
**Pacific Northwest
National Laboratory**

Operated by Battelle for the
U.S. Department of Energy

**Fieldable Fourier Transform
Spectrometer: System Construction,
Background Variability Measurements,
and Chemical Attack Warning
Experiments**

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C.R. Batishko
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T.L. Stewart
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October 2002



Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Summary

The infrared sensors task at the Pacific Northwest National Laboratory (PNNL) is focused on the science and technology of remote and in-situ chemical sensors for detecting proliferation and countering terrorism. Missions to be addressed by remote chemical sensor development include detecting proliferation of nuclear or chemical weapons, and providing warning of terrorist use of chemical weapons. Missions to be addressed by in-situ chemical sensor development include countering terrorism by screening luggage, personnel, and shipping containers for explosives, firearms, narcotics, chemical weapons, or chemical weapons residues, and mapping contaminated areas. The science and technology relevant to these primary missions is also likely to be useful for battlefield chemical weapons defense, air operations support, monitoring emissions from chemical weapons destruction facilities or industrial chemical plants, and law enforcement applications. PNNL seeks to serve organizations with direct interest in these missions through collaborative research and development efforts approved by NA-22.

During FY02, PNNL began development or commercial acquisition of the experimental remote and in-situ infrared chemical detection systems and support equipment needed to conduct field experiments. Fieldable systems under development include a commercial Fourier Transform Spectrometer (FTS) that operates in the 3 to 5 micron and 8 to 14 micron bands of the infrared spectrum, a frequency-modulation differential-absorption LIDAR (FM-DIAL) system, and a short-wave infrared cavity ring-down spectrometer (SWIR CRD). To provide environmental protection for the FTS and FM DIAL systems and facilitate field deployments and operations, a large, well insulated, temperature controlled trailer was specified and procured. The trailer is being outfitted with an optical bench, a turning mirror on a gimbal, an electrical power generator, and computers. The trailer may also be useful for field SWIR CRD experiments. While the FTIR system was field-ready as purchased, the FM-DIAL system required considerable development to permit field deployment. This document provides an overview of the FTS, summarizes modifications made to the FM-DIAL system, and describes the salient features of the remote systems trailer. At this writing, the trailer system is expected to be ready for field experiments within two to three weeks.

During FY03, FM DIAL field experiments will be conducted to assess the performance of FM DIAL techniques versus other chemical sensing techniques for scenarios, settings, and collection methods (i.e. platforms, flight or ground based movement patterns, dwell times, etc.) of greatest interest to potential users. PNNL will also use the FM DIAL and FTS systems to conduct bi-static chemical attack warning experiments. Based on the results of these experiments, PNNL will assess the operational utility of FM DIAL and FTS systems for chemical attack warning through analysis of experimental data and modeling results, and interactions with potential users. Objectives for the user interactions will include identification of opportunities for demonstrations and joint efforts aimed at technology transfer and advanced engineering development.

During FY03, PNNL and the Aerospace Corporation will collect data to develop and test background variability measurement methods, and to generate sets of measured data for use in assessing the importance of developing a database of measured variability data. Measured variability data will also be used in IR SAGE to analyze sensor performance. The experiments will use an existing dispersive imaging infrared spectrometer (the SEBASS High Altitude Research Platform (SHARP)), as well as the

Bruker OPAG-22 FTS mentioned above. During FY02, initial planning for these experiments was completed, and general specifications for a controlled temperature and emissivity blackbody were established. The conceptual design for a blackbody panel to be used for isolating ground and atmospheric variability effects is described in this report. PNNL had hoped to conduct the first measurements during the fourth quarter of FY02, but key Aerospace personnel and equipment were unavailable due to higher priority missions, and key PNNL personnel were engaged in measurement of CW spectra at Dugway Proving Ground. Revised plans call for use of the OPAG-22 during the first quarter of FY03, and a full field measurement campaign supported by Aerospace during the third quarter of FY03. All FY03 measurements will be conducted on the Hanford Reservation and its environs.

Acknowledgments

This work is funded through the Department of Energy (DOE) NA-22 Office.

The Infrared Sensors Task within the NNSA/NA-22 Remote Spectroscopy Program at the Pacific Northwest National Laboratory (PNNL) is focused on the science and technology of remote and in-situ chemical sensors for detecting proliferation and countering terrorism. PNNL will seek to serve organizations with direct interest in these missions through collaborative research and development efforts approved by NA-22. For more information contact:

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Contents

Summary	iii
Acknowledgments.....	v
Acronyms.....	ix
1.0 Introduction	1.1
2.0 FTIR System.....	2.1
3.0 FM-DIAL System.....	3.1
3.1 FM-DIAL Optical System.....	3.1
3.2 Mirror and Gimbal	3.3
3.2.1 Gimbal Testing.....	3.4
3.2.2 Mirror Mount Design	3.8
4.0 Remote Sensing Trailer	4.1
4.1 Specifications	4.1
4.2 Ancillary Items.....	4.3
4.3 Overall Weight and Electrical Requirements.....	4.3
5.0 Development of a Blackbody for Background Variability Measurements.....	5.1
6.0 References	6.1
Appendix: Trailer and LIDAR Optical System Drawings.....	A.1

Figures

2.1	Bruker OPAG-22 FTIR Spectrometer	2.1
3.1	Original FM-DIAL Configuration.....	3.2
3.2	FM-DIAL Configuration for Field Applications.....	3.2
3.3	Overview of the Gimbal Inertia Test Set-up.....	3.5
3.4	Gimbal Total Positioning Error Versus Rotational Inertia (V=1 deg/sec)	3.6
3.5	Gimbal Total Positioning Error Versus Rotational Inertia (V=3 deg/sec)	3.6
3.6	Gimbal Angular Velocity Versus Rotational Inertia (V=1 deg/sec).....	3.7
3.7	Gimbal Angular Velocity Versus Rotational Inertia (V=3 deg/sec).....	3.7
3.8	Turning Mirror Gimbal Design	3.9
3.9	Estimate of Turning Mirror Surface Distortion for 3-Point Support.....	3.10
3.10	Results from Mirror Mount Finite Element Analysis – Planar Deflection at 45°	3.11
4.1	Remote Sensing Trailer at PNNL	4.1
5.1	Pixel for Background Variability Measurements	5.2
5.2	Concept for a Blackbody Panel	5.2
5.3	Routing Heated Water Through Aluminum Panel with Internal Channels	5.3

Tables

2.1	Specifications for the Bruker OPAG 22 FTIR Spectrometer	2.2
4.1	Trailer Weight Breakdown	4.4
4.2	Trailer Systems Power Consumption	4.4

Acronyms

DOE	US Department of Energy
FM-DIAL	Frequency-Modulation Differential-Absorption LIDAR
FTIR	Fourier Transform Infrared
FTS	Fourier Transform Spectrometer
GPS	Global Positioning System
GSD	Ground Sample Distance
IR	Infrared
IR SAGE	Infrared Systems Analysis in General Environments
LIDAR	Light Detection and Ranging
LWIR	Long-wave Infrared
MWIR	Medium-wave Infrared
PNNL	Pacific Northwest National Laboratory
QCL	Quantum Cascade Laser
SEBASS	Spatially Enhanced Broadband Array Spectrograph System
SHARP	SEBASS High Altitude Research Platform

1.0 Introduction

The infrared sensors task at the Pacific Northwest National Laboratory (PNNL) is focused on the science and technology of remote and in-situ chemical sensors for detecting proliferation and countering terrorism. Missions to be addressed by remote chemical sensor development include detecting proliferation of nuclear or chemical weapons, and providing warning of terrorist use of chemical weapons. Missions to be addressed by in-situ chemical sensor development include countering terrorism by screening luggage, personnel, and shipping containers for explosives, firearms, narcotics, chemical weapons, or chemical weapons residues, and mapping contaminated areas. The science and technology relevant to these primary missions is also likely to be useful for battlefield chemical weapons defense, air operations support, monitoring emissions from chemical weapons destruction facilities or industrial chemical plants, and law enforcement applications. PNNL seeks to serve organizations with direct interest in these missions through collaborative research and development efforts approved by NA-22.

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Bruker OPAG-22 FTS mentioned above. The conceptual design for a blackbody panel to be used for isolating ground and atmospheric variability effects is described in this report. During early FY-03, a single panel will be fabricated to determine temperature uniformity, to optimize the design for performance and cost, and to support measurements with the OPAG-22 FTS. Once the blackbody panel design is proven, a larger blackbody will be fabricated using multiple panels.

During FY02, initial planning for these experiments was completed, and general specifications for a controlled temperature and emissivity (MWIR and LWIR) blackbody were established. PNNL had hoped to conduct the first measurements during the fourth quarter of FY02, but key Aerospace personnel and equipment were unavailable due to higher priority missions, and key PNNL personnel were engaged in measurement of CW spectra at Dugway Proving Ground. Revised plans call for use of the OPAG-22 during the first quarter of FY03, and a full field measurement campaign supported by Aerospace during the third quarter of FY03. All FY03 measurements will be conducted on the Hanford Reservation and its environs.

2.0 FTIR System

A fieldable FTS system was procured by PNNL to develop and test background variability measurement methods, and to generate sets of measured data for use in assessing the importance atmospheric variability data. The Bruker OPAG 22 (Open Path Gas Analyzer) is an FTIR (Fourier Transform Infrared) spectrometer, which is optimized for remote sensing of hazardous atmospheric compounds. The system consists a sensor module, portable PC, power supply, and tripod (see Figure 2.1). The system performance allows real-time field screening analysis over an operating range of several miles. Internal calibration sources are included to provide field-calibration for radiometric measurements. The system has been extensively hardened for field operations in harsh environments. The procurement included acceptance testing at PNNL followed by operational training. The system specifications for the OPAG 22 is provided in Table 2.1.



