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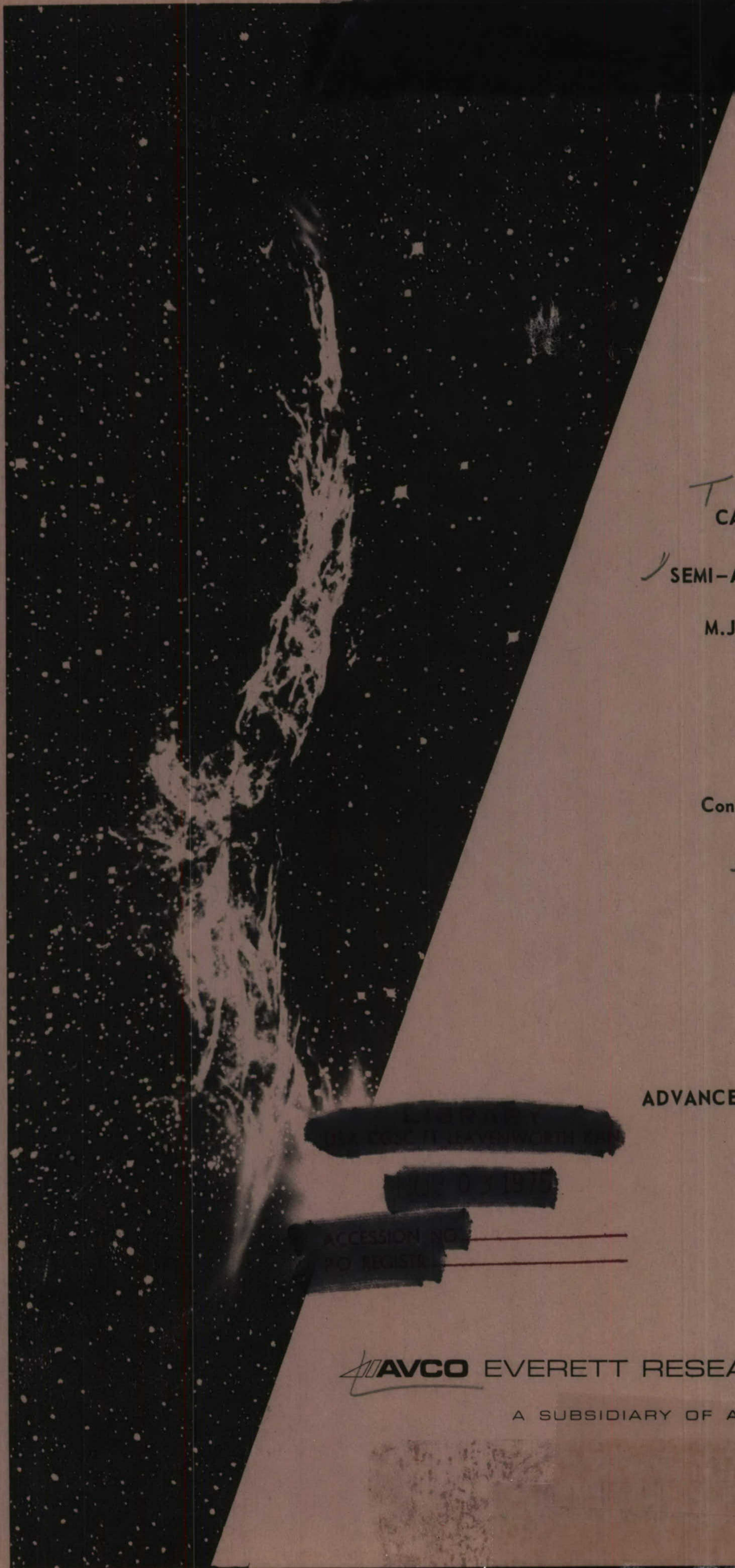

CARBON MONOXIDE LASER

SEMI-ANNUAL TECHNICAL REPORT

M.J.W. Boness and R.E. Center

Contract No. N00014-72-C-0030

September 1975

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FOREWORD

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ABSTRACT

During this reporting period fabrication and assembly of the laser cavity and heat exchanger were completed. Near diffraction limited medium quality in the passive cold flowing gas over the active volume of the cavity has been achieved.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The main objective of this program is the investigation of the pulsed electrical CO laser to determine the relative scaling parameters and the usefulness of high power CO lasers in systems applications.

During this six month period the laser cavity and heat exchanger have been fabricated and assembled. Initial interferometric measurements indicated considerable turbulence in the flow which was greatly improved by introducing a fine stainless steel screen above the heat exchanger. However the original tests performed at a flow velocity of 50 cm/sec did not yield the desired medium uniformity and near-diffraction limited medium quality was eventually obtained by increasing the flow velocity to approximately 400 cm/sec. Hot wire anemometer temperature measurements indicated that the gas temperature was close to the temperature of the heat exchanger, 77^{o}K. The 500 cfm Stokes pump was found to introduce disturbances into the gas flow and preparations are underway to install and connect the system to a 300 cf dump tank facility. Currently the electrodes are being installed and the E-beam interfaced with the discharge cavity. Once completed further flow tests will be performed using the dump tank facility and the effect of the electrode structures upon the medium uniformity investigated. Finally gain and power measurements will be performed.

II. MK II CAVITY AND HEAT EXCHANGER

The design goal of the Mk II cavity and flow system was to overcome the thermal nonuniformities encountered in the original 20 liter discharge system.(1) A schematic of the laser cavity, E-beam and heat exchanger is shown in Fig. 1. The basic concept of the new transverse flow system is to introduce the gas through a porous plate heat exchanger and allow free convection boundary layers to be established on the room temperature side and end walls of the discharge cavity. The flow direction is vertically upwards to ensure that buoyancy effects are favorable and to avoid recirculation zones. Boundary layer calculations were performed(2) which indicated that the variations in optical path between the upper and lower portions of the boundary layers which will develop across the windows at the end of the cavity will be compatible with 1.5 times diffraction limited quality of the laser beam. Similarly the thickness of the boundary layers which develop along the side walls indicated that the required medium uniformity was preserved across the active portion of the medium.

