58 5275 [redacted]

15103
8-OCT 1958

Copy 240
RM E58G17

NACA RM E58G17

7058

TECH LIBRARY KAFB, NM
0143733

RESEARCH MEMORANDUM

EXPERIMENTAL STUDY OF BALLISTIC-MISSILE BASE HEATING WITH OPERATING ROCKET

By J. Cary Nettles

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

Classification ~~cancelled (or~~ changed to Unclassified
By authority of NASA CEN #1, 1 Dec 1963
(OFFICER AUTHORIZED TO CHANGE)
By N. Goddard
NAME AND
A/K
GRADE OF OFFICER MAKING CHANGE)
22 Nov 1963
[redacted]NT

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

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

September 23, 1958

[redacted] [redacted]

TECH LIBRARY KAFB, NM
0143733

 [redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EXPERIMENTAL STUDY OF BALLISTIC-MISSILE BASE HEATING WITH OPERATING ROCKET*

By J. Cary Nettles

5206

SUMMARY

A rocket of the 1000-pound-thrust class using liquid oxygen and JP-4 fuel as propellant was installed in the Lewis 8- by 6-foot tunnel to permit a controlled study of some of the factors affecting the heating of a rocket-missile base. Temperatures measured in the base region are presented from findings of three motor extension lengths relative to the base. Data are also presented for two combustion efficiency levels in the rocket motor. Temperature as high as 1200° F was measured in the base region because of the ignition of burnable rocket gases. Combustibles that are dumped into the base by accessories seriously aggravate the base-burning temperature rise.

CH-1

INTRODUCTION

Early attempts to launch IRBM- and ICBM-type missiles indicated that a very probable cause of malfunction of the missile was excessive temperature in the motor compartment. The existence of this condition was evident in failures of the motor directional drives and premature shutdown of the rocket-motor fuel supply. Current successful firings are made with missiles that have closed-in bases and insulation around all the vital parts. Although this arrangement does make the missile operational, it is not considered satisfactory because the base closure and insulation add weight that reduces the final velocity of the missile and consequently its range. In addition, the closing-in of the motor compartment makes this cavity highly susceptible to explosions due to fuel and oxygen leaks.

EXPERIMENTAL INSTALLATION

A rocket of the 1000-pound-thrust class was installed in the Lewis 8- by 6-foot tunnel to permit a controlled study of some of the factors affecting the heating of a rocket-missile base. Liquid oxygen and JP-4

*Title, Unclassified.

[redacted]

[redacted]

fuel were used as propellants. A photograph of the rocket in operation is shown in figure 1. The model body diameter is 7.875 inches, and the rocket-nozzle discharge diameter is 3.4 inches with a throat-to-discharge area ratio of 8. The nozzle was contoured according to present large-scale motor designs. All of the test firings reported herein were made with a chamber pressure of 500 pounds per square inch absolute. The duration of firing was controlled by the time required to reach an apparent stable temperature in the base region. Average firings were about 45 seconds in duration.

ANALYTICAL STUDY

A simplified diagram that depicts the flow in the base of a typical missile is shown in figure 2. The idea that bound-vortex flow exists in a base such as this has been advanced in numerous references dealing with the study of base pressure (e.g., ref. 1). The generation of vortex flow is associated with mixing profiles that are found between the base region and both the stream and jet flow. Quantities of stream and exhaust gas are transported into the base and mixed together to create a base temperature. The gas that enters the base from the jet also contains unburned products that become potentially combustible when mixed with the stream air.

A calorimetric process for the base was assumed, and the resulting computed temperatures are shown in figure 3. The values of jet-gas concentration w_j/w_a of 0.03 and 0.06 that were selected for the computations were based on experimental measurements made with an NACA fuel-air-ratio meter. For the mixing calculations, all the jet gas was assumed to arrive in the base at jet temperature. The curves indicate that with mixing alone the base temperature can range from 300° to 500° F for the jet-gas concentrations considered. The change of temperature with oxygen-fuel ratio is small. For the case where burning is occurring, the additional assumption was made that all the heat of combustion available in the jet gas was released in the base. Therefore, the values of temperature indicated are theoretical limits and have no special significance.

