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(Quarterly Progress Report No. 1)

ROCKET BASE FLOW FIELD STUDIES
USING AN ELECTRON BEAM PROBE

Contract No. NSR 33-009-030
Project No. PR 10-6188

Reporting Period: 25 June 1965 through 25 September 1965

Objective

The objective of this program is to extend the electron beam rotational temperature measurement technique to the state where a system capable of making a base flow field survey of a scale model rocket vehicle will be realized. Test data are to be taken using CAL short-duration flow techniques in the static altitude-simulation tank with shock-heated nitrogen as the model working fluid. A secondary objective is concerned with the determination of the practicality of adapting the electron beam probe to density measurements in the base region flow of scale model rockets in the presence of combusted gases.

Rotational Temperature Measurement

1. The Rotational Temperature Measuring Apparatus

At the inception of this program, the basic components of the rotational temperature apparatus were available from earlier projects (NASA/MSFC Contracts NAS 8-823 and NAS 8-20027). This apparatus consists of two discrete major components; the electron beam generating system (Fig. 1) and, the optical sensing equipment. The former was already assembled and in working order whereas the latter existed merely as fabricated but unassembled parts. The first task therefore involved the assembly and the alignment of the optical instrumentation.

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Initial design consideration of the optics package had been oriented toward compatibility with scale model rockets. However, actual utility was contemplated to be restricted to static or bench testing. As a consequence, several modifications were incorporated into the optics assembly that would allow reliable operation in the unique environment of the altitude tank tests required under this program. New, adjustable mirror mountings, that will preserve their optical alignment in a shock and vibrational environment, were designed and fabricated. In addition, a special, remotely-operable, fast-operating mechanical shutter was fabricated and installed. This shutter, whose function is described later, facilitates an in situ calibration of the apparatus during test operations.

Figure 2 is a picture of the optical system whose physical shape is dictated by the requirement that it be insertable behind the model heat shield. The lower, cylindrical portion of the assembly is a pressurized chamber that contains the photomultiplier detectors. Figure 3 is a schematic of the optical arrangement. In essence, this instrument is a two-color pyrometer wherein the intensity ratio of two selected portions of the nitrogen rotational fine structure is sensed.^{1,2} Energy from the fluorescent beam is focussed upon the instrument aperture slit whose dimensions define the size of the sampled volume. This light energy is then collimated and separated into two collimated beams of approximately equal intensity by a beam splitter. An interference filter is placed in each beam and the transmitted energy is directed to a pair of photomultipliers. The interference filters each have a half width of about $15 \text{ \AA}$ with one filter peaking of $4262 \text{ \AA}$ and the other at $4282 \text{ \AA}$. Thus, the filter transmission bands lie in the first negative system of nitrogen which has a band head at $4278 \text{ \AA}$.

A calibrating lamp is included in the assembly and its function is to establish the relative sensitivity (gain) of the two channels just after each test event. This is accomplished immediately after the test by opening the lamp shutter when the electron beam has been extinguished. Detailed descriptions of the beam generating apparatus, its operation and control,

are to be found in Ref. 3.

A necessary experiment involves the calibration of the ratio of the photomultiplier outputs against gas temperature. To accomplish this calibration, a special oven or furnace has been fabricated. This unit, shown in Fig. 1, attaches to the electron beam apparatus. Temperature and pressure of the nitrogen gas can be maintained at varied and known levels of temperature and pressure. Pressures will generally be at a few tenths torr and temperatures will range from ambient room temperature to a maximum of about 1000° R. The fluorescent beam generated within the oven is sensed by the optical assembly through an aperture provided for this purpose.

A static calibration of the ratio of the detector outputs will be obtained over the full temperature range of the oven. Assembly and checkout of the entire apparatus have progressed to the point where calibration tests are expected to begin in the immediate future.

