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NASA STAR SIMULATOR

FINAL REPORT

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In Response To
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FIGURES & TABLES

1. INTRODUCTION

1.1 SYSTEM OVERVIEW

This document describes Eastman Kodak's Star Simulator built for NASA under contract NAS8-36761. This equipment is a duplicate of a star simulator designed for use in Kodak's Electro-Optics Laboratory. A photograph of the completed Star Simulator may be seen in Figure 1.1-1.

The Star Simulator is composed of two major self contained subsystems, the Light Source and Filter Wheel assembly and the Translation Stage assembly; linked together through three flexible fiber optic cables. Section 2 describes the Light Source and Filter Wheel assembly while section 3 describes the Translation Stage assembly. An operational modes summary is provided in section 4, and a summary and conclusions in section 5. Appendix A provides a list of contract deliverables.

1.2 CONTRACT REQUIREMENTS AND COMPLIANCE SUMMARY

The contract technical requirements, taken from the Scope of Work, are listed in Table 1.2-1. The Star Simulator meets these requirements, as indicated in the table. Table 1.2-1 states the requirement first and the actual star simulator capabilities are listed below each item. Background technical information is discussed in later sections.

Table 1.2-1 Requirements and Compliance

(1) Requirement: Simulate a field of three or more stars.
Result: 3 pinholes on a common plate in an L pattern with 1 inch centers.

(2) Requirement: Position the field in response to electrical signals from a standard computer interface.
Result: Computer controllable through an IEEE 488 interface (see section 3.2).

(3) Requirement: Package as a self contained system.
Result: System is modular and self contained.

(4) Requirement: Mount assemblies on optical bench or individual bases.
Result: Each module is mounted on its own 2' x 2' base.

(5) Requirement: Operate in a laboratory environment, upgradable to vacuum without extensive modification.
Result: Lab compatable. Light source assembly may be isolated in a pressurized area, translation stage is vacuum prepared, translation motor is not, but easily replaced for a vacuum upgrade.

(6) Requirement: Power supplies: standard 115 vac, 1 phase, 60 Hz.
Result: Complies.

(7) Requirement: Provide standard computer interfaces.
Result: Standard IEEE 488 interfaces provided (see section 3.2).

(8) Requirement: Simulate stars of -2 to +9 visual magnitude (Mv).
Result: Xenon source capable of generating -2 to +9 Mv with no spectral filters and with the BG 39 filter but only -0.60 for the BG 39, BG 12 combination. Tungsten source capable of -2 Mv with no filter (red stars), -1.3 for the BG 39 filter and +2.4 for the BG 39, BG 12 combination. Range of ND filters provides for steps of 0.5 Mv over the entire range. (see Tables 2.3-1 and 2.4-1)

(9) Requirement: Independently control star magnitude.
Result: Two independent sets of filters, manually adjusted with click stops (see section 2.4).

(10) Requirement: Alter spectral output to simulate different color temperatures.
Result: Three colors possible for each light source; unfiltered, BG 39 and BG 39 x BG 12 combination. Two expansion slots are available on the filter wheel. Manually adjusted with click stops (see section 2.4).

(11) Requirement: Provide an angular subtense of no more than 0.5 arcseconds with an f/16, 8 inch diameter collimator.
Result: 8 micron pinhole selected. With the 128 inch focal length GFE collimator, it subtends 0.5 arcseconds.

(12) Requirement: Operate over a 2 degree field with a precision of 5 milliarcseconds. (single axis configuration selected by NASA)
Result: Single axis translation, 5 inches of travel, generates a 2.2 degree field with 128 inch focal length collimator. Minimum step size is 1 micron (0.063 arc seconds). GFE HP gauge provides 0.01 micron resolution in translation, corresponding to 0.00063 arc seconds (see section 3.4).

(13) Requirement: Provide absolute measurements of position with GFE laser gauge, HP model 5528.
Result: GFE HP hardware incorporated into system (see section 3.3).

Figure 1.1-1 Star Simulator

ORIGINAL PAGE
COLOR PHOTOGRAPH

2. LIGHT SOURCE AND FILTER WHEEL ASSEMBLY

2.1 DETAILED LAYOUT

A photograph of the completed Light Source and Filter Wheel assembly is presented in Figure 2.1-1. Figure 2.1-2 shows the assembly without its cover. Three stars are simulated, two from the xenon source and one from the tungsten source. Details of the layout are shown in Figure 2.1-3. Figure 2.1-3 shows the locations of the light sources, optical elements, and the filter wheels used for intensity and spectral selection.

As seen in the figure, an aspheric lens focuses the light onto a pinhole. The transmitted light is collimated using a microscope objective. Thereafter, it goes through neutral density filters (intensity control) and spectral filters. After passing through these filters a second microscope objective focuses the light onto a fiber optic. The light travels through the fiber optic to an 8 micron pinhole and thus simulates a star. Two stars are simulated using the xenon source while the tungsten source simulates one star. The optical system will be further described in this section.

2.2 SOURCE STABILITY

Intensity measurements were taken of the xenon stars and the tungsten star as a function of time. For comparison, the xenon star measurements were taken with and without the feedback amplifier operational. ILC xenon arc lamps were chosen for their good stability characteristics.

To perform the experiment, an EG&G (model #550) radiometer was placed in front of each pinhole at a distance of 8 inches. The intensity was measured at timed 1 minute intervals. The recorded intensity variations are summarized in Table 2.2-1.

Figure 2.2-1 shows xenon star #1 intensity versus time with and without the feedback amplifier active. The intensity stability improved considerably with the feedback amplifier active. Using the feedback circuit increases the intensity of the output. The one sigma variation is greater than 1% for an inactive feedback amplifier and within 1.0% with the feedback amplifier active. With the feedback circuit active, both xenon stars are stable to within 1%. As expected, since both stars are derived from the same source, their intensity fluctuations are identical. The tungsten source intensity variations were also measured to be less than 0.4%. Therefore, it was decided to operate the xenon lamp with the feedback circuit and the tungsten lamp without one.

Figure 2.1-1 Ligh: Source Assemby (With Cover)

