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THE DESIGN, DEVELOPMENT AND TEST OF BALLOONBORNE AND GROUNDBASED LIDAR SYSTEMS
Volume 2: Flight Test of Atmospheric Balloon Lidar Experiment, ABLE II

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13. ABSTRACT *(Maximum 200 words)*
This final report is in three volumes which describe the work performed under the above contract. This if Volume 2 of the three. Volume 1 describes the design and fabrication of a balloonborne CO_2 coherent lidar payload whose purpose is to measure the 10.6 μm backscatter from atmospheric aerosols as a function of altitude. Volume 3 describes groundbased lidar development and measurements, including the design of a telescope dome lidar installation, the design of a transportable lidar shed for remote field sites, and field measurements of atmospheric and cloud backscatter from Ascension Island during SABLE 89 and Terceira, Azores during GABLE 90.

In this volume, Volume 2, we describe the tasks performed to modify, refurbish, and test the Atmospheric Balloonborne Lidar Experiment (ABLE II) which is capable of performing nighttime atmospheric density measurements from a typical balloon float altitude of 30 km to the ground, with a range resolution of 150 meters. Successful backscatter measurements were made during field operations which included a balloon launch from Roswell, NM and flight over the White Sands Missile Range.

These tasks have been successfully completed, and recommendations for further lidar measurements and data analysis have been made.

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1. INTRODUCTION

1.1 Background

Project ABLE (Atmospheric Balloon Lidar Experiment) is part of Air Force Phillips Laboratory's continuing interest in developing techniques for making remote measurements of atmospheric quantities such as optical transmission, density, pressure, temperature, and wind motion. The system consists of a balloonborne lidar payload designed to measure neutral molecular density as a function of altitude from ground level to 70 km. The lidar provides backscatter data at the doubled and tripled frequencies of a Nd:YAG laser, which will assist in the separation of the molecular and aerosol contributions and subsequent determination of molecular density vs. altitude.

Previous work on the proposed experiment was performed by General Electric Space Division in a feasibility study[1], by Visidyne, Inc. in a design study[2], and again by Visidyne, Inc. in a program to fabricate and field test a lidar payload[3]. The development performed under the present contract is a continuation of the effort to define a precursor for future space-based lidar systems.

At 20:21 hours MDT, 30 August 1987, the ABLE II payload was launched from Roswell, NM on a trajectory which took it over White Sands Missile Range (WSMR). Backscatter lidar data were acquired. At 02:52 MDT, 31 August 1987, the flight was terminated and the payload subsequently recovered. A post flight engineering evaluation of experiment performance was done.

1.2 Experiment Objective

The object of this phase of the contract was to design, fabricate, refurbish, and flight test balloonborne lidar instrumentation to measure particulate scattering (corrected for molecular scattering) at several wavelengths (355, 532, and 1064 nm) to determine the nature of the particulate size distribution, the concentration of particulates, and their distribution with altitude. These results are to be applied to studies of optical extinction in the atmosphere and to the study, evaluation, and specification of Doppler lidar techniques and systems for the measurement of wind velocity. This report documents the test flight, in which the ABLE payload (redesignated as ABLE II and shown in Fig. 1) was refurbished, recalibrated, and flown over the White Sands Missile Range.

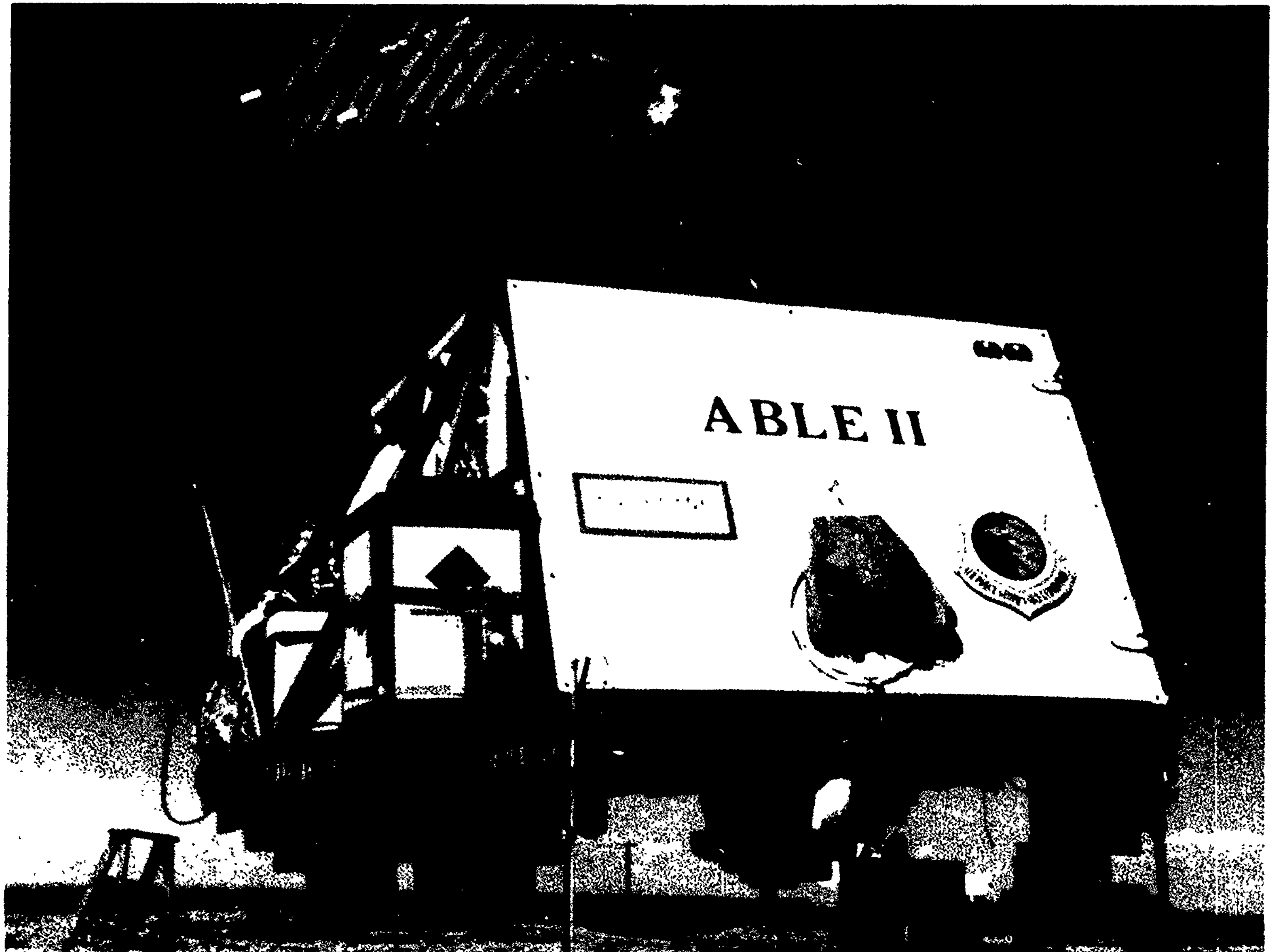


Figure 1. ABLE II payload.

2. FLIGHT PLAN

The flight plan of the ABLE II payload was similar to that of ABLE I, namely to deploy the balloonborne payload to measure neutral atmospheric molecular density as a function of altitude from ground level to 70 km. Also, as with ABLE I, launch was to be from Roswell, NM with the winds at float altitude blowing the payload over White Sands Missile Range (WSMR).

2.1 Experiment Technique

The principal objective of the ABLE experiment was to design, fabricate, and deploy a balloonborne lidar system to measure neutral atmospheric molecular density as a function of altitude from ground level to 70 km.

The basic scattering geometry of the ABLE experiment system for measurements of atmospheric density is shown in Fig. 2. The balloon floats at some altitude as laser pulses are fired into the atmosphere at a zenith angle θ. The laser pulse propagates through the atmosphere, and in each volume element, $\delta V = \Omega_L D^2 \delta D$, a small fraction of the photons are Rayleigh scattered by air molecules or suffer other scatterings and absorptions due to aerosols and other constituents. For each laser pulse, the number of photons from δV that are Rayleigh backscattered into the collecting mirror on the balloon payload is given by

$$N_\lambda = \frac{\epsilon_\lambda}{h\nu} f\sigma_\lambda N(z)\delta D \frac{A}{4\pi D^2} T_\lambda \tag{1}$$

where ϵ_λ is the energy in the laser pulse at wavelength λ, $h\nu$ is the photon energy, f is the fraction of the atmospheric element δV visible to the detection system, σ_λ is the Rayleigh scattering cross section at 180°, N(z) is the atmospheric molecular number density vs. altitude, A is the area of the collecting mirror, and T_λ is the atmospheric transmission for a photon traversing a path length of 2D at the specified altitude and zenith angle.

To separate the Rayleigh backscatter from the aerosol Mie backscatter, a two wavelength lidar is required. In Reference 2, the two pioposed wavelengths were the fundamental (1064 nm) and the frequency-tripled (355 nm) outputs of a Nd:YAG laser. However, the manufacture of the proposed detector for the 1064 nm was discontinued and no suitable replacement existed. For this reason, the effect on the density data of using other detectors and/or the

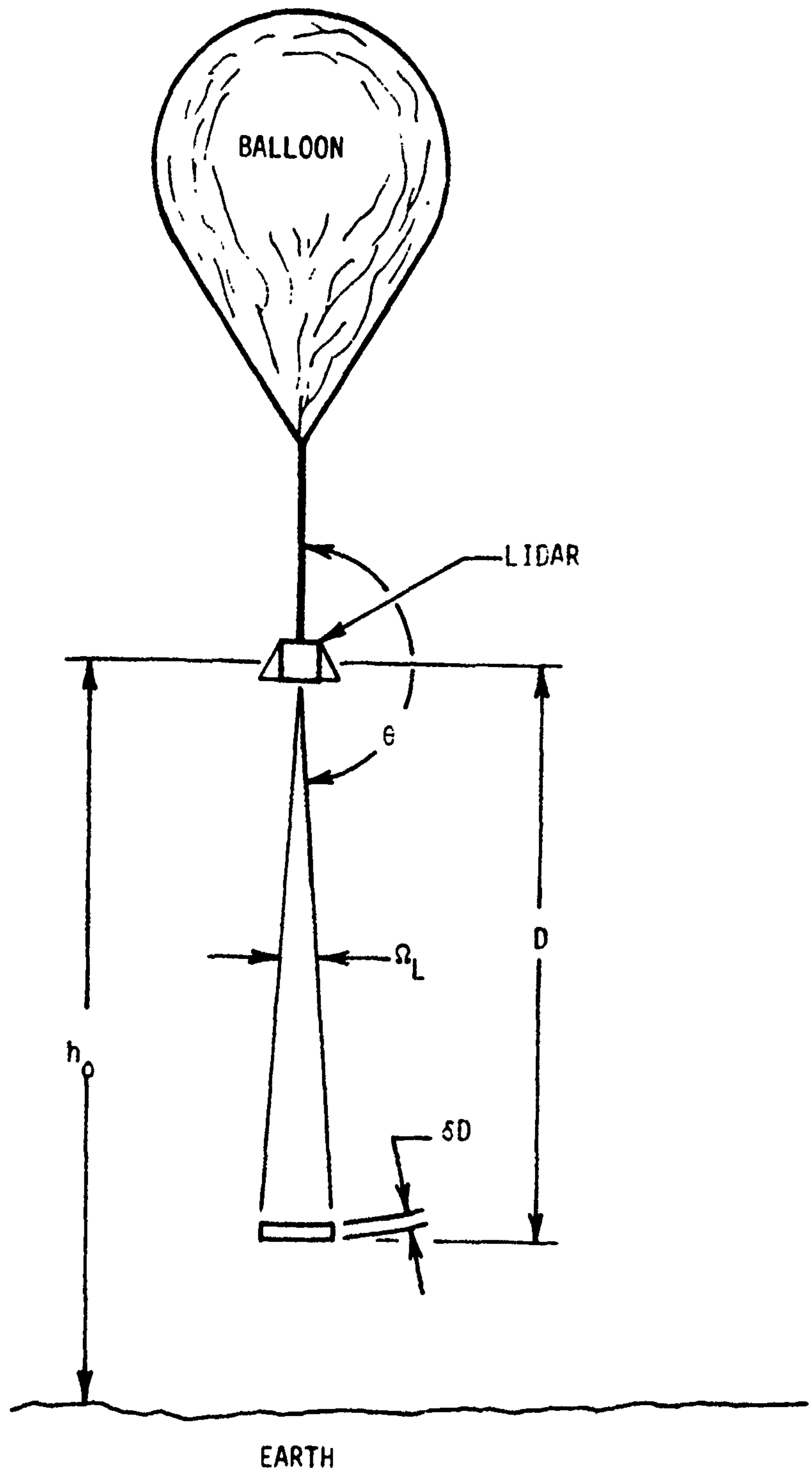


Figure 2. Predicted signal level calculation geometry.

frequency-doubled (532 nm) output of the Nd:YAG laser was investigated. The statistical errors in the Rayleigh backscatter measurement data for two measurements techniques, 1064 nm/355 nm and 532 nm/355 nm, were calculated and compared. It was shown that by using the 532 nm/355 nm technique with an S-22 532 nm detector, the resulting density data would have significantly less statistical error than that which would be obtained by using the 1064 nm/355 nm technique with a cooled S-1 detector at 1064 nm.

The requirement for low background levels in the two spectral bands of interest dictated that the data flight be at night. Thus the balloon launch was scheduled for around sunset. The selection of a launch time also depends upon the low level ground wind conditions, wind shear, and high altitude winds. It was desirable to keep the payload flight path over the controlled airspace of White Sands Missile Range (WSMR) for as much of the flight as possible. Thus, low velocity winds are a launch criterion. As long as the payload was over the controlled airspace, the lidar could be directed downward, thereby providing the most complete density distribution data.

2.2 Flight Outline

Briefly the outline of the flight phase of the ABLE II experiment was as follows: The balloon was to be launched with the lidar in standby mode. At an altitude of 20 kft, the laser would be commanded to "ARM" status in preparation for firing. All firing of the laser was to be commanded by the AFGL technical contract monitor, Dr. D.E. Bedo. To help control the coolant temperatures, the laser could be fired into a dump when the pointing mirror was in the horizontal mode. When the payload reached an altitude of 30 kft, the pointing mirror would be commanded to direct the lidar to the upward mode; laser firing could then begin and backscatter data taken. When the balloon flight was over the restricted area of WSMR, the pointing mirror could be commanded to the downward mode, and the backscatter data taken until the balloon drifted out of the restricted area. At that time, data taken would again be confined to the upward mode only.

After a mission operating time of approximately six hours at float altitude, the lidar system was to be turned off and the pointing system slewed into stow configuration. The balloon would then be valved down to a lower altitude (about 23 km) and ruptured on command. The payload parachute would then open after which the payload would drift down and impact on the ground.

An on-board beacon transmitter would lead search aircraft to the downed payload, and experiment project personnel would be guided to inspect the payload to determined that it was in a nonhazardous condition. The payload would then be transported back to the payload buildup area.

During the time of flight, other experiment personnel would be in the balloon mission control center evaluating data quality and instrument performance from the real-time readout of the raw telemetry data. In addition, lidar experiment data would be displayed in real time to provide experiment personnel with sufficient data to permit a preliminary evaluation of the mission's scientific success.

3. PREFLIGHT TESTING

3.1 System Description

The ABLE experiment payload consists of a dual frequency lidar system for measuring atmospheric backscatter signals at 355 and 532 nm as a function of altitude from ground level to 70 km. Specifications are listed in Tables 1, 2, and 3. The principal components of the payload are as follows:

1. Payload structure.
2. Nd:YAG laser transmitter.
3. Telescoped receiver with 355 and 532 nm detectors.
4. Command-controlled optical pointing system.
5. Payload thermal control system.
6. Telemetry, command, and power systems to support the experiment.

These components are discussed in detail in Reference 3.

3.2 Laser

The Nd:YAG laser used in the ABLE I experiment was refurbished in preparation for the ABLE II flight. In March 1987, the laser was shipped to the Orlando, FL facilities of the manufacturer, Litton Laser Systems, where the refurbishment was witnessed by a technical representative of Visidyne. The major refurbishment tasks are listed in Table 4. The major problem found with the laser was that the second harmonic generator (SHG) crystal had incurred laser damage during operation. Replacing the crystal would take six to eight weeks. Approval was given to Litton to proceed with replacement.

In June 1987, technical personnel from AFGL and Visidyne visited Litton for the purpose of monitoring the alignment, calibration, and acceptance testing of the refurbished ABLE laser. The resulting test report is in Appendix A.

During testing at Litton, the Laser Energy Monitor (LEM) was installed, and beam divergence measurements made. At the conclusion of these tests, it was observed that the LEM output window had been damaged. This was due to the laser beam not being centered on the LEM optical axis. This was later corrected by a minor mechanical modification to the LEM.

Table 1

ABLE II Payload Specifications

Weight	958 kg (without ballast)
Structure	Welded Aluminum
Size	2.8 x 2.8 x 1.5 m
Power	1600 W (without T/M)
Primary Coolant	30% Deionized Water - 70% Ethylene Glycol
Secondary Coolant	Tricloroethylene

Table 2

ABLE II Transmitter Specifications

Laser	
Model:	ILS 104-10 with DC Power Supply
Type:	Nd:YAG
Output Wavelengths:	1064 nm 532 nm 355 nm
Typical Simultaneous Output Energies:	190 mJ 153 mJ 37 mJ
Exit Beam Divergence:	≤2 mrad ≤1 mrad ≤1 mrad
Polarization:	Horiz. Verti. Horiz.
Amplitude Stability: (Pulse to Pulse)	≤3% ≤5% ≤10%
Repetition Rate (Nominal):	10 pps
Pulse Width:	15 ns
Pulse Jitter: (Sync to Pulse)	< 50 ns
Exit Beam Diameter:	6.35 mm (Beams are coaxial)
Primary Cooling System	
Coolant:	30% Deionized Water - 70% Glycol
Coolant Flow:	0.5 ± 0.25 gal/min
Coolant Pressure:	12 psig (max.)
Outlet Coolant Temperature:	55° C (max.)
Inlet Coolant Temperature:	5° C (min.)
Harmonic Generator Crystals	
SHG Crystal:	CD*A
THG Crystal:	KDP
Laser Energy Monitor	
Detectors:	PIN Diodes
Beam Sample:	2%
Angle of Incidence:	12.5°
Filters:	Neutral Density Narrow Band at 1,064, 532, and 355 nm

Table 3

ABLE II Receiver Specifications

Field of View	4 mrad
Telescope	
Type	Cassegrain, Dall-Kirkham
f/no.	5.0
Primary Mirror	
Material	Aluminum
Diameter	50.4 cm
Coating	Aluminum + SiO
Secondary Mirror	
Material	Aluminum
Diameter	10.1 cm
Coating	Aluminum + SiO
Effective Collecting Area	1875 cm^2
Effective Focal Length	241.3 cm
Reflection	
at 355 nm	0.79
at 532 nm	0.74
Relay Lens	
Material	Fused Silica, UV Grade
Type	Plano-Convex
Focal Length	6.99 cm
Diameter	3.81 cm
f/no.	1.8

<u>Beamsplitters</u>	
Material	BK-7 Glass
First Beam Splitter	
355 nm Reflection	0.95
532 nm Transmission	0.95
Second Beam Splitter	
532 nm Reflection	0.95
<u>Interference Filters</u>	
Clear Aperture	4. 5 cm
Bandpass	
355 nm	21.6 Å
532 nm	10.8 Å
Transmission	
355 nm	0.125
532 nm	0.463
Temperature	Oven-Controlled
<u>Detectors</u>	
Type	Photomultiplier EMI 9815A
Photocathode	Bialkali
Gain	3.1×10^{5}
Range Gating Method	Dynode 1 Switch
Amplifier Dynamic Range	<u>Equivalent Counts</u>
	<u>Min</u> <u>Max</u>
Hi Gain	0.5 256
Med Gain	10 5120
Low Gain	200 1.30 x 10[illegible]
Dark Count Rate	150 Counts/Sec
Probability of a Dark Count in a Range Bin	1.5×10^{4}ond
Range Bin Length	150 m

Table 4

ABLE Nd:YAG Laser Refurbishment

1. Oscillator	Replated oscillator box with silver and polished reflectors. Installed new flashlamp.
2. Porro Prisms	Replaced both.
3. First Amplifier	Polished reflector and box. Installed new flashlamp.
4. Second Amplifier	Polished reflector and box. Installed new flashlamp.
5. THG (UV)	Crystal was not damaged. Both cell and windows were reinstalled.
6. SHG (Green)	Crystal was found to have internal damage and was replaced. One cell end window also was replaced.
7. Laser Cooling System	Replaced all tubing, replaced coolant reservoir, and repaired old reservoir.
8. Optical Bench	Replaced all coolant tubing. Moved Pockels cell cable away from He-Ne alignment laser. Replaced spring on THG (UV) gimbal mount.