Figure 2.1. Bruker OPAG-22 FTIR Spectrometer

Table 2.1. Specifications for the Bruker OPAG 22 FTIR Spectrometer

SUBSYSTEM	SPECIFICATION
Sensor Module	
Type	Michelson type patented ROCKSOLID™ Interferometer
Size	400 x 370 x 250 mm
Weight	18 kg
Power Supply	12 - 36V
Power Consumption	40W
Maximum Operating Time On Battery Power	10 hrs
Optics	
Field of View	30 mrad (1.7°) 7.5 mrad (0.43°) with 4:1 telescope
Optical Throughput	0.0082 steradian cm ²
f-number	0.9
Entrance Window	ZnSe
Beam Splitter	ZnSe
Detector	Closed Cycle Cryogenic Cooler
Spectral Resolution	0.5 cm ⁻¹
Scan Speed	8 spectra/sec at $\Delta\nu = 4 \text{ cm}^{-1}$
Noise Equivalent Delta Temperature for a Single Spectrum	0.02 K at $T_b = 30 \text{ }^\circ\text{C}$ and $\nu = 1000 \text{ cm}^{-1}$
Noise Equivalent Radiance for a Single Spectrum	0.033 mW/(m ² steradian cm ⁻¹) at $T_b = 30 \text{ }^\circ\text{C}$ and $\nu = 1000 \text{ cm}^{-1}$
Spectral Range	$\nu = 700\text{-}8000 \text{ cm}^{-1}$
Internal Black Bodies (BB)	(a) hot BB: 75 °C (accuracy $\pm 0.1 \text{ K}$) stabilized (b) cold BB: not heated (accuracy $\pm 0.1 \text{ K}$) variable

3.0 FM-DIAL System

PNNL is developing frequency-modulation (FM) techniques for remote probing over long optical paths by means of differential-absorption LIDAR ranging (DIAL). The effects of propagation through the inhomogeneous atmospheric medium complicate remote interrogation of trace absorption features at distant ranges and/or over long path lengths. FM coding of the probe signals offers potentially higher common-mode rejection of atmospheric scintillation noise and technical noise. This technique can easily monitor large areas, or volumes, that could only be accomplished with a large network of point sensors. The project is focusing on the infrared detection of gaseous species including: chemical warfare agents and gases associated with the production of chemical and nuclear weapons of mass destruction.

Techniques for frequency-modulating various laser systems including CO₂, OPO, alexandrite, and newly developed high-power tunable semiconductor diode lasers, are being evaluated for use in DIAL applications. Particular attention is being given to understanding the effects of optical distortion and turbulence on ultimate detection limits. New post-detection signal averaging and optimal filtering algorithms are being developed to improve upon the signal recovery and to help increase the useful averaging dwell time. These systems are being tested to determine the delectability of process chemicals from several kilometers.

The basic idea behind the experiment is to direct a laser beam toward a scattering or reflective target. In some cases this may be a target of opportunity, such as a building or vehicle, or a deployed target. The Quantum Cascade Laser (QCL) source at PNNL is able to produce up to 100 mW of power at about 8.2 microns and has useful properties for FM experiments. After the laser hits a surface, the scattered light is collected with a receiver telescope and imaged onto a Mercury Cadmium Telluride (MCT) detector and the resulting signal is processed to recover laser transmission. The result of signal processing provides the signal transmission both on and off of a molecular absorption feature, allowing the calculation of a column-integrated concentration (concentration*length). This concentration may be used directly to monitor chemical concentrations as a function of time and position. The trailer, discussed in Section 4, will be used to allow FM-LIDAR experiments to be performed at a number of locations where the system will be used to monitor chemical emissions and background variability.

3.1 FM-DIAL Optical System

The original FM-LIDAR configuration at PNNL consisted of a laser, beam expander, LIDAR telescope, mirror, and various supporting electronic and optical components. The telescope beam was directed to the target of interest by manually rotating a large rectangular mirror in the horizontal plane. The entire system was installed on a 2-tiered aluminum frame (see Figure 3.1).

To adapt this system for mobile operations, a number of modifications were implemented. First, the 2-inch thick optical mounting surface was replaced with a 4.5-inch breadboard for increased rigidity. The breadboard was attached to 4 shock-mounts to reduce shock and vibrational loads to the optical set-up during transport. A computer-controlled gimbal-mounted mirror was added to allow the telescope beam to be accurately pointed in both the vertical and horizontal plane. This turned out to be the most

complicated addition, and will be described in detail in the following sections. The system needed to have the capacity to accommodate a larger telescope (up to 16 inch diameter) in the future. Finally, to reduce the effects of thermal distortion, the system had to be operated from within a temperature-controlled trailer. The “2nd generation” FM-LIDAR configuration is shown in Figure 3.2.



Figure 3.1. Original FM-DIAL Configuration

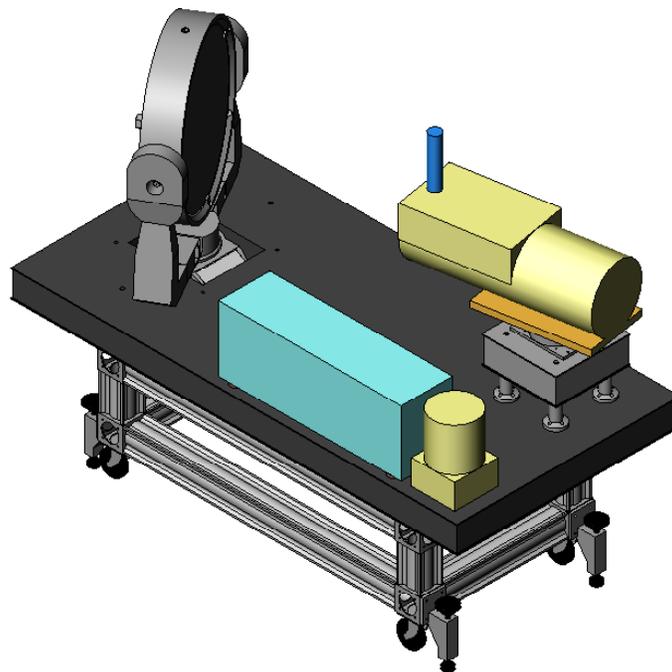


Figure 3.2. FM-DIAL Configuration for Field Applications

3.2 Mirror and Gimbal

To perform LIDAR experiments, it is desirable to manipulate the telescope beam in the vertical and horizontal trajectories while keeping the telescope stationary. One way to accomplish this is to point the telescope at the center of a gimbal-mounted mirror, and use the gimbal to modify the optical field of view. In designing the optical setup using a gimbal-mounted mirror, various competing objectives were soon revealed. For example, to examine various atmospheric and terrestrial targets, a wide range of view is desirable. As a minimum, the viewing cone needed to span 30° below the horizon to zenith and allow for ±20° adjustment in the horizontal plane. To achieve adequate temperature control, the size of the optical opening in the trailer shell needed to be minimized. This required the mirror to be placed as close to the side of the trailer as possible. The size of the mirror needed to be minimized to reduce cost and space requirements. By rotating the telescope with respect to the length of the trailer, it was possible to reduce the size of the mirror. But this resulted in moving the mirror away from the optical opening, which increased the required size of the optical opening. A practical compromise was reached by rotating the telescope 7.5° with respect to the trailer and positioning the optical table as close as possible to the trailer side wall.

A 21.875-in diameter, borosilicate glass (Pyrex®) mirror was available from Steve Swayze Optics at an economical price^(a). Even though the mirror was larger than required by the current 10-inch, FM-LIDAR telescope, the availability of the mirror was seen as an opportunity to obtain not only a high quality mirror for the FM-LIDAR system, but would allow the use of a larger telescope in the future. The mirror was 3.5 inches thick and weighed 106-lbs and was obtained through a government surplus sale.

Various options were considered for fabricating the mirror gimbal, from in-house design to custom fabrication. During the time of this evaluation, a staff member from PNNL visited the Aerospace Corporation and learned that they had converted a Meade Instruments Corporation 12-inch LX200GPS telescope mount into a workable gimbal for a 17-inch turning mirror. The mount is readily available, has high resolution (0.375 arc sec) and precision (2 arc minutes), and could be controlled either by a PC or hand-held pendant. Furthermore, the modifications required to accommodate a large mirror mount were cost-effective. Since the mount had the pointing accuracy required for LIDAR/FTIR experiments, this course was taken at PNNL as well.

The cost to fabricate the turning mirror gimbal using the Meade telescope gimbal is estimated to be \$20,000 (\$5,000 for the telescope, \$5,000 to design the mirror mount and extensions to the gimbal arms, and \$10,000 for machining). The cost to obtain a custom gimbal with comparable capabilities to the Meade gimbal is estimated to be \$80,000. Overall, the cost to procure the turning mirror and Meade telescope and to modify the Mead gimbal were less than \$25,000, compared to \$135,000 for custom fabrication, for a substantial savings of \$110,000.

(a) The cost of the 22-in mirror from Swayze Optics was \$2,000 with the coating in good condition. A quotation of \$55,000 was obtained from a primary large mirror manufacturer of research quality optics to custom fabricate and coat a similarly sized turning mirror.

