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FINAL TECHNICAL REPORT

Characterization of Infrared Diode Laser Beams and Atmospheric CO Imaging Instrument

BY

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INTRODUCTION

During June–August 1997 Dr. Jonathan Miles, assistant professor in the program of Integrated Science and Technology (ISAT) at James Madison University (JMU), participated in the ASEE-sponsored summer faculty research program at NASA Langley Research Center (LaRC). The Aerospace Electronic Systems Division (AESD), Sensor Systems Branch (SSB), at NASA LaRC had proposed a new mission, GEOstationary TROpospheric Pollution SATellite (GEO TROPSAT), to address critical science questions of tropospheric chemistry. The troposphere is a complex system, comprising "point" and distributed sources of natural and anthropogenic origin; complicated transport processes, both lateral and vertical; and photochemistry driven by UV flux, temperature, atmospheric composition, and other variables. GEO TROPSAT would be implemented about a geostationary Earth orbital (GEO) position at the equator between 60° and 80° West longitude to observe the Americas and large portions of the oceans of either coast. This mission would advance our knowledge of the atmosphere by capturing the wide temporal and spatial variability of tropospheric phenomena which is undetectable from low Earth orbit.

A pre-prototype imaging carbon monoxide (CO) imaging system operating within a narrow waveband about 4.7 μm was built, demonstrated, and evaluated. This system applies the gas-filter correlation radiometry (GFCR) technique and produces digitized images comprising 4096 pixels, each representing a single CO mixing ratio measurement inferred from radiometric data. Associated tasks accomplished included specification for the next-generation prototype system to operate in the 2.3-μm waveband; characterization of a 64×64, InSb focal-plane-array (FPA) imager; design, fabrication, and assembly of a filter wheel; and software development. Laboratory evaluation of this system involved imaging of a test cell placed in the path of radiant flux emanating from a blackbody source used to simulate the radiant energy reflected by Earth in real application. The cell was evacuated for system balancing and then charged with measured quantities of CO to provide a means for system characterization.

Two related research efforts were undertaken during the term of the study reported here – continued development of an atmospheric CO imaging instrument and characterization of diode-laser beams. Both efforts were successful and are described within the body of this report. A second objective was to provide a means for undergraduate ISAT majors to become involved with the research described, to be afforded the opportunity to learn the technologies associated with the work performed. Two ISAT students gained a comprehensive understanding and interest in missions supported by NASA through direct involvement in this project. Many more students were exposed to these technologies though demonstrations, laboratory tours, and explanations provided in lecture.

ATMOSPHERIC CO IMAGING INSTRUMENT

GEO TROPSAT is a scientifically compelling mission designed to provide a means for imaging and characterization of tropospheric pollution from geostationary orbit through the use of advanced instrument technology (large focal plane arrays) and novel access to orbit (commercial communications satellite partners). Peer review of the successful ESSP (Earth System Science Pathfinder) Step 1 proposal stated clearly that a "strong advantage [was] associated with the rapid update and spatial continuity" of the GEO TROPSAT science data; that GEO TROPSAT provided an "innovative approach for tropospheric chemistry measurements; "and" a unique approach relative to traditional tropospheric chemistry missions."

Dr. Miles, with the assistance of Mssrs. Keith Holland and Payam Yazdani, undergraduates in the ISAT program at JMU, continued the development of an infrared imaging system to perform GFCR for imaging and measurement of CO in the troposphere. This work followed from the previous development by Dr. Miles of a pre-prototype instrument at LaRC during June–August 1997. The goal of this effort was to produce an improved GFCR system for CO imaging. The objectives, and related tasks completed or attempted in order to address this goal, are described below.