When the laser was unpacked at Visidyne after shipment back from Litton, it was observed that the THG (UV) crystal had a light cloudy appearance when viewed from the input end. Also, there was a laser-burned area on the Teflon crystal mount within the cell. The THG cell was then removed from the laser and returned to Litton for evaluation.

Upon inspection it was determined that the THG crystal had been damaged at Litton during final testing by backscattering of the laser beam, probably from a test filter. The backscatter beam had been directed onto the Teflon crystal mount. Coincidentally, an aluminum chip was embedded in the Teflon at this point. The presence of this chip resulted in the observed burn, and thus the contamination of the harmonic generator cell. Litton recommended that the crystal ends be repolished and that the cell and window be polished and recoated. Litton performed these repair operations to the THG crystal, which was then hand carried to AFGL where it was installed into the laser on 1 August 1987 for testing.

3.3 Optical Components

All of the lidar system optical components in addition to those in the Nd:YAG laser were visually inspected, and the following procedures taken:

1. The ABLE telescope was returned to the fabricator, Optical Systems Technology, Inc., for inspection and realignment. The inspection report is Appendix B.
2. The ABLE pointing mirror surface was found to have a layer of dust on it. It was cleaned by Visidyne, Inc.
3. The receiver optical filters were sent out for recalibration. The spectral transmission curves for those filters selected for flight are in Figs. 3 and 4.

The optical alignment procedures were essentially the same as those used for the previous flight. Optical alignment of the pointing mirrors and the lidar system is simplified through the use of a unique optical bench shown in Fig. 5. We installed two mirrors on adjustable mounts separated by 30" in a 4" square structural steel beam in which we had cut appropriate ports. The mirrors have protective aluminum coatings on clear, plane-parallel substrates so that they could be used as either first or second surface mirrors. The two mirrors were adjusted parallel to each other by the method shown in Fig. 5(a). Using a telescope focused on a distant (many

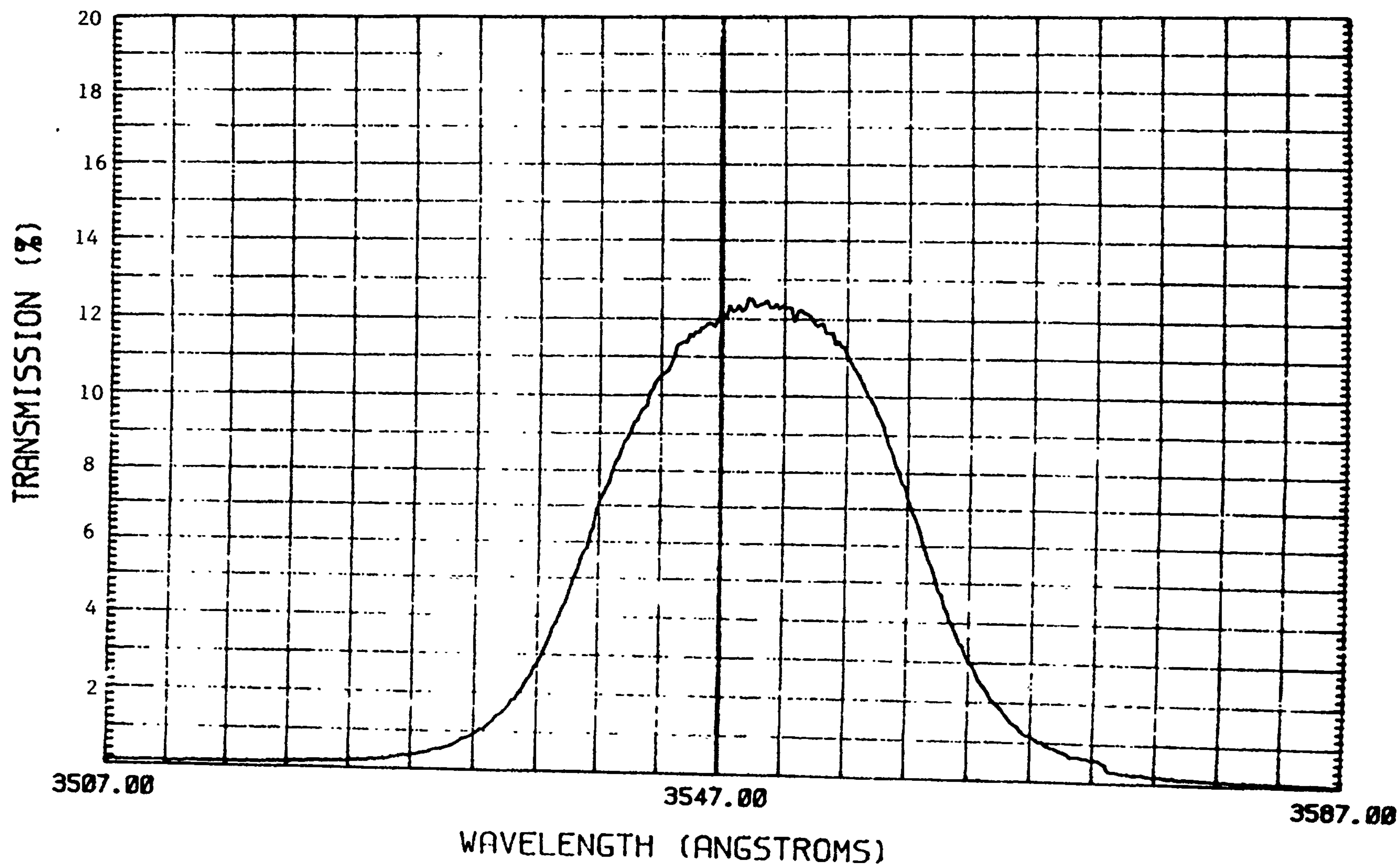


Figure 3. UV filter spectral transmission.

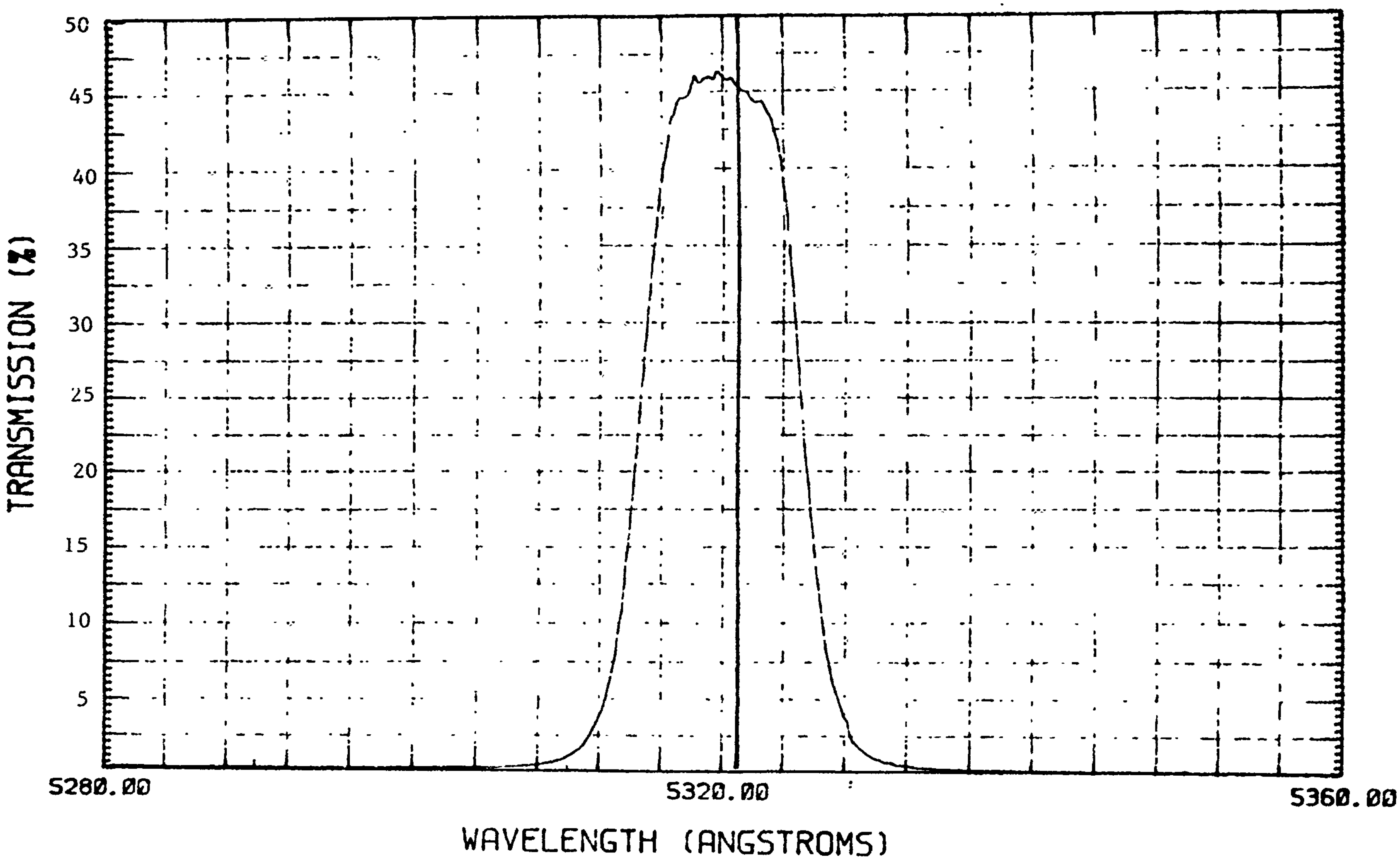
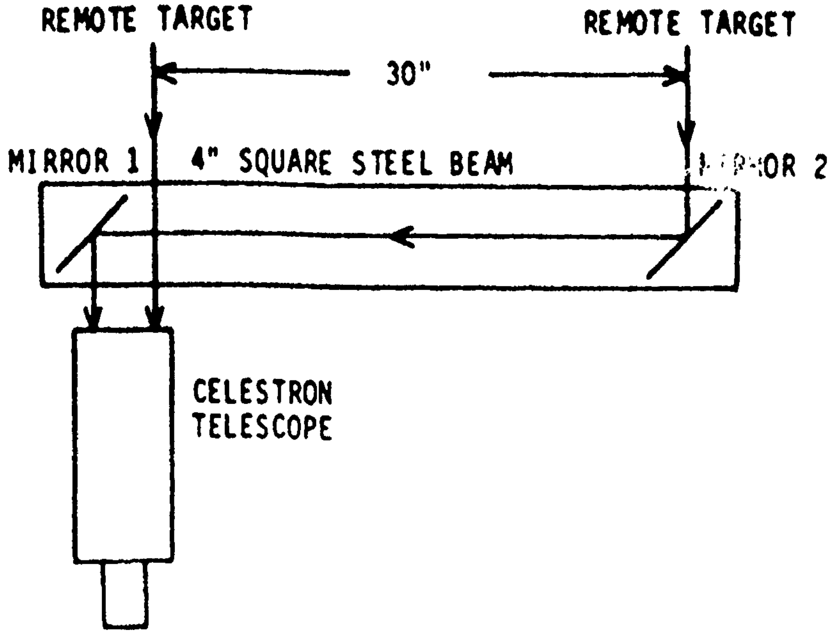
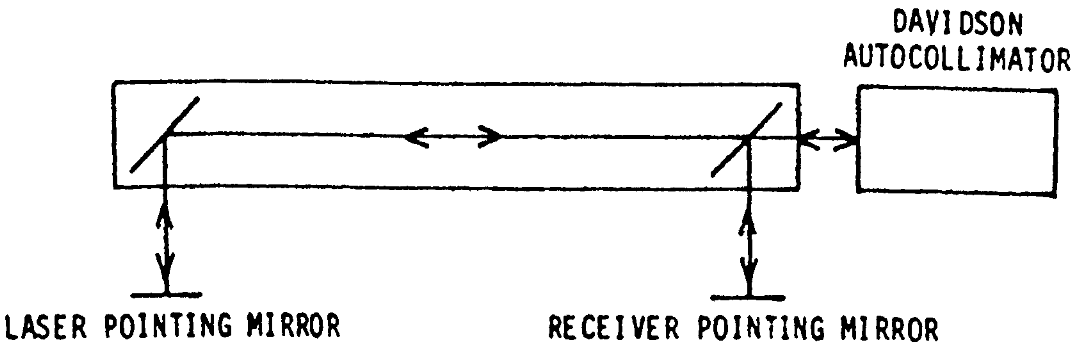


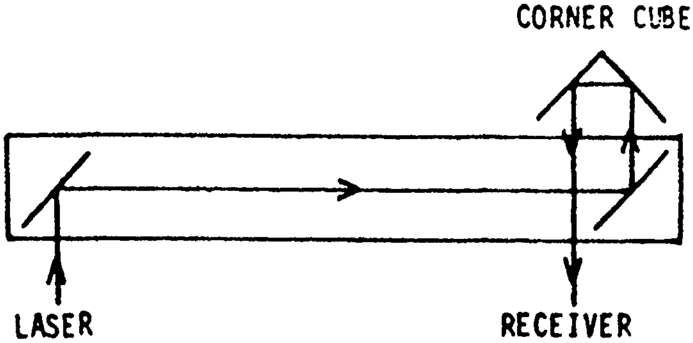
Figure 4. Green filter spectral transmission.



(a) Optical Beam Alignment



(b) Pointing Mirror Alignment



(c) Lidar System Alignment

Figure 5. Optical alignment methods.

miles) target, the mirrors were adjusted and set so that the direct image and the mirror-deflected image of the target are coincident. The possible error in this alignment procedure is estimated to be 0.02 mrad.

The method for aligning the pointing mirrors is shown in Fig. 5(b). The pointing mirror shaft is rotated until the two pointing mirrors are reflecting away from the payload. Using an autocollimator, the reticula pattern reflected from the laser pointing mirror is made coincident with the reticula pattern reflected from the receiver pointing mirror by adjusting the mounting of the former. Both reflected beams can be seen in the auto-collimator because Mirror 2 is shorter than Mirror 1.

For the present contract, we added an eyesafe He-Ne laser which was permanently mounted on the Nd:YAG laser optical bench. By using an adjustable mirror, the He-Ne laser was directed at the Nd:YAG polarizer and oriented so that a transmitted portion of its beam could be observed at the lidar laser output. Then by alternately firing the Nd:YAG laser and adjusting the position of the He-Ne laser, the two beams were made coincident as determined by noting their locations on a remote surface. Next, the optical bench, with the addition of corner cube reflector, was set up on the front of the lidar system as shown in Fig. 5(c). At the receiver telescope focus, we installed a translucent screen with concentric rings calibrated in milliradians. The He-Ne laser beam was centered on the screen by using the payload's optical axis alignment system. Finally, the alignment was checked by firing the Nd:YAG laser (strongly attenuated by filters) and photographing the position of the 532 nm radiation on the screen. The estimated alignment accuracy of the lidar system by this method is 1 mrad, which places the 2 mrad laser beams well within the receiver's 4 mrad field-of-view.

3.4 Other Payload Modifications and Tests

The refurbishment of the lidar system also included the following:

1. The Laser Energy Monitor electronics were modified and bench tested.
2. The receiver detectors were modified and bench tested. Modification included disabling the low gain amplifiers and enabling the test sources.
3. The Thermal Control System was modified and stand-alone tested. The system incorporate separate cooling loops and used a trichloroethylene cooling fluid.

4. The Harmonic Generator remote tuning system was modified to permit absolute position monitoring through the CAMAC telemetry.
5. A test was performed on the Stepper Motor Gear Box for the ABLE Pointing Mirror. The gear box was put under a vacuum bell jar together with two clean witness surfaces, one glass, the other polished metal. The bell jar was evacuated, and approximately five hours later, the vacuum pump was stopped, the bell jar removed, and the witness surface examined for contamination. No contamination from the gear box lubricant was detected on the glass or polished metal surfaces.

3.5 Payload Integration and Testing

The payload was shipped to the AFGL/LC "High Bay" (Fig. 6) on 23 July 1987 for payload integration. The integration schedule is in Table 5.

On 1 August 1987, an all-up test of the lidar was performed. After sunset the payload was rolled out of the High Bay, the lidar was pointed up at an angle of approximately 30° from the zenith, and the laser was fired for a short period. Figs. 7 and 8 show the measured lidar return signals for the 532 nm and 355 nm detectors.

3.6 Thermovac Chamber Test

After the ABLE II payload had been shipped from AFGL to Holloman AFB, it was transported from Bldg. 850 to the Holloman AFB Thermovac test chamber and prepared for an all-up test. Figure 9 shows the payload being installed in the test chamber. On 12 August 1987, the Thermovac test defined in Table 6 was performed. The temperature and pressure profiles are shown in Figures 10 through 13. Because there was some question about the usable life remaining for the laser THG crystal, it was not installed for this test.

During the test the laser firing stopped abruptly. After a several minute wait the laser was restarted, but again stopped firing shortly thereafter. After the conclusion of the Thermovac test the laser was inspected and tested. It was found that the primary coolant pump motor had failed during the Thermovac test, and a thermal interlock on the laser had shut the system down. When it had cooled, it could be restarted but operated only for a short period. The faulty pump motor, which had a brush failure, was replaced with a spare.

Figure 6. ABLE II payload in AFGL/LC high bay.

