Apparatus Design for Atomization Studies of Plant Oils

by

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ABSTRACT

Many researchers conclude that one of the major obstacles to overcome in the widespread acceptance of plant oils as a fuel source in diesel engines is the elimination of residues that wear engine parts, contaminate engine lubrication systems, and lower engine efficiency. There is evidence that atomization of the fuel is an important factor in reducing harmful effects of residue. The purpose of this project is to design and construct an apparatus to study the degree of atomization and the atomization pattern of the plant oils under varying parameters of injection pressure and fuel viscosity. This information, in turn, may help achieve optimum atomization patterns and increase the possibilities of plant oils as a viable alternative energy source in diesel engines.

[1] The citations used in this paper will follow the style of the <u>Transactions of the ASAE</u> (American Society of Agricultural Engineers).

ACKNOWLEDGEMENTS

Many people who have aided my progress towards the completion of this project. I would especially like to thank my advisor, Dr. Wayne A. LePori, Associate Professor of Agricultural Engineering at Texas A&M University, for his guidance and support throughout this project. His insight into the Fellows Program is great because he made the student perform the work. His patience and concern for the student when "everything" went wrong enabled me to learn more than I otherwise would have learned.

Mr. Bill Morton, Supervisory Engineer for Diesel Injection at Bendix Corporation gave important design considerations of the injection pump, cam, and nozzle spray tip.

Dr. Fred Bouse, USDA Specialist, who gave information on the use of the PDPS-11c Particle Measurement System.

Mr. Bill Zingery, Agricultural Engineering lecturer at Texas A&M University, added ideas of pressure and temperature measurement of the pressurized fuel.

Mike Yarbrough, Agricultural Engineering researcher, provided the idea for measuring the mass flow rate of fuel.

Dave Carney, for his excellent machine work on the cam follower assembly and drive stand.

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1. INTRODUCTION

1.1 BACKGROUND

Until recently, plant oils had been receiving increased attention as alternative energy sources in modern diesel engines. Due to the current surplus of world petroleum supplies, interest has slowed. It is important however to continue the search for alternative energy sources. Plant oils are a plentiful, natural, renewable resource. Often referred to as vegetable oils, plants that are most commonly grown for oil are soybeans, sunflowers peanuts, and cottonseed. Most farmers are attracted to the prospect of producing their own fuel and possibly increasing the value of their farm commodities.

Plant oils are similar to diesel fuel in energy content as shown in Figure 1. In spite of this, plant oils, differ from diesel fuel in physical properties and chemical structure states Ziejewski, (1982). Plant oils have viscosity levels nine times higher than diesel fuel as illustrated in Figure 2.