It is important to note from the curves of mixing plus burning that large temperature rises can occur even with moderate concentrations of jet gas if the mixture is ignited. Also, with burning, the trend is toward reduced temperature rise as the oxygen-fuel ratio is increased toward the stoichiometric value of 3.4. In fact, the reason that the computed temperature rise due to burning does not coincide with the mixing value at an oxygen-fuel ratio of 3.4 is that the rocket-motor combustion efficiency is less than unity.

EXPERIMENTAL RESULTS

Data are shown in figure 4 for firings made with an open base that simulates a missile configuration. Each test point shown represents an individual rocket firing. The temperatures presented are the maximum values observed with thermocouples mounted to measure air temperature; however, the spread between the maximum and the minimum was not great. The temperatures are the result of operation of the rocket motor only; the effect of accessory discharge will be discussed later. In spite of the apparent scatter, the data at Mach numbers of 2.0 and 1.6 tend to fall in two categories. One is a relatively low level and the other is much higher, the higher level being about 1200° F at a Mach number of 2.0. Photographic observations confirm that the high-temperature data coincide with visual burning in the base. A trend of decreasing temperature with increasing oxygen-fuel ratio is observed in most of the high-temperature data.

The base of the missile was closed, and the data from this configuration are shown in figure 5. Temperatures inside the closed cavity were just slightly above stream stagnation temperature and are not shown in this figure. The temperature outside the closed base was somewhat different from that in the open base, but the over-all level was about the same.

The data presented in the previous figures were obtained with nitrogen as the pressurizing gas for the liquid oxygen. Nitrogen dissolves in liquid oxygen and causes a deterioration of the combustion efficiency at a given indicated oxygen-fuel ratio. The use of nitrogen was an expedient, and the reduction in combustion efficiency was not at first considered to be important. Data obtained with helium as the pressurizing gas are shown in figure 6, where it can be seen that the improved combustion efficiency has reduced the temperature, presumably because a smaller quantity of combustibles is present. The difference in combustion efficiency is about 8 points.

If the simplified base flow of figure 2 is recalled, it is logical to surmise that one way of reducing the amount of jet gas entrained in the base is to move the jet rearward so that the mixing zone intercepted by the base streamlines is reduced. The data that were obtained with the motor extension increased from 0.32D to 0.59D, where D is the diameter of the base, are presented in figure 7. It is apparent that moving the motor relative to the base was very effective in reducing the temperature, even though the base was open. Pursuing the idea that, if a little helps, a lot is better, the motor was extended to 0.78D, and the data for this configuration are presented in figure 8. The temperatures indicated in figure 8 are essentially the stagnation values for the tunnel. Independent measurements of the jet-gas concentration in the base indicated that the amount of jet gas in the base was also greatly reduced, being essentially zero for the 0.78D configuration.

5206

Ch-1 back

NACC DAS '58-7300

Extending the motor out of the base introduces the possibility of increased pressure on the motor, especially as the trailing shock is approached in the supersonic case. Typical pressures measured on the motor shroud at a Mach number of 2.0 are presented in figure 9. The computed expansion angle for flow around the base corner into the base pressure region is shown schematically for reference. The pressure rise indicated for the two extended-motor cases is probably due to a feeding forward of the pressure rise of the trailing shock. It is apparent that an estimate of loads on a motor actuator would be very difficult because of the complex flow field.

Four configurations of turbine exhaust are shown in figure 10. Propane was used to simulate the fuel-rich turbine-discharge gas. The configuration at the upper left is an early design that proved to be very poor with respect to base heating. The temperatures measured were well above 1500° F, and violent burning was observed in the base. The configuration at the lower left was an attempt to keep the burning downstream of the base in the hope that the hot gas would be swept away instead of being trapped in the base. The temperature and burning with this configuration were worse than with the first configuration. The configurations on the right were a result of a more comprehensive study of the base flow. The discharge at the upper right is located outboard of the base by an amount that was believed to be outside the base stagnation streamline. This configuration showed no increase in base temperature even when hydrogen was discharged. Another version of this same concept is shown at the lower right. This configuration also showed no temperature rise with propane.

