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Operating Manual Holographic Interferometry System for 2 x 2 Foot Transonic Wind Tunnel

James E. Craig

Spectron Development Laboratories, Inc.

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James E. Craig

Spectron Development Laboratories, Inc.
3303 Harbor Blvd., Suite G-3
Costa Mesa, California 92626

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National Aeronautics and
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Ames Research Center
Moffett Field, California 94035

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1.0 INTRODUCTION

Interferometry which utilizes the mixing of two coherent waves for the purpose of measuring the distortion in one of the waves, has been used in small scale wind tunnels and is well-understood. The introduction of holography as an intermediary to store the light wave information allows a great deal of versatility in the use of the technique and significantly extends the possible applications.

With holography, the amplitude and phase distribution of a light-wave passing through the flow field at some instant of time can be stored and later reconstructed for comparison to waves formed at other conditions. This allows the storage of several test conditions for later comparison and analysis outside of the test facility. In addition to the interferometry techniques, the shadowgraph and Schlieren flow visualization techniques are also available. The ability to reconstruct the light field outside of the wind tunnel allows a much greater flexibility in spatial filtering and photographing the images.

A comparison of the Mach-Zehnder and the holographic interferometer will best explain why the optical and mechanical stability requirements can be relaxed. In the case of the Mach-Zehnder interferometer, a coherent light beam is split into two paths, one of which passes through the test region. Hence, the interference is between two light waves following different paths interfering at the same time. On the other hand, with holographic interferometry the interference is between two reconstructed waves taken at different times but that have followed the same optical paths. It can be seen that optical imperfections in the system will tend to cancel. Vibration, which is ever present in large-scale wind tunnel facilities, is not a difficulty if a pulsed laser is used (pulse duration $\sim$ 10 nanoseconds). The reconstruction and analysis of the interferogram is sensitive to vibration, but this part of the interferometry is done outside of the wind tunnel facility.

Transonic flows are especially suitable to the application of interferometry since compressibility occurs but the density changes are not all stepwise through shocks as in supersonic flow. In addition, the shocks present in the transonic flow fields are weak so that the entire flow field can be assumed to be isentropic. Thus, the interference fringes are at the same time a mapping of the constant density and the flow speed contours. These data can be readily reduced, with the use of other wind tunnel conditions, to the surface static pressure and viscous layer temperature profiles.

Based on work completed in the Ames 2'x2' transonic facility on the application of holographic interferometry by Spectron personnel using a makeshift interferometer system, a permanent system has been designed and constructed. The system was developed to alleviate some of the difficulties in applying the holographic interferometer technique. These difficulties included setting up the optics system, meeting safety requirements, aligning the pulsed ruby laser and maintaining alignment during testing. Basic to the design philosophy of the permanent system was the requirement that the system be as easy as possible to operate.

The present system utilizes a Quanta Ray DCR-1 Nd:YAG laser as the light source. This laser is capable of producing pulse rep rates between 2 and 20 per second at up to 80 millijoules of energy in the green line (.532 μm). Because of the high rep rate capability, a separate HeNe laser is not required for aligning the optics as in the case of a pulsed ruby laser system. Aligning the ruby laser to the HeNe laser over the long optical paths was one of the most time consuming features of the previous makeshift system.

A modification to the Q-switch electronics of the Nd:YAG laser was made by SDL to allow single pulse and double pulse operation. Single pulse operation is used to obtain holograms for double plate or double exposure interferometry and shadowgraphy flow visualization. Using the double pulse capability with variable time separation between pulses, interferograms detailing the dynamic features in the flow field can be produced.

In the following sections, the optical system is described, alignment and maintenance instructions are given, and the interferogram construction and reconstruction are described. The energy produced by the Nd:YAG laser can cause severe burns and permanent eye damage. Potential system operators should be trained and experienced operators of high power or repetitively pulsed lasers (i.e. Class IV Lasers). The potential operator should carefully study the operating manual and become completely familiar with the operating procedure. Under the supervision of a fully experience and qualified laser operator, the potential operator should undertake a course of training. Finally with the recommendation of the qualified laser operator, the potential operator should be deemed a qualified operator with sufficient knowledge and experience to operate the system in a correct and safe manner. Other potential operators should not be trained by newly qualified, novice operators.

2.0 SYSTEM DESCRIPTION

The hologram recording system is composed of a transmitting and a receiving optical stage, Figures 1 and 2, connected by two optical paths for the object and reference beams. Optical component schematics are shown in Figures 3 and 4 for the transmitting and receiving stages, respectively. The system can be broken down into 9 separate components listed below:

1) Laser/Beam Separation Optics

2) Spatial Filtering

3) Beam Splitter

4) Reference Beam Steering Mirrors

5) Reference Beam Expanding/Collimating Lenses

6) Object Beam Expansion

7) Schlieren Mirrors

8) Object Beam Collimating/Imaging Lenses

9) Hologram Plate Holder

The components are described in the following sections:

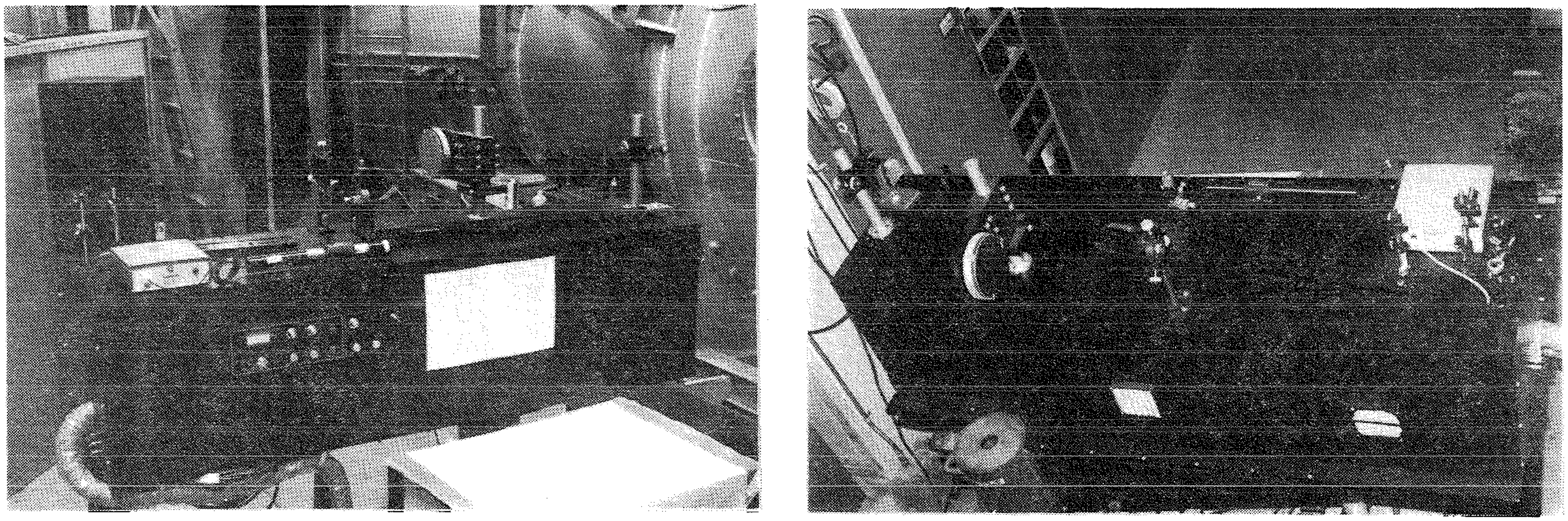


FIGURE 1. TRANSMISSION STAGE

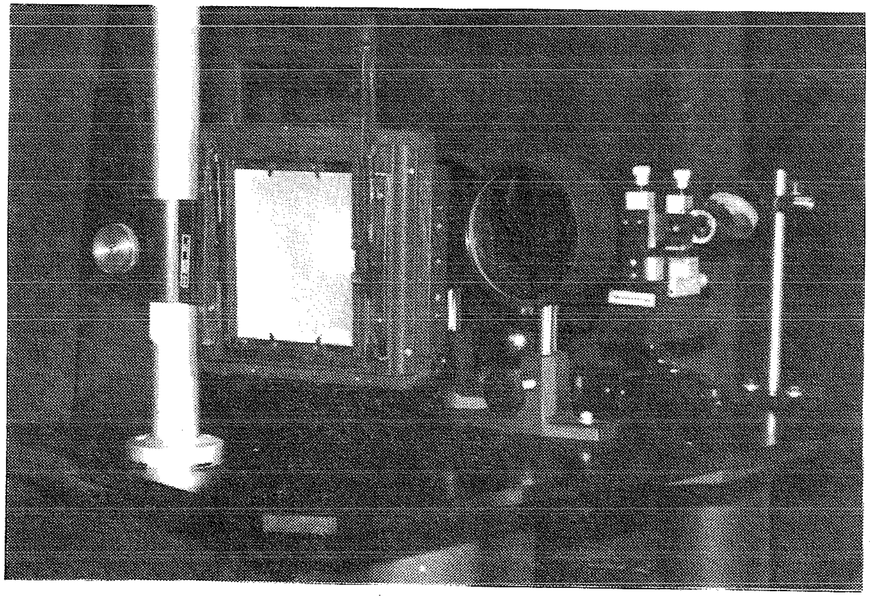


FIGURE 2. RECEIVING STAGE

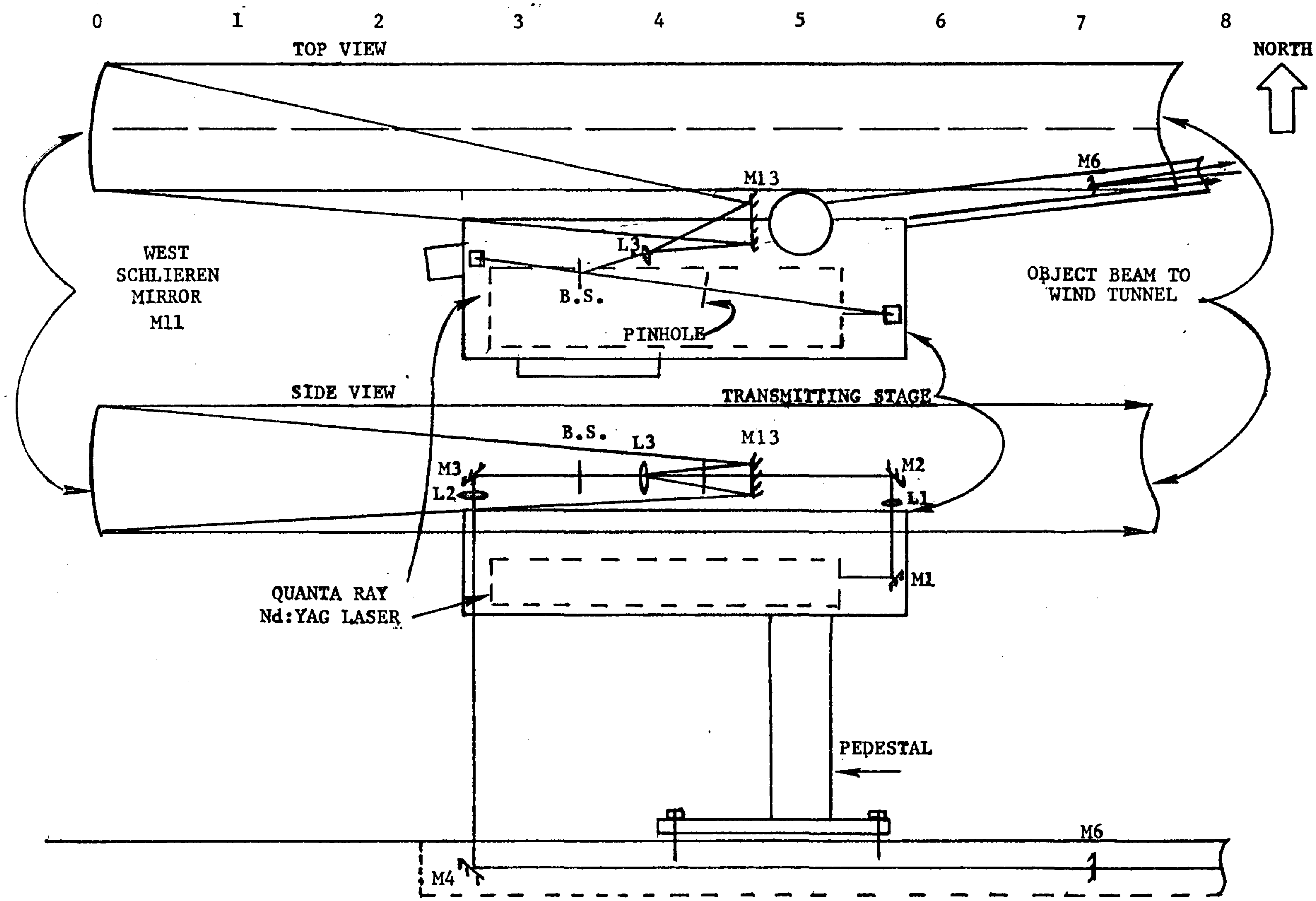


FIGURE 3. TRANSMITTING STAGE SCHEMATIC

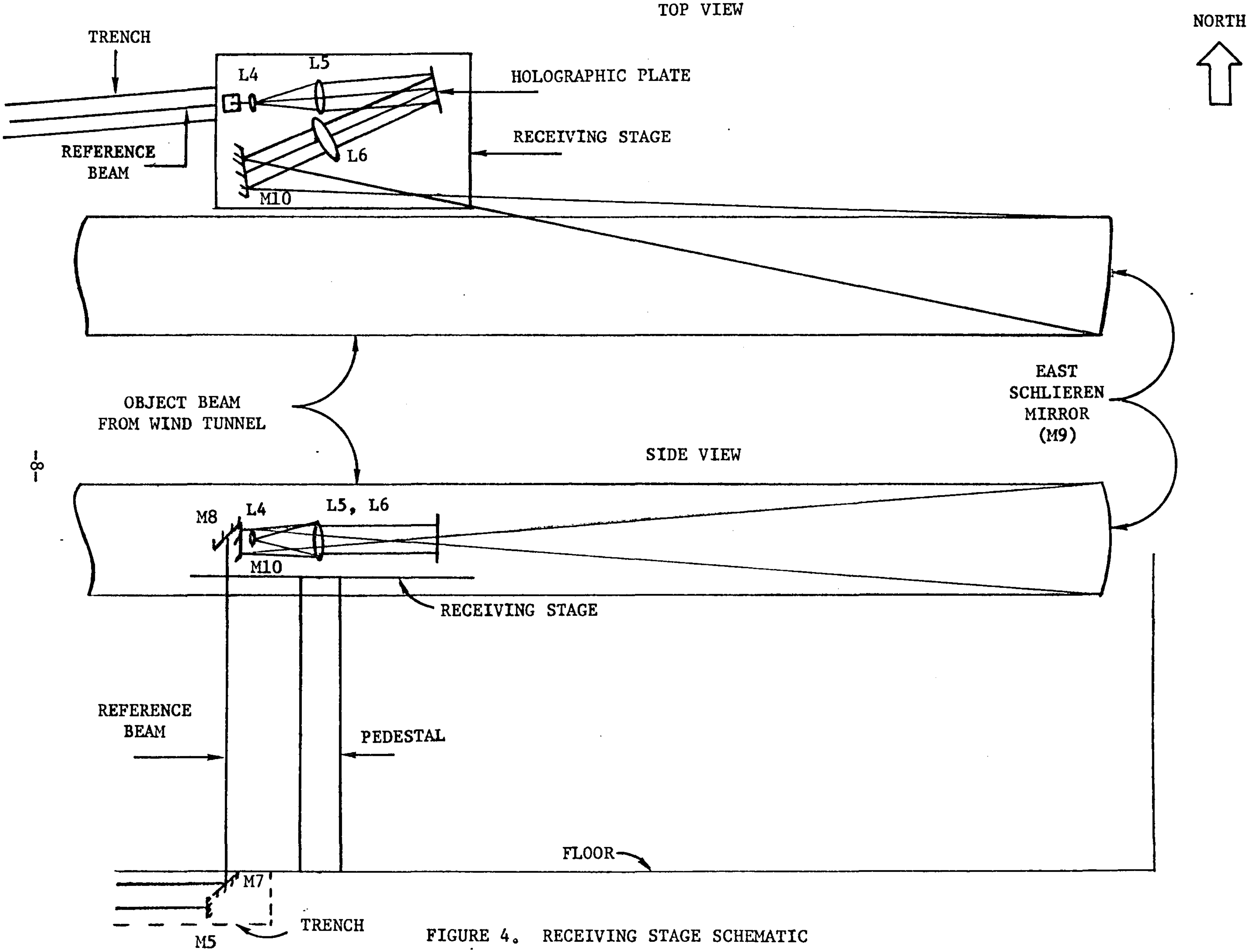


FIGURE 4. RECEIVING STAGE SCHEMATIC

1) The laser is a Quanta Ray DCR-1 pulsed Nd:YAG laser (Figure 5). The laser produces Q-switched pulses of 1.064 μm wavelength with a 10^{-8} sec pulse width. Lasing is achieved for flash lamp discharge energies above 40 joules and the system can provide over 80 joules of energy. At maximum flash lamp energy, the energy in the raw beam is about 0.25 joules. The short pulse from the laser oscillator is directed into a frequency doubling crystal in which a nonlinear conversion produces 0.532 μm radiation. Both the 1.064 and 0.532 μm radiation exits the doubling crystal coaxially. Frequency doubling produces about 0.08 joules of 0.532 μm radiation with the remainder of the energy in the 1.064 μm beam. The 0.532 μm radiation is green in color and quite suitable for holography. The two color coaxial beam is separated by a diachroic beamsplitter which reflects the 1.064 μm radiation onto an absorbing filter, Figure 6. The dichroic coating is designed to maximize the reflection at 1.064 μm wavelength while minimizing the reflection at 0.532 μm wavelength. The separation efficiency is quite good in that one part in 10^4 of the 1.064 μm radiation and 85 percent of the 0.532 μm radiation is transmitted. An additional 99 percent of the 1.064 μm radiation is removed in an infrared absorbing filter which also absorbs 15 percent of the 0.532 μm radiation. The overall separation is quite good, one part in 10^6 of the 1.064 μm radiation is transmitted with a 30 percent loss of the 0.532 μm radiation (the visible beam).

2) Spatial Filtering: After exiting the separation optics the beam is spatial filtered (Figure 7). The beam is brought to a focus where a pinhole is positioned to pass the central lobe and block the outer lobes.

