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Two-Phase Flow Measurement

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INTRODUCTION:

Liquid fuel engines have many applications in today's world. Diesel, spark-ignition, and gas turbine engines, and furnaces are just a few of the many applications of liquid fuel sprays. With the rising cost of fuel and need for energy conservation it is imperative that more efficient engines be developed. Analyzing liquid fuel spray characteristics non-intrusively could unlock the door to powerful highly efficient engines in the future.

The vaporization of fuel is mandatory in liquid fuel combustion. Vaporization and the fuel to air ratio are important characteristics of the spark-ignition engine. Compression ignition is controlled by the parameters of the injected fuel spray. By developing an accurate non-intrusive method of measuring the fuel spray parameters, data collected could be used to develop fuel injection methods that increase the power output, and raise the fuel effeciency of an engine.

The infrared absorption method of determining fuel spray characteristics provides a non-intrusive method to measure vapor concentration, but little is known of its accuracy. The goal of this project, which is being sponsored by the National Science Foundation, is to develop an accurate method of measuring evaporating sprays and their spray distribution. The non-intrusive laser method uses the known absorption of hydro-carbon fuels at a wavelength of 3.39 microns to measure spray characteristics namely accurate quantitative measurements of the vapor phase.

GOALS OF THE PROJECT:

The goal of the project is to develop a method to test the accuracy and limitations of the infrared absorption method. To do this the infrared method will be used in an environment with a known flow rate in order to test the accuracy of the hardware as well as the method itself. To simulate the two-phase spray, polystyrene seed will be injected into a methane gas spray. This "two-phase flow" gives more flexibility in two-phase measurement because of the range of vapor-solid ratios that can be varied. Since the vapor-solid ratio is known, the accuracy of the infrared technique can be easily tested. In order to develop an environment with a known flow rate and an adjustable vapor-solid ratio input, a two-phase flow test section was developed.

The focus of the summer project was to develop a two-phase flow test section to meet the criteria of the project as suggested in the NSF proposal. This test section injected a methane spray with polystyrene seed into a moving air flow. A window in the test section would allow the laser based diagnostic equipment to measure the characteristics of the two-phase spray including particle size, and fuel vapor concentration. A schematic of the test section is attached. A design for the air moving system and preliminary sizing of the test section had to be completed. In addition, a translating fuel nozzle system, and an air filtration system, which provided clean air, had to be developed for the test section. Supply companies needed to be contacted for materials, and organization of the building of the section needed to be completed.

PROJECT OVERVIEW:

To begin the project a review of the project proposal was necessary. Jumping into the design cold could be time consuming as well as lead to a faulty design. The design criteria, which were outlined in the proposal, would be met more completely when a solid feel for the project was gained. Although the design criteria did not specifically outline the size and shape of the test section, certain characteristics needed to be met. First, a two meter per second flow speed in the section was needed. This speed provided ample exhaust for the combustible gases, but maintained uniform flow in the test section. Secondly, the test section must be wide enough to accommodate the spray patterns to be tested. It was decided that the test section needed to sustain a 30 degree cone 15 inches from the injector. To maintain this spray pattern the section needed to be 10 inches wide. Finally, the section must be long enough to provide a relatively smooth uniform flow in the section. A flow straightener, which is nothing more than an aluminum sheet with a honeycomb pattern, helped develop the uniform flow. The added length of the test section above the view window helped maintain uniform flow as well. By skimming other similiar project proposals, ideas were developed on how to overcome these obstacles and develop the best test section design possible.

DESIGN:

Section Size and Shape:

Preliminary sizing of the section was needed next. The test section shell shape, which would be either square, round or hexagonal, needed to be determined. After discussion with Professor Drallmeier, a ten inch square design was decided upon. This would allow for the nozzle movement necessary for testing. This size would also provide the needed fuel nozzle spray area. A square design would allow for easy placement of fused quartz windows in each side providing the viewing area for the laser based infrared extinction equipment. In the round or hexagonal shape the window placement would be more difficult. The square design also provided an easy method of attachment to the support stand, and could be easily fabricated out of the materials purchased. (Diagrams of the test section are attached following the report.)