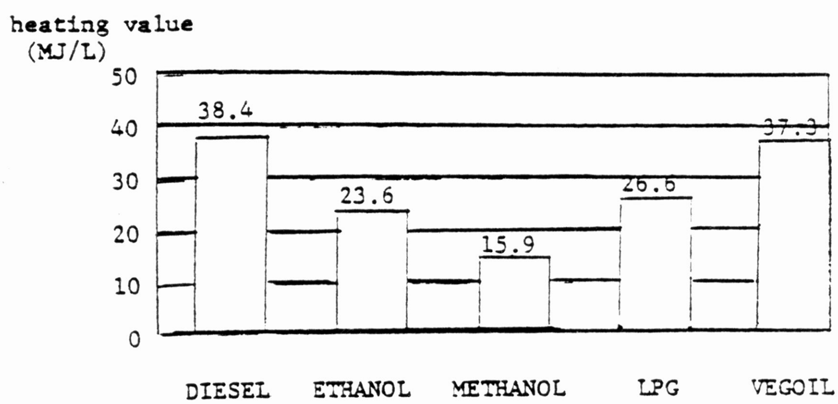


Figure 1: Specific Volume Energy Content of Various Fuels

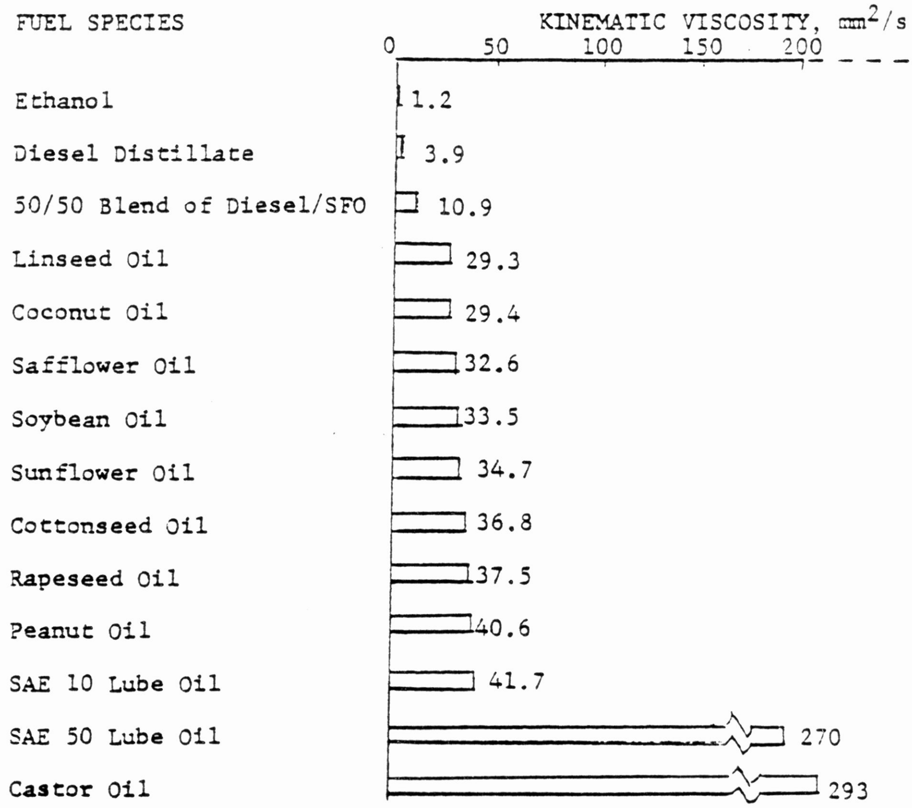


Figure 2: Viscosity Levels of Commonly Tested Plant Oils.

From the engine performance standpoint, these differences materialize in the fuel injection, air/fuel mixing, and combustion initiation and development. Ziejewski, among others, state that after a short period of time, the test showed excessive carbon buildup on the nozzle tip. He attributes the responsibility of carbon buildup to: (1) the sunflower oil tendency to polylmerize, (2) the small quantity of fuel which remains at the nozzle tip after the end of the main injection, and later (3) injection nozzle "micro" reopenings, (4) secondary injection and (5) needle sticking.

Soot forming in the combustion chamber of a diesel engine seems to be a function of two variables; (a) the chemical structure of the fuel, and (b) the localized zone of fuel/air mixture in the combustion chamber.

1.2 PURPOSE

This report concentrates on the fuel injection and air/fuel mixing processes controlled by atomization of the fuel entering the combustion chamber. Atomization is the process of reducing a body of fluid to a fine spray. By achieving an atomization pattern similar to diesel, I theorize plant oils will achieve better engine test results.

From a durability standpoint, Barnescu and Lusco (1982) found that atomization characteristics of plant oils are likely to effect the amount of engine and fuel deposits, the rate of engine wear, and the low temperature operation.

The quantification of atomized particles and distribution patterns present a challenging problem. But atomization studies with the aid of modern technology, high performance injection pumps and nozzles, enable us to pursue the characteristics of atomization to higher pressure levels than conventional engines.

Since very limited data concerning plant oil atomization exists, this study was undertaken to develop and construct a sophisticated and diversified apparatus to produce, control, and record the atomization patterns of plant oils.