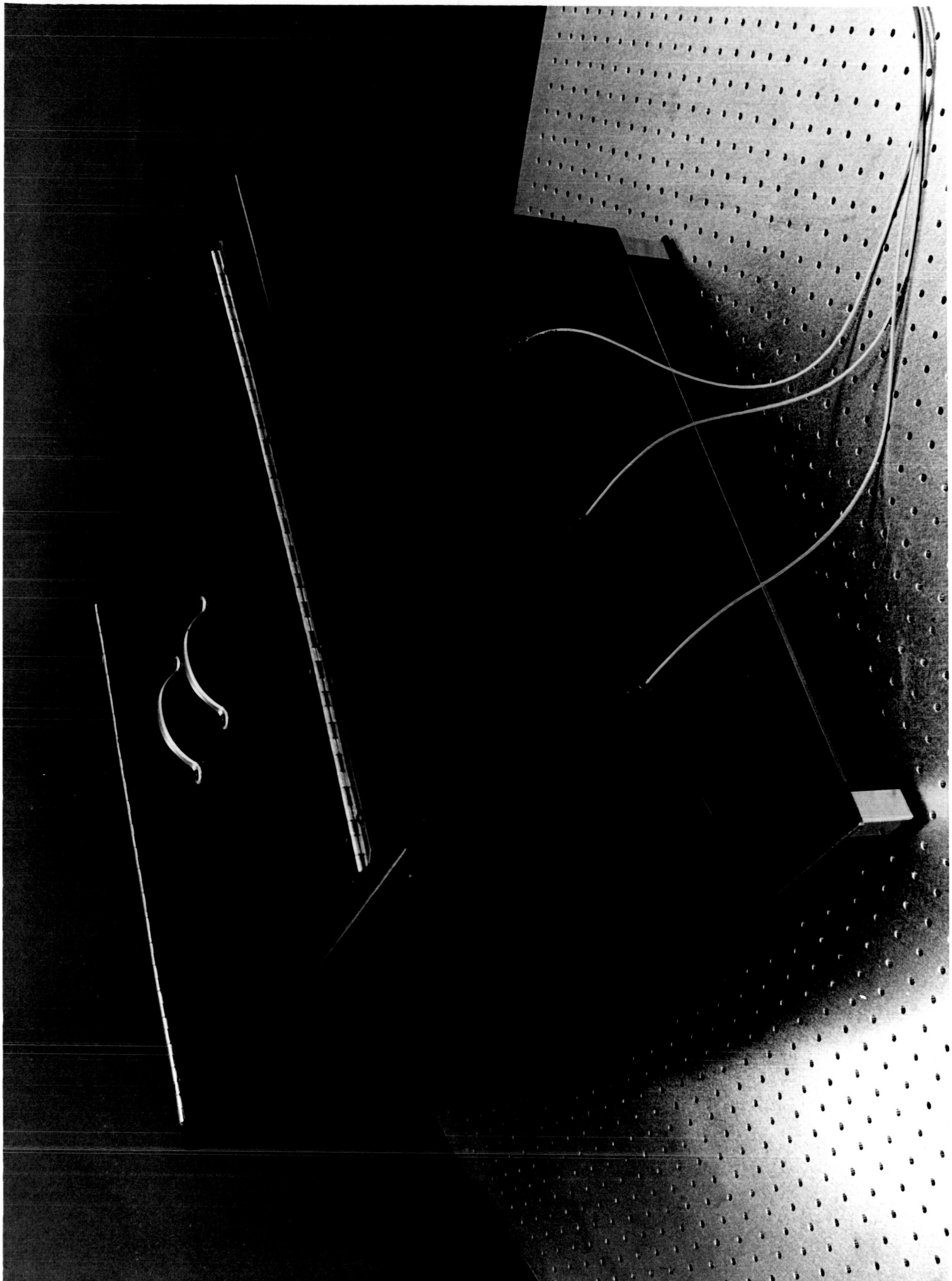


Figure 2.1-2 Light Source Assembly (Without Cover)