Meade does not provide the specifications for the 5.75-in diameter worm gears used to drive the azimuth and elevation stages. A series of gimbal tests, discussed in the next section, were undertaken to verify that the gimbal drives had sufficient capacity to handle the additional inertia of the large 22-inch diameter mirror.

3.2.1 Gimbal Testing

Inertia calculations indicate that the mirror and mounting hardware would have a rotational inertia 5 times greater than the Meade 12-inch telescope. Tests were conducted to determine if the Meade mount could tolerate addition mass and inertia without malfunction or loss of accuracy. An “inertia” beam was attached to the elevation bearing; by adjusting the location of additional weights, the rotational inertia of the system could be varied. An overview of the test set-up is shown in Figure 3.3. The following inertial cases were tested:

- Inertia beam installed, no extra masses. $I=1323 \text{ lb-in}^2$
- Inertia beam installed, 5 lb weights at 8.23 inches, $I=2000 \text{ lb-in}^2$
- Inertia beam installed, 5 lb weights at 15.58 inches, $I=3750 \text{ lb-in}^2$
- Inertia beam installed, 5 lb weights at 20.44 inches, $I=5500 \text{ lb-in}^2$ (representing the 22 inch mirror)

For each inertia, the mount was commanded to move to various positions involving elevation stage movement, azimuth stage movement, and combined elevation/azimuth stage movement. Slew rates of 1 and 3 degrees per second were tested. Even though the mount can operate up to 8 degrees per second, this high speed will not be tested for conservatism. After each movement, the actual positions of the azimuth and elevation stage were recorded using data from the Meade encoders. For the maximum inertia, the test was repeated with a laser mounted to the beam to independently evaluate accuracy and repeatability.

The angular position data provided by the Meade controller was recorded for each position move and compared with the desired position. The time required to move from point to point was converted into an average angular velocity. These acquired results are discussed below.

The internal positioning error is defined as the square root of the sum of the squares of the azimuth and elevation errors, where error is the angular difference between the actual position and the desired position, based on the Meade encoder data. Referring to Figures 3.4 and 3.5, an increase in rotational inertia or angular speed did not affect the positioning error. Fortunately, the technique used by Meade to incrementally ramp down the speed near the desired point allows additional mass to be added without loss of accuracy. The angular velocity was slower than the set slew rate for both speeds tested (1 deg/sec and 3 deg/sec). The azimuth stage tended to be faster than the elevation stage. Referring to Figures 3.6 and 3.7, additional inertia did not result in a reduction in velocity or additional time for the controllers to reach position.



Figure 3.3. Overview of the Gimbal Inertia Test Set-up

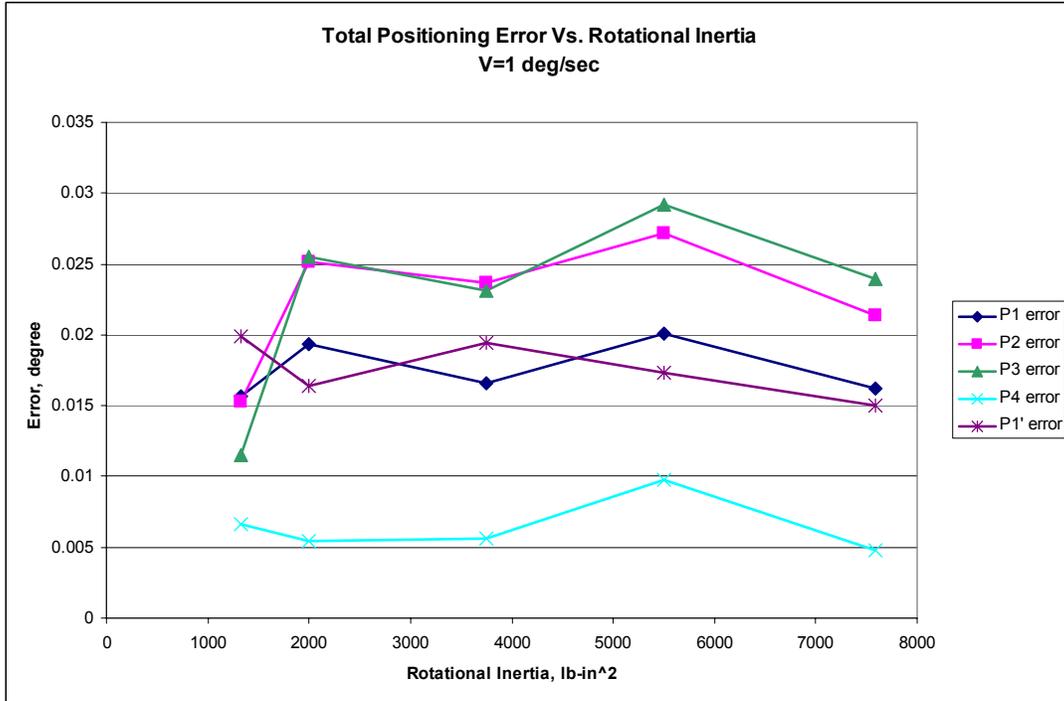


Figure 3.4. Gimbal Total Positioning Error Versus Rotational Inertia (V=1 deg/sec)

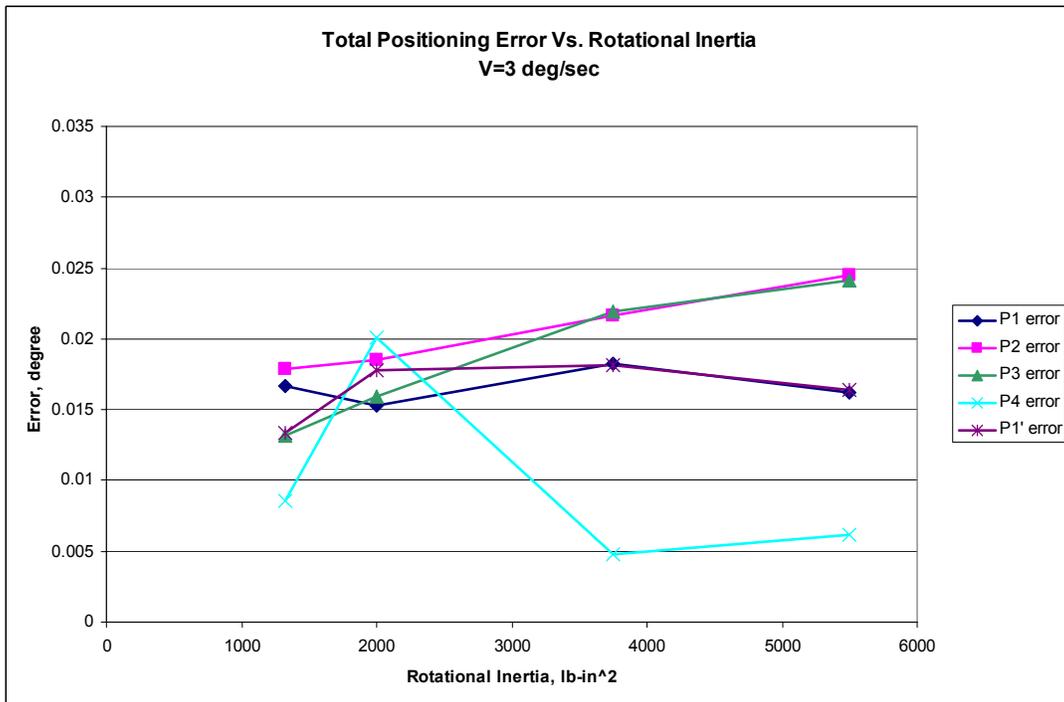


Figure 3.5. Gimbal Total Positioning Error Versus Rotational Inertia (V=3 deg/sec)

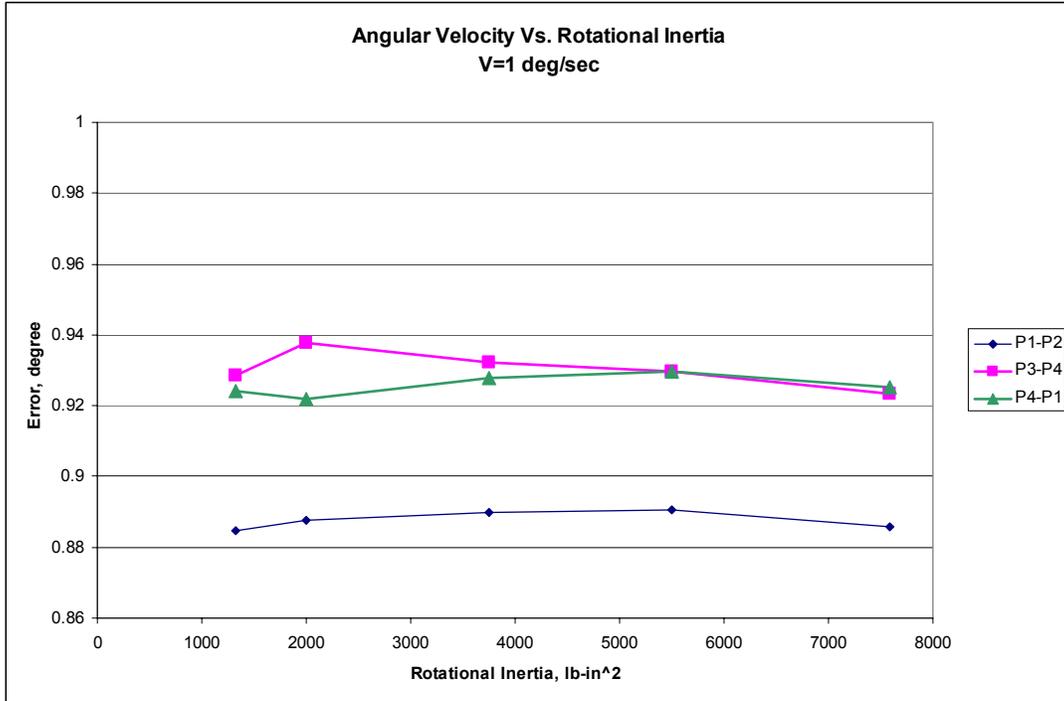


Figure 3.6. Gimbal Angular Velocity Versus Rotational Inertia (V=1 deg/sec)