Table 5

Payload Integration Schedule

July 23 - Thur	Ship Payload to AFGL Payload Assembly
July 24 - Fri	Balloon Control/TM Integration Payload Testing
July 25 - Sat	Payload Testing
July 26 - Sun	Open
July 27 - Mon	TM Test Laser Test
July 28 - Tues	TM Test Receiver Test
July 29 - Wed	TM Test Receiver Test
July 30 - Thur	TM Test Laser Test
July 31 - Fri	TM Test Payload Test
August 1 - Sat	THG Installation UV Test Laser Operation for 2 Hours All-Up Lidar Test

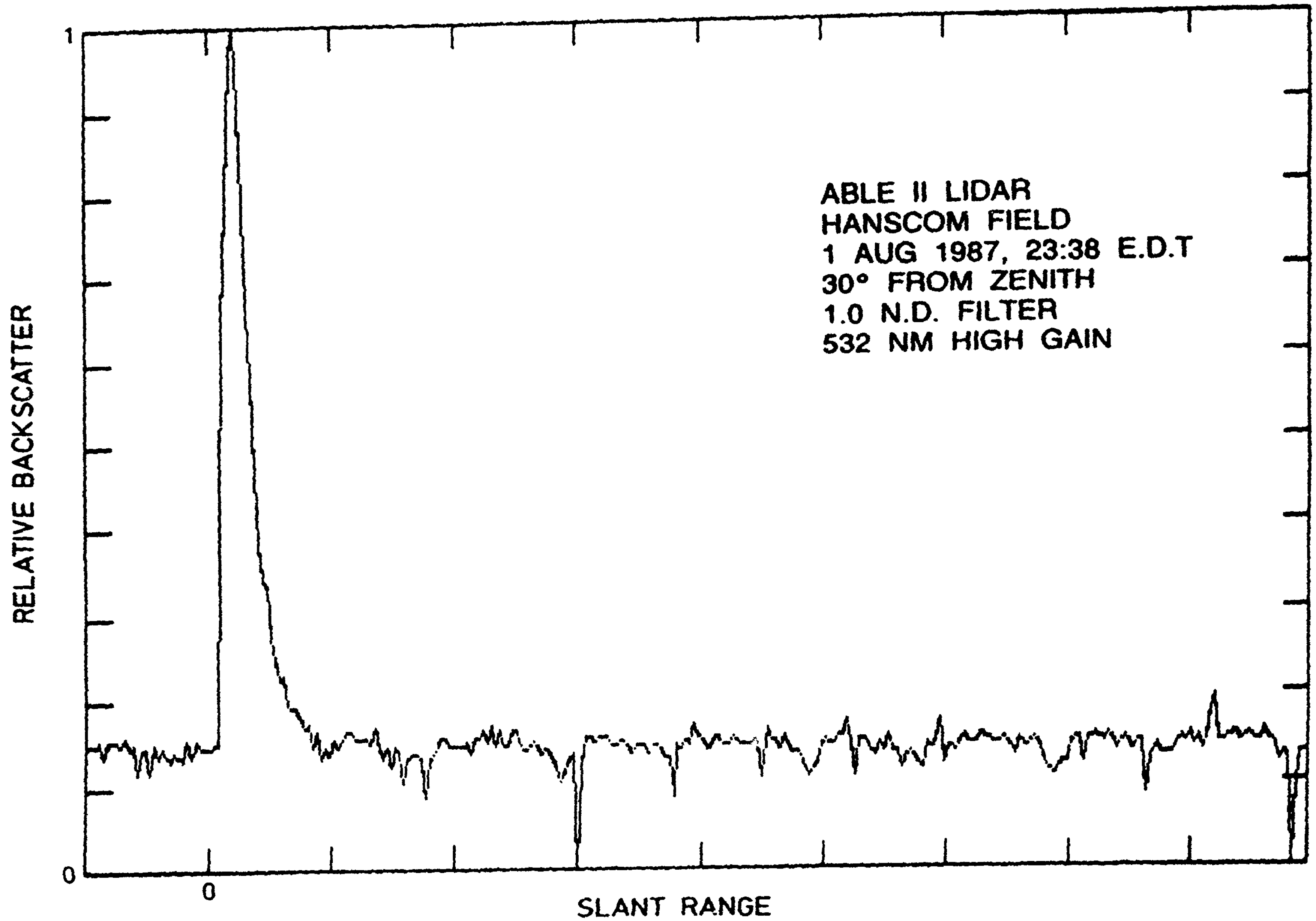


Figure 7. ABLE II lidar return signals at 532 nm.

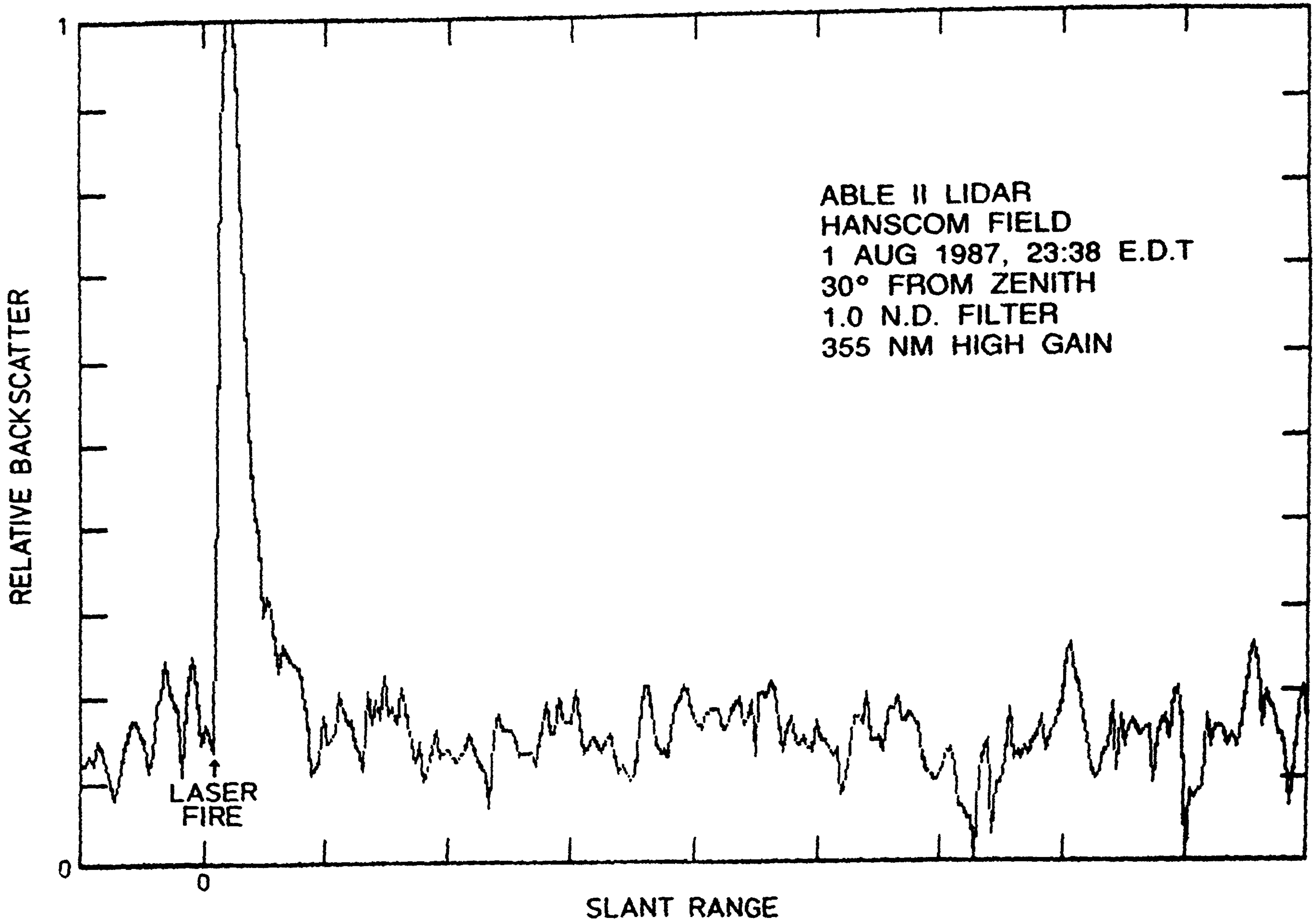


Figure 8. ABLE II lidar return signals at 355 nm.

Figure 9. ABLE II payload being installed in the thermovac test chamber.

Table 6

ABLE II Payload Thermo-Vacuum Test Specifications

1. Dry purge liquid nitrogen lines and chambers as much as possible.
2. Operate at 800 ft/min altitude and ~ -1° c/min temperature drop for 65 minutes to 52 000 ft and -40°C respectively.
3. Hold for 30 minutes.
4. Operate at 800 ft/min altitude rise to 104 000 ft for 65 minutes. Maintain 40°C temperature.
5. Hold for 2 hours 30 minutes.
6. With payload power on, vent chamber with dry nitrogen.
7. Turn power off and maintain positive chamber pressure overnight.

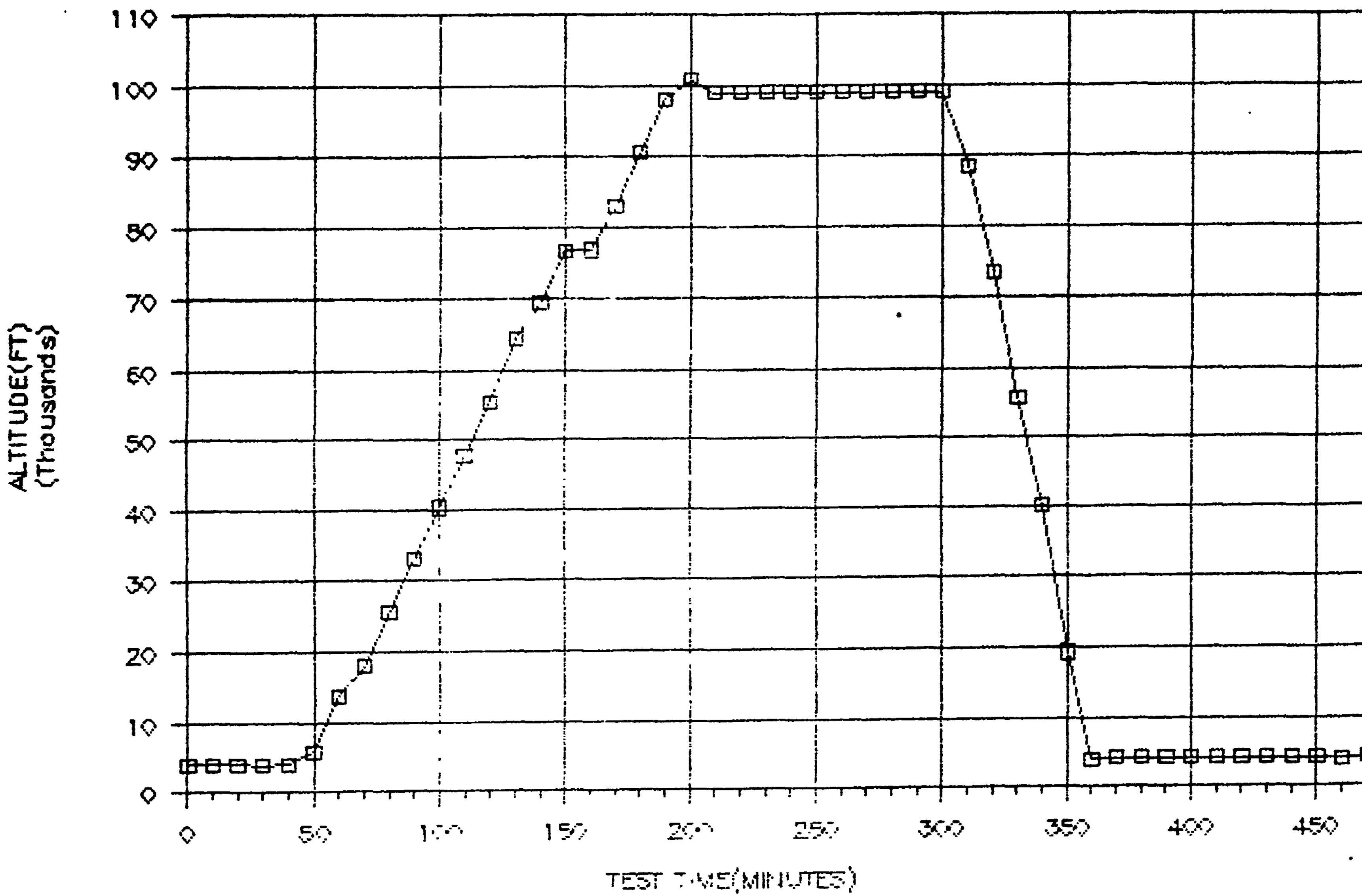


Figure 10. Chamber test altitude during ABLE II thermovac testing.

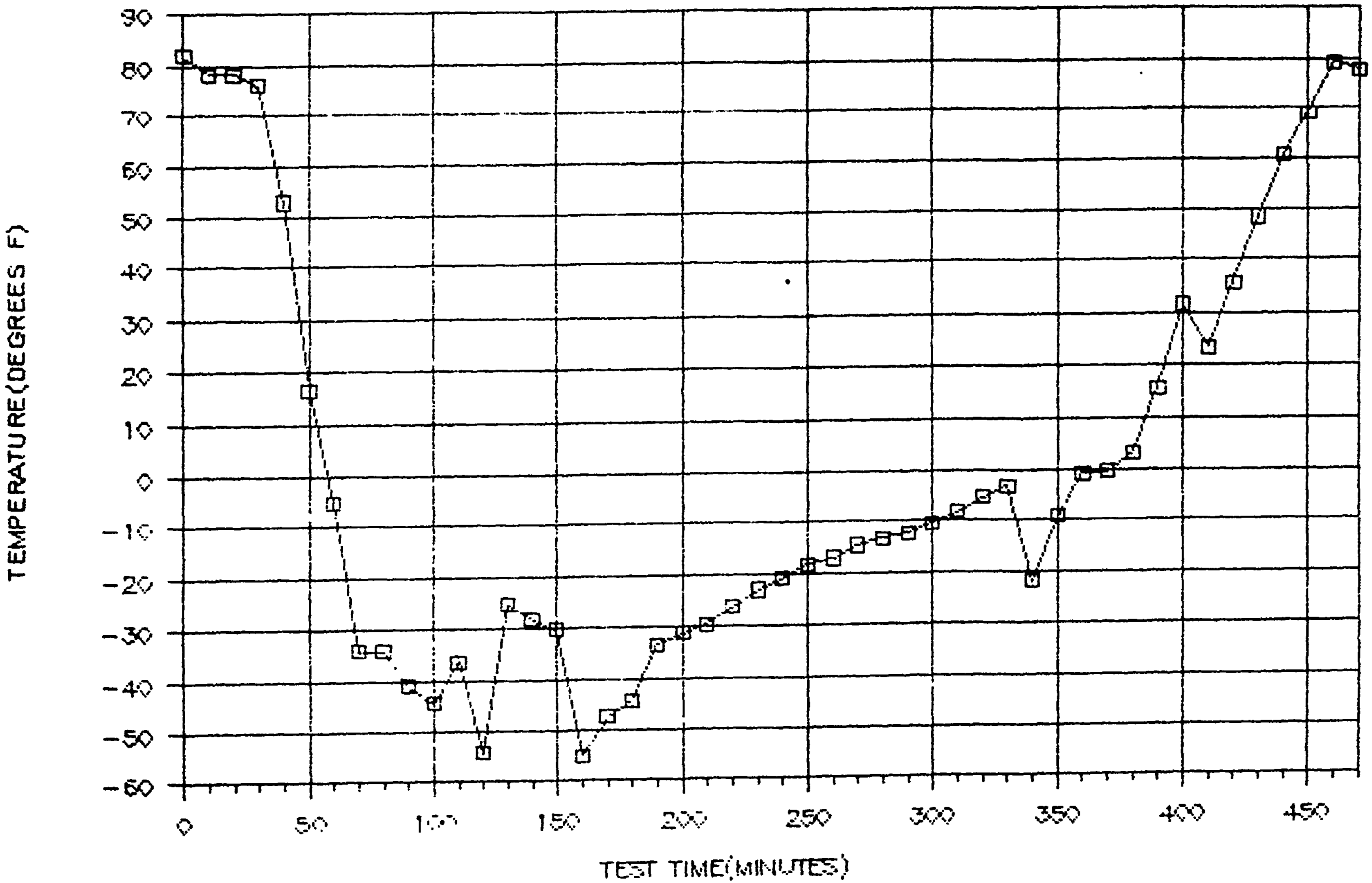


Figure 11. Payload temperature during ABLE II thermovac testing.

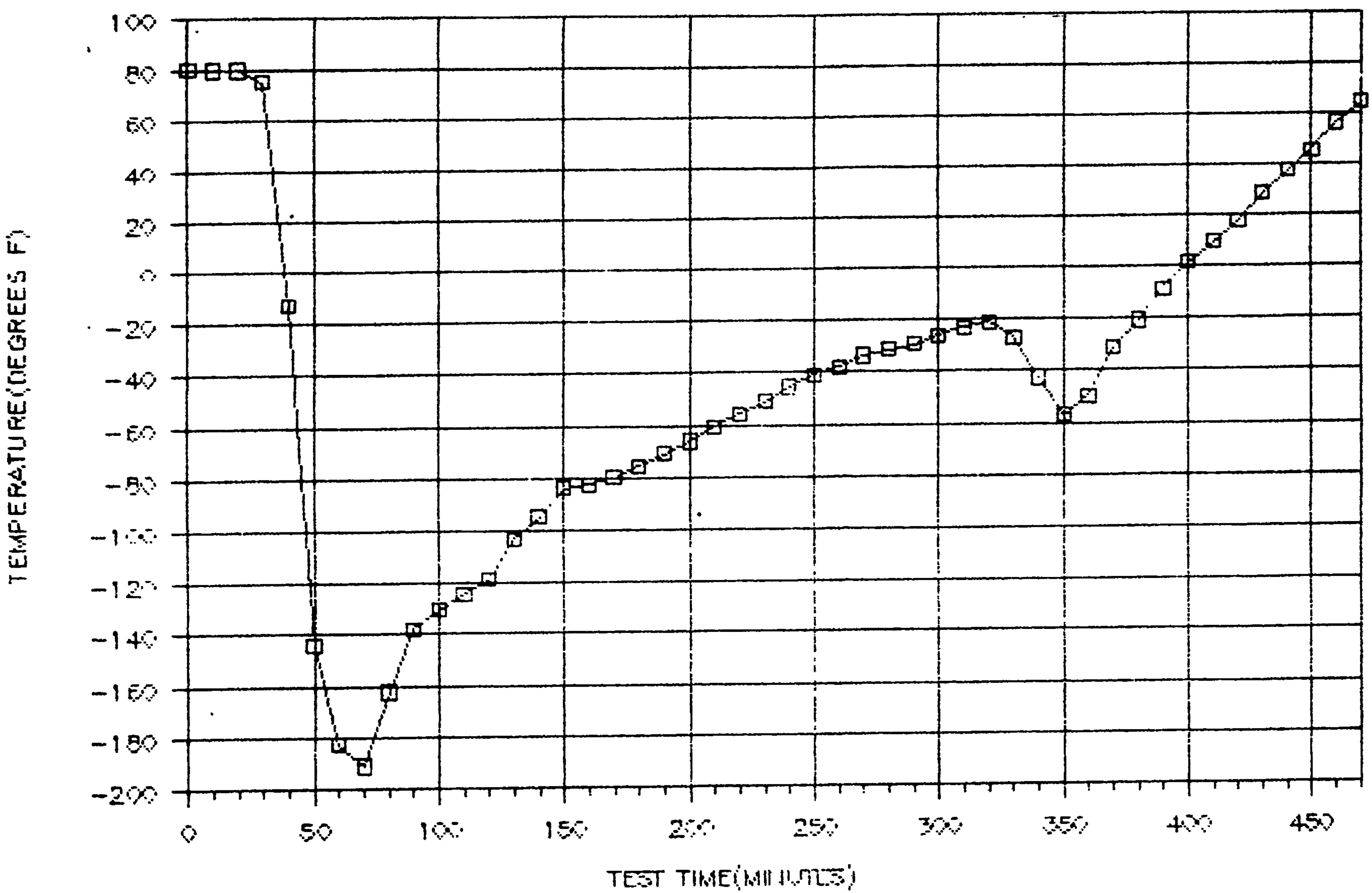


Figure 12. Chamber air temperature during ABLE II thermovac testing.

