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REPORT NO. RN-S-0498

To AEC-NASA Space Nuclear Propulsion Office

HIGH-TEMPERATURE WATER PENETRATION TEST RESULTS

NERVA Program

Contract SNP-1

January 1969

NUCLEAR ROCKET OPERATIONS

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AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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HIGH-TEMPERATURE WATER PENETRATION TEST RESULTS

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I. INTRODUCTION

Testing of a single stage of a nuclear rocket engine using hydrogen as a propellant necessitates a duct to carry the exhaust gases away from the stand to a point where they can be burned without damage to the test stand. With the engine mounted in a downward firing attitude, the exhaust duct carries the gases downward through a second throat diffuser that aids in achieving a low pressure environment for the engine, and through a 90° elbow where the gases are turned and subsequently directed away from the base of the stand.

This report is directed toward the study of a wet-duct system, or an exhaust gas system in which water is injected into the exhaust gases immediately after exiting from a supersonic diffuser. Injecting water into the gas stream results in an immediate reduction of the effective temperature of the gas stream, eliminating the need for secondary cooling of the duct walls and simplifying structural design problems. The point of water injection in a nuclear rocket engine exhaust duct will be at the inlet to a 90° elbow; therefore, the term wet-elbow is applied to the system. Prior to the start of the test program covered in this report, several small-scale tests were conducted to demonstrate feasibility and to identify problem areas. These tests demonstrated that water injected in sufficient quantities and uniformly distributed in the gas stream would result in reducing the effective temperature of the gas stream, and indicated that structural-cooling problems were minimal. Exhaust gas cooling by the direct injection of water is not a new concept for test stands. This method of cooling is currently used in several test installations. The unique part of the system is the requirement that the gases be turned in some manner immediately after leaving the diffuser. In other systems the water is sprayed into the gas stream from wall-mounted nozzles, and turning is not attempted without film cooling the elbow or until it is assured that the gases are cooled. Due to test stand height limitations, the exhaust duct system currently under study is restricted in the length of duct prior to turning; therefore, rapid cooling of the exhaust gases is required.

Previous small-scale tests have been conducted using exhaust gas ducts about 8-in. in diameter, with flows of heated hydrogen ranging from 1 to 2 lb/sec. The water injection nozzles ranged in size from 0.032 to 0.125 in. in diameter. Analytical techniques were developed that enable prediction of the performance of water-injection systems for full-scale engine testing. A high-temperature test of a quarter-scale wet system was recommended that would determine the validity of these analytical techniques. The desired features of the test facility and rocket engine are:

- a. A test stand with a self-pumping diffuser to reduce the rocket engine exhaust from a supersonic to a subsonic gas system.
- b. A rocket engine with a high-temperature or high-enthalpy level exhaust gas.
- c. An engine with a propellant flow rate an order of magnitude greater than the 1 to 2 lb/sec level achieved in the basic scale-model studies.

The Aerojet-General Propulsion Division's high-altitude test facility (Test Cell J-4) in Sacramento has a system that will meet the preceding requirements. The facility consists of a horizontal test stand with the engine exhausting into a 30-in.-diameter cylindrical diffuser and then into a 6-ft plenum. In the 6-ft plenum, water was injected to cool the exhaust gases. The high-temperature gas source could be provided by a liquid fluorine, mixed-hydrazine-fueled rocket engine operating at a chamber temperature of 7000°R and a propellant flow rate of 20 lb/sec.

This test facility in conjunction with the fluorine engine contained the desired features. The stand was equipped with a supersonic diffuser, a section where water was sprayed into the gas stream and with a steam ejector system to exhaust the gases. The chamber temperature of 7000°R was higher than the 4500° exhaust gas of a nuclear engine; however, the enthalpy level is lower. The

diffuser exit diameter of 30 in. was nearly half the diameter of the diffuser envisioned for a 75,000 lb-thrust nuclear rocket engine. This resulted in a scale size of nearly one-half and was larger than the quarter-scale test size originally recommended. Special test instrumentation was needed to measure system performance. The required special instrumentation consisted of a rake to measure temperatures and pressures in the gas stream. This rake was uncooled and measured gas conditions at distances of 30, 60, 90 and 120-in. downstream from the point of water injection. The only water added to the gas stream was injected at the diffuser exit plane.