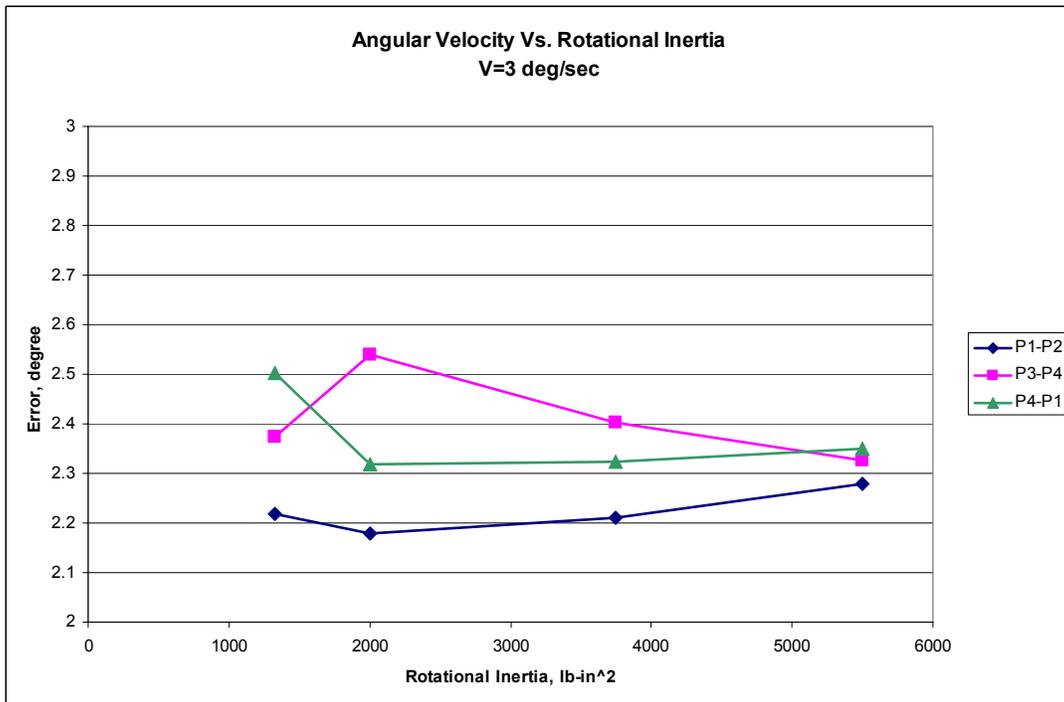


Figure 3.7. Gimbal Angular Velocity Versus Rotational Inertia (V=3 deg/sec)

After the inertia tests were completed, a mirror was mounted on the inertia beam and a laser was reflected from the mirror to a point on the wall. The landscape mode of the telescope control system was used to capture the initial point, and the mount was commanded to move away from the point and then return. The pointing repeatability was found to be within the specification for the mount (2 arc-minutes, or 0.033 degree). After the mount returned to the original position one time, the distance between successive points was much smaller, indicating that backlash in the gears is the greatest source of positioning error. This test was conducted without weight added to the inertia beam ($I=1323 \text{ lb-in}^2$) and with the 5 lb weights located at 20.44-inch radius ($I=5500 \text{ lb-in}^2$). More inertia did not affect the repeatability.

Based on these tests, the mount can easily handle additional rotational inertia up to the effective inertia of a 22-inch diameter by 3.5-inch thick Pyrex mirror, if the center of gravity of the mirror and mount is centered on the rotational axis. Centering the reflective surface on the rotational axis was desirable, but would require a large counterweight, which would double the inertial loading and was deemed to be unfeasible. The actual offset between the mirror and the center of the bearing posts is 1.97 in.

3.2.2 Mirror Mount Design

A mirror mount was designed and fabricated to attach the mirror to the Meade telescope gimbal (see Figure 3.8). The mount consists of a large aluminum flange, a three point back support, spring-loaded mirror clips, and bearing posts. Large, upward-pointing optical mirrors are usually supported from the rear using a multi-point flotation system to minimize surface distortion due to gravity loading. For FTIR and FM-DIAL applications, the reflective surface of the mirror will be nearly vertical for most situations, but it will be desirable at times to point the mirror upward up to 45° (for zenith viewing) and downward by up to 15° (for a 30° downward line-of-sight). Due to the downward viewing requirement, and the fact that the mirror will be usually oriented vertically, a simple 3-point support at the outer radius was chosen. This will maintain a consistent support system for upward and downward viewing. The spring-loaded mirror clips will maintain contact during downward viewing. The springs also accommodate the mismatch in thermal expansion between the glass and the aluminum. While in the vertical orientation, the weight of the mirror is supported by 2 pins. Flat sections on the pins distribute the weight of the mirror over 4 in^2 .

The mirror flatness criterion was 10 microns, which needed to be achieved at the 45° mirror inclination. Nelson et al. (1982) studied the surface deflections of circular plates with discrete numbers of support points ranging from 1 to 36. The surface deflection derived by Nelson is used in the calculation shown in Figure 3.9 to estimate the effect of using a non-optimal 3-point support at the rim of the mirror. A factor of 4 is applied to account for the rim loading (versus the optimized mounting at 0.645R) per Barr (1998). The surface distortion was found to be less than 0.2 micron.

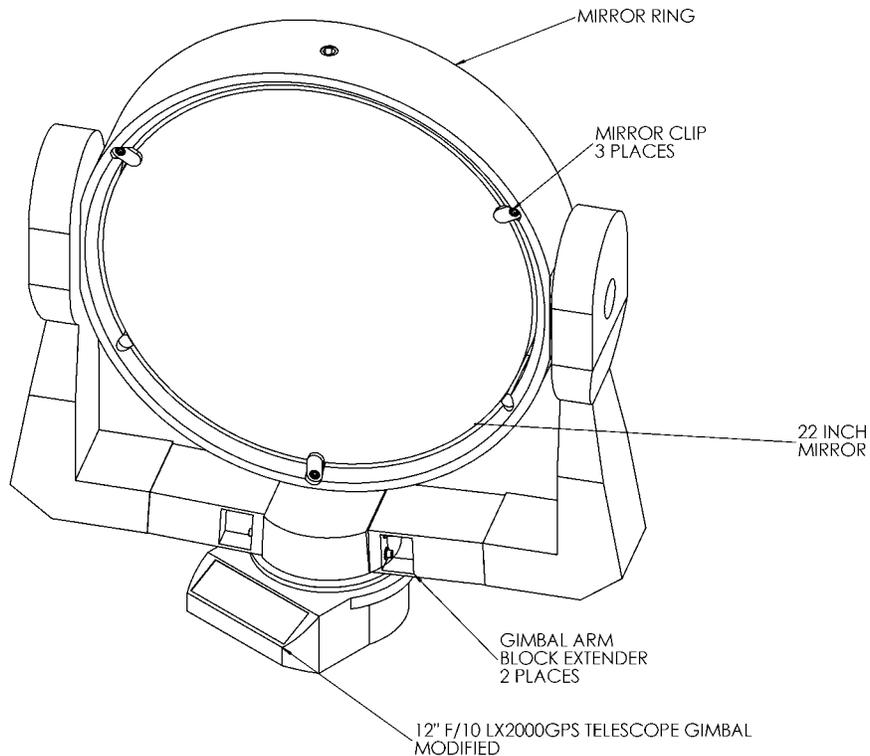


Figure 3.8. Turning Mirror Gimbal Design

A structural finite element model of the mirror ring was developed to minimize the weight of the ring while maintaining adequate stiffness. Three equal loads on the ring simulated the mirror weight. Since there are 1 support point on the upper section of the ring, and 2 on the bottom, the mirror load on the ring is not symmetric; on the side with one load, the load is applied at the maximum distance from the axis of rotation. This affects the pointing accuracy of the mount, if the deflection is not accounted for. The goal of the analysis was to insure that this deflection would result in a loss of accuracy less than 1/20 the pointing accuracy of the Meade mount. The results of the analysis (Figure 3.10) were used to calculate the angular deflection of the ring due to the asymmetric loading and indicate the loss of accuracy is 1/75 the pointing accuracy of the Meade mount at the most severe 45° orientation.

