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AIR TEMPERATURE NEAR A ROCKET MOTOR EXHAUST FLAME

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ABSTRACT

The temperature distribution of the gases adjacent to a 200-pound-thrust rocket motor flame has been investigated using thermocouples with radiation shields. Measurements were made out to a distance of three feet from the flame center line, at two-foot intervals along the flame length. From the measured values, isotherms in this region have been determined and are shown in graphical form.

Close to the motor thrust, the air temperature at a distance of 10″ or more from the plane center line did not exceed 100°C. However, out near the tip of the flame, temperatures of 300°C were obtained at 24″ from the flame center line.

PROBLEM STATUS

This is an interim report; work is continuing.

AUTHORIZATION

NRL Problem R11-13
RDB Project NR 511-130

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INTRODUCTION

Considerable effort has been expended developing suitable instrumentation for use in investigating various characteristics of the exhaust flames from rocket motors (1 through 9). Since some of the measuring equipment used and proposed must be located near the flame, the temperature distribution near a representative flame has been investigated.

INSTRUMENTATION

Temperature measurements were conducted using the rocket-firing facilities of the U. S. Naval Air Rocket Test Station, Lake Denmark (Dover), N. J., on June 21 and 22, 1952. A modified Aerojet rocket motor was used with monoethylaniline and mixed acid as the fuel and oxidizer. This motor was operated at 300 pounds chamber pressure, and at this pressure developed approximately 2000 pounds thrust. The fuel-to-oxidizer ratio was 0.33 by weight.

Chromel P-Alumel thermocouples with silver radiation shields, a National Bureau of Standards development, were used as the thermal elements (10). Thermocouple temperature was recorded on a Brown 16-channel potentiometer, Model No. 153X62P 16-X-50, which records successively the voltage from each of 16 input connections. Figure 1 shows the thermocouple arrangement at the motor test stand. The circular disks behind the row of couples were used for determining the shock and temperature durability of electromagnetically transparent materials. Figure 2 shows a rocket motor firing with the thermocouple instrumentation beyond the visible tip of the flame. Figure 3 gives the positions of the thermocouples and their support with respect to the flame center line and motor throat for each motor run. The position and size of the large disk shown in Figure 1 is given since it apparently influenced the readings on thermocouple 1. Other observations (not reported here) were made on the disk material. The positions and corresponding highest temperatures of the thermocouples obtained from a number of motor runs are shown in Figure 4. The circled temperature figures are for thermocouple No. 1. Thermocouples 6, 7, and 8 were removed and their support cut off for motor runs 9 through 15.

RESULTS

Considerable variation in the indicated temperature at any thermocouple position was observed during any particular rocket motor run. The firings were of one minute duration, and the recorded temperature fluctuations during this period indicated a thermocouple lag