Fabrication of the cavity and pumping system were completed and the vacuum integrity of the system shown to conform with the experimental requirements. Initial flow tests and medium quality measurements were performed prior to installing the electrode structures and interfacing the cavity with the E-beam. A photograph looking from one end of the cavity is shown in Fig. 2. Smooth lucite sheets defined the flow walls. These were eventually to be replaced by slotted walls through which the tubular electrodes penetrated and with a rectangular opening on the cathode flow wall to smoothly interface with the E-beam foil. The heat exchanger was constructed according to the design described in a previous report.(2) A schematic of the construction is shown in Fig. 3. The heat exchanger consisted of three uniform sintered bronze plates mounted in an isothermal aluminum base. A series of 1/4-inch-diameter copper tubes, spaced two inches apart, were embedded in the sintered bronze plates and connected via manifolds to the coolant supply. Two manifolds provided opposite coolant flow in adjacent copper cooling tubes in order to reduce any transverse temperature gradients. Two views of the heat exchanger are shown in Figs. 4 and 5. Temperature monitoring was provided by instrumenting both the sintered plates and the aluminum box with thermocouple sensors.

The heat exchanger was mounted inside a lucite box which bolted to the bottom of the cavity via a viton o-ring seal. Care was taken to thermally isolate the heat exchanger by supporting it on thin lucite strips and by sealing it to the flow walls by compressible polyethylene strips. In addition the lucite box was lined with aluminum foil to reduce thermal radiative coupling with the surroundings. The large thermal capacity of the heat exchanger required the removal of approximately 10^7 joules in order to reduce the

