—	—
SHORT TRANSVERSE	R 4	RT	—	—	—	—	91	46	12	15	—	—	—	—
SHORT TRANSVERSE	R-4	RT	—	—	—	—	112	46	27	32	—	—	—	—
AXIAL	R-1	400°F	79	38	10.5	12.0	85	37	13.5	14.2	101	38	27.5	24.9
AXIAL	R 1	1200°F	80	30	19.0	20.0	—	—	—	—	88	30	38.0	34.6
AXIAL	R 1	1200°F	80	30	18.5	20.0	84	29	25.0	24.5	88	30	40.0	38
TANGENTIAL	R-1	1200°F	85	32	46.5	41.8	84	29	43	43	87	30	42.5	39.4
AXIAL	R-3	1200°F	71	26	35	31	71	26	47	38	73	—	52	44

* PROCURED TO AMS 5754

and reduction in area values and originated with inadequate hot forging and the presence of the M_6C (Prime) phase. Improved hot working and/or long time thermal diffusion treatment will reduce or eliminate the M_6C (Prime) phase; therefore, the subsequent forgings procured from Viking Forge were cross-forged prior to ring rolling to approximately double the amount of hot work imparted to Heat No. X5-2718EE. The low values of the elongation from the inside diameter portion of the ring, compared to the central and outer diameter portions, further demonstrate the variance possible with inadequate hot working. Ring rolling imparts a higher degree of work on the outside diameter where the test values (Note: Axial -OD specimens in Table 8) were representative of properly worked Hastelloy X. Examination of specimens from the central and inside diameter areas demonstrated in-homogeneity in the form of the M_6C (Prime) phase which forms brittle planes throughout the forging. The tangential specimens were less affected by the in-homogeneity than the axial specimens with the exception of axial specimens near the OD of the ring where they were essentially the same (see Figures 53 and 54).

Note that the yield stress values were not greatly affected by the specimen orientation or the location within the ring, as shown in Figure 55. These data suggest that the in-homogeneity did not alter the elastic properties but induced premature failure after substantial plastic deformation had occurred.

The yield stress values at elevated temperatures fall progressively below the typical values for Hastelloy X, as shown in Figure 55. This is believed to be related to the heavy section (3 inch) of the ring further aggravated by the minimal hot working and forging reduction achieved in this first Hastelloy X heat.

ULTIMATE TENSILE STRENGTH HASTELLOY X FORGED RING, HEAT X5-2718EE
 AFTER THREE BRAZE CYCLES

Figure 53
 Ultimate Tensile Strength, Hastelloy X Forged Ring

% ELONGATION VALUES FROM HASTELLOY X FORGED RING, HEAT X5-2718EE
 AFTER HEAT TREATING THREE BRAZE CYCLES
 ROUND (R1) TENSILES EXCEPT AT -423°F (R-3)

Figure 54
 % Elongation Values from Hastelloy X Forged Ring

0.2% YIELD STRENGTH VS TEMPERATURE--HASTELLOY X FORGED RING, HEAT X5-2718EE
AFTER THREE BRAZE CYCLES--ALL SPECIMENS R-1 EXCEPT AT -423°F WHICH WERE R-3

Figure 55
0.2% Yield Strength vs Temperature, Hastelloy X Forged Ring

The influence of several heat treatments on in-homogeneity and on the mechanical properties was determined on tensile specimens that were re-solution heat treated for a long time at 2150°F (see Table 9). Significant improvement in tensile ductility occurred with the improved homogeneity resulting from the high temperature diffusion.

The notch tensile strength data from the same forged ring (Heat X5-2718EE) are shown in Table 10. The effect of specimen location and orientation was less pronounced for the notched tensiles than for the unnotched specimens.

(2) Work Planned for the Next Quarter

Testing will be initiated on two ring forgings and 0.012 strip material.

Table 9
Effects of Various Heat Treatments on Hastelloy X
(Heat X5-2718 EE)

<u>Specimen Type</u>	<u>Max Temp, °F</u>	<u>Approx Cooling Rate, °F/sec</u>	<u>Ultimate Ten-sile Strength, ksi</u>	<u>0.2% Yield Strength, ksi</u>	<u>Elastic Limit, ksi</u>	<u>Elongation, %</u>	<u>RA, %</u>
Tangential	2150	1000	100	45	8	55	66
Axial (center)	2150	1000	101	43	8	51.5	50
Tangential	1910	17	107	45.5	28	40	50
Tangential	1910	2	108	44.5	28	40	42
Tangential	1750	15	109	46.2	28	37.5	38

EFFECTS OF PRIOR HEAT TREATMENT ON PROPERTIES AFTER 3 BRAZE CYCLES*

<u>Specimen Type</u>	<u>Prior Heat Treat, °F</u>	<u>Time, hr</u>	<u>Approx Cooling Rate, °F/sec</u>	<u>Ultimate Ten-sile Strength, ksi</u>	<u>0.2% Yield Strength, ksi</u>	<u>Elastic Limit, ksi</u>	<u>Elongation, %</u>	<u>RA, %</u>
R-1 Tangential (Avg of 2 spec)	1910	3	2	109	43.5	28	32	30
R-1 Tangential	2150	8	1000	108	45	--	26.5	24
R-1 Axial, OD	2150	8	1000	103	44	28	24	19
R-1 Axial, ID	2150	8	1000	87.4	43.5	28	14.6	14.2
R-3 Axial, ID	2150	6	1000	100	49	--	14.5	16.8
R-1 Axial, ID	Not Re-Heat Treated (for comparison)			89	46	--	11.0	11.6
R-1 Axial OD	"			112	46	--	27	23

* NOTE: Braze cycles for this test were: 1830°F/cool 75°F/hr to 1000°F, 1800°F/cool 100°F/hr to 1000°F, and 1780°F/cool 100°F/hr to 975°F (all in hydrogen).

Table 10
Notched Tensile Data for Hastelloy X Heat X5-2718EE

Specimen		Test Tempera- ture (°F)	Location in Forged Ring Notch Tensile Strength (ksi)		OD
<u>Orientation</u>	<u>Size</u>		<u>ID</u>	<u>Central</u>	
Axial	R-3N	-423	150 (140)	149 (124)	154 (128)
Axial	R-3N	-320	128 (120)	124 (116)	138
Axial	R-3N	R.T.	99 (94)	94 (96)	115
Axial	R-1N	-320	117 (118)	130 (126)	131 (149)
Axial	R-1N	-110	90 (99)	107 (129)	113 (106)
Axial	R-1N	RT	89, 91 (88.5)	97 (92.5)	101 (112.5)
Axial	R-1N	400	77 (79)	86 (85)	93 (101)
Axial	R-1N	1200	77 (80)	80	84 (88)
Axial	R-1N	1200	71 (80)	79 (84)	83 (88)
Tangential	R-1N	-320	130 (146)	130 (150)	138 (148)
Tangential	R-1N	RT	101 (109)	101 (109)	102 (112)
Tangential	R-1N	1200	81 (85)	84 (84)	86 (87)

Numbers () are corresponding unnotched tensile strength values.

(d) DISCUSSION

The tensile data for Hastelloy X Heat No. X5-2718EE, as shown in Table 8 , further illustrates the elongation values previously reported(RP-MR -0005)for the forged ring. The room temperature elongation values and reduction of area were as low as 11% for the axial specimens after the braze cycle heat treatment.

Further examination of the results in Table 8, reveals variation of properties at selected locations and orientations within the forging. The elongation and reduction of area values as indicated for the room temperature axial specimens from the ID were less than half the values shown for the OD. Such variations are clearly outside the normal property variations for this nickel-base alloy forging. The yield strengths (Figure 55) and the elastic properties did not show significant anisotropy or variation with the radial location.

Metallographic examinations of the ring forging, Heat X5-2718EE, and of one tensile specimen which had shown only 11% elongation at room temperature were performed. The as-received forging (solution heat treated 2150°F water quenched) exhibited an unexpected large amount of a second phase that appeared to be carbides. Figure 56 shows the large grouping of carbides, identified as M_6C prime carbides, which are carried over from the original ingot. (The carbon analysis was rechecked and found to be normal, namely 0.07%.) Further repeated solution heat treatment at 2150°F dissolved the grain boundary carbides, but had only a slight effect on the M_6C prime phase.

Hastelloy X, Heat X5-2718
M₆C prime carbides retained
from original ingot formed
brittle planes oriented
transverse to the axial
specimens (untested)

100X

Schantz Etch

Figure 56
Hastelloy X Grain Structure

Visual examination of the tested axial specimen having only 11% elongation at room temperature, revealed a wide distribution of fine cracks, such as shown in Figure 57. The microstructure of the same specimen demonstrated that the internal cracks were due to the brittleness of the M_6C prime phase, as shown in Figure 58. The fracture surface contained fractured grains of the prime phase, while the grain boundary carbides generated by the brazing cycle were not fractured. The losses in elongation and ultimate tensile values were obvious in view of the extensive fracturing within the prime phase, as shown in Figure 58. The internal microcracks were apparent where elongation during testing amounted to about 10% or more; however, the elastic portion of the stress strain curves (Figure 59) and the yield strength were not altered significantly by the M_6C prime phase. Information available from Union Carbide and Haynes Stellite indicated that the M_6C prime phase is normally eliminated in the hot working and forging operations prior to fabricating finished forms. The control of this phase should be assured by more hot working of the ingot and more heating time above 2150°F in the early stages of conversion.