Air Moving System:

Next the design consisted of developing an air moving system for the test section. The air moving system had to develop two meter per second flow in the section but also have a high enough exhaust flow rate so that back pressure would not develop in the section. Two meter per second flow in a 10 inch square section, requires a flow rate of about 300 cfm. A flow rate greater than 300 cfm was needed from the lab hood exhaust. Checking the specifications of two blowers owned by the University indicated that at the proper speed one of the blowers would provide the air flow needed for the experiment. After finding the proper blower, aluminum ducting to run from the blower to the section entrance and from the section exit to the exhaust hood was ordered. With the proper blower found, sufficient exhaust provided, and the adiquate duct work ordered the air moving system was complete.

Acquiring Materials:

In order to build the section and get the project off the ground supply companies needed to be contacted. One task was to determine materials that were needed for the test section and then order those from various companies. Names and telephone numbers of various supply companies were found in the Thomas Register. By consulting the Thomas Register an idea of the materialsthat were available for the design of the test section was obtained. After studying the register it was decided that many of the designs had to be adjusted to fit the materials that could be acquired for the test section, with material availability being a limiting factor. Minumum orders hampered the material acquisition process. The first design for the test section was a ten inch square tube. This tube could not be purchased without a sizeable order, therefore the design needed to be changed. The square test section needed to be formed out of four aluminum sheets. Problems such as this one slowed the project and forced many design changes.

Leveling Mechanism and Test Section Shell:

After gaining an understanding of the materials available, plans for the design were put down of paper. The plans were to be developed using the MacIntosh Draw II software available for project use, after gaining a working knowledge of the software.

A leveling stand for the structure was needed to insure accurate experimental results. This leveling stand provided a means not only to level the two-phase flow test section but also to transverse the section in the horizontal direction. Movement of the section was important to provide enough measurement positions for the laser based flow measuring device. Drawings of the leveling stand are attached. Plans were also drawn for the test section shell itself. It was to be constructed of one-fourth inch aluminum plate on the viewing sides and one-eighth inch aluminum sheet on the non-viewing sides. The one-eighth inch sides would then be screwed to the one-fourth inch viewing side plate. This method provided a sturdy section which resists buckling and also provided a thick side to attach the fused quartz window. The drawings of all designs were reviewed, approved by Professor Drallmeier and then turned into the machine shop for construction. The test section shell drawings are attached.

Window:

The window design was a baffling problem, but with a few ideas from Professor Drallmeier the problem was soon conquered. The window was to be rigidly supported but also maintain a smooth inside surface so as not to disrupt air flow inside the test section. A four and one-half inch window was agreed upon to give the needed size for the spray measurements to be taken by the laser. To support the window to the front plate of the test section the plate was machined to a depth of three-sixteenth of an inch to fit the window dimensions. The one-sixteenth of an inch of aluminum supported the quartz on the inside, and a small aluminum plate was added over the outside edge to fasten the fused quartz firmly to the text section shell. This design provided the needed support of the window, and the small inside section variation would not disrupt the air flow inside the test section. (Figure attached)

Injector Movement:

Now that the support stand and test section shell had been completed it was time to concentrate on the fuel injector movement. The injector needed to be capable of horizontal movement and vertical movement. As mentioned before, the support stand provided horizontal movement in one direction. A mechanism for vertical and perpendicular horizontal movement needed to be designed. This movement problem was overcome by using threaded rod movement of a small support inside the section itself. By turning the threaded rod outside the section the injector inside is moved horizontally to the correct position. A simple set screw in the block is loosened to allow the fuel injector vertical movement to any position needed in the desired test zone. The traversing method provided the means to measure the fuel spray in any position deemed necessary.

Intake and Exhaust Convertors:

Intake and exhaust from the ten inch square section was also a design problem that developed during the summer project. The unusually large size of the test section shell raised problems in finding the necessary duct work fittings. From the blower a six inch round aluminum duct was used in order to provide enough air flow and because of the ease with which the flexible aluminum duct could be positioned. But a round six inch to square ten inch convertor was needed to complete the blower connection. After consulting the Thomas Register again it was decided that this fitting could not be purchased and would have to be designed. A local sheet metal shop fabricated a convertor for both the top and bottom of the section. The bottom convertor section consisted of a sheet metal box with a six inch exhaust outlet, enough room at the bottom for any liquid that might collect there if a liquid spray were used, and a small drain to allow for the removal of this liquid. The much simpler top convertor section again consisted of a sheet metal box, but the six inch air inlet was at the top instead of the side as in the bottom section. The top convertor was long enough so that the entering air would become relatively uniform over the test section cross-section before being probed with the laser. These convertors completed all but one major part of the air flow network.