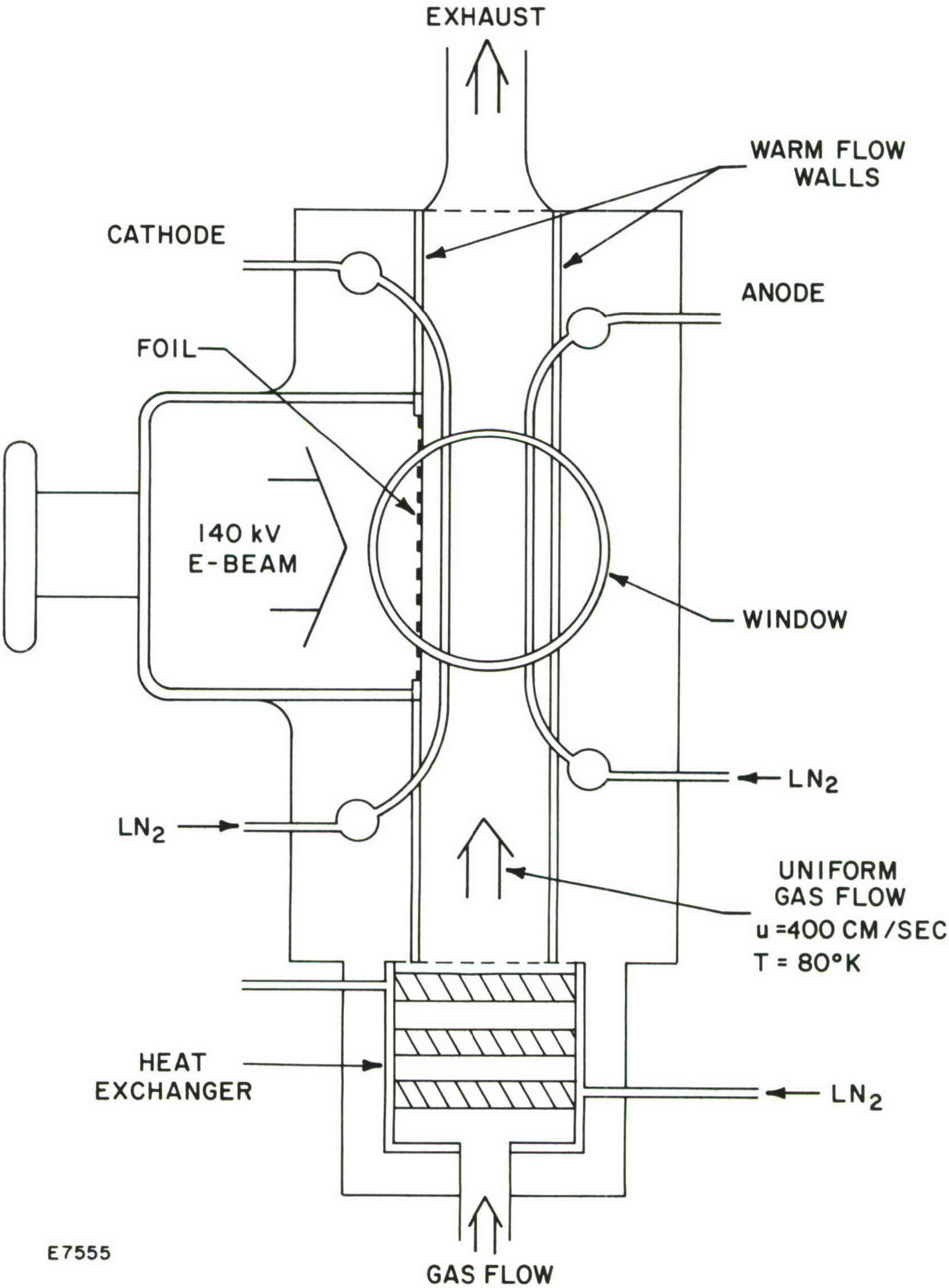

Fig. 1 Schematic of Complete Laser Discharge Cavity and E-Beam

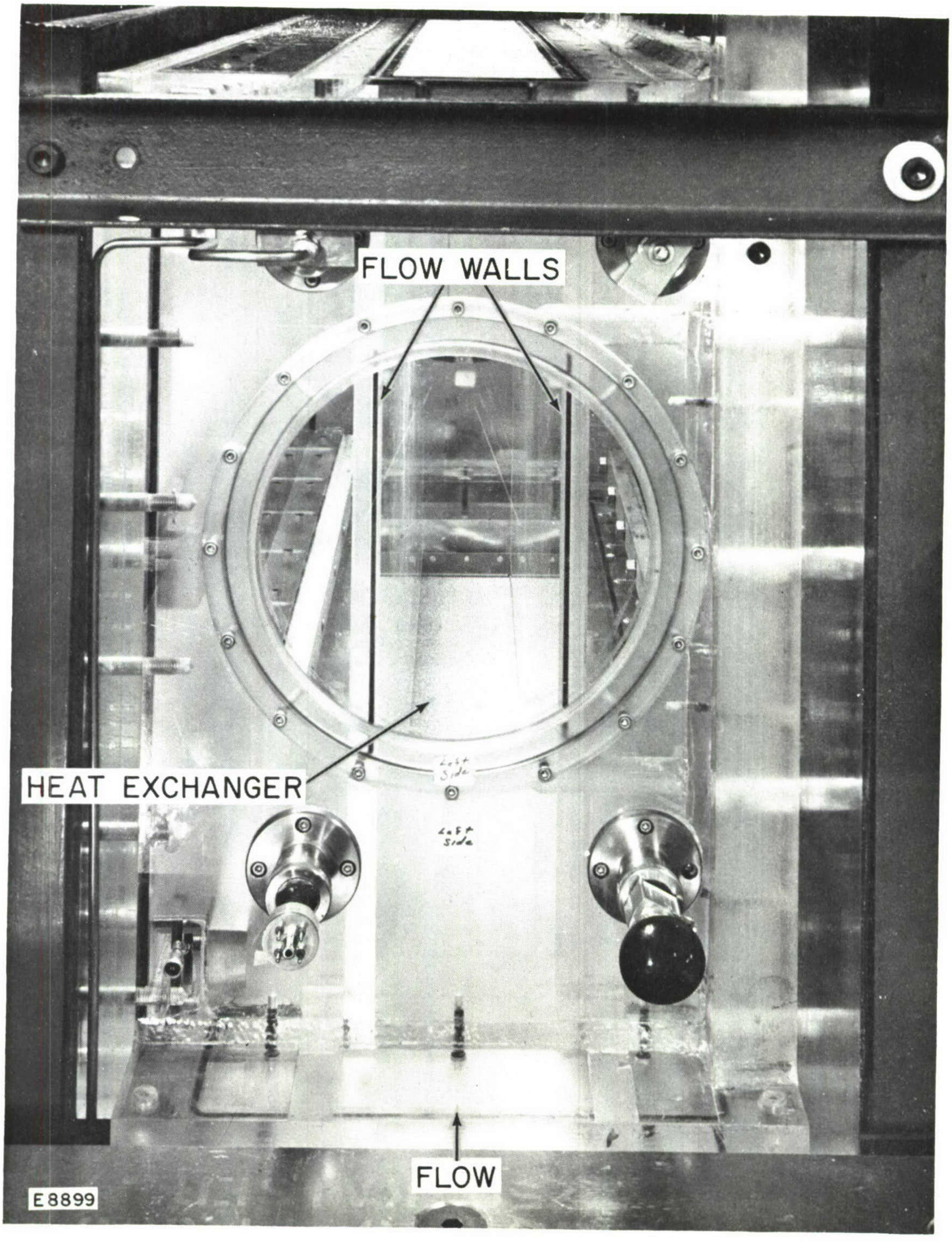

Fig. 2 End-On View of Mk II CO Laser Cavity Prior to Installation of the Electrodes and Interfacing with the E-Beam