The influence of various stress relieving cycles as well as long solution heat treatment on this ring forging, prior to the brazing cycle, was determined. Previously, it was indicated that the M_6C prime phase did not cause a substantial effect when the alloy was solution heat treated and water quenched. This was confirmed by the specimen having 55% elongation (Table 9) and it still retained some M_6C prime.

Axial (center) tensile
specimen (XA-49) ruptured
outside gage marks after
11% elongation.

NOTE: Numerous fine cracks
not associated with
any localized condition.

10X

Unetched

Figure 57
Axial Tensile Specimen After Elongation

Fracture surface of tensile specimen (XA-49) showing partly intergranular fracture at room temperature.

NOTE: Areas of M_6C prime phase along fracture surface.

500X Glyceregia Etch

Internal cracks in specimen (XA-49) were associated with planes which were rich in M_6C prime phase.

500X Glyceregia Etch

M_6C prime phase exhibited numerous cracks in areas where the grain boundary carbide did not develop cracks.

1000X Glyceregia Etch

Figure 58
 M_6C Prime Phase Etched Specimens

Figure 59

Elastic and Plastic Properties of Hastelloy X

Tests on the effect of stress relieving at 1900^oF were made since no data were found for this condition. Evaluation of the effect of stress relieving at 1900^oF followed by the three brazing cycles were also required. Heat treatment evaluation employed the tangential specimens in all cases except where the axial specimens were specifically required.

The results shown in Table 9 indicate that the stress relieving at 1910^oF had the effect of increasing the ultimate strength slightly and reducing the elongation from about 55% down to 40%. There was no apparent effect due to the difference in cooling rates from the 1910^oF stress-relieving temperature. Stress relieving (1910^oF) prior to brazing appeared to produce better ductility than the 2150^oF/water quench treatment exposed to the same braze cycle. The elongation after stress relieving at 1910^oF was 40% and the three braze cycles lowered this to 32%. In all other cases where three braze cycles were used the elongation fell below 30%.

The improved elongation values for the axial ID specimens that were solution heat treated for eight hours prior to the braze heat treatment were significant while the axial OD specimen was not improved.

It is concluded that the heat treatment procedures may be revised to enhance ductility, but no firm conclusions are justified until a better, homogeneous heat is employed for evaluation. The M₆C prime phase should be greatly diminished in future heats to minimize the apparent anisotropy.

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TASK K - FABRICATION

1. Convectively Cooled Nozzle

a. Work Performed During the Quarter

Nozzle forging die blocks for the convergent and divergent sections were completed.

Cylindrical section forging P/N 1114856-13 is completed and ready for shipment to AGC.

Convergent section P/N 1114856-7 is being ultrasonic inspected prior to shipment. A detail discussion of nozzle forging progress is included in the materials fabrication section of this report.

An order for 400 lbs of 0.06-in.-dia Hastelloy X weld wire, and 100 lbs of 0.045-in.-dia weld wire was initiated.

Work on dissimilar metal weld evaluation is suspended due to lack of Hastelloy X material, which is on order.

Fabrication orders on the following components were initiated:

Bolt Coolant Line Assembly	P/N 1115344
Venturi Meter	P/N 1115346
Instrumentation Boss	P/N 1115347-5
Adapter Bolt Coolant Line	P/N 1115380
Nozzle Torus	P/N 1115335-A
Holding Fixture	P/N T-1015209-A
Access Platform	P/N T-1015222
Weldment	P/N 1114857

b. Work Planned for the Next Quarter

Fabrication orders will be issued on the following components.

Coolant Inlet	P/N 1115349
Inlet Flange	P/N 1115350
Handling Brackets	P/N 1115343
Manifold Bolt Coolant	P/N 1115205
Adapter-Bolt Coolant	P/N 1115805
Jacket Machining	P/N 1114831

2. Fuel Film Cooled Nozzle

a. Work Performed During the Quarter

The first fuel film cooled nozzle forging was completed through the 1013602 level and is scheduled for delivery to machining source for final machining.

The second forging is approximately three weeks behind the first forging.

The samples for evaluating the fabrication and hydraulics of the film cooling injection system were completed. From these evaluations tooling design and fabrication were initiated for the rolling and knurling tools.

b. Work Planned for the Next Quarter

Complete fabrication of 2 each fuel film cooled nozzles P/N 1115279.

3. Pressure Test Nozzle

a. Work Performed During the Quarter

Completed fabrication of I.D. and O.D. contour templates.

An order for cover plat P/N 1115354 was placed in the event that the as forged closure is not feasible.

b. Work Planned for the Next Quarter

Completion of nozzle forging operation and initiation of final machining.

4. Multi-Orifice Injector

a. Work Performed During the Quarter

The first multi-orifice injector is due for completion early in the next report period. No major problems have been encountered in fabrication.

The second injector is approximately four weeks behind the first injector.

All the component parts for both injectors have been fabricated except for the leg baffles for the second injector which are in rework at the present time.

b. Work Planned for the Next Quarter

Fabrication of one injector will be completed.

5. Co-axial Injector

a. Work Performed During the Quarter

All components for the injector were ordered. An order was issued for the final assembly, 1115321-9.

Work has been initiated on the final machine of the dome, 1115315-9.

Rough machine of the plate, 1115084, was completed and the braze assembly, 1115313, was initiated.

Fabrication on all other components was initiated.

b. Work Planned for the Next Quarter

The first co-axial injector will be completed.

The second injector with baffle will also be completed.

6. Adapter, Nozzle-to-Injector

a. Work Performed During the Quarter

Adapter S/N 880698 completed forging, rough machining, ultrasonic inspection, contour machining, grooving and all prebraze machine work. Adapter S/N 880699 completed forging, rough machining, ultrasonic inspection, contour machining and grooving.

Adapter leg S/N 880609 has been cast, preliminary ultrasonic inspected, soaked, ring forged, rough machined, heat treated and ultrasonic inspected. Adapter legs S/N 880610 and S/N 880611 have been cast, soaked, preliminary ultrasonic inspected, rough machined and heat treated.

The following components were received:

Shim tube coolant	1115466	700 sets
Coolant channel	1013606	21 each
Ring closing	1115174	4 each

Ring closing	1115176	4 each
Keensert	AG 21 & AG 33	300 each
Plug	1013603-3	20 each
Plug	1013603-1	20 each
K-seals	12100-CL-24	10 each
K-seals	12100-CL-32	20 each
K-seals	12100-CL-4	120 each

b. Work Planned for the Next Quarter

Complete fabrication on adapters S/N 880698 and S/N 880699. Complete fabrication on adapter legs S/N 880609, 880610, and 880611.

7. Adapter Support Assemblies

a. Work Performed During the Quarter

Advanced Quotation Requests were received, reviewed and a vendor was selected.

Purchase Order with the vendor was placed and fabrication of two adapter supports was initiated.

After the rough machining of the rings an ultrasonic inspection was performed by AGC Product Assurance Department, and parts were accepted.

b. Work Planned for the Next Quarter

Two adapter support assemblies are to be completed.

8. Test Assembly

a. Work Performed During the Quarter

With the exception of propellant lines, all components were ordered for the build up of the first test assembly.

Fabrication of the assembly cart was begun. Completion is scheduled for early in the next report period.

b. Work Planned for the Next Quarter

Fabrication of the first test assembly (film-cooled nozzle) is scheduled to be completed.

9. Test Assembly Lines

a. Work Performed During the Quarter

Advance Quotation Request responses were received for all lines, seals, and flanges. Orders will be placed based on the responses. Material availability was established.

b. Work Planned for the Next Quarter

Fabrication will be completed on all lines required for the film cooled nozzle test assembly. Fabrication of the lines required for the convectively cooled nozzle test is expected to be approximately 80% complete by the end of the next quarter.

10. Materials Program

a. Procurement

(1) Work Performed During the Quarter

(a) General Procurement

All original Hastelloy X material requirements for the material development program were received with the exception of the 3/4-in.-dia. bar and one heat of the 0.012 strip stock. There were Hastelloy X material requirements added during September in the form of weld wire, plate, and 347 stainless steel plate stock which have not arrived. The Hastelloy X and 347 stainless steel plate will be rolled into cylinders and sectioned. One section of each material will be welded together to evaluate the joining of these dissimilar materials. Weld wire will be used primarily on the deliverable hardware; however, a portion will be used on deliverable properties material to correlate data and establish continuity with the end item. Table 11 summarizes all material procurement to date.

A dimensional change was made to existing purchase orders for Hastelloy X ring forgings (P.O. 201277 and P.O. 201272) from Viking Forge and Steel Company. There are three ring forgings of each heat on these purchase orders and AGC has reduced section size as follows: One forging 23 x 17 x 6-in. for material design properties and two forgings 20 x 17 x 6-in. for welding qualification and design properties.