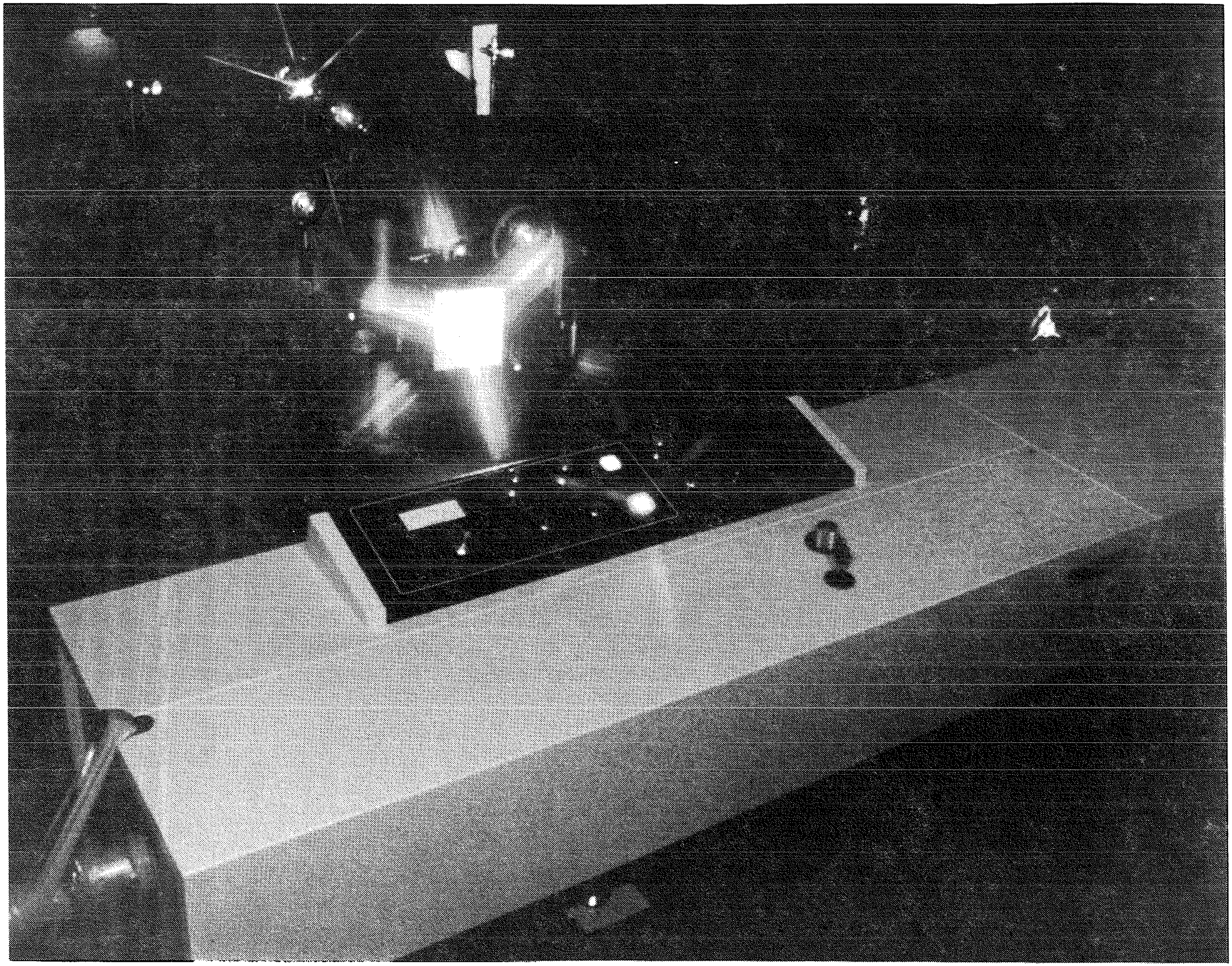


FIGURE 5. QUANTA RAY DCR-1 LASER

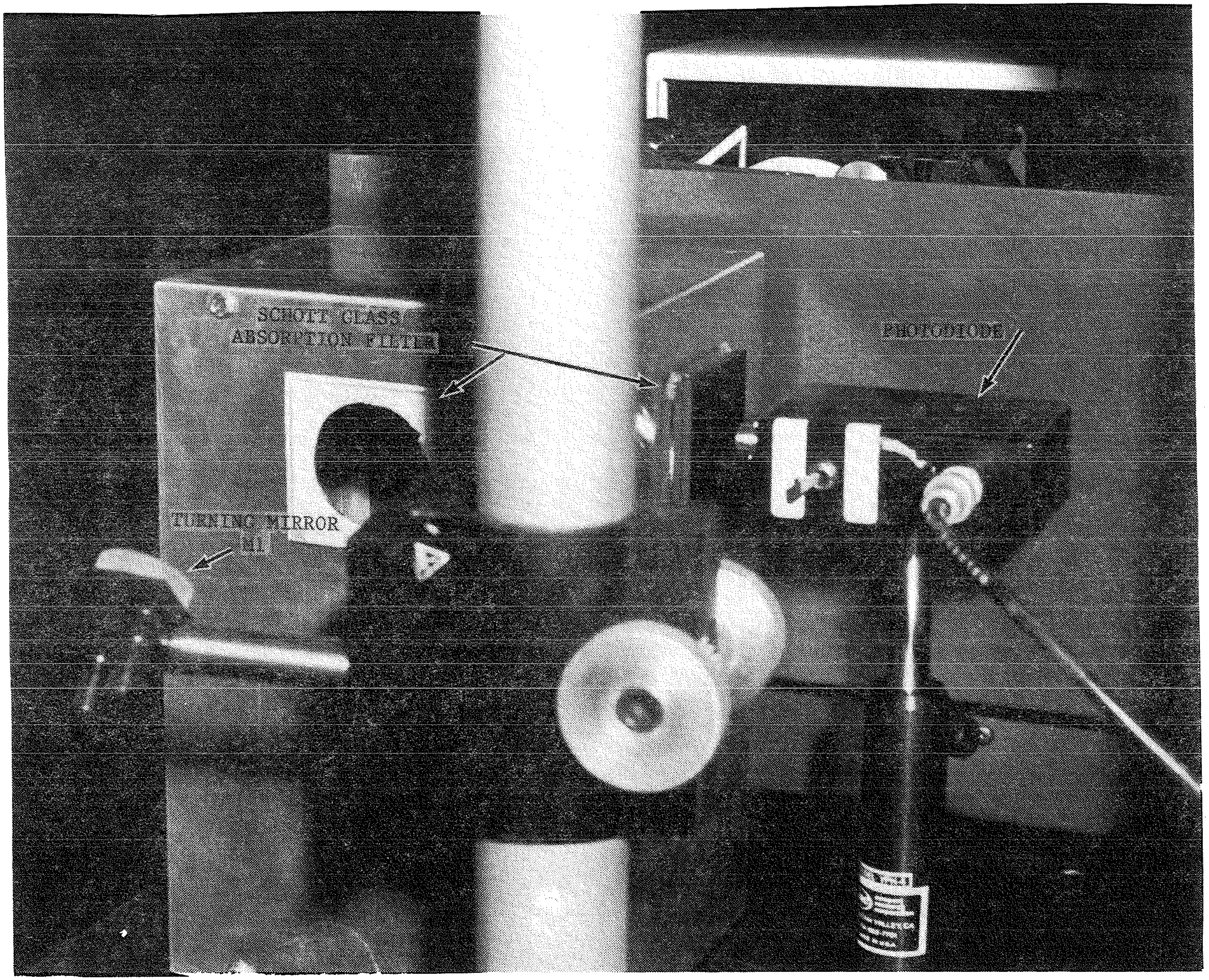


FIGURE 6. INFRARED/GREEN BEAM SEPARATION OPTICS

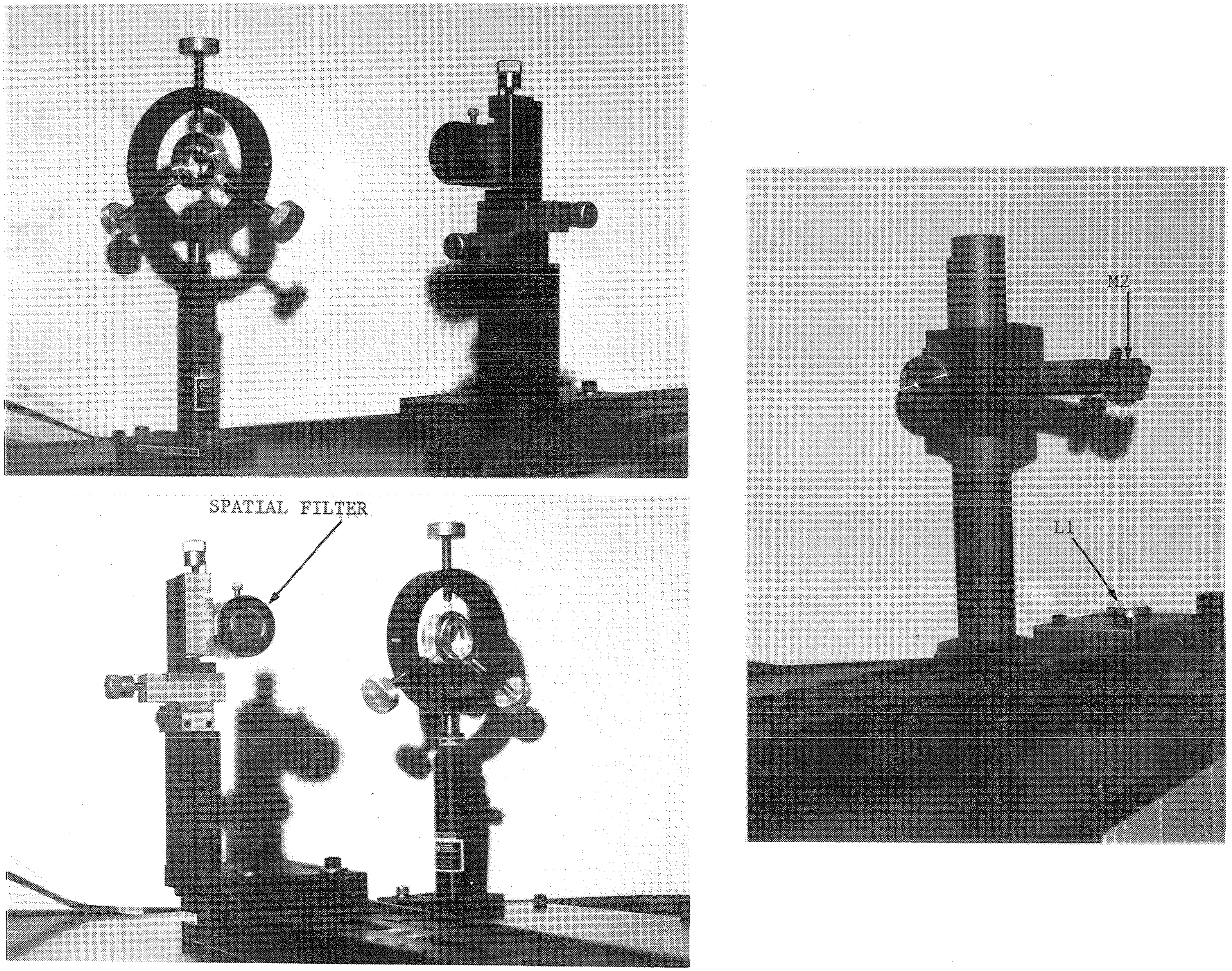


FIGURE 7. SPATIAL FILTER FOCUSING LENS L1, AND TURNING MIRROR M2

To minimize the beam intensity at the focus a long focal length lens (f = 1.0m) is used, which brings the unfiltered, 6mm diameter beam to a central lobe diameter of 216 μm. A spatial filter pinhole diameter of 150 μm was found to produce a very smooth beam intensity distribution; hence, the beam is quite suitable for holography.

3) Beamsplitter: The diverging beam is divided at the beamsplitter (Figure 8) into two beams of equal amplitude. The object beam is produced by reflection and the reference beam in transmission.

4) Reference Beam Steering: The diverging beam is turned towards the trench and passed through a positive lens (f = 1.0m) at a point along the beam where its diameter is 6mm. The positive lens is positioned so that the beam is almost collimated (i.e., the divergence angle is reduced). This allows the reference beam to pass easily along the trench without over filling any mirrors (Figure 9). Some divergence is required since, if collimated, the 6mm diameter beam would not have sufficient diameter after the 6.5 beam expansion on the receiving stage to cover the object wave on the hologram. The object beam diameter on the hologram is almost 70mm; hence, a 90mm reference beam diameter was selected. To achieve a 90mm reference beam diameter the input beam diameter at the beam expander must be 14mm and the positive lens on the transmitter stage is positioned to allow the beam to expand to 14mm diameter at the receiving stage.

5) Reference Beam Expansion and Collimation: The reference beam is turned into the horizontal plane on the receiving stage and passed into a positive lens (f = 37mm) used for beam expansion (Figure 10). A second positive lens (f = 240mm) is used to collimate the beam at 90mm diameter.

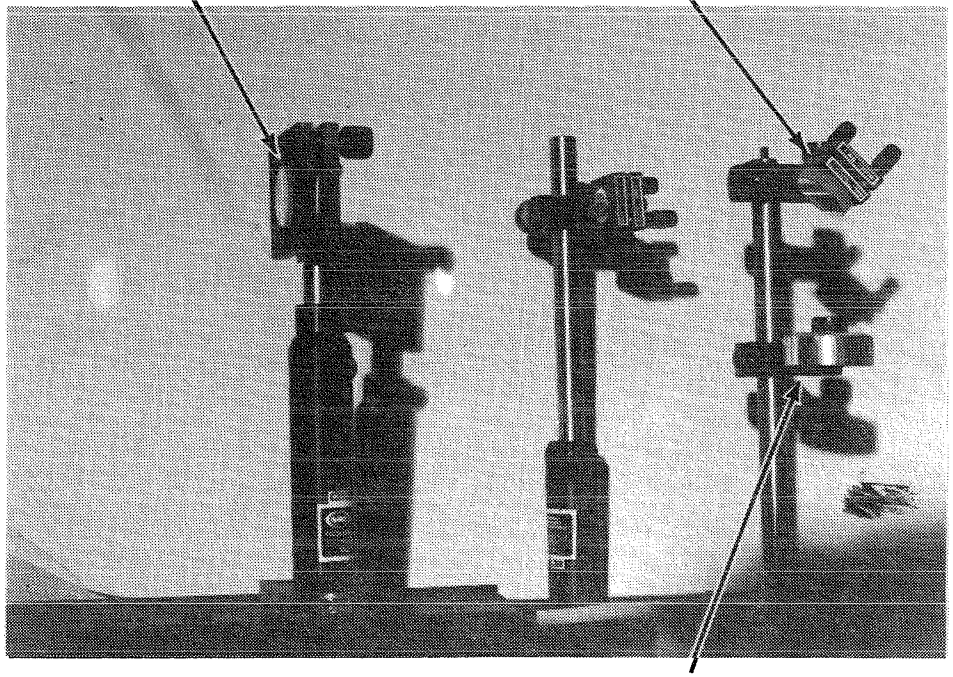
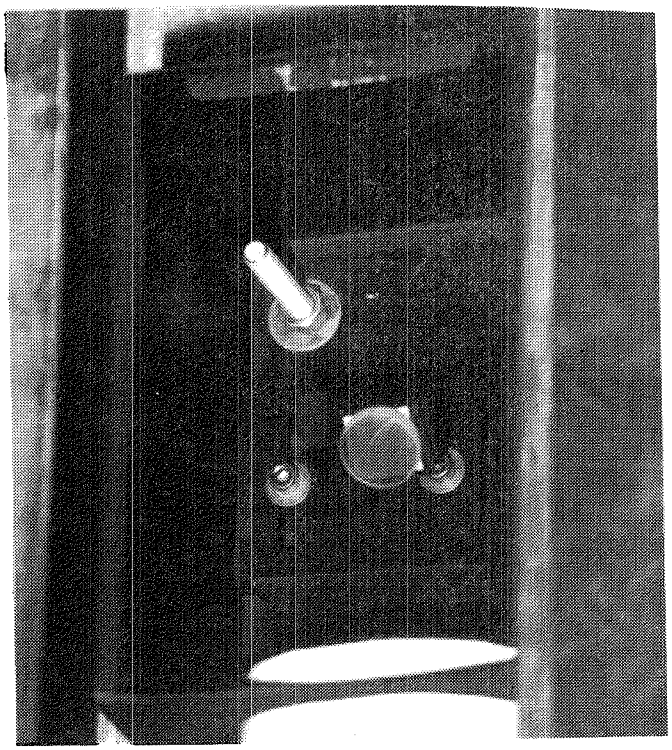
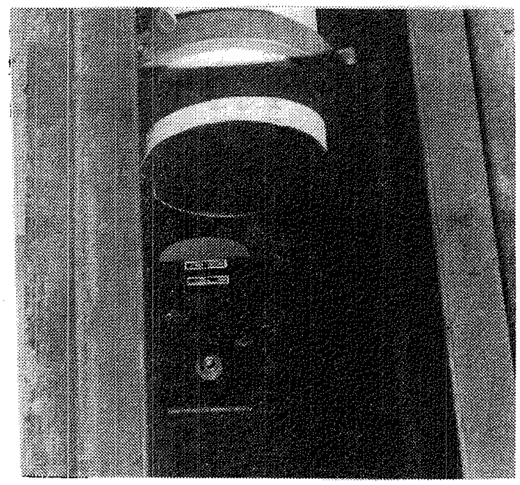


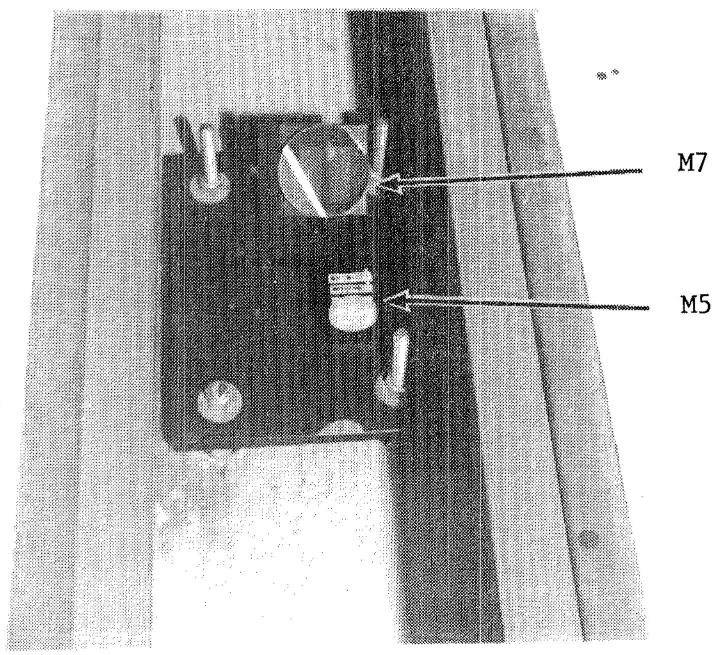
FIGURE 8. BEAMSPLITTER, TURNING MIRROR M3, COLLIMATING LENS L2



9a. ENTERING TRENCH, M4



9b. PATH MATCHING MIRROR, M6



9c. EXITING TRENCH, M5 AND M7

FIGURE 9. REFERENCE BEAM STEERING MIRRORS IN TRENCH

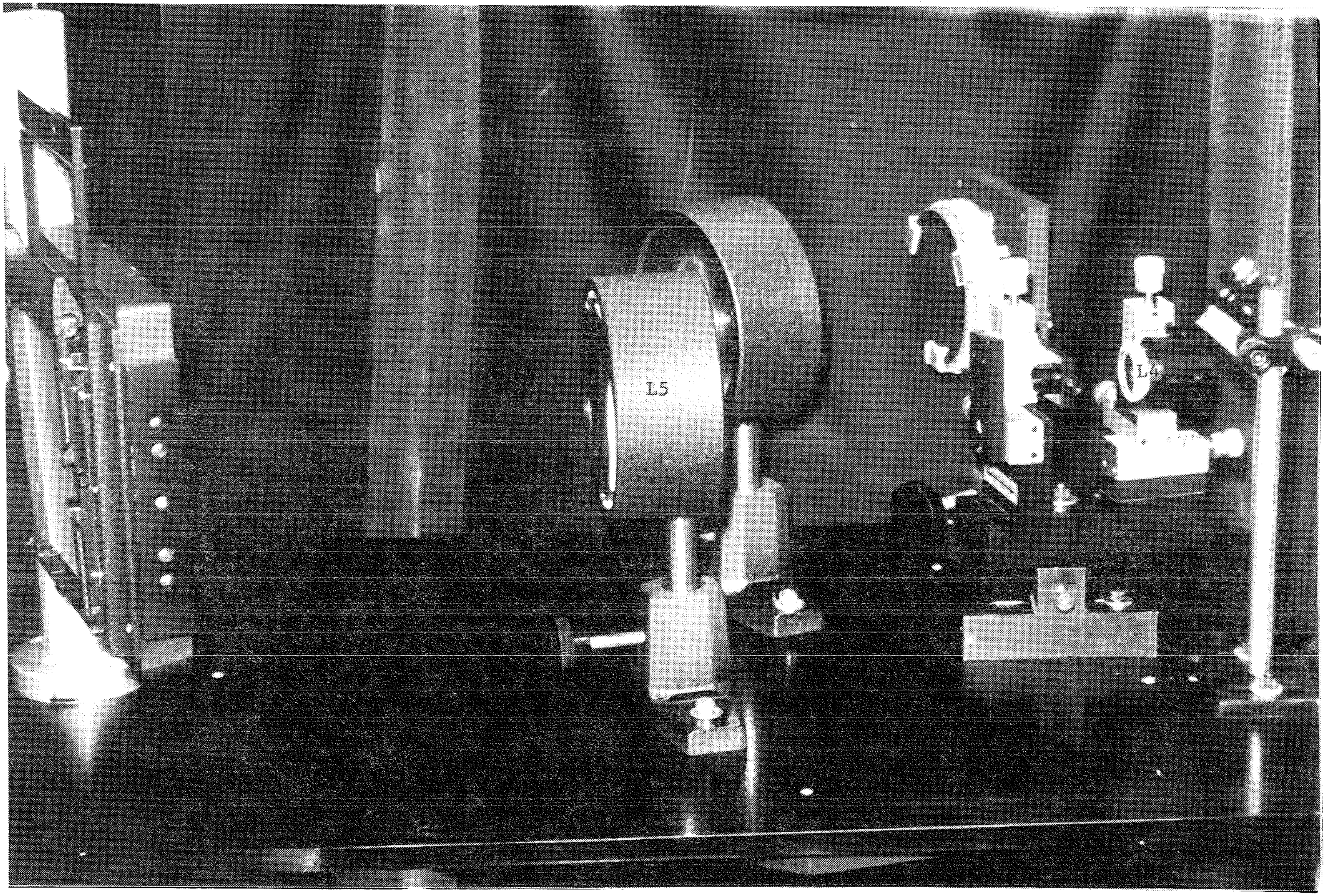


FIGURE 10. REFERENCE BEAM EXPANDING L4, AND COLLIMATING LENS L5

6) Object Beam Expansion: The object beam is expanded from 6mm diameter with a short focal length positive lens, F = 37mm, to over-fill the West Schlieren mirror. The expanding beam is directed into the Schlieren mirror by a 150mm diameter mirror, M5, as shown in Figure 11.

7) Spherical Mirrors: The expanding object beam is intercepted by the West Schlieren mirror, Figure 12a, and reflected as a collimated beam through the wind tunnel. The collimated wave is intercepted by the East Schlieren mirror, Figure 12b, after exiting the wind tunnel. The East Schlieren mirror reflects the object beam into the receiving stage where it passes through a focus.