The geometric difference between a scale test using this test installation and a scale test of a NERVA exhaust gas duct was the absence of a 90° turn in the duct. This feature could not be included in the test hardware. The tests on the J-4 test stand, although not a direct simulation of a nuclear rocket engine exhaust, fulfilled the need for a large scale test. The test results served as a basis for evaluating the applicability of the analytical methods to the prediction of temperatures and pressures in very hot (7000°R) gas streams with large (30 in.) diameter diffusers and with the injection of water sufficient to cool the gas to saturation temperatures.

These methods were previously compared with relatively low temperature (1500°R) gas flows in small (7 in.) diameter diffusers.

II. SUMMARY

An experimental test program of a water-injection system designed to cool a rocket engine exhaust gas stream was conducted. Analytical predictions of temperatures and pressures in the exhaust gas stream following water injection were made based on two different analytical methods. One analysis method ignored influence of evaporation and was strictly a mixing model. The other method essentially ignored mixing and calculated temperatures resulting from evaporation. The analytical methods were evaluated on the basis of these tests. The first two tests were short-duration tests to measure the subsonic

flow field leaving the diffuser. Subsequent tests were of longer duration, with instrumentation at various distances downstream of the point of water injection to measure the temperature and pressure in the exhaust gas stream. Four tests incorporating a temperature rake were scheduled. However, only two tests could be conducted during the contract year due to limitations in time and availability of test hardware.

Temperature and pressure profiles were measured at distances of 90 and 30 in. downstream from the plane where the 30-in.-diameter duct exhausts into the 72-in.-diameter duct, which is also the plane of water injection. The data were compared with pretest predictions* and found to be adequately represented by the Aerojet water-evaporation model.

It is concluded that the evaporation model is applicable to the design of a water-injection system to rapidly cool a high-temperature gas stream, and is applicable to the design of a wet elbow for a nuclear rocket test stand.

III. DISCUSSION OF HIGH-TEMPERATURE TEST PROGRAM

A. DESCRIPTION OF TEST EQUIPMENT

The high-temperature tests were conducted at the Propulsion Division's high-altitude test facility (Test Cell J-4). The test facility consists of an engine test compartment and an exhaust duct system to scrub the exhaust gases before releasing them to the atmosphere. The exhaust duct system has three sections: (1) a convectively cooled, cylindrical supersonic diffuser section, 30-in. in diameter and 24-ft long which discharges into a 6-ft diameter carbon steel duct, where direct cooling of the exhaust gases by water injection occurs, and (2) a 12-ft-diameter scrubber section. The gases are exhausted from the scrubber by a series of steam ejectors that augment the cylindrical supersonic diffuser in achieving low test-cell pressures. Figure 1 shows the facility for the high-temperature tests.

*Nuclear Division Report, RN-TM-0570, High-Temperature Water Penetration, Pretest Prediction, dated September 1968.

Figure 1 - High-Altitude Test Facility

The selection of fluorine engine thrust chamber hardware for the test was predicated on availability and predicated test life in excess of 300 seconds. It was subsequently decided that reliable test data would be assured only if water-cooled engine hardware were tested. This necessitated the installation of a high-pressure water supply system for the test cell. No other problems were encountered.