Table 11
Material Development Procurement

HASTELLOY X

ITEM	MATERIAL FORM	MELT	SIZE	QUANTITY	HEAT NO.	SPECIFICATION	SPEC.DEVIATIONS	NO. OF HEATS	END USE	VENDOR	P.O.NO.	P.O.DATE	DEL.DATE
1	Plate	CEVM	1½"x4"x12"	6	X5-2752	AMS 5536	None	1	Development	Union Carbide	201260	4-6-65	4-26-65
2	Weld Wire	CEVM	.060 dia.	50 lbs.	X4-2941	AMS 5798	None	1	Development	Union Carbide	201261	5-21-65	5-28-65
3	Weld Wire	Air Melt	.045 dia.	50 lbs.	X5-4485	AMS 5798	None	1	Development	Union Carbide	201261	4-6-65	4-21-65
4	Ring Forging	CEVM	23"x17"x6"	4	X5-2718EE	AMS 5754	None	1	Deliverable Prop.	Viking Forge	201262	4-7-65	4-15-65
5	Weld Wire	CEVM	.062 dia.	25 lbs	262-5-2735	AGC-90058A Amend.I	None	1 Other Than X5-2712EE	Deliverable Prop.	Union Carbide	201263	6-11-65	9-29-65
6	Weld Wire	Air Melt	.062 dia.	25 lbs	260-4-4450	AGC-90058A Amend.I	None	1 Other Than X4-4485	Deliverable Prop.	Union Carbide	201263	6-11-65	7-15-65
7	Weld Wire	CEVM	.062 dia.	50 lbs	260-5-2783 260-5-2784	AGC-90058A Amend.I	*	2 Other Than X5-2712 & Item 5	Deliverable Prop.	Union Carbide	201263	6-11-65	10-21-65
8	Weld Wire	CEVM	.045 dia.	50 lbs	260-5-2783 260-5-2784	AGC-90058A Amend.I	*	2 Other Than X5-2712 & Item 5	Deliverable Prop.	Union Carbide	201263	6-11-65	10-21-65
9	Bar	CEVM	¾" dia.	150 ft.	260-5-2783	AGC-90060	(*)(**)(#)(##)	1	Deliverable Prop.	Union Carbide	201263	6-11-65	10-21-65
10	Plate	CEVM	1½"x6"x12"	4	260-5-2783 260-5-2784	AGC-90057A Amend.I	(*)(**)	2 Other Than X5-2752EE	Deliverable Prop.	Union Carbide	201263	6-11-65	9-22-65 SDAR Reject
11	Sheet	CEVM	.050"x12"x48"	1	261-5-4000	AGC-90057A Amend.I	@	1	Development	Union Carbide	201264	6-11-65	10-25-65
12	Strip	CEVM	.021"x8"x90"	12		AGC-90057A Amend.I	@@	3	Deliverable Prop.	Union Carbide	201264	6-11-65	11-8-65
13	Weld Wire	CEVM	.045 dia.	50 lbs.	260-4-2941	AMS 5798	None	1	Development	Union Carbide	201265	6-24-65	7-1-65
14	Weld Wire	Air Melt	.062 dia.	50 lbs.	260-4-4485	AMS 5798	None	1	Development	Union Carbide	201265	6-24-65	7-26-65
15	Plate	CEVM	1½"x6"x12"	2	260-5-2813	AGC-90057A Amend.I	(*)(#)	1 Other Than Item 9	Development	Union Carbide	201266	7-20-65	11-8-65
16	Plate	CEVM	1"x4"x60.5"	6	260-5-2784	AGC-90057A Amend.I	(*)(#)	1	Development	Union Carbide	201266	7-20-65	10-18-65
17	Plate	CEVM	3/12"x2"x60"	1	260-5-2784	AGC-90057A Amend.I	@	1	Development	Union Carbide	201266	7-20-65	10-27-65
18	Strip	CEVM	.012"x2"x60"	30		AGC-90057A Amend.I	@@	1	Development	Union Carbide	201266	7-20-65	(11-22-65)
19	Strip	CEVM	.008"x12"x60"	1		AGC-90057A Amend.I	@@	1	Development	Union Carbide	201266	7-20-65	11-18-65
20	Ring Forging	CEVM	20/23"x17"x6"	3	261-5-4001	AGC-90056B	*	1	Deliverable Prop.	Viking Forge	201277	6-17-65	11-5-65
21	Ring Forging	CEVM	20/23"x17"x6"	3	261-5-4000	AGC-90056B	*	1 Other Than Item 19	Deliverable Prop.	Viking Forge	201277	6-17-65	11-5-65
22	Ring Forging	CEVM	20/23"x17"x6"	3	261-5-2813	AGC-90056B	*	1 Other Than Item 19 or 20	Deliverable Prop.	Viking Forge	201272	7-20-65	11-22-65
23	Weld Wire +	CEVM	.045 dia.	50 lbs.	260-5-2735	AGC-90058 Amend.I	None	1	Deliverable Prop.	Union Carbide	201876	8-25-65	9-30-65
24	Weld Wire +	CEVM	.060 dia.	25 lbs.	260-5-2735	AGC-90058A Amend.I	None	1	Deliverable Prop.	Union Carbide	201876	8-25-65	11-5-65
25	Weld Wire +	CEVM	.060 dia.	25 lbs.	260-5-2735	AGC-90058A Amend.I	None	1	Deliverable Prop.	Union Carbide	201876	8-25-65	9-30-65

Legend - * .005 Boron Max.
 ** .020 Phosphorous Max.
 # 38,000 R.T. Yield Strength
 ## 0.50 in./min. Crosshead Speed Permissible, Yield to Rupture
 @ 35% Min. R.T. Elongation
 @@ Min. Elongation - 30% and 15%, R.T. and 1200°F.
 + Replacement For Defective Material Items 2 and 12.
 () Promise Date

Billet material was left over at Viking Forge due to this change; the excess material was forged into flats to allow continuity of the plate material in the welding program. In addition, all the rings were cross-forged to provide hot working (approximately double) compared to the previous forgings. These rings are being processed at AGC.

(b) Weldability Tests for Material Heats of Hastelloy X

Successful weldability tests (AGC 90059) were performed at Union Carbide Corporation Stellite Division (UCCSD) on the following Phoebus-2 material heats:

<u>Heat No.</u>	<u>Customer</u>	<u>End Use</u>
261-5-4000	AGC, Viking Forge	Strip Stock, Ring Forgings
261-5-4001	AGC, Viking Forge	Strip Stock, Ring Forgings
260-5-2813	AGC, Viking Forge	Ring Forging
260-5-4002	AGC	Strip Stock
**260-5-2784	AGC	Plate, Wire
**260-5-2783	AGC	Plate, Wire
260-5-2735	AGC	Weld Wire
*260-5-2798	Wyman-Gordon (Rejected)	Not Known

* Weldability test on this material heat was for the purpose of evaluating the revised weld procedure. The material heat had previously been rejected by Wyman-Gordon for defects in the ingot.

** The weldability tests on these two heats were re-tests, which were authorized per disposition as noted on SDAR 12763, dated 23 August 1965, to evaluate the revised weld procedure.

After evaluating the results of previous weldability tests which failed to meet the requirements of AGC 90059, it was concluded that the defects were basically attributable to welding technique.

The UCCSD welding procedure was reviewed and the following changes were made:

1. Allow a maximum of two additional root passes not to exceed 0.188-in. thickness prior to restraint of the weldment.
2. Allow repair of defects in the root welds detected prior to restraint.
3. Require that an inert gas back-up, argon or helium, be provided to shield the underside of the joint during deposit of the root passes.
4. Limit the amount of underbead penetration of the initial root pass to a maximum of 1/8 inch.
5. Require that the interpass temperature shall not exceed 200°F prior to the deposit of each pass.
6. Permit the use of a rotary File to remove surface oxides at the edges of the weld beads and as required on the surface of the weld prior to depositing each pass.
7. Require that each length of weld wire be checked for cleanliness prior to use and cleaned as required. Where used, gloves shall be clean and free of loose particles which may cling to wire or drop in weld deposit.
8. The number of weld passes shall be approximately 30 to 40 and the size of individual weld beads is restricted to a maximum width of 0.5-in.

The ORNL welding engineers were consulted on these technique variations and they concurred in making the foregoing changes.

The results of the weldability tests for the seven material heats indicated that the changes which were made were effective in producing good welds. The weldability specification, AGC 90059, was revised to incorporate the described changes and was released on 13 October 1965.

(c) Weld Wire Procurement

To evaluate the weldability of wire containing surface defects, such as cracks or seams, AGC Phoebus Materials Engineering devised a "bead on plate" performance test. This test consists of depositing a total of six weld beads on a plate of the same material type as the wire being used. The first three beads are deposited side by side with sufficient overlap to completely cover the plate surface. The next two beads are deposited on top of the first three and the final bead on top of the previous two to complete the pyramid effect.

Evaluation of the wire includes consideration of the deposition characteristics of the wire during welding; i.e., it must be free of sparking or bubbling, it must have a visually smooth appearance with a visible weld ripple, and it must be free from foreign matter which would disrupt the ripple or solidification pattern. The completed weld must meet the requirements of penetrant inspection per AGC-STD 3010 Method C and radiographic inspection per AGC-STD 9005 Class 1.

The foregoing performance test will be applied to wire from one spool of each lot; that is, of the same composition, diameter, and form from the same material heat.

In addition, wire from each spool of a lot shall be penetrant inspected for surface defects. If defects are found, a weldability performance test shall be required for each spool of defective wire.