8) Object Beam Collimating/Imaging: The object beam is collimated by a positive lens (F = 500mm) on the receiving stage, and the hologram plate holder is positioned at the image plane of the wind tunnel (Figure 13).

9) Hologram Plate Holder: The hologram plate holder is oriented with its normal bisecting the object and reference beams.

A comprehensive optical component parts list is given in Table 1.

TABLE 1

PARTS LIST

COMPONENT NUMBER	DESCRIPTION *
M1, M2, M3, M4, M5	ϕ = 1" Dielectric Coated Mirror
M6, M7, M8	ϕ = 2" Dielectric Coated Mirror
M11, M12	Schlieren Mirrors
M10	ϕ = 4" Silver Coated Mirror
M13	ϕ = 6" Silver Coated Mirror
L1, L2	ϕ = 1", f = 1.0 Meter
L3, L4	ϕ = 37 mm, f = 37 mm
L5	ϕ = 110 mm, f = 240 mm
L6	ϕ = 110 mm, f = 490 mm
Beamsplitter	ϕ = 1.0", T = 50% and R = 50% @ 5320. Å
Pinhole	ϕ = 150 µm
Graflex Camera Back	4 x 5 Inch Plates

* Contact SDL Purchasing for Vendor and Part Number Information for Replacement Parts.

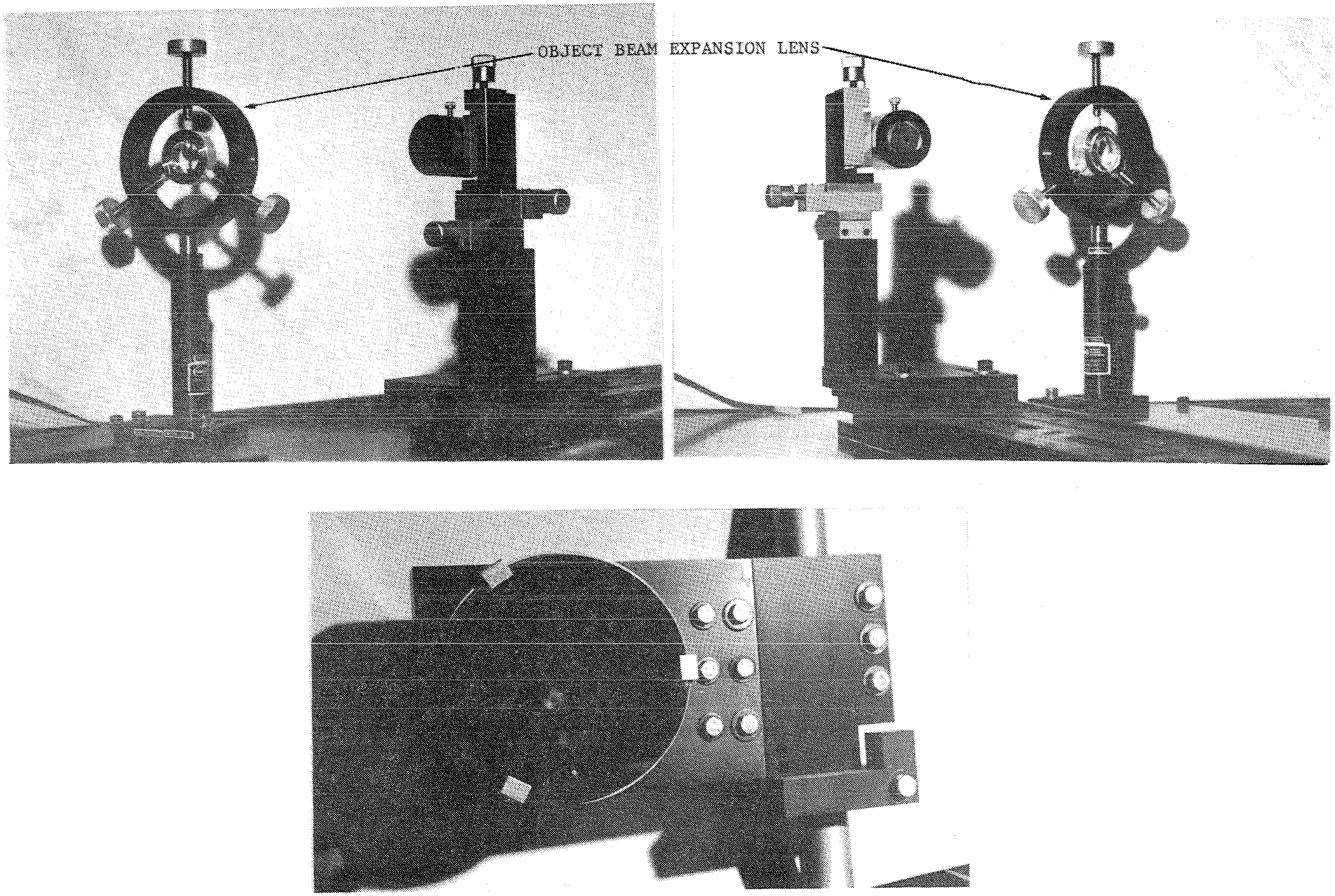


FIGURE 11. OBJECT BEAM EXPANSION L3, AND TURNING MIRROR M13

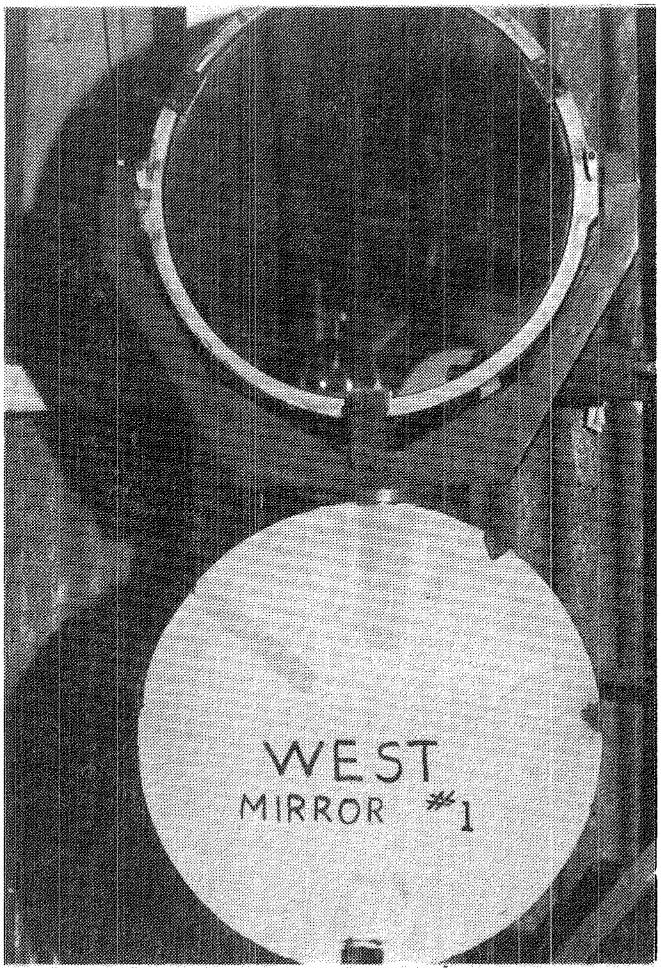


FIGURE 12. WEST MIRROR

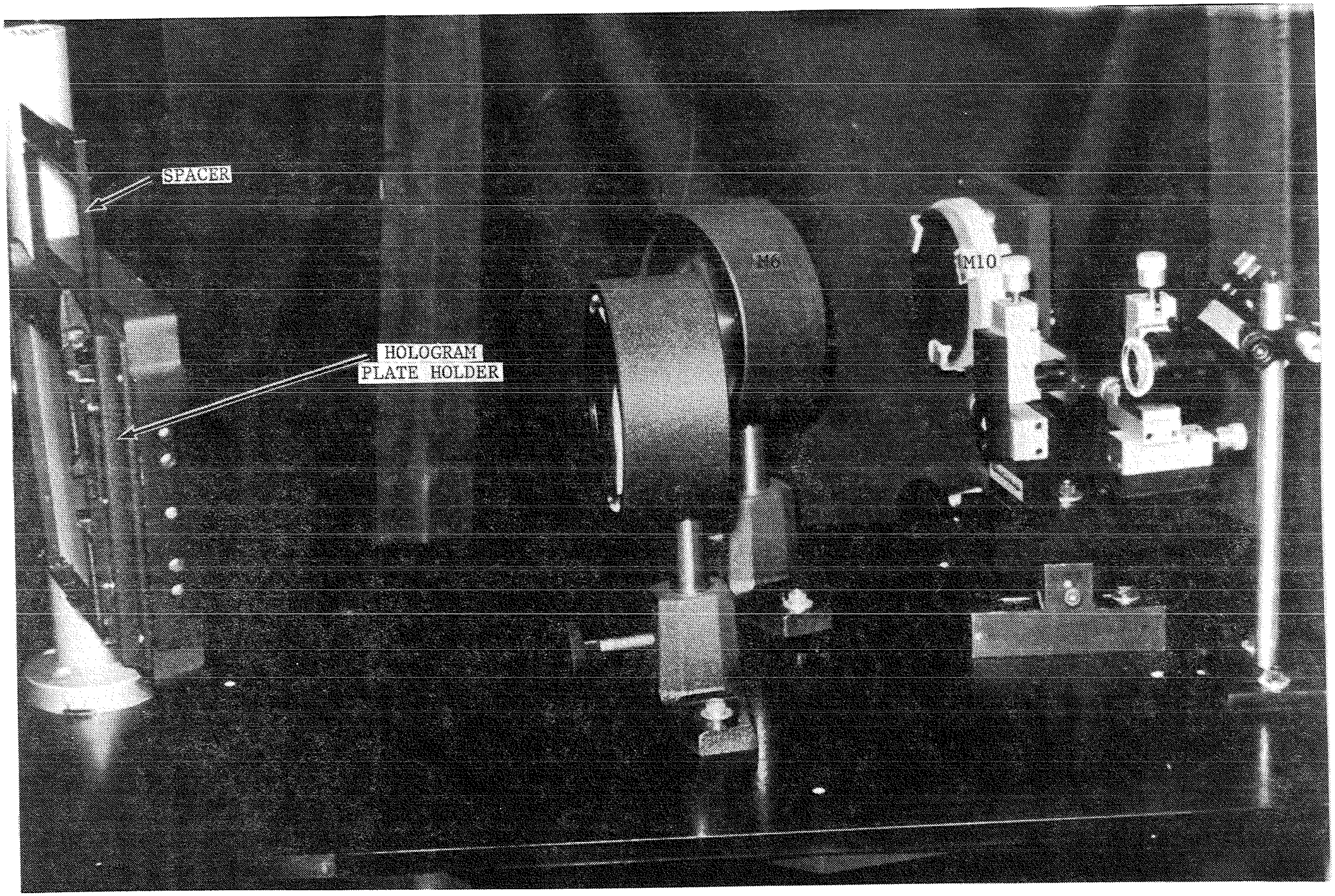


FIGURE 13. TURNING MIRROR M10, OBJECT BEAM COLLIMATING LENS L6, HOLOGRAM PLATE HOLDER AND SPACER

3.0 SAFETY

Complete safety analysis and planning has been performed in the design of the optical system. Since the wind tunnel center line height is head level the entire optical system has a very dangerous beam height. Therefore, the entire beam has been enclosed in the control room and partially enclosed in the West room (Figure 14) which is also a restricted area during hologram recording. Beam intensities have been calculated along the optical path and positions for safe viewing of diffuse reflections are defined for alignment purposes. Where required, eye protection is defined. Warning lights and signs and interlock circuits are described, as well as emergency and safety procedures.

3.1 Beam Intensities

Beam intensities have been calculated for all important points along the optical path between the laser oscillator and the hologram plate holder. As is the convention for pulsed lasers, the energy and energy densities are actually calculated. The laser output energy was measured upon delivery at the following flash lamp energies:

ENERGY (joules)

Flash Lamp	Laser Oscillator (@ 1.064 μm)
40	.012
50	.072
60	.150
70	.210
80	.250

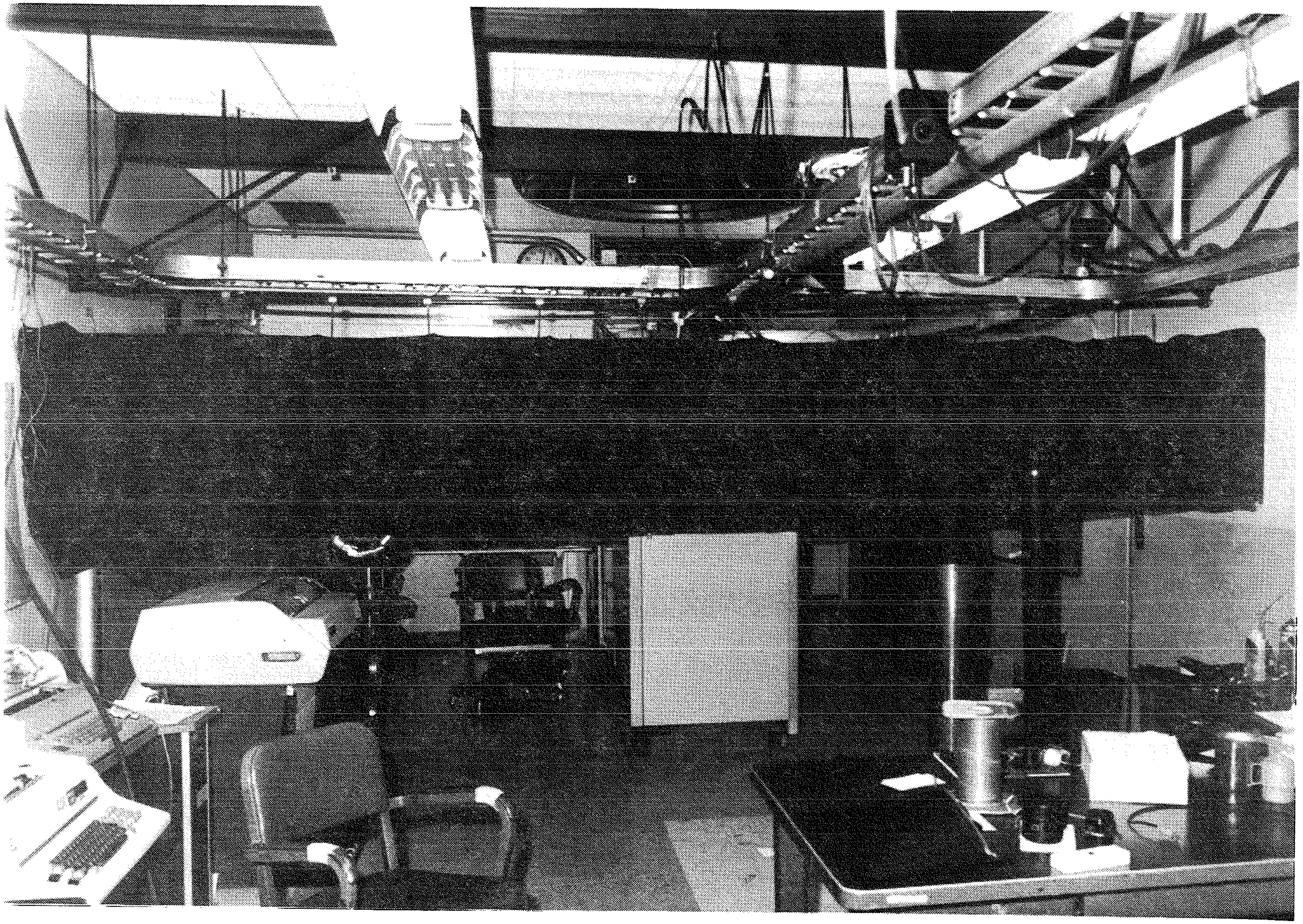


FIGURE 14. BEAM ENCLOSING TUBES AND CURTAINS

These numbers allow the operator, who can select the flash lamp energy, to be knowledgeable of the output laser power. The frequency doubling crystal is assumed to double the frequency of one third of the input energy.