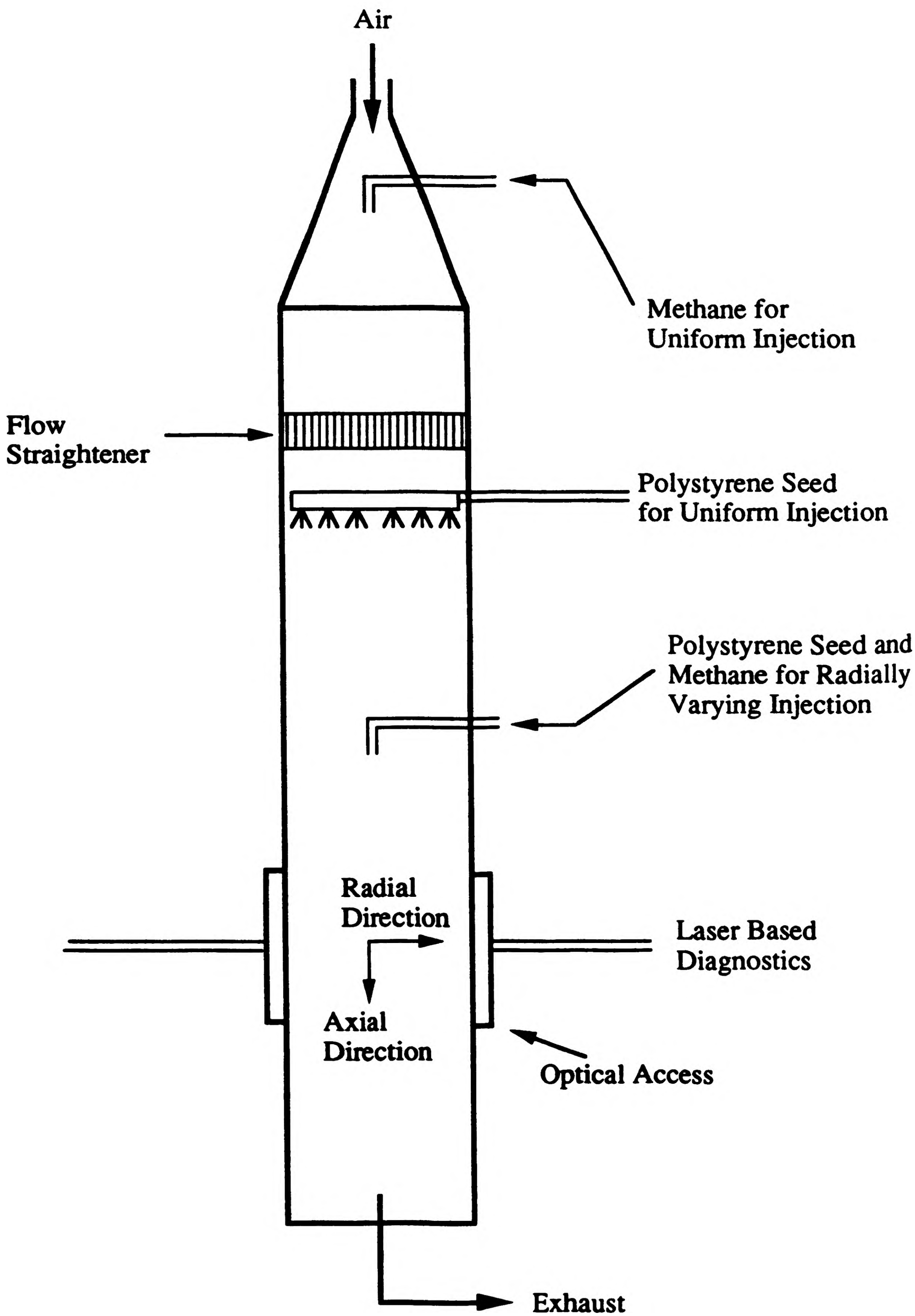
Filters:

Filters are used to clean the entering air, and collect seed from the exiting air. Both the entrance and exit filters needed a small pressure drop with a flow rate of nearly three hundred cubic feet per minute, and also required a high efficiency at the one to three micron range. Filtering particles of this size would eliminate some measurement errors caused by particle interference. Also, due to the expense of the polystyrene seed a method of recovering the seed was necessary to keep experimental cost as low as possible. An exit filter would be needed to carry out this task. After discussing the project and filter parameters with several companies it was found that the necessary filters could be acquired, and the design of the test section as a whole was then complete.

Conclusion:

The design of the test section components was not an easy task and many difficulties arose. Many first designs were changed because better ideas were suggested, or because of the lack of the necessary materials needed to build the design. A minimum order, which was required by many companies, also hampered plans for the project. But despite the problems encountered along the way I enjoyed working on the project tremendously and I believe I learned a great deal from working one on one with Professor Drallmeier.

The summer research program is not only an excellent method to attract students to graduate school, but it is also a good learning experience for undergraduate students. By working with the professors in a one on one environment much can be learned about project design, research, and personal relation with outside companies. The research program gives the student an opportunity to get a taste of graduate studies and also gain knowledge that will help in the outside world. Professor Drallmeier used the test section project to give me first hand knowledge of research work but also showed me design techniques, company research, and methods to communicate project needs with outside companies. When a professor works closely with a student the many problems encountered in a project can be overcome.