The weldability performance requirements stated above were applied to each spool of wire drawn from Material Heat 260-5-2735. As a result, 100 pounds of this heat of wire were accepted by Phoebus Materials Engineering on the basis of meeting the weldability performance test. This wire was received at AGC.

A sample illustrating acceptable and unacceptable weld beads was produced which will be utilized as the standard accept-reject criteria for future weld wire procurement. The weld wire specification, AGC 90058, was revised and released on 13 October 1965.

(d) Nozzle Welding Specification

Welding Process Specification, Phoebus-2 Jacket, AGC 90067, Amendment 1, was released 19 October. Amendment 1 reflects the knowledge gained thus far in the Welding Development Program and presents the basic procedure to be used to weld the Phoebus nozzle.

(e) Welding Equipment, Fixtures, and Tooling

To obviate any nozzle fabrication delays due to equipment failures or conflicting priorities, a second welding boom was introduced into the development program for eventual use in fabricating deliverable hardware. This unit, the Reed-Avery Boom Welder, was refurbished, installed in the same bay with the existing Cayuga Boom Welder, and its operation is being verified. A Hastelloy X ring will be welded with this machine as a final verification of its suitability.

The welding cart and the associated external tooling to weld the Phoebus nozzle were delivered. The turning roll "cages" that provide external support for the nozzle were assembled onto the cart turning rolls and will be positioned in the boom weld area to confirm positioning alignment with the Reed-Avery and Cayuga Welding Booms. This operation will accomplish a tool proofing of the nozzle weld tooling.

(f) Channel Forming

Straza Industries was awarded the contract to manufacture U-channels for the Phoebus-2 Program. The channels will be stretch formed to the configuration of the Phoebus jacket grooves. A review of Straza Industries' forming program was held at their plant the last week in September. Progress to that date was confined to applicable forming calculations, preplanning, initial form die configuration development, and contour inspection gage design.

A close tolerance blank of the Hastelloy X strip material will be made. The blank will then be longitudinally formed to the U-configuration by a double-phase die. The first phase will effect approximately 40% of final configuration and the latter phase will complete the envelope including all of the crown radii.

This forming will be accomplished with a steel punch and a rubber die. The contour will be formed over a steel male die while longitudinal tension sufficient to relieve compressional wrinkling is applied. Figure 60 schematically illustrates the channel forming steps.

Considerable development work is necessary to establish final die configuration and meet print requirements; therefore, in view of the long Hastelloy X material delivery dates and the unknown parameters, a limited quantity of commercial quality Hastelloy X strip was obtained for the preliminary development forming studies now in progress at Straza.

The Ulbrich Stainless Steel Company, Wallingford, Connecticut, is producing the 0.012-in.-thick channel tube strip as a converter to UCCSD for eventual delivery to Straza. Stellite delivered 0.062-in.-thick annealed sheet to Ulbrich slit into 10-in.-wide by 120-in.-long pieces. The pieces were TIG butt welded end-to-end and are to be cold rolled in a Sendzimer mill to 0.012-in. thick. All welds will be removed from the finished product, which will be supplied as 2-in.-wide by 100-in.-long pieces to Straza Industries for channel forming.

Ulbrich will also produce the 0.008-in.-thick Hastelloy X shim stock, which will be supplied in weld-free coils with a 2-in. width.

Figure 60
Tentative Channel Form Process

(g) Hastelloy X Ingot

In early September, both Hastelloy X ingots from Union Carbide Corporation Stellite Division's (UCCSD) Heat 2793 were rejected by Wyman-Gordon because of extensive porosity in the hot top portion of each as-received 23-in.-dia x 73-in. (approx.) -long ingot (See Figure 61). Removal of the top defects resulted in ingot multiples of marginal weight to produce the inlet cone (P/N 1114856-7) or exit cone (P/N 1114856-11) forgings.

Concurrent with the discovery of the ingot top porosity, the Stellite Division commenced weldability tests (in accordance with AGC 90059) on several heats of material. One of three heats was scheduled for delivery to Wyman-Gordon for inlet cone, exit cone, and inlet ring forgings. Difficulties encountered during the weldability test indicated Heats 2783, 2784, and 2798 were possibly destined for rejection. Heat 2798 had been scheduled for nozzle forging at Wyman-Gordon.

The weldability testing problem at UCCSD was evaluated by UCCSD, AGC, and ORNL personnel and found to be primarily a question of technique variables. Within a short time resolution of the problem appeared imminent and Heat 2798 was released for shipment to Wyman-Gordon. Heat 2813, a back-up to 2798, also was released for weldability testing.

Sectioning the top of the two ingots from Heat 2798 revealed porosity in one ingot, similar to Heat 2793, and porosity as well as a circumferential crack in the second ingot. The third ingot of Heat 2798 had been successfully forged at UCCSD to an 18-in. octagonal cross section weighing about 3000 pounds and a 14-in.-square cross section weighing approximately 6000 pounds. The 18-in. octagonal forging was shipped to Wyman-Gordon for the inlet ring forging (P/N 1114856-13) and the 14-in.-square forging was retained at UCCSD for weldability plates (1-in. thick x 4-in. wide x 12-in. long) and other as-yet unscheduled uses.

The rejection of Heat 2798 at Wyman Gordon resulted in discussions between UCCSD and AGC personnel; it was resolved that the following action should be taken for improved ingot availability:

Figure 61
Large Porosity in Hastelloy X Ingot

1. Heat 2813, the back-up for 2798, was produced under identical melting schedules and therefore was not to be shipped to Wyman-Gordon.
2. Two heats, 2819 and 2820, had already been melted with a modified "hot-top" procedure and were to be shipped to Wyman-Gordon.
3. UCCSD was to investigate the production of longer and heavier ingots of the same diameter to permit a greater amount of cropping with retention of forging multiple weight.
4. UCCSD would investigate hot-topping procedures further.
5. UCCSD would offer an ingot from Heat 2793 at no cost if failure occurred in forging.

Heats 2819 and 2820 were also found by Wyman-Gordon to be marginal for forging multiple weights after cropping. One ingot from Heat 2820 was considered satisfactory, therefore, plans were made to forge with the ingot from Heat 2793.

Ingots from three additional heats of Hastelloy X were rushed to Wyman-Gordon, but they were also rejected. A second meeting between Aerojet, Wyman-Gordon, and UCCSD was held and plans were reformulated on ingot procurement and several supplier funded development efforts were initiated. To further assure a forgeable, high quality Hastelloy X ingot UCCSD commenced thorough evaluation of processing practices and several self-funded melting studies apparently unique to 24-in. CEVM ingot. In addition, the OD of the ingots (see Figure 62) was now to be turned prior to penetrant inspection.

Heat 2849 was the outcome of the foregoing activities and the two improved quality ingots were forged by Wyman-Gordon utilizing a revised forging program. The revision was based on company-sponsored studies verified by UCCSD on actual production ingots for mill products. The basic changes were an increase in the initial forging temperature from 2150 - 2190°F to 2225 - 2250°F, and addition of a long time homogenizing treatment after the initial forging operations. Following the initial upsetting operations and subsequent to the homogenization treatment, one ingot was found to be cracked transversely into two pieces (Figure 63) and the second ingot appeared satisfactory. On the basis of possible

Figure 62
Ingot Surface as Received for Forging

Figure 63
Ingot No. 1, Heat 2849, Depicting Crack Surfaces
after Homogenization Treatment

cracking due to rapid cool-down (air cool) from homogenization temperature, the second ingot was stress relieved at 1900°F and furnace cooled. Subsequently, a surface crack was noted and after local milling to a depth of 1-3/4-in. was still evident (Figure 64). Examination of the ingots revealed the following:

Ingot No. 1

1. Fracture surface was not oxidized; therefore, cracking occurred during cool-down at less than about 1000°F.
2. Fracture origin was at the center core.
3. Fracture path was intergranular through grain boundary carbide network.
4. No internal melting defects (porosity, shrinkage) or incipient melting were observed.
5. The OD was hot worked, as evidenced by grain refinement, to a depth of about 6-in.

Ingot No. 2

1. Fracture surface oxidized; therefore, cracking occurred during original cool-down.
2. Fracture morphology was identical to ingot No. 1.
3. The crack extended through 90 to 95% of the cross section.

Mathematical analysis by UCCSD and Wyman-Gordon revealed high tensile stresses (of the order of 50,000 psi) were generated because of the thermal gradient developed during heat-up and cool-down of these large diameter ingots. Hence, the instances where cracking possibly occurred were varied and included the following:

1. During cool-down following consumable electrode melting.
2. During heat-up or cool-down for ingot homogenization.
3. During heat-up for forging.
4. During cool-down after homogenization of partially forged ingot.

Figure 64
Ingot No. 2, Heat 2849, Depicting OD Crack
Machined to Depth of 1-3/4-in.

Consistent with a current in-house study, UCCSD has revised their heat-up and cool-down procedures for the 24-in.-dia ingot Hastelloy X.

(h) Hastelloy X Forging

Forging was begun on Heat 2793 to make an inlet cone (P/N 1114856-7). Likewise, Heat 2820 was started immediately after Heat 2793. The forging of the two inlet cone ingots proceeded well into the pancake form when a single center burst occurred in Heat 2793 when it attained a thickness of 9.3-in. and edgebursting developed on Heat 2820 at 7.9-in. thickness.