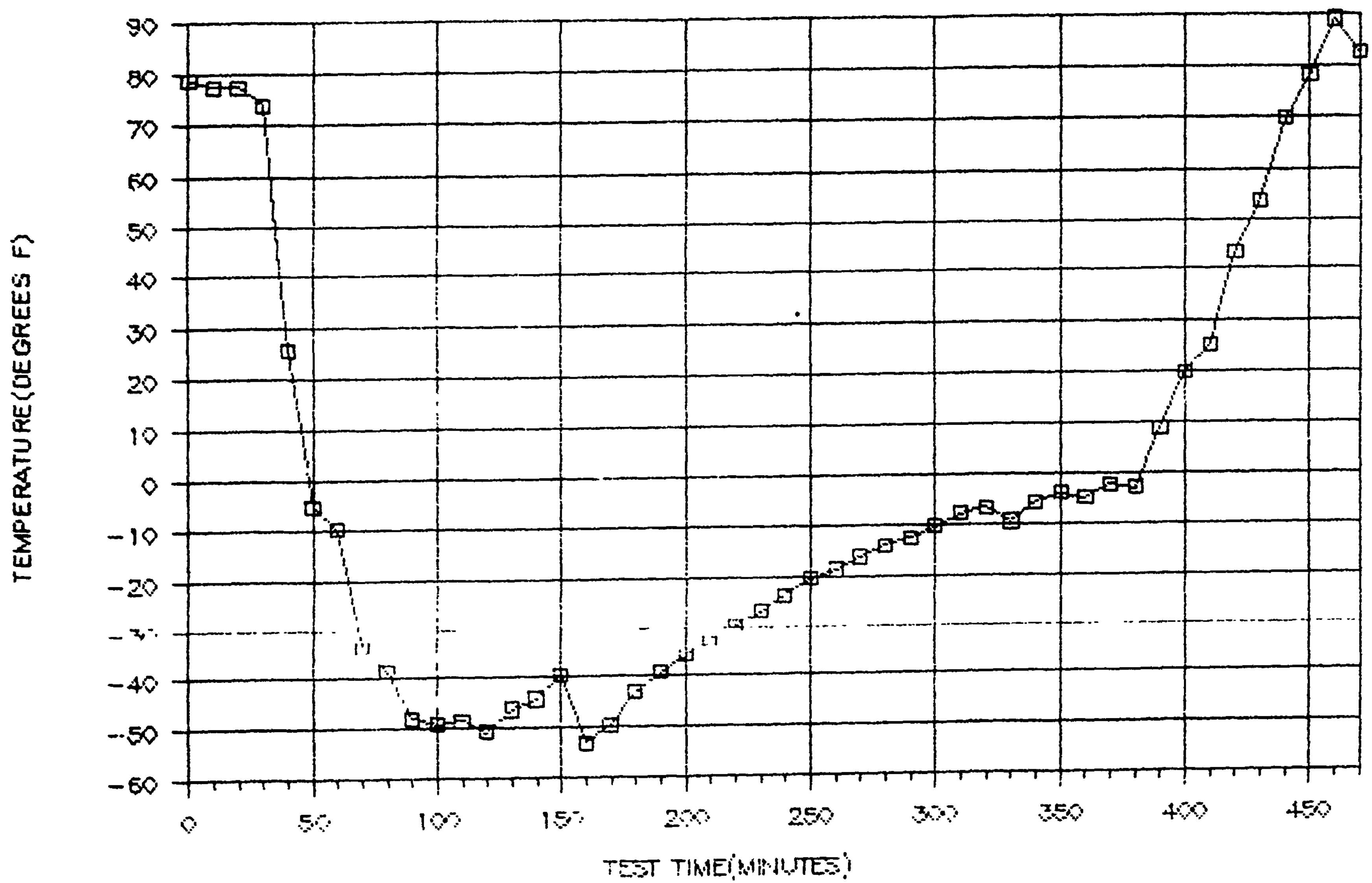


Figure 13. Chamber wall temperature during ABLE II thermovac testing.

During the Thermovac test the laser chamber heaters did not operate because of an incorrect battery connection, which was subsequently corrected. Also, during the test, the temperature sensor data were observed to be noisy. The temperature monitor contained a different circuit board from that which had flown on the first flight of the ABLE payload in August 1984. The addition of a filter capacitor eliminated the problem. As the laser temperature went down during the test, an increase in the LEM noise was observed. This was later corrected by adding filtering to the LEM signals.

Except for the above problems, the ABLE II system met all of its operational requirements during the Thermovac test. Based upon these results the payload was shipped to Roswell, NM to be readied for flight.

4. CALIBRATION

4.1 Laser Energy Monitor (LEM) Calibration

Figure 14 shows the calibration of the laser energy monitor as it was being performed in the High Bay in Bldg. 850 at Holloman AFB. Figure 15 shows the test setup and lists the calorimeters and the types of filter glasses used for each of the three wavelengths. The results of this test as performed during the final calibration are described in Section 4.3. Table 7 summarizes the LEM calibration.

4.2 Receiver Calibration

The ABLE II lidar receiver system was calibrated using the setup shown in Fig. 16. The standard lamp was a 1000 watt GE Quartzline Lamp, Type DXW, which had been calibrated by Eppley Laboratories for its spectral irradiance, shown in Fig. 17. The standard white reflectance surface was prepared by AFGL using Eastman White Paint, which is a nearly perfect scatterer. An opaque cover with a 10 x 10 cm opening was mounted on the receiver telescope.

To keep direct illumination from the lamp out of the telescope, the distance from the lamp to the screen was set at 150 cm, which is three times the distance used in the Eppley calibration.

To calculate the production rate of photoelectrons produced by the setup, we used the following relationship:

$$P = (I)\ \{\frac{\lambda}{hc}\}\ \{\frac{A\Omega}{\pi}\}\ \{\Delta\lambda\}\ \{T_R\}\ \{Q.E.\}\ \{T_F\} \tag{2}$$

where

P is the number of photoelectrons produced per second,

I is the irradiance from the lamp calibration corrected for the increased distance (divided by 9) as determined from Fig. 17,

λ/hc is 1.79×10^{18} photons/W at the 355 nm UV lasing wavelength and 1.68×10^{18} photons/W at the 532 nm green lasing wavelength,

A is the telescope aperture opening (100 cm^2),

Ω is the steradiancy of the receiver, which is $\pi/4\ (4 \times 10^{-3}$ radian$)^2$,

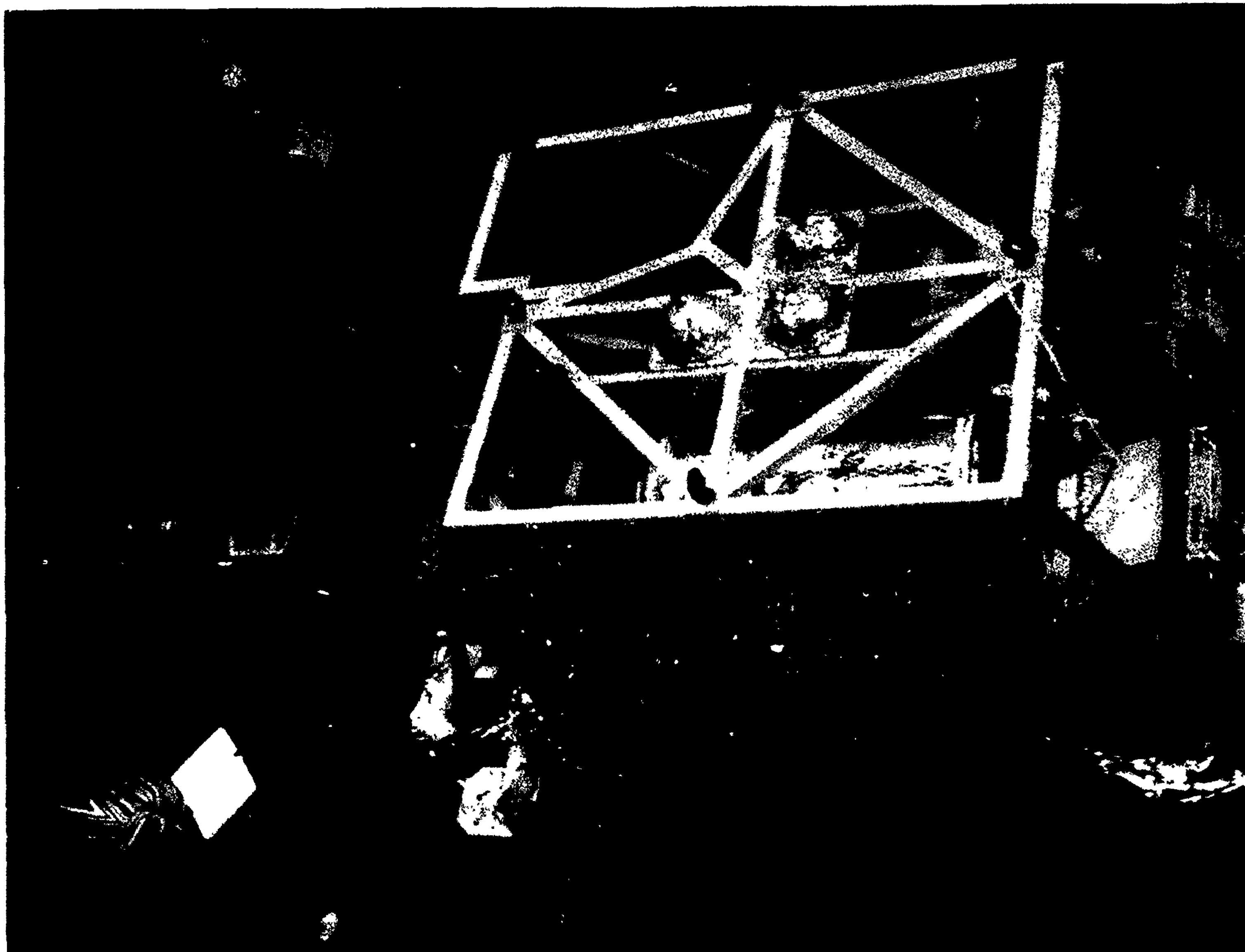
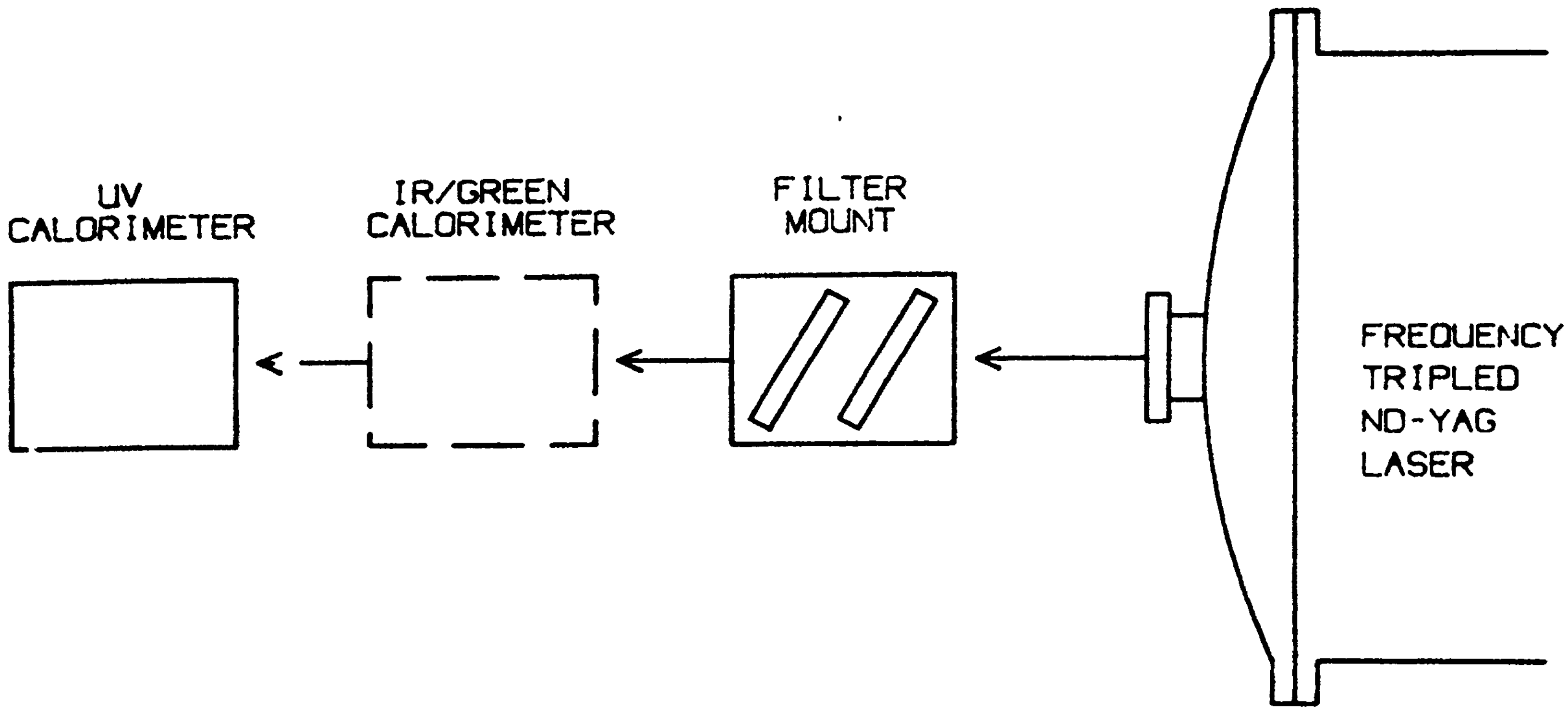


Figure 14. Calibrating the laser energy monitor, Holloman AFB.



λ (nm)	CALORIMETER CONTROLLER	CALORIMETER	FILTERS	TRANS.
1064	SCIENTECH MODEL 365-002 SN 1060	SCIENTECH MODEL 380106 SN 1004	RG830	0.911
532			KG3. GG475	0.662
355	SCIENTECH MODEL 365-002 SN 1031	SCIENTECH MODEL 380105 SN 133	KG3. BG3	0.500

Figure 15. Laser Energy Monitor calibration setup.

Table 7

Laser Energy Monitor Calibration

λ	Laser Energy/Pulse	LEM Signal Counts	LEm Offset Counts
1064 nm	87 mJ	164	96
532 nm	77 mJ	300	18
355 nm	19.6 mJ	174	57

<u>Calibration Factor</u>

1064 nm	E(mJ) = (N-96) x 1.261
532 nm	E(mJ) = (N-18) x 0.271
355 nm	E(mJ) = (N-57) x 0.166 $N \leq 1023$

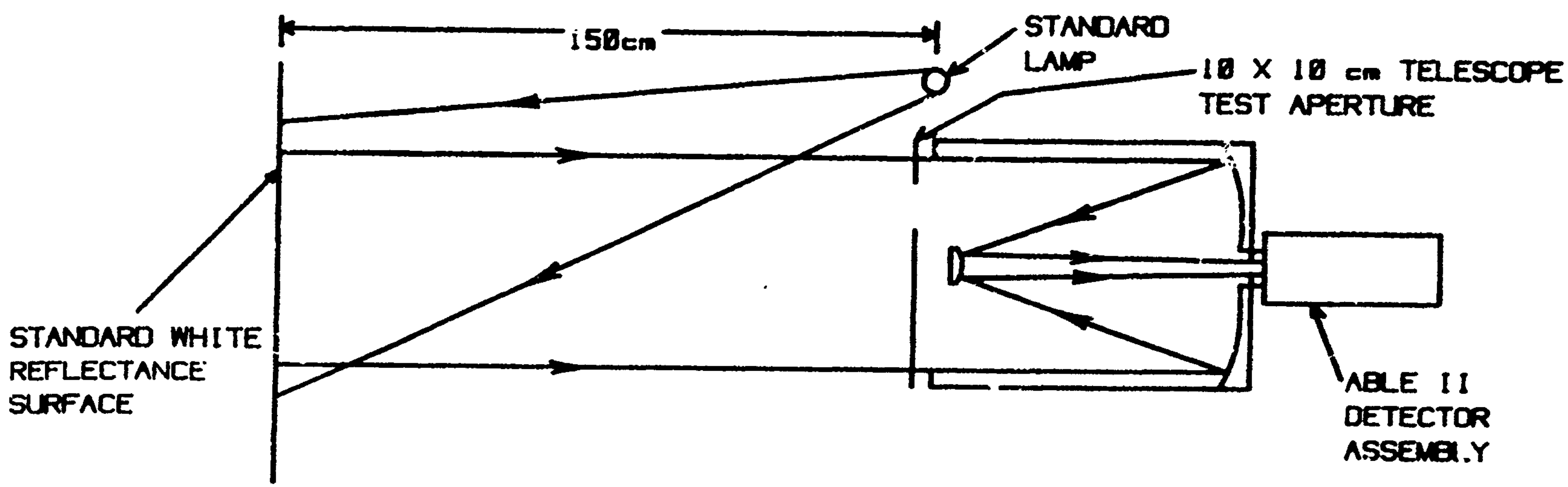


Figure 16. ABLE II receiver calibration.

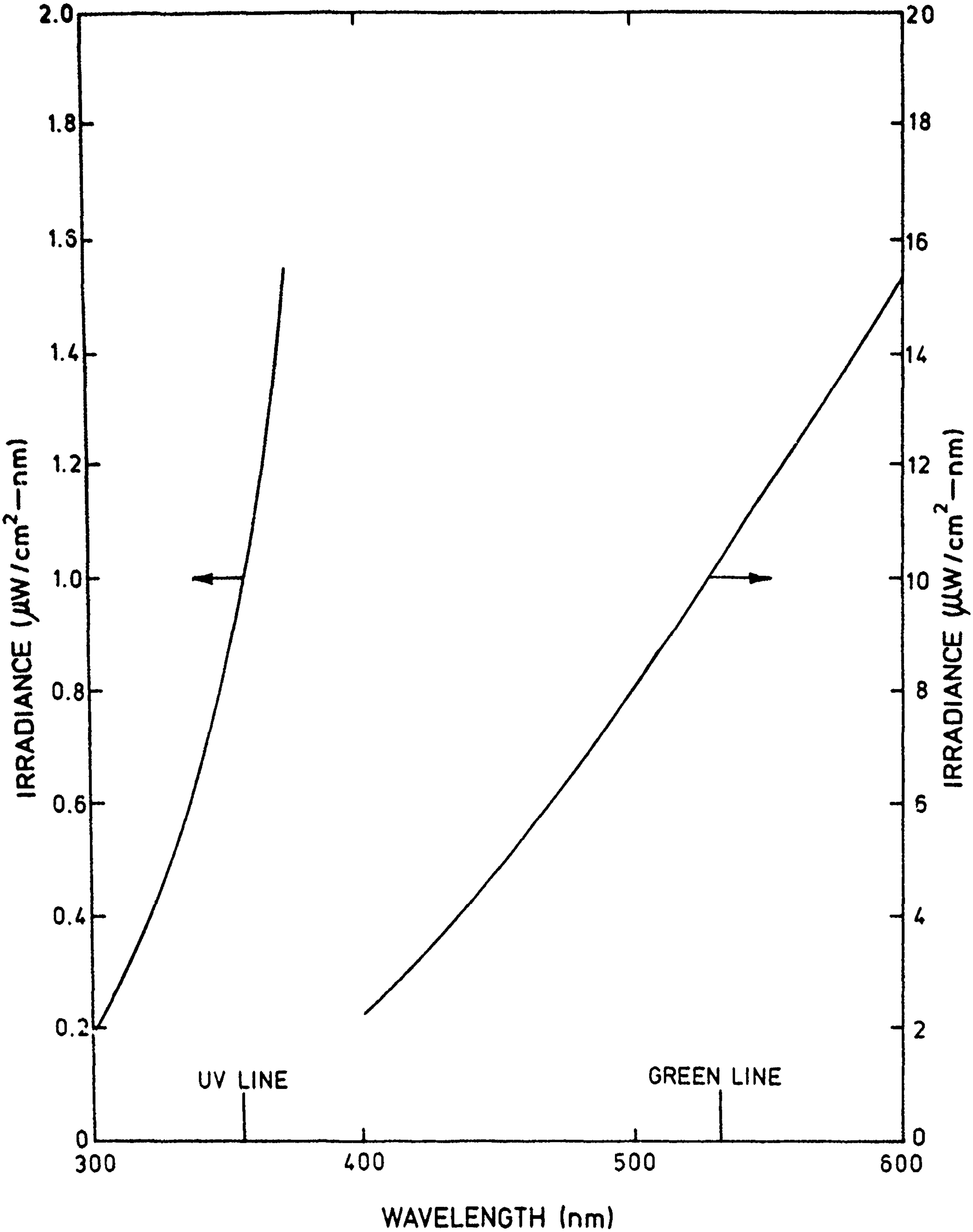


Figure 17. Standard lamp spectral irradiance.

$\Delta\lambda$ is the detector filter half-power bandwidth, which is 3.3 nm for 355 nm and 1.06 nm for 532 nm,

T_R is the receiver optics transmission, which is 8.3×10^{-2} for 355 nm and 3.1×10^{-1} for 532 nm,

Q.E. is the photocathode quantum efficiency, which is 1.6×10^{-1} for 355 nm and 1.3×10^{-1} for 532 nm, and

T_F is the neutral density filter transmission, which is 0.1.