Borosilicate Glass Properties

$$E_{\text{PYREX}} := 9100000 \text{ psi} \quad \rho_{\text{PYREX}} := 0.08056 \frac{\text{lb}}{\text{in}^3} \quad \mu_{\text{PYREX}} := 0.2$$

$$D_{\text{Mirror}} := 21.875 \text{ in} \quad T_{\text{Mirror}} := 3.5 \text{ in} \quad M_{\text{Mirror}} := 106 \text{ lbf}$$

$$\text{Area}_{\text{Mirror}} := \pi \cdot \left(\frac{D_{\text{Mirror}}}{2} \right)^2 \quad \text{Area}_{\text{Mirror}} = 375.825 \text{ in}^2$$

$$\text{Pressure} := \frac{\cos(45 \cdot \text{deg}) M_{\text{Mirror}}}{\text{Area}_{\text{Mirror}}} \quad \text{Pressure} = 0.1994 \text{ psi}$$

$$D_{\text{pc}} := \frac{E_{\text{PYREX}} \cdot T_{\text{Mirror}}^3}{12 \cdot (1 - \mu_{\text{PYREX}}^2)} \quad D_{\text{pc}} = 3.387 \times 10^7 \text{ in} \cdot \text{lbf} \quad \text{Plate constant}$$

$$\text{Flat}_{\text{criteria}} := 10 \cdot 10^{-6} \cdot \text{m} \quad \text{Flatness criteria}$$

Nelson et al. (1982) studied the surface deflections of circular plates with discrete numbers of support points ranging. The surface deflection derived by Nelson is used in the following calculations to estimate the effect of using a non-optimal 3-point support at the rim of the mirror. factor of 4 is applied to account for the rim loading (versus the optimized mounting at 0.645R) per Barr (1998).

$$v_N := 5.76 \cdot 10^{-3} \quad \text{For a three point support}$$

$$K_{\text{rim}} := 4 \quad \text{Amplification factor for rim mounting}$$

$$N_{\text{sp}} := 3 \quad \text{Number of supports}$$

$$\text{PV} := 4.2 \quad \text{Converts RMS deflection to Peak-Valley}$$

$$\delta_{\text{PV}} := K_{\text{rim}} \cdot \text{PV} \cdot v_N \cdot \left(\frac{\text{Pressure}}{D_{\text{pc}}} \right) \cdot \left(\frac{\text{Area}_{\text{Mirror}}}{N_{\text{sp}}} \right)^2$$

$$\delta_{\text{PV}} = 2.271 \times 10^{-7} \text{ m} \quad \frac{\text{Flat}_{\text{criteria}}}{\delta_{\text{PV}}} = 44.024 \quad \text{Still meet criteria even with non-optimized 3-point mount}$$

Figure 3.9. Estimate of Turning Mirror Surface Distortion for 3-Point Support

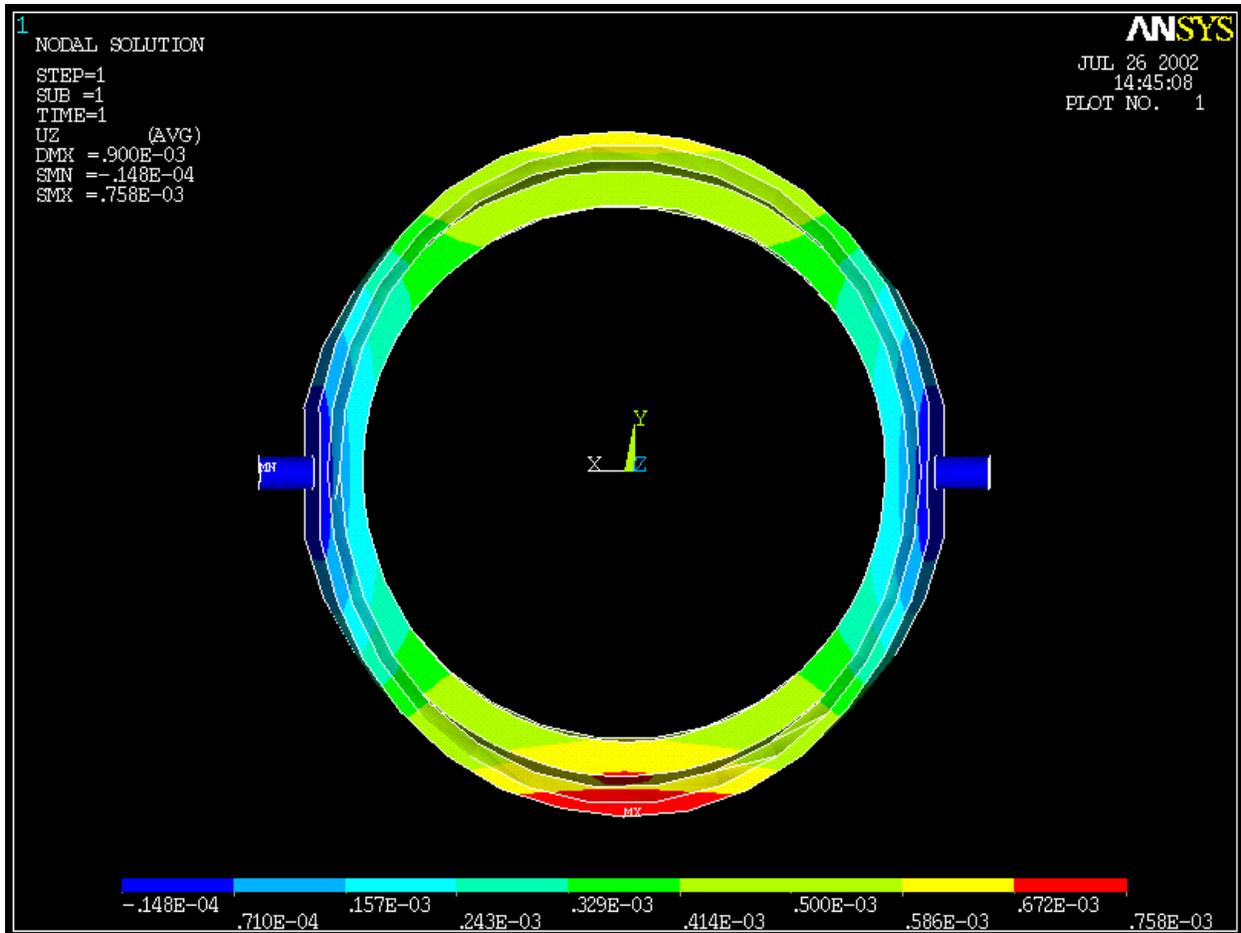


Figure 3.10. Results from Mirror Mount Finite Element Analysis – Planar Deflection at 45°

4.0 Remote Sensing Trailer

This trailer will be used as a mobile laboratory to conduct remote IR sensing studies for the Department of Energy. The trailer (Figure 4.1) will protect the optical system and provide a control room for scientists while data is taken. The trailer will be pulled with a government pool or rental vehicle. Detailed trailer drawings are provided in the Appendix.



Figure 4.1. Remote Sensing Trailer at PNNL

4.1 Specifications

The follow specifications were used to generate a procurement specification for the trailer. They are listed for reference here primarily as a source of information for future hosting sites.

- 1) Wells Cargo 4-Ton Express Wagon EW2024
 - a) 20 ft long body
 - b) Maximum GVWR 10,000 lbs

- c) Maximum GAWR 10,000 lbs
- d) Average payload capacity 7,015 lbs
- e) Color: white
- 2) Nose cone to reduce wind resistance
- 3) Interior headspace 6.5-ft
- 4) Scissor-type stabilizer jacks with detachable hand cranks, on all 4 corners
- 5) ST225/75R15 load range “D” radial tires mounted on 15-in by 6-in, 6 bolt aluminum wheels with matching spare tire with aluminum rim and carrier located on exterior front
- 6) Mud flaps and standard fenders
- 7) Flooring and wall coverings
 - a) One-piece vinyl floor over 2 layers of ¾-in pressure treated plywood
 - b) White Kemlite® covered ¼ plywood on sides, ends, and ceiling
- 8) Two roof-mounted air conditioners.
 - a) Cooling capacity 14,800 BTU/hr each, 29,600 BTU/hr total
 - b) Heating capacity 5,600 BTU/hr each, 11,200 BTU/hr total
- 9) Doors and hatches
 - a) Ceiling hatch, rear ramp door, main entry door, cable slot door with brush seal, two large optical opening
- 10) Overhead cabinets on front of trailer
- 11) 2 wheel electric brake with break-a-way system and electric brake controller
- 12) 14 ft roll-up awning
- 13) Electrical
 - a) 100 amp 120/240 Volt 16 Circuit Panel with 25 ft shoreline
 - i) The connector on the shoreline is Appleton ACP1034CD 4-pin and sleeve connector
 - ii) The matching connector used at PNNL to connect to facility power is Appleton ARC1034CD 3W-4P connector body, Appleton AJA610 mounting unilet, and Appleton ADR1034 3W-4P receptacle
 - b) Quantity 4, 4 ft 4-tube AC fluorescent fixture with diffusers, recessed, evenly distributed. Each bank to have its own switch. Switches (4) to be located near the side access door.
 - c) 6 sets of double duplex GFI electrical receptacles in the trailer, 2 on left wall, 2 on right wall, 2 on rear wall, wiring to be run in the wall.
 - d) DOT exterior signal lights (brake, turn, back-up) and reflectors connected to tow vehicle with 7-way plug
 - e) 12 Volt Battery, 100 amp hour deep cycle battery, vented battery box, and 6-circuit fuse panel. Battery recharged through the 7-way plug.
 - f) 2 Exterior 120V GFI double duplex outlets
 - g) 12 Volt dome interior light with optics lens with 3-way wall switches at front and rear of trailer. Connected to the 12 Volt battery
 - h) Two recessed 500-W weatherproof exterior halogen flood light fixtures on side of trailer with interior wall switch near the side door.
 - i) Breaker Box Layout
 - (1) For AC#1
 - (2) For AC#2
 - (3) Interior Lights

- (4) Flood Lights 1 and 2
 - (5) Double Duplex Outlet 1
 - (6) Double Duplex Outlet 2
 - (7) Double Duplex Outlet 3
 - (8) Double Duplex Outlet 4
 - (9) Double Duplex Outlet 5
 - (10) Double Duplex Outlet 6
 - (11) GFI Double Duplex Outlet 1
 - (12) GFI Double Duplex Outlet 2
 - (13) Spare
 - (14) Spare
 - (15) Spare
 - (16) Spare
- 14) Insulation
- a) Ceiling R22 Fiberglass – 7 inch, requires flat ceiling
 - b) Sidewall 2 ½ inch deep vertical posts and R11 Insulation
 - c) Floor 3.5 inch fiberglass insulation
- 15) 2 5/16-in top mount coupler with DOT compliant 5/16-in safety chain with clevis safety slip hook and latch
- 16) 7-way trailer end connector
- 17) Two 5000-lb Torflex® 4-in drop axles

4.2 Ancillary Items

An electric generator and cryogenic container were added to the remote system trailer to support field operations. The generator is a Porter Cable H1000 and has a continuous power output 10 kW. The 7-gallon gas tank can provide 4.2 hours of run-time at full load. A connector was fabricated to allow connection to the trailer power cable. A Chart MVE Cryo-Cyl 180 was purchased to store up to 185 liters of liquid nitrogen and will be transported with the trailer.