The center burst pancake 2793 was removed by machining and the forging was successfully completed through the blocker and finish dies. Figure 65 shows the forging with the flange end rough machined.

Machining of the deepest edgeburst in the pancake forging from Heat 2820 revealed defect free material at a depth of 4 to 5-in. from the O.D. Further operations on Heat 2820 were suspended pending completion of the forging from Heat 2793 (above) to ascertain metal flow and die fill to aid in deciding the optimum method of conditioning the O.D. Complete and concentric removal of the O.D. would have resulted in an unacceptable loss of material. Following the successful forging of 2793 it was decided to hot work and roundup the perimeter of 2820. This was satisfactorily accomplished by the UCC Stellite Division and the pancake forging is awaiting scheduling at Wyman-Gordon.

A nozzle ring (P/N 1114856-16) was forged from an 18-in. octagon from Heat 2793 at Standard Steel in Burnham, Penna. The forging sequence employed was as follows:

- Upset forge
- Punched out center
- Mandrel forged to size

After initial mandrel forge the ring was to have been rolled to size. However, the ring-roll fractured and forging was completed on the mandrel.

The nozzle ring (Heat 2793) was machined, satisfactorily passed sonic inspection, and is being readied for shipment to Aerojet.

Ingots 1 and 2 of Hastelloy X Heat 2849 were processed by Wyman-Gordon through the initial barrel upsetting operations and were then placed in a furnace for

Figure 65
Inlet Cone Forging (with Flange Rough Machined),
P/N 1114856-7

a homogenization heat treatment. After cool down, both ingots were found to be cracked into two pieces (refer to section (h), Hastelloy X Ingot). The cracked, partially forged ingots were returned to UCCSD for analysis. The follow-on ingots, from heat 2850, are being expedited as replacements.

(i) AISI 347 Stainless Steel

The following AISI 347 stainless steel components were processed by Wyman-Gordon:

Adapter Forging

An original 32-in. dia ingot forged by Wyman-Gordon that had hour-glassed (Figure 66) was reformed by Allegheny-Ludlum Steel Company to produce a 34-in. dia x 66-in. high billet. This billet for Adapter No. 1 was then upset by Wyman-Gordon in a barrel die, with a starting temperature of 2190°F, to 47-in. high. After reheating to 2190°F, the barreled billet was upset in three pressings to 14-3/4-in. high x 70-in. dia pancake and then cooled to room temperature for conditioning. Next, the pancake was further flattened to about 8-in. high x 85-in. dia, followed by a "dishing" operation and then into the finished die. The first adapter was machined and shipped to Standard Tool and Die for machining of grooves.

The second adapter multiple was a virgin cast ingot 30-in. dia x 77-in. high. The ingot was heated to 2190°F and, because of the unusual height, could not enter between the press platens. It was reheated to 2190°F and then forged to 74-in. high with a top flat die and a bottom barrel diameter. The billet was then reheated and forged in a full barrel die to a height of 64-in. After the next reheat the billet was upset in the barrel die to 58-in. high and two small indented areas were observed on the OD. The upset forging was cooled to room temperature for conditioning. The barrel forging was reheated to 2190°F and in successive operations forged to an 8-in. high x 85-in. dia pancake requiring 33,000 tons of pressure. Using a top flat die and a bottom contour die, the pancake forging was "dished" and then forged to size in contour closed dies (Figure 67). Machining was completed on Adapter No. 2.

Figure 66
Upset Forging of Original 347 Stainless Steel Ingot

Figure 67
AISI 347 Stainless Steel Adapter Forging

Adapter No. 3 was forged from a virgin cast ingot and resulted in an hour-glass configuration about 56-in. high, which was then forged to about a 30-in. height in a barrel die. Following upset machining to remove the laps on the OD, upset forging will be employed to produce the desired pancake size.

Table 12 summarizes the forging operations.

Brazing Adapter

Assembly and brazing specifications were prepared for the Phoebus-2 nozzle and adapter.

The Phoebus-2 Adapter was received at Pyromet and is currently being prepared for brazing of the coolant channels.

Film Cooled Nozzle Forging

A 31-in. dia x 65-in. high ingot was heated to 2190°F, then forged in a barrel die to 55-in. high. Following reheat to 2190°F, the billet was forged to 53-1/2-in. high and stopped for cool-down and conditioning of an indented area on the OD. Following reheating to 2190°F, the billet was upset forged to 26-in. high x 40-in. dia. Next, the billet was forged successively through the contour blocker and finish contour dies to produce a satisfactory forging for film cooled nozzle No. 1 (see Figure 68).

The second film cooled nozzle forging was begun with an early partially forged billet originally scheduled for an adapter. The hour-glassed billet was machined and conditioned from a 56-1/2-in. high x 39-in. dia upset forging and then forged at 2190°F to a 17.46-in. high x 66-1/2 in. dia pancake. Next, the pancake forging was successfully forged in one operation at 50,000 tons in the contour blocker die. Following machining, to even-off the skirt face, the forging was completed in the finish contour dies.

Table 12 summarizes the forging operations.

Table 12
Forging History Summary of AISI 347
Stainless Steel Components

<u>Part Name/No.</u>	<u>Dies</u>	<u>Final Dimensions</u>	<u>Comments</u>
Adapter No. 1/1114738	Flat	56" high	Hour-glass shape
	Flat	66" high x 34" dia.	Reforged at Allegheny-Ludlum
	Barrel	47" high	--
	Flat	8" high x 85" dia.	--
	Flat top, contour bottom	"dished"	--
	Contour (final)	to size	--
Adapter No. 2/1114738	Flat top, barrel bottom	74" high	--
	Barrel	58" high	--
	Flat	8" high x 85" dia.	--
	Flat top, contour bottom	"dished"	--
	Contour (final)	to size	--
Adapter No. 3/1114738	Flat	56" high	Hour-glass shape
	Barrel	30" high	--
Film Cooled Nozzle No. 1/1013602	Barrel	55" high	--
	Flat	26" high x 40" dia.	--
Film Cooled Nozzle No. 1/1013602 (cont.)	Contour (blocker)	to size	--
	Contour (final)	to size	--
Film Cooled Nozzle No. 2/1013602	Flat	56-1/2" high	Hour-glass shape, machined to size
	Flat	17.46" high x 66-1/2" dia.	
	Contour (blocker)	to size	--
	Contour (final)	to size	--

Figure 68
Film Cooled Stainless Steel Nozzle Forging

(2) Work Planned for the Next Quarter

Monitoring of Hastelloy X ingot procurement and forging will
continue.

b. Welding Development Program

(1) Work Performed During the Quarter

Welding of Hastelloy X ring forgings from Heat No. X5-2718EE and plates from Heat No. X5-2752, both purchased to AMS 5754, was continued in October to provide welding technology experience pending delivery of the rings and plates procured to AGC Specifications 90056 and 90057, respectively, from Viking Forge.

Groove land thicknesses of the AMS test plates were varied from 0.062 to 0.130-in. to establish appropriate weld penetration parameters. Preliminary results indicated that full penetration of a 0.130-in.-thick mating land was possible, providing mismatch of mating lands was minimized. Tests were also conducted to establish beneficial effects of increasing the weld joint preparation from an included angle of 45° to 60° to reduce the possibility of cold lap defects, such as those experienced on previous tests. Radiographic examination of a 1-1/2-in.-thick completed plate weldment having a 60° included angle, using 0.045-in.-dia filler wire, revealed no defects. A similar test plate was automatic welded using 0.062-in.-dia filler to further substantiate the beneficial effects of the greater included angle.

Welding of the AMS ring forgings (S/N's 003 and 004), which was continued during this period, demonstrated the advantages of employing 0.045-in.-dia filler wire for welding the ID joint of the 17-in. dia rings. The application of the 0.045-in.-dia filler wire appeared to improve the fluidity and wetability of the molten puddle. Test results to date show that 0.045 or 0.062-in.-dia filler wire may be used with equal success for the 17-in.-dia OD weld joint. The application of special gas trailing shields for the welding torch was tested and found to improve the surface condition of the weld deposit. This will minimize the extent of the interpass cleaning operations of the weld deposit.

Weld Wire Specification AGC 90058, Revision B, was released 13 October. The revision incorporated pertained primarily to details of the weldability performance test for spooled wire. These tests are required for wire from each lot and for each diameter ordered. A penetrant inspection of a specified length of wire from each spool is required. Spools which reveal defect indications (such as

laps, pits, and cracks) are rejected pending successful completion of the welding performance test which is required for each spool containing such defects.

Weld wire from Material Heats 260-5-2783 and 260-5-2784, which was procured per the provisions of AGC 90058B, was received from UCCSD and is being used in the Welding Development Program. This wire did not show any indications of defects when penetrant inspected, and acceptable beads-on-plate performance tests were accomplished at UCCSD. The weld performance test plate samples were shipped with the wire, as required by AGC 90058B, and will be retained by the Phoebus Materials Department.

Results obtained thus far in using wire from the above material heats in the Phoebus welding program indicate a definite improvement in the wire quality and in the deposited weld metal.