Substituting these values in the above equation yields the following values:

At 355 nm, P = 6.4 photoelectrons per μs

At 532 nm, P = 97 photoelectrons per μs

The voltages measured at the receiver output on the high gain channels were 0.086 V for the UV and 0.92 V for the green. The number of least significant bits (LSB's) for the 5 V full scale output is 512. Then the UV signal totaled

$$\frac{5\ V}{512\ LSB} = 9.77\ x\ 10^{-3}\ V/LSB$$

$$\frac{0.086\ V}{9.77\ x\ 10^{-3}\ V/LSB} = 8.8\ LSB,$$

and the green signal totaled

$$\frac{0.92\ V}{9.77\ x\ 10^{-3}\ V/LSB} = 94\ LSB.$$

Using the previously calculated values for P yielded the following:

355 nm: 0.73 photoelectrons/μsec$\cdot$LSB

532 nm: 1.03 photoelectrons/μsec$\cdot$LSB

Based on simulations made at AFGL using the laser energy levels of the 1984 ABLE flight, the number of photoelectrons per range bin (1 μs) per shot for range bins at the lower altitudes would be approximately 86 for the UV and 220 for the green. This would put the signals for each laser shot at LSB levels of

$$\frac{86\ photoelectrons/\mu s}{0.73\ photoelectrons/\mu s \cdot LSB} = 118\ LSB$$

for the UV, and

$$\frac{220\ photoelectrons/\mu s}{1.03\ photoelectrons/\mu s \cdot LSB} = 214\ LSB$$

for the green. This indicated that the two signal channels would be operating at levels which were essentially optimum.

4.3 Final Calibration and Checkout

The final calibration was done at Roswell, NM, prior to flight. Considerable experimental testing in preparation for the calibration had been done at Visidyne, Inc. and AFGL facilities at Hanscom AFB and Holloman AFB.

During the optical co-alignment of the Nd:YAG laser and the lidar receiver telescope, it was found that there was a 2.3 mrad misalignment. The cause of this was attributed to the more accurate measurement of alignment made at Roswell. The previous alignment at Visidyne used a measurement distance of approximately 80 inches while the distance used in the Roswell hanger was 426 inches.

To correct this error, the lidar telescope mount was readjusted to bring the misalignment to less than 0.2 mrad. When the subsequent receiver calibration was done it was found that the responsivity of the 532 nm detector and the 355 nm had decreased by approximately a factor of two compared to the previous measurements made in the AFGL High Bay. By adjusting the position of the lidar detector assembly with respect to telescope field stop, the 532 nm responsivity was brought back to its previous value, but the 355 nm could not be significantly changed. The reason for this discrepancy was not resolved.

As part of these tests the responsivity of each detector was measured for each quadrant of the receiver telescope to see if there were any variation across the telescope aperture. No significant variations were observed.

On 24 August 1987 the LEM calibration was performed. The results are in Table 7. During the calibration it was initially observed that the laser output was considerably lower than had been measured at AFGL. An inspection revealed laser beam radiation damage to the laser chamber window, LEM diverging lens, and LEM beamsplitter. All three components were rotated approximately 90° to remove the damaged areas on each component away from where the laser beam was incident. After these adjustments were made, the laser was turned on, the SHG and THG crystals adjusted for peak output in the UV, and the LEM calibration data recorded.

On 22 August 1987 the ABLE II payload was rolled out of the hangar, and an L-3 day test performed. The launch and flight checklists included in Appendix C were completed. The payload, attached to the launch crane, was subjected to a simulated launch. Payload operation tests were successfully completed prior to and after the launch run.

5. FLIGHT

In preparation for the flight of the ABLE II payload, Visidyne submitted an Interface Control Document to AFGL/OPA and AFGL/LC[4]. On 3 August 1987, the payload and support equipment were loaded onto an air ride van for shipment to Holloman AFB. Following the previously described calibration and testing, including the Thermovac chamber test, the payload was shipped to Roswell, NM for prelaunch preparations. The launch, originally scheduled for 25 August 1987, was delayed for five days because of poor weather conditions. Appendix C includes the ABLE II Operational Procedures. The Balloon Flight Requirements are given in Fig. 18.

At 20:21 hours MDT, 30 August 1987, the ABLE II payload was launched from the taxiway of the Roswell Industrial Air Center. Figure 19 shows the launch operations. The payload launch was very smooth, and no shocks to the payload were evident.

Approximately 30 minutes after launch, a malfunction occurred in the lidar housekeeping data electronics which resulted in erroneous temperature and pressure data being read out at the ground stations. When the malfunction was detected, the lidar system power was recycled and the CAMAC computer rebooted, but no change in the data was observed. After examining the data, corrections were generated which permitted system operation monitoring to continue.

When the laser was initially turned on, at an altitude of 60 kft as per the experiment plan, low beam energy output in the UV was observed. In addition, the green LEM data indicated greater than predicted beam energy. Angle tuning of the THG did not significantly increase the UV output as measured by the LEM. When the payload arrived over WSMR, the pointing mirror was directed toward the nadir. At 02:53 MDT the payload was put into the stow configuration in preparation for flight termination. The payload parachuted to a ground impact point on the eastern slope of the San Andres mountains near Gardner Peak. Figure 20 shows the ABLE II flight path and payload altitude as a function of time, and Fig. 21 summarizes the flight data.

JOCAS: 7670 1602

SCHEDULED LAUNCH DATE	BALLOON FLIGHT REQUIREMENTS	LAUNCH SITE
August 25, 1987		Roswell, NM

I. GENERAL

1. PROJECT NUMBER & TITLE: ABLE - 7670
2. PROJECT OFFICER: Mr. Ground/LCI
3. EXPERIMENTER: Dr. Bedo/OPA
4. FLIGHT OBJECTIVES
   a. Obtain uplooking and down looking LIDAR Data
   b. Obtain low light data.
   c. Obtain dropsonde data.
5. REQUIRED FLIGHT PROFILE: Climbout to 109 Kft + float over WSMR - Terminate
6. DESIGN CEILING ALTITUDE: 109 Kft
7. FLIGHT DURATION: 7 hours
8. PAYLOAD RECOVERY: Mandatory
9. DOCUMENTARY PHOTOGRAPHY: LAUNCH: STILL X ~~MOTION~~ Video X RECOVERY STILL X MOTION N/A
10. TELEMETRY: RANGE MOBILE VAN N/A FIXED STATION N/A AFCRL MOBILE VAN X FIXED STATION X

II. BALLOON

1. BALLOON NUMBER 5 OF 5 ITEM N/A S/N 5 CONTRACT PO 24342
2. MANUFACTURER: Winzen
3. VOLUME(S): 8.74×10^6 cu ft
4. MODEL NUMBER(S): SF 277.88-100-NSC-01
5. BUBBLE TO BE ~~UPWIND~~/DOWNWIND OF PAYLOAD
6. PULL OUT LOWER N/A FT OF DUCTS
7. CUT OFF LOWER N/A FT OF DUCTS
8. ~~DO~~ DO NOT USE CORNSTARCH ON LAUNCH ARM
9. OTHER: Two 1.0 mil caps 160 and 186 ft long.

III. WEIGHTS

1. BALLOON(S): 2415 lbs
2. TOP MOUNTED PAYLOAD: N/A
3. SUSPENDED PAYLOAD *(Incl. Ballast, Rigging, Chutes)*: 2900 lbs
4. GROSS WEIGHT: 5315 lbs
5. MINIMUM DROPPABLE BALLAST: 500 lbs
6. DESIRED DROPPABLE BALLAST: 500 lbs
7. DEAD WEIGHT BALLAST: N/A
8. % FREE LIFT: 12%

IV. INSTRUMENTATION

1. PACKAGE TYPE(S): ~~PCM-2-modified~~ ABLE II
2. ALTITUDE SENSOR(S): CICs 0-15, 0-2, 0-0.5
3. RADIOSONDE: STANDARD ___ EXTENDED X OMEGA ___
4. PRIMARY COMMANDS: IRIG ___ SEQUENCED ___
   (1) (4) See Tech Data (7)
   (2) (5) (8)
   (3) (6) (9)
5. BACK-UP COMMANDS: SEQUENCED ___ NON-SEQUENCED ___
   (1) (2) See Tech Data (3)
6. DROPPABLE BALLAST *(Type, Container, Total Flow Rate)*: Glass/Two Hoppers/60 ppm

V. MISCELLANEOUS

1. PARACHUTE(S): QUANTITY 1 TYPE Flat Circular DIAMETER(S) 100 ft
2. SEPARATION DEVICE: Tufts
3. BURST SWITCH: YES X NO ☐
4. IMPACT SWITCHES: QUANTITY 4 TYPE AFGL
5. CAMERA(S): VIDEO UP N/A DOWN N/A OTHER N/A
6. FLASHING LIGHT LOCATIONS: Package & Balloon Top
7. RECOVERY BEACON: YES X NO ☐
8. TRANSPONDER: FAA Code 4455 YES X NO ___
9. REEL DOWN PACKAGE: WEIGHT N/A DISTANCE TO BE LOWERED N/A
10. ATTACHED DOCUMENTS: See Operational Plan

REQUIREMENTS INITIATED BY: J. Ground *John Ground* DATE: 21 July 1987

COORDINATION: LCA BY *A. A. Korn* DATE *22 July 87* LCC BY *Hans Lapin* DATE *22 July 87*

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Figure 18. Balloon flight requirements.

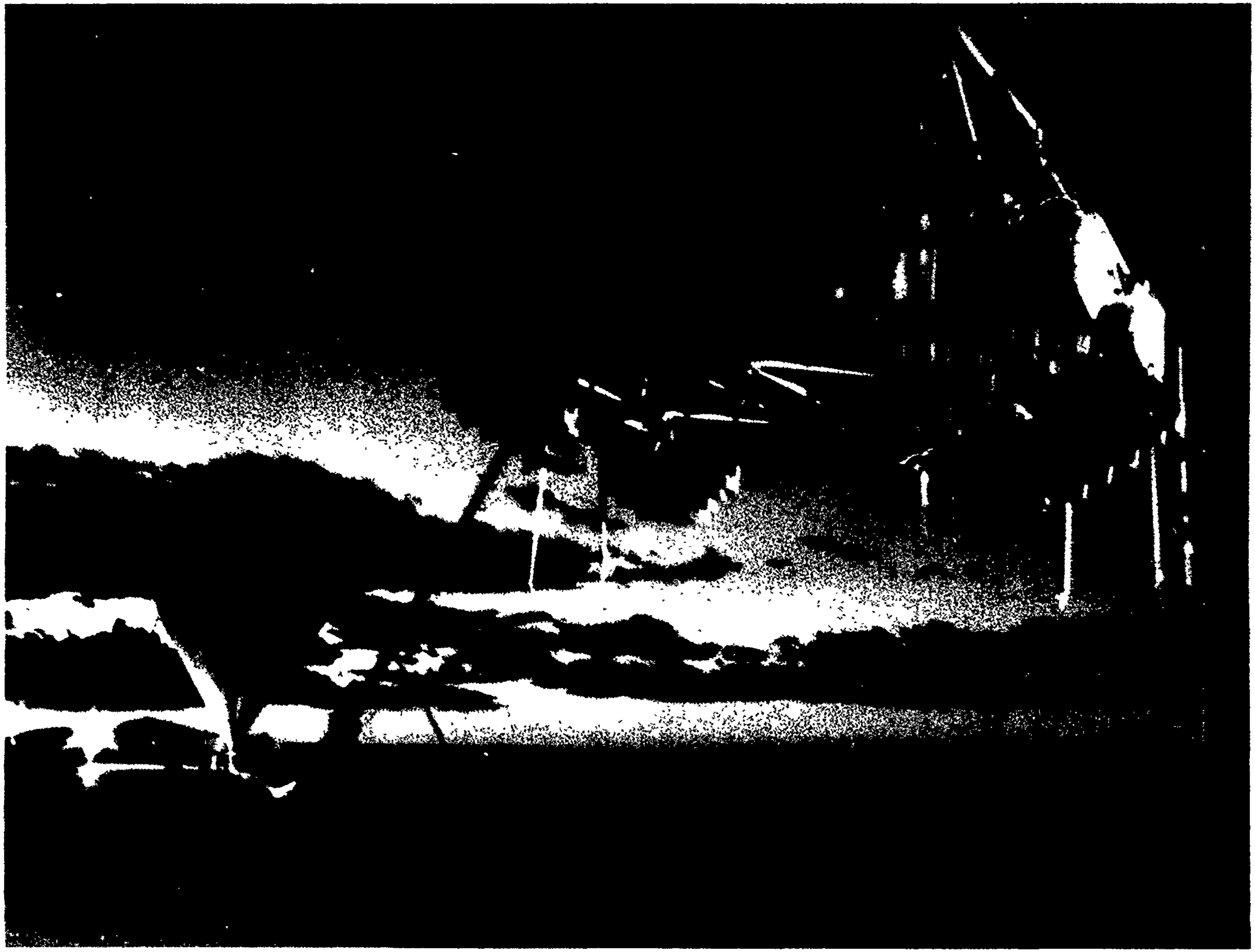

Figure 19. ABLE II payload launch operations.

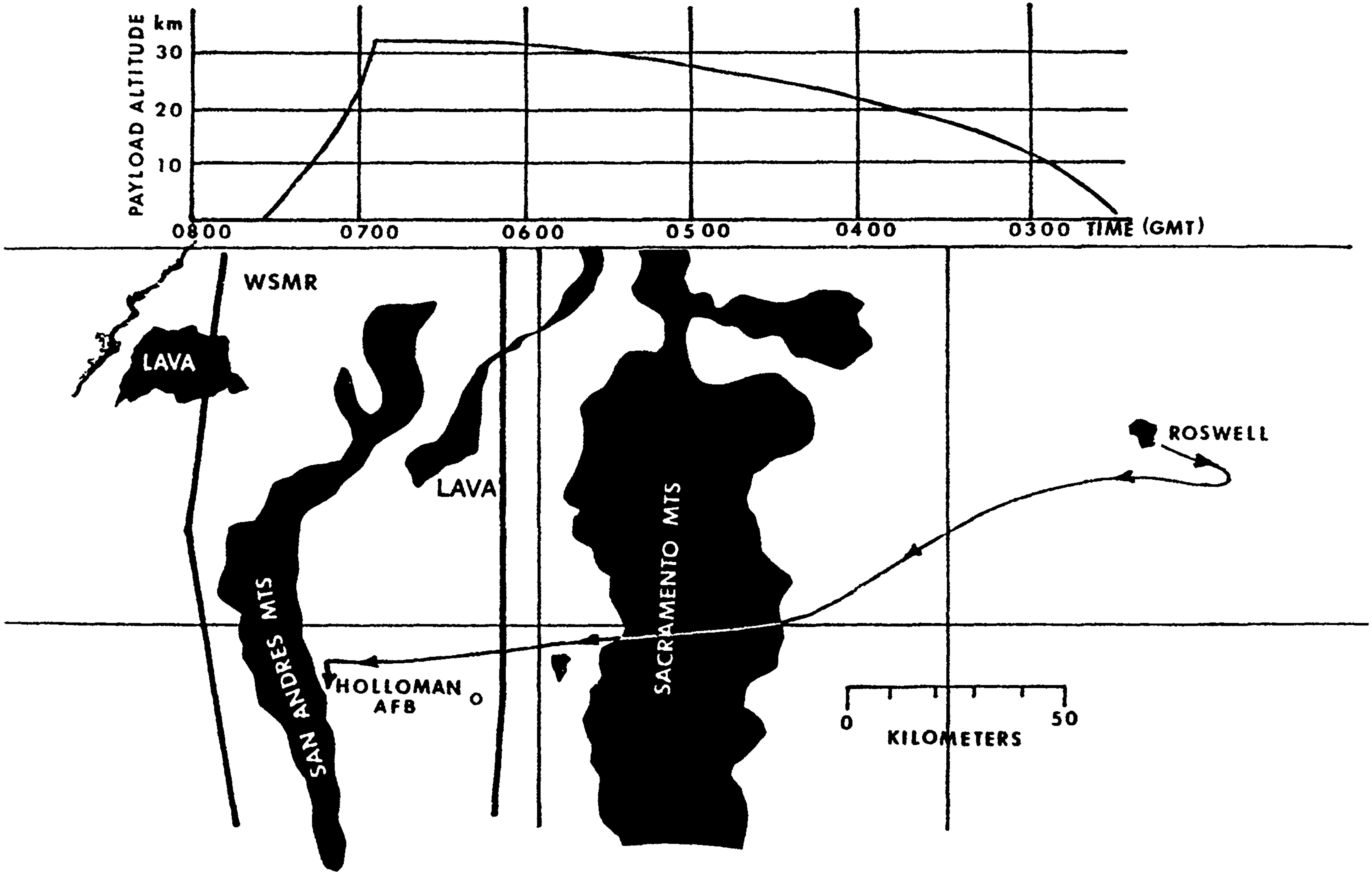

Figure 20. ABLE II flight path.

DATE LAUNCHED	BALLOON FLIGHT SUMMARY	FLIGHT NUMBER
31 Aug 87		H87-07

I. GENERAL DATA

1. PROJECT NUMBER & TITLE	2. PROJECT OFFICER	3. EXPERIMENTER
76701602 ABLE II	J. Gound/LCE	Dr. Bedo/OP

4. FLIGHT OBJECTIVES

a. Obtain up & down looking LIDAR data.

b. Obtain low light data.

c. Obtain dropsonde data.

5. REQUIRED FLIGHT PROFILE	6. TEST COORDINATOR
Climb to float over WSMR, terminate.	W. Kieffer/Det 1, AFGL

7. LAUNCH CREW CHIEF	8. METEOROLOGIST(S)	9. MALFUNCTION REPORTS
J. Fumerola/PSL	~~J. Ground/LCE~~ R. Reynolds /PSL	BLN 0 INSTR 0 OTHER 0

II. BALLOON DATA

1.	2. MANUFACTURER
BALLOON NUMBER 5 OF 5, ITEM - S/N 5 CONTRACT P024342	Winzen

3. DIAMETER(S)	4. LENGTH(S)	5. VOLUME(S)
277.9 ft	399.9 ft	8.74×10^6 ft^3

6. WEIGHT(S)	7. MATERIAL & THICKNESS
2402lbs + 13lbs(V & SL)	Stratofilm; 1.0 mil

8. MODEL NUMBER(S)	9. VALVE & VALVE MOTOR SERIAL NUMBERS	10. REMARKS (Caps, Defects, Tusses, Duct Cuts, etc.)
SF 277.88-100-NSC-01	EV-13; BX 016/#1029	(2) 1.0 mil caps: 186 & 160ft

III. PAYLOAD DATA

1. WEIGHT	2. PARACHUTE(S) - (Number, Type, Diameter, Weight)	3. DROPPABLE BALLAST (Type, Weight, Rate)
3004 lbs	1; flat circular; 100ft; 184lbs;#437162	Glass, 500 lbs, 60 PPM

4. PRIMARY CONTROL PKG(Type)	5. TRANSMITTER(S) MFGR. MODEL S/N	MFGR. MODEL S/N
ABLE II	** See H. Laping	**

6. RECEIVER(S) MFGR. MODEL S/N	MFGR. MODEL S/N	7. ALTITUDE SENSOR(S)
**	**	Cic's: 0-15;0-2;0-.5

8. SEPARATION DEVICE	9. SPECIAL ITEMS (Description & Weight)
Tufts	NA

IV. LAUNCH DATA

1. SITE	2. SURFACE WIND	3. TEMPERATURE	4. CLOUDS
Roswell, NM	160/05 KTS	22°C	Clear

5. GROSS WEIGHT	6. FREE LIFT	7. GROSS INFLATION	8. LAUNCH ARM & RELEASE VEHICLE
5419 lbs	650.3 LB 12 %	6069.3 lbs	Anderson Greenwood; Crane

9. LAUNCH METHOD	10. LAUNCH RUN LENGTH; CHARACTER OF LAUNCH	11. LAUNCH TIME
Dynamic	400ft; Smooth	SCHEDULED 0400Z ACTUAL 0221Z

V. FLIGHT DATA

1. ASCENT RATES: TO TROPOPAUSE 1159 fpm, TROPOPAUSE TO FLOAT 652 fpm, OVERALL AVERAGE 774 fpm

2. TROPOPAUSE	3. MINIMUM TEMPERATURE
TEMP. -59.1°C ALTITUDE 41K ft PRESSURE 179mb	-65.7 ALT 57K ft PRESS. 83 mb

4. GROSS WEIGHT AT CEILING ALT.	5. DESIGN CEILING ALT	6. ACTUAL FLOATING ALTITUDE(S)
5311 lbs	108.2 K ft	107.6 Kft(TM); Max: 107.8 Kft

7. FLIGHT DURATION TIMER SETTINGS	8. COMMAND FREQUENCIES
PRIMARY 6 hrs SECONDARY None	423.6 & 437.5 MHZ

9. TELEMETRY FREQUENCIES	10. TELEMETRY DATA CYCLE(S)
2233.5; 2215.5; 2258.5 MHZ	~~Continuous~~ See Tech Data

11. VOICE COMMUNICATIONS FREQUENCIES	12. TRACKING METHODS
141.6 thru 138.875 MHZ; 282.7 MHZ	Radar; FAA

13. TERMINATION (Altitude, Method, Initiated By, Date/Time)	14. FLIGHT DURATION	15. DESCENT LOAD
107.4 Kft; Command; C.C.C.; 31/0700Z	4 hrs 39 min	2504 lbs

16. PAYLOAD IMPACT (Position, Date/Time)	17. DESCENT TIME	18. BALLOON IMPACT (Position, Date/Time)	19. BLN DESCENT TIME
268/27 NM ALM ; 31/0742Z	42 min	271/30 NM ALM; 31/unkn	unkn

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Figure 21. Balloon flight summary.