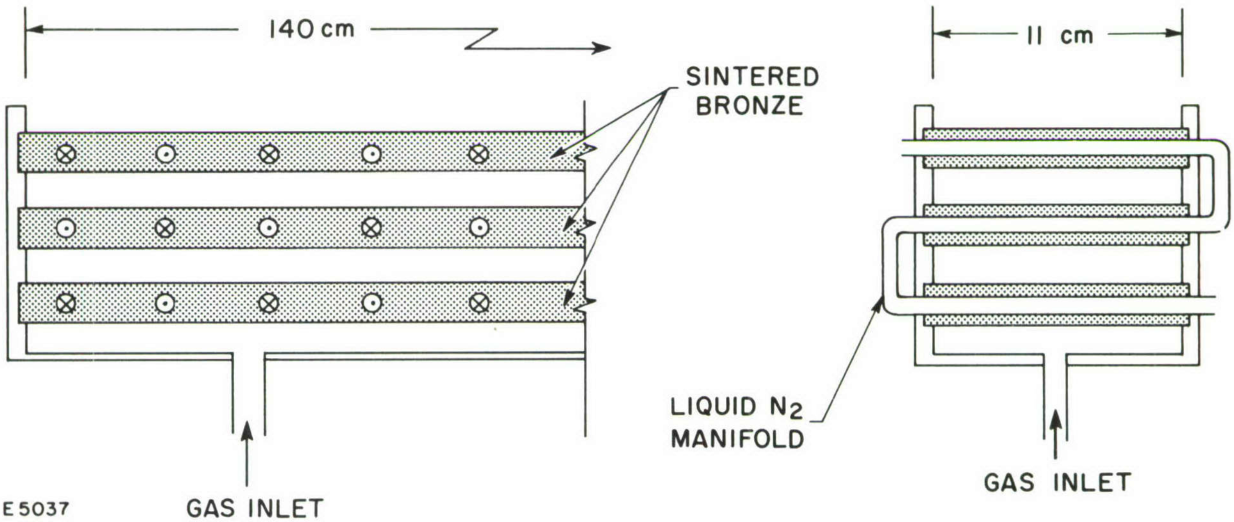

Fig. 3 Schematic of the Porous Plate Heat Exchanger

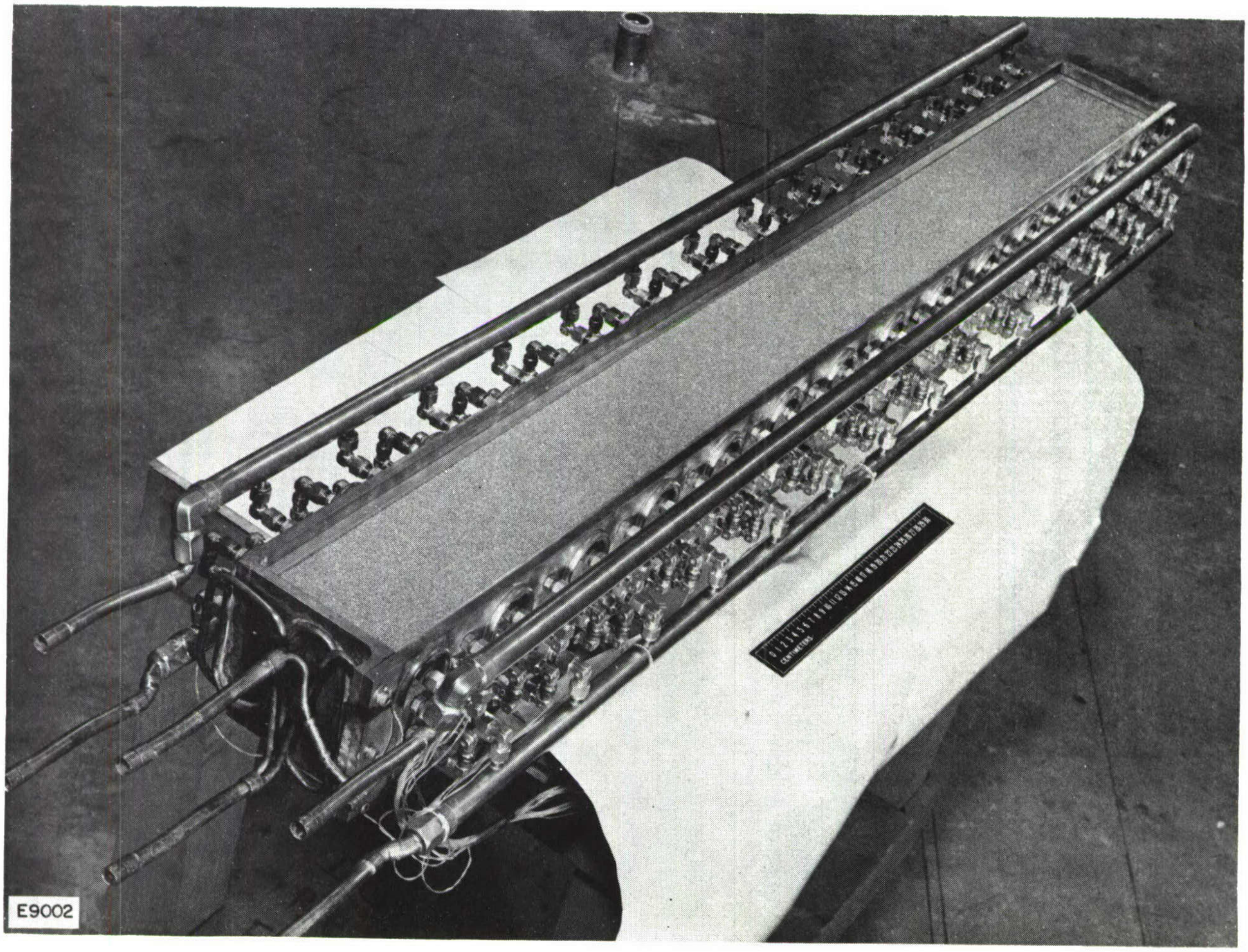

Fig. 4 Photograph of the Porous Plate Heat Exchanger and LN_2 Supply Manifolds. The stainless steel screen is visible on the top of the heat exchanger.