2. Tentative Test Plan

Consistent with the first objective of the present program, it is felt that the most meaningful test program to demonstrate the feasibility of obtaining temperature measurements and using them to more fully understand base flow phenomena would be a program utilizing the same model (see Figure 4) and duplicating the operating conditions of the electron beam density program.³ It is anticipated that these operating conditions should be compatible with requirements of the probe technique for temperature measurements. With the results of the density program already in hand (see Figures) a combined density-temperature (and, as a direct result, pressure) map of the reverse flow field may be generated. The program will be conducted without the use of a splitter plate to preclude any questions of flow separation and possible data anomalies. Experience gained during the electron beam density program has demonstrated that excellent data may be obtained with such a mode of operation. Hence, the program will initially be conducted with a combustion chamber pressure of 200 psia and a chamber temperature of 2500° R. The program will be carried out in the 13 ft.

diameter x 15 ft. long altitude chamber at a test altitude at least equal to the base region choking altitude to prevent reflected blast waves from affecting the quality of the data. This altitude was approximately 230,000 ft. (50 μ Hg) for the density program and will be retained for this program. (Blast wave monitoring experiments carried out in this facility have indicated that the blast wave reflection time for this model at altitudes of about 230,000 ft. is approximately 7 msec., more than adequate for this test). High vacuums in the test chamber are also desirable to minimize ambient leaks from the altitude chamber to the electron beam apparatus which relies on extremely low internal pressures for successful operation.

Since the 2500°R combustor temperature recommended for the initial experiments is considerably lower than typical rocket engine chamber temperatures (normally on the order of 6000°R), the test program will include a second series of tests at more representative reservoir temperatures. This type of operation should also help to identify some of the problems that may be encountered when trying to perform temperature measurements with combustion products as the test gas.

Theoretical (ideal, non-viscous) shock-tube tailoring conditions for providing chamber temperatures of approximately 5000°R are possible with an unheated hydrogen driver. The attainment of these conditions with any practical test times may be difficult due to viscous effects (the shock tube L/D is about 120) and interface mixing problems such as those encountered on the electron beam density program (Ref. 3). Increasing the combustor pressure in the same ratio as the temperature will result in base densities somewhat lower than nominal operation (base pressure does not increase in proportion to chamber pressure - Ref. 4), but still within the limits required for making successful temperature measurements. More stable shock tube operation usually results with increased operating pressure and it is hoped that these new test conditions may be successfully realized.

Base region density data were obtained during the electron beam density program for eight different locations downstream of the base plate (0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50 and 3.00 inches) and at five radial positions (see Figure 5) along a ray between engines (.050, 1.50, 2.60, 3.50, 4.50 inches from the heat shield center). Thus data were taken at 40 different geometric locations. With the single objective lens and radial position mobility it is anticipated that temperature data can be taken at 30 corresponding locations excluding axial distances of more currently available than two inches downstream. In the event data are required at axial distances beyond 2 inches, appropriate changes in the objective lens system can be made. The test program will thus consist of about 60 runs of operation at nominal conditions (assuming two runs per geometric location for repeatability checks) with an optional number of runs at the increased chamber temperature and pressure conditions, and at other axial locations.

Scheduling now calls for the test program to be initiated during January, 1966.

Density Measurements in Hot Combusted Gases

The second objective of the present program involves an exploratory investigation of the applicability of the electron beam probe technique to measurement of density in flows of hot combusted gases. Considerations are to be given to the utilization of tracer techniques (seeding the flow with a gas such as nitrogen, for example) or the use of certain gas species that are naturally present in rocket engine exhaust gases.

To place the analysis on a quasi-quantitative basis, calculations were made to define the minimum nitrogen semi-density measurable as a function of the test parameters. For a given gas, the intensity of the fluorescence resulting from inelastic electron-molecule collisions is related to beam current, beam voltage, and gas density. Thus a lower limit of measurable density may be defined for a given set of system parameters where the criterion used is the limitation on the accuracy of light flux measurement that is imposed by statistical considerations associated with photon counting.

If on the average N photoelectrons per second are emitted from a photocathode, the exact number emitted in a time interval Δt is not $N\Delta t$ but differs from this amount by an amount d . From probability theory, the average square deviation is given by

$$\bar{d}^2 = N\Delta t$$

The relative accuracy of the measured photocurrent (under ideal conditions is given by ϵ .

$$\epsilon = \sqrt{\frac{\bar{d}^2}{N\Delta t}} = \frac{1}{\sqrt{N\Delta t}} = \frac{1}{\sqrt{N_c}}$$

$$N_c = \text{number of photoelectrons counted}$$

Thus, for an accuracy of 1% in measurement, a total of 10^4 photoelectrons would have to be counted and a total of 10^5 photons would need to be incident on a photocathode with a 10% quantum efficiency.

