~~CONFIDENTIAL~~

SNPO-C

MASTER

~~Records~~

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

RN-TM-0143
3 December 1964

DECLASSIFIED
Class u
RBM U 3-1-82

REON TECHNICAL MEMORANDUM

Tube Wall Temperature Evaluation Program

Summary To Date : ,

Classification cancelled for changed to
by H.F.C. TIC, date SEP 11 1973

GROUP 3

DOWNGRADED AT 12 YEAR INTERVALS
NOT AUTOMATICALLY DECLASSIFIED
DOD DIR 5200.10

DOD OFFICIAL (NAME, TITLE AND MIL. DEPT. OR AGENCY)

AGC OFFICIAL CERTIFYING CLASS ☐ AND/OR GROUP ☐
INDICATE NAME (TYPED OR PRINTED) SIGNATURE AND DEPT. NO.

Author:

Approved:

REON Technical Staff:

RE Rice
R E Rice

L. A. Shurley
L A Shurley

J. J. Peterson
J J Peterson

~~This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., section 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.~~

UNITED

(00 0)

~~CONFIDENTIAL~~

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

~~CONFIDENTIAL~~

RN-TM-0143
3 December 1964

REON TECHNICAL MEMORANDUM

Tube Wall Temperature Evaluation Program

Summary To Date ()

GROUP 3

DOWNGRADED AT 12 YEAR INTERVALS
NOT AUTOMATICALLY DECLASSIFIED
DOD DIR 5200.10

DOD OFFICIAL (NAME, TITLE AND MIL. DEPT. OR AGENCY

AGC OFFICIAL CERTIFYING CLASS ☐ AND/OR GROUP ☐
INDICATE NAME (TYPED OR PRINTED) SIGNATURE AND DEPT. NO.

Author:

RE Rice
R E Rice

Approved:

L A Shurley
L A Shurley

REON Technical Staff:

J Peterson
J Peterson

(99.0)

~~CONFIDENTIAL~~

TABLE OF CONTENTS

	<u>Page No.</u>
I INTRODUCTION	1
II CONCLUSIONS	1
III RECOMMENDATIONS	2
IV EXPERIMENTAL METHODS	3
V TEST PROGRAM	5
VI TEST RESULTS AND DATA DISCUSSION	7
VII APPENDIX	
Chart 1 - Summary of Tests Related to Hot Gas Wall Temperature Measurement	
Figure 1 - Pre-fire Photo of S/N 012 Nozzle with Tempilaq Paint	
Figure 2 - Post-fire Photo of S/N 012 Nozzle with Tempilaq Paint	
Figure 3 - Shielded Thermocouple	
Figure 4 - Thermocouple Installation	
Figure 5 - Braze Alloy Application - NERVA Nozzle	
Figure 6 - Chamber Heat Markings - S/N 012 Nozzle	
Figure 7 - Post-fire View of Braze Deposits - S/N 012 Nozzle	
Figure 8 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-001	
Figure 9 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-002	
Figure 10 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-003	
Figure 11 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-004	
Figure 12 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-005	
Figure 13 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-006	
Figure 14 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-008	
Figure 15 - Results of Braze Alloy Deposition Test 1.2-04-NNJ-010	
Figure 16 - Results of Braze Alloy Deposition Test 3.4-05-NNJ-001	
Figure 17 - Results of Braze Alloy Deposition Test 1.2-05-NNJ-001	
Figure 18 - Results of Braze Alloy Deposition Test 1.2-05-NNJ-002	
Figure 19 - Results of Braze Alloy Deposition Test 1.2-05-NNJ-004	
Figure 20 - S/N 0260 Injector	

I. INTRODUCTION

A basic activity in the development of a liquid rocket thrust chamber is the design of the regenerative coolant tubes.

Since the inception of the NERVA program, the various coolant tube designs have been based on heat transfer correlations derived from scale model laboratory tests. The application of the scale model heat transfer correlations to full scale thrust chambers under maximum operating conditions has never been fully justified.