SUMMARY OF RESULTS

This work, to date, can be summarized as follows:

1. With single rocket-type missiles, very high temperatures can occur in the base region because of ignition of burnable rocket gases. It might be presumed that multiple rocket installations will suffer from the additional complication caused by jets impinging on adjacent jets.

2. The spacing between the end of the base and the end of the rocket motor is a very important parameter affecting the base temperature. Rational methods for selecting the proper spacing are not readily apparent.

3. The estimation of airloads on the rocket motor is difficult, because a pressure rise feeds forward from the trailing shock.

4. Combustibles that are dumped into the base by accessories seriously aggravate the base-burning temperature rise. Discharges that

extended well past the base radius or that were located in such a manner as to protrude outside the base stagnation streamline were effective in eliminating the burning of accessory exhaust in the base.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, March 18, 1958

5206

REFERENCE

1. Baughman, L. Eugene, and Kochendorfer, Fred D.: Jet Effects on Base Pressures of Conical Afterbodies at Mach 1.91 and 3.12. NACA RM E57E06, 1957.

ROCKET INSTALLATION IN 8×6

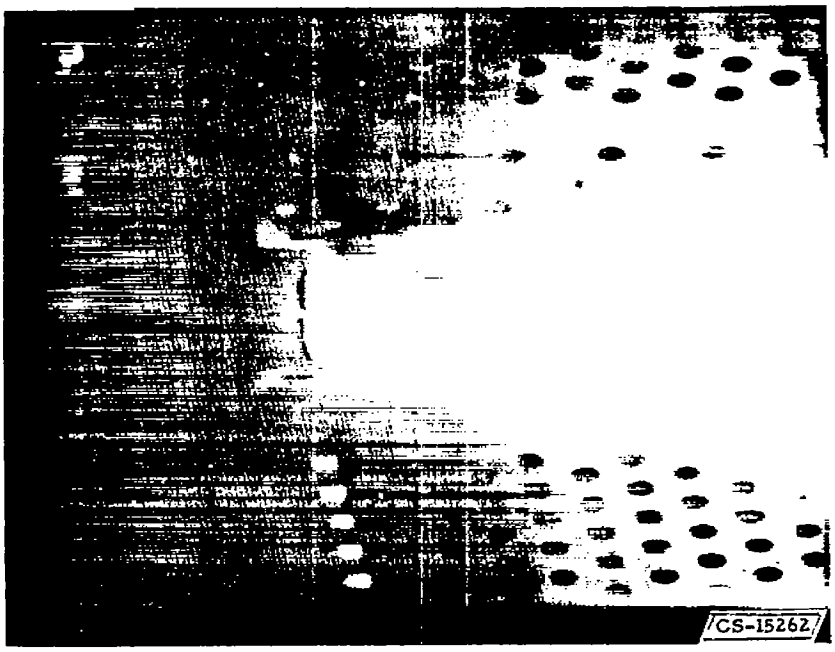

Figure 1

5206

FLOW IN BASE REGION

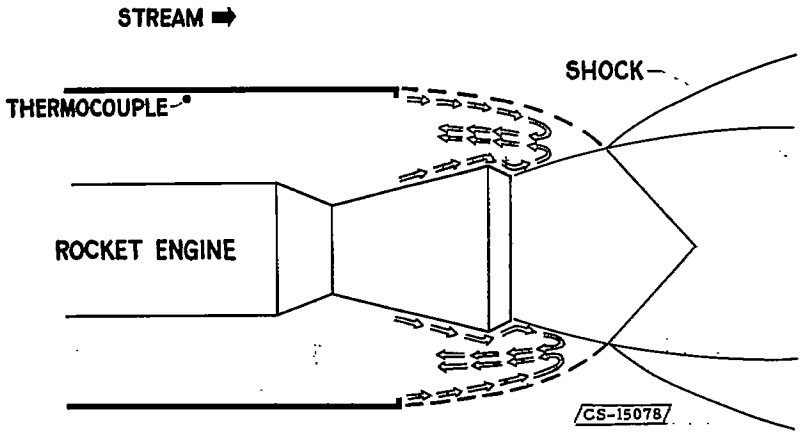

Figure 2

[redacted]