6. RECOVERY

Figure 22 shows the ABLE II payload and parachute at the impact site in the foothills of the San Andres Mountains on WSMR land below Gardner Peak. Fortunately, the impact force was somewhat lessened because the payload struck a small juniper tree, and although the slope was steep, as shown in Fig. 23, the low center of gravity of the payload kept it from rolling over. The balloon landed near Knob Hill in the San Andres Mountains and was not recovered. On 31 August 1987, the morning following the launch, the recovery crew drove out to the impact area and located the payload. A small Army helicopter met them at the WSMR RAD site, the nearest approach by land vehicles. It then ferried Visidyne personnel in one by one to a safe landing spot from which they hiked the remaining half mile to the impact site. By following the established recovery safety procedures, they determined that the laser was off and all payload power was shut down. Upon confirmation that the payload was safe, the other members of the recovery team were airlifted in, one at a time.

Since the payload weight was too great for lifting by a waiting UH-1H Iroquois helicopter, the recovery crew stripped the payload of all separable packages, such as batteries, balloon control, backup balloon control, FAA transponder, etc. After this, it was concluded that the payload was still too heavy for the Iroquois helicopter, which was used instead for carrying out all the stripped equipment in a cargo net, as shown in Fig. 24. Recovery was rescheduled for the following morning.

The next morning on 1 September 1987, two helicopters, another Iroquois and a VH-60 Black Hawk, met the recovery crew at the RAD site. The Iroquois airlifted the crew into the landing spot from where they hiked in and secured the payload for lifting. Then the Black Hawk helicopter, which has a lift capacity of up to 8000 lb[5], lifted the payload (Fig. 25) to the nearest road where it was loaded onto a truck (Fig. 26) for shipment back to Bldg. 850 at Holloman, AFB.

Figure 22. View of impact site.

Figure 23. Payload at impact site.

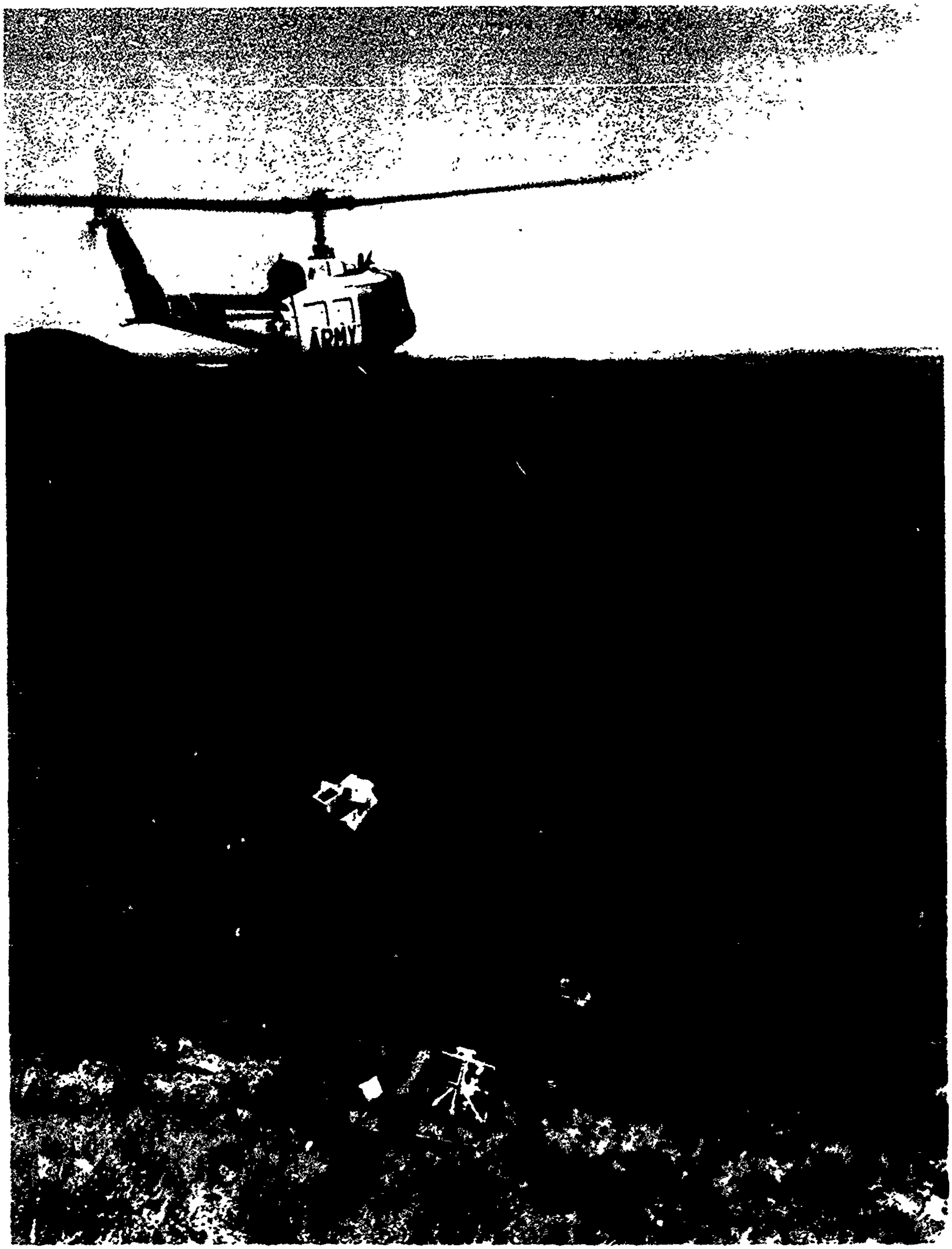


Figure 24. Iroquois helicopter carrying out payload packages.

Figure 25. Recovery of the ABLE II payload by Black Hawk helicopter.

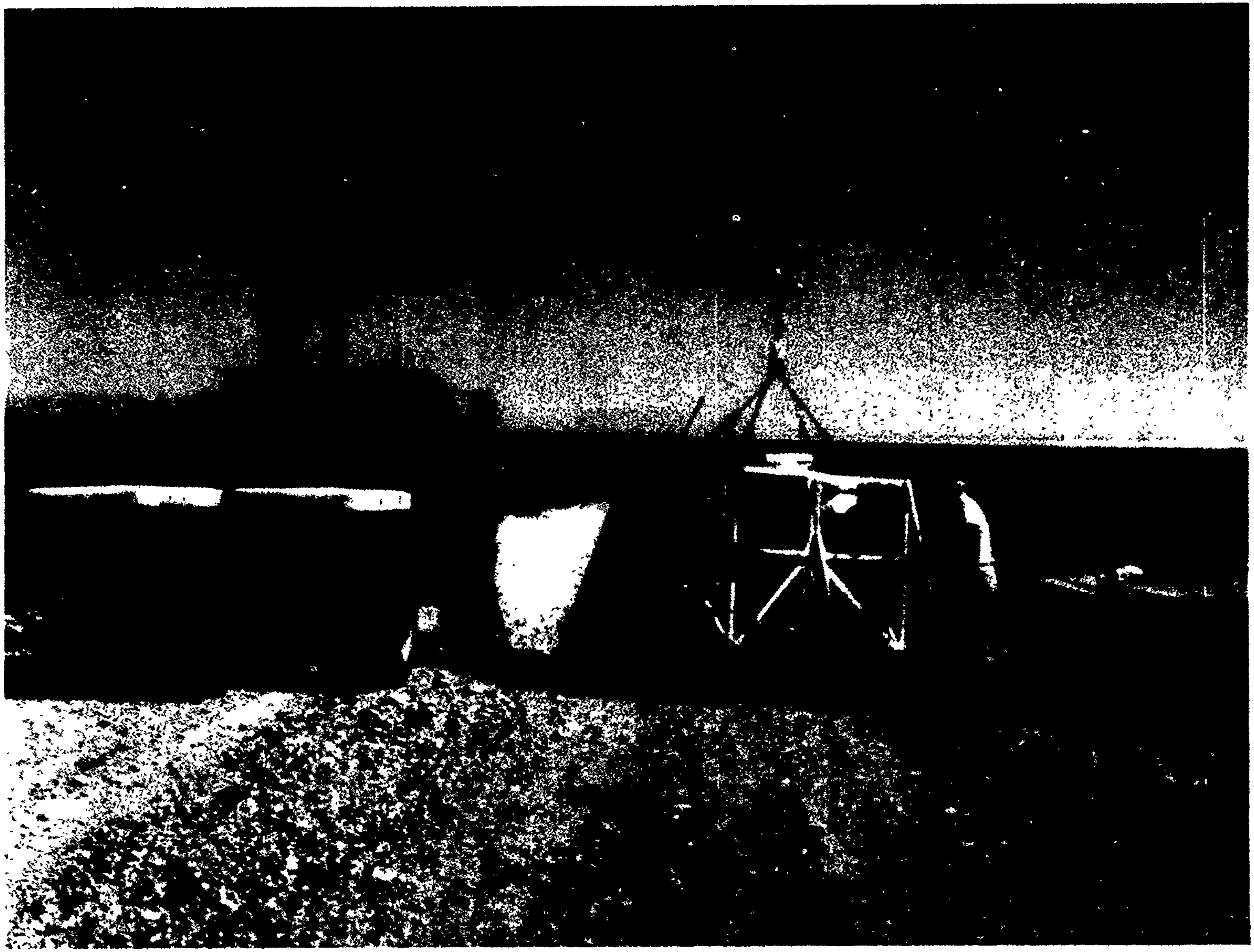


Figure 26. ABLE II payload being loaded onto truck.

7. POST FLIGHT ENGINEERING EVALUATION

7.1 External Examination

After the payload had been recovered from WSMR and returned to Bldg. 850, an external examination of the payload structure was performed. The only evident damage was minor deformation to the bolted-on outrigger structure frame. The forward left side was broken and the aft left side was bent. These damages were designed not to effect the major welded frame, and indeed the major frame was not affected. There was no visible deterioration of the laser pointing mirror or the chamber windows. A small amount of the glass ballast and vegetation from the juniper tree were inside the telescope mount, but the mirrors were essentially unaffected.

7.2 Internal Examination

On 10 September 1987 the ABLE II payload and field support equipment were returned from Holloman AFB, NM, to the AFGL/LC high bay at Holloman AFB. The payload was then set up for post flight inspection and full power test. The payload was then returned to Visidyne, Inc., for subsystem testing. The results of these tests are discussed below.

1. Upon opening the hermetically sealed laser chamber, a strong order of trichloroethylene was immediately apparent. An internal inspection of the laser chamber and power supply chamber did not indicate the source of the leak. The trichloroethylene cooling loop was then over-pressurized by 20 psi and a local inspection done. No leaks were observed.

   The trichloroethylene odor in the chambers was apparent only after they had been sealed for several hours. In an attempt to identify the source of the leak, individual cooling system components were removed from the chamber one at a time and the chamber sealed after the removal of each component. The following two sources of the coolant leaks were identified in this way:

   a. A cracked tubing fitting on the liquid-air heat exchanger. The cause of the crack is attributed to a manufacturing flaw in the fitting.

b. The liquid-to-liquid heat exchanger has four fill and drain plugs. When the exchanger was leak tested by pressurizing it under water, it was found that all of the plugs leaked. These leaks were caused by trichloroethylene attacking the thread sealant used on the plugs.

2. When the laser chamber was initially opened for inspection at AFGL, it was observed that many of the laser optics exhibited blemishes in the regions where the laser beam was incident. At the time of inspection this was thought to have been laser damage to the optics. When the laser was removed form the chamber approximately two weeks later, none of the previously observed optical blemishes were evident. It has been concluded the blemishes were the result of water condensation on the optics. Had it been trichloroethylene it would have evaporated immediately when the chamber was opened at AFGL. The laser chamber was sealed prior to flight at Roswell, NM, during a period when the humidity was very high. After the laser and power supply chambers were closed, they were purged with dry nitrogen for approximately one hour. It is concluded that the chamber preflight purging was not adequate, and that more rigorous purging procedures should be followed for future flights.

3. After the completion of the laser inspection at AFGL, the ABLE II payload was powered up using the external power supplies. The lidar experiment was found to be fully operational. Further inspection of the laser revealed large areas burned on the LEM divergence lens and the LEM beamsplitter. The regions of damage are shown in Fig. 27. When the LEM beamsplitter was cleaned, the cloudiness on the side towards the divergence lens disappeared. The deposit on the optical surface of the beamsplitter was also only on the side towards the divergence lens. Cleaning of the divergence lens revealed that optical damaged occurred only near where a black rubber lens spacer had been burned by the laser beam. Black smoke from the spacer had deposited on the lens. The first test performed on the laser was to check the laser alignment. The He-Ne laser was turned on and the location of the He-Ne beam marked. The Nd:YAG laser was then fired, and it was found that their axes were coincident. The positions of the He-Ne beam on the LEM optics, laser optics, and exit window were noted. It was concluded that the beam position was the same as observed during preflight testing.

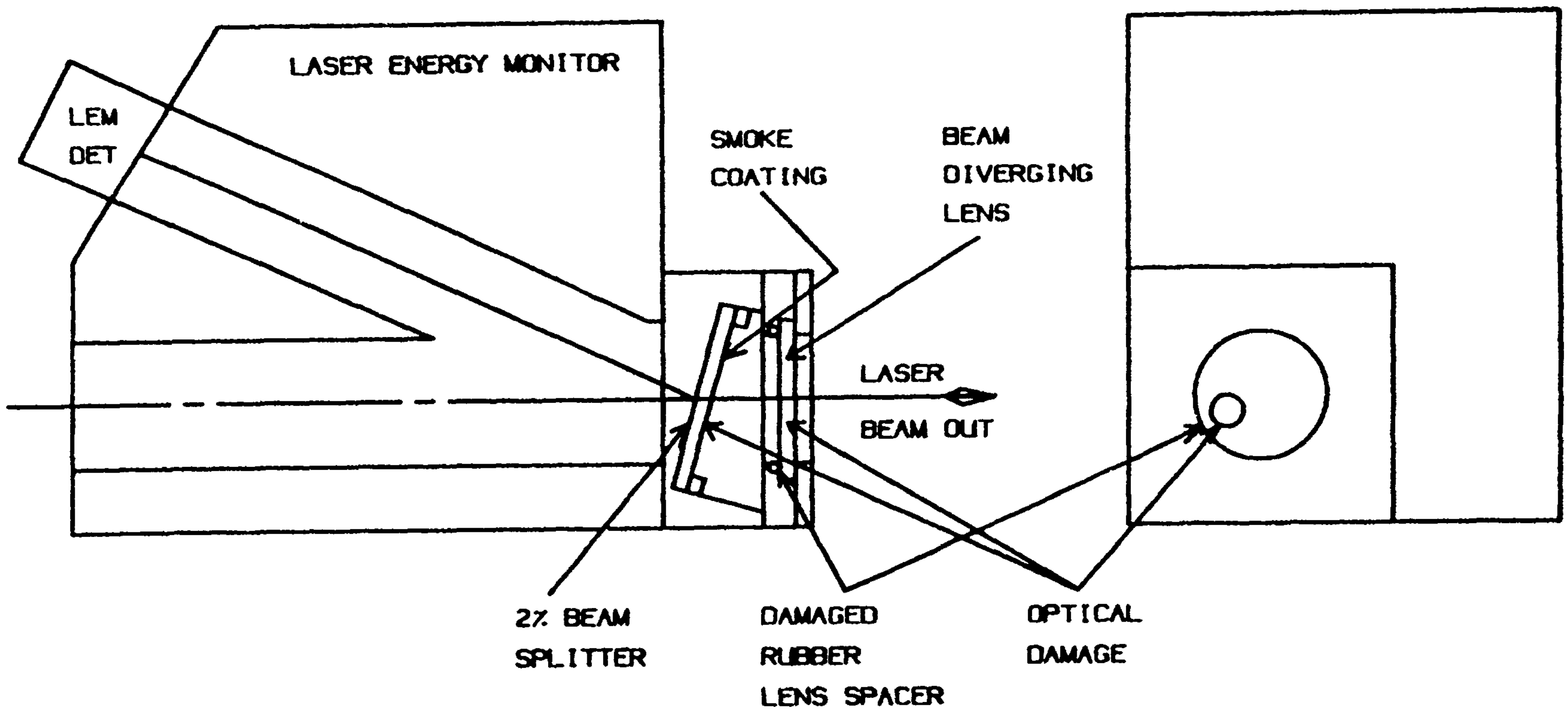


Figure 27. ABLE II optical damage.

The laser energy calorimeters were calibrated and set up to measure the output beam energy at the three wavelengths. The laser was test fired, and the flashing of the three pump lamps was confirmed. The temperatures of the SHG and THG modules were measured, and the crystal ovens were found to be at the proper temperatures. The laser was initially fired with the LEM and the chamber window removed. Initial turn on resulted in low output power. Angle tuning of the SHG resulted in a significant energy increase. The post-flight laser testing is summarized in Table 8. The LEM was tested and found to be operational. Burn testing of the rubber divergence lens spacer was performed, and when placed in the Nd:YAG laser beam, it was observed that it emitted dark smoke.

Table 8

ABLE II Post Flight Laser Test Summary

Wavelength (nm)	Preflight Energy (mJ)	Post Flight Energy (mJ)
1064	191	201
532	77	81
355	20	15

4. During laser testing it was found that a tuning micrometer operated very slowly in the CW direction, but operated properly in the CCW direction. By using the laboratory tuning driver, the micrometer operated equally well in both directions.
5. It has been concluded that during the flight that the laser beam was displaced on the divergence lens so that a part of the beam was incident on the rubber spacer in the lens mount. The resulting vaporized rubber was deposited on the inner surface of the lens and the LEM beamsplitter. Some of the deposited smoke was burned off by the incident laser beam, and this resulted in removal of the A-R coating on the optics. This scattering off of the deposited smoke and the absence of A-R coating resulted in increased detection of 532 nm signal by the LEM detectors. The LEM beamsplitter was cleaned and installed for testing. The divergence lens was not reinstalled. Based upon the results of this post-flight testing, we have concluded the following:

a. The lasers alignment had not changed significantly from the preflight alignment.

b. The Nd:YAG laser energy outputs measured postflight were comparable to those measured preflight.

c. No laser energy degradation or optical damage occurred during the approximately two hours of laser test and calibration on 24 August 1987 at Roswell, NM.

d. Due to laser damage, although some optical degradation occurred during the Thermovac test, it did not result in the sudden reduction of laser output energies observed during the ABLE II flight.

e. The major differences between the Thermovac test and the flight were the following:

   1) The THG was not installed for the Thermovac test.

   2) The laser chamber heaters were not operational for the Thermovac test.

   3) There was an increased presence of moisture and trichloroethylene vapor in the laser chamber during the flight.

f. The nadir-viewing flight data indicate that the lidar, and thus the laser, maintained alignment throughout the flight. Post flight testing showed that no permanent misalignment had occurred.