Material procurement delays (weldability testing, defective wire, etc.) affected the Materials Development Welding Program schedule as presented in the Phoebus-2 Quarterly Report for the period of 18 May through 31 August 1965 (Report No. RP-QR-0001). As a result, the time schedule has tightened and this, coupled with the schedule delay risks if the existing Cayuga boom welder were to breakdown, necessitated incorporation of a second welding machine into the Materials Development and Hardware Welding Program. A meeting was held at Aerojet on 20 October 1965, with J. J. Lombardo and K. E. Estes of SNPO-C and J. J. Beereboom and L. F. Glasier of AGC. The welding schedule and the introduction of the second welding machine (Reed-Avery Boom Welder) were discussed and the decision to proceed was reached.

The revised Materials Development Welding Program time schedule is presented in Table 13.

Semi-automatic welding of two Hastelloy X plates from Material Heats 261-5-4000 and 261-5-4001 was completed. Figure 69 illustrates a plate weldment, S/N 001 from Heat 261-5-4000, after 19 of the 50 passes required to complete this weldment. Plate Weldment S/N 011 (Heat 261-5-4000) was welded with 0.062-in.-dia weld filler wire from Heat 260-5-2784 and plate weldment S/N 012 (Heat 261-5-4001)

TABLE 13
 SCHEDULE FOR MATERIALS DEVELOPMENT
 WELDING PROGRAM
 (Revised 10-25-65)

	<u>START</u>	<u>FINISH</u>
1. Heat 1 (2718EE) rings		10-20-65*
2. Weld and test plate from Heat No. 2 for qualification	10-29-65	11-19-65
Weld and test ring from Heat No. 2 for qualification	11-3-65	12-3-65
3. Weld and test plate from Heat No. 3 for qualification	11-12-65	12-7-65
Weld and test ring from Heat No. 3 for qualification	11-17-65	12-17-65
4. Verification of second welding machine	11-15-65	12-30-65
Weld and test plate from Heat No. 4 for qualification	11-15-65	12-14-65
Weld and test ring from Heat No. 4 for qualification	11-29-65	12-30-65
5. Weld design properties from Heat No. 1		10-20-65*
6. Weld design properties from Heat No. 2	11-30-65	1-20-66
7. Weld design properties from Heat No. 3	12-9-65	1-31-66
8. Weld design properties from Heat No. 4	11-29-65	1-9-66

NOTES:

- a. All welding operations on two shift basis.
- b. Welding of ring from Heat 4 represents final schedule variation and therefore will be used for design properties testing (Item 8) concurrently with qualification (Item 4).

*Suspended by verbal direction of J. J. Lombardo and K. E. Estes of SNPO-C on 20 October 1965.

Figure 69

Hastelloy X Plate Weldment
at Completion of 19 Passes
Heat 261-5-4000, S/N 011

was welded with 0.062-in.-dia filler wire from Heat 260-5-2783. The weldments were submitted for final radiographic, penetrant, and ultrasonic inspections.

The weldment of plate S/N 011 was found to be sound by radiographic and ultrasonic inspection techniques. Plate weldment S/N 012 had one defective area containing linear fusion. This defect was first detected by radiographic inspection and verified by ultrasonic. A section through this imperfection is being taken for metallographic examination. Additional sections for chemical analysis, metallographic analysis, tensile testing, and hardness testing were cut from both of the above test plates.

The welding of two sets of Hastelloy X 20 inch OD ring forgings, S/N's 000006 and 0000010 from Material Heats 261-5-4000 and 261-5-4001, respectively, was completed. Filler wire (0.062-in.-dia) from Material Heat 260-5-2784 was employed for the welding of S/N 000006 ring forging. Filler wire (.045-in.-dia) from Material Heat 260-5-2783 was employed for welding of S/N 0000010 ring forging. Ring weldment S/N 000006 satisfactorily passed final radiographic and penetrant acceptance tests. This weldment is undergoing final ultrasonic inspection, after which qualification testing will be initiated. The completed weld of S/N 0000010 ring forging was found to be acceptable in the final radiographic, penetrant, and ultrasonic inspections. This weldment is being sectioned for weld qualification tests. Figure 70 illustrates the welding of the final weld passes on ring forging, S/N 0000010.

One set of 20-in. OD ring forgings from Material Heat 261-5-2813 was machined in preparation for welding and passed initial ultrasonic inspection. This set of rings, designated as "Heat No. 4" in the test program, is awaiting welding operations.

(2) Work Planned for the Next Quarter

Weld qualification tests will be completed on Hastelloy X plate weldments S/No's 001 and 012 from material heats 261-5-4000 and 261-5-4001, respectively.

Weld qualification tests will be completed on Hastelloy X forged ring weldments S/No's 000006 and 0000010 from material heats 261-5-4000 and 261-5-4001, respectively.

Figure 70
Hastelloy X Ring Weldment
Shown Near Completion
Heat 261-5-4001, S/N 0000010

The Phoebus-2 nozzle jacket welding development specification AGC 90067 will be revised and submitted to SNPO-C for approval.

The 1st Phoebus-2 development nozzle jacket will be semi automatic welded per revised specification AGC 90067.

Welding of ring forgings from material heats 261-5-4000, 261-5-4001, and 261-5-2813 will be initiated and completed per revised specification AGC 90067 (to be adopted into the weld properties program).

c. Brazing Development

(1) Work Performed During the Quarter

The Materials Development Brazing Program was revised using time schedules based on tentative Hastelloy X delivery dates. The Phoebus-2 Nozzle Brazing Program is correlated with the channel forming development, electrical discharge machining and cleaning of the nozzle grooves, Hastelloy X strip conversion for shims, final proof of assembly hand tooling, and verification of the new retort and furnace modifications at the Pyromet Company. The Materials Development Brazing Program consists of three major sub-programs, namely, Braze Alloy Diffusion, Electrical Discharge Machining, and Fabrication of Simulated Specimens and Sectors. The program and the time schedule were transmitted to SNPO-C.* Briefly, the sub-programs are as follows:

Braze Alloy Diffusion: Metallographic examination of braze alloy diffusion using pre-drilled holes in Hastelloy X plate and seven braze alloys (Palniro-1, Copper, Palniro-7, Mioro, 40Au-60Cu, Nicoro, and Nicoro 80) over a temperature range of 1700°F to 2150°F. Specimen preparation and brazing were accomplished and the test results are being reviewed.

Mechanical property effects will be determined with flat and 1/4-in. round tensile specimens. Simulated seal-joint specimens and Miller-Peaslee specimens are being prepared for irradiation testing at ORNL.

* Ltr 7120:1566L, H. E. Pharr to A. A. Madeiros, dtd 5 Nov 1965, Subj: Revised Phoebus Materials Development Welding and Brazing Program.

Electrical Discharge Machining: The electrical discharge machine (EDM) grooving process was exhibited by Tracer Laboratory on flat 347 stainless steel plates. The grooved plates were cleaned, assembled with strip 347 stainless steel material simulating the U-tubes, and then satisfactorily brazed, employing the tentative nozzle brazing cycles. The brazed samples were sectioned and metallographically examined. The braze joint was good but variations in groove contour were evident. The EDM process is being upgraded by Tracer Laboratory to a full scale contoured convergent and throat section for evaluation of groove dimensions and contour, and confirmation of cleaning capabilities. A preliminary short contoured part was prepared by Tracer. It was sectioned and will be metallographically examined, dimensional control measured, and cleaning evaluated. The ability to inspect on a comparable basis with conventionally machined grooves also will be scrutinized.

Straight specimens 4-in. wide x 10-in. long are being prepared for thermal fatigue testing and full length, contoured sectors also are being fabricated to establish brazing procedures for specification use. The sectors will be nondestructively inspected and subjected to leak, proof, and burst hydrotests prior to metallographic examination.

(2) Work Planned for the Next Quarter

(a) Mechanical property tests will be conducted on brazed joints.

(b) Bronze alloy diffusion studies will be completed.

(c) Evaluation of EDM grooving, cleaning, and brazing will be continued.

(d) Brazing studies will be initiated using short, straight specimens and full length, contoured sectors.