The water-injection system in the 6-ft duct originally consisted of three rings of cone spray nozzles arranged around the circumference of the duct. For the current tests these nozzles were replaced with water penetration nozzles located near the exit of the supersonic diffuser as shown in Figure 2. The nozzle spray system consisted of two different nozzle configurations as shown in Figures 3 and 4. The VeeJet 1/2-in. U00200 nozzles were the only nozzles used in the current test program. As originally planned, one test would have included water spray from both the 1/2 and 1-in. VeeJet nozzles to achieve a water-to-gas flow ratio simulating the flow ratio representative of a NERVA engine test. Special orifices were inserted in each water flow line to reduce the water pressure to the nozzle and control the penetration. The water-injection system for the tests was as follows:

Nozzle Code	Water Manifold Pressure, psig	Flow, gpm	Number of Nozzles	Total Flow, gpm
W-2	140	37.5	8	300
X	50	72.2	4	88.8
Y	20	14.16	4	56.6
Z	7	8.38	14	117.2
Total Flow				562.6 gpm
				or 78 lb/sec

The predicted water-spray pattern for this nozzle configuration is shown in Figure 5.

B. SPECIAL INSTRUMENTATION:

The primary method of measuring test conditions was by the use of a special instrumentation rake. The measurements made with the rake are shown

Figure 2 - Water-Injection System High-Temperature Test

NOTE: NOZZLE CONFIGURATION 2 SEE FIGURE 4

Figure 3 - Spray Nozzle Array and Nozzle Configuration 1

SECTION C-C

Figure 4 - Nozzle Configuration 2

Figure 5 - Water-Spray Pattern in Duct

in Figure 6, and additional measurements made in each test are indicated in Figure 7, which show the instrumentation rate location for high-temperature tests -003 and -004.

Included in the instrumentation on the rake are three moisture probes designated as MP-1 through -3. As a heterogeneous mixture of gas-water droplets and water vapor moves from the water-gas interaction plane through the duct, the gas temperature drops as heat is transferred from the gas to the water. The water evaporates and forms steam. The time for complete droplet evaporation is a function of the gas temperature and of the drop size. The evaporation model can be used to predict an average initial droplet size and the amount of water evaporated as the water-gas mixture moves through the duct. To check the calculations it was intended that the gas temperature would be measured at various points in the duct. A probe was designed to perform this measurement. This device is termed a moisture probe (Figure 8) and was designed with an aerodynamic shape to minimize gas disturbance. The stagnation point at the nose of the probe was instrumented with a thermocouple to sense the temperature of the stagnated water and gas, or the local equilibrium temperature, which is the saturation temperature of the water if water droplets are present in the stream. Embedded in the base of the probe is a second thermocouple to sense the temperature of the gas that is free of water droplets. Two small holes were drilled through the housing to provide a means of inducing gas flow into the probe cavity. A probe of this design was included in a series of subscale tests with limited success, and was subsequently included in this series of tests. A series of laboratory tests described in the appendix were conducted simultaneously in an attempt to better define the operational characteristics of the probe. This study indicated that gas temperatures in excess of 1000°F and droplet velocities in excess of 400 ft/sec are necessary to obtain interpretable results.

C. EXPERIMENTAL TEST RESULTS

The parameters specified for the high-temperature tests were: a plenum pressure of 6.5 psia which, based on previous test data, would result in a high subsonic gas velocity exiting from the diffuser; a nominal chamber pressure of 100 psia and a mixture ratio of 1.6; and a test duration of 60 sec, which allows about 15 seconds to achieve a steady-state flow field and up to 45 seconds to record test data.