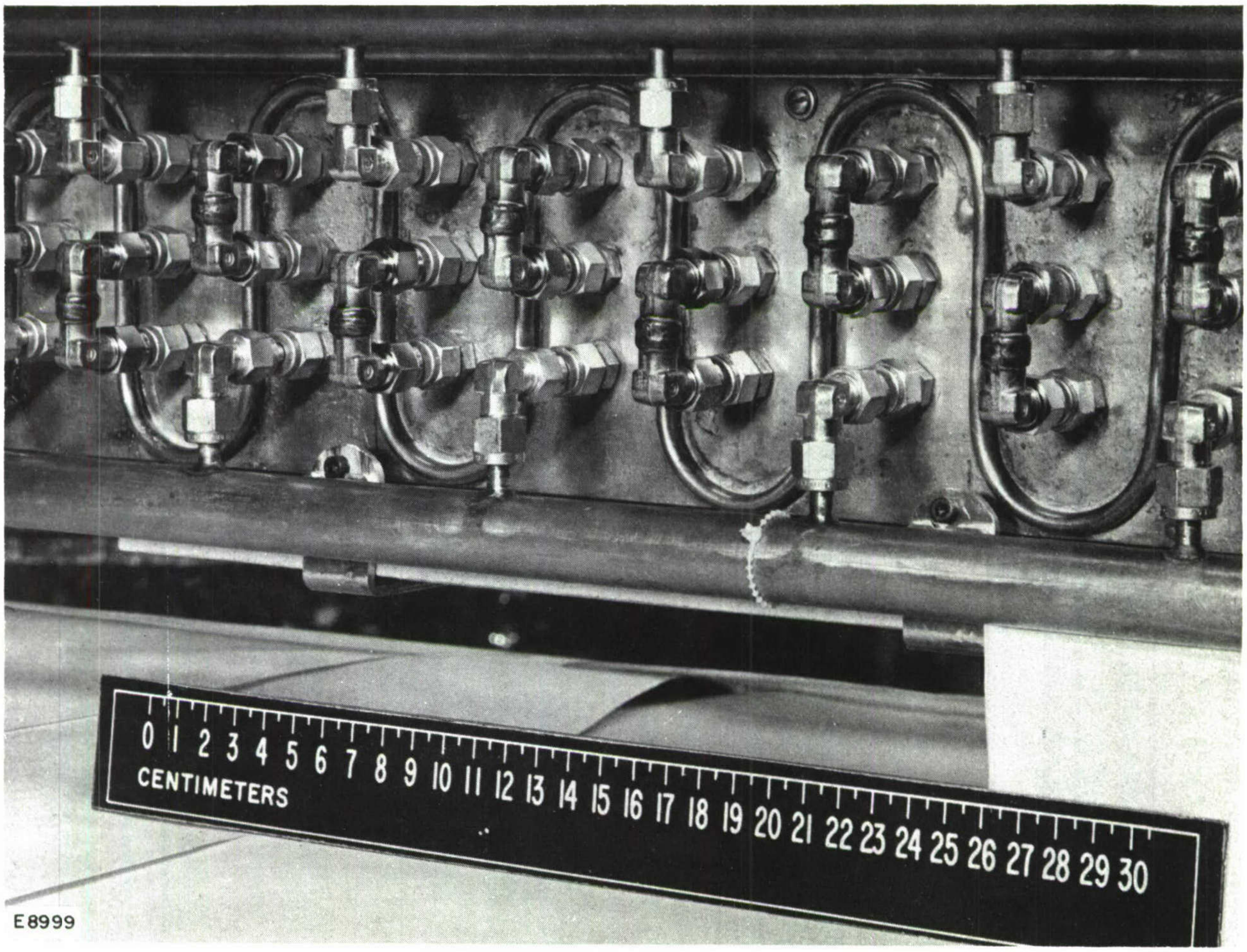

Fig. 5 Detail of the Side of the Heat Exchanger showing the Counterflowing LN_2 Supply Manifolds and the Swagelok Couplings between the Copper Cooling Pipes Embedded in the Porous Plates

temperature by the desired 200°C. The cooling procedure was performed by circulating liquid nitrogen and typically required two hours. The overall thermal cycling time was important since initially minor modifications required frequent disassemblies, therefore to reduce the time required to regain room temperature two electric heaters were mounted immediately below the heat exchanger and their temperatures monitored with thermocouples.

Consideration was given to ensuring an uninterrupted flow surface between the heat exchanger surface and the flow walls while at the same time preserving good thermal isolation between their components. Thin phenolic strips mounted flush with the surface of the flow walls and projecting ~1/2-inch below them extended to within 0.020-inch of the surface of the heat exchanger and provided good flow continuity. One phenolic strip is visible in Fig. 2 across the far end of the cavity immediately above the surface of the sintered bronze plate.

III. MEDIUM QUALITY MEASUREMENTS

Interferometric investigations of the medium homogeneity were performed using a conventional Mach-Zehnder optical interferometer arrangement together with a Xenon laser light source.

The system was initially connected to a 500 cfm stokes pump and cold mass flow measurements performed in order to deduce the flow velocity through the cavity. At a cavity pressure of 1/6 atmosphere (corresponding to 1/2 amagat at $77^{\circ}K$) the measurements indicated a cavity flow velocity of 60 cm/sec, close to the expected value. However the interferometric measurements performed with cold flow revealed extremely poor medium quality. One contributory source of interference was found to be the 500 cfm Stokes pump which introduced pulsations into the gas flow even though care had been taken to isolate the cavity from the pump using multiple nylon screens. Thus further testing was performed by initially evacuating the cavity then isolating the Stokes pump and using the 150 cu ft capacity of the pumping line as a dump tank while preparations were made to install and connect the system to a 300 cu ft dump tank facility and to fabricate the necessary choking orifice. Subsequent measurements were performed as the system filled and interferograms taken at the instant that the cavity pressure reached 1/6 atms. Inspection of the interferograms revealed considerable turbulence in the gas flow and since the only portion of the flow region available for interferometric testing was the region defined by the cavity windows, some 25 cm downstream of the surface of the heat exchanger, it was not possible using this diagnostic to determine whether the turbulence developed during the flow, due presumably to turbulent mixing of the boundary layers or whether the turbulence was intially present in the flow emanating from the porous heat exchanger plates. To resolve this question a moveable hot wire anemometer probe was installed one cm above the surface of the heat exchanger and semi-quantitative measurements performed under ambient temperature flow conditions to determine the velocity fluctuations and distribution across the cavity. These measurements revealed the presence of considerable velocity fluctuations in the flow and also indicated that the flow velocity close to the flow walls was approximately 10% higher than in the bulk of the flow. The former effect has been previously reported by several authors and thought to be due to the appearance of instabilities resulting from coalescence of neighbouring jets emanating from the porous plate.[3] The latter effect was ascribed to the method by which the porous plates were held and supported which produced dead spaces in the sintered bronze plates immediately beneath the flow walls and thus introduced perturbations in the flow close to the wall. A remedy for both effects was sought by introduction of a stainless steel fine mesh screen close to the surface of the heat exchanger.