Air
Methane for
Uniform Injection
Flow
Straightener
Polystyrene Seed
for Uniform Injection
Polystyrene Seed and
Methane for Radially
Varying Injection
Radial
Direction
Laser Based
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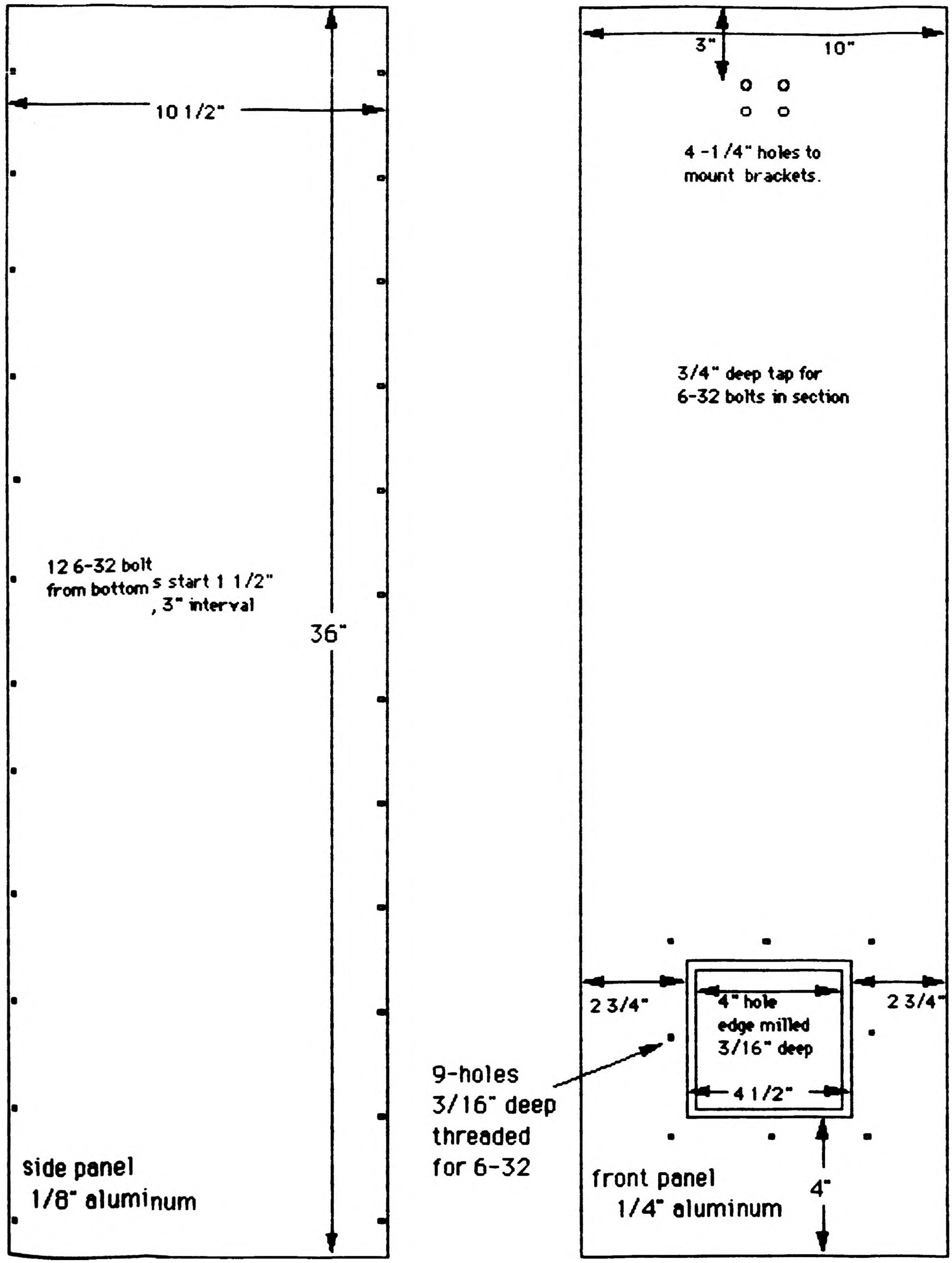
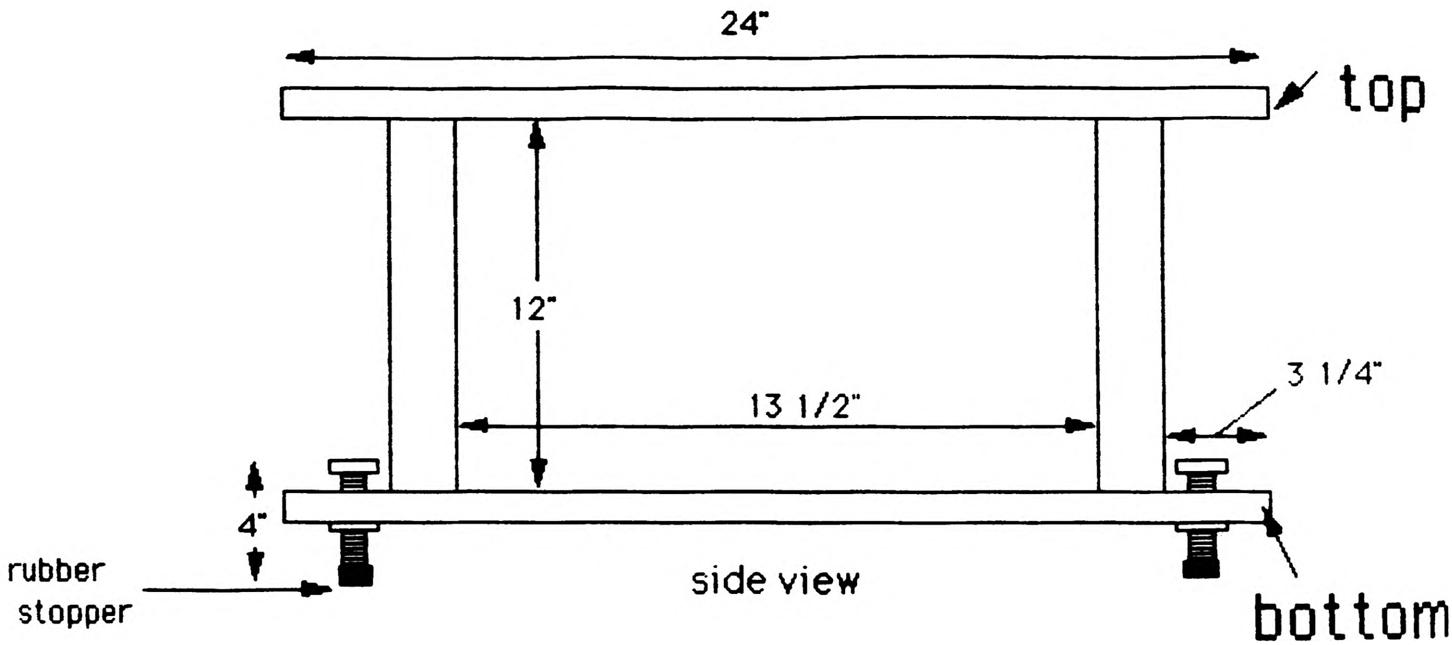
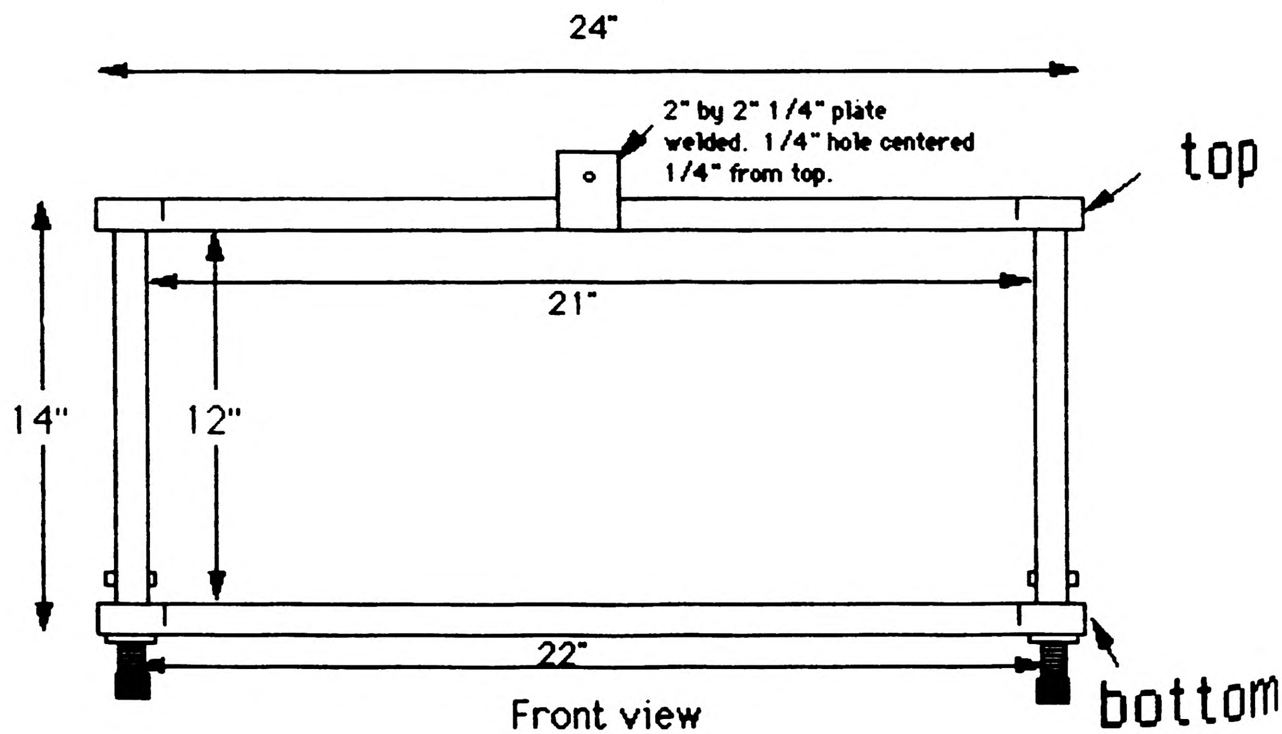
Axial
Direction
Optical Access
Exhaust