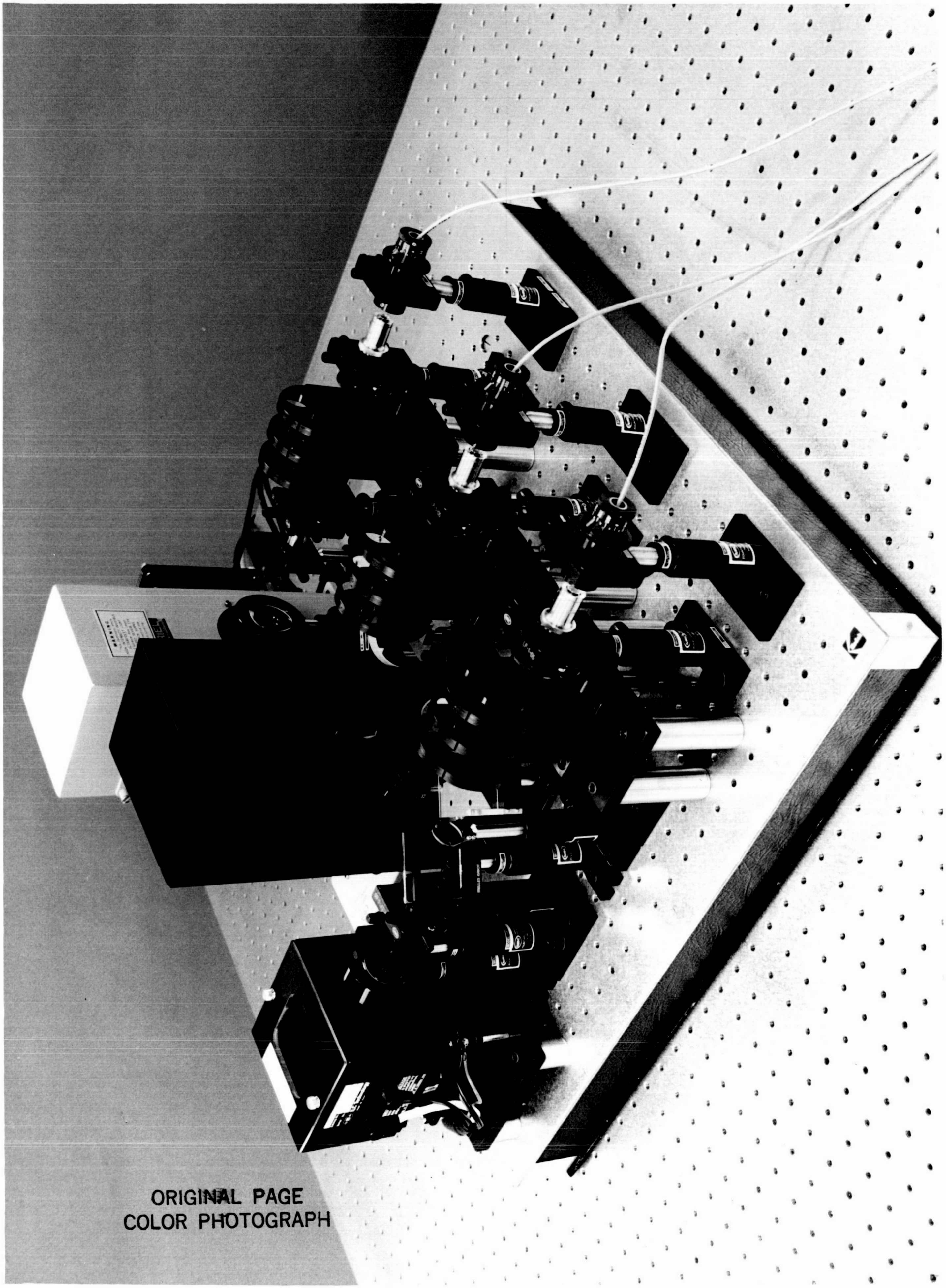


Figure 2.1-3
Detailed Sketch of Light Source Assembly

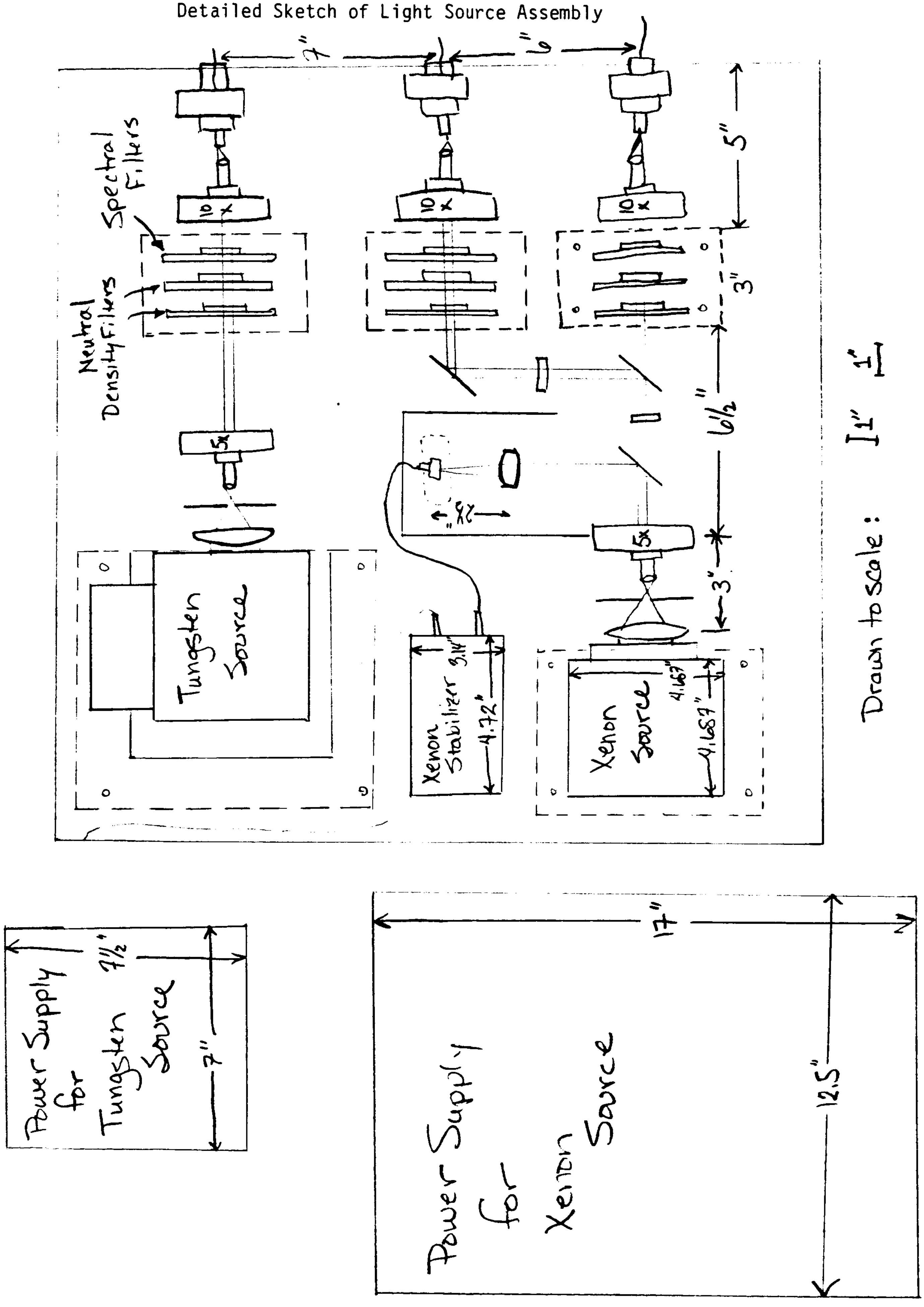


Figure 2.2-1

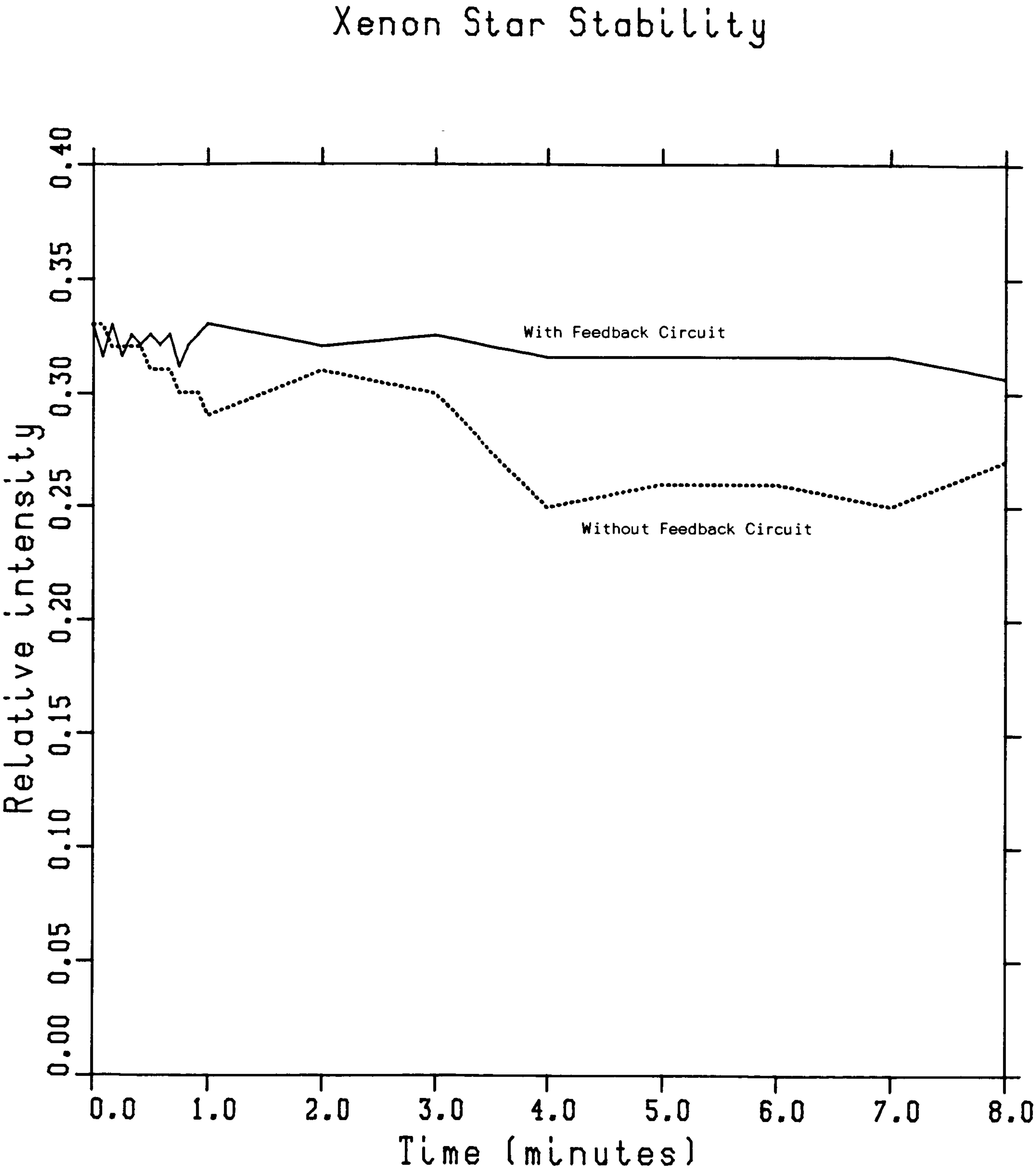

Xenon Star Stability
Relative Intensity
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
With Feedback Circuit
Without Feedback Circuit
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Time (minutes)

Table 2.2-1 Experimental Stability Results

Light Source	Feedback Circuit	Intensity Variation (One Sigma)
Tungsten	No	•0.4%
Xenon	No	1.25%
Xenon	Yes	•0.98%

2.3 RADIOMETRY

The maximum stellar magnitude is a function of the lamp and filter combinations. Radiometric measurements have been made on the stars with and without the spectral filters to determine the maximum stellar magnitude for each combination. A calibrated EG&G radiometer/photometer system (model #550, calibrated in March 1986) with photometric filter was used throughout.

The fiber optic system for the star simulator uses a Siecor #104-005004 fiber (50 micron core diameter) with SMA connectors and microscope objectives of 5x (NA = 0.10) and 10x (NA = 0.25). The first pinhole has a diameter of 0.635 mm. Radiometric calculations show that by assuming the pinholes and fiber optics are overfilled, the dimensions of importance are the collimator f-number and collimating pinhole diameter. The collimating pinhole has a diameter of 8 microns (to satisfy the 0.5 arcsecond angular subtense requirement) and is the limiting aperture in this system.

The radiometer, with the photometric filter attachment, was placed a distance of 81.28 cm from the collimating pinhole. For stellar magnitude calculations, we assumed a collimator focal length of 325.12 cm (as specified for the GFE collimator). The measured values were scaled to the 325.12 cm collimator distance using an inverse square law relationship. The results of these radiometric measurements are shown in Table 2.3-1.