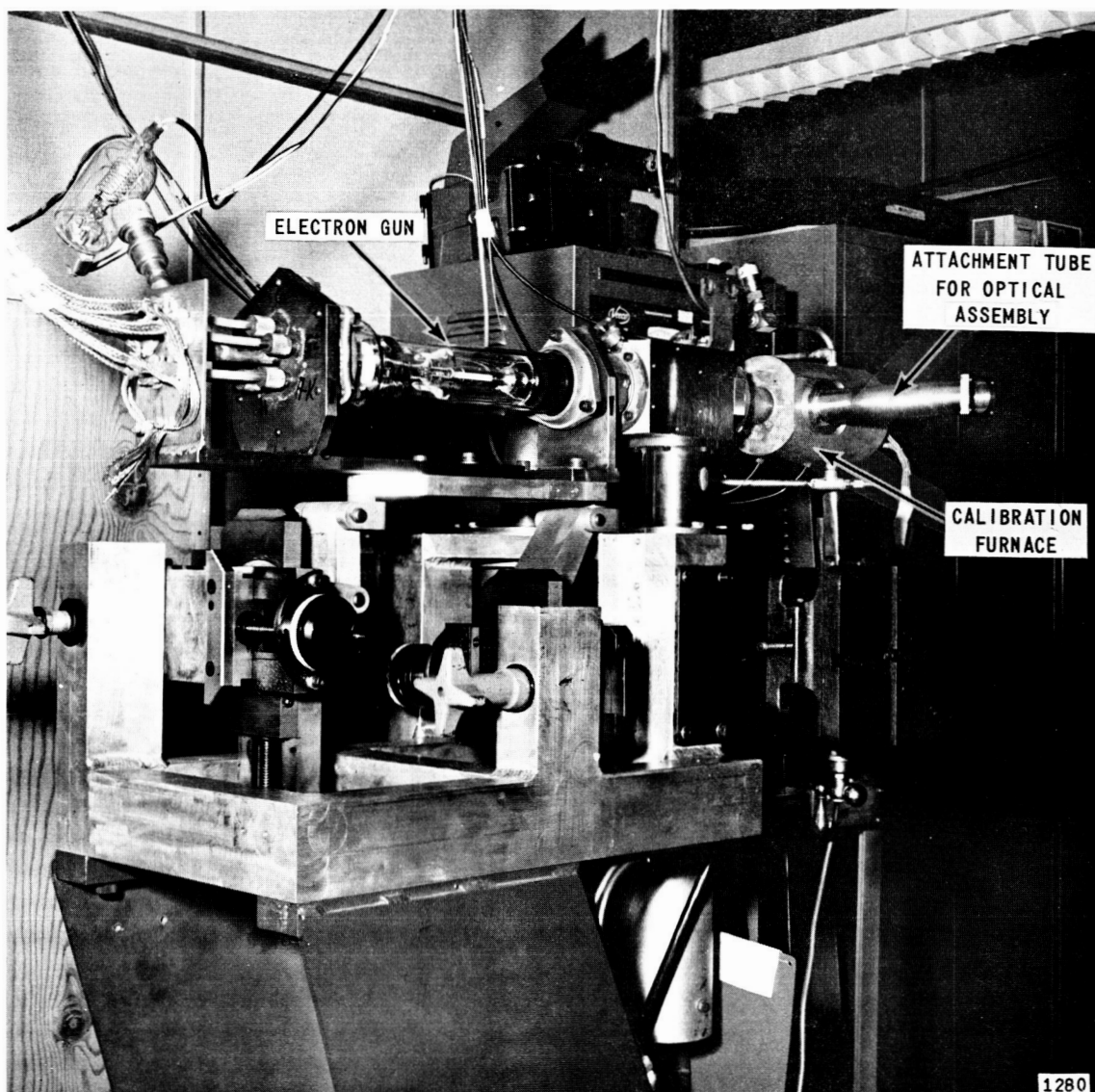
Based on experimental results, Muntz² has calculated a constant which represents the number of photons emitted per second per microampere beam current per unit solid angle per nitrogen molecule. Using these data, minimum measurable densities of nitrogen have been calculated as a function of measurement accuracy and test time. These results are graphically illustrated as Fig. 6. The specific apparatus parameters that were assumed are shown and although they may not represent optimum possible values they do represent realistically attainable and usable levels.

For implementing the tracer technique, the data from Fig. 6 are useful in defining tracer gas concentrations. This requirement however represents only one of a number of subtle factors that are involved. Some of these considerations involve: manner and location of tracer gas injection to obtain a homogeneous flow mixture; effect of tracer on the aerothermodynamics of the flow; beam length and total number density insofar as they affect beam scattering and quenching of the radiation; and others.