- The GFCR technique was applied using an existing 4.7-μm CO-imaging system (Cincinnati Electronics IRC-64) in order to test concepts pursuant to imaging of tropospheric CO from space. The system developed by Dr. Miles at NASA LaRC was re-engineered and new software tools were developed to improve the performance of the re-engineered system.
- A new infrared imaging system (Cincinnati Electronics IRRIS-256LN) was delivered during the term of this study and was exercised. A complementary frame-grabber package was purchased and tested with the new imager. Testing was performed to determine the maximum rate at which images can be acquired and stored (6 to 10 images per second is desired) and the capability of the system in terms of organization of image files.
- Experiments were to be developed and executed for the new imager to characterize properties and phenomena inherent in the new imager such as signal-to-noise ratio, effects on measurement due to the presence of window etalon, and effects on measurements as a function of tilt between windows. The experiments were conducted at JMU and additional ones were conducted at NASA LaRC during Summer 1998.
- Demonstration of CO imaging and measurement was to be attempted using a continuously-rotating filter wheel radiometer system tuned to 2.3 μm.

I. In regard to the first bulleted item above, the entire system developed to perform GFCR for imaging and measurement of CO was re-engineered in order to make a more flexible and robust system. This was accomplished by incorporating a friction-drive system to replace the existing direct drive system that proved to be difficult to control.

A laser/detector system was added to the apparatus to provide position monitoring. The laser detector is interfaced with the data-acquisition/motor-control system, thus providing real-time indication of position and LabVIEW™ interfacing through which the motor can drive the filter wheel in either start-and-stop or continuous mode.

The original filter wheel was re-engineered and machined in order to accommodate the improved friction-drive system, the laser/detector position-monitoring system, and gas filters larger than those used in the initial development of the CO-imaging system. The drawings for the upgraded filter wheel system as shown below. All engineering and machining was performed by Mssrs. Holland and Yazdani under the supervision of Dr. Miles and Mr. Mark Starnes, chief machinist for ISAT.

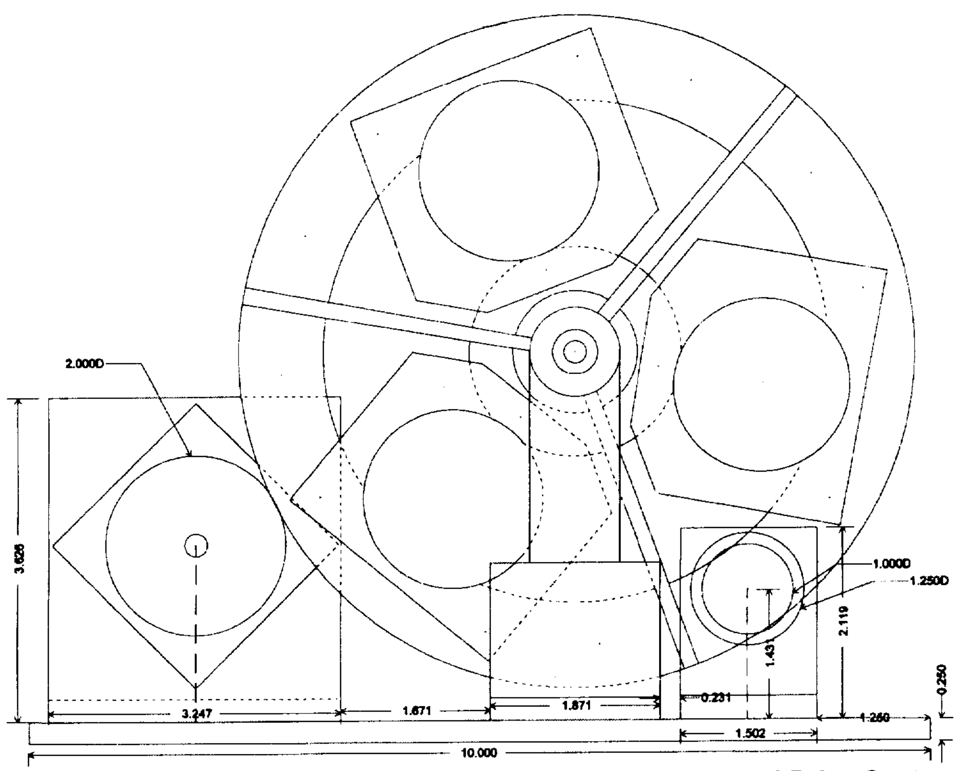

Figure 1 CAD Drawing of Re-Engineered Filter Wheel and Drive System.