Prediction of hot gas side tube wall temperature is one of the principal factors in the selection of a coolant tube design. The accuracy of the heat transfer correlations in predicting wall temperature is one of the primary unknowns in the nozzle program at this point.

The purpose of this document is to present the current status of the experimental program for gas side wall temperature determination. Included within are the methods considered, the results of these methods to date and comparison of the data obtained to predicted values. The conclusions drawn from the test results lead into future tasks to improve existing techniques and to extend the techniques to new applications.

II. CONCLUSIONS

The following statements summarize the conclusions reached thus far in the program to evaluate gas side wall temperature.

1. The two types of temperature sensitive paint used are not feasible for this application. Their use has been discontinued.
2. Data from the shielded thermocouples is inconclusive. Since the use of these devices is limited to only a few locations on obsolete cast nozzles and tests in the future will be concentrated on steel nozzles, their use is being discontinued.

~~CONFIDENTIAL~~

3. The data obtained from the braze deposits have shown that the method is feasible. However, it is apparent that a closer resolution of temperature is needed in the range below 1125°F and above 1600°F.

4. The injector induces a hot gas flow stratification in the chamber. Heat markings on the tubes indicate that the stratification has a significant effect on local wall temperatures. A greater number of braze deposits are needed to determine both hot and cold zone heat transfer characteristics.

5. The chamber non-uniformity has made it difficult to tie the braze data in with wall temperature predictions. At present, no conclusions have been reached regarding the agreement of data and predictions.

III. RECOMMENDATIONS

The partial success to date of the braze deposit method for determining wall temperature indicates the need for further work in this area. The required tasks have been outlined as follows:

1. Make post-fire examinations of the deposits and relate the indicated temperatures to predictions. Continue to apply braze alloys to nozzles slated for chemical firing. Expand the number of alloys used to indicate wall temperatures in both hot and cold zone.

2. Continue a parallel effort in heat transfer analysis to more clearly define the actual conditions in the chamber from test data, braze alloy indications, and qualitative observations such as the chamber heat marks.

3. Locate and evaluate new braze alloys to improve the range of the alloys currently in use. Particular temperature regions are below 425°F, between 425°F and 725°F, between 725°F and 1125°F and over 1600°F.

~~CONFIDENTIAL~~

4. Extend the same technique to the coolant tubes of the nozzle to injector adapter. Data from this location would be useful for interpretation of the injector fuel film cooling effect.

5. Consider application of the alloys to the entrance section of the hot gas bleed port to evaluate operating wall temperatures of the port. Compare the data to predictions.

6. Investigate a flamespray method for plating the alloys over the entire length of coolant tubes. Determine feasibility, method of application and effect on alloy remelt temperature.

7. Evaluate the braze alloy - coolant tube bond for thermal resistance. Compare the resistance of an untreated coolant tube with that for tubes with braze deposited with a torch and braze deposited by flame spraying.

8. Consider use of an injector without baffles or with modified baffles to prevent stratification of fuel under each baffle leg.

IV. EXPERIMENTAL METHODS

The following three methods for determination of gas side wall temperature have been studied:

1. Application of Temperature Sensitive Paints

There are several paint-like products on the market which exhibit a visual change in appearance when subjected to elevated temperatures. Of these products, two were selected for trial in the wall temperature program.

One is marketed under the trade name of "Tempilaq" by the Tempil Corporation. A series of paints are available with calibrated reaction temperatures ranging from 100 to 3200°F. Upon reaching the specified temperature the paint reacts by melting. The surface glazes over and is distinctly different in appearance.

The other paint is marketed as "Dectectotemp" by Curtiss-Wright. This series of paints comes in several colors. Upon reaching the calibrated reaction point, the paints change to a vividly different color. Some of the paints have two or even three color changes at progressively higher temperature points. The paints are applied by spray or brush to the nozzle coolant tubes. A range of melting points is represented by using several of the appropriately calibrated colors of paint. Documentation of the procedure is made by color photographs taken before and after the tests.