Table 2.3-1 Radiometric Measurements for a 325.12 cm (128") focal length collimator

Source	Spectral Filter	Color	Measured Magnitudes
Tungsten	None	Yellow/red	-2.0
	BG 39	Green	-1.3
	BG 39 x BG 12	Blue	+2.4
Xenon	None	Yellow/red	-2.0
	BG 39	Green	-1.8
	BG 39 x BG 12	Blue	+2.4

To obtain MV values of -2, the two sources required attenuation. Neutral density filters were added in order to reduce the maximum brightness of the stars to a -2 visual magnitude. Therefore, in the position where the filter wheels are all open the visual magnitude is -2.

2.4 FILTERS (ND and Spectral)

Each star has three filter wheels for intensity and color temperature (spectral) selection. These filter wheels can be manually rotated through five click stop positions.

Two filter wheels contain neutral density (ND) filters, for intensity selection. The first wheel has filters of 0.0 to 0.8 in steps of 0.2 while the second provides filters from 0.0 to 4.0 in steps of 1.0. Together, the two filter wheels provide ND values from 0.0 to 4.8 inclusive in steps of 0.2. The comparable visual magnitudes are from -2.0 to +10.0 in steps of 0.5 Mv. Table 2.4-1 shows the measured visual magnitudes vs. filter wheel position for the three stars. Our radiometer is not accurate enough to measure intensities corresponding to ND 2.0 and above. Therefore, we must use manufacturers data for the neutral density filters above this value. The included notebook, which contains manufacturers manuals and data sheets, includes traces provided by Melles-Griot of the optical density of each ND filter. The filters are labeled to show their position in the star simulator.

The third filter wheel contains spectral filters. The first position (slot A) in the filter wheel is for unfiltered light, spectral filters are provided for two positions (BG 39 in slot B and a combination of BG 39 and BG 12 in slot C), while the fourth and fifth positions are available for future use.

Table 2.4-1 Measured Visual Magnitudes vs. ND Filter Wheel Position for no Spectral Filters

		Visual Magnitude	
ND Value	Xenon Star #1	Xenon star #2	Tungsten Star
open	-1.9	-2.0	-1.9
0.2	-1.4	-1.5	-1.3
0.4	-1.0	-1.0	-0.8
0.6	-0.4	-0.4	-0.3
0.8	0.0	0.0	0.0
1.0	+0.5	+0.4	+0.7
1.2	+1.0	+0.9	+1.2
1.4	+1.5	+1.4	+1.7
1.6	+2.1	+2.0	+2.2
1.8	+2.6	+2.5	+2.8
2.0	+3.2	+3.0	+3.3

3. TRANSLATION STAGE ASSEMBLY

3.1 DETAILED LAYOUT

Photographs of the translation stage assembly are shown in Figures 3.1-1 and 3.1-2. The top view photograph (Figure 3.1-2) shows the arrangement of the translation stage assembly components. The optical fibers enter the assembly from the side, are clamped by a strain relief clamp, and terminate at the pinhole plate using SMA style connectors. The three pinholes are clamped within the pinhole plate using two hex head bolts. The pinholes are aligned to the fiber using small x,y set screws and leaf springs prior to clamping. A two plate optical baffle controls stray light in the field of view of the GFE collimating optic.

The position of the translation stage is monitored using a GFE laser measurement system. The laser head is mounted parallel to the translation stage to minimize its overhang from the breadboard plate. The beam bender and linear interferometer mounting posts are threaded into the breadboard plate using post adapters.

To minimize the effect of stage yaw on measurement accuracy, the retroreflector and pinhole plate are located directly above the translation stage ball screw. The distance from the retroreflector to the interferometer is short to minimize the effect of temperature changes on measurement accuracy. If the Hewlett Packard temperature sensors are to be used eventually, the material temperature sensor should be mounted on the translation stage slide, and its cable must be clamped under the fiber strain relief to control extraneous forces on the slide. The air sensor should be mounted on the breadboard plate between the laser head and the translation stage.

Figure 3.1-3 is a photograph of the front view of the translation stage assembly. The simulated stars form a right isosceles triangle, two sides of which are 2.54 cm. long. The center of the cluster is 15.25 cm above the mounting surface and has a full range of travel of 12.7 cm centered 30.5 cm from the motor edge of the breadboard plate.

3.2 COMPUTER INTERFACE

Both the translation stage and the measurement system are commandable and readable through a standard IEEE 488 interface. Device protocol and commands are presented in the manufacturer's data sheets. No software is supplied with the Star Simulator.

3.3 GFE HARDWARE

The GFE hardware consists of the Hewlett Packard Laser Position Transducer Equipment 5528A. The items included in this