5206

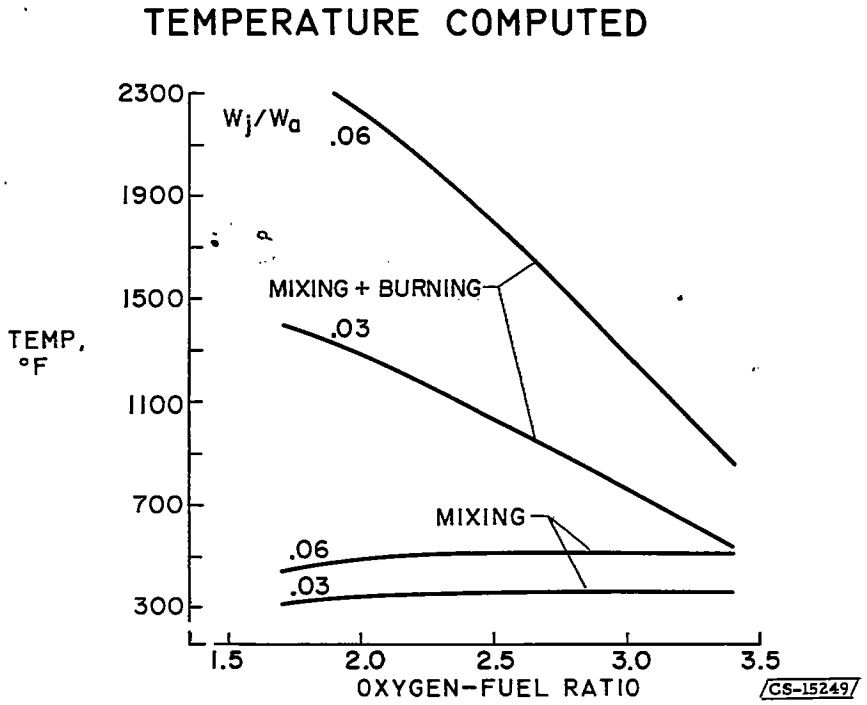

Figure 3

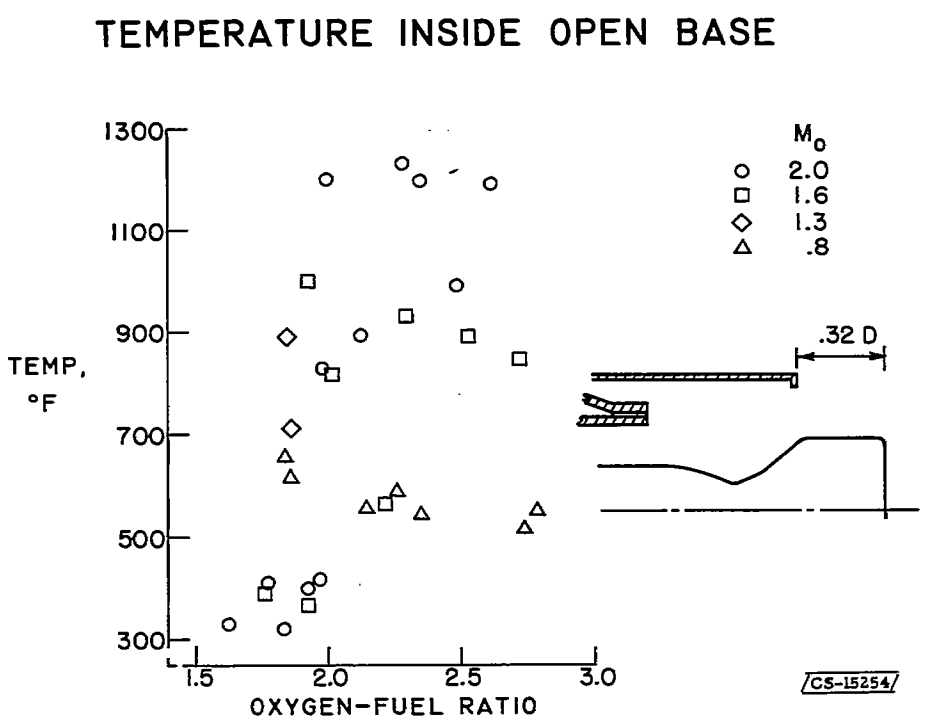

Figure 4

[redacted]