Figure 6 - High-Temperature Water Penetration Tests,
Instrumentation Rake

Figure 7 - High-Temperature Gas Test Instrumentation

Figure 8 - Moisture-Sensor Probe

1. Test 1186-X01-07-003

Test -003 was conducted on 24 September 1968. Figure 9 is a plot of the chamber pressure and the static pressure in the test cell and the evaporation sections. The chamber pressure after the initial 10 seconds of the test became steady at a pressure level of 120 psia, which is higher than the 100 psia that was expected. The static pressure in the evaporation section oscillated as expected for about 30 seconds at a frequency of 0.75 cycles/sec, then slowly began to increase. As the back pressure increased, the average velocity of the gas exiting from the diffuser decreased, and consequently the dynamic pressure decreased. The total pressure across the duct at a rake location of 90 in. (Figure 10) shows a slightly higher pressure core persisting to this point, with the result that after 37 seconds the transducer was over-ranged and no further pressure data were obtained. It required 12 seconds for the test cell to be evacuated, during which time the rake temperatures all read essentially the same temperature. However, after about 15 seconds, the temperature of thermocouples at radial distances of 0.6 to 0.8 (T_{c-4} and T_{c-5}) and an axial length of 90 in. showed an increasing temperature as indicated in Figure 11. In Figure 11 only the impact thermocouples are indicated, since they have the highest response and are indicative of the presence or absence of water in the stream. Test data for this test show that the temperatures at a radius of 21 to 36 in. increased with time as shown in Figure 12. The moisture probe data shown in Figure 13, with the exception of MP-3 located at a radial location of 0.8, did not vary throughout the test. Figures 2 and 14 are pretest and posttest views of the duct interior. Limited damage of the spray nozzles that extended into the gas stream and were not adequately cooled and blistering of paint are the only apparent effects of the test.

2. Test -004

The final high-temperature test was conducted on 26 September. In this test the instrumentation rake was moved to a station 30 inches from the discharge end of the diffuser. This test was terminated after about 14 seconds

Figure 9 - Test 1186-X01-OJ-003 Vacuum Conditions Plot B

Figure 10 - Test 1186-X01-OJ-003 Total Rake Pressures Plot 2

Figure 11 - Test 1186-X01-OJ-003 Rake Temperatures Plot 3

Figure 12 - Temperature Profile at Sta 90 During Test -003

Figure 13 - Temperature Profile at Sta 90 During Test -003
 Moisture Temperatures Plot 4

Figure 14 - Posttest View Duct Interior, Evaporator Section

due to evidence of poor engine performance. The engine pressure, evaporation section pressures, and test cell pressures are shown on Figure 15. After approximately 9 seconds the chamber pressure trace indicated an adverse condition in the engine, which terminated the test after approximately 14 seconds. Pressures and temperatures (Figures 16 and 17) as recorded on the rake appeared to be very steady for the first 8 seconds, and then simultaneously with stabilization of the test cell pressure the temperature at a radial location of 0.8 (T_{c-5}) began to increase. Posttest inspection of the hardware did not indicate any damage of the test hardware. During this test the total pressure transducer, P_{T-2} , failed 2 seconds after FS-1 (Fire Switch 1).

IV. COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

The pretest predictions based on the two analytical models developed to represent the water-injection cooling system were reported in RN-TM-0570. The test data at essentially the same time during the tests, 13 to 14 seconds after ignition, have been compared with the pretest predictions.

A. DUCT TOTAL AND STATIC PRESSURES

The total and static pressure for tests -003 and -004 are compared with the Greyrad prediction and with the Aerojet prediction in Figures 18 and 19. The Aerojet prediction is lower than the Greyrad prediction and the test data. However, the Greyrad prediction is in close agreement with the actual test results, particularly if the predictions based on a mixing coefficient of 0.0375 are used. Only for this case does either program predict an increase in total pressure near the duct centerline. A Mach number curve has been calculated for these two tests and is shown in Figure 20. As Figure 20 shows, the velocity core exists for some distance, which may be indicative of the rate or degree of evaporation.

Figure 15 - Test 1186-X01-OJ-004 Vacuum Conditions Plot B

Figure 16 - Test 1186-X01-OJ-004 Total Rake Pressure Plot 2

Figure 17 - Test 1186-X01-OJ-004 Rake Temperatures Plot 3

Figure 18 - Duct Pressure Profile at Station 90 in.

Figure 19 - Duct Pressure Profile at Station 30 in.