The subject of the reduction of turbulent fluctuations by screens has been the subject of many investigations. Screens of open-area ration, β, less than about 0.57 have been shown to suffer from flow instabilities through the pores which cause the emerging jets to coalesce in random patterns.[4] The reduction in turbulence intensity is given by $(1 - k)^{-n/2}$ where n is the number of screens and k the resistance coefficient of the screen defined by

$$k = \frac{\Delta p}{1/2 \, \rho \, u^2}$$

where Δp = static pressure drop across the screen

ρ = density of fluid

u = fluid velocity

Thus screens possessing high opacity (small β) are more effective in damping turbulence intensity however. However too large an opacity ($\beta < 0.57$) can lead to generation of instabilities due to the effect of coalescing jets, thus a compromise between the two effects must be sought. 220 mesh stainless steel mesh constructed of 0.001 inch diameter wire was chosen possessing a transparency of 50%.

Using the Wieghardt correlation[5] for the screen resistance coefficient

$$k > 6 \, (1 - \beta) \, \beta^{-5/3} \left(\frac{ud}{\nu}\right)^{-1/3}$$

where d = the wire diameter

ν = kinematic viscosity of fluid

the screen resistance coefficient appropriate to the following parameters,

$d = 2.5 \times 10^{-3}$ cm

$u = 10^2$ cm/sec

$\nu = 0.4$ cm^2/ sec (1/2 amagat)

$\beta = 0.5$

was calculated to be,

$k = 11.3$

which for a single screen would produce a reduction in turbulence intensity by approximately a factor of 3.5.

A single screen was installed 1/2 inch above the heat exchanger. Calculations indicated that the screen would accommodate to the gas temperature within 0.5 secs and should therefore not affect either the absolute temperature or uniformity of the medium.

Hot wire anemometry and interferometric measurements were repeated following installation of the 220 mesh stainless steel screen. The hot wire measurements indicated a reduction in the warm flow turbulence intensity to below the level of the instrumental sensitivity. The increased flow velocity in the vicinity of the sidewalls was also eliminated. However the cold flow interferograms while indicating an improvement in the medium quality were still not compatible with near-diffraction limited performance. The thickness of the boundary layers established on the sidewalls was more consistent with a turbulent rather than laminar development. These layers completely merged together in the upper half of the cavity. Improved performance was therefore sought by conducting tests at increased mass flow rates. Increasing the flow velocity to 100 cm/sec showed clearly discernible improvements in medium quality. Eventually the flow velocity was increased to approximately 400 cm/sec. Since the heat exchanger had not originally been fabricated to conform to pressure loadings appropriate to these flow velocities, further increases in flow velocity would have jeopardized the integrity of the aluminum box which supported the sinter bronze plates.

Temperature measurements performed using the hot wire anemometer confirmed that the medium temperature was indeed within the sensitivity of the measurement, $77^{o}K$. Therefore under the prescribed experimental conditions interferometric measurements of the medium uniformity were performed. The following procedure was adopted. After cooling the heat exchanger to $77^{o}K$, a settling time of five minutes was allowed for equilibriation and then flow tests commenced. Typical interferograms are shown in Figs. 6 and 7, the vacuum reference interferogram is shown in Fig. 8.

The interferogram shown in Fig. 6 was taken at $-175^{o}C$ and that shown in Fig. 7 some five minutes later at a temperature of $-170^{o}C$. In both cases the vertical temperature gradient along the center line of the cavity is approximately $0.4^{o}K$, (equivalent to four fringes). In each case the sidewalls of the cavity are apparently displaced outwards. This effect arises due to the strong refractive effect of the boundary layers combined with the location of the film plane with respect to the focussing mirror. These combine to exaggerate the apparent thickness of the boundary layers. The actual location of the sidewalls and hence an estimate of the thickness of the boundary layers is best obtained by comparing the flow interferograms with the vacuum pattern, Fig. 8.

During these flow tests liquid nitrogen was continuously circulated in the heat exchanger. This technique provided improved medium uniformity but introduced the transverse temperature gradient indicated by the inclined fringes and which is ascribed to the asymmetry of the cooling coil arrangement. Over the active volume of the discharge defined by the position of the