2. Shielded Thermocouples

A second approach was to install thermocouples directly on the crown of the coolant tubes. The application was very difficult and required a custom made thermocouple. The chromel-aluminal thermocouple, as shown in Figure 3, was utilized. The installation was through the thermocouple pass-through located in the nozzle convergent section. The shielded thermocouple was brazed between the tubes to the tube division where it passed up the crotch of the tube division joint to be brazed in a small notch virtually on the tube crown. See Figure 4.

Millivolt response during the hot firing was to indicate the tube wall temperature at the thermocouple junction.

3. Braze Alloy Application

The third and most elaborate approach was the application of braze alloys to the coolant tube crowns. After a series of metallurgical tests, the nine braze and solder alloys tabled below were selected for use in the program:

Alloy

No.	Trade Name	Manufacturer	Composition	Solidus	Liquidus
1	Eutecrod 157	Eutectic	Sn - Ag*	400°F	425°F
2	Eutecrod 155	Eutectic	.95Sn-.05Ag	700	725
3	Easyflow 45	Handy & Harman	.45Ag-.15Cu .16Zn-.24Cd	1125	1145

* Composition proprietary

~~CONFIDENTIAL~~

Alloy .

No.	Trade Name	Manufacturer	Composition	Solidus °F	Liquidus °F
4	E.R.	Handy & Harman	.56Ag-.22Cu .17Zn-.05Sn	1145	1205
5	Easy	Handy & Harman	.65Ag-.20Cu-.15Zn	1235	1310
6	Hard	Handy & Harmon	.75Ag-.22Cu-.03Zn	1365	1450
7	A.T. Special	Handy & Harmon	.20Ag-.45Cu-.35Zn	1430	1500
8	N.E.	Handy & Harmon	.25Ag-.525Cu-.225Zn	1500	1575
9	T.E. Special	Handy & Harmon	.05Ag-.58Cu-.37Zn	1575	1600

The alloys are applied by oxy-acetylene torch on the tubes of nozzles to be tested as shown on Figure 5. The .250 inch patches are hand dressed to a thickness of two to four mils.

The melting pattern of the braze alloys during a test would indicate the approximate hot gas tube wall temperature. For documentation purposes, close up color photographs are taken of all alloy deposits before and after firings.

V. TEST PROGRAM

Chart one presents a summary of the chemical tests where one or more of the techniques for wall temperature evaluation were utilized. Included on the chart is the hardware tested, the test conditions and the experimental technique(s) utilized.

Details on each of the three methods are discussed below:

1. Temperature Sensitive Paint

Hybrid Nozzle S/N 002H was tested three times with "Detecto Temp" paint applied to the coolant tubes in the convergent section, (tests 3.4-04-NNN-003, 004 and 005). The paint was re-applied after each of the first two tests. The paint was sprayed on for tests 003 and 004 and applied by brush for test 005. On the second re-application, a protective shellac was applied over the paint in an attempt to improve its tenacity. "Tempilaq" was brushed on the tubes of S/N 012 nozzle prior to Test

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

1.2-04-NNJ-001. Pre-fire and post-fire documentary photographs from this test are included as Figures 1 and 2. The reaction points of the paints shown on the figures are, reading clockwise: 600°F (red), 700°F (yellow), 800°F (light green), 900°F (light yellow), 1000°F (chalk white) and 1200°F (white).

2. Shielded Thermocouples

Three thermocouples were brazed into S/N 015 nozzle as shown on Figure 4. One junction was damaged during handling, but the remaining two returned data during Test 3.4-05-NNN-001. The test assembly was removed from the stand after this test for repair of the injector. The two remaining thermocouples were subsequently damaged beyond repair during handling. No other tests have been conducted with thermocouples installed.