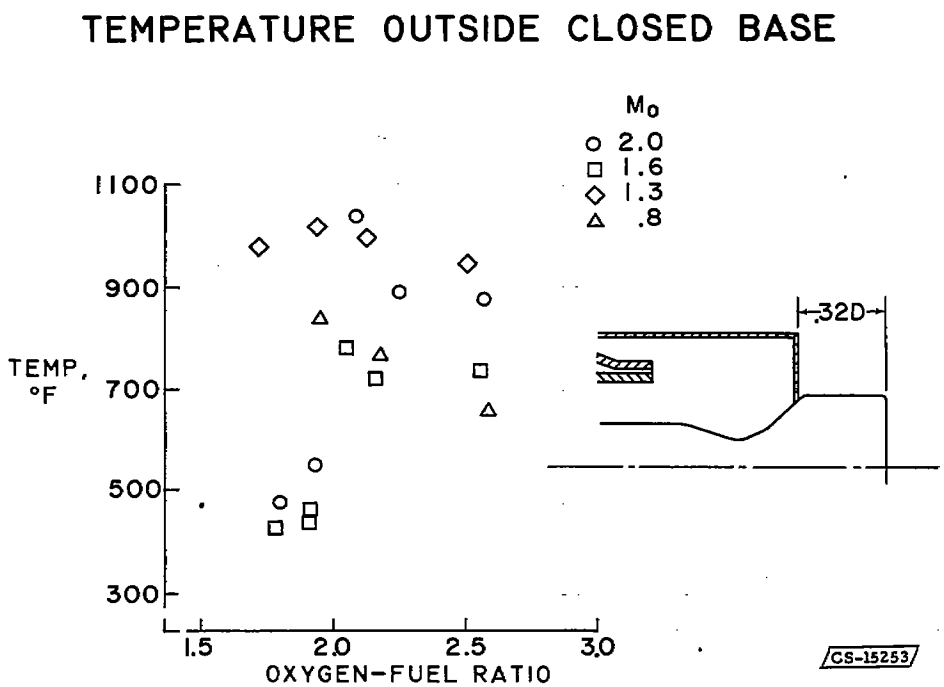

Figure 5

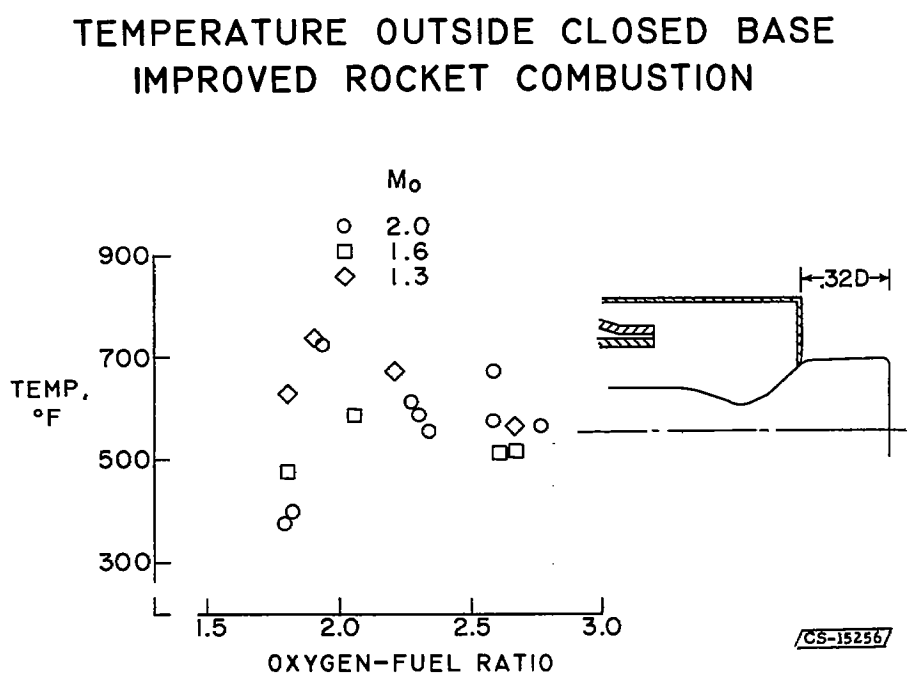

Figure 6

[redacted]

5206

INCREASED MOTOR EXTENSION