2. REVIEW OF LITERATURE

2.1 BASIS OF ASSUMPTIONS

The basic assumption of the test is that the transient liquid fuel spray can be analyzed as an isothermal turbulent gas jet. This approach has been taken by Thring and Newby (1953), Abramovich (1963, Sinnamon (1980) for use in model of piston engine fuel sprays.

Abramovich reasoned that the fuel droplets in a spray could be treated as a very dense admixture in air. Although the fuel spray is initially pure liquid, it both entrains air and vaporizes as it moves downstream of the nozzle. The liquid fuel droplets soon become a small fraction of the jet volume. Since the velocity of the small droplets relative to the vaporized fuel and entrainment air is small, the spray acts as a gas jet.

The assumption that the transient spray can be treated as a steady-state phenomenon is an extension of Abramovich's approach which arises more from necessity than from sound physical justification. The empirically determined similarity profiles normal to the axis of a steady state jet are applied to concentrations and velocities in the unsteady fuel spray. While there is no data available on time dependent local concentrations or velocities within a fuel spray the Lasa-Raman measurements reported by Johnston (1979) for gaseous propane injection into an engine cylinder indicate that steady-state assumptions are reasonable. Johnston showed that fuel concentrations at a fixed location within the gas jet remained nearly constant during injection. The concentration profiles across the jet were not unlike the steady-state profiles assumed in the model.

2.2 PROPERTIES THAT EFFECT ATOMIZATION

Modern atomization theory for steady state flow systems has found that particle size is a function of surface tension and viscosity properties of the liquid as well as the pressure drop across the injector, orifice type, and diameter, and the mass flow rate states Jasuga (1979). Viscosity being a function of temperature while pressure drops result from changes in the mass flow rate and the nozzle diameter.

Viscosity and surface tension are physical properties of fluid. A fuel droplet, however small, consists of a number of molecules arranged in inner and outer layers. In a fuel oil, as in all liquids - the cohesive forces give rise to two characteristics, viscosity and surface tension.

The unbalanced force acting on the outer layer of the molecule pulls them inward, and thus they act as a skin around the droplet. Viscosity in a liquid results form the resistance to pulling apart or seperation of the molecules. Molecular theory has shown that the distance between two molecules increases as temperature increases. The increased distance results in a smaller cohesive force between the molecules. Since the seperation of molecules lowers molecular cohesion, viscosity is lowered and fluid flows more readily through pumps and nozzles.

Besides altering the physical properties of the fuel, the injection system could also be modified. Pressure drop across the spray tip nozzle is essential because it imparts a velocity to the injected fuel. The velocity of the fluid molecule is essential to atomization because of the tremendously unbalanced force of the ambient air on the molecular forces. The transfer of the fluid's kinetic energy to the static and entrainment air causes the liquid to undergo rapid deceleration. The external forces thus formed exceed the internal molecular cohesion and the particles atomize until equilibrium is reached between external air and internal molcular forces.

2.3 PARAMETERS OF ATOMIZATION STUDY

The basic energy equation for fluid flow states that velocity is proportional to the square root of the pressure drop across the orifice. The parameters of mass flow rate, nozzle type, and nozzle orifice diameter are signigicant factors in achieving injection pressures. The studies of Dana Lee (1932), A. K. Jasuga (1979), and W. S. Janna and J. E. John (1979) confirm this fact.

The experiments indicated that for a given fuel the fineness and uniformity of the atomization increased by increasing the jet fuel velocity and decreasing the orifice diameter. Orifice length-diameter ratio and chamber-air density had no decided effect on the spray atomization. Impinging jets sprays, and sprays formed by a jet striking a metal lip were found to have no better atomization than sprays from plain orifice nozzles, provided that jet velocity was the same, but the distribution of fuel within these sprays was found to be much better than for plain sprays.

According to Sinnamon, four conservation equations comprise the steady-state jet model. These include conservation of fuel mass, conservation of total mass, and conservation of both the horizontal and vertical components of momentum. The equations, which are integral in form, are written for a cylindrical element of thickness ds normal to the jet axis as shown in Figure 3.