3. Braze Alloy Application

To date, two nozzles have been fired with braze alloy deposits on the coolant tubes can be seen from Chart 1. The test objectives of the 1.2-01-NNJ series on S/N 012 nozzle called for an incremental reduction of coolant flow rate on each succeeding test. The purpose was to induce incipient erosion in the nozzle coolant tubes. This objective was fully satisfied on Test 010 of the series when post-test inspection revealed minor erosion in the throat area.

The 3.4-05-NNN series with S/N 015 nozzle was terminated after one test due to injector erosion. Subsequently, an injector of different design replaced the damaged part and the 1.2-05-NNJ series was conducted with the same nozzle. This series being for injector development was conducted at approximately the same flow and chamber conditions on each of the tests as noted on Chart 1.

Complete inspection of the braze deposits was not possible on the test stand. Only those deposits in the divergent section can be viewed directly. Inspection of the area above the throat must be made after the injector is removed from the test assembly when the test series is completed.

~~CONFIDENTIAL~~

Thus, the complete experimental temperature profile was obtained only from Tests 3.4-05-NNN-001, 1.2-04-NNJ-010 and 1.2-05-NNJ-004. The other tests in these series have inspection of the deposits in the divergent section only.

Figure 7 depicts a typical post-test photograph of the alloys. This figure applies to S/N 012 nozzle, Test 1.2-04-NNJ-010. Note that alloys number 1 and number 2 have melted indicating a temperature between 725° and 1125°.

VI. TEST RESULTS AND DATA DISCUSSION

1. Temperature Sensitive Paint

The results of the four tests where temperature sensitive paint was used were all equally discouraging. It is evident from Figures 1 and 2 that the hot gas environment is too severe for this application of otherwise excellent products. The Figures show the paint was "washed" off the tubes without leaving an indication of temperature. Only the red (600°F) paint showed an indication of temperature on the tube crown. The paint that remained in place in the tube valleys did not show any color or appearance changes.

Although the Figures are of "Tempilaq" as applied to S/N 012 nozzle, the results were similar for the "Detecto Temp" as applied to Hybrid nozzle.

2. Thermocouples

The two thermocouples in S/N 015 nozzle indicated an operating wall temperature of 400 to 430°F at the tube division. The data is shown in comparison to predicted and braze alloy indicated values on Figure 16. It can be seen from the figure that the temperature indicated by the thermocouples is hundreds of degrees lower than either the predicted or braze alloy indicated wall temperatures at that point.

It has not been established if the lower temperature indicated by the thermocouples is due to a misleading millivolt response or if the local wall temperature is near that value indicated. Analysis of the tube division for wall temperature is very complex due to the flow disturbances on both the liquid and gas side.

3. Braze Alloy Application

The results obtained to date from the braze alloys are presented on Figures 8 through 19. For comparison purposes, the predicted wall temperature profile at the test conditions is included on each figure. The predictions are based on 75% of the Lewis equation on the coolant side and Bartz 3D Cg's on the gas side.

It can be seen from the Figures that the agreement with test data is good in some cases and very poor in others. For example, on Test 1.2-04-NNJ-010 (Figure 15) the predicted wall temperatures fall within the range of temperature indicated by the braze alloys at all but on location. On the other hand, on Test 3.4-05-NNN-001 (Figure 16), the indicated temperature was several hundred degrees lower than the predicted values from the tube division aft, but they indicated higher temperatures in the cylindrical and convergent portion. On Test 1.2-05-NNJ-004 (Figure 19), the indicated temperatures were lower at all locations except one in the convergent section.

4. Discussion of Test Program

In reviewing the results above, the discrepancies from test to test may cause one to question the validity of the braze alloy method. But, before judgement is passed, it is pertinent to discuss some additional observations made thus far during the Test Program.

The detailed post-test inspections of the nozzle interior required for evaluation of the braze alloys, have also revealed a pattern of heat markings on the tubes. The pattern consists of eight zones located in the nozzle convergent section. Each of the eight zones is oriented exactly under eight spaces between baffle blades on the injector.