The laser beam divergence is minimized for 60 joules per pulse and the manufacturer recommends operation at this condition. Therefore, beam conditions were calculated for 0.150 joules of laser output energy in the 1.064 μm wavelength line, or for 0.05 joules of energy at the 0.532 μm wavelength line from the frequency doubling crystal. The energy density varies from a maximum of 0.52 to a minimum of 0.8×10^{-6} joules/cm^2 at unfocused points along the beam path as shown in Table 2. The highest energy density occurs at the pinhole, 120 joules/cm^2.

The laser is single pulsed at 60 joules per pulse flashlamp energy to produce 40 mjoules laser energy in the green line for hologram recording. For alignment, the Q-switch delay is adjusted to reduce laser pulse energy to 4 mjoules per pulse.

Holograms can be recorded by one or two operators; for the case of one operator, the laser is remote fired from the East control room, and for the case of two operators, the laser can be fired at the laser head. In either case, the beam is completely enclosed in the East control room where no eye protection is required, and in the West room where the beam is partially exposed, operators must wear safety glasses with an optical density of 5 at the 0.532 μm wavelength (note that no protection is required for the 1.064 μm radiation because only 10^{-7} joules exits the laser transmitter box).

TABLE 2: LASER BEAM INTENSITY DISTRIBUTIONS

(LASER OUTPUT @ 60 JOULES/PULSE INTO FLASH LAMPS
Q-SWITCH SET FOR MAXIMUM ENERGY [250 μSEC])

COMPONENT	DIAMETER (cm)	ENERGY (joules)		ENERGY FLUX (joules/cm^2)	
		1.064 μm	0.532 μm	1.064 μm	0.532 μm
Laser Oscillator	0.6	0.150	0	0.52	0
Frequency Doubling Crystal	0.6	0.100	0.050	0.35	0.17
Dichroic Beamspliter					
Transmitted Beam	0.6	10^{-5}	0.040	3.5×10^{-5}	0.14
Reflected Beam	0.6	0.100	0.010	0.35	0.035
Reflected Beam Absorber					
Schott Glass KG3	0.6	10^{-5}	0.010	3.5×10^{-5}	0.035
Schott Glass	0.6	10^{-5}	10^{-5}	3.5×10^{-5}	3.5×10^{-5}
Transmitted Beam Absorber					
Schott Glass KG1	0.6	10^{-7}	0.038	3.5×10^{-7}	0.13
Positive Pinhole Lens (F = 10^3mm)	0.6	"	0.030	"	0.10
Pinhole	0.02	"	"	"	120.
Beamsplitter (50/50)	0.4	"	0.018	"	0.14
Object Beam					
Positive Expanding Lens f=37mm	0.4	"	0.08	"	0.062
Focal Point	5×10^{-4}	"	"	"	62×10^3
Steering Mirror 10	8.	"	0.007	"	0.14×10^{-3}
West Schlieren Mirror	60.	"	0.006	"	2.1×10^{-6}
East Schieren Mirror	40.6	"	0.001	"	0.8×10^{-6}

TABLE 2 : LASER BEAM INTENSITY DISTRIBUTIONS continued

COMPONENT	DIAMETER (cm)	ENERGY (joules) 1.064 μm	ENERGY (joules) 0.532 μm	ENERGY FLUX (joules/cm^2) 1.064 μm	ENERGY FLUX (joules/cm^2) 0.532 μm
Focal Point	0.02	10^{-7}	0.001	3.5×10^{-7}	0.31×10^{4}
Steering Mirror 13	5.0	"	"	"	0.51×10^{-4}
Ground Glass Viewing Screen	6.7	"	"	"	91×10^{-6}
Reference Beam					
Positive Collimating Lens (f = 10^3mm)	0.6	"	0.008	"	0.028
Steering Mirrors	0.6/20	"	0.007	"	0.024/ 0.002
Positive Expanding Lens (f = 37mm)	2.0	"	0.006	"	0.002
Positive Collimating Lens (f = 240mm)	11.0	"	0.006	"	63×10^{-6}
Ground Glass Viewing Screen	"	"	"	"	"

For alignment, the beam enclosure tube and the transmitter and receiver cover boxes are removed. The laser is operated at 60 joules per pulse but the Q-switch is adjusted to reduce the laser output energy by a factor of 10. This is accomplished by turning the Q-switch delay completely counter-clockwise, where the delay is 150 μsec. For this condition the laser beams DIFFUSE REFLECTION from a white card can be safely viewed without eye protection at many points; however, eye protection is required to view the beam before the beamsplitter.

For the special case in which the diachroic beamsplitter needs to be aligned, infrared eye protection is required. To align the diachroic beamsplitter, first remove the frequency doubling crystal from the optical axis so that eye protection is required only for 1.064 μm wavelength. With appropriate eye protection, use an infrared phosphor card to locate the beam and to direct the reflection from the beamsplitter into the absorbing filter. Since the beamsplitter will only transmit the green radiation, install the frequency doubling crystal and observe that the green transmitted beam is not apertured by the beamsplitter. Infrared eye protection is required for this alignment, but is not required for alignments beyond the infrared absorbing filter in the beam transmitted from the diachroic beamsplitter.

3.2 Warning Lights, Signs and Interlocks

Safety lights have been placed at the South entry door to the wind tunnel control room where the laser holography system is located. The lights are activated by a switch near the transmitter stage.

Laser radiation warning signs have been posted at all points of entry to the holography system location. Laser radiation warning signs are also posted on the transmitter and receiver state cover boxes.

The laser power supply is key interlocked and the key should be kept with the laser operator.

3.3 Emergency Shutdown Procedure

In the case of any type of emergency, the emergency shutdown procedure shall be conducted by the authorized laser operator. Potential emergencies include:

1) unexpected occurrences or conditions with the holography system,
2) emergency wind tunnel shutdown,
3) electrical sparks or fires, and
4) building fire or water flood.

The EMERGENCY SHUTDOWN PROCEDURE is to position the power supply ON/OFF switch (Figure 15) into the OFF position, thus disconnecting all power to the holography system.

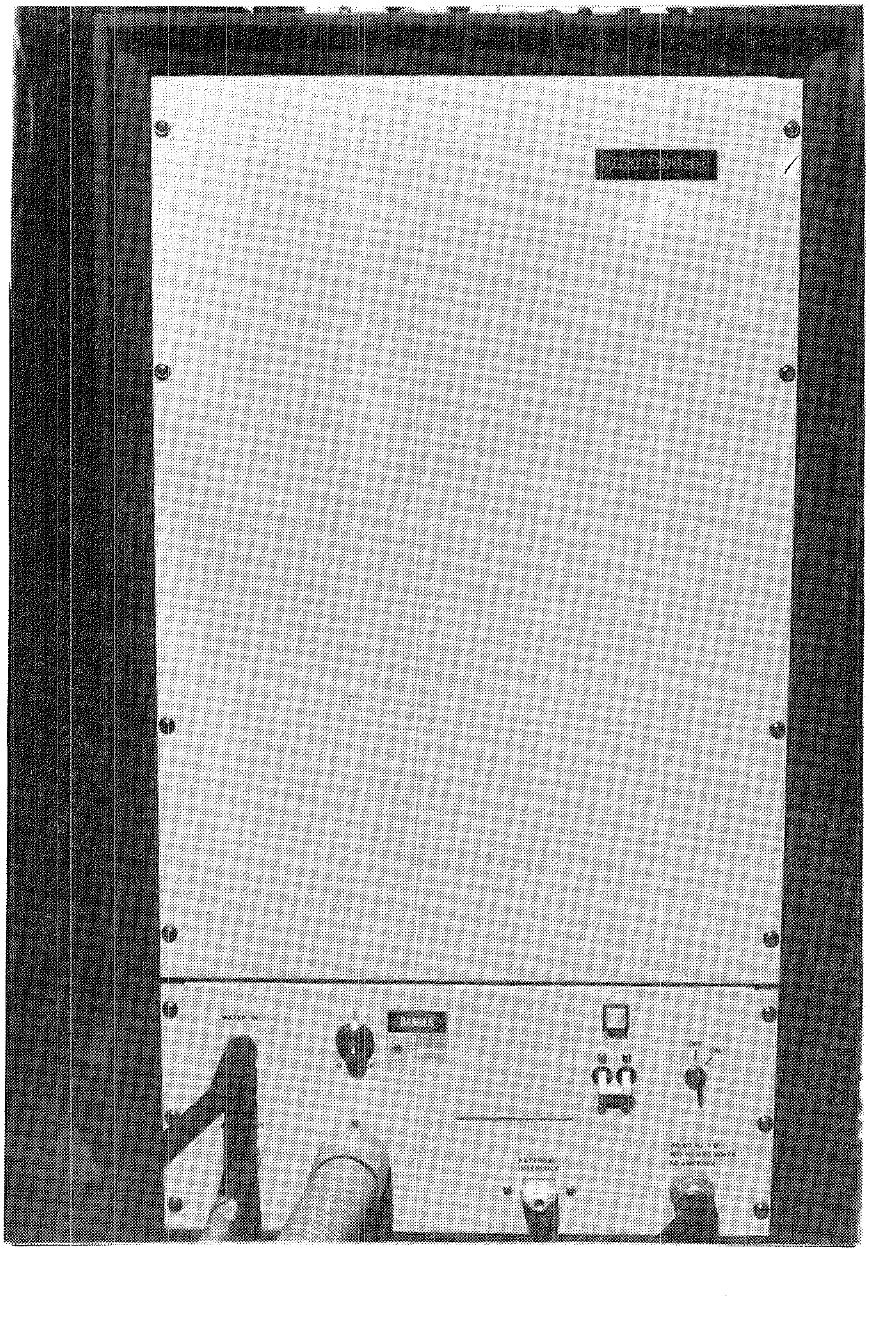


FIGURE 15. QUANTA RAY LASER POWER SUPPLY

4.0 SYSTEM OPERATION

The pulsed laser holography system is designed and intended to be used only by a trained and experienced operator. Two modes of routine operation, initial setup and hologram recording, can be conducted by a single operator. For the initial setup phase the operation may require assistance where adjustments are required over long distances such as in the trench. With the system on and its operation and alignment verified, the operator proceeds to the hologram recording phase, in which holographic plates are inserted into the camera back and exposed to the required pulse.

4.1 Electronics

The Quanta Ray DCR-1 laser control electronics has been expanded to allow the generation of individual laser pulses. The design operating mode allows for flashlamp pumping and Q-switching initiated repetitively by an internal clock whose frequency is variable from 2 - 22 Hz. The laser cavity design includes the effect of thermal focusing within the Nd:YAG media for an average flashlamp power of 600 watts. The Nd:YAG rod is optically pumped by capacitive discharge through a pair of linear, xenon-filled flashlamps. The design operating point is achieved by 60 joule discharges at a repetition rate of 10 pulses per second. High power, short duration laser pulses are obtained by Q-switching the cavity during the most energetic portion of the flashlamp discharge.

For normal operation, the flashlamps are repetitively triggered by an internal oscillator. The flashlamp trigger also arms a one-shot which, after a preset delay, triggers the Q-switch. Individual laser pulses are obtained by repetitive flashlamp operation (to maintain the required thermal condition of the Nd:YAG rod) and selective Q-switching when a pulse is desired. The laser head external inputs and sync outputs are used to generate individual laser pulses. Specifically, a one-shot in the single pulse circuit is armed by the signal from the external fire button and is fired by the next flashlamp sync output. The one-shot output triggers a second one-shot whose output triggers the Q-switch after a preset delay.

To synchronize the laser pulse to an external event the internal oscillator can be replaced by an external oscillator. The oscillator frequency must be in the 8 to 12 Hz range to achieve thermal requirements in the Nd:YAG rod.

An electronics flow diagram for laser operation is shown in Figure 16.

To obtain single pulses:

1) position the Q-switch selector, Figure 17, into EXTERNAL, thus enabling the single pulse electronics;
2) position the single pulse Q-switch selector into SINGLE and depress the fire button for single pulses (for remote firing use the portable fire button);
3) to adjust the pulse energy, block the beam in front of the pinhole to avoid damage. Position the single pulse Q-switch selector into SET. Adjust DELAY 1 to obtain desired pulse energy by monitoring photodetector output.