Upon completion of re-engineering and machining, an upgraded system for GFCR was available as shown in Figure 2. The elements that were added to the system during the term of this study include:

- a new motor mount on side of filter wheel for friction-drive;
- a new camera mount with micro-positioning capability;
- a new base plate to support entire system;
- a re-designed filter wheel that accommodates larger gas filters;
- re-engineering of filter mounts;
- laser/detector positioning system.

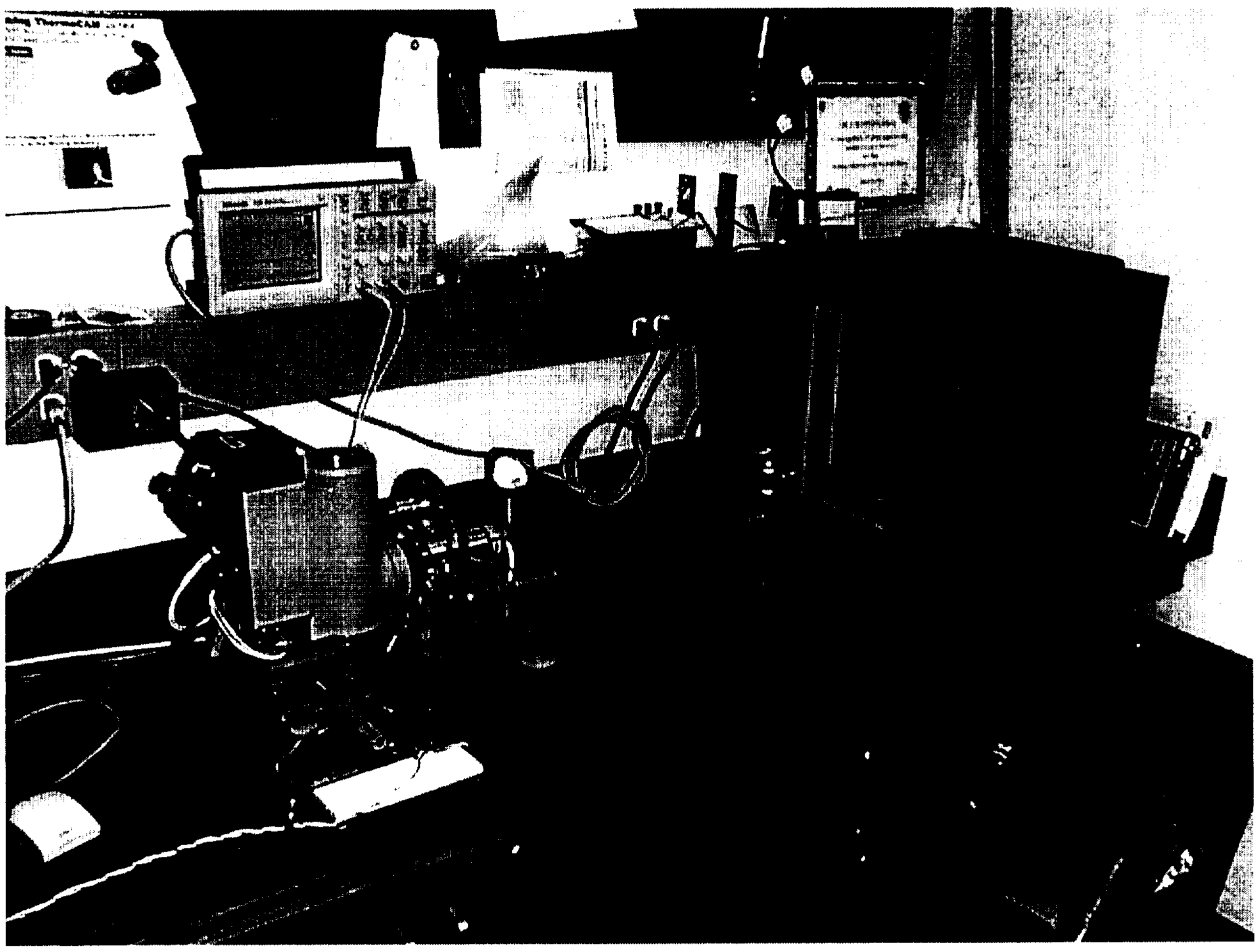

Figure 2 GFCR CO-Imaging System at JMU.