Figure 3.1-1 Translation Stage Assembly

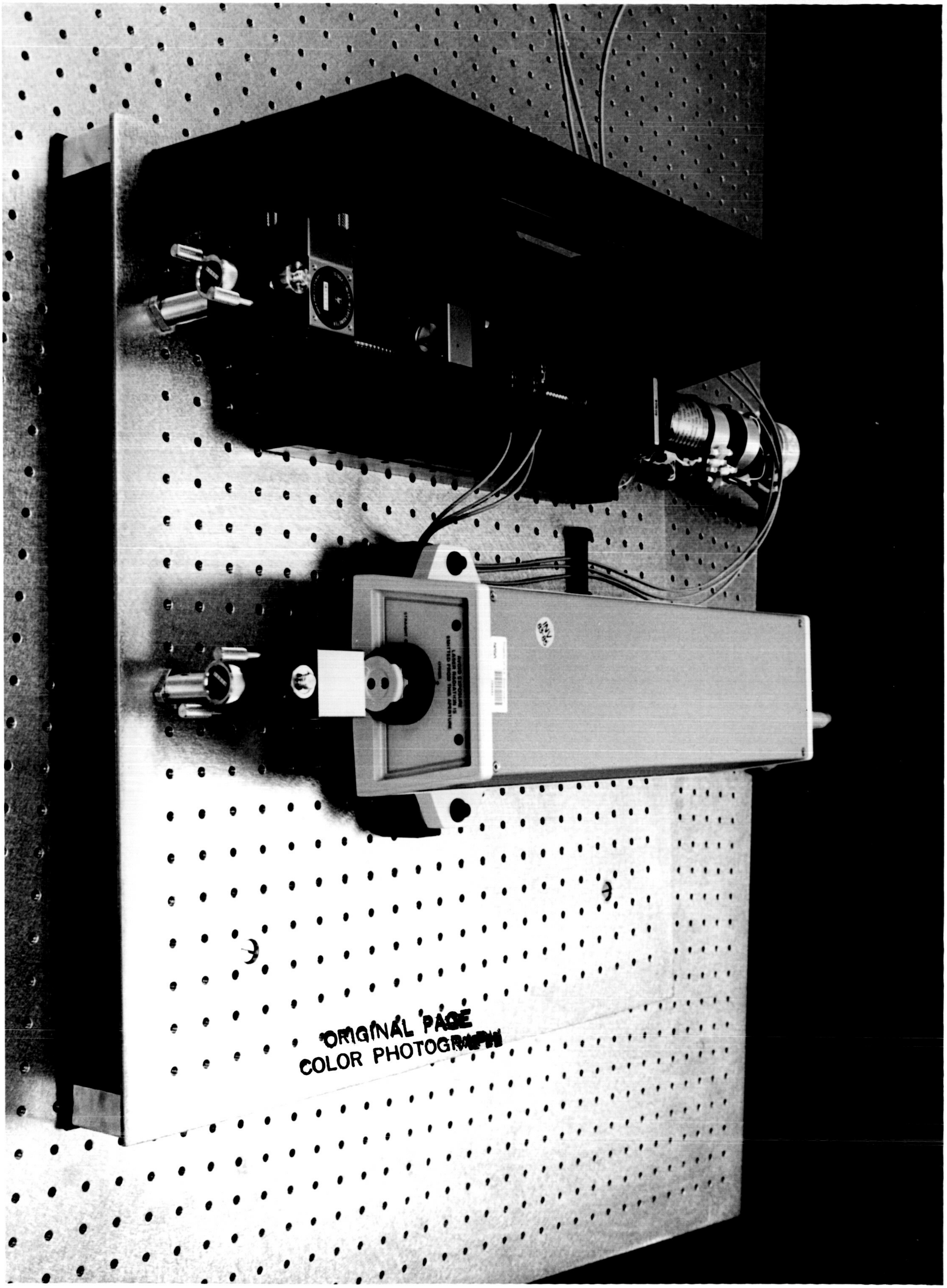


Figure 3.1-2 Top View Layout

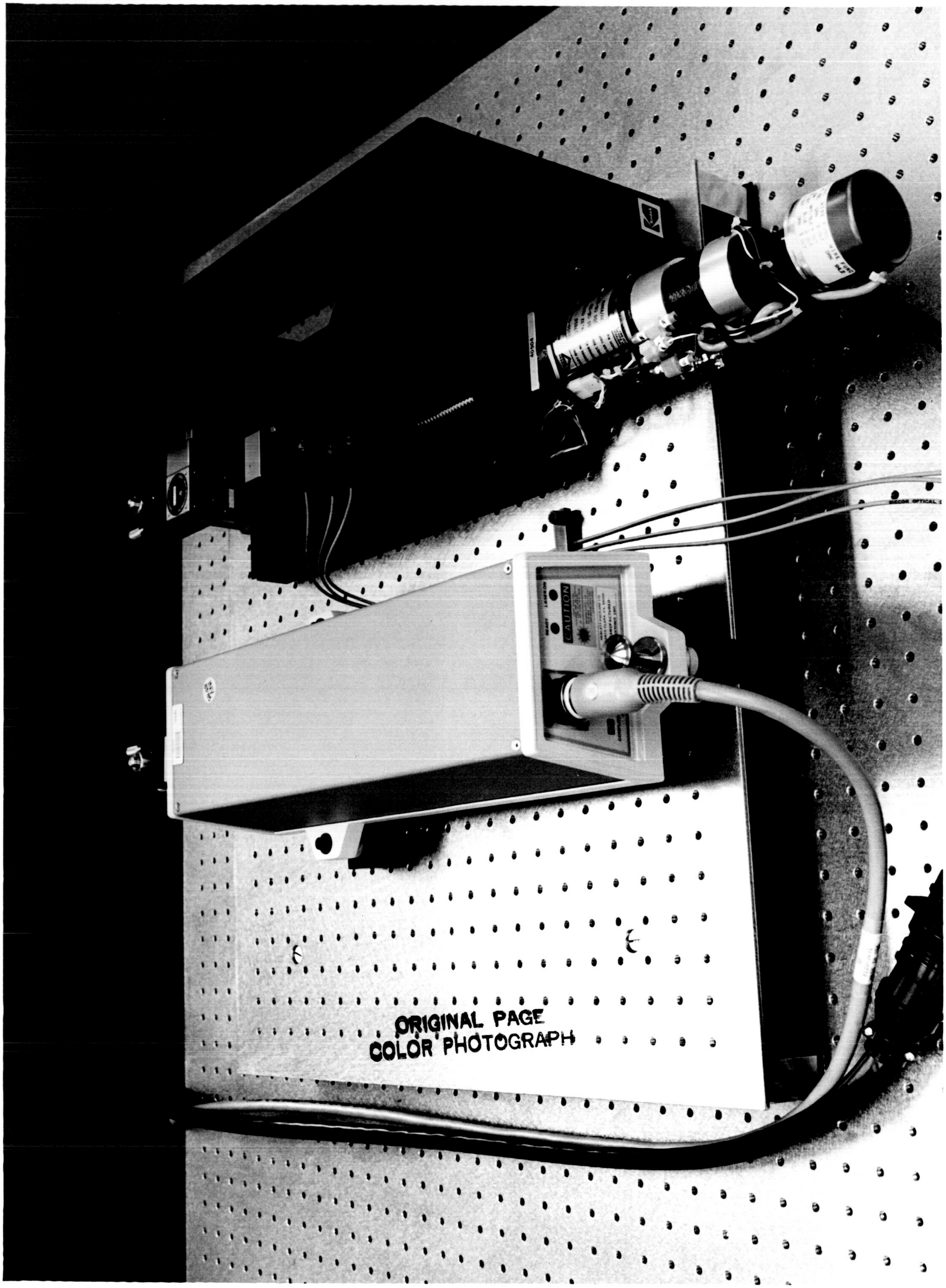
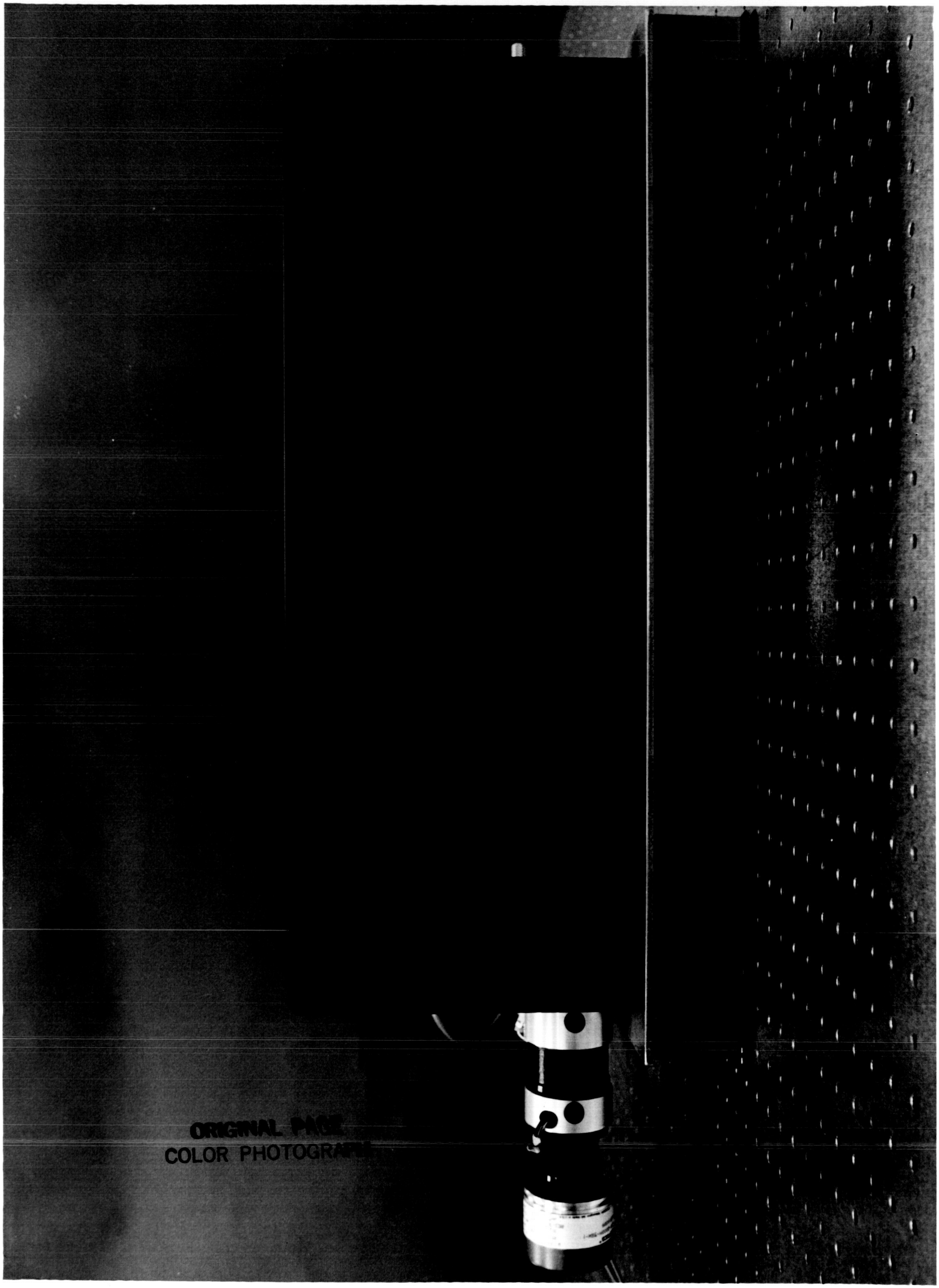


Figure 3.2-1 Front View Layout



equipment are

ITEM

5508A Measurement Display
5518A Laser Head
55280A Linear Measurement Kit
10751A Air Sensor
10752A Material Temperature Sensor

This hardware will be returned to NASA at contract's end. It shall be shipped along with the star simulator.