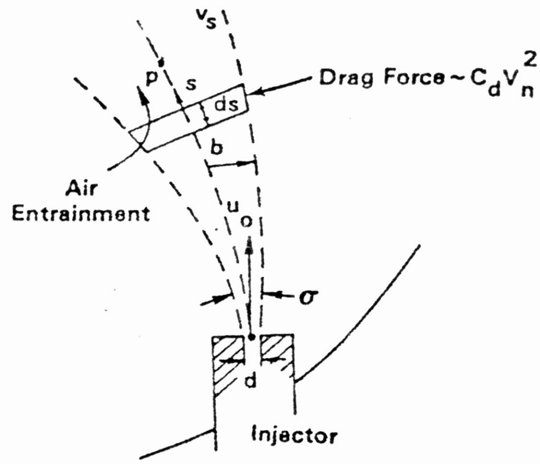


Figure 3: Steady State Jet Model

A thorough explanation of the momentum equations is given by Sinnamon (1980).

His conclusions were:

1. Conservation of Fuel Mass,

$$\frac{d}{ds}\left[\int C \rho \, u \, dA\right] = 0$$

2. Conservation of Momentum,

$$\frac{d}{ds}\left[\int \rho \, u \, dA\right] = (\rho_m \rho_\infty)^{1/2} \, 2 \, b = \frac{d\dot{m}}{ds}$$

3.

$$\frac{d}{ds}\left[\cos(\theta) \int \rho \, u^2 \, dA\right] = V \cos(\varnothing) \frac{d\dot{m}}{ds} + F_d \cos(\theta)$$

4.

$$\frac{d}{ds}\left[\sin(\theta) \int \rho \, u^2 \, dA\right] = V \sin(\varnothing) \frac{d\dot{m}}{ds} + F_d \sin(\theta)$$

where d - orifice diameter

ρ - liquid fuel density

u - jet velocity at injector orifice

b_t - jet radius at transition point.

ρ_∞ - air density outside jet.

f - distribution function (also f(ε))

ε - dimensionless distance from the jet axis to radius

β - $\left[1 - \rho_\infty/\rho\right]$ - fuel mass fraction on jet centerline at transition point.

Assumptions:

1. air entrained by the jet prior to the transitor point does not change the jet momentum.
2. jet centerline velocity at transition point is equal to the initial velocity.
3. fuel leaves the nozzle with a uniform velocity over its cross-section.

2.4 METHODS OF ATOMIZATION STUDY

2.4.1 particle measurement

The National Advisory Committee for Aeronautics, presently NASA, studied diesel fuel atomization in a 1932 report. The report studied the effect of nozzle design and operating conditions on the atomization and distribution of the fuel sprays.

The system was designed for a single stroke of injection and to have the following characteristics:

1. constant time for a given fuel quantity to be discharged regardless of engine speed.

2. sharp start and cut-off of fuel spray.

3. constant fuel dispersion and penetration regardless of engine speed; except for the effect of air flow.

A single injection of fuel was essential because the particles had to be manually trapped, counted, and sized. This mechanical means of measuring atomized particles disturbed the spray pattern and caused error in the recording of data as the smaller particles evaporated, drifted, or combined with larger drops.

Modern methods to gather data of atomization include lasers, light scattering, and high-speed photography, among others. Many studies have been done on on fuel sprays in diesel engines. The studies of Borman and Johnson (1962) and Alder and Lyn (1969) are extensive lists of references on diesel engines and sprays in general. Visualization has been used to study unsteady sprays and combustion in engine conditions by several investigators including studies by Wakuri et al. (1960), Lyn and Valdmanis (1962), Huber et al. (1971), and Rife and Heywood (1974).

Spray pattern photographs taken by Barnescu (1982) compared jet spray plume geometry of diesel to blends of sunflower oil. The sunflower oil provided a heavier, more dense core of large sized particles in the spray plume.