All results pertaining to the performance of the upgraded system are documented. A LabVIEW™ program was also developed that permits flexible control of the wheel rotations while operating in either stop-and-go or continuous mode and interfaces digitally with both the laser/detection system and the image-acquisition system that supports the Cincinnati Electronics IRRIS-256LN infrared imaging system.

II. During the course of this study, a new Cincinnati Electronics IRRIS-256LN 256×256 infrared imaging system was delivered and tested. An after-market image acquisition and analysis system was also purchased. The task of interfacing the imager, image-acquisition hardware/software, and PC with Windows NT was tedious, but completed successfully. The LabVIEW™-based motor-control system was also interfaced with the aforementioned equipment, thus providing a complete GFCR system based upon the newer imaging technology.

The IRRIS-256LN infrared radiometric imaging system was characterized with respect to background noise in each pixel and the extent of the near photon noise limitation. This task was accomplished by Mr. Yazdani during Summer 1998 at NASA LaRC through a series of experiments in which the IRRIS-256LN imaging system, an open-faced dewar, a high-reflective optical flat mirror, metal breadboard, and blackbody were utilized. Programs used on the PC were *Take.C*, *PDV Display*, *Raw2Ascii.C*, and *MS-Excel*.

Phase 1

To test for background noise in each pixel, an open-faced dewar was filled with liquid nitrogen and placed below the IRRIS-256 camera. A metal breadboard was attached to the table. A highly reflective mirror was then attached to the breadboard and placed at a 45° angle to capture an image of the dewar. It was checked to ensure the mirror was only imaging the liquid nitrogen and not the sides of the dewer. The camera was then placed so that it could only image the mirror and therefore the liquid nitrogen (Figure 3). Using *Take.C* a picture could be taken and converted to an ASCII file using *Raw2Ascii.C*. This file could then be opened in *MS-Excel* to record pixel values. To acquire a clear, unadulterated indication of pixel values, the camera was operated in uncorrected mode.

Phase 2:

To test for near photon noise limitations, the IRRIS 256 camera was placed in front of the blackbody. The camera should only look at the black surface of the blackbody. To achieve this, some sort of stand was used to elevate the camera. The lens of the camera should also be very close to the blackbody surface but not touching. For better data, a black cloth could be draped over the camera and blackbody thereby minimizing external interference.

Once this configuration is set up, *Take.C* could be utilized to acquire ten successive images. These raw values could then be converted to ASCII format using the *Raw2Ascii.C* code. Once converted, these values could be converted into a spreadsheet format using *MS-Excel*. The standard deviation and mean are then calculated. And used for analysis.