Figure 20 - Duct Flow Velocity Profile

B. DUCT TEMPERATURES

The thermocouples used to record the stream temperatures were either probes inserted through the duct wall (thermocouples T_{c-6} , T_{c-7} , and T_{c-8}) as shown in Figure 7 or were built into the instrumentation rake. The thermocouples in the rake can be described as impact thermocouples, which are junctions welded to plates designed to stagnate the flow; and moisture probes, in which both an impact or forward thermocouple and free stream or aft thermocouple are employed in measuring duct temperatures.

The temperatures recorded at Station 30-in. are shown on Figure 21 together with predictions by Greyrad and Aerojet. The Aerojet temperature predictions indicated a hot zone (stream tube 1) adjacent to the duct wall where little water was predicted to be present, and a zone (stream tube 3) at a radial distance of 0.63 to 0.78 where the equilibrium temperature was calculated to be 720°R . At other regions, a temperature of approximately 620°R was predicted. The test results at an axial distance of 30 inches tend to support all the predictions, except the hot zone adjacent to the wall. The same results are shown at an axial distance of 90 inches as shown in Figure 22. The Greyrad temperature predictions for these two axial positions do not agree that closely with the test data. The calculated temperatures for a mixing coefficient $C_m = 0.15$ agree with the temperatures at 30 inches but not at 90 inches, and show the increase in temperature recorded at a radial distance of 0.8. Figure 23 is a three-dimensional plot of the temperatures at approximately 14 sec after FS-1 for both tests. The Aerojet temperature predictions were generally good, except for temperatures predicted in the hot zone near the wall. The experimental temperatures did not exceed 670°R during the time interval of the test, which is not consistent with the exceedingly high temperatures indicated by the pretest analysis.

The moisture probe results at the duct centerline, at an axial distance of 30 inches, show evidence of a slightly hotter core. The higher temperature of the aft thermocouple indicates that evaporation is not complete and hot gas exists at this duct position. No other moisture probe results indicated gas stream temperatures higher than the temperature of the leading edge of the probe.

TEST 1186-X01-0J-004
TIME 13.6 TO 14.1 SEC

- THERMOCOUPLE PROBE
- MOISTURE PROBE - FORWARD THERMOCOUPLE
- △ MOISTURE PROBE - AFT THERMOCOUPLE

Figure 21 - Duct Temperature Profile at Station 30 in.

TEST 1186-X01-0J-003

TIME 13.5 TO 18 SEC

Figure 22 - Duct Temperature Profile at Station 90 in.

Figure 23 - Comparison of Measured and Predicted Gas Temperatures

V. CONCLUSIONS

The conclusions in the pretest document appear to be substantiated by the results of these two tests. The Aerojet program adequately predicted all measured temperatures up to a radial distance of 0.8. Near the wall the Aerojet program underestimated the water concentrations. This is a basic program weakness in this region.

The two-dimensional nature of the Greyrad program makes the prediction of pressures in the duct meaningful, and the Greyrad predicted pressures reasonably represented the test data. It is inferred from these test results that increasing the water-gas mixing coefficient from 0.0375 to 0.15 to improve the temperature prediction would result in a correspondingly poorer total pressure prediction.

It is suggested that the Aerojet program be reviewed to improve the prediction of water concentrations in the regions near the wall. When this is accomplished, the program should be quite adequate to predict temperatures of a system in which water from penetration nozzles is injected into an expanding gas stream. The system pressure predictions using the Aerojet program required further analytical work. The Greyrad local pressure predictions appear quite good; however, the temperature predictions are not adequate for short mixing lengths. Using an empirical correction for the mixing coefficient to improve the temperature predictions is apparently not warranted at present.

APPENDIX

LABORATORY EVALUATION OF MOISTURE PROBE

Appendix

I. OBJECTIVE

Determine the operational characteristics of the Aerojet-designed moisture probe.