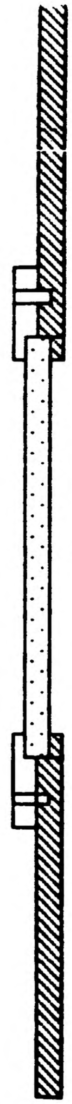
section size



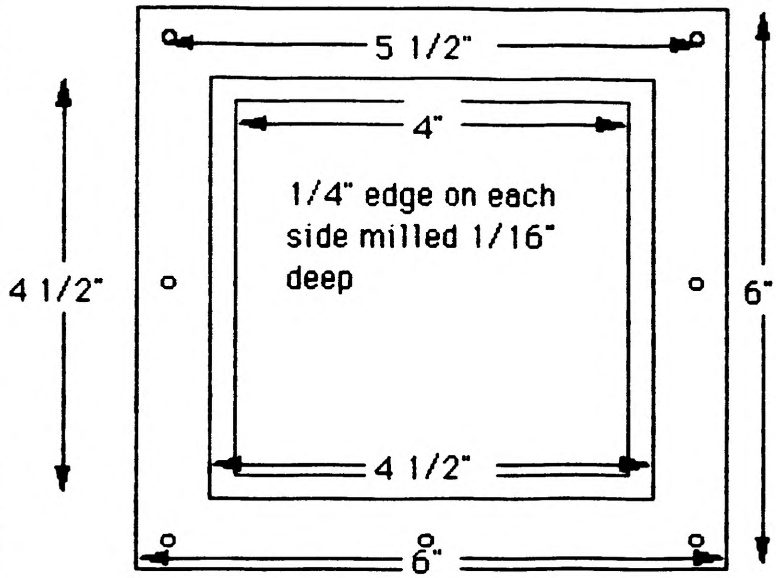


Leveling Stand

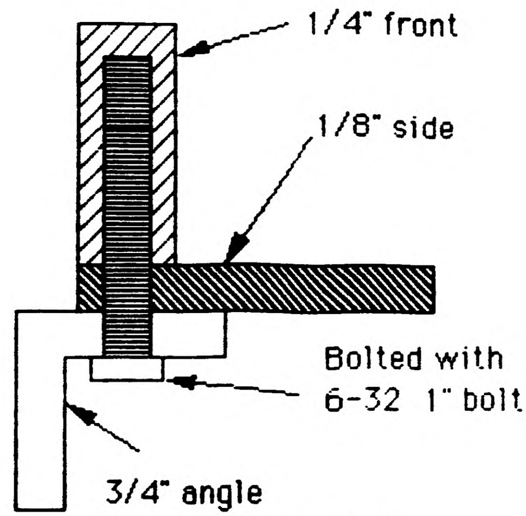
All structural material 1 by 2" tubing.