3.4 EXPERIMENTAL DATA ON TRANSLATION STAGE

The translation stage experiment was conducted in the manual mode. The experimental procedure followed was to move the stage 10 single steps in one direction, then 10 single steps back to its starting position. This experiment was performed once with no load, and a second time with a 2.2 kg weight placed upon the stage.

The measurement device was a Hewlett Packard Laser Measurement System identical to that specified for use in the Star Simulator.

RESULTS:

Measurement Uncertainity	$\pm$ 0.1 micron
Step Size	1.0 microns
Step Size Variability	$\pm$ 0.1 micron (3 sigma)
Backlash	$\pm$ 0.1 micron

NOTE: 0.005 ARCSECONDS X 128" FOCAL LENGTH = 0.079 MICRONS

4. OPERATIONAL MODES SUMMARY

An essential part of this operational modes summary is the notebook which contains all the manufacturer's manuals and data sheets that were provided with the purchased equipment. The operational modes summaries and assembly instructions assume familiarity with this notebook. Details and sketches of the manufactured components may also be found in this notebook.

4.1 LIGHT SOURCE AND FILTER WHEEL ASSEMBLY

4.1.1 Operational Notes

The only routinely adjustable optical system components are the filter wheel assemblies which contain the neutral density and spectral filters. All electrical equipment for the optical system assembly operates on conventional 115 VAC, 60 Hz power. The optical system needs four (4) outlets for operation. The operator responsiblities include turning on and off the light source unit, changing intensity and star color, checking the calibration and replacing the lamp bulbs when necessary. These tasks are accomplished as follows.

1. Turning on the light sources.

The optics assembly contains tungsten and xenon light sources. The tungsten source is an Oriel model #6430 and has two power cords (one for the transformer and the other for the housing fan). There is no interlock to insure that the housing fan is running when the light source is turned on. The Xenon source is an ILC 300 Watt xenon arc source. There are also two cords for this source (power supply and feedback circuit cords). One should observe cautions pointed out by the source manufacturers with respect to looking into the light sources. The manufacturers manuals are provided in the accompanying notebook. The bulb used by ILC in their xenon source is coated to absorb the ultraviolet and thus protect against ozone creation. Proper clearances must be provided near the air vents to insure that the unit does not overheat.

2. Changing Intensity

Two filter wheels of five (5) positions each are provided to change intensity. The relationship between star visual magnitudes and filter wheel positions is shown in Table 4.2-1. These visual magnitudes are based upon a 128" focal length collimator (GFE).

Table 4.2-1 Star Visual Magnitude vs. Filter Wheel Position

Wheel Position #1	Wheel Position #2	ND	Mv	Wheel Position #1	Wheel Position #2	ND	Mv
1	1	0	-2.0	4	3	2.6	+4.5
2	1	0.2	-1.5	5	3	2.8	+5.0
3	1	0.4	-1.0	1	4	3.0	+5.5
4	1	0.6	-0.5	2	4	3.2	+6.0
5	1	0.8	0.0	3	4	3.4	+6.5
1	2	1.0	+0.5	4	4	3.6	+7.0
2	2	1.2	+1.0	5	4	3.8	+7.5
3	2	1.4	+1.5	1	5	4.0	+8.0
4	2	1.6	+2.0	2	5	4.2	+8.5
5	2	1.8	+2.5	3	5	4.4	+9.0
1	3	2.0	+3.0	4	5	4.6	+9.5
2	3	2.2	+3.5	5	5	4.8	+10.0
3	3	2.4	+4.0				

The filter wheels are rotated by lifting the hinged cover of the optical assembly and rotating the wheels. The filter wheels are labeled (on top) and have click stops.

3. Changing Colors

Color changes are accomplished through use of a five hole filter wheel. Slot A is empty, slot B contains a Schott BG

39 filter, Slot C a combination of Schott BG 39 and BG 12 while the last two slots (D & E) are empty and available for future filter combinations. The filter wheels have click stops and the positions are labeled A through E (on top of the filter wheel) corresponding to the description above. The hinged cover of the optical assembly must be lifted in order to rotate the filter wheels.

4. Turning off the unit

Turn off and unplug the power supplies. Then open the box and turn off the feedback circuit. Be careful of the xenon and tungsten lamps. Prolonged use will cause these sources to get hot. Care should be taken to avoid touching the sources for about 15 minutes after the unit has been turned off.

5. Changing the Bulb

Manufacturers manuals for the light sources are provided in a separate notebook. They explain the bulb changing operation in detail. Again, use the hinged box top for access to the lamps. To remove the lamps, unbolt the four corners of the mounting plate. Care should be exercised in changing the bulb since the lamp housing will be very hot for 15 minutes after the Star Simulator is turned off.

6. Calibration Check.

The calibration of the star simulator may be checked by placing a photometric detector (e.g. EG&G model #550 radiometer/photometer) at a known distance from the pinhole. The illuminance is measured and then scaled for the collimator to be used. The scaling is accomplished via use of an inverse square law relationship. The equation is

$$E_v = E_s \, s^2/f^2,$$

where f is the focal length and s is the measured distance. The visual magnitude is then calculated from the equation

$$Mv = - \log (Ev) - \log (2.54 \times 10^{-6}) /\log(2.512)$$

For example, if the flux, E_s, is measured as 1×10^{-3} lux at s = 32", this would correspond to an illuminance of 6.25×10^{-5} at the collimator (128 inch focal length collimator) and a visual magnitude of -3.47. For this collimator, a visual magnitude of -2 corresponds to an illuminance of 1.603×10^{-5} lux, 128 inches from the pinhole.

4.1.2 Initial Assembly (Light Source and Filter Wheel Assembly)

The light source and filter wheel assembly will be shipped in four containers. The first two contain the power supplies for the two light sources; the third contains the baseplate, housing and mounting hardware; the fourth contains the items listed below.

Xenon arc lamp
Tungsten bulb
2 Aspheric lenses
5 microscope objectives
2 beamsplitters
Achromat lens
Detector
Mirror
3 Filter Wheel assemblies
3 Fiber optics
2 round ND filters

The assembly and alignment procedure for each of these assemblies is described below. If desired, remove the housing before beginning alignment. The housing is removed by unbolting the screws on the side connecting it to the baseplate. Refer to Figure 2.1-2 for a photograph of the assembled system.

(1) Xenon Arc Lamp
Install the xenon arc lamp according to the manufacturer's directions packaged with the lamp.

(2) Tungsten Bulb
Install according to the manufacturer's directions on page 1 of the Operating Instructions. Be sure not to put fingerprints on the bulb as these may cause bulb failure.

(3) Power Supplies
Connect the power supplies according to the manufacturer's instructions. Turn on the lamps to check for proper lamp operation.