We have concluded from the above that during the flight, the Nd:YAG laser beam had either become more diverged, displaced, or angularly deflected so as to vaporize the LEM divergence lens spacer and subsequently damage the LEM optics. The cause of this beam motion has not been established. It is recommended that the Nd:YAG laser and the LEM be refurbished and that the payload be subjected to a Thermovac test where the Nd:YAG laser beam angle, divergence, and position be monitored throughout the test.

6. During the August 1987 flight of ABLE II, a problem occurred with the experiment housekeeping data. The ground station computer readouts suddenly all become erroneous. A postflight inspection of the CAMAC chamber revealed a loose ground connection for the Receiver Electronics Voltage Monitor circuit (See Fig. 28). This loose connection, caused by a loose screw on a terminal block, resulted in an open circuit in the voltage monitor ground. This caused a 28 Vdc common mode voltage

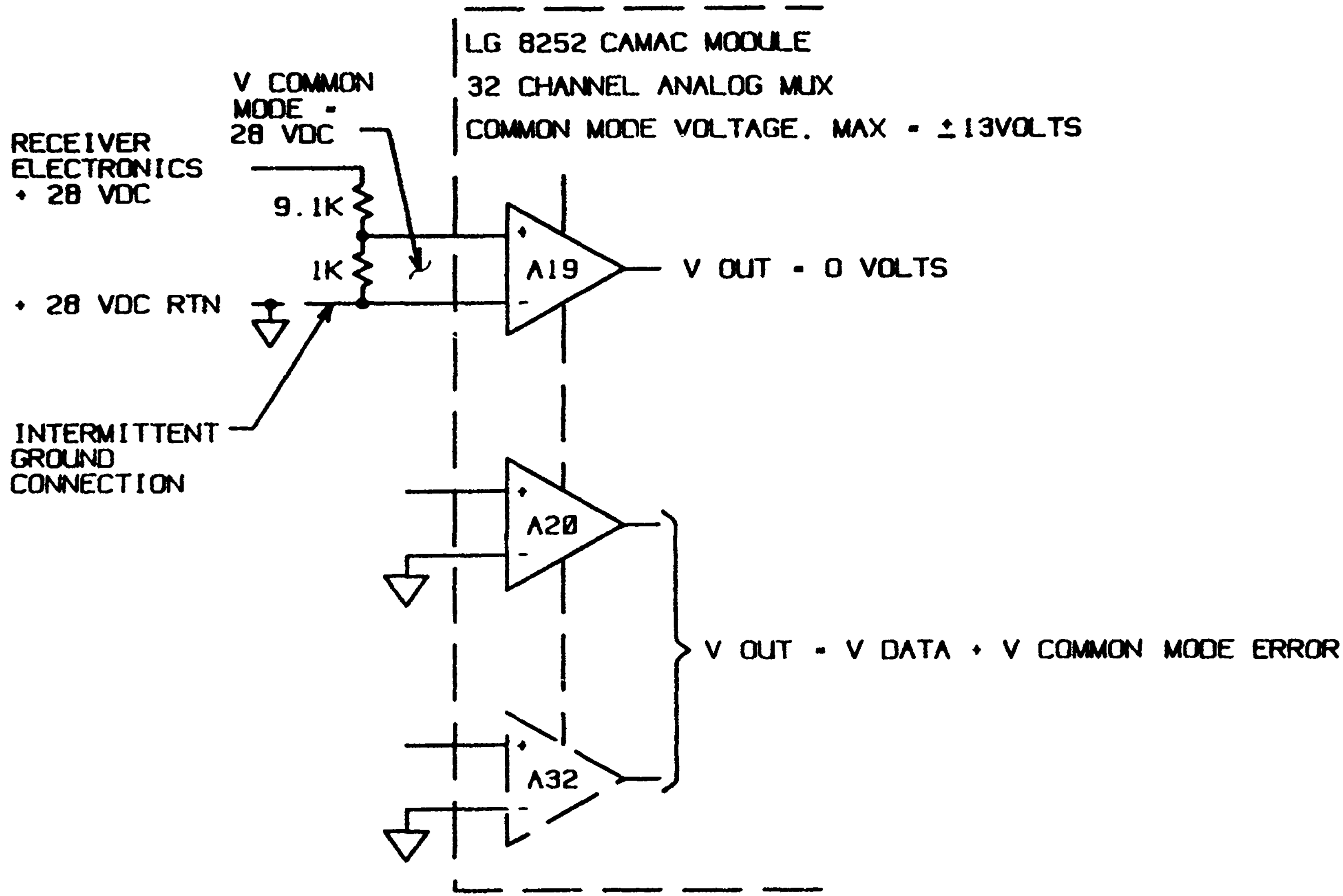


Figure 28. Housekeeping data common mode errors.

to be applied to the input differential amplifier of the housekeeping multiplexer. Since this common mode voltage exceeded the rated $\pm$ 13 volt common mode voltage for the multiplexer input, an offset error voltage was added to the output voltage of each of the 32 multiplexed voltages. A laboratory test was performed where the housekeeping data were read out with the monitor ground connected and then when they were open circuited. The test data exhibited the same general behavior as the flight data. It is thus concluded that the flight data failure was caused by the faulty ground in the Receiver Electronics Voltage Monitor circuit.

A partial list of the data offsets, in counts, is shown in Table 9. The offset error appears to be dependent upon the source impedance of each individual housekeeping channel; thus each channel correction factor is different.

The ABLE II post mission critique of AFGL/LC is in Appendix D.

Table 9

ABLE II Housekeeping Data Correction

ADC Chan	PCM Word	Function	Error Count
1	5	LEM RED	32
2	6	LEM GRN	50
3	7	LEM UV	36
4	8	OPEN	--
5	9	NADIR-X	79
6	10	NADIR-Y	58
7	11	OPEN	--
8	12	UV DET TMON	
9	13	UV DET PMON	
10	14	UV DET HV MON	
11	15	GRN DET TMON	
12	16	GRN DET PMON	
13	17	GRN DET HV MON	
14	18	LASER POWER SUPPLY PMON	31
15	19	LASER POWER SUPPLY TMON	34
16	20	LASER TMON	35
17	21	LASER VMON	68
18	22	HK VMON	69
19	23	RCVR VMON	
20	24	THERMAL CONTROL VMON	79
21	25	UV FIL TMON	
22	26	GRN FIL TMON	
23	27	PRI COOLANT RES TMON	
24	28	RAD 1 TMON	

25	29	RAD 2 TMON	
26	30	RCVR PWR 1 TMON	
27	31	RCVR PWR 2 TMON	
28	32	RCVR ELEC PMON	
29	33	RCVR ELEC TMON	
30	34		--
31	35		--
32	35		--
		CORRECTED COUNTS = COUNTS - ERROR COUNTS	

8. CONCLUSIONS AND RECOMMENDATIONS

Based upon this preliminary investigation it is concluded that:

1. The lidar experiment payload launch, flight, and recovery operations were successfully performed.
2. Payload telemetry uplink command functions and ground based telemetry support all operated per the flight plan.
3. Although lidar backscatter data were acquired, the experiment operation was degraded by an observed reduction in laser pulse energy. In addition, the monitoring of lidar experiment status was impaired due to an intermittent monitor ground connection.

It is recommended that first, the Nd:YAG laser be refurbished and the output laser beam be closely aligned with the laser and the LEM optical axis, and second, the ABLE payload be subjected to a Thermovac test where a simulated flight altitude-temperature profile is provided. During this test the output laser beam would be monitored with a video camera. The laser beam parameters which would be monitored during this simulated flight are

1. beam diameter,
2. Beam divergence, and
3. Beam displacement

Upon successful completion of these tasks, it is recommended that the ABLE payload be flown to obtain additional backscatter data.

9. REFERENCES

1. W.F. Brehm and J.L. Buckley, "Design Study of a Laser Radar System for Spaceflight Applications", G.E. Space Division, AFGL-TR-79-0264 (Dec. 1979). ADA082332.
2. O. Shepherd, G. Aurilio, R.D. Bucknam, R.W. Brooke, A.G. Hurd, and T.F. Zehnpfennig, "Balloonborne Lidar Experiment", Visidyne, Inc., AFGL-TR-80-0373 (Dec. 1980). ADA095366.
3. O. Shepherd, G. Aurilio, R.D. Bucknam, A.G. Hurd, and W.H. Sheehan, "Project ABLE: Atmospheric Balloonborne Lidar Experiment", Visidyne, Inc. AFGL-TR-85-0064 (March 1985). ADA160372
4. "ABLE II Interface Control Document/Revision F", VI-1056, Visidyne, Inc. (April 1987).
5. D. Wood, "Jane's World Aircraft Recognition Handbook", Biddles Limited, Guidford, Surrey, (1982).

APPENDIX A

Nd:YAG Laser Test Report

TEST REPORT

Operational and performance parameters of this laser system were carefully tested prior to shipment in accordance with standard ILS procedures. This report summarizes some of the data recorded and/or verified during the operation and testing of the system at the time of shipment. Final performance parameters were witnessed by the ILS Quality Assurance Department.

Customer HANSCOM AFB Order No. Sales Order 2335

ILS Model No. LL-104-100 ILS Job No. 70294

Date Complete JUNE 27, 1982 Location

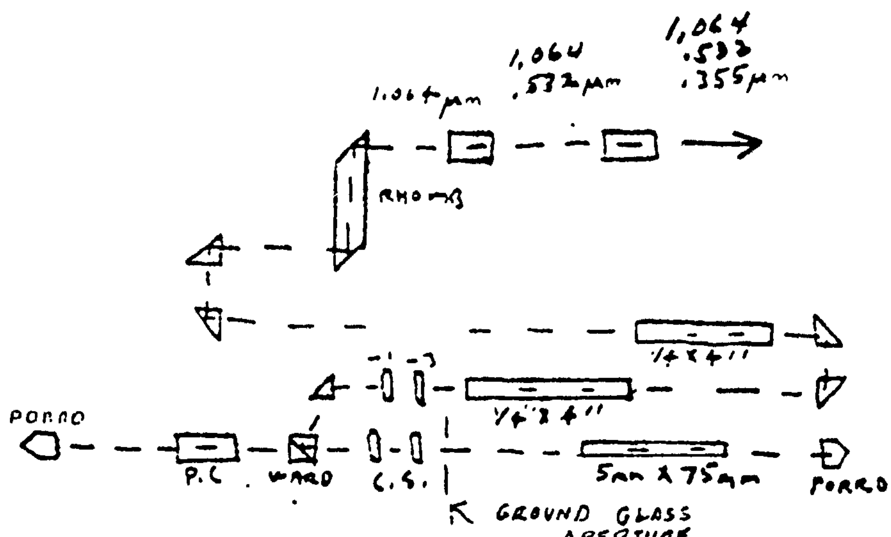
System Configuration TRANSMITTER, MASTER P.S., SLAVE P.S., COOLING SYSTEM, TWO LINE CONVERTERS - 28 VOLT SYSTEM

Options: SIMMER PS. Accessories: 2 LINE CONVERTERS

Serial Nos: TX 20513 P.S. 20524 P.S. SLAVE 20525 C.S.

L.C. 20514 LC. 20515 RX R.C.

OPTICAL SCHEMATIC



Lamp Type: OSC L-1244 1st AMP L-96 2nd AMP L-176

Rod Type: OSC 5 x 75mm 1st AMP 1/4" x 4" 2nd AMP 1/4" x 4"

Scope #1 0.4

Scope #2 - -3

Scope #3

Pockels Cell LITHIUM NIOBATE

Doubler CDA

TRIPLER KDP

SYSTEM PERFORMANCE

Rep Rate; 10 PPS

Output Energy (mJ)	OSC	1st AMP	2nd AMP	.532µ	UV
Multimode @ 1.06µ					
Low Order @ 1.06µ	92	263	580*	275	32
Pump (volts)	700	745	815		
PFN Capacitor (µfds)	42.5	41.7	41.6		
Pump (J)	10.4	11.6	13.9		

Pulsewidth; @ 1.06µ 17.5NS @ .532µ 11.5 UV 11.5NS

Beam Divergence; Raw ______ Collimated ______ Variable ______ to ______

Pulse Amplitude Stability; @ 1.06µ ± 3 @ .532µ ± 4 UV ± 4%

Pulse to Pulse Jitter; —

Pockels Cell Delay; 138.6 µsec

Cooling System; 50 / 50 (glycol/water)

Notes: * SHIPPED RED + GREEN = 407 mJ
ADDED GROUND GLASS APERTURE .145" DIA
TO OSC.

TEST PARAMETERS

Line Voltage; ± 28VDC

Radiometer; Model EG+G 581 Serial No. 237/3128 Cal Date 4/10/8-

Oscilloscope; Model Tek 465 Serial No. B263893 Cal Date 1/15/8-

Freq. Counter; Model ____ Serial No. ____ Cal Date ____

Location; Lab No. 2131

Est. Operating Time; Transmitter 250,000 1st + 2nd AMP 350,000 OSC System ____

Dates of Tests; JUNE 26, 1987

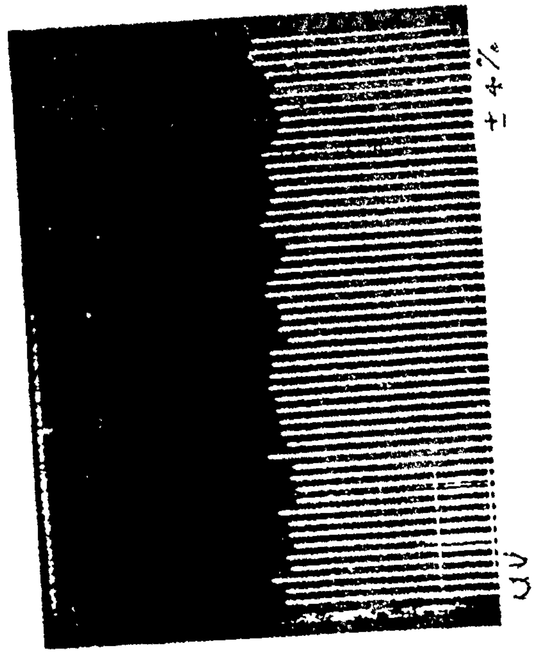
Technician(s) LEN GRENEVICH

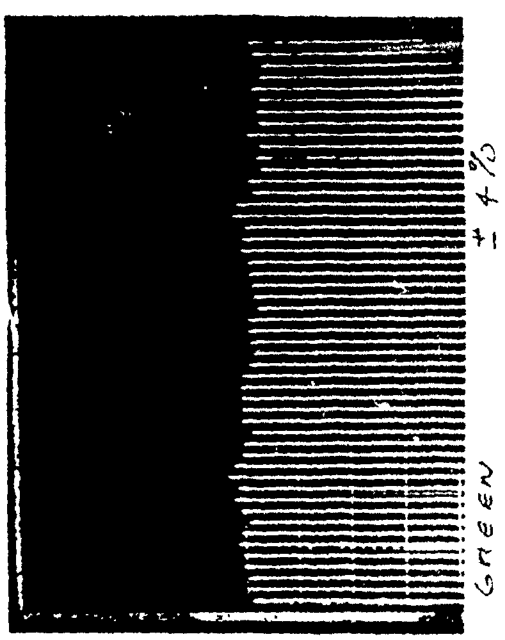
Approvals For Shipment:

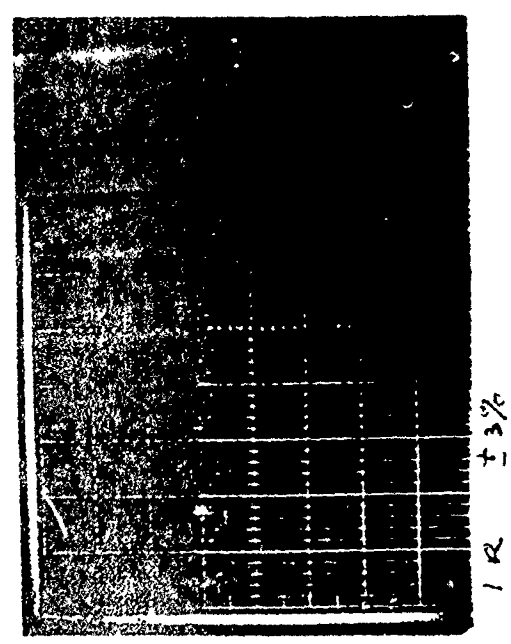
Quality Assurance; Charles R Brown Date 6-26-87

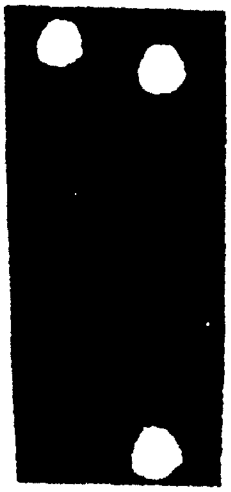
Program Manager; Samuel P. Fairchild III Date 26 June 87

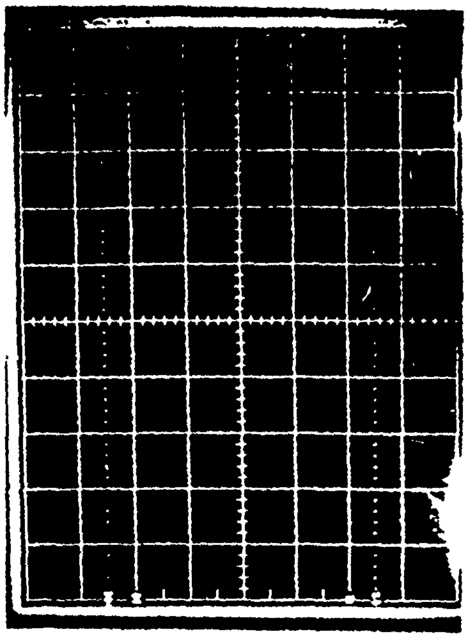
Customer (as applicable) ____ Date ____

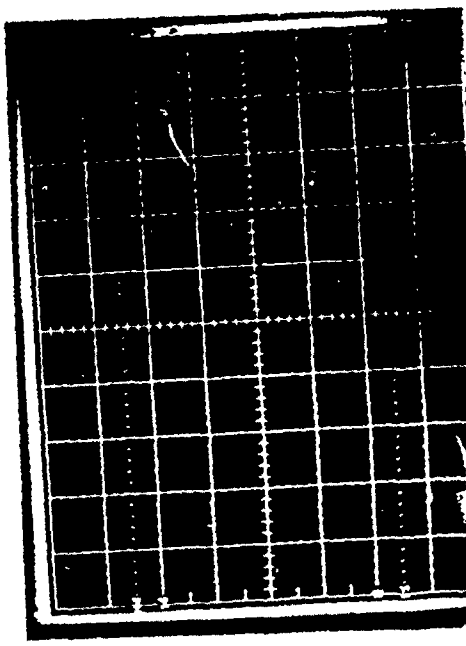

± 4%
UV

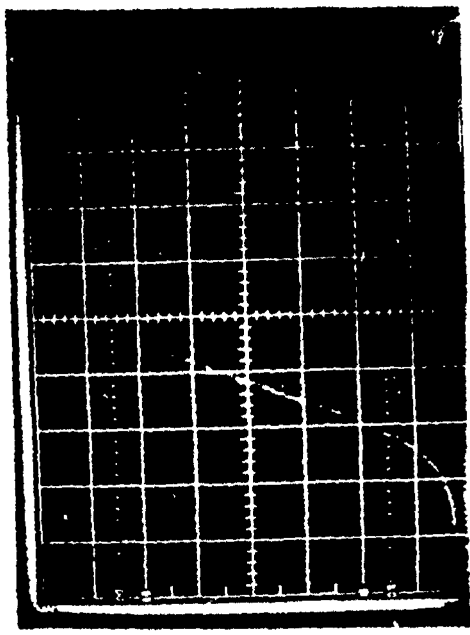

± 4%
GREEN


± 3%
IR


IR


4V 5NS/cm 11.5NS


GREEN 5NS /cm 11.5NS


I.R. 5NS/cm 17.5NS

APPENDIX B

ABLE Telescope Test Data Report

OPTICAL SYSTEMS AND TECHNOLOGY, INC.
152 RANGEWAY ROAD, NORTH BILLERICA, MA., 01862
(617) 667-4350

TEST DATA REPORT

after refurbishment of

"ABLE" Balloonborne LIDAR Telescope

for

Visidyne, Inc.

under

P.O. No: 15353 - OS

OSTI: 87/3049

May 15, 1987

Optical Systems and Technology, Inc.