It must be emphasized that the electron beam technique is relatively new and its full potential still remains to be exploited.² Much of the available experimental and theoretical data is limited to nitrogen, air and several other gases. Very little is known about collision cross-sections, excitation mechanisms, and quenching as they are related to the gaseous constituents of combusted flows. Since this program is limited in scope, the evaluation of the beam technique to density measurement in combusted gas will perforce be limited to the extent that the available data are limited.

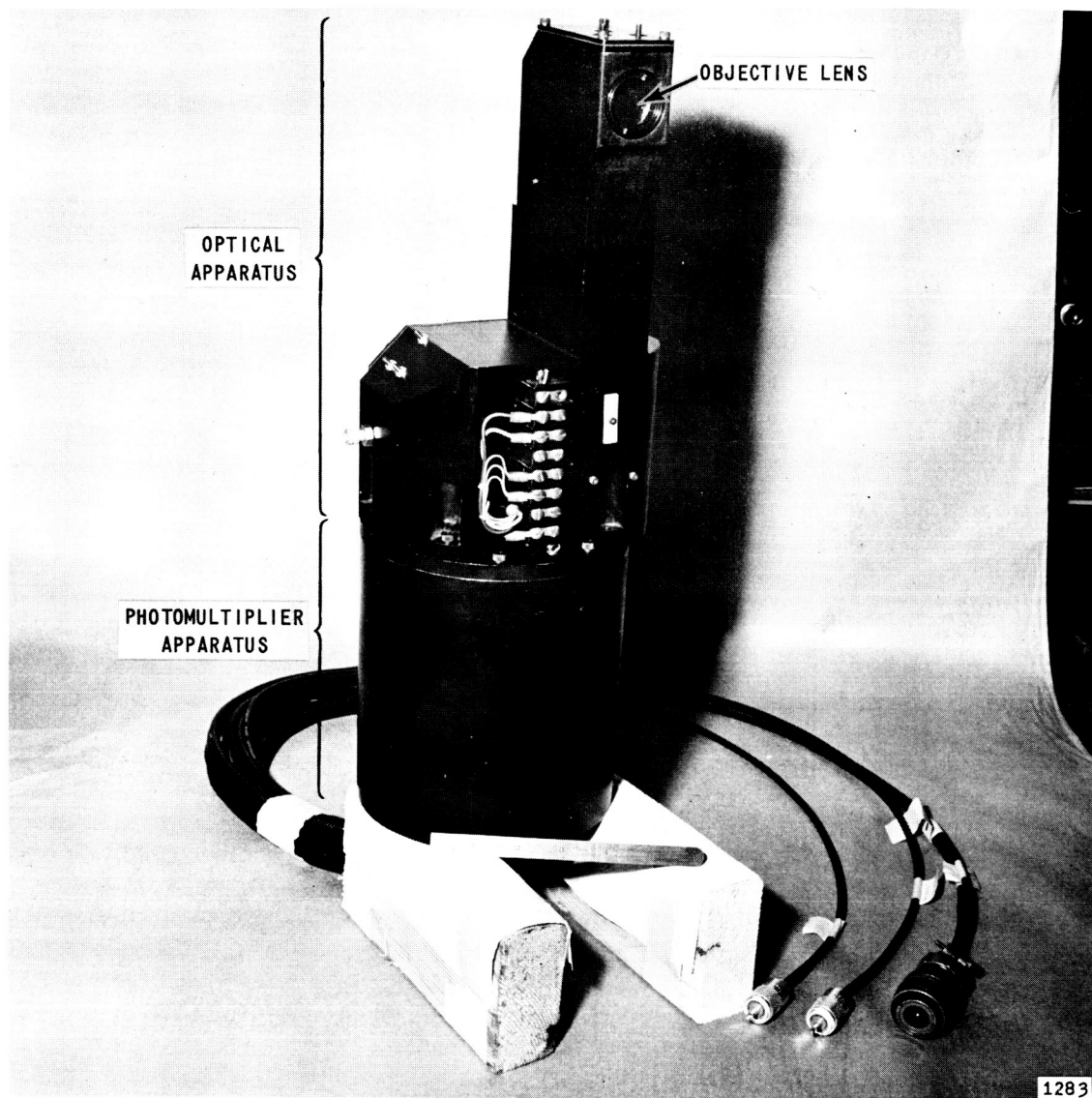
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2. Muntz, E. P., Abel, S. J. and Maguire, B. L.: "The Electron Beam Fluorescence Probe in Experimental Gas Dynamics," Supplement to IEEE Trans. on Aerospace, Vol. AS-3, No. 2, June 1965.
3. Muench, R. K. and Bogdan, L.: "Density Measurements in the Reverse Flow Field of a Four-Engine Rocket Cluster Model Using the Electron Beam Technique," Cornell Aeronautical Laboratory, Report No. HM-2045-Y-1 (to be published).
4. Bird, K. D., Matthis, C. L. and Reece, J. W.: "The Application of Short-Duration Techniques to the Experimental Study of Base Heating. Part I: High-Altitude Testing Technique and Experimental Results for a 4-Engine Rocket Configuration, CAL Report No. HM-1510-Y-1 (I), April 1962.