2.4.2 computer modeling

Computer modeling to simulate fuel sprays in engines has become common practice in recent years. The work of J. Sinnamon (1980) gave an explanation of the types of modeling used. They range from the highly empirical correlations to detailed, multidimensional models which require finite difference solutions to the basic conservation equations. The intermediate approach taken by Sinnamon uses integral-type continuity and momentum equations and relies heavily on empirical data. He states that this model type includes enough basic physics to respond reasonably well to conditions outside the range of the empirical data on which it is based, giving it an advantage over purely empirical models. It also avoids the problems of large computer times associated with detailed multi-dimensional models.

3. FINAL APPROACH TO PROBLEM

The test apparatus is designed to atomize plant oils under varying parameters of flow rate, pressure drops across the orifice,and orifice diameters. The system to measure the atomization of the test fuels must be accurate and should not interfere with the natural trajectory of the fuel.

3.1 GENERAL CONSIDERATIONS

General considerations were that:

1. the type of particle measurement apparatus available for my use was the PDPS-11c Particle Measurement System. This unit cannot withstand or be adapted to high pressues and combustion of fuel in the diesel engine cylinders. Therefore, the apparatus the fuel must be "injected" into a non-combustable atmosphere in order to detect the particle sizes of the atomized stream.
2. Injection pressures should be considerably higher than conventional pressure ratings for diesel engines in use on farms.

The highly viscous plant oils will experience a lower injection velociy than diesel under equal pressures. To compensate for viscosity, injection pressures must be increased accordingly.

3. The apparatus must have constant and controllable parameters such as mass fuel flow rate, peak injection pressures, drive speed temperature to give consistent results. Control must be precise but the system must also allow flexibility in the ability to vary the parameters of study.

4. Fuel temperature should be controlled and measured to help determine the effect temperature has on atomization of the plant oils.

5. The purpose of particle measurement will be to study both the degree of atomization - actual particle size - and the atomization pattern - particle velocity and relative distribution of the different sized particles in all sections of the spray pattern.

4. DESIGN OF THE APPARATUS

The apparatus can basically be broken into four main functions; (1) fuel storage and transfer to the injection pump, (2) fuel injection pump and drive, (3) measurement of pressurized fuel and atomization, (4) measurement of the atomized particles. Figure 4 depicts the outlay of the entire system. Each portion will be discussed in detail with supplementary calculations located in the Appendix.