No. Billerica, Ma., 01824

OPTICAL SYSTEMS AND TECHNOLOGY, INC.

152 RANGEWAY ROAD, NORTH BILLERICA, MA., 01862

(617) 667-4350

Date: 15 MAY 1987

O.S.T.I. Project 87/3049

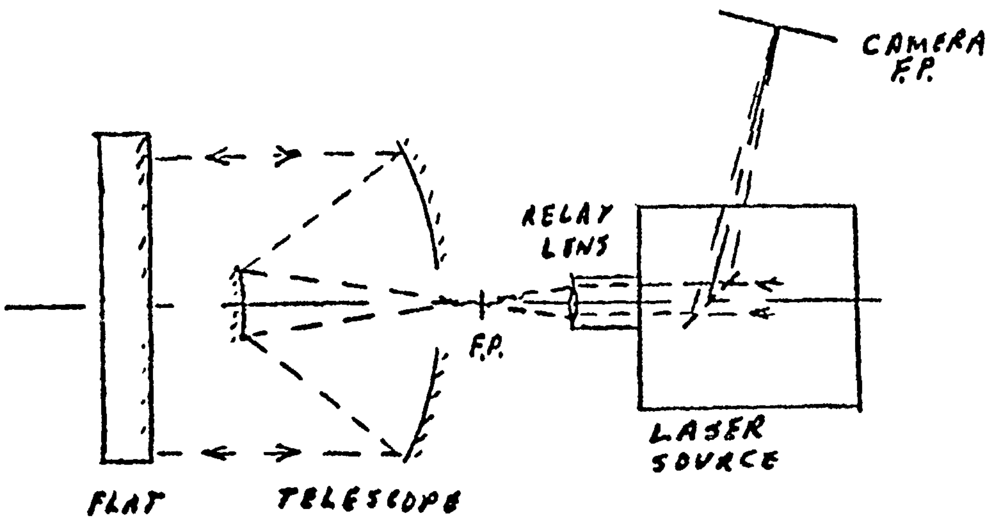
VISIDYNE Dall-kirkham TELESCOPE

Determination of Blur Circle Diameter (BCD)

Specification: 85% energy in .031 diam. BCD

TEST METHOD: Autocollimation = double pass test, therefore, surface slopes and wavefront errors are doubled.

TEST SETUP:



ALLOWABLE BCD =.031 X 2 =.062 < 85% > at telescope focal plane.

LUPI microscope objective Relay Lens = 40 mm. EFL

WORKING DISTANCE = EFL (M+1) or, M = (W.D./EFL)-1

M= effective Magnification

W.D. measured from relay lens to camera F.P. = 901.7 mm.

$$M = \frac{901.7}{40} - 1 = 21.5\text{X}$$

CLEAR APERTURE yields image diameter of 1.375" at film plane.

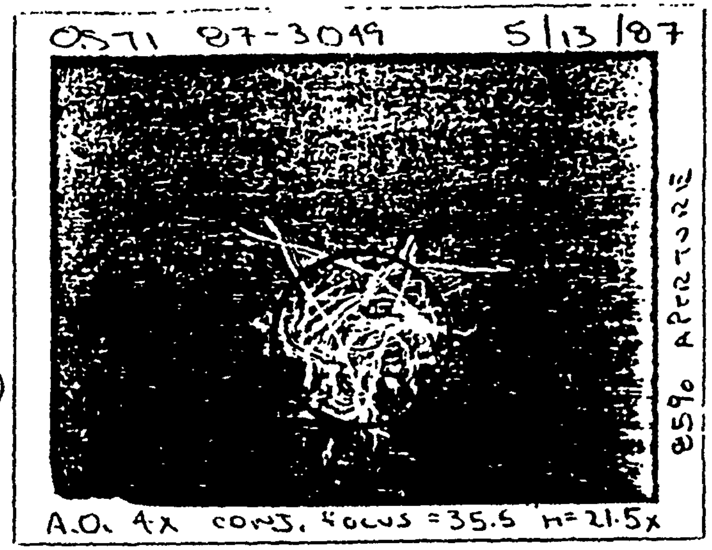
85% of C.A. yields image diameter of 1.125" See Photos.

$$1.375/21.5 = 0.064\text{" BCD}$$

$$1.125/21.5 = 0.052\text{" BCD}$$

RESULT : SINGLE PASS BCD = 0.026" for 85% energy.

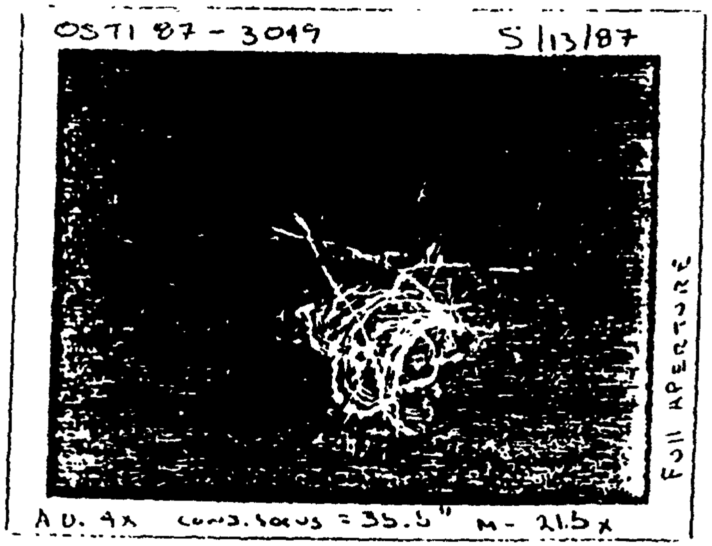
OPTICAL SYSTEMS & TECHNOLOGY, INC.
152 RANGEWAY ROAD
NORTH BILLERICA, MA 01862
(617) 667-4350



$1\frac{1}{8}$ DIA. CIRCLE =

$\frac{1.125}{21.5} = .052''$

$\div 2 = .026''$
BLUR SINGLE PASS



$1\frac{3}{8}$ DIA CIRCLE $= \frac{1.375}{21.5} = .064''$

$\div 2 = .032''$ BLUR
SINGLE - PASS

APPENDIX C

ABLE II - Operational Procedures

ABLE II LAUNCH OPERATION PLAN

Time From Launch/To Target Hrs/Min	Time (MDT)	Event
L-36:00	24/1000	Preflight/weather briefing
L-24:00	24/1700	Begin windfinder data
L-22:00	25/0000	Radiosonde release from Holloman
L-07:00	25/1500	Radiosonde release from Holloman/Weather briefing at Roswell
L-05:30	1630	Roswell Crew report/Weather briefing/Go-no go decision/Doc Photo reports/Begin windfinder data
L-03:45	1815	Deploy to launch pad
L-03:30	1845	Arrive launch pad/Set launch arm/Begin checkout
L-03:00	1900	Tethersonde up 100ft/Pibals up/PSL crew on station N200
L-02:26	1934	Surface sunset/Army Aircraft arrives Roswell
L-02:15	1945	Holloman crew on station
L-02:00	2000	Checkout complete/Report status from N200 site Holloman Control/TM/Experimenter Range Roswell TM, Contractor, Meterology, Launch Go No-go decision Initiate balloon layout/Power off/Arm/System
L-01:50	2010	Balloon sunset at 110 kft
L-01:30	2030	Arm complete/Power on/Valve check
L-01:00	2100	Status reports from all stations/Go No-go decision/Begin inflation
L-00:15	2145	Inflation complete/Launch clearance request Check experimenter readiness at Holloman
L-00:10	2150	Launch clearance approved/Assess area
L-00:05	2155	Safeties off/Pibal away
L-00:00	2200	Launch

L+00:40	2240	Balloon at 40 kft/Holloman acquires lock/Army Aircraft departs/N200 site acquires lock
L+00:50	2250	Balloon at 50 kft/Control passes to Holloman
L+01:00	2300	Balloon at 60 kft/Begin up laser fire
L+02:00	26/0000	Balloon at float (109 kft)/Drop first dropsonde. Range radar coverage begins
L+03:00 (T-01:00)	0100	Balloon at eastern Range boundary/Begin downward laser fire/Drop second dropsonde/Release radio-sonde at Holloman/Chase aircraft airborne/ Termination NOTAM issued
L+03:45 (T-00:15)	0145	Balloon over western Range boundary/Cease laser fire/Stow for termination./Open gas valve
L+04:00 (T-00:00)	0200	Descent rate 300 fpm/Balloon 105 kft/Termination
L+04:15 (T+00:15)	0215	FAA transponder altitude on (45 kft)
L+04:45 (T+00:45)	0245	Impact/Radar coverage ends/Secure N200 site
L+07:51 (T+02:21)	0551	Balloon sunrise (110 kft)
L+08:27	0627	Surface sunrise
L+09:00	0700	Recovery deploys from Holloman
L+13:00	1100	Helicopter deploys from Holloman
L+14:00	1200	Helicopter and recovery crews on site
L+15:00	1300	Payload secured
L+16:00	1400	Mission complete

PRE-ROLL OUT CHECK

1. Five (5) Battery Boxes Connected Plus Switch Connector on Thermal Control Battery Box.

2. All Battery Box Fuses Bussed (Fuses for TVAC and L-3 Tests).

3. Diode Plate Fuses Bussed (Fuses for TVAC and L-3 Tests).

4. Pointing Mirror Motor Drive Connector, Connected, Installed

5. All (4) Temperature Sensor Connected.

6. All Cooling Fluid Lines Connected.

7. Crush Pads Installed (Off for the TVAC Test).

8. Turn on Accelerometer, Thermal Control Switch - Up Position.

9. Housekeeping Switch - Up Position.

10. GSE Connector (P201) Out, (P49) Out and Remove T/M Cable Plugged into P201. Check P201 and P200 are Connected to T/M Box.

11. Ind. Switch to On Position.

12. Visual Inspection of Payload

13. Clean Payload.

14. Bag Payload.

All Purge Valves OFF and Capped, Arm Key and Fire Key, Switch On.

PRE-FLIGHT CHECK LIST

1. Telescope Cover - Off (Cn for TVAC ANDL-3 Tests)
2. Pointing Mirror Cover - Off (On for TVAC and L-3 Tests)
3. Laser Up and Down Baffle Covers - Off (On for TVAC and L-3 Tests)

   Remove Horizontal Laser Dump

   Visual Inspection of Laser Pointing Mirror

   Install Horizontal Laser Dump
4. Power Distribution

   Housekeeping Power Switch On (Bat Up)
5. Thermal Control Power Switch On (Bat Up)
6. Laser Heat Power Switch On

   Status IND Switch - OFF
7. Arm Key - Installed - Arm Switch in Arm Position
8. Fire Key - Installed - Fire Switch in Fire Position

ABLE II EXPERIMENT INSTRUMENTATION CHECKLIST

Commands	Function	Verify
239	RCVR POWER-ON	VALID PCM LOCK
248	THERMAL CONTROL POWER-ON	THERMAL CNTRL VMON
244	SEC COOL PUMP 1-ON	PCM(38,30) BITS 1&5 HI
250	SEC COOL PUMP 2-ON	PCM(36.30) BITS 4&5 HI
232	LASER POWER-ON	LASER VMON
241	COMPUTER BOOT	5 SEC PCM LOSS
	VERIFYING POINTING MIRROR STOW	PCM(56,30)=1936
247	INTERLOCK OVERRIDE-ENABLE	PCM(41,30) BIT 4 HI
247	INTERLOCK OVERRIDE DISABLE	PCM(41,30) BIT 4 LO
MODEM		
ACREQPU	POINTING MIRROR-UP	
ACREPD	POINTING MIRROR-DOWN	PCM(56,30)=1536
ACREPH	POINTING MIRROR-HORIZONTAL	PCM(56,30)=1024
ACREQD1	UV AND GRN DETECTORS-ON	UV DET TMON GRN DET TMON UV DET PMON GRN DET PMON UV DET HVMON GRN DET HVMON
ACREQDA	UV AND GRN DETECTORS TEST	PCM(41,30) BIT 9 HI PCM(40,30) BIT 1 HI
VERIFY THAT UV AND GRN DETECTORS ARE OPERATIONAL		
ACREQDO	UV AND GRN DETECTORS-OFF	UV DET TMON GRN DET TMON UV DET PMON GRN DET PMON UV DET HVMON GRN DET HVMON

ACREQD1	UV AND GRN DET-ON	UV DET TMON GRN DET TMON UV DET PMON GRN DET PMON UV DET HVMON GRN DET HVMON
234	LASER ARM	PCM(36,30) BITS 1&2 HI
236 HOLD	LASER FIRE	RED LEM GRN LEM UV LEM LASER STATUS
235	LASER SAFE	PCM(41,30) BIT 1 LO BIT 2 HI

VERIFY LEM DATA
VERIFY LASER STATUS DATA
VERIFY TEMPERATURE DATA
VERIFY PRESSURE DATA
VERIFY VOLTAGE MONITOR DATA
VERIFY VIDEO DATA

ACREQDO	UV AND GRN DETECTOR-OFF	UV DET TMON GRN DET TMON UV DET PMON GRN DET PMON UV DET HVMON GRN DET HVMON
ACREQPS	POINTING MIRROR-STOW	PCM(56,30)=1936
245	SEC COOL PUMP 1-OFF	PCM(38,30)BITS 1&5 LO
251	SEC COOL PUMP 2-OFF	PCM(36,30)BITS 4&5 LO

PAYLOAD IS READY FOR LAUNCH 23N

233	LASER POWER-OFF	LASER VMON
249	THERMAL CONTROL POWER-OFF	THERMAL CONTROL VMON
240	RECEIVER POWER-OFF	PCM LOS

END OF TEST

ABLE II EMERGENCY SHUT DOWN PROCEDURE

COMMAND	FUNCTION
133/233	LASER POWER OFF
149/249	THERMAL CONTROL POWER OFF
140/240	RECEIVER POWER OFF

ABLE II FLIGHT OPERATIONS

PAYLOAD PRELAUNCH STATUS

239 - RECEIVER POWER ON
248 - THERMAL CONTROL POWER ON
(SEC COOL PUMPS OFF)
232 - LASER POWER ON
(LASER SAFE)

POST LAUNCH OPERATIONS

T+10 MIN

ACREQPD - POINTING MIRROR DOWN
ACREQD1 - UV AND GREEN DETECTORS ON

115/215 - VIDEO XMTR ON
124/224 - VIDEO CAMERA ON

CHECK TEMPERATURE AND PRESSURE MONITORS

AT APPROX T+25 MIN(ALT=20 KFT)'AT ALT' WILL BE ENABLED AND 'OK TO FIRE' WILL BE ENABLED

WHEN ALT=60KFT
ACREQPU - POINTING MIRROR UP
PER APPROVAL OF D. BEDO
234 - LASER ARM
236 HOLD - LASER ARM

WHEN PAYLOAD IS OVER WSMR AND PER D. BEDO APPROVAL
235 - LASER SAFE
ACREQPD - POINTING MIRROR DOWN
234 - LASER ARM
236 - LASER FIRE

CRITICAL TEMPERATURES TO BE MONITORED AND CONTROLLED
PRIMARY COOLANT
IF T=OR>40 DEG C THEN TURN ON SEC COOL 2 PUMP
IF T=OR<20 DEG C THEN TURN OFF SEC COOL 2 PUMP
IF T=OR<-20 DEG C THEN TURN ARM AND FIRE LASER INTO HORIZONTAL DUMP

LASER TEMPERATURE
IF T=OR>35 DEG C THEN CONSIDER NOT FIRING LASER
IF T=OR<0 DEG C THEN ARM AND FIRE LASER INTO HORIZONTAL DUMP

LASER POWER SUPPLY TEMPERATURE
IF T=OR<15 DEG C THEN TURN OFF SEC COOL 1 PUMP
IF T=OR>35 DEG C THEN TURN ON SEC COOL 1 PUMP

PAYLOAD CONDITION AT HANDOVER

ALT=50 KFT(APPROX)
POINTING MIRROR DOWN
LASER SAFE UNLESS DUMP FIRING HAS BEEN REQUIRED
CHECK PRIMARY COOL TEMP, LASER TEMP, AND LASER P.S. TEMP AND SET
PUMPS ACCORDINGLY

PAYLOAD TERMINATION PROCEDURE

125/225 VIDEO CAMERA OFF
116/216 VIDEO XMTR OFF

ACREQPS - POINTING MIRROR-STOW

233 LASER POWER OFF
245 SEC COOL 1 PUMP-OFF
251 SEC COOL 2 PUMP-OFF
249 THERMAL CONTROL POWER OFF
240 RECEIVER POWER OFF

APPENDIX D

ABLE II - Post Mission Critique

18 November 1987

POST MISSION CRITIQUE FOR H87-07

1. Flight H87-01 was a flight for the ABLE program. An 8.74 MCF balloon was used to carry the ABLE payload to 108,000 ft. The flight was launched form Roswell Air Industrial Center at 2021 MDT on Aug 30, 1987.

2. The requirements for this flight were to collect data for a one hour period over White Sands Missile Range at an altitude above 100,00 ft MSL. Data were to be taken between balloon susnset and balloon sunrise on a night when the moon was not above the horizon or in the last/first quarter phase. Thirty percent cloud cover was desired but not required.

3. Pre-launch activities were conducted between Aug 18 and Aug 21. The launch minus three day tests were held on Aug 22 with the first launch day set for the evening of Aug 25. Weather delayed launching until Aug 30. The weather problems encountered were evening thunderstorms and low level winds.

4. On Aug 30 the system was smoothly launched. At about ten minutes into the flight several unexplained aberrations occurred in the experimenter data. These data indicated serious problems with the experiment. However, since the recovery crew was on station at Holloman AFB, we decided to continue the flight so that payload impact would occur west of the Sacramento Mountains and on WSMR. At 2142 MDT, when the balloon was at 70,000 ft MSL, command and control were passed to the Holloman Control Center.

5. During flight two dropsondes were deployed to obtain and atmosphere profile directly under the balloon. The first sonde dropped at 2305 MDT on Aug 31. Laser down fire began at 0030 MDT, Aug 31. The balloon flight was terminated at 0100 MDT and impact at 0143 MDT.

6. During the flight, while reviewing checklists, it was discovered that the safety pins on the Tufts parachute release had not been removed. The recovery crew was dispatched to the payload early so that the system could be secured before the late morning surface winds could re-inflate the parachute and cause damage to the payload through dragging. The system was secured during the early monring hours without damage occurrring to the payload. The system was not recovered until the following afternoon because a heavy lift (black hawk) helicopter was needed to lift the payload from the impact site to the road.

7. The problems encountered during this flight were as follows:

a) The #1 dropsonde began transmitting without being commanded on. This malfunction was traced to a faulty relay which was affected by cold temperatures and RF signals.

b) The #2 dropsonde parachute did not deploy properly, causing a short data period.

c) The laser aberrations were traced to a misaligned beam, caused by inadequate, warm up, which vaporized a portion of a rubber gasket and smoked the lenses.

d) The safety pins were left in the Tufts parachute release. This was caused by a change in a checkout procedures. The squib continuity had been checked at the release device and at the same time the safety pins were removed. A new procedure where squib continuity was checked at the payload. In this change the removal of the safety pins was overlooked. This item is now flagged with a safety streamer and added to the pad check lists.

e) The low level jet wind which occurs at 300 - 1,000 ft above the surface continued to be a problem as well as the evening thunderstorms which occur at Roswell, NM during the summer months. One needs to plan for several cancellations if evening or early night launches are attempted from this location.

f) Scheduling for range support is a continuing problem because launches must be scheduled a minimum of forty eight hors in advance of the launch time. With the unpredicatability of thunderstorms and the low level jet this situation is frustrating and expensive. All projects considering launching under these conditions should rely on the range for as little support as possible.

g) No good data were obtained from the down looking television camera. The most probable cause was insufficient light as the moon was not above the horizon. However, the green laser was also not seen by this system.

8. In summary, this was a well planned flight effort. Execution was excellent which reflected pride and professionalism from all the persons involved.

John R. Ground

JOHN R. GROUND
AFGL ABLE Project Officer