(4) Filter Wheel Assemblies
The filter wheel assemblies are labeled A, B and C. With the light sources turned off, mount the filter wheel assemblies on top of the 3" platform posts, using the screws provided. In order to maintain the performance described in this report, mount assembly A in the path of the Tungsten source, assembly B in the reflected path of the xenon source (middle fiber optic cable, Xenon star #2) and assembly C in the transmitted path of the xenon source (Xenon star #1). Mount the assemblies with the neutral density filter wheels facing the light sources.

(5) Aspheric Lenses
Place the two aspheric lenses in the post holders directly in front of the light sources. The post collars have been placed to maintain the proper beam height. Orientate the lenses such that the aspheric

surface is toward the light sources.

(6) Large Pinholes
Place the large pinhole (diameter = 1/40") in the post holder behind the aspheric lens in the xenon beam. With the light source on, rotate the aspheric lens and adjust the pinhole position to maximize transmission through the pinhole. The source will be very intense at the focus. The pinhole will cut down on the unwanted light propagating through the rest of the system. Since it blocks most of the unused light, the pinhole and its holder will get hot after prolonged use.

Place the 200 micron pingole in the post holder behind the aspheric lens in the tungsten beam. Repeat the alignment procedure described above.

(7) Microscope Objectives
Place the two 5x microscope objectives in the post holders directly behind the pinholes. Again, the post collars have been placed to maintain the proper beam height. Adjust the axial and angular position of the microscope objectives until the beam passes straight through the filter wheel assemblies.

Place the 10x microscope objectives in the post holders between the filter wheel assemblies and the fiber optics holders.

(8) Fiber Optics
Insert one end of the fiber optic into the fiber optic holder. Use the adjustments on the fiber optic holder and the microscope objective holder for axial and angular alignment. The fiber optics are identical and thus interchangable.

(9) Detector for Xenon Feedback Circuit
Place the detector in the post holder inside the stray light baffle, passing the cable through the opening in the rear of the baffle. Connect the detector to the feedback amplifier according to the manufacturer's directions.

(10) Achromat lens
Place the lens in the post holder directly in front of the detector.

(11) Beamsplitters
Place the uncoated beamsplitter (plate glass) in the single filter holder directly behind the 5x microscope objective in the xenon beam. It should be at approximately a 45^{o} angle. This beamsplitter sends part of the beam to the detector for the feedback

circuit. Adjust the beamsplitter and the achromat until the focused beam falls at the center of the detector.

Place the coated beamsplitter in the single holder directly in front of the filter wheel assembly in the xenon beam. This beamsplitter should also be at a 45^{o} angle. It's job is to split the beam equally between the two stars. One beam should go straight through while the other goes to the mirror. Each side of the beamsplitter is labeled 1 or 2. The side labeled 1 should face the filter wheel in the transmitted beam.

(12) Mirror
Place the mirror in the post holder in front of the filter wheel assembly for the second xenon star. Rotate the mirror until the beam passes straight through the filter wheels. Use the fine angular adjustments on the mirror mount as necessary. Align the microscope objective and fiber optic as described previously.

(13) ND Filters
Place the ND 1.0 filter in the single filter holder between the two beamsplitters. Place the 0.2 ND filter in the single filter holder between the coated beamsplitter and the mirror.

(14) Feedback Amplifier
Connect the feedback amplifier according to manufacturer's instructions.

(15) Housing
To replace the housing, remove the fiber optics from their holders and disconnect the power supplies. Pass the cords through the openings in the back of the housing and lift the housing over the top of the assembly. Reconnect the power supplies and reinsert the fiber optics. Adjust the alignment if necessary.

(16) Final Alignment
Connect the fiber optics to the pinhole plate on the translation stage assembly. Using a radiometer, adjust the alignment of the 10x microscope objectives and the fiber optics until the light through the 8 micron pinhole simulates a -2 Mv star. Be sure all the filter wheels are in the open position. Refer to section 2.3 for a calculation of the visual magnitude.

4.2 TRANSLATION STAGE ASSEMBLY

4.2.1 Translation Stage

The manual mode capabilities of the translation stage include the abilities to

1. Move a Single Step
2. Slew at selected rate
3. Step selectable number of steps at selectable rate
4. Step to absolute position with respect to home position

The operator has the option of displaying the relative or absolute position, in steps.

Refer to the manufacturer's operating instructions for details of these capabilities.

For the computer control mode, an interface is available which allows manual mode capabilities to be exercised by a user-supplied computer.

4.2.2 MEASUREMENT SYSTEM

The manual mode capabilities of the laser measurement system include the abilities to

1. Set Home Position
2. Select Resolution down to 0.01 microns
3. Read Stage Position

An interface is available which allows manual mode capabilities to be exercised by a user-supplied computer.

Refer to the user's guide provided by the manufacturer for details of operation.

4.2.3 INITIAL ASSEMBLY

The initial assembly of the translation stage subassembly consists of seven steps. The proper locations of the components are marked on the breadboard plate and labeled with removable tags. The components are fastened with 1/4-20 bolts unless otherwise stated.

(1) Translation Stage
Install two of the four bolts, then manually rotate the drivescrew on the translation stage until the final two bolts can be installed.

(2) Mounting Fixtures and Baffles
Install Laser Mount 1 with the countersinks facing upwards. Install laser mount 2 so that it overhangs the breadboard as shown in Figure 4.2-1. Screw the two

post adapters into the locations marked on the breadboard. DO NOT overtighten.

Bolt the pinhole baffle onto the front face of the translation stage. Mount the stage baffle onto the front edge of the breadboard.

Install the retro mount onto the translation stage with the countersinks facing the translation stage motor.

(3) Interferometer Components

Bolt the front mounting pads of the laser head to laser mount 1 so the rear mounting pad floats on laser mount 2. Screw two Hewlett Packard posts onto the post adapters.

Attach the beam bender to the rear post using the HP post clamp and mounting bolts so the beam is deflected toward the front of the assembly.

Similarly, mount the linear interferometer to deflect the beam toward the translation stage motor. The retroreflector component is on the front side of the beam splitter component.