ELECTRON BEAM TEMPERATURE PROBE - CALIBRATION SETUP

Figure 1



HOUSING FOR OPTICAL AND PHOTOMULTIPLIER APPARATUS

Figure 2

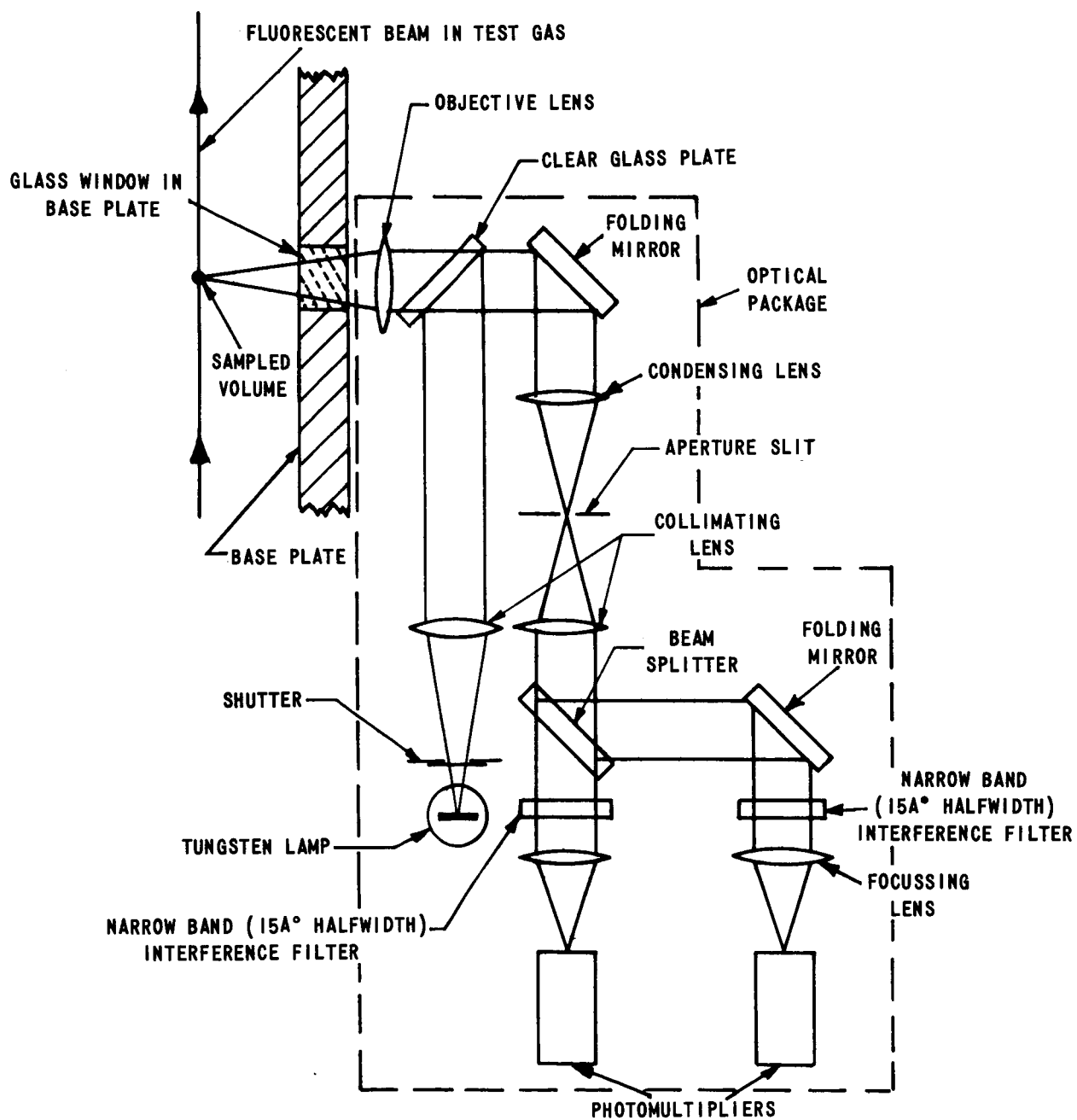
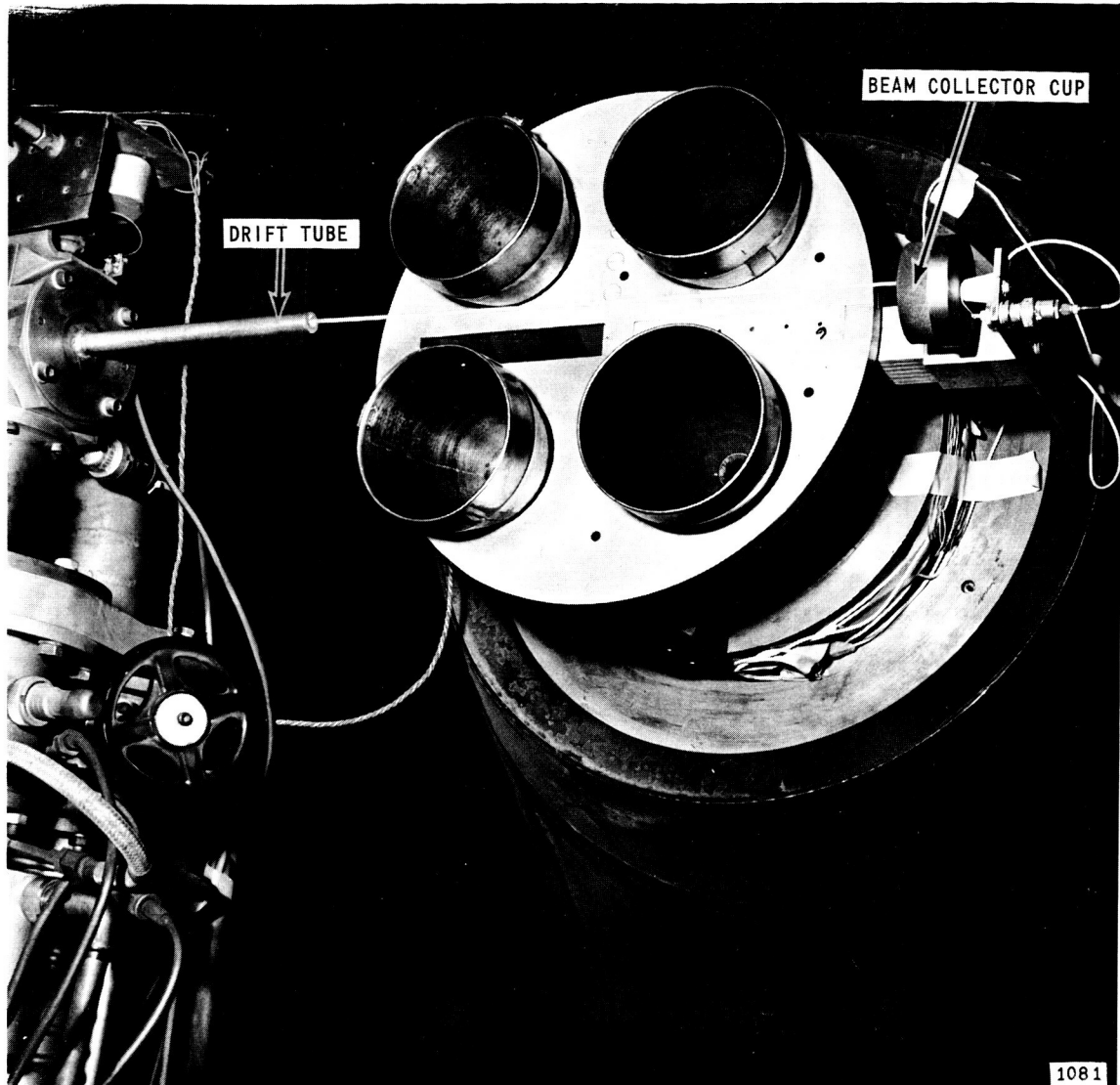
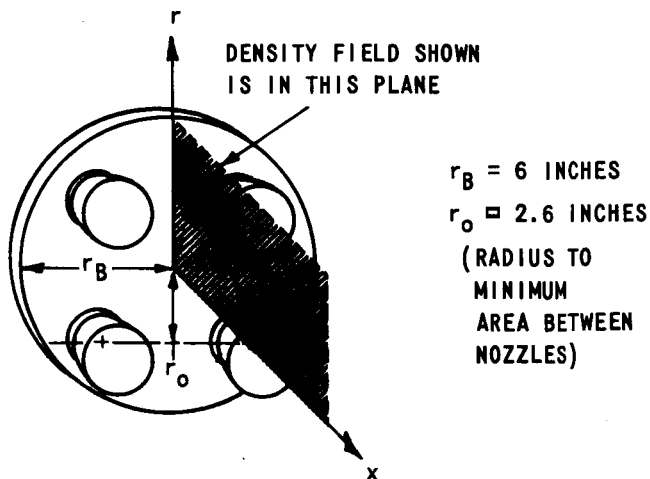