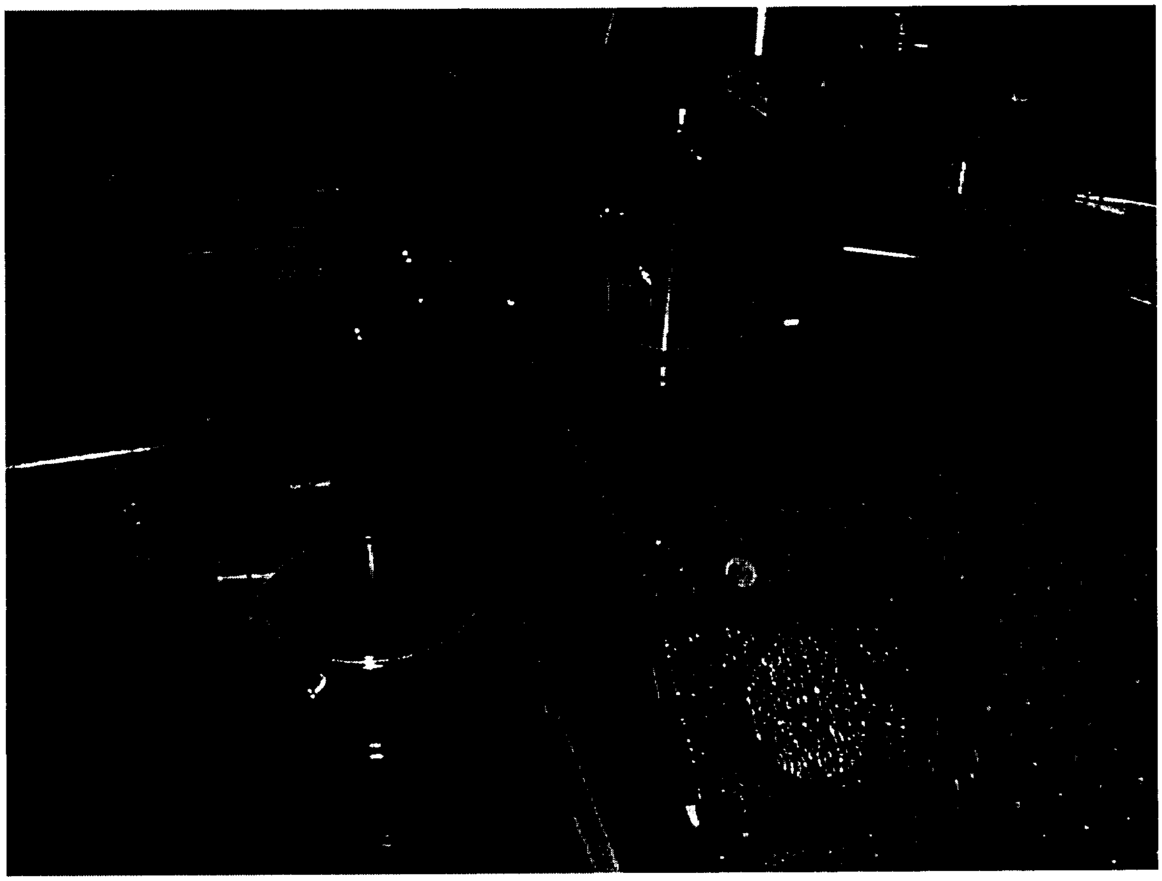

Figure 3 IRRIS-256LN infrared radiometric imaging system set up for system characterization.

DIODE-LASER BEAM CHARACTERIZATION

A second effort was undertaken to support the DACOM mission through which high-precision measurements of atmospheric gases are made from an aircraft platform. In-situ trace gas sensors based on diode lasers have, over the past two decades, proven their value to the atmospheric science community by providing high sensitivity and fast-response measurements of key atmospheric gases. Even with this highly successful application of diode lasers, the performance of such sensors rarely achieves theoretical limits (e.g. detector- or photon-noise-limited operation.)

In practice, the sensor performance is limited by the non-ideal properties of the mid-infrared (generally Pb-salt-based) diode lasers that result in "optical noise." Difficulties in growing high-quality Pb-salt crystals, and fabricating good optical resonators in these inferior materials, lead to degraded optical performance that ultimately limits sensor sensitivity.

A good indicator of laser quality is its far-field pattern, yet this property has rarely been observed due to the high cost of mid-infrared imaging instrumentation. Fortunately, relatively low-cost mid-IR cameras are now available that could enable the rapid diagnosis of far-field patterns. With such a diagnostic tool, many lasers may be characterized quickly, enhancing the selection process for good diode lasers. This tool may also be used to investigate methods to improve diode laser radiation patterns (e.g. placement of pinholes in the near field, creation of simple external cavities, blocking radiation from the rear laser facet, etc.)

The objective of this component of the JMU research effort was to develop an imaging apparatus to routinely observe and record diode laser far-field patterns. The anticipated approach was to allow the rapidly diverging diode laser beam to scatter off a diffusive material. This scattered radiation, in turn, would be imaged by an infrared camera sensitive in the 2 to 5-μm wavelength region. Primary tasks included the finding of a suitable "projection screen" and the development of camera software.