II. DISCUSSION

A simple probe was designed by Aerojet to measure the temperature of a two-phase, two-component water-gas stream. Spraying water into a high-temperature gas stream will cool the gas stream through evaporation of the water. The rate of heat transfer is a function of droplet size and gas temperature. Because of the complex nature of the process, certain simplifications have been made in an analytical prediction of the gas temperature in such a system. To check the analytical model, a measure of the gas temperature at different places in the system was desired. Ideally, the gas system would be simplified, the water droplets removed from the gas, and the gas temperature sensed, but this was difficult in practice. The moisture probe was devised in an attempt to make this type of measurement without actually removing the water droplets, only preventing them from contacting one of the thermocouple sensors. Figure 1 shows the probe. The stagnation point at the nose of the probe was instrumented with a thermocouple to sense the temperature of the stagnated air and water or the local equilibrium temperature of a film-cooled surface. Imbedded in a cavity at the base of the probe was a second thermocouple to sense the temperature of the gas that is free of water droplets. The aerodynamic shape of the probe results in a low-pressure region near the maximum diameter of the probe. By venting the cavity in the base to this low pressure region, gas flow can be induced into the base of the probe, which increases the response of the probe to system changes, and does not depend exclusively on diffusion as the mode of energy exchange between the thermocouple and the gas stream.

This probe design was tested in several scale-model tests with some qualitative evidence of success, but the operational characteristics of the probe were undefined. A series of laboratory tests was therefore devised to evaluate the probe in a controlled environment.

Appendix

Figure 1 - Sensor Probe Measures Degree of Evaporation in Non-Equilibrium Flow

Appendix

III. EXPERIMENTAL EQUIPMENT

The experimental test setup, as indicated in Figure 2, consisted of a hot gas source, a water spray nozzle, a mixing section, and a measurement section.

The hot-gas supply system for these tests was capable of supplying air, heated by combustion of hydrogen to 1000°F, flowing at 2 lb/sec. The system was known to produce a gas flow across the 3.5-in.-diameter pipe with a temperature variation of not more than $\pm 5\%$ of the mean. The Mach number in the 3.5-in.-diameter duct could be established by flowing a metered amount of ambient temperature air through the heater and diffuser section. By changing the energy input from the chamber it was possible to increase the gas temperature and velocity without affecting the Mach number.

Water was injected into the gas stream through a pneumatic atomizing nozzle. In this series of tests the water supply pressure was held constant and the pneumatic pressure was varied. This had the effect of varying both the droplet size and the liquid capacity of the nozzle.

Two temperatures, 1000° and 1500°R, were selected for testing, which required two water flow rates, 0.061 and 0.125 lb/sec, respectively, to cool the gas. According to the nozzle manufacturer's data, these flow rates were achieved at a water pressure of 60 psig and a pneumatic pressure of 54 and 70 psig, respectively. The mean mass droplet diameters for these flow conditions, according to the manufacturer, are 300 and 600 microns, respectively.

The flow field was observed optically. To obtain visual data, a sheet of near-parallel light, generated by a high-intensity mercury-vapor light, was aligned with the plane of intended observation. Droplets passing through this plane of light were illuminated and could be seen and photographed. Large droplets were readily observed and fine mists of droplets appeared as fog. The flow-visualization data could be correlated with quantitative temperature measurements to identify the probe characteristics.

Figure 2 - Moisture Probe Evaluation Experimental Test Setup

Appendix

IV. TEST PROCEDURE AND DISCUSSION OF RESULTS

Initial tests were with ambient air to permit direct visual observation and to make the necessary manual adjustments of the system. Later tests were with hot air, and all observations were based on photographic results.

A. COLD-FLOW TESTS

Water droplets passing through the light plane reflected light, causing a fog-like appearance and making their presence readily detectable optically. Droplets impacting on the front of the probe often resulted in subdivision of the water into extremely fine particles, which were dispersed into the gas stream. Also, some of the water droplets impacting on the surface remained attached and continued flowing along the probe surface, reforming as large droplets in the turbulent wake behind the probe.