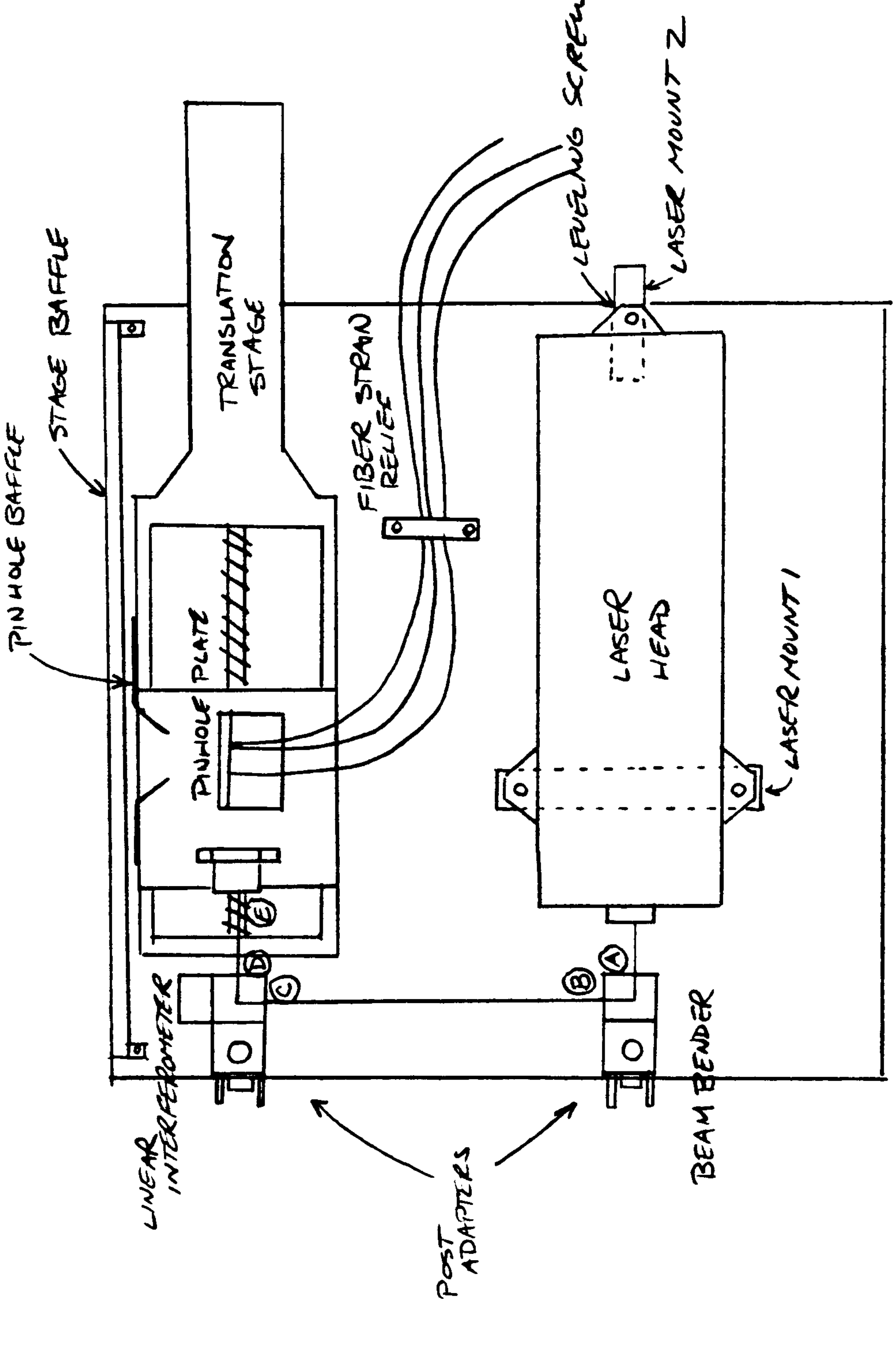
Use HP mounting bolts to reach through the holes in the retro mount and thread into the retroreflector.

(4) Interferometer Alignment

With the laser on, and the small aperture in place, use the magnetic alignment aids in the following positions, as indicated in Figure 4.2-1

OPERATION	ALIGNMENT AID POSITION	ADJUSTMENT
Set beam bender height	A	Move the beam bender up the post until the beam passes through the upper hole in the alignment aid
Set beam bender angle	A,C	Rotate the beam bender and adjust the interferometer height until the beam passes through the upper hole in the alignment aid at C

Figure 4.2-1



COMPONENT LOCATION AND OPTICAL SURFACE DEFINITION

FIGURE 4.2-1

Set interferometer angle	C,E	Rotate the interferometer until the beam passes through the upper hole in the alignment aid at E. If the beam level is wrong, adjust the angle of the laser head using the leveling screw.
Tweak Component angles	B	With the beam passing through the top hole in the alignment aid at B, adjust the beam bender and interferometer until both return beams hit the lower crosshair on the alignment aid (within 1mm).
Final Check	None	Both return beams should be aligned with the lower aperture of the laser head. Open the lower aperture and remove the small aperture from the upper aperture.

(5) Pinhole Alignment

Connect the fiber optic cable to the back of the pinhole plate using the SMA connectors. The pinholes have been installed in the pinhole plate. Directions for adjustment or replacement, if desired, are presented here.

Install pinholes and leaf springs in the clamp plate so that the leaf spring pushes the pinhole against the x,y set screws. Install the clamp plate on the pinhole plate and finger tighten the clamp bolts. Adjust the pinhole positions using the set screws to maximize the light output from each star. Finally, tighten the clamp bolts.

(6) Pinhole Plate

Install the pinhole plate onto the translation stage so that the pinholes are located over the drive screw and are centered on the pinhole baffle aperture.

(7) Fiber Strain Relief

Install and finger tighten the fiber strain relief so that some slack exists throughout the range of stage travel.

5. SUMMARY AND CONCLUSIONS

Eastman Kodak has manufactured a Star Simulator for NASA under contract NAS8-36761. The Star Simulator is a single axis system which consists of two assemblies; a light source and filter wheel assembly and a translation stage assembly as described in sections 2 and 3. The assemblies are self contained on 60.96 x 60.96 cm breadboards and are connected via three fiber optic cables. The Star Simulator satisfies the requirements outlined in the section 1.2. Table 1.2-1 details the contract technical requirements and the results achieved. A numerical summary is provided as Table 5.1-1.

Table 5.1-1. Numerical Summary

Dimensions:	Base: 60.96 cm x 60.96 cm Height: 40.64 cm
Pinhole Size:	8 microns
Fiber Optic:	Siecor 50 micron 104-005004 multimode fiber with SMA connectors (approx. 182 cm)
Lamp Stability:	Tungsten: better than 1% Xenon: better than 1%
Intensity Range:	Red & Yellow (Tungsten) -1 Mv to +10 Mv Blue/White (Xenon) -2 Mv to +10 Mv (see section 2.3)
Spectral Control:	Schott BG 12 and Bg 39 filters, 25 mm diameter, with manual filter wheels (independent control). The filter wheels have the options: A. No filter D. Expansion B. BG 39 E. Expansion C. BG 39 x BG 12
Intensity Control:	Neutral density filters with steps of 0.2 (Mv steps of 0.5) with manual two stage filter wheel.
Number of Stars:	3
Power Requirements:	115 VAC, 60 Hz.

Auxiliary Power Supplies:

Xenon arc lamp:	Model #PS300-1 (ILC)
Power requirements:	115/230 Vac, 50/60 Hz.
Weight:	16 kgs
Dimensions:	18.7 x 44.5 x 33.0 cm.

Tungsten:	Model #6395 (Oriel)
Power requirements:	115 Vac, 50/60 Hz.
Weight:	13 kgs
Dimensions:	17.2 x 18.6 x 17.8 cm.

Star Parameters:

Number of Stars	3
Star Configuration	Isosceles Right Triangle
Star Spacing	2.54 cm
Star Diameter	8 microns

Translation Stage Parameters:

Nominal Step Size	1.0 microns (0.063 arcsec)
Range of Motion	12.7 cm (2.2 degrees)
Maximum Rate	5.08 cm/second
Computer Interface	IEEE 488

Measurement System Parameters (HP Manual Specifications):

Resolution	0.01 microns (0.00063 arcseconds)
Accuracy	$\pm$ 1.5 ppm
Range	Greater than 12.7 cm
Computer Interface	IEEE 488
Update Rate	40/second

Maximum Dimensions:

	LxWxH (cm)
Breadboard	81.28 x 63.5 x 22.9
Translation Stage Controller	58.42 x 48.26 x22.9
Measurement System Display	45.72 x 22.9 x 20.32

Power Requirements: 110 VAC, 2 outlets

6. Appendix A: Recommendations for Further Work

The Star Simulator produced under this contract provides a versatile tool for breadboard and calibration experiments of star tracker systems. As with any test fixture, additional capabilities could be added, and the modularity of this design makes it practical to consider upgrades.

Options for follow-on activities include

1. Vacuum upgrade of the translation stage by replacing the translation stage motor with a vacuum prepared unit, and the appropriate isolation of the HP laser head and the light source assembly in ambient pressure containers,

2. Upgrade of the translation system from a one dimensional to a two dimensional stage,

3. Motorization and computer control of the filter wheel assemblies for unattended, automatic test operation,

4. Spectral output characterization of the existing filters (which could be done with Kodak's unit), and selection of additional filters or filter combinations for the two expansion slots, and

5. Production of a duplicate backup unit.