III. Efforts were also conducted by Mr. Yazdani to determine the effects that two different lenses would have on radiometric data acquired from a diode laser (see Figure 4). The focusing of these optical devices were tested at different lengths from the infrared imager. This experiment was conducted using a Laser Diode, the IRRIS-256 imager, and germanium zinc-selenide optical lenses. Computer programs used for imaging the data included *PDV display*, *GraphPDV*, and *Take.C*.

The setup consisted of the imager placed 12 inches from the laser diode being imaged. Initially the diode should not have either lens focusing the beam and the imager should be equipped with lens. The camera should then be focused onto the laser window. Once the camera is focused on to the front of the laser diode, the lens on the camera should be removed. One of the optical lenses should be placed in front of the diode to focus the beam into the imager. Upon the best focus of the lens, a picture can then taken using the *Take.C* program. The *GraphPDV* program can then be opened and the file saved using *Take.C* can be opened. *GraphPDV* is a program that determines the centroid of the picture and then takes data 20 pixels into each direction. The midway point of the graph provides the width of the laser beam, measured in pixels. This process should be continued every inch for each of the lenses. The setup is shown below.

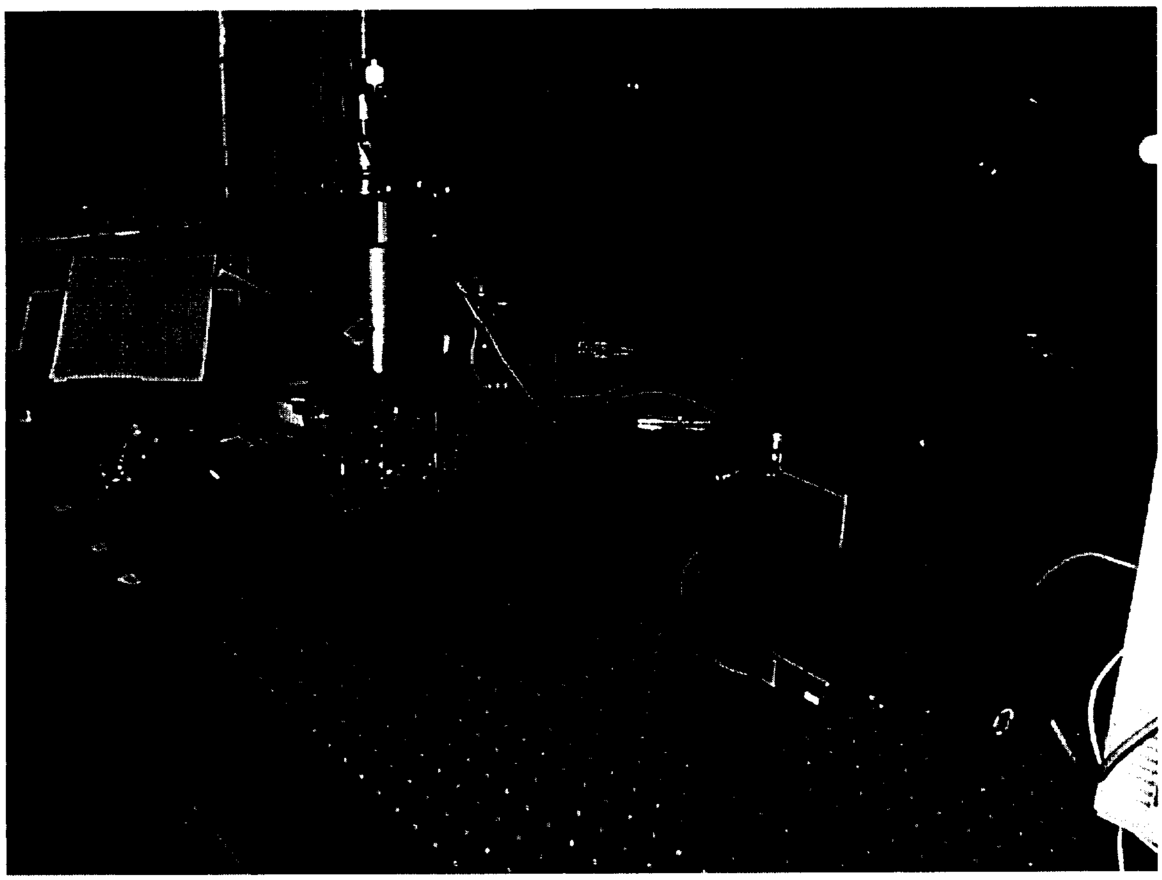

Figure 4 IRRIS-256LN infrared radiometric imaging system set up for lens characterization study.