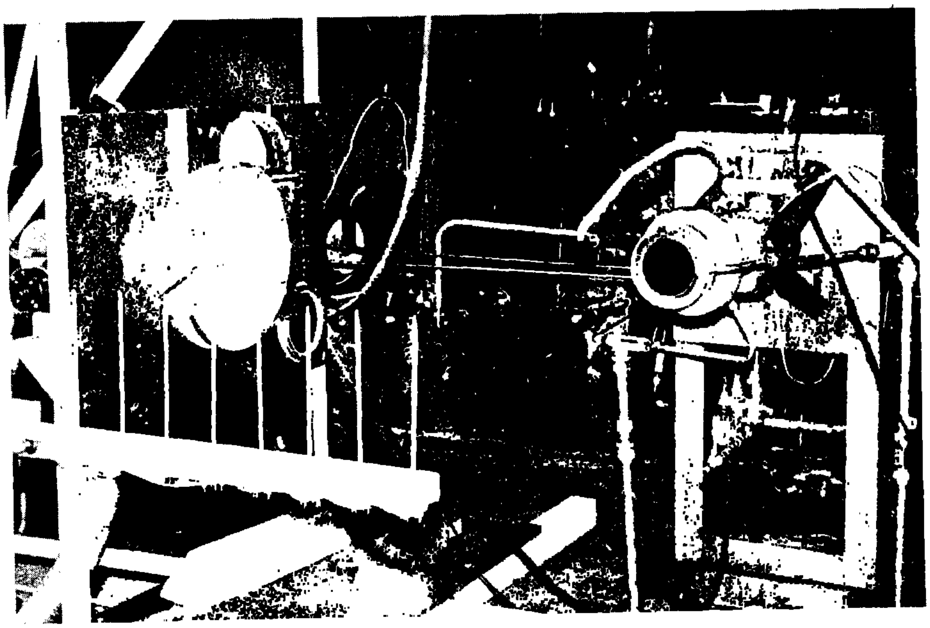

Figure 1 - Thermocouple setup at motor test stand

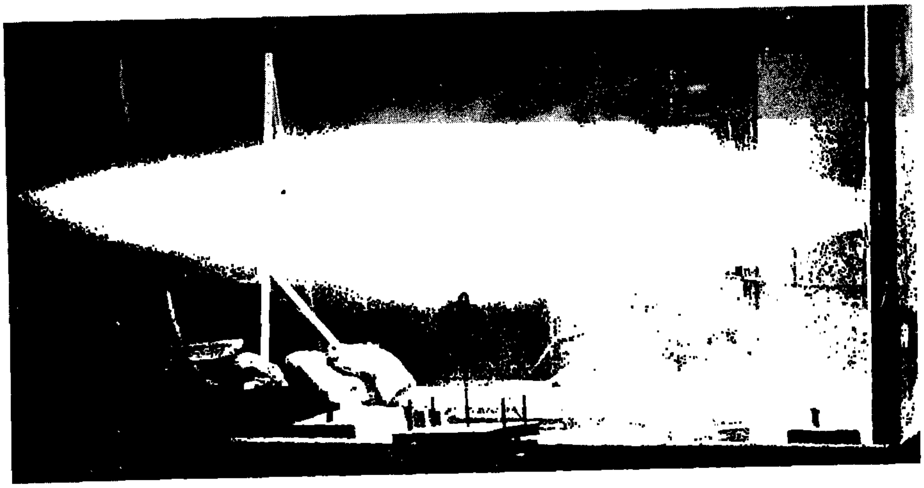

Figure 2 - Rocket motor firing with instrumentation near the tip of the flame

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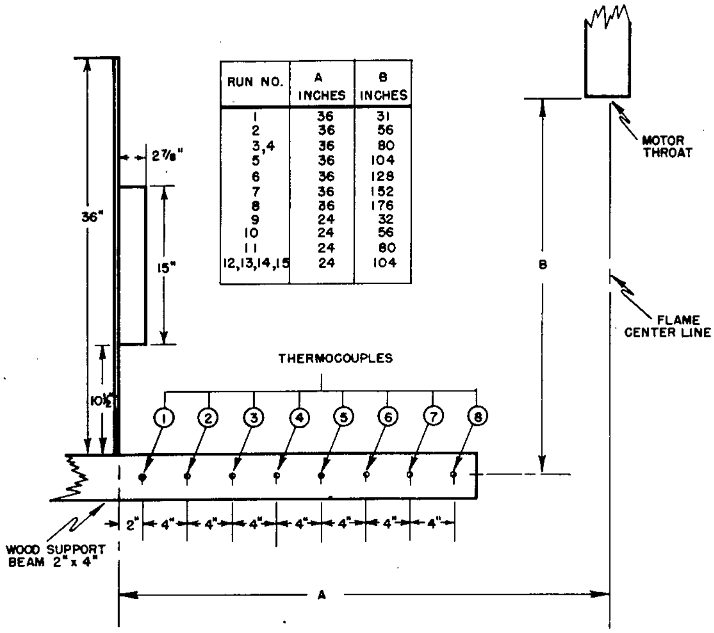

RUN NO.	A INCHES	B INCHES
1	36	31
2	36	56
3,4	36	80
5	36	104
6	36	128
7	36	152
8	36	176
9	24	32
10	24	56
11	24	80
12,13,14,15	24	104

Figure 3 - Plan position of thermocouples

not exceeding five seconds. Although attempts were made to maintain constant rocket-motor performance, small variations in operating conditions were obtained during each run. In addition, the motor used appeared to have poor combustion stability, the shock nodes being visible only to a high-speed camera, and the motor occasionally cut itself off. The temperature variations during a run are assumed to be a result of such instabilities. The highest recorded temperature at each thermocouple position for each run is shown in Figure 4. The temperature variations observed during some runs were as large as fifteen percent of the indicated value.

The radiation shield on thermocouple 8 was torn off by the flame and the thermocouple junction opened during run 2. The thermocouple was not replaced, since later runs would have subjected it to more severe temperature and flame conditions. After run 8, thermocouples Nos. 6, 7, and 8 were removed, the section of 2" x 4" wood beam used for their support cut off, and the supporting frame moved in closer to the flame for the remaining runs. During run 9, the radiation shield on thermocouple No. 5 was torn off by the flame and the junction opened, duplicating the results of run 2 in this respect. Thermocouple No. 5 had the same spatial position during this run that thermocouple No. 8 had during run 2. The thermocouple was not replaced.

As shown in Figure 3, thermocouple No. 1 was partially protected from any air stream parallel to the flame axis. This apparently influenced the temperature reading of this thermocouple, as may be observed by comparing results shown in Figure 4.

Generally, after a motor run, the thermocouple closest to the flame was free of any carbon or aniline deposit, the metal being hot enough to burn this off. Usually the shields of the two thermocouples next closest to the flame were coated with a black deposit after each run, the deposit appearing to be a combination of carbon and unburned aniline. This deposit was removed after each run, though how much its presence interfered with proper thermocouple performance during a run has not been determined. Thermocouples further away from the flame generally remained clean and bright, occasionally being splattered with unburned aniline.