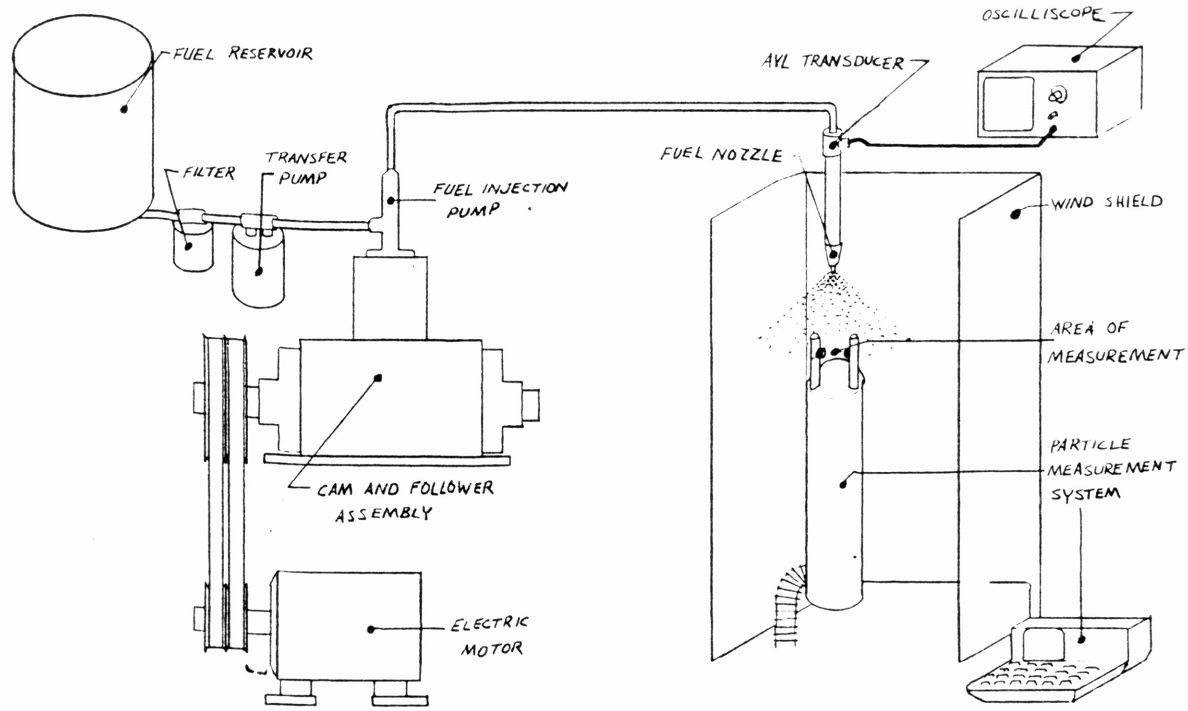


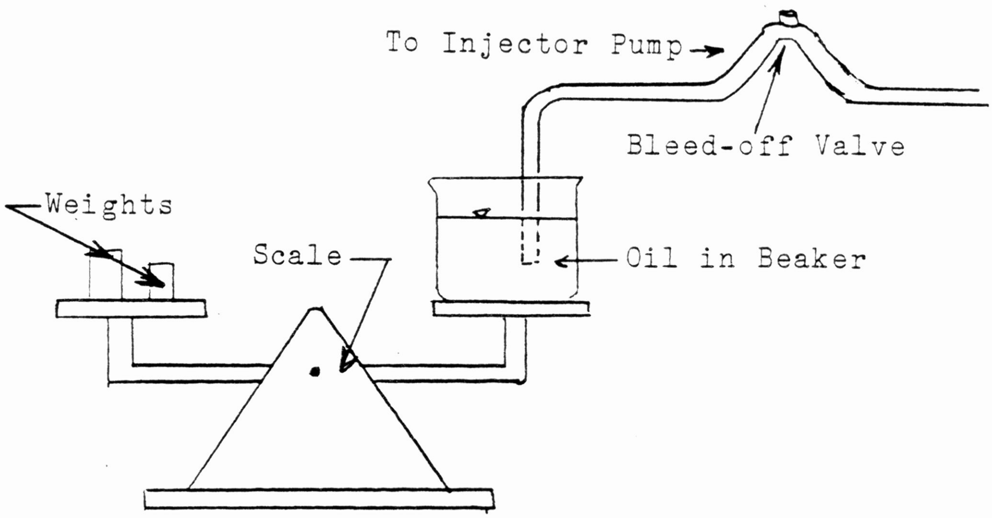
Figure 4: General Outline of Apparatus

4.1 FUEL STORAGE AND TRANSFER

Fuel storage and transfer to the injection pump is the first portion of the apparatus. This portion contains a storage tank, filter, transfer pump, and heating element.

The fuel tank is a 2 gallon metal container. The fuel is drawn out of the tank through a 10 micron fuel filter and then through a fuel transfer pump. The 10 micron filter was selected to adequately eliminate particles that might harm the injector pump or spray tip. The transfer pump is used to maintain enough pressure at the injection pump inlet port to prevent cavitation by insuring proper fluid flow. The transfer pump delivers a maximum pressure of 14 psi and is powered by a 12 volt battery. Connecting the storage tank to the filter is a clear, plastic tubing. The tubing allows for flexibility and detection of air in the fuel line. Stainless tubing is used to connect the filter, transfer pump, and injection pump components. The 1/8 inch diameter fuel line is long enough to allow for the heating of fuel between the transfer and injection pumps. A 300 Watt, 1/2 inch by 72 inch, electrical variable resistance heating tape is used to wrap around the tubing. Preheating of the fuel is performed by a band heater placed on the fuel storage tank.

