REON

SACRAMENTO PLANT

REPORT NO. RP-MR-0012
TO
SPACE NUCLEAR PROPULSION OFFICE - CLEVELAND EXTENSION

PHOEBUS-2 MONTHLY PROGRESS REPORT (U)
FOR THE PERIOD OF
1 JULY THRU 31 JULY 1966

AUGUST 1966

CONTRACT SNPC-35

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ROCKET ENGINE OPERATIONS - NUCLEAR

CONTRACT SNPC-35

AUGUST 1966

CLASSIFICATION CATEGORY

UNCLASSIFIED

JM Bodley
CLASSIFYING OFFICER

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DATE

AEROJET - GENERAL CORPORATION
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FOREWORD

This report is published in response to and in partial fulfillment of item 4, Task I, Article I - Statement of Work, of Contract SNPC-35 and item 3, Task N, Article I - Statement of Work, of Modification No. 1, Supplemental Agreement to Contract SNPC-35.

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TASK G - RELIABILITY AND QUALITY ASSURANCE (STE)

1. Work Performed in July

The High Voltage Engineering contractor personnel schedule for the 2-Mev X-ray unit was arranged and confirmed.

2. Work Planned for August

Installation of the 2-Mev X-ray is to commence August 16.

TASK I - REPORTS (CPFF)

1. Work Performed in July

Weekly reports to SNPO-C were prepared and transmitted each Friday (RP-TWX-0066 through 0070).

Ten copies of the Financial Management Report, NASA Form 533, for the CPFF portion of the Contract were submitted to SNPO-C on 25 July.

On 14 July, Heat Transfer To Cryogenic Hydrogen Flowing Turbulently In Straight and Curved Tubes at High Heat Fluxes, RP-TR-0008, and on 15 July, Gas-Side Heat Transfer Experiments on Scale Model Nuclear Nozzle With Reactor Core Simulators, RP-TR-0009, were submitted to SNPO-C.

2. Work Planned for August

Work for August will include reports required by the Work Statement, plus others contractually required to SNPO-C.

TASK J - DESIGN

1. Work Performed in July

a. Convectively Cooled Nozzle

A meeting was held at Los Alamos on 29 July 1966 between LASL and AGC personnel. The purpose of this meeting was the presentation of AGC's Phoebus-2 nozzle operating map and equations. The following is a summary of the material presented:

The coolant pressure drop and the enthalpy rise through the Phoebus-2 nozzle over a range of conditions have been expressed in closed form equations. The six distinct regimes considered were:

- (1) Full nozzle flow, supercritical coolant, no film cooling.
- (2) Separated nozzle flow, supercritical coolant, no film cooling.
- (3) Separated nozzle flow, subcritical coolant, no film cooling.
- (4) Full nozzle flow, supercritical coolant, film cooling.
- (5) Separated nozzle flow, supercritical coolant, film cooling.
- (6) Separated nozzle flow, subcritical coolant, film cooling.

The ranges of conditions considered were:

Chamber Temperature	1000-5000°R
Chamber Pressure	50-800 psia
Gas Flow Rate	18-560 lb/sec
Coolant Inlet Pressure	77-1600 psia
Coolant Inlet Enthalpy	6 - -98 Btu/lb

The principal use for the integral correlations is in systems studies. With the correlations it is easy to depict the interaction between component characteristics and system behavior over a wide range of operating parameters; it is not necessary to include the detailed information which is needed for component design.

A transient-state, two-dimensional conduction analysis was made for the chemical simulation nozzle jacket and aluminum pressure vessel adapter leg. The purpose of this analysis was to update a previous analysis to meet the latest hardware configuration and fluid-flow sequencing during the chemical simulation test. This was done in order to provide the temperature distribution in the component parts to serve as a basis for computing differential contraction during the testing environment. This data is necessary in order to compute the maximum deflection between the adapter and nozzle during the chemical simulation test.

b. Bolt Coolant Circuit

An end-to-end fluid analysis and a steady-state conduction analysis of the flange and bolts were performed in order to determine the adequacy of the nozzle flange coolant system and the minimum total coolant flow rate required. The system was analyzed for flows of 10, 5, 2 and 1 lb/sec respectively. It was found that neither the bolts nor the flange are very sensitive to flow rate. Therefore, coolant maldistribution is not a problem. The minimum recommended coolant flow rate is 2 lb/sec.

c. Stress Analysis

A revision to Phoebus-2 Pressure Vessel/Nozzle Interface Analysis, Part IV, Stress Analysis was completed and forwarded to LASL.