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TASK L - RELIABILITY AND QUALITY ASSURANCE (NOZZLE DEVELOPMENT)

1. Work Performed During the Quarter:

Nozzle Design

The following drawings and changes were reviewed and approved:

1013603A - Plug, Screw Thread	1115335A - Torus, Nozzle Fuel
1013605 - Flange, Bolting	1115343 - Lifting Bracket, Nozzle
1013606C - Channel Coolant, Adapter	1115344 - Tube Assembly, Metal
1013607B - Adapter Leg, Forging	1115346 - Venturi Meter Tube
1114172 - Ring, Screen-Strainer Element	1115347 - Adapter Tube Fitting
1114173 - Frame, Screen-Strainer Element	1115352 - Adapters, Tube Fitting
1114174 - Screen Strainer Element	1115354A - Plate, Pressure Test Nozzle
1114175 - Strainer Element, Sediment	1115380 - Adapter, Torus, Bolt Coolant
1114738C - Forging, Adapter	1115452 - Line-Coolant, Dump
1114831A - Jacket, Tube Coolant	1115454 - Line, Inlet-Adapter Fuel
1114857A - Nozzle Weldment	1115456 - Line - Coolant-Nozzle Inlet
1115058B - Channel, Coolant	1115458A - Leg, Baffle, Injector
1115082A - Adapter, Instrumentation	1115466A - Shim - Coolant Tube
1115084A - Plate, Injector, Co-Axial	1115468B - Adapter, Assembly
1115085A - Dome, Weldment	1115482 - Face Plate, Injector
1115086A - Element, Fuel	1115483A - Ring, Injector Baffle
1115088B - Plate, Rigmesh	1115484 - Leg, Injector Baffle
1115089A - Flange, Bolting	1115486 - Adapter, Injector & Nozzle
1115090 - Injector, Plate, Weldment	1115493B - Leg, Adapter
1115091A - Segment, Manifold	1115495 - Bellows Assy, Rod Restrained
1115173B - Jacket Tube Coolant Adapter	1115497 - Adapter Blank, Torus
1115192D - Injector Pattern	1115499A - Flange, Bolting
1115193A - Tube, Injector Face, Coolant	1115607B - Elbow
1115202A - Leg, Adapter	1115610 - Support, Adapter Assembly
1115205 - Torus, Bolt Cool. Line, Nozzle	1115629A - Torus, Adapter
1115224B - Injector Assembly, Welded	1115639A - Injector, Plate Assy, Brazing
1115279A - Nozzle, Fuel Film Cooled	1115645 - Line, Inlet-Oxidizer Injector
1115304 - Nozzle, Pressure Test-Weldment	1115650A - Element - Oxidizer
1115307 - Final Mach. Pressure Test Nozzle	1115748 - Line, Coolant Film
1115309C - Injector Assy, Machined & Welded	1115749 - Venturi
1115310 - Injector Assy, Braze	1115750 - Coupling, Valve and Line
1115311A - Injector Assy, Final	1115751A - Line, Coolant-Fuel Film Supply
1115312A - Plate Face	1115752 - Line, Coolant-Fuel Film Supply
1115313 - Injector Plate Assy, Brazing	1115805 - Adapter, Bolt Coolant Torus
1115314 - Injector Plate, Machined	1115838 - Gasket Flange
1115315A - Support, Injector	1115860 - Jacket, Tube, Coolant
1115316 - Adapter, Igniter	1115886A - Support - Adapter Assembly
1115317 - Washer	1115925 - Flange, Adapter Support
1115320 - Cover Protective - Inj. Plate	1115950 - Torus, Nozzle Uncooled
1115321 - Injector Assy - Co-Axial	1116038 - Dowel Pin

The following specifications were reviewed and approved:

AGC-STD-9008 Method 101 - Hydrotesting, Injector Assembly, Phoebus-2
AGC-90058B Ni-Mo-Cr-Alloy Bare Welding Filler Wire

AGC-90059C Weldability Tests for Ni-Mo-Cr Alloy Plate, Forgings and Wire
AGC-90067 Welding, Phoebus-2 Jacket
Amend. 1
AGC-90070 Cleaning & Protection of Phoebus-2 U-Tube Adapter Components
AGC-90071 Annealing (Bright) of Ni-Mo-Cr Alloys

SNPO-C Reliability and Quality Assurance comments in TLX No. 004, dated 1 November 1965 in regard to Purchase Order 201880, Channel Coolant P/N 1115058B, were coordinated with Aerojet Phoebus-2 Project personnel. A report will be presented in December 1965.

Final Design Reviews were held on the following assemblies:

Co-Axial Injector	1115321
Multi-Orifice Injector	1115311A
Fuel Film Cooled Nozzle	1115279

The following modes of failure analyses were completed:

Fuel Film Cooled Nozzle	1115279
Multi-Orifice Injector	1115311
Adapter Support Assembly	1115886
Pressure Test Nozzle	1115307
Co-Axial Injector	1115321

A statistical analysis of the Materials Program tensile tests on AMS Heat 5X 2718EE was begun. The analysis indicates that temperature and radial location have significant effects on the axial ultimate strength properties, and specimen size (R_1 vs R_3) has a significant effect on tangential ultimate strength. The effect of specimen size, radial location and orientation of specimens does not have a significant effect on the yield strength properties.

Nondestructive Testing

The tentative procedure for ultrasonic testing of welds was completed. Four forged ring weldments and seven plate weldments were tested in accordance with

procedure. Several weld defects were found which were not revealed radiographically due to their unfavorable orientation. Metallurgical sections verified the presence of these defects. The procedure is sufficiently refined for application to the Materials Development Program and will be tentatively approved for use with the Nozzle Development hardware.

Designs were completed for a nozzle rotating and support fixture to be used for ultrasonic investigation of the coolant channel braze bond and a 300 Kv rod anode tube head support.

Tentative radiographic and ultrasonic inspection procedures were developed for Phoebus Nozzle welds. These procedures consist of technique sketches and operation sequences and are being reviewed by inspection personnel.

A preliminary technique was developed for ultrasonic testing of sheet and strip. The technique utilizes a through-transmission, pulse-echo reflection method and has demonstrated sensitivity capable of detecting artificial flaws of less than 0.0025 square inch reflecting area (.05 x .05 inch square). It is planned to test 12 Hastelloy X strips 0.012-in. thick, 8-in. wide and 90-in. long and one sheet 0.050 x 12 x 48-in.

Special process suppliers' surveys and approvals were conducted as follows:

Beckmann Welding and Engineering Co.- Fusion Welding, P.O. 201270 and 201271, Weldability tests for Allvac Metals Co.

Gladstone Laboratories - Radiographic inspection, P.O. 201270 and 201271, Weldability tests for Allvac Metals Co.

Orbit Industries - Ultrasonic and penetrant inspection, P.O. 201270 and 201271 - Mill stock for Allvac Metals Co.

Supplier ultrasonic inspection procedures were reviewed and approved as follows:

P.O. 201560, P/N 1114856-7, -11, -13; Nozzle Forgings; Wyman-Gordon

P.O. 201562, P/N 1114738; Forging, Adapter; Wyman-Gordon

P.O. 201563, P/N 1114685; Forging, Injector: Ultrasonic Associates, subcontractor to Arcturus Mfg.

P.O. 201567, P/N 1115081; Injector Forging; Automation Industries, subcontractor to Viking Forge

P.O. 201567, P/N 1115087; Injector Dome Forging, Automation Industries, subcontractor to Viking Forge

P.O. 201870, P/N 1013607-3, Adapter Leg Forging; ALCOA

NDT source inspections were witnessed and verified as follows:

P/N 1114738, Adapter Forging; ultrasonic inspection; Wyman-Gordon. Part was accepted to AGC-36163, Class I.

P/N 1013607-3, Adapter Leg Forging; ultrasonic inspection, ALCOA. Part was accepted to AGC-36163, Class I.

P/N 1115886-15, Adapter Support Forging; ultrasonic inspection, Jet Air Engineering Corporation. Part was accepted to AGC-36163, Class I (Contact) and AGC-STD-9006.

Fabrication Control

Inspection guidelines for Manufacturing Integrated Planning required by Quality Procedure 11-1-21, Inspection Planning, Fabrication and Assembly Operations, were reviewed.

The Phoebus-2 Nozzle Component and Test Assembly Inspection and Test Plan was published in Report No. RP-TR-0006.

The following actions were accomplished on supplier manufacturing and inspection procedures:

P/N 1115309-1, Injector Assembly weld procedure was approved.

P/N's 1115088-1, 1115088-9, 1115085-1, -3, -5, 1115085-9, Plate Rigimesh weld procedure was approved.

P/N's 1115058-9, -19, -29, Channel Coolant Assembly planning were returned for incorporation of comments.

P/N 1115173-9, Jacket Tube Coolant Adapter planning and weld procedure was approved.

P/N 1114856-13, Nozzle Forging planning was approved.

The following integrated manufacturing and inspection planning was reviewed and approved for AGC fabrication:

751006	Weld Test Sample
1115102	Fuel Injector Ring
1115192-11	Ring Set Injector Pattern
1115192-25	Injector Pattern
1115192-41	Injector Pattern
1115193	Tube Injector Face Coolant
1115304	Nozzle Pressure Test Weldment
1115344-1	Tube Assembly
1115344-7	Adapter
1115346-1	Venturimeter Tube
1115379	Film Cooled Nozzle Test Plate
1115380	Adapter Torus
1115458	Leg Baffle
1115477	Splitter
1115484	Injector Baffle
1115485	Spacer
1115925	Flange Adapter Support
1116038	Dowel Pin

Procurement Control

The following inspection planning was approved by the Supplier Quality Control Representative:

1115313-9 n/c	Injector
1115312-1A	Plate
1115487-5	Bolt

Ultrasonic inspection of two forged rings for the support, P/N 1115886-1A, was completed.

Source acceptance of the following components was completed:

1013607-3	Adapter Leg Forging
1013606-1A	Adapter, Channel Coolant, 320 pcs.
1115224-9	Injector Assembly Weldment
1115085-9 n/c	Support
1114856-13	Forging, Nozzle
1114738-3	Adapter Forging, 2 pcs.
1115173-9A	Adapter, Machined and Grooved
1115466-3	
thru	Shim Coolant Tube (700)
1115466-17	
1115057-1A	Plate Injector
1115173-9	Tooling for Adapter Forging
1115081-31	Forging Injector Co-axial
1115087-3	Dome Co-axial Injector
1115201-9	Adapter, Inlet Torus Assembly, 4 pcs.
1115191	Segment, Manifold, 30 pcs.
1115191	Rib, Injector Plate, 30 pcs.
1115083-1	Torus, Injector, 4 pcs.
1115083-1	Torus, Injector, 6 pcs.