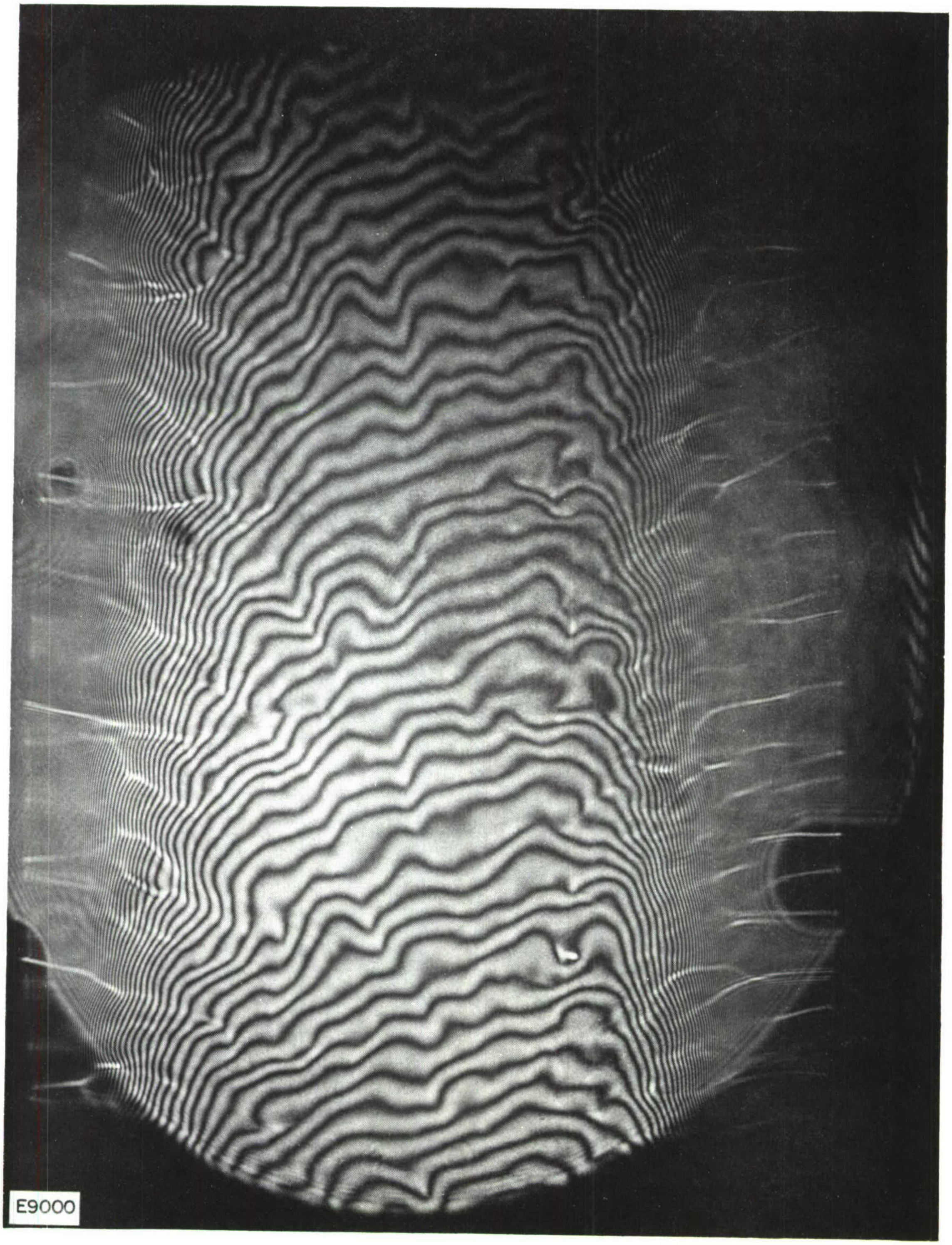

Fig. 6 Interferogram of the Medium Homogeneity looking along the Lasing Axis, taken at -175°C, a Flow Velocity of 400 cm/sec and a Pressure of 1/6 atm