Figure 3 SCHEMATIC VIEW TEMPERATURE MEASURING APPARATUS



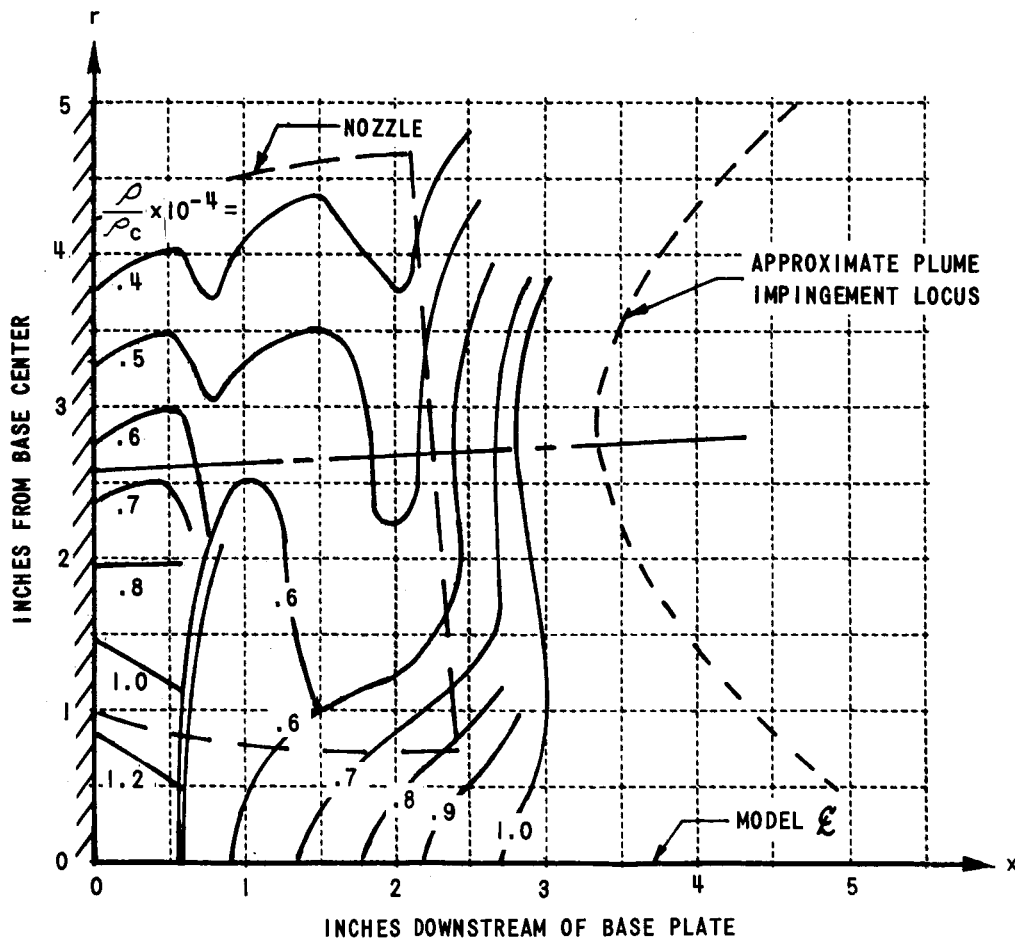
1/10 SCALE S-IV - 4 ENGINE MODEL SHOWING BASE PLATE
AND ELECTRON BEAM APPARATUS

Figure 4



PROPULSION GAS: NITROGEN
 PLENUM PRESSURE = 200 PSIA
 PLENUM TEMP. = 2500°R
 $P_\infty / P_{\text{plenum}} \approx 1 \times 10^{-5}$