To obtain double pulses:

1) position the Q-switch selector into EXTERNAL;
2) position the single pulse Q-switch selector into DOUBLE, and depress the fire button;

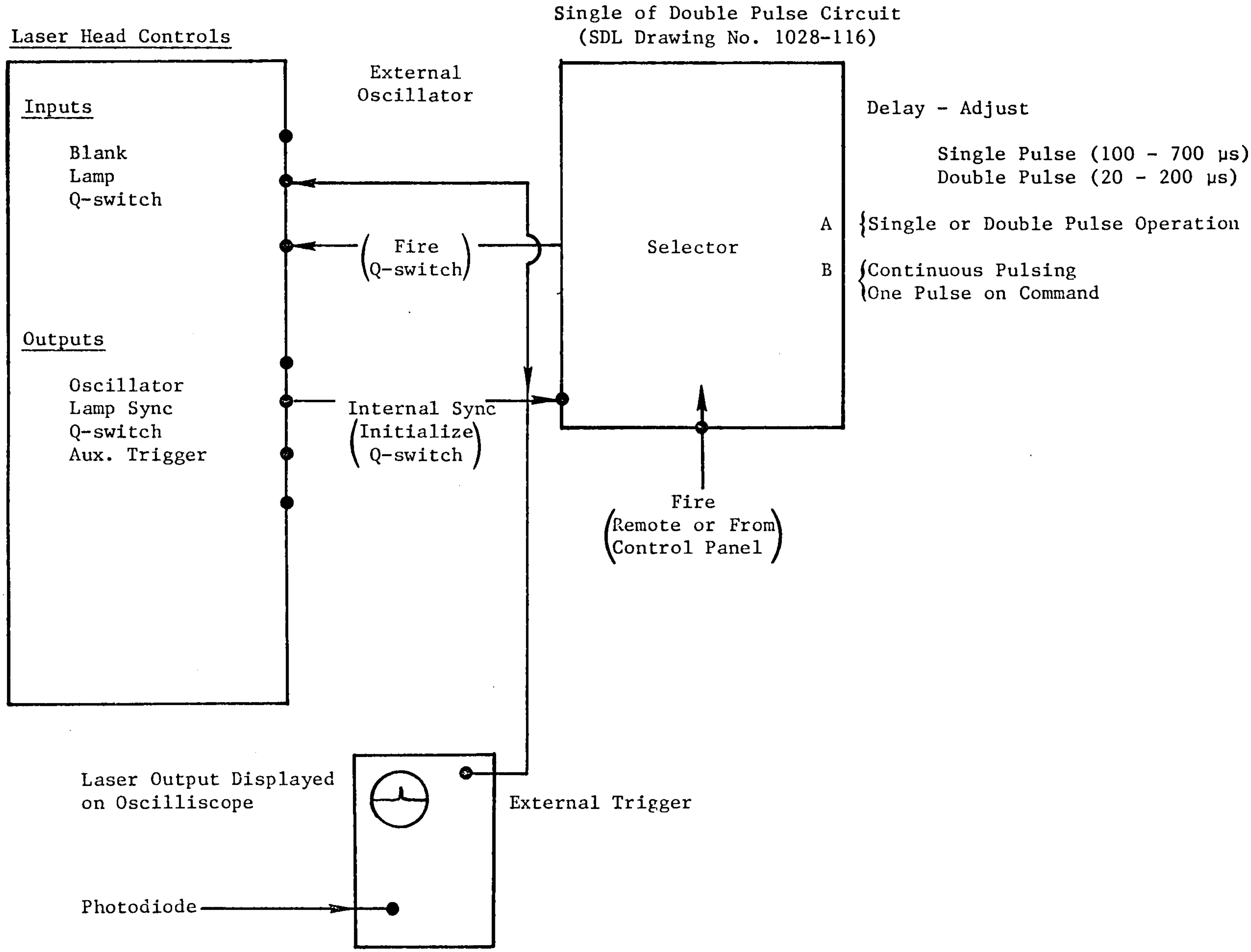


FIGURE 16. ELECTRONICS FLOW DIAGRAM FOR LASER OPERATION

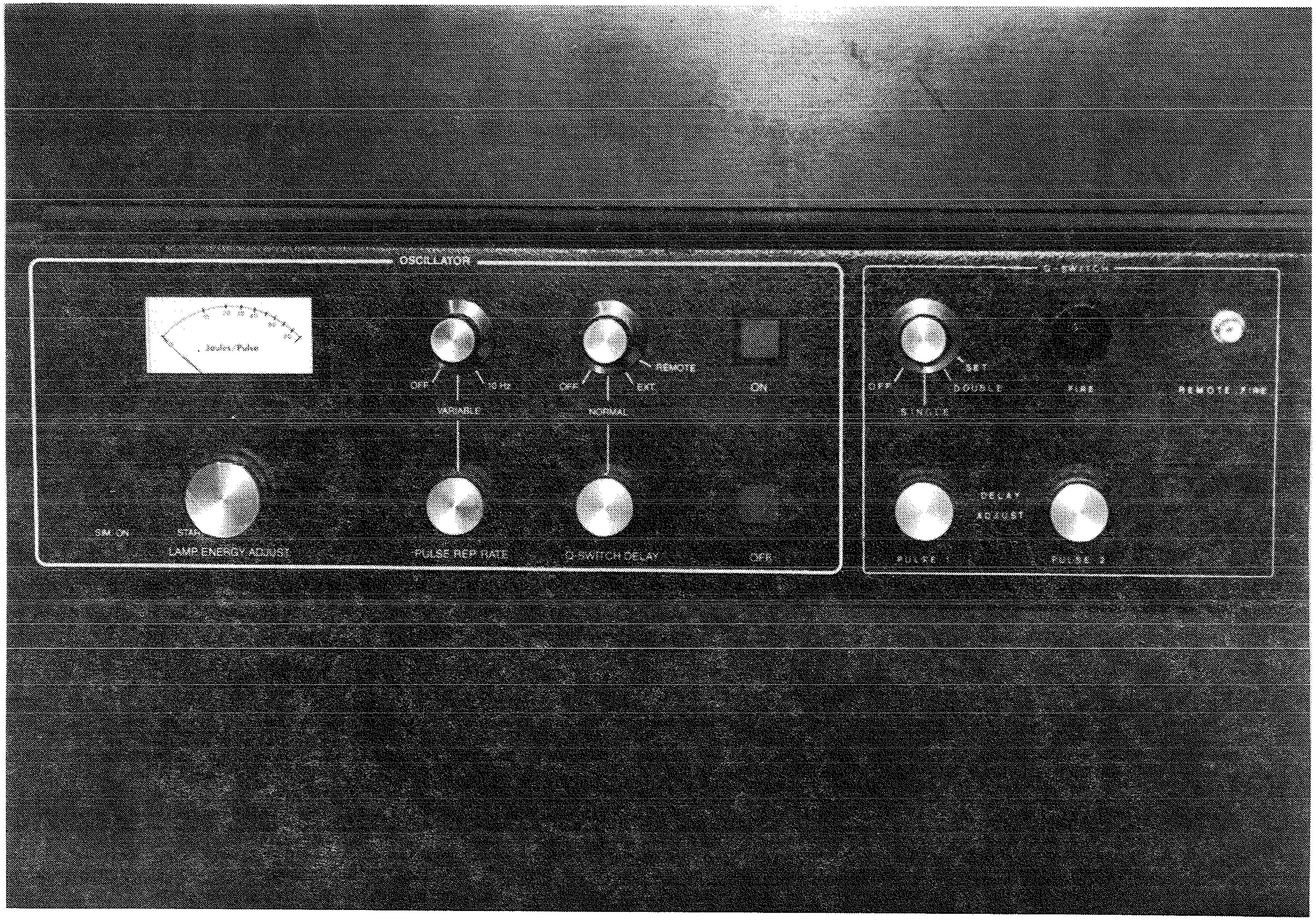


FIGURE 17. MODIFIED QUANTA RAY LASER CONTROL PANEL

3) to adjust the energy of each pulse, block the beam in front of the pinhole. Position the single pulse Q-switch selector into SET. Adjust DELAY 1 and DELAY 2 to obtain desired pulse energy by monitoring the photodetector output.

4) For double pulsing it is desirable to obtain pulses of near equal energy, which can be achieved for pulse spacings between 50 and 150 μs. Longer and to some degree shorter pulse spacings can be obtained but pulse energies will be as much as a factor of four different.

4.2 Holography System Operation

Before the initial setup the operator must initiate the proper safety precautions which include clearing the area of all unauthorized personnel, issuing laser safety glasses to all people who remain, locking of exit and entrance doors, turning on of warning lights and bells, and placement of warning signs outside all points of entry. After initiation of all safety precautions the operator shall energize the system.

To energize the system the operator shall (as described in the Quanta Ray Operating Manual):

1) turn on the water cooling supply,
2) turn on the laser power supply,
3) unlock safety key on the power supply,
4) turn on the laser head (note green simmer light after 13 seconds),
5) set the pulse selector to 10 Hz.

6) adjust the Q-switch delay to minimum time,

7) adjust the flashlamp energy to 60 joules, and verify lasing, and

8) adjust the position of pinhole to achieve proper spatial filtering by monitoring beam intensity after the beamsplitter.

For recording holograms, the operator shall:

1) Verify system alignment

   a) set laser to run in multiple pulse mode (10 Hz) at 60 joules per pulse flashlamp energy,

   b) the laser pulse energy is adjusted by varying the flashlamp to Q-switch delay. For visual alignment verification from diffuse reflectors reduce the laser pulse energy by setting the Q-switch delay to a minimum,

   c) observe object and reference beam alignment on the ground glass viewing screening,

   d) a better way to monitor alignment is to expose a Polaroid. To expose Polaroids, enable the Q-switch single pulse electronics by placing the Q-switch selector into EXTERNAL. Block the beam with a diffuse reflector in front of the pinhole. Place single pulse Q-switch selector into SET. Monitor Q-switch delay on oscilliscope and set the DELAY 1 to achieve 400 μsec. Place single pulse Q-switch selector into SINGLE. For 400 μsec delay, the laser energy will correctly expose Polaroid Type 52 film. The exposure is made using the remote fire cable at the receiving stage. Load the Polaroid film back with Polaroid Type 56 film

(ASA400) and expose it with a single pulse. Observe that the exposure is uniform and centered. It is useful and good practice to expose Polaroid before recording reference (no flow) and test (flow) plates. If the Polaroid exposure reveals incorrect alignment, follow the instructions in Section 5.0 for correct alignment.

2) With alignment verified, holograms can be exposed:

   a) Set Q-switch DELAY 1 to maximum laser pulse energy (i.e., $\Delta t \simeq 250$ μs) by MONITORING pulse detector. Since the laser is in multiple pulse mode and operating at high power, place a beam stop in front of the pinhole. At high power, the laser should not be fired through the pinhole in the multiple pulse mode, as excessive pinhole damage will occur. The laser is single pulsed to expose holograms.

   b) Load AGFA 10E56 holographic plates into plate holder with the emulsion side facing outward.

   c) Darken room and tunnel lights.

   d) To record reference holograms, place the plate holder into the camera back, lift the slide, fire the laser, and close the slide.

   e) For test holograms (flow on) use the spacer between the plate holder and the camera back.

   f) Develop each hologram by visibly monitoring its density.

5.0 GENERAL SYSTEM ALIGNMENT

-NOTICE-

GENERAL ALIGNMENT PROCEDURES INVOLVE USE OF RAW UNEXPANDED LASER BEAM AND SHOULD NOT BE ATTEMPTED BY NOVICE LASER OPERATORS

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The complete system alignment is described below, and partial system alignments can be accomplished by starting at appropriate mid-points in the procedure.

Complete system alignment is accomplished in a stepwise fashion as described below:

1) Any of the following conditions should be corrected before recording holograms (note that these conditions apply equally to both reference and object beams):

   a) Reference and object beams should be concentric and centered on the ground glass viewing screen.

   b) Each beam should have a uniform intensity distribution (Figure 18) and not exhibit any traces of dark diffraction rings.

   c) Both object and reference beams should be collimated. This can be checked by blocking each beam one at a time and allowing the other beam to pass across the room where its diameter is measured. When collimated, the reference beams' vertical and horizontal dimensions should not change along the beam path; however, only the object beam's vertical dimension will remain constant. Off-axis use of the Schlieren mirrors produces astigmatism in the object beam