2. Work Planned for the Next Quarter

Final Design Review reports for the Co-axial Injector, Multi-Orifice Injector, and Fuel Film Cooled Nozzle will be published.

Modes of Failure Analyses will be completed on the Propellant Lines, Adapter, Assembly, Convectionally Cooled Nozzle, and Nozzle Test Assembly.

Twelve Hastelloy X strips, 0.012 x 8 x 90-in. and one sheet 0.050 x 12 x 48-in. will be ultrasonically tested.

Tentative ultrasonic weld test and radiographic weld inspection procedures for the Phoebus-2 Nozzle will be published.

Ultrasonic inspection of the Hastelloy X convergent section nozzle forging, P/N 1114856-7, will be source verified and monitored.

Scheduled support to Materials Development Program will include:

ultrasonic, radiographic, and penetrant inspection of various weldments and mechanical test specimens removed from weldments.

TASK M - TESTING

1. Work Performed During the Quarter

No work was performed during the quarter.

2. Work Planned for the Next Quarter

The film-cooled nozzle test assembly will be fabricated for development of chemical test components.

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TASK N - REPORTS (CPIF)

1. Work Performed During the Quarter

Compilation and transmittal of the weekly TWX reports to SNPO-C continued each Friday. (RP-TWX-0023 through 0035).

PERT reporting under General Provision 54.3 of the Contract continued on a biweekly basis. (RP-PR-0006 through 0010).

On 23 and 24 September an oral presentation was made on the technical status of the Program.

In compliance with General Provision No. 48, Materials Report (September 1962) SNPO - Form 417 (Mod.) of the Contract, the Materials Report for the first 6-month period of the Contract from 15 February through 15 August 1965 was submitted to the Contracting Officer in September. (RP-DR-0001)

On 12 October 1965 lithographed copies of the Technical Status Report view-graphs were distributed to the attendees of the 23 and 24 September 1965 presentation. (RP-TM-0001)

The first Quarterly Report (RP-QR-001) for the period 18 May through 31 August 1965 was distributed in final form on 22 October according to the list furnished by the SNPO Technical Director.

Monthly Progress Reports for September and October were submitted on 22 October and 19 November, respectively. (RP-MR-0005 and 0006)

2. Work Planned for the Next Quarter

Reports required by the Work Statement plus other contractually-required or customer-requested reports will be submitted to SNPO-C. Included will be the revised and finalized edition of the second Quarterly Report (specified under this task).

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TASK 0 - PROCUREMENT OF ADDITIONAL MATERIALS

a Work Performed During the Quarter

(1) General Procurement

The INOR-8 material requirements received to date include all the plate and bar on order, (See Table 14). Samples of the INOR-8 weld wire considered sub-standard at Allvac were shipped to AGC for evaluation. Successful weldability tests per the requirements of AGC 90059C were completed on INOR-8 CEVM material Heats 5911, 5913 and 5914. Ring forgings, sheet, and strip stock are scheduled for shipment in December.

None of the Allvac 625 materials on order have been received at AGC. (See table 14). Weldability tests and the drawing of weld wire are precluding any shipments

(2) INOR-8 Weldability Tests

Successful weldability tests per the requirements of AGC 90059C were completed on INOR-8 CEVM Material Heats 5911, 5913, and 5914.

Metcut Research Associates, Inc., Cincinnati, Ohio, conducted the tests under contract to Allvac Metals Co., Monroe, North Carolina. Metcut contracted with Beckmann Welding and Engineering and Gladstone Laboratories of Cincinnati to perform the welding and radiographic inspection, respectively, as required by AGC 90059. The foregoing companies were previously visited by a Phoebus Quality Assurance representative and the facilities and personnel surveyed and certified as acceptable for their separate functions in the performance of the weldability tests.

Test welding proceeded satisfactorily and all of the weldability test operations were conducted under the observation of a Phoebus materials representative.

Table 14
Material Development Procurement

INOR-8

ITEM	MATERIAL FORM	MELT	SIZE	QUANTITY	HEAT NO.	SPECIFICATION	SPEC. DEVIATIONS	NO. OF HEATS	END USE	VENDOR	P.O. NO.	P.O. DATE	DEL. DATE
30	Plate	CEVM	1½"x4"x12"	6	294-5-0100	Controlled Chemistry		1	Development	Union Carbide	201260	4-6-65	6-7-65
31	Weld Wire	Air Melt	.045 dia.	50 lbs.	NI-5059	Controlled Chemistry		1	Development	Union Carbide	201261	4-6-65	6-21-65
32	Weld Wire	CEVM	.045 dia.	50 lbs.		Controlled Chemistry		1	Development	Union Carbide	201261	4-6-65	(9-19-65)
33	Weld Wire	CEVM	.062 dia.	25 lbs.		AGC-90058A Amend.I		1	Deliverable Prp.	Allvac Metals	201271	6-16-65	(11-5-65)
34	Weld Wire	CEVM	.062 dia.	100 lbs.		AGC-90058A Amend.I		2	Deliverable Prp.	Allvac Metals	201271	6-16-65	(11-5-65)
35	Bar	CEVM	¾" dia.	150 ft.		AGC-90060	(*)(#)	1	Deliverable Prp.	Allvac Metals	201271	6-16-65	11-10-65
36	Plate	CEVM	1½"x6"x12"	4		AGC-90057A Amend.I		2	Deliverable Prp.	Allvac Metals	201271	6-16-65	11-16-65
37	Sheet	CEVM	.050"x12"x48"	1		AGC-90057A Amend.I		1	Deliverable Prp.	Allvac Metals	201271	6-16-65	(12-20-65)
38	Strip	CEVM	.012"x8"x90"	12		AGC-90057A Amend.I	**	3	Deliverable Prp.	Allvac Metals	201271	6-16-65	(12-31-65)
39	Ring Forging	CEVM	23"x17"x6"	2		AGC-90056B		1	Deliverable Prp.	Viking Forge	201278	7-1-65	(12-1-65)
40	Ring Forging	CEVM	23"x17"x6"	2		AGC-90056B		1 Other Than Item 39	Deliverable Prp.	Viking Forge	201278	7-1-65	(12-1-65)
41	Ring Forging	CEVM	23"x17"x6"	2		AGC-90056B		1 Other Than Items 39 & 40	Deliverable Prp.	Viking Forge	201278	7-1-65	(12-1-65)
42	Plate	CEVM	1½"x4"x12"	4		AGC-90057A Amend.I		1 Other Than Item 36	Development	Allvac Metals	201877	9-10-65	12-26-65
43	Plate	CEVM	1"x4"x60½"	2		AGC-90057A Amend.I		1	Development	Allvac Metals	201877	9-10-65	(12-1-65)

Legend - * .001 Boron Max.
 ** Min. Elongation - 30% and 15%, R.T. and 1200°F
 # 0.50 in./min. Crosshead Speed Permissible, Yield to Rupture
 @ Delivery dates contingent upon successful weldability tests.
 () Promise Date

ALLVAC-625***

50	Weld Wire	CEVM	.062 dia	75 lbs.		AGC-90058A Amend.I	A	3	Deliverable Prp.	Allvac Metals	201270	6-17-65	(12-31-65)
51	Bar	CEVM	¾" dia.	150 ft.		AGC-90060	A	1	Deliverable Prp.	Allvac Metals	201270	6-17-65	(11-12-65)
52	Plate	CEVM	1½"x12"x36"	9		AGC-90057A Amend.I	A	3	Deliverable Prp.	Allvac Metals	201270	6-17-65	(11-19-65)
53	Sheet	CEVM	.050"x12"x48"	1		AGC-90057A Amend.I	A	1	Deliverable Prp.	Allvac Metals	201270	6-17-65	(12-3-65)
54	Strip	CEVM	.012"x8"x30"	3		AGC-90057A Amend.I	A	3	Deliverable Prp.	Allvac Metals	201270	6-17-65	(12-10-65)
55	Plate	CEVM	3/16"x2"x60"	1		AGC-90057A Amend.I	A	1	Development	Allvac Metals	201878	9-9-65	(11-15-65)
56	Strip	CEVM	.012"x2"x60"	9		AGC-90057A Amend.I	A	1	Development	Allvac Metals	201878	9-9-65	(12-10-65)
57	Strip	CEVM	.008"x3"x60"	1		AGC-90057A Amend.I	A	1	Development	Allvac Metals	201878	9-9-65	(12-17-65)

Legend - A 7.50 - 10.00 Molybdenum Range
 () Promise Date
 *** All Procurement Pending Weldability

INOR-8 material possessed good weldability characteristics and the weld passes did not contain surface oxide deposits previously noted and considered an apparent characteristic of Hastelloy X welds.

Metallographic specimens were prepared on four weld cross sections which were removed from each weldment per the requirements of AGC 90059. No crack defects were found in the parent metal or in the transition zone.

b. Work Planned for the Next Quarter

Monitoring procurement of INOR-8 and Allvac 625 materials will continue. Shipments will be placed in bonded storage as directed.