Figure 20 is a photograph of the injector face showing the eight hydrogen cooled baffles. Typical heat marks are shown in Figure 6, a photograph of the coolant tubes in the nozzle convergent section.

~~CONFIDENTIAL~~

These heat marks have been observed on both S/N 012 and S/N 015 nozzles, but appeared to be less severe on S/N 012. This secondary effect may be due to the relative variations in mixture ratio distribution radially across the injector face.

The physical location of the braze alloys in the chamber have, at some locations, been in both the "hot" and "cold" zones. As a result, the relative temperatures have been ascertained and compared. In the convergent section, the wall temperature has been indicated to vary by as much as 800°F in a circumferential direction by moving from a "hot zone" to a "cold zone". Values of experimental wall temperature presented in this document are the highest indication obtained. This is not necessarily in the "hot zone" however, as not enough deposits were placed to get complete resolution of the temperatures.

~~CONFIDENTIAL~~

CHART 1
SUMMARY OF TESTS RELATED TO HOT GAS
WALL TEMPERATURE DETERMINATION

TEST NUMBER	NOZZLE	INJECTOR	Pc		$\dot{W}_{fn}$	DURATION SECONDS	PAINT	METHODS USED	
			PSIA	MR	lb/sec			THERMOCOUPLES	BRAZE
3.4-04-NNN-003	02H	0241	510	8.00	69.4	6.55	x		
-004	02H	0241	537	7.65	73.6	10.10	x		
-005	02H	0241	525	4.70	78.2	3.63	x		
1.2-04-NNJ-001	012	0242	544	4.60	62.0	4.04	x		x
-002	012	0242	553	4.83	65.3	7.68			x
-003	012	0242	558	5.19	53.5	15.65			x
-004	012	0242	551	5.09	50.2	15.69			x
-005	012	0242	566	4.85	48.5	15.49			x
-006	012	0242	559	4.90	45.1	15.48			x
-008	012	0242	569	4.29	47.2	15.36			x
-010	012	0242	564	4.89	39.2	15.50			x
3.4-05-NNN-001	015	0241	548	4.57	70.6	5.25		x	x
1.2-05-NNJ-001	015	0260	566	4.78	69.1	4.67			x
-002	015	0260	564	5.30	65.2	8.15			x
-003	015	0260	557	5.43	65.0	15.17			x
-004	015	0260	559	5.32	63.8	15.16			x

3

Prefire Photo of S/N 012 Nozzle
with Tempilaq Paint
Figure 1

CONFIDENTIAL

CONFIDENTIAL
TEST TYPE 001
0012
CHAMBER S/N
INJECTOR S/N
DATE
TEST NUMBER 12-04-NNJ
9-14-64

Post Fire Photo of S/N 012 Nozzle
with Tempilaq Paint
Figure 2

CONFIDENTIAL

FIGURE 3

FIGURE 4

BRAZE ALLOY APPLICATION NERVA NOZZLE

ALLOY GROUP

ALLOY NUMBER	TRADE NAME	MANUFACTURER	SOLIDUS	LIQUIDUS
1	EUTECROD 157	EUT. WELD ALLOYS	410 °F	425 °F
2	EUTECROD 155	" " "	700	725
3	EASYFLOW 45	HANDY & HARMAN	1125	1145
4	E. R.	" "	1145	1205
5	EASY	" "	1235	1310
6	HARD	" "	1365	1450
7	A. T. SPECIAL	" "	1430	1500
8	N E	" "	1500	1575
9	T. E. SPECIAL	" "	1575	1600

FIGURE 5

Angie Grant CORPORATION

CONFIDENTIAL

CONFIDENTIAL

1A

Post Fire View of Braze Deposits
S/N 012 Nozzle
Figure 7

CONFIDENTIAL

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 8

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 9

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 10

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 11

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 12

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 13

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 14

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 15

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 16

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 17

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 18

RESULTS OF BRAZE ALLOY DEPOSITION

FIGURE 19

Figure 20

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

33