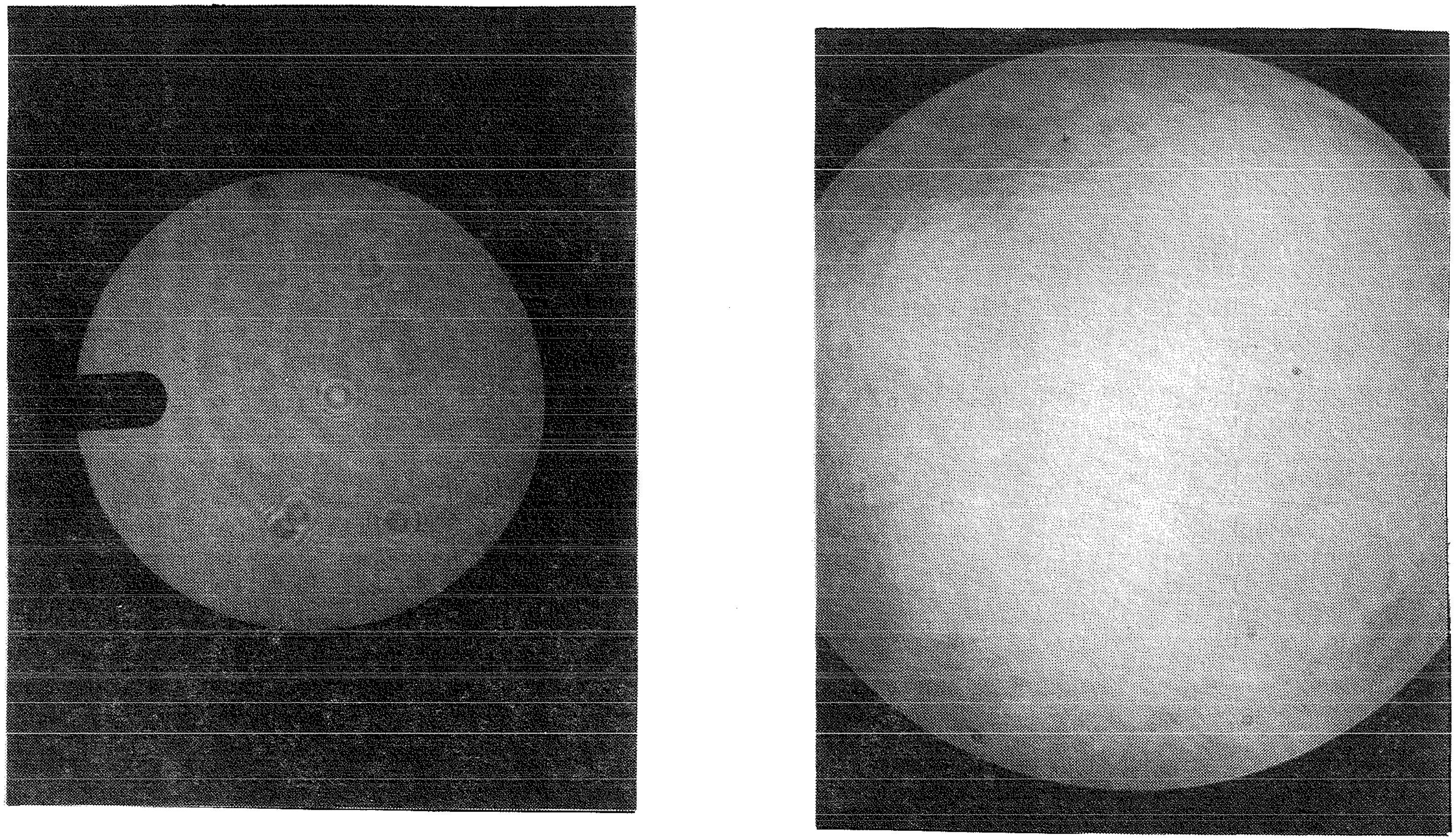


FIGURE 18. POLAROID P/N FILM EXPOSURE OF OBJECT AND REFERENCE BEAMS

which causes its horizontal dimension to converge beyond the hologram plane. This distortion in the object beam is not readily observable at the hologram plane.

2) If either object or reference beam is not aligned remove the pinhole and proceed with the required alignment described below. For all alignment procedures the laser should be operated in the multiple pulse mode, at 60 joules per pulse and a Q-switch delay to produce minimum laser energy (full counterclockwise turn).

3) Reference Beam: To align the reference beam begin by removing the expanding, L4, and the collimating lens, L5, on the receiving stage. Carefully observe that the beam is accurately centered on all the turning mirrors in the trench, the transmitting and receiving stages, M3 through M8. Alignment is observed by placing a diffuse reflector over each mirror; and when misalignment is detected adjustment of the previous mirror is required. This will also require the remaining mirrors to be readjusted and finally for the raw beam to be centered on the ground glass viewing screen. Install the expanding and collimating lenses and check that the beam is coaxial with the raw beam and that the beam is collimated.

4) To accuractely align the object beam, remove the expanding lens, L3, on the transmitter stage, and the collimating lens, L6, on the receiver stage. There can not be any obstruction in the center of the wind tunnel windows to perform this alignment procedure; however, this method insures accurate

alignment. If the center of the wind tunnel window is obstructed proceed to Step 5. Direct the object beam into the center of the West Schlieren mirror, M11, by adjusting the turning mirror, M5. Observe that the beam also passes through the center of the wind tunnel windows and onto the center of the East Schlieren mirror, M9. If the beam is not centered on the windows increase or decrease the angle of incidence into the West Schlieren mirror depending on whether the beam passes to the South or the North of the window center, respectively. The angle of incidence is adjusted by rotating the beamsplitter to move the point where the beam strikes the turning mirror, M5. Then readjust the turning mirror to center the beam in the West Schlieren mirror. The up and down adjustment is accomplished in the same manner. With the beam passing through the center of the West Schlieren mirror and the wind tunnel windows, the beam should be centered on the East Schlieren mirror, where the beam is reflected into the turning mirror, M10, on the receiving stage. Adjust this mirror to center the beam on the ground glass viewing screen.

Now replace the collimating lens, L6, and the expanding lens, L3, and adjust their transverse position to center the expanded beam about its unexpanded axis.

5) If an obstruction in the wind tunnel prohibits completing Step 4, the beam must be expanded to continue beyond the step where the beam is centered on the West Schlieren mirror and the wind

tunnel window. Install the beam expanding lens and adjust its traverse position by centering the beam on a white sheet placed over the wind tunnel window. After removing the sheet, observe that the transmitted beam is centered on the East Schlieren mirror. Now Step 4 can be completed with the expanded beam.

6) Replace the pinhole (Figure 19) and center it upon the focused beam. Pinhole alignment can be visibly verified by observing the diffuse reflection of the beam beyond the beamsplitter. The dark diffraction rings should be concentric with the central bright spot. When suitable alignment is achieved the diffuse reflection of the expanded object beam can be observed at mirror M5, to further verify alignment. After installing the pinhole the expanding lens may need to be readjusted to achieve a uniform beam intensity in the object beam.

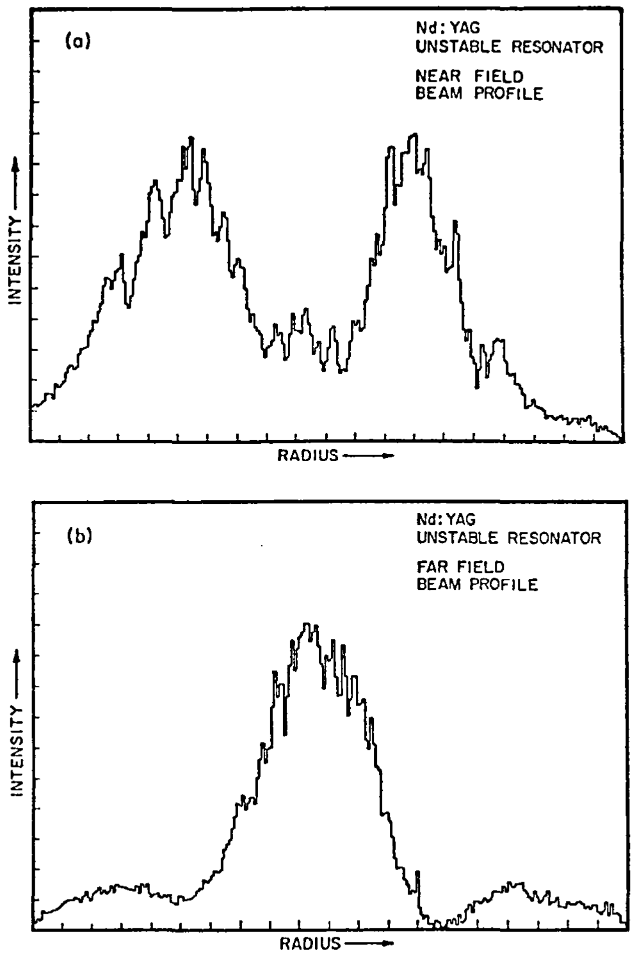


FIGURE 19. TAKEN FROM LASER FOCUS ARTICLE "THE UNSTABLE RESONATOR YAG", R. L. BYER AND R. L. HERBST.

6.0 RECONSTRUCTION SYSTEM

The reconstruction system has been carefully designed to reproduce the reference wave. Since the holograms are not reconstructed in the construction system, care must be taken to reproduce both the reference beam/hologram plate interception angle and the reference beam radius of curvature. The reference beam interception angle is attained by reconstructing with the unexpanded reconstruction beam. This beam will reconstruct only the 2mm diameter portion of the center of the hologram. If the reconstructed object wave is reflected back on itself and allowed to transmit through the hologram, the hologram can be rotated until the front surface reflection overlaps the reconstructed wave reflected back through the hologram. To achieve equal reference beam radius of curvature, both systems use collimated waves.

6.1 Optics

Reconstruction system is located in Building 227. It is composed of an argon laser tuned to the 0.5145 μm wavelength line, dielectric steering mirrors, spatial filter, collimating lens, double plate holder, imaging lens, 4 x 5 camera with ground glass focusing screen, and television monitor (Figures 20 and 21, Table 3).

6.2 Photographic Image Recording

After processing exposed holograms, the reconstruction system may be used for viewing and photographing the aerodynamic flow field. For

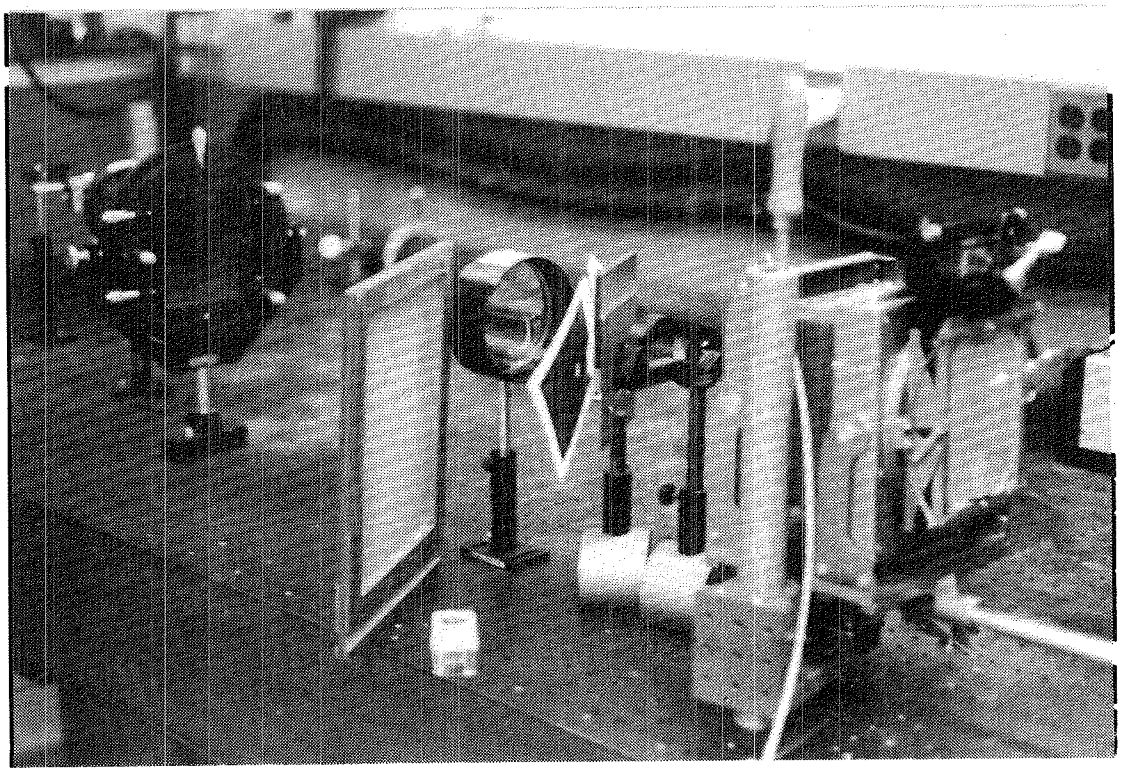
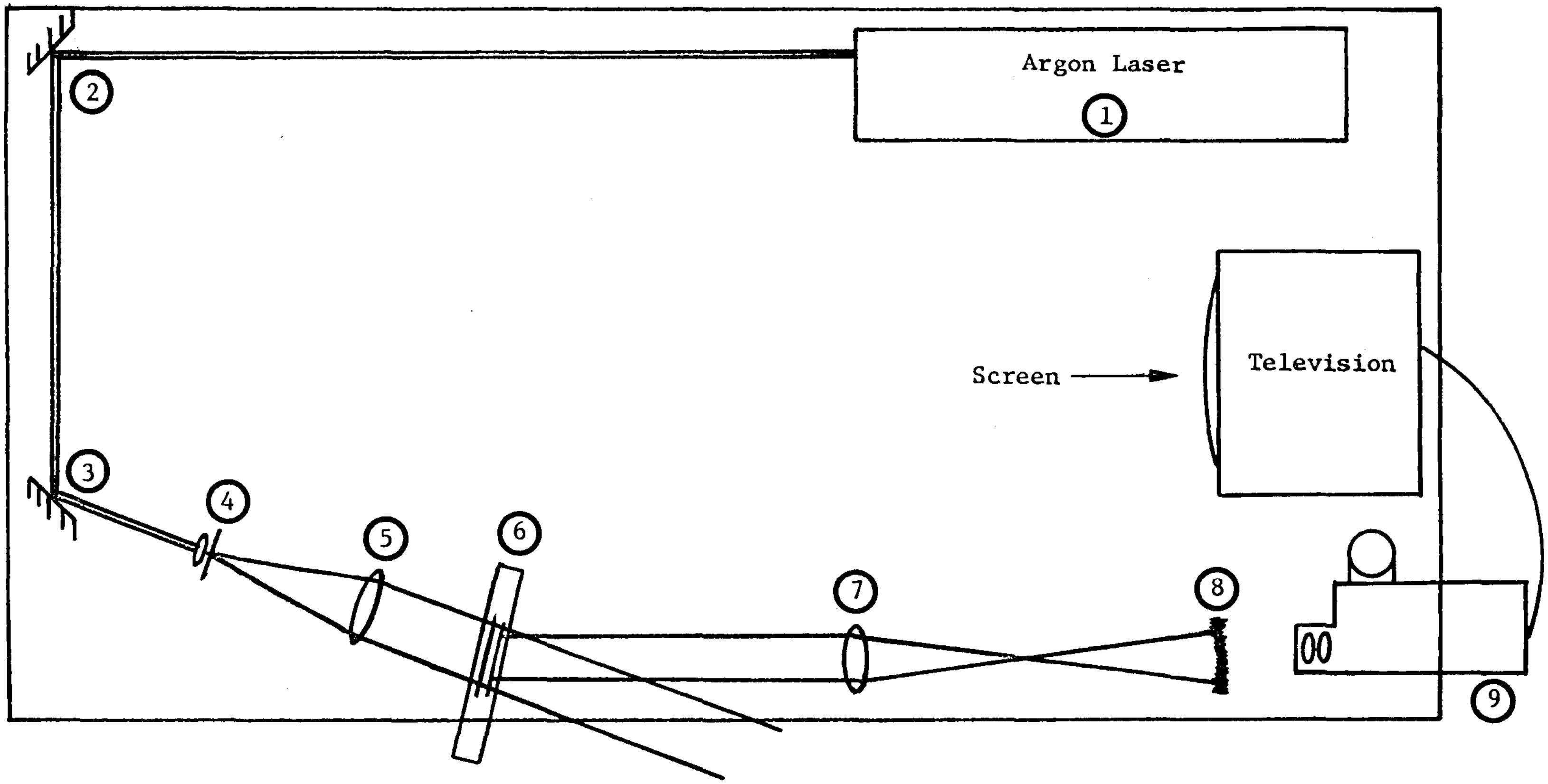