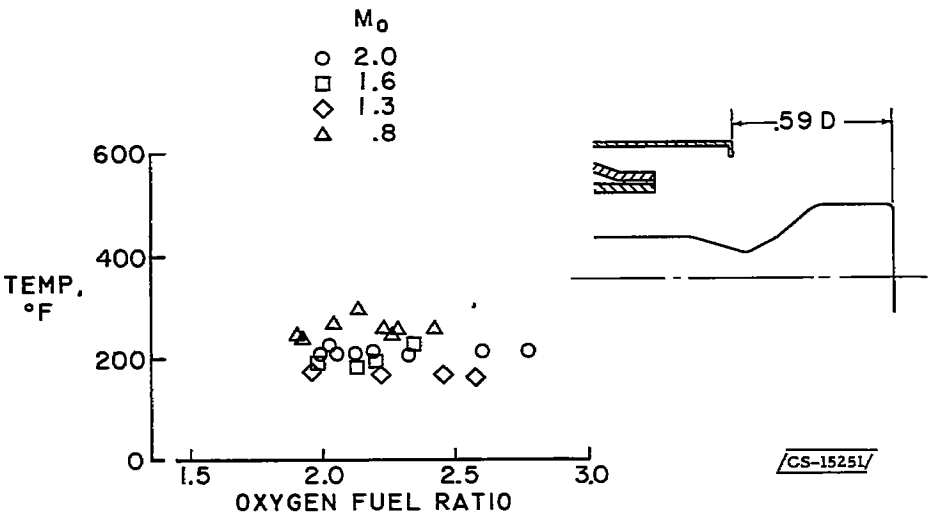

Figure 7

INCREASED MOTOR EXTENSION

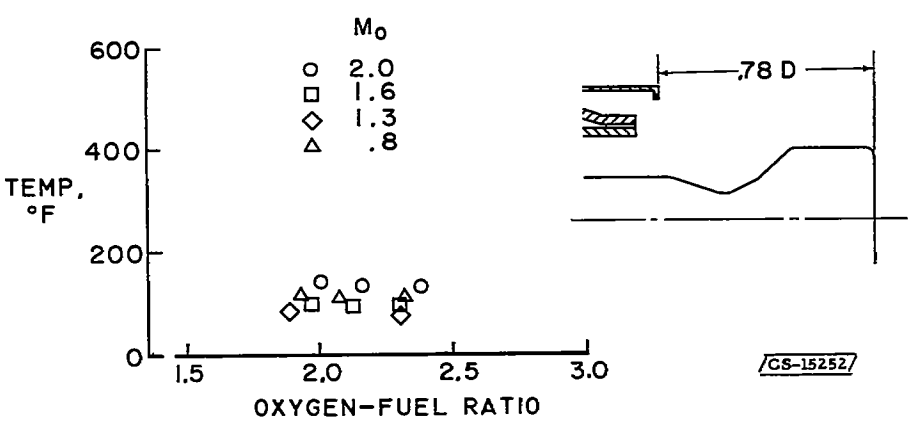

Figure 8

[redacted]