glass seal



cover plate

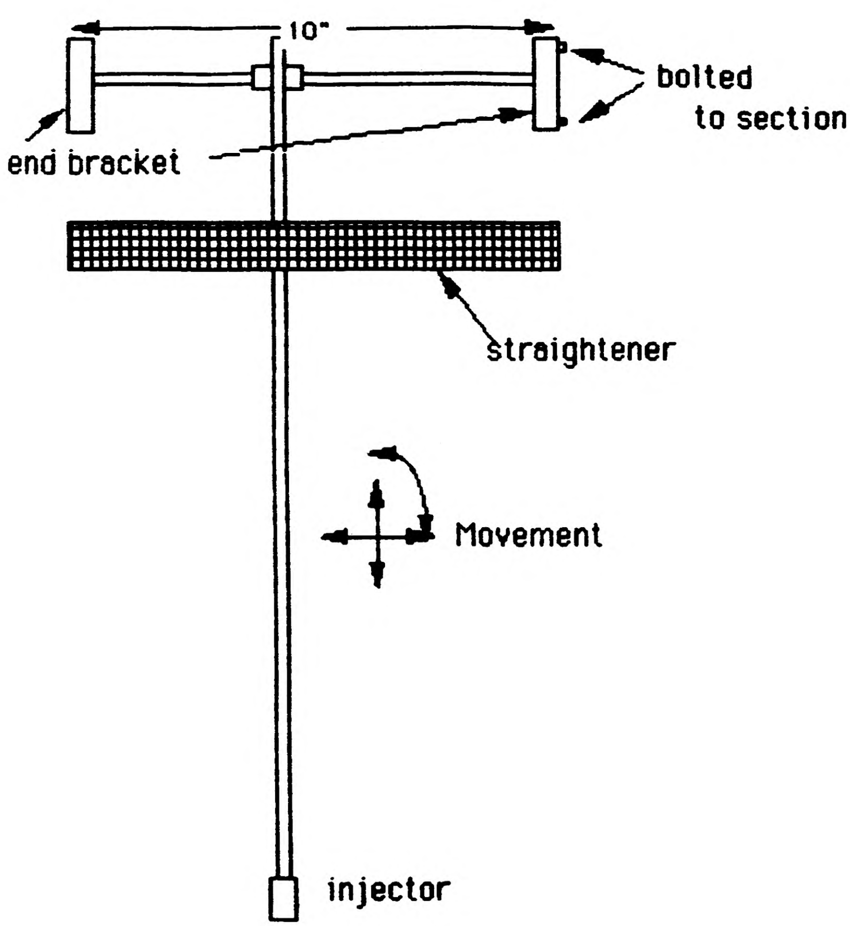


side fixing

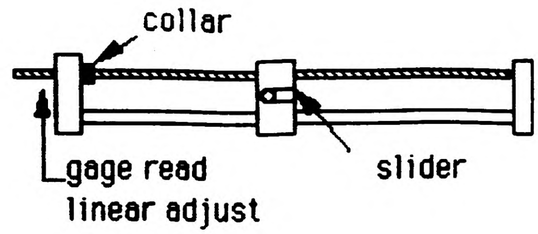
1/4" plate aluminum

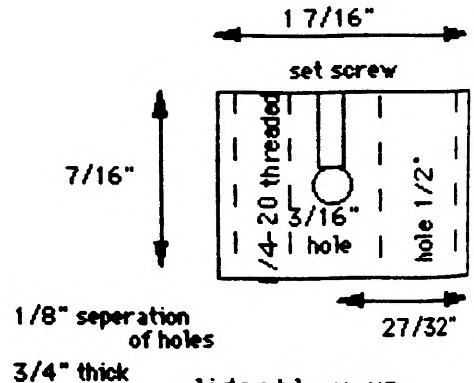
9 6-32 screws
3/16" into front plate

Window Mount



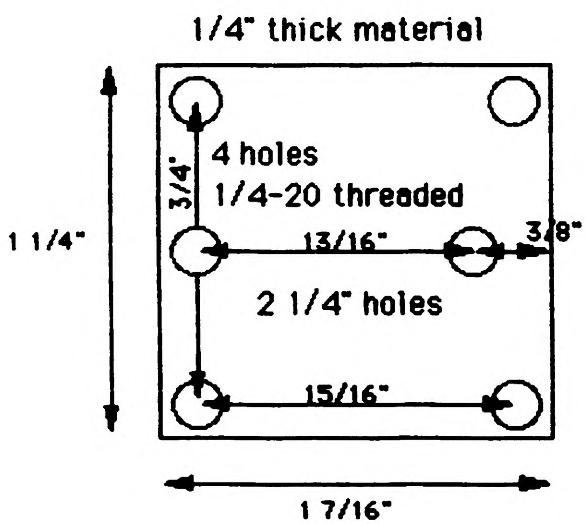
side view



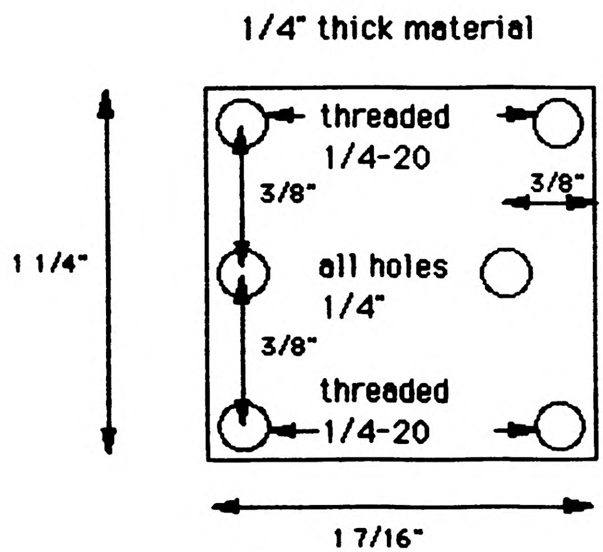


slider blow-up

top view



End Bracket
Back Side



End Bracket
Front Side

Injector Movement