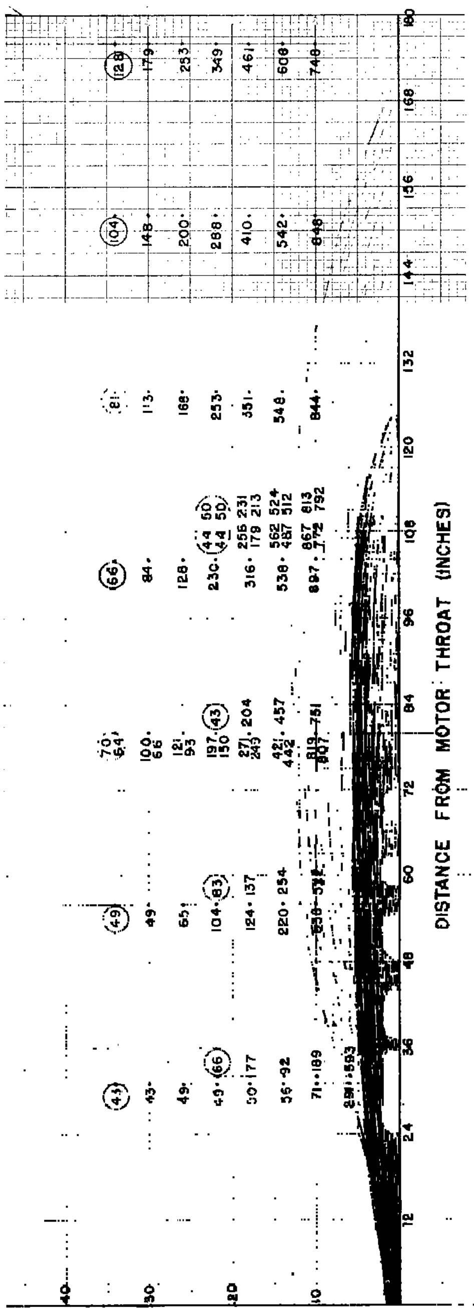

Figure 4 - Air temperature (°C) distribution near the exhaust flame from a 2000-pound-thrust acid-aniline rocket motor

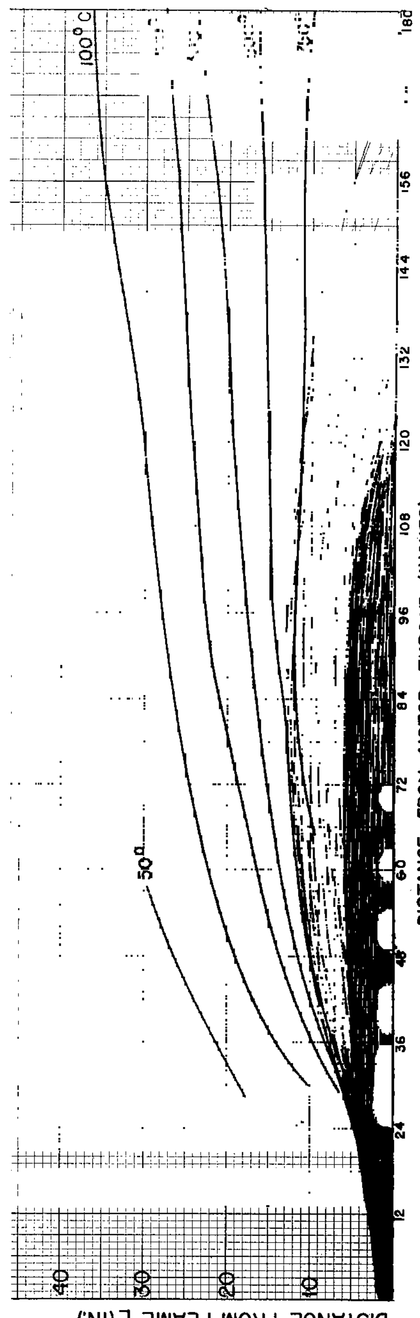

Figure 5 - Air temperature (°C) distribution near the exhaust flame from a 2000-pound-thrust acid-aniline rocket motor

DISCUSSION OF RESULTS

The recorded temperatures are subject to errors resulting from (1) improper functioning of the thermocouple radiation shields, and (2) energy transfer to the thermocouples by impact phenomena from high-velocity gas flow. These two subjects have been discussed extensively in a series of monthly and quarterly reports issued by the National Bureau of Standards during the years 1946 through 1951 under the heading of "Report of Progress on the Development of Thermocouple Pyrometers for Gas Turbines." These and other instrumentation errors are apparently negligible compared to the real temperature variations observed during any one motor run, the variations resulting presumably from instability of rocket-motor operating conditions.

From the results as shown on Figure 4, lines of constant temperature have been estimated and shown in Figure 5. These contours are estimated to be accurate to within ±10 percent.

CONCLUSION

It is concluded that for distances greater than 3 feet from the rocket-motor-flame center line no great instrumentation difficulties will be encountered as far as gas (air) temperature is concerned. Protection from radiant energy however may be required.

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