The revision included a change in maximum jacket shell thickness from 0.800 to 0.850 in. Jacket wall temperatures were based on 125% of the November 1965 nominal heating rates. Allowable yield stresses were based on the 0.4% offset, minus a 3-sigma strength-versus-temperature curve obtained from the materials test program.

d. Bolt Coolant Line

The bolt coolant line, P/N 1115344, was analyzed for chemical firing start transients and for chemical firing and nuclear steady state conditions. Differential motion of the ends of the line was considered. All margins of safety are positive.

e. Material Design Properties

Initial proof-testing was started, with the biaxial, elastic-plastic strain test using a full reverse bend. The specimen was cycled 17 times, at which point the roughened (orange peel) surface condition - noted also on the previous specimen - developed dye penetrant indications. The specimen also experienced some reduction in cross-section with the concomitant increase in length. Testing will continue to failure. The test parameters being used are as follows:

Temperature, °F	Room
Axial Load, lb	11,700*
Lateral Load, lb	5260
Center Deflection, in.	0.270
Equivalent Stress, ksi	320**
*85% of 0.2% offset yield stress	

**Theoretical outer fiber stress assuming all elastic behavior

The first test specimen (87 cycles without failure) which was exposed to a uni-directional lateral load was found to be Rockwell C28 in the test section compared to an original hardness of 90- to 95-Rockwell B. The hardness qualitatively corresponds to about 10% cold work and indicates a tensile and yield strength of about 130 ksi and 100 ksi, respectively.

f. Adapter Leg

Drawing 1117833 for reworking film cooled to convectively cooled adapter leg was released.

2. Work Planned for August

Work will be initiated to investigate the newly defined emergency shutdown. Complete biaxial testing of material specimens will be performed.

TASK K - FABRICATION

1. Work Performed During July

a. Convectively Cooled Nozzle

(1) Fabrication

Electric Discharge Machining (EDM) of nozzle jacket S/N 880600 grooves, scallops and feed holes was completed on 29 July 1966.

Contour machining of the I.D. and O.D. and drilling of the 144 bolt coolant feed holes was completed on S/N's 880601 and 880603. S/N 880601 was set up for mechanical grooving and S/N 880603 will be prepared for E.D.M. S/N 880604 completed welding and annealing and was delivered to the machining vendor for contour machining.

Welding of nozzle jacket S/N 880605 was initiated.

(2) Nozzle Welding

This month's welding activity was marked by the successful completion of proof-of-station welding tests for the Cayuga boom welding unit installed in the new Phoebus welding facility in Building 20004, and the utilization of the plastic canopy for the first time in welding Nozzle Jacket S/N 880604 (Figure 1). The final radiographic inspection of the forward and aft joints (Nozzle S/N 880604) revealed no rejectable weld defects per the acceptance criteria of AGC 9005 Class 1, and no discontinuities were detected by ultrasonic inspection.

(3) Braze Development

The first two 20-inch braze specimens were assembled and brazed at Pyromet, Inc. During the first braze cycle of Specimen No. 1 a heating rate slightly faster than the NERVA braze cycle was allowed (approximately a 100°F metal parts differential instead of 50°F) in order to limit aluminum oxide formation. Otherwise, the first

Figure 1
The Transparent Plastic Canopy in Position Over
Phoebus Weld Station

and second cycles conformed to AGC 90006. The changes in the third cycle involved variations in the application of Nicoro-80; one tube joint had all the fine mesh alloy, another the coarse, and two other joints had commercial Nicoro-80 alloy with an 0.5% phosphorous addition. The 0.5% phosphorous Nicoro-80 displayed improved flow characteristics; however, intermetallic compounds of phosphorous were identified during microexamination.

The significant changes to Specimen No. 2 were the use of nickel plating on one-half the tubes and the use of non-plated tubes for the other half. The nickel plated tubes were brazed with standard Nicoro-80 while the unplated tubes were brazed with Palcusil on the last cycle. Palcusil has better wetting and flow characteristics than the Nicoro-80 as a final cycle braze alloy on unplated channels. Four different commercial heats of Nicoro-80 have been subjected to comparative flow tests with no appreciable differences in wetting angles at normal brazing temperatures.