FIGURE 20. RECONSTRUCTION SYSTEM



1. Argon Laser

2 - 3. 1 or 2-inch diameter dielectric coated mirrors reflective @ 45° incidence @ λ = 5320 A

4. Lens pinhole assembly

5. Collimating lens - ϕ = 110 mm diameter, fl = 240 mm Rolyn #20.1325

6. Dual plate holder

7. o imaging lens - ϕ = 110 mm diameter, fl = 240 mm, Rolyn #20.1325

8. Ground glass viewing screen

9. Camera head

FIGURE 21. RECONSTRUCTION SYSTEM SCHEMATIC

TABLE 3.
RECONSTRUCTION SYSTEM COMPONENT LIST

COMPONENT NO.	PART NO.	DESCRIPTION
2	NRC 10D10 DM.2	Dielectric Mirror, 1" Dia., 45° incidence, 4880/5145Å
	NRC B2	Base
	NRC SP-6	6" Post
	NRC SP-2	2" Post
	NRC CA-1	90° Mount
	NRC MM-1	1" Adjustable Mirror Mount
3		Same as 2
4		Spatial Filter
5	ROLYN 20.1325	Positive Lens $f_1 = 240mm$, $\phi = 110mm$
	NRC B2	Base
	NRC SP-3	3" Post
	NRC VPH-3	3" Post Holder
	JAEGERS 35B1542	Lens Cell, $\phi = 110mm$
6		Dual Plate Holder
7		Same as 5
8		4" x 5" Camera
9		TV Monitor
10		Same as 2

shadowgraph imaging, the ground glass screen should be focused on the east wind tunnel window. With the desired image obtained, 4 x 5 film can be loaded and the image recorded. After processing, the negative can be printed directly or enlarged to full scale (16" diameter). For holographic interferometry, a reference plate of the quiescent wind tunnel must also be recorded and interfered with the reconstructed image of another hologram containing an aerodynamic flow field.

6.3 Holographic Interferometry

Interferometry accomplished when two or more waves are superimposed and the resulting construction and destructive interference causes bright and dark fringes, respectively. Holographic interferometry allows the storage of two waves separated in time to be superimposed in reconstruction. The two waves can be stored on a single hologram (double pulse holographic interferometry) or on two separate plates (double plate holographic interferometry). The double pulse technique is easily accomplished but is less flexible in that the orientation of the waves is fixed (i.e. the fringe spacing is fixed). The reconstruction waves are superimposed and viewed or photographed directly. The double plate technique is much more difficult to accomplish but is infinitely more flexible than the double pulse technique. A two plate holder is required for repositioning the plates. One of the plates is recorded with a spacer in front of the hologram holder and the other without the spacer. The two plate holder is designed to allow the rear plate to be repositioned with respect to the front plate in exactly the same orientation as they were recorded. For such positioning, the reconstructed waves are nearly superimposed in the infinite fringe configuration. If both waves are recorded without aerodynamic flow, then both waves have exactly the same phase distortion and the reconstructed images may be superimposed to obtain an infinite dimension between fringe (i.e. perfectly realigned). This orientation is called infinite fringe. For fringes created by aerodynamic flows, the fringes are contours of constant phase shift which represent constant density contours in two dimensional flows.

The double plate alignment procedure is accomplished as follows:

1) install the front plate in the fixed position holder and rotate holder to achieve the correct interception angle between the reference beam and the plate,

2) install the second plate in the rear position (Figure 22). Adjust the plate position until the focal points of the reconstructed object wave overlap. This can be observed by placing a card at the focal point of the wave reconstructed from the front hologram,

3) adjust the rear plate position until the solid objects in the image overlap (wings, etc.),

4) further adjust the rear plate position until the undisturbed part of the flow displays infinite fringe,

5) the infinite fringe image may be observed on the ground glass screen on the 4 x 5 camera and then photographed for data reduction (Figure 23).

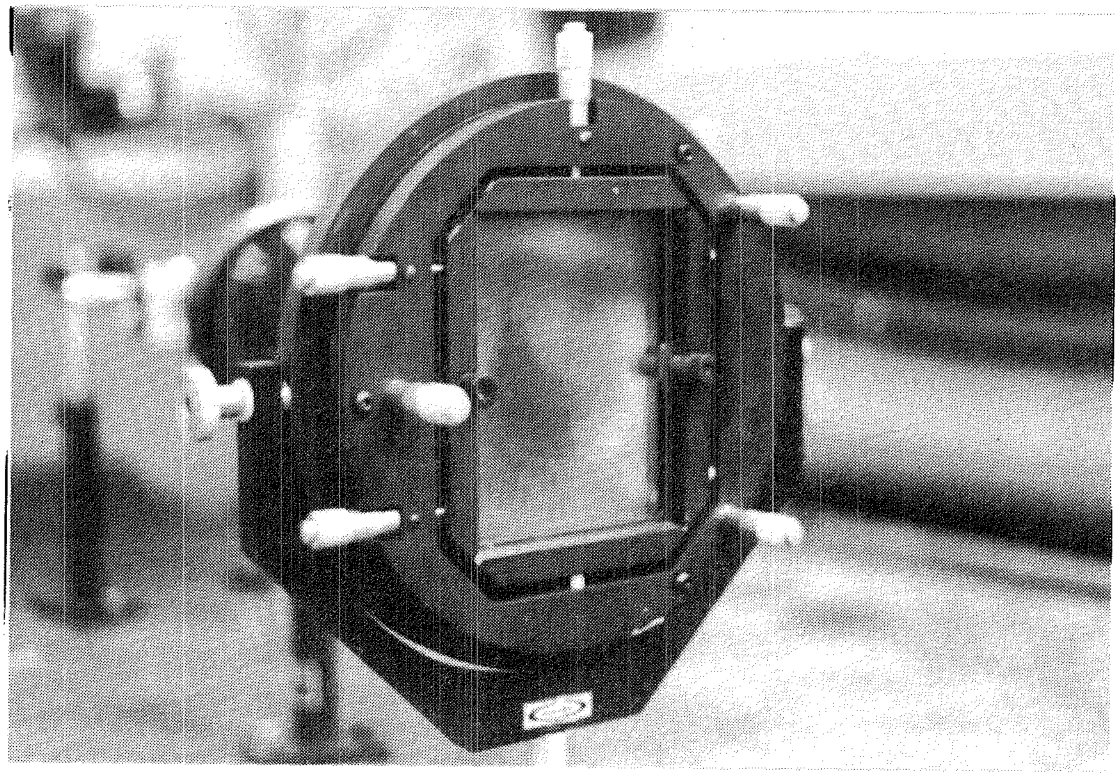


FIGURE 22. DOUBLE PLATE HOLDER OPERATION

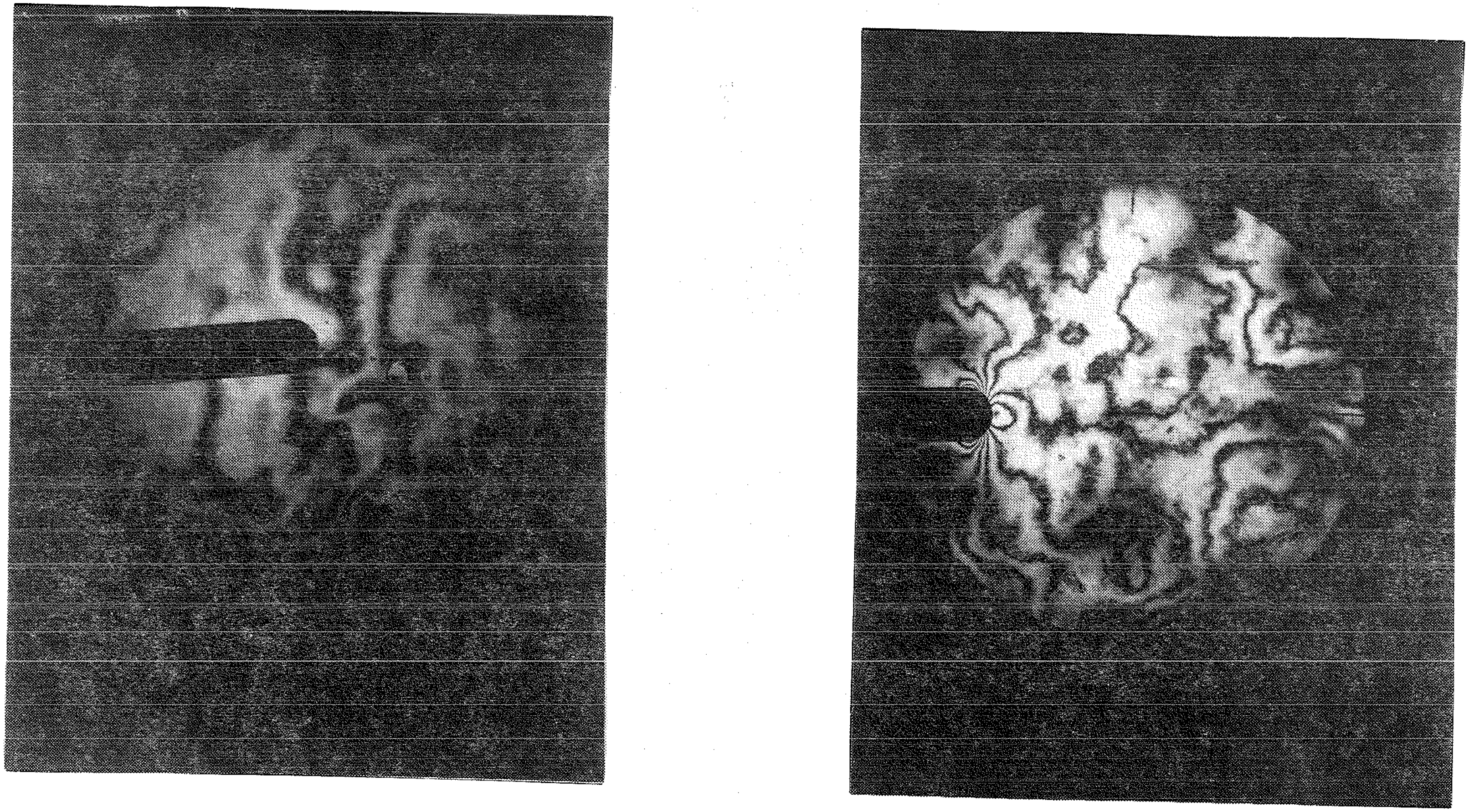


FIGURE 23. INFINITE FRINGE INTERFEROGRAM

Quantitative measurements using interferometry are straightforward in two-dimensional flows. The pathlength through the flow field was two feet and the density changes is sufficient to produce enough fringe shifts in the infinite fringe mode. If greater spatial resolution of nonlinear density gradients was required, then finite fringe interferometry could have been used. The infinite fringe mode is preferred in this case because the fringes map the constant density lines convert directly to Mach contours.

Evaluation of the density change per fringe can be determined using the following relationships. In an inhomogeneous density test field the phase shift of the light wave is

$$\left(\frac{\Delta\phi}{2\pi}\right) = \frac{1}{\lambda} \int_{\zeta}^{\zeta_1} \left[n(x,y) - n_o\right] dz$$

where λ is the laser wavelength and n is the index of refraction. When the interferometer is aligned in the infinite fringe mode, the equation of the fringes is

$$\int_{\zeta}^{\zeta_1} \left[n(x,y) - n_o\right] dz = N\lambda$$

there N is an integer. Applying the Gladstone-Dale Constant relating phase variation to density, the integrated relationship is

$$\rho(x,y) = \rho_o + \frac{N\lambda}{KL}$$

The constant values in the present case are:

$$L = 609.6 \text{ mm}$$

$$\lambda = 0.532 \ \mu\text{m}$$

$$K = 0.226 \ (\text{gm/cm}^3)^{-1}$$

$$\frac{\lambda}{KL} = \frac{0.532 \times 10^{-3} \text{ mm}}{0.226 \ (\text{gm/cm}^3)^{-1} \ 609.6 \text{ mm}}$$

Combining the constants results in:

$$\rho_1 - \rho_o = 3.86 \times 10^{-6} \ \frac{\text{gm/cm}^3}{\text{fringe}}$$

It remains to identify a particular fringe to be used as the reference with its corresponding density. This can be done in several ways. If there is a region of undisturbed flow in the field of view, the wind tunnel conditions can be used. Unfortunately, this is not generally the case. Instead, a surface pressure measurement can be converted to density by using the total temperature, T_0, and the total pressure, P_0. Another independent reference can be obtained from the inviscid flow velocity measured with the laser velocimeter.

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15. Supplementary Notes

Technical Monitor: George Lee, Mail Stop 227, NASA Ames Research Center, Moffett Field, CA 94035 (415) 965-5861, FTS 448-5861

16. Abstract

A holographic interferometer system has been installed in the NASA Ames 2x2 Foot Transonic Wind Tunnel. The system incorporates a modern, 10 pps, Nd:YAG pulsed laser which provides reliable operation and is easy to align. The spatial filtering requirements of the unstable resonator beam are described as well as the integration of the system into the existing Schlieren system. A two plate holographic interferometer is used to reconstruct flow field data. For static wind tunnel models the single exposure holograms are recorded in the usual manner; however, for dynamic models such as oscillating airfoils, synchronous laser hologram recording is used.

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