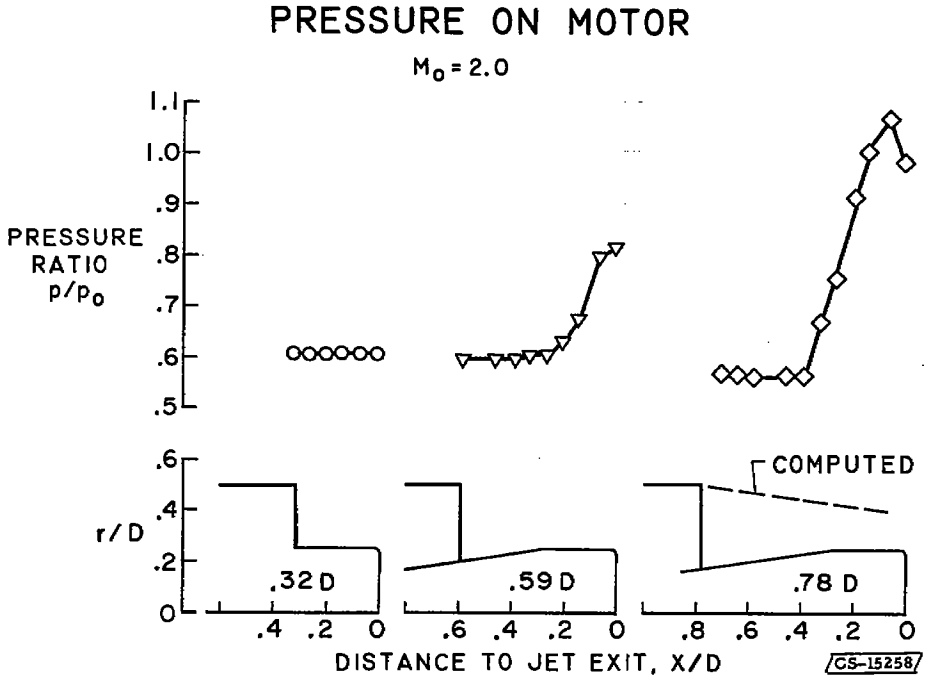

Figure 9

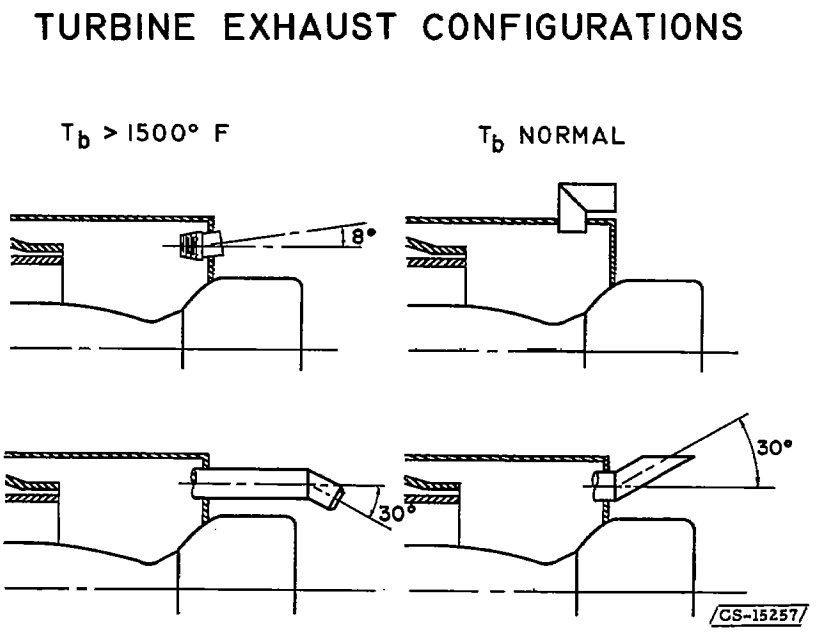

Figure 10

[redacted]

5206