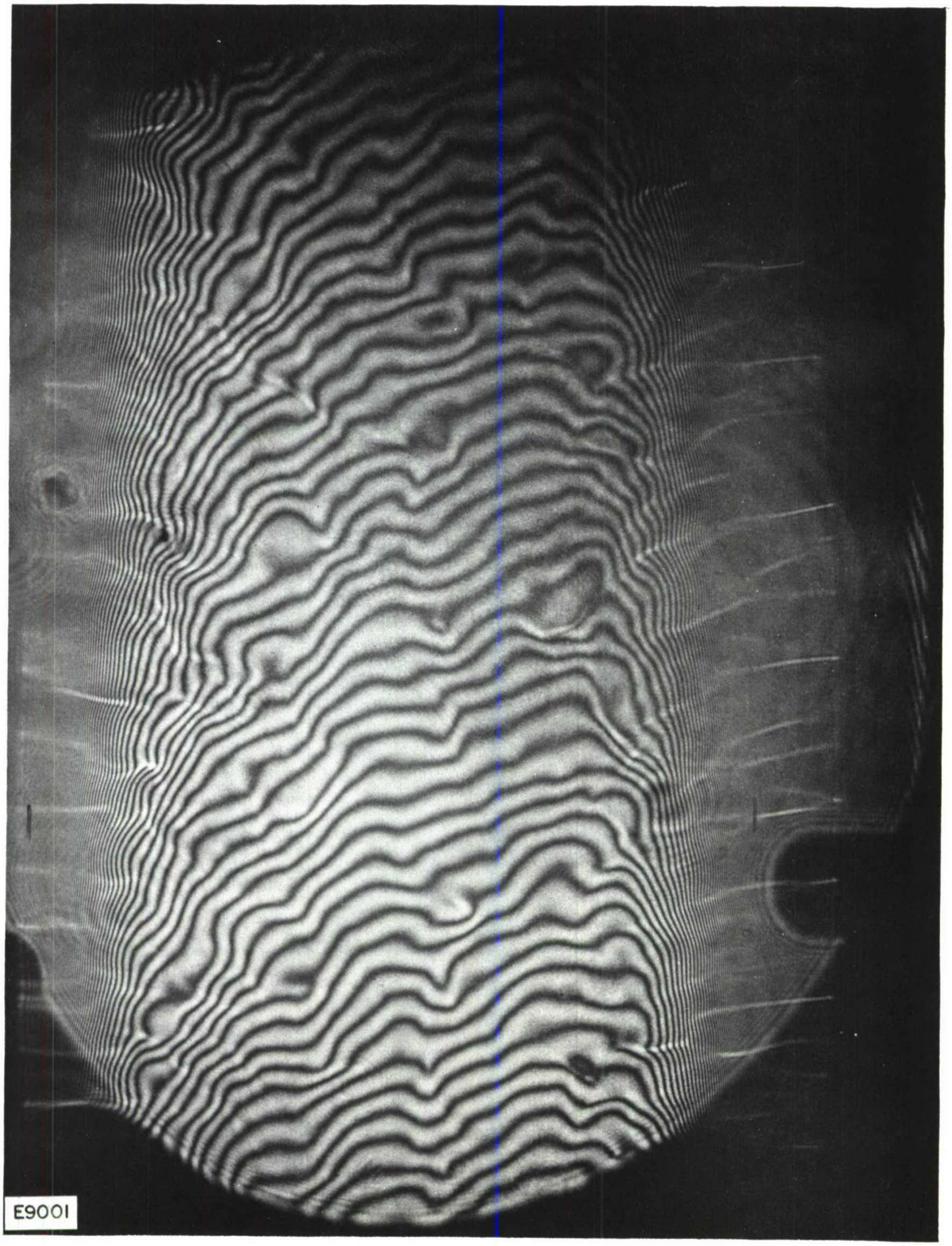

Fig. 7 Interferogram taken under Conditions Similar to Fig. 6 but at a Temperature of -170°C. The vertical temperature gradient along the center line of the cavity is approximately 0.4°. The inclined fringes represent a linear transverse gradient of approximately 1.5°C across the active volume of the discharge.

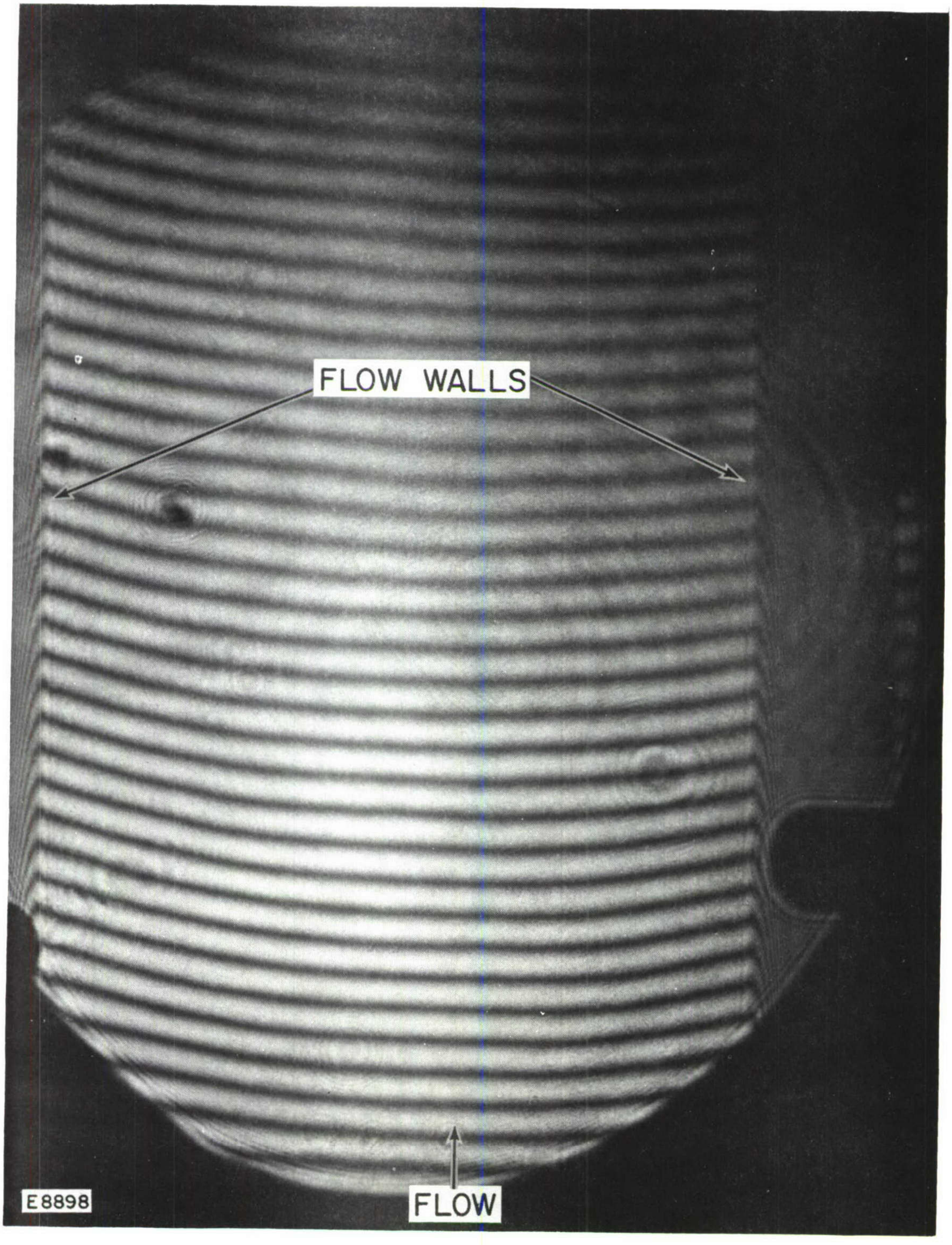

Fig. 8 Vacuum Reference Interferogram for Figs. 6 and 7, the Location of the Side Walls and Direction of Flow are Indicated

electrodes this gradient amounts to 1.5° and can be compensated for by suitably tilting the cavity optics. Under this configuration the medium quality would conform to near-diffraction limited operation of the laser.

Since this phase of the project has been satisfactorily completed, the next step will be to install the flow walls and electrodes, to interface the cavity with the E-beam and then to repeat the flow tests. The electrodes have been constructed to permit cooling by circulating liquid nitrogen should this be found necessary in order to preserve the medium uniformity. Arcing considerations due to the increased E/p in the vicinity of the electrodes due to the warm thermal boundary layers may also dictate the cooling requirements to be employed for the electrodes. Following interferometric measurements in the passive cavity measurements will also be performed on the active meidum and finally gain and power measurements performed.

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