By moving the plane of light along the axis of the probe, the flow field around the probe could be observed. A reversed circulation of the gas was observed in the aft cavity of the probe. Gas was observed (due to reflection of water droplets in the gas) entering the wake and exiting through the vent holes. At a Mach number of 0.2, a misty jet of fine water droplets was observed spouting from the vent holes about 0.12 in. into the gas stream. At lower Mach numbers this effect was not as dominant but still existed. Attempts to achieve a boundary layer trip along the surface of the probe and to reduce the quantity of water entering the wake of the probe were made by wrapping a layer of wires around the probe. The wires appeared to disperse the unwanted water into fine droplets, which were ejected into the gas surrounding the probe.

The water-droplet sizes generated by the pneumatic nozzle at air pressures of 70 and 54 psig were, according to the manufacturer, 300 and 600 microns, respectively. Optical measurements were made across the test section of the location where the moisture probe was mounted. Photographs were taken

Appendix

of the flow field by adjusting the depth of focus to indicate only the desired measurement location. A 500-micron-diameter wire located in this focal plane was related to the diameter of the in-focus droplets in photographs. These tests indicated that the droplet sizes at this point in the duct were on the order of 200 and 400 microns.

B. ELEVATED TEMPERATURE TESTS

The rate of evaporation of the water droplets depends on the available gas temperature and the droplet velocity. If the droplets in the gas stream are not evaporated and they mix with the gas and are drawn into the aft cavity, then the forward and aft thermocouples will show essentially the same temperature. If the droplets are atomized on the front of the probe and no water flows along the probe, the uncooled gases are drawn into the cavity and the gas temperature is either the same or hotter than the forward thermocouple, depending on whether there is sufficient water in the stream to completely cool and saturate the stream. If all the water in the stream is evaporated, the forward thermocouple will be slightly hotter than the aft thermocouple, since it is subjected to stagnation conditions of the gas.

Results of the high-temperature tests are shown in Table 1. The variables in the test conditions are gas temperature water-injection rate and initial mass mean drop size.

Conclusions from this series of laboratory tests are:

1. Changes in drop size had no significant effect on the recorded probe temperatures.
2. Increasing the water-flow rate by a factor of nearly two had no significant effect on the measured gas temperatures.

Appendix

TABLE 1

MOISTURE PROBE EVALUATION TEST CONDITIONS

Run No.	Gas Temp. °R	Gas Mach No.	Gas Velocity ft/sec	Water Injection lb/sec	Meas. Mean Dia. Microns	Probe Temperatures			
						Probe 1*		Probe 2	
						Forward °R	Aft °R	Forward °R	Aft °R
102	530	0.207	233	0.0695	200	526	523.5	52.9	525.5
1102*	530	0.207	233	0.0695	200	526	523.5	529	525.5
202	1489	0.205	389	0.0695	---	606	1017	604	1050
1202	1485	0.214	406	0.0695	---	605	1070	604	1092
302	1020	0.211	332	0.0695	---	585.5	587.5	585	592
1302	1019	0.213	335	0.0695	---	585	740	584	739
402	1023	0.207	325	0.123	---	585	588	585	591
1402	1020	0.207	325	0.123	---	584	720	583	781
502	1500	0.214	405	0.123	---	605	1038	605	1070
1502	1523	0.213	405	0.123	---	604	1047	604	1090

*1000 Series Test Performed with Probe 1 Modified.

Appendix

3. Even when the flow of water was not sufficient to saturate the gas stream the front thermocouple showed a saturated temperature

4. Probe temperatures with or without a boundary layer trip did not differ; therefore, the attempts to alter performance by adding a trip wire were inconclusive.

5. At the water-to-gas flow rates evaluated in this study, the probe appears to indicate a reasonable gas temperature.

6. Probe response to temperature changes is slow.

7. The probe performance should be determined over an extended range of operating conditions so the limits of its applicability are known.

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