The mass flow rate method of measurement involves the apparatus shown in Figure 5



1. fill beaker and overbalance to the beaker side.
2. prime fuel line.
3. begin testing the fuel oils
4. remove fuel through line until balance is zeroed.
5. remove 100 gram weight and start watch.
6. when balance is level - record time
7. account for tube density in fluid.

Figure 5: Apparatus for Determing Mass Flowrate

The buoyancy effect is path independent and therefore can be found by recording the distance between the starting and ending levels of fuel in the beaker. The difference between tube density and fuel density can then be added to find the corrected mass flow rate

4.2 INJECTION PUMP AND DRIVE

The second stage is the fuel injection pump and drive of the apparatus, illustrated in Figure 6. A Bendix FCX single-cylinder, plunger-type, high performance fuel injection pump is designed for pressure levels exceeding the conventional injection pumps in modern farm machinery. The pump can accomodate pressures up to 15,000 psi and 280 ^{o}F temperatures. The pump has flow rate settings from 0.2 to 3.8 gallons per hour. The one cylinder output was used for the simplicity of measurement and the lower power requirements.

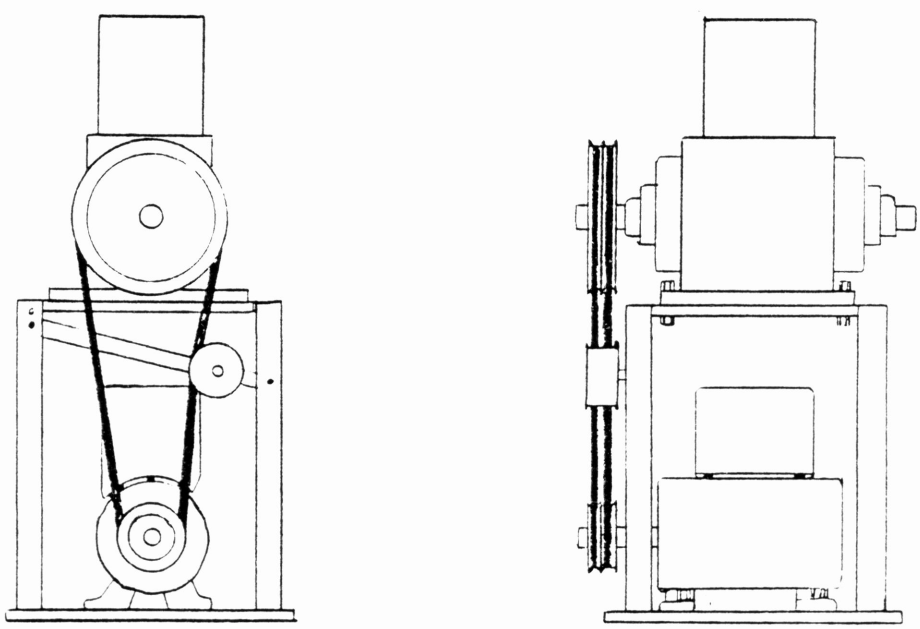


Figure 6: Motor and Drive Assembly

The power required to drive the pump at 15,000 psi is 4.6 Hp. The simulated engine that drives the pump is a 5 Hp, (1760 rpm) electric motor and a cam and follower assembly. The drive stand contains both the motor and the cam follower units. The drive stand will give a constant speed of 500 rpm to the cam and follower assembly. The motor has a high capacitance starter to engage the power needed for startup. A belt drive system was designed for the unit because of the smoothness and quietness of operation. A two belt system is needed to adequately transfer the power between the V-belt sheaves. The stand will have sufficient weight to resist vibration and deflection. The stand is approximately two feet tall and is made of 4340 cold rolled steel.