4.3 Overall Weight and Electrical Requirements

The total weight of the trailer for a typical application involving both FTIR and LIDAR systems is approximately 5500 lbs. Table 4.1 provides a weight breakdown of the various components in the system. Power consumption has also been estimated for the various trailer functions. Table 4.2 provides total power for consumption assuming the maximum cooling capacity is being utilized.

Table 4.1. Trailer Weight Breakdown

Equipment	Weight, LB	Comment
Trailer	2985	
LIDAR Optics Trailer	500	
Mirror and Gimbal	260	
LIDAR Equipment	200	
FTIR Equipment	200	
Cryo-Cyl	540	With 185 liters of liquid N ₂
Generator	425	Including 7 gallons of gas
Workstation	150	
Miscellaneous Hardware	250	
Total Weight	5510	

Table 4.2. Trailer Systems Power Consumption

Component	System	Power, W	Current, Amps	Voltage, Volts
FTIR Battery Charger	FTIR	30	1	120
Sender telescope	FTIR	15	0.5	120
Brooker computer and monitor	FTIR	525	4.8	110
Griddle	FTIR	1500	15	120
System components	FM-DIAL	1000	8.3	120
Gimbal Drive and Controls	FM-DIAL			
Chiller	Trailer	1400	12	120
Mini weather station for local weather	Trailer	30	1	120
Data acquisition computer and monitor	Trailer	525	4.8	120
Interior Lights	Trailer	550	4.6	120
Exterior Lights	Trailer	200	1.7	120
AC # 1	Trailer	2117	16	120
AC # 2	Trailer	2117	16	120
Total for the FTIR System		9009	77.4	
Total FM-DIAL		7939	64.4	
Total, Simultaneous Operation		10009	85.7	

5.0 Development of a Blackbody for Background Variability Measurements

During FY03, PNNL and the Aerospace Corporation will collect data to develop and test background variability measurement methods, and to generate sets of measured data for use in assessing the importance of developing a database of measured variability data. Measured variability data will also be used in IR SAGE to analyze sensor performance. The experiments will determine the variability in atmospheric radiance and transmission, and ground radiance and reflectivity in the 3 to 5 micron and 8 to 12 micron regions of the spectrum. The experiments will use an existing dispersive imaging infrared spectrometer (the SEBASS High Altitude Research Platform (SHARP)). A database of IR clutter will be developed that can be used in modeling remote chemical detection sensor systems and data analysis algorithms. The experiments will be performed to measure clutter (fluctuations due to changes in atmospheric and ground temperature or emissivity) and to measure temporal and spatial variability with adequate spectral resolution.

PNNL had hoped to conduct the first measurements during the fourth quarter of FY02, but key Aerospace personnel and equipment were unavailable due to higher priority missions, and key PNNL personnel were engaged in measurement of CW spectra at Dugway Proving Ground. Revised plans call for use of the OPAG-22 during the first quarter of FY03, and a full field measurement campaign supported by Aerospace during the third quarter of FY03. All FY03 measurements will be conducted on the Hanford Reservation and its environs.

The spectrometer will be aimed at a controlled temperature and emissivity (MWIR and LWIR) blackbody large enough to excite at least one pixel of the sensor. To perform this experiment, the blackbody needs to be roughly two times the ground sample distance (GSD) of the instrument. During FY02, initial meetings were held to plan these series of tests and to establish the general specifications for a controlled temperature and emissivity (MWIR and LWIR) blackbody. To be useful, the blackbody must be sufficiently large to span 1 pixel of the SEBASS instrument with significant overlap on the adjacent pixel. At a range of 2-km, this requirement translated into a minimum blackbody size of 2-m. An even larger blackbody would be needed at 5-km. Due to the need to conduct experiments at different ranges, and the difficulty in maintaining a single large blackbody at constant temperature, the decision was made to develop a blackbody panel approximately 2/3-m square. Once this blackbody was designed and tested, a larger blackbody of almost unlimited size could be fabricated (see Figure 5.1) using a number of individual panels.

The basic panel will be fabricated with aluminum, chosen for high thermal conductivity. The surface of the aluminum will be hard anodized and painted with Kryon® Ultra Flat Black spray paint, which has an emissivity greater than 0.96 for MWIR and greater than 0.943 for LWIR. To distinguish the panel from the surrounding landscape, the panel will be maintained at an elevated temperature (approximately 50°C) by pumping hot water through channels inside the panel (see Figure 5.2). The water will be heated inside a large reservoir using a thermostatically controlled heater. To maintain the overall blackbody at a

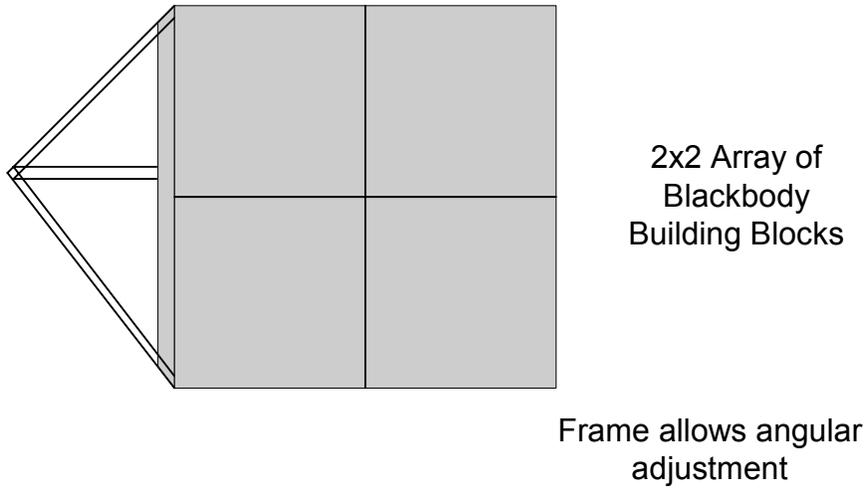


Figure 5.1. Pixel for Background Variability Measurements

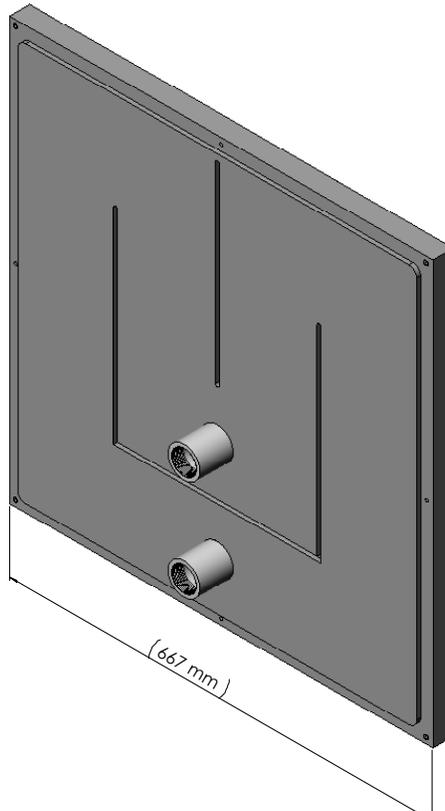


Figure 5.2. Concept for a Blackbody Panel

constant temperature, a single reservoir will service all panels. A schematic of the system is provided in Figure 5.3. The backside of the panel will be insulated. Once at temperature, the heat loss from each panel has been estimated to be 85 W, assuming an ambient temperature of 75°F.