IV. Using two separate types of diffusing paper, Mr. Yazdani also compared the infrared images generated through these two papers at different laser currents and compounds using both carbon monoxide and methane lasers.

A diode laser, new and old pieces of Spectralon material, a Kodak DC120 digital camera, and the IRRIS-256LN imager were used for this study. Programs used included *Take.C*, *Take12.C*, *Raw2Ascii.C*, and *PDV Utilities*.

The imager was positioned directly in front of the laser with the focal point approximately 21 inches from the laser. The piece of Spectralon material used was taped in front of the laser window and the laser turned on to just above threshold current. The current was then changed and the material switched from the old to the new diffuse material sample. Pictures of the image would then to be taken using the Kodak camera.

V. A final study was performed by Mr. Yazdani to characterize diode laser beams using the IRRIS-256 infrared imager. Characteristics of the laser changed frequently due to the method used for cooling. Several of the characteristics discovered could have changed due to new lasers being used and replaced parts.

Phase I

This experiment used the diode laser, two plastic deflectors and the IRRIS-256 imager and computer programs *PDV Display*, *PDV Utilities* and *Take.C*.

The Diode Laser was placed facing one of the plastic deflectors set at a 45° angle. Another deflector was then place in order to receive the beam and deflect it into the camera. This second deflector was also oriented at a 45° angle. This beam was deflected directly into the camera (Figure 5). These deflectors help to attenuate the laser beam in order to observe the change of power over a wide range of currents.

Phase II

This experiment used the diode laser, Spectralon reflectance target, and the IRRIS-256 imager. Computer programs used included *PDV Display*, *PDV Utilities*, and *Take.C*. The diode laser was placed facing the Spectralon reflectance target, and the imager was placed adjacent to the diode laser. The imager was also placed in position to take pictures of the Spectralon. The laser power was then varied over a range of different currents and pictures of the Spectralon were taken. Several different pictures were taken and used to analyze various laser patterns.