Cursory evaluation of the final braze cycle difficulties caused by aluminum oxide formation revealed that the best results were obtained, as judged by braze alloy fillet appearance and flow characteristics, by nickel plating the coolant tubes and spacer faying surfaces. Hand torch braze repair of furnace braze leaks will also be enhanced by the high fillet retained on the nickel plated tubes.

A review of the brazing results was conducted during a meeting at Pyromet on 26 July 1966. The meeting was held among representatives of Pyromet, SNPO-C, and Aerojet-General. The difficulties were reviewed, test results from ORNL and Pyromet were analyzed (including quality of atmosphere) and the various solutions thoroughly discussed. The agreed upon effort was to proceed with the nickel plating, using the Palcusil alloy as a back-up, and to conduct a qualitative experiment on the benefits of a titanium getter addition to the 30-inch diameter retort furnace at Pyromet. Specifically, the following plan was devised: first, the remaining full-length contoured braze sector will be processed with one-half of the tubes nickel plated using Nicoro-80 for the final braze cycle and the remaining tubes using Palcusil alloy for the final cycle; and second, the remaining 20-inch specimen will be brazed in Pyromet's 30-inch retort furnace with suitably distributed containers of titanium chips to evaluate its getter-qualities for atmosphere improvements.

Ten coolant tubes were sent to Model Plating in Los Angeles for nickel plating. The tubes will be used for plating evaluation and three will be employed in the fullscale sector for brazing.

b. Injector

The face rings of the second article injector were installed and brazed. Work on the installation of the baffles was initiated.

c. Nozzle Test Assembly

The nozzle and adapter leg were disassembled from the test assembly without difficulty following the test assembly hydrostatic proof test.

2. Work Planned for August

a. Convectively Cooled Nozzle

Complete brazing evaluation of full length sector.

Thermocouple pass through holes will be drilled in S/N 880600. It will then be shipped to Pyromet where brazing preparation will begin.

Mechanical grooving of S/N 880601 will be initiated

S/N 880603 will be installed in EDM tooling and grooving will be initiated.

I.D. and O.D. machining will be initiated on S/N 880604.

Welding of S/N 880605 will be completed.

b. Injector

The baffles will be installed and brazing will be completed. Final machining will be initiated.

c. Nozzle Test Assembly

The film cooled adapter leg will be reworked to a convectively cooled leg, in accordance with Drawing 1117833.

TASK N - REPORTS (CPIF)

1. Work Performed in July

Transmittal of weekly reports to SNPO-C continued each Friday (RP-TWX-0066 through 0070).

Ten copies of the Financial Management Report, NASA Form 533, for the CPIF portion of the Contract were submitted to SNPO-C, 20 July.

Biweekly PERT Reports were submitted to SNPO-C, 1, 15, 29 July (RP-PR-0026 through 0028).

The Monthly Report for the period, 1 June through 30 June, was submitted to SNPO-C on 29 July, with distribution as directed by the SNPO-C Technical Director.

2. Work Planned for August

Reports required by the Work Statement plus other contractually required or customer requested reports will be submitted to SNPO-C.

TASK 0 - MATERIALS PROCUREMENT

1. Work Performed in July

Allvac has completed an annealing evaluation on strip stock and recommends the use of $1825^{\circ}\text{F} \pm 25^{\circ}\text{F}$ to provide adequate yield strength to meet the requirements of AGC 90057, but with some decrease in tensile elongation. Typical results with the 1825°F annealing treatment were as follows:

<u>TEST TEMP ($^{\circ}\text{F}$)</u>	<u>UTS (KSI)</u>	<u>YS (KSI)</u>	<u>ELONG (%)</u>
Room	129.0	69.5	39.5
1200	100.0	55.2	24

The results are consistent with the room temperature properties guaranteed by Huntington Alloys which are 120 ksi UTS, 60 ksi YS, and 30% elongation for process annealed material (nominally 1800°F) and will meet the requirements of Specification AGC 90057. The 0.012-in. and 0.008-in. thick strip will be accepted in this condition.

2. Work Planned for August

Continue monitoring Allvac 625 procurement.