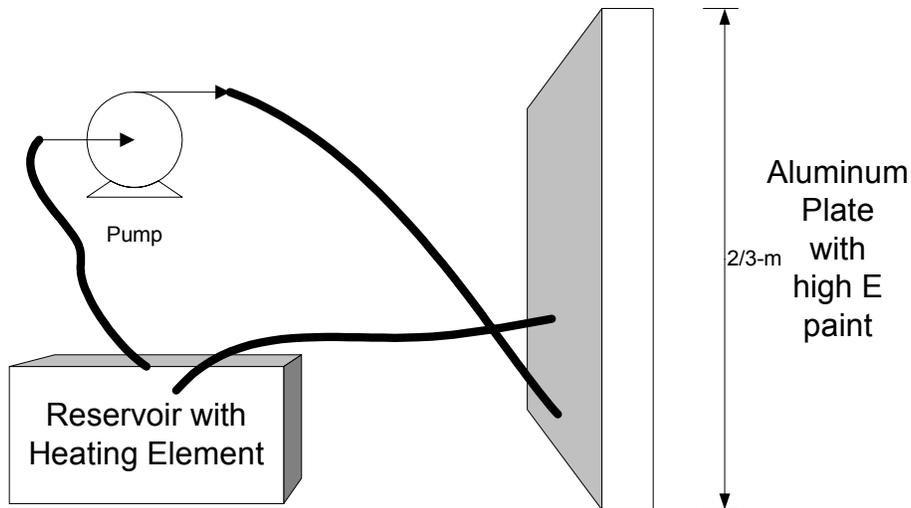


Figure 5.3. Routing Heated Water Through Aluminum Panel with Internal Channels

The current plan is to fabricate a prototype panel in early FY-03, evaluate the prototype for temperature uniformity, optimize the design for performance and cost, and then build the remaining panels. A second FTS system or IR camera will be used to monitor the spectra of the surface of the controlled radiance blackbody during preliminary tests and during the actual experiment.

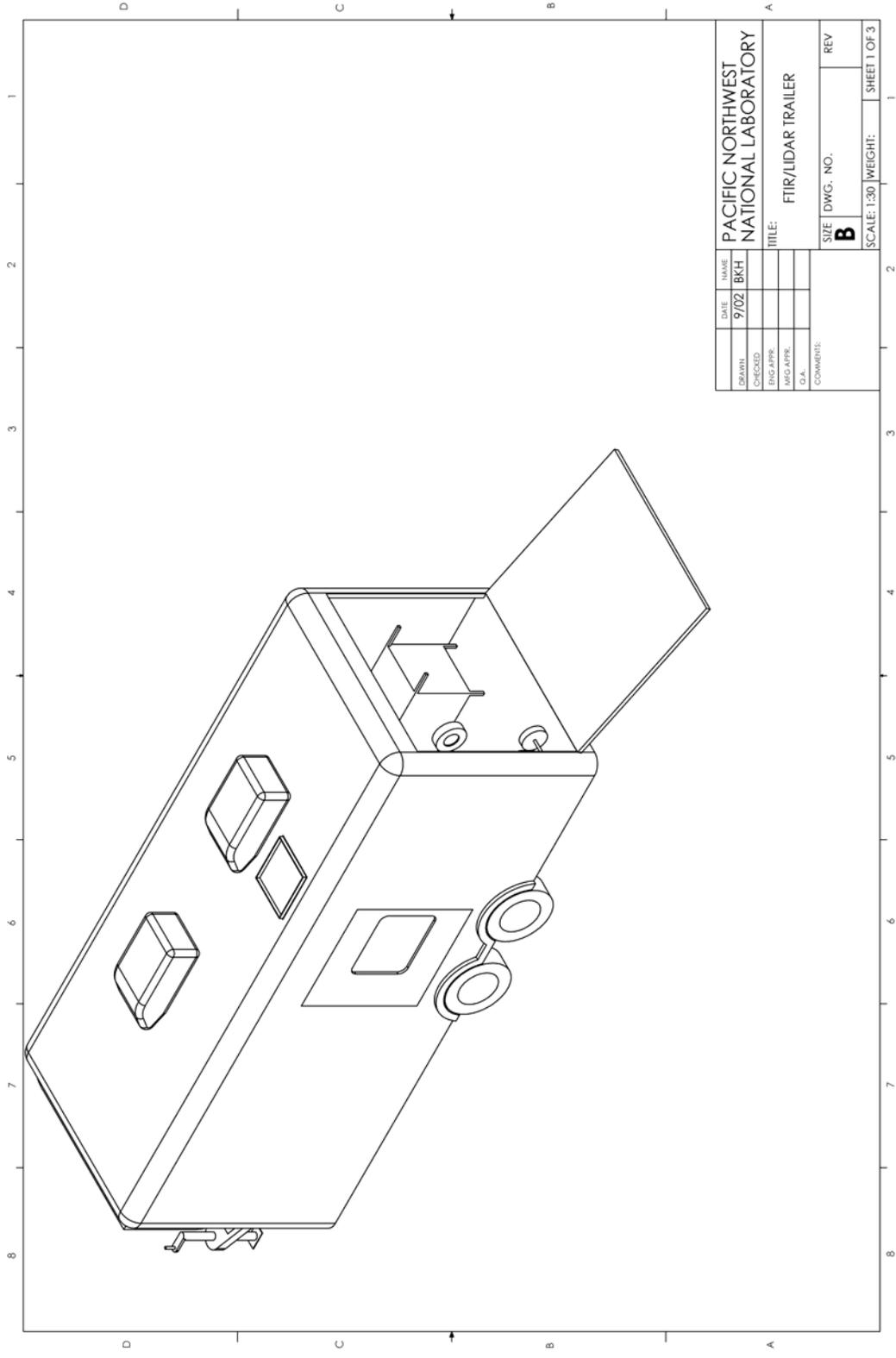
6.0 References

Barr L, and ST Ridgway. 1998. "Self-weight Deflections of 8-inch Diameter Flats," CHARA Technical Report No. 62.

Nelson JR, J Lubliner, and T Mast. 1982. SPIE, 332, 212.