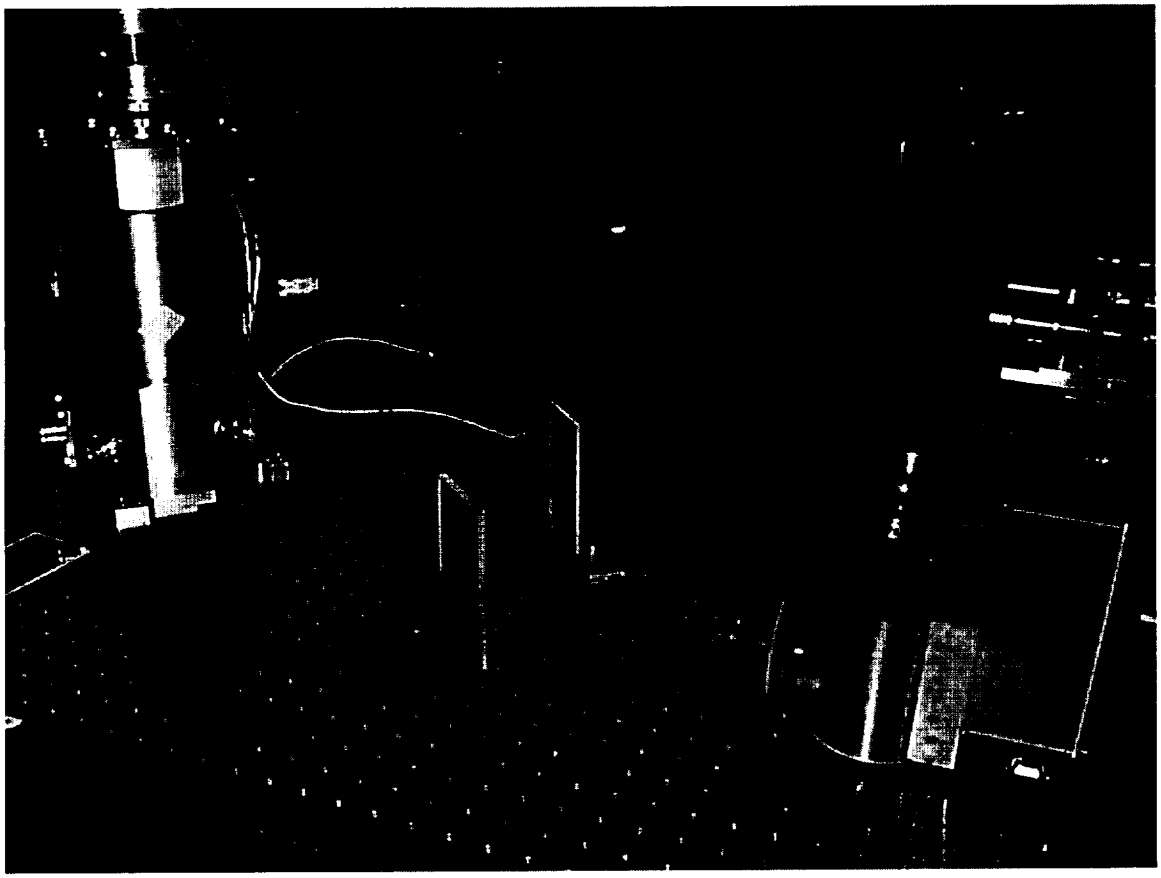

Figure 5 IRRIS-256LN infrared radiometric imaging system set up for laser characterization.

UNDERGRADUATE RESEARCH EXPERIENCE

The program of Integrated Science and Technology at James Madison University is an exemplary response to calls for creative, discovery-oriented learning environments and educational reforms. The educational component of this cooperative agreement provided students at the undergraduate level an opportunity to focus on innovative research important to the community of atmospheric scientists and engineers who develop precision optical measurement systems. The research assistantships offered through this funding provided students a discovery-oriented learning opportunity that capitalizes on the power of new technologies and learning paradigms, and also increased the range of postgraduate opportunities available to the students who participated.

This project included a formal agenda to provide undergraduates a significant early research experience in current research areas of importance to NASA. The students selected to participate directly in this project, Mssrs Holland and Yazdani, were afforded the opportunity to:

- develop a knowledge base with respect to the fundamentals of infrared detection and imaging including radiative heat transfer, detector parameters and types, radiometric operation and testing, and instrument development;
- develop an understanding of the relationship between atmospheric gas constituents and associated radiative properties;
- provide assistance to the principal investigator with respect to the research objectives and activities described above;
- develop senior project ideas.

The ISAT program at JMU mandates to all students the development of a senior project idea and associated proposal during the second semester of the junior year. Students must complete the project during their senior year and prepare a thesis that is graded and presented orally to the faculty and student body. This represents the capstone activity of the ISAT program. Many students seek activities such as summer internships or research opportunities through which they acquire experience upon which to base a meaningful senior project. One student who participated in the efforts described in this proposal will convert his experience into his senior projects, the other will apply the knowledge and techniques he has gained to applications in the field of biotechnology

SUMMARY

The studies and tasks described in this report were instrumental in addressing the objectives described. An improved CO imaging and measurement system has been developed, the performance attributes of the Cincinnati Electronics IRRIS-256LN 256×256 infrared imaging were determined, and a number of techniques for diode-laser characterization were developed. Some of these techniques have since been adapted for use in the DACOM mission.

A new research and educational proposal has been approved. Under this new project, several objectives have been developed that will lead to further refinements in the CO-imaging system already developed. This new instrument will also support the continued growth of the Infrared Testing and Development Laboratory at James Madison University, and many new opportunities for undergraduate research experiences of a highly technical nature.

Many thanks to Mr. Glen Sachse, Ms. Pamela Rinsland, and Mr. Alan Little of NASA Langley Research Center for their tireless support of the educational mission of James Madison University and development of a research capability at this institution that will benefit many future students.