$$\frac{\rho}{\rho_c} = \frac{\text{DENSITY}}{\text{PLENUM DENSITY}}$$



DENSITY FIELD FOR 4-ENGINE CLUSTER

Figure 5

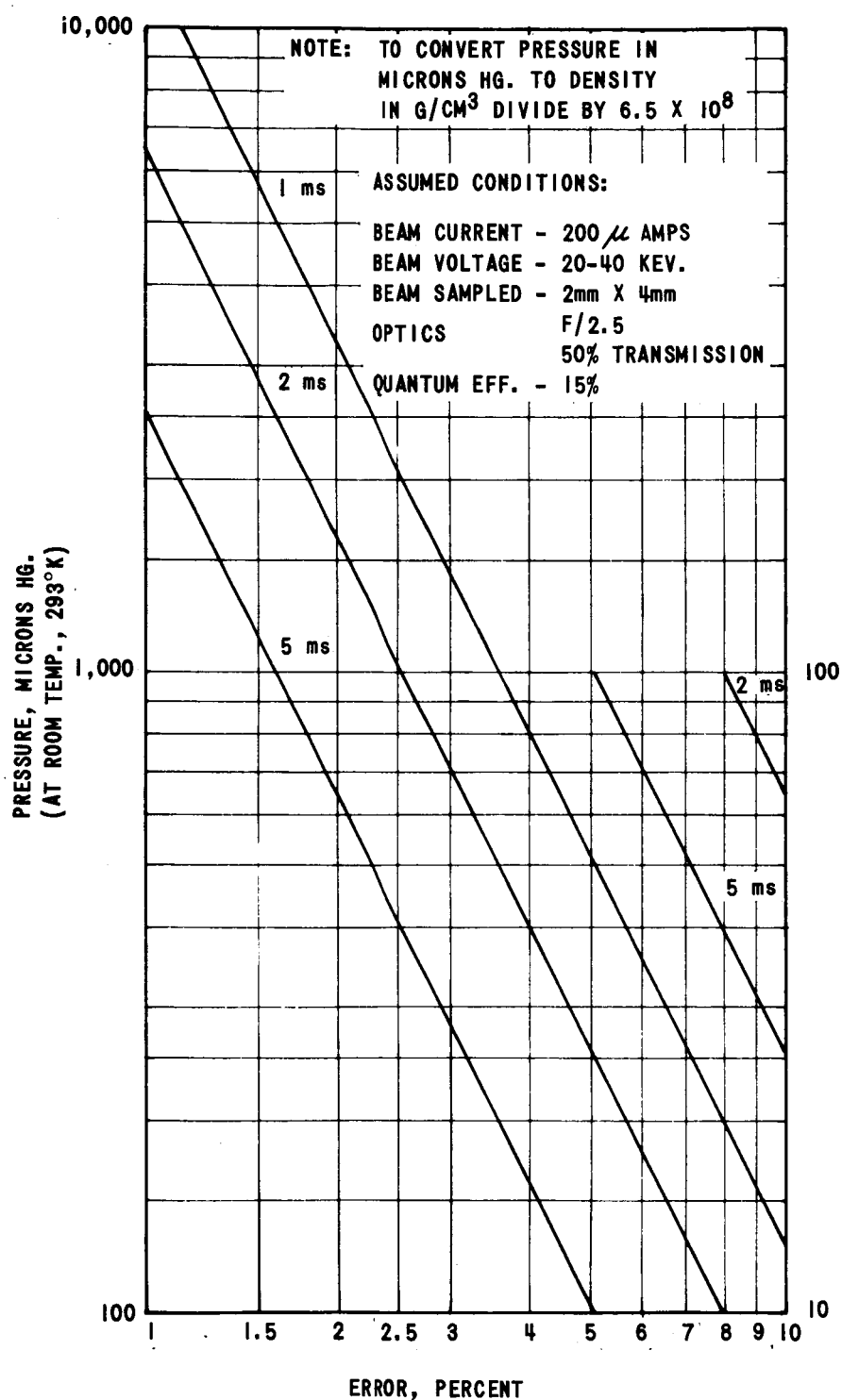


Figure 6 MINIMUM N₂ DENSITY MEASURABLE WITH ELECTRON BEAM DENSITY PROBE AS A FUNCTION OF ACCURACY AND TEST TIME