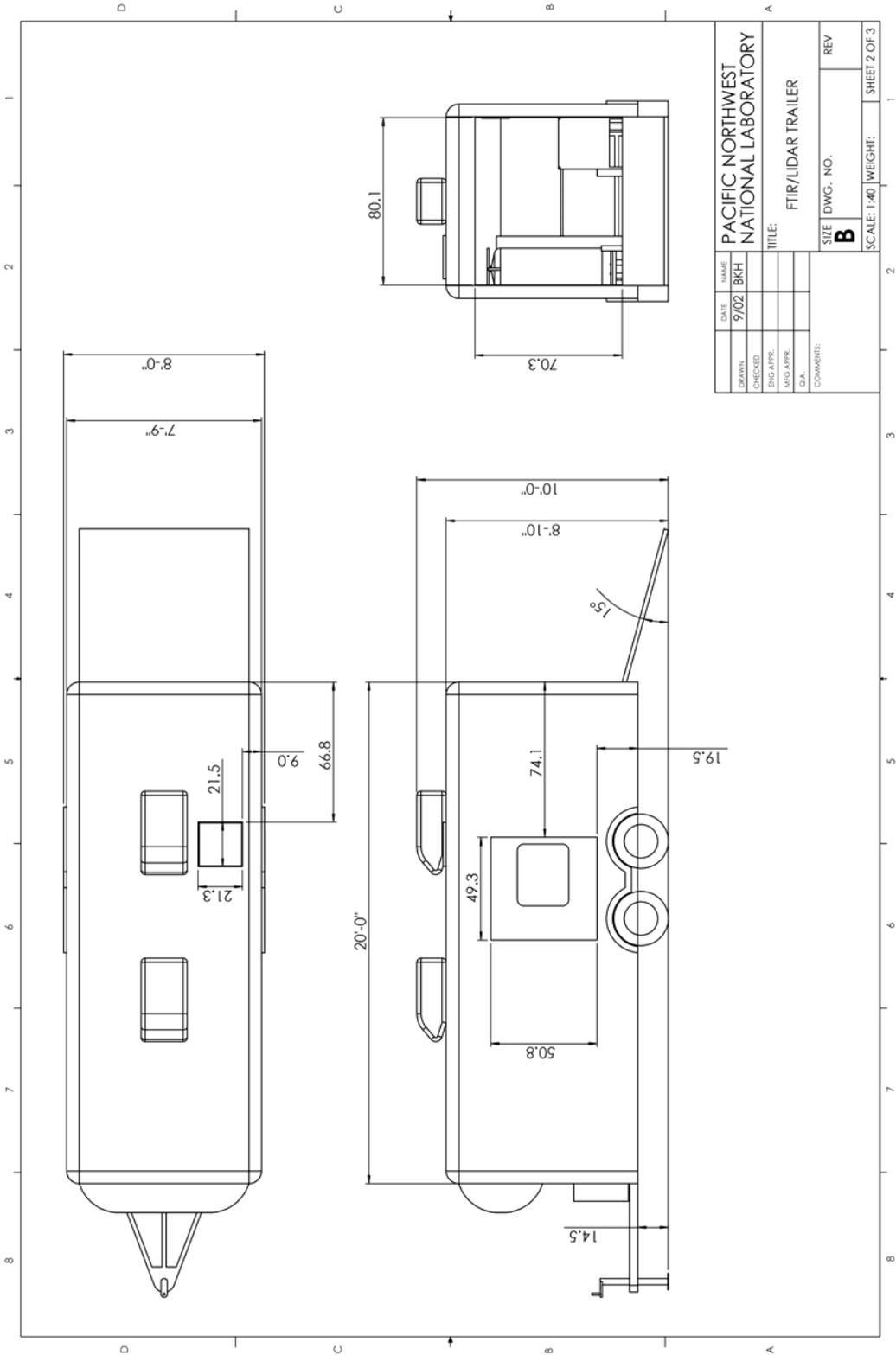
Appendix

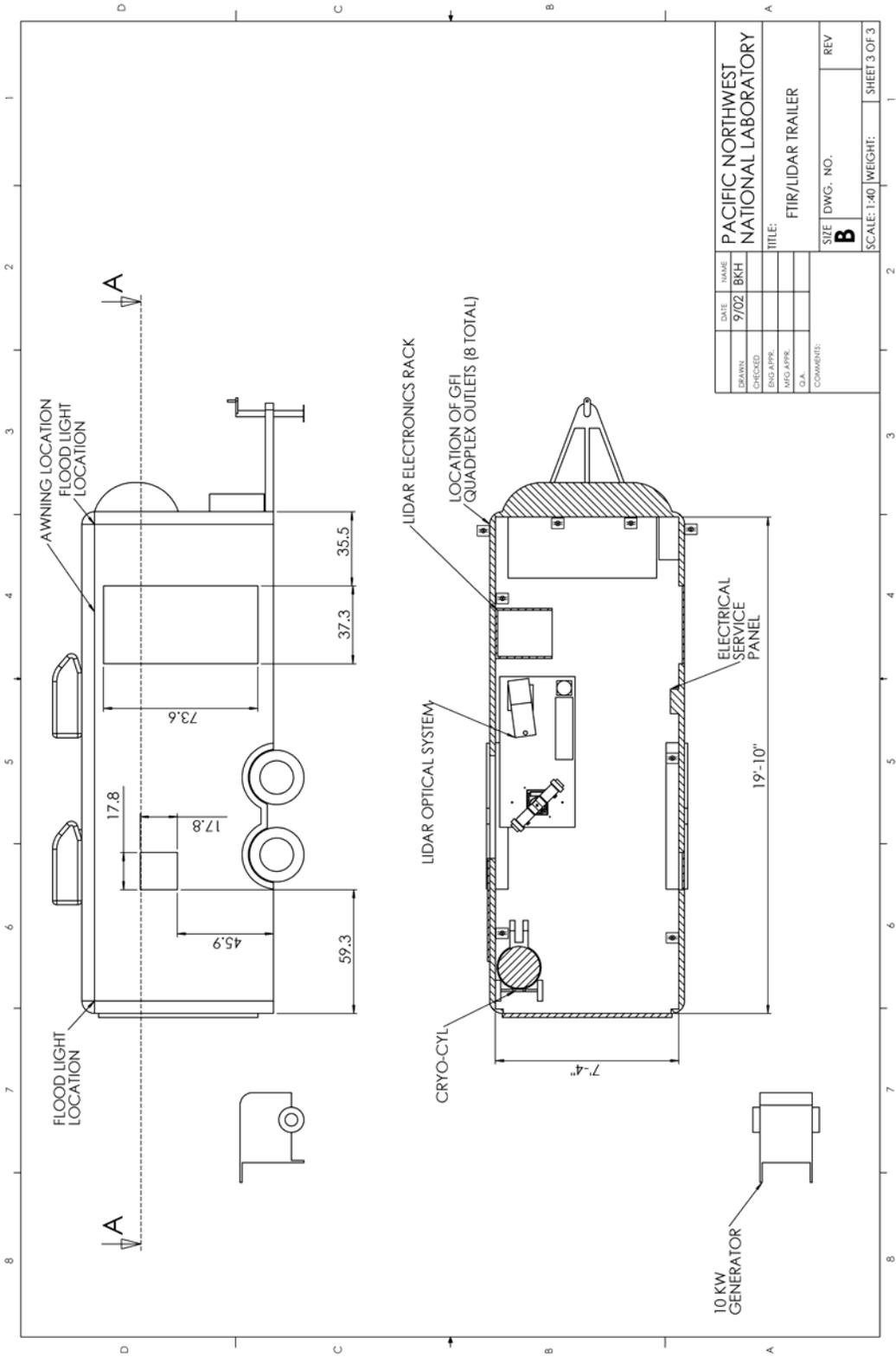
Trailer and LIDAR Optical System Drawings

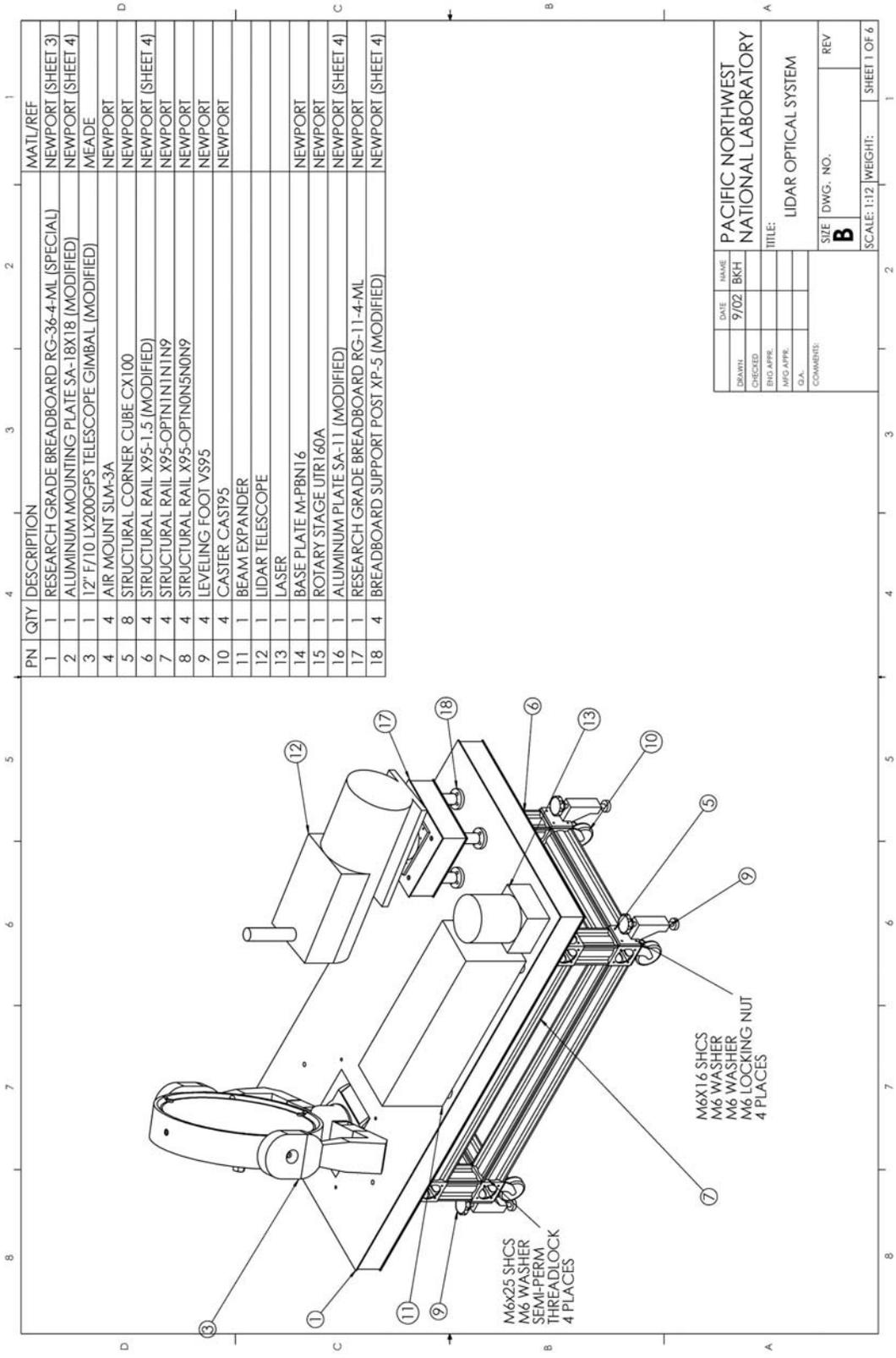


DATE	NAME	PACIFIC NORTHWEST NATIONAL LABORATORY	
9/02	BKH	TITLE: FTIR/LIDAR TRAILER	
DRAWN	CHECKED	SIZE	DWG. NO.
ENG APPR.	MFG APPR.	B	REV
D.A.	COMMENTS:	SCALE: 1:30	WEIGHT:
			SHEET 1 OF 3

A.1







PN	QTY	DESCRIPTION	MATL/REF
1	1	RESEARCH GRADE BREADBOARD RG-36-4-ML (SPECIAL)	NEWPORT (SHEET 3)
2	1	ALUMINUM MOUNTING PLATE SA-18X18 (MODIFIED)	NEWPORT (SHEET 4)
3	1	12" F/10 LX200GFS TELESCOPE GIMBAL (MODIFIED)	MEADE
4	4	AIR MOUNT SLM-3A	NEWPORT
5	8	STRUCTURAL CORNER CUBE CX100	NEWPORT
6	4	STRUCTURAL RAIL X95-1.5 (MODIFIED)	NEWPORT (SHEET 4)
7	4	STRUCTURAL RAIL X95-OPTINININ9	NEWPORT
8	4	STRUCTURAL RAIL X95-OPTINON5N0N9	NEWPORT
9	4	LEVELING FOOT VS95	NEWPORT
10	4	CASTER CAST95	NEWPORT
11	1	BEAM EXPANDER	
12	1	LIDAR TELESCOPE	
13	1	LASER	
14	1	BASE PLATE M-PBN16	NEWPORT
15	1	ROTARY STAGE UTR160A	NEWPORT
16	1	ALUMINUM PLATE SA-11 (MODIFIED)	NEWPORT (SHEET 4)
17	1	RESEARCH GRADE BREADBOARD RG-11-4-ML	NEWPORT
18	4	BREADBOARD SUPPORT POST XP-5 (MODIFIED)	NEWPORT (SHEET 4)

DATE	9/02	BY	BKH
DRWN		CHEK	
ENG APPR		MFG APPR	
D.A.		COMMENT	

PACIFIC NORTHWEST NATIONAL LABORATORY

TITLE: LIDAR OPTICAL SYSTEM

SIZE DWG. NO. **B** REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 6