The assembly, illustrated in Figure 7, is the mechanism to transform the motor rotary motion into a precision stroke for the injection pump. The cam and follower assembly is designed for deflections of 20,000 psi peak pressures. The cam is a Bendix test cam L-8645-TC with lift, velocity, and acceleration profiles shown in the Appendix. At a speed of 500 rpm, the cam will provide the proper delivery of fuel to the nozzle for the 15,000 psi peak pressure range. Depending upon the mass flow rate and orifice diameter the pressure range is 5,000 psi to 15,000 psi. The cam is made of 4140 cold rolled steel and was machined using a numerically controlled lathe.

The follower assembly allows flexibility for different sized cams, variable operating speeds, different mounts for injection pumps, elimination of crankcase lubrication, and durability. Different sized cams that have a minimum base circle of 3 inches and maximum diameter of 6 inches can be used. Operating speeds can range up to 650 rpm. The

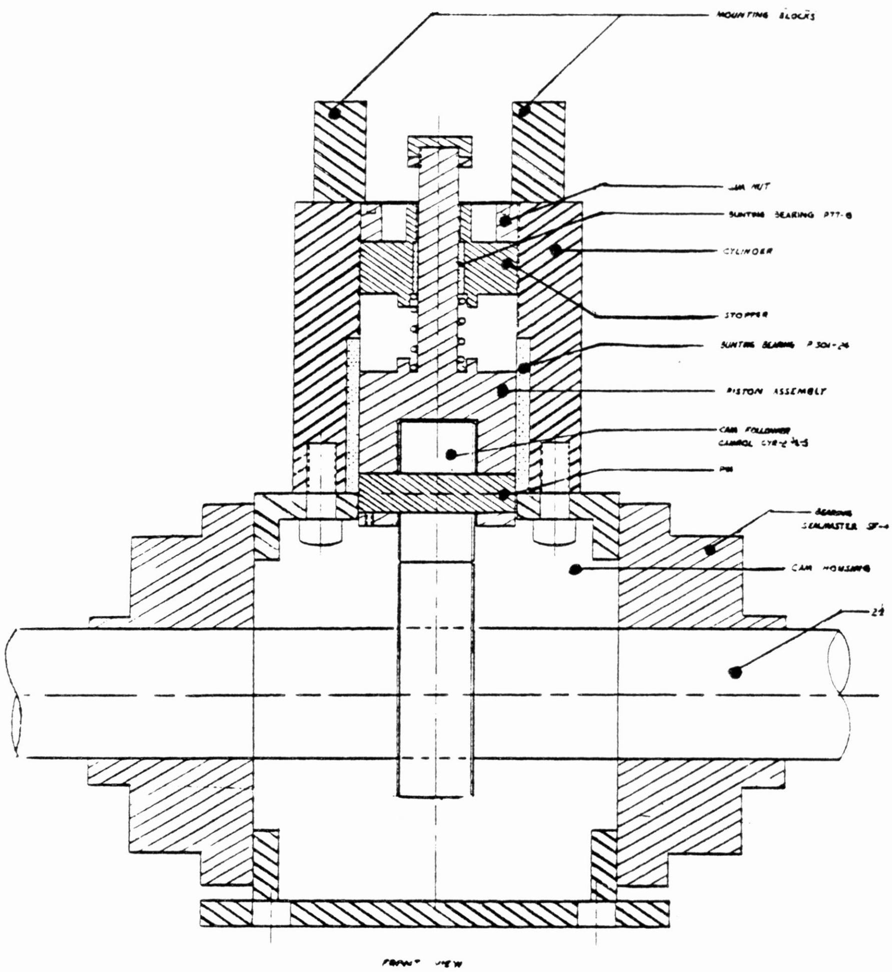


Figure 7: Cross Section of the Cam Follower Assembly

removable mounting blocks and plunger cap make the unit adaptable to almost any plunger type fuel pump. The cylinder wall is made of an oil-filled bronze bushing collar insert that provides adequate lubrication of the piston without an oil crankcase. The sleeves are also replaceable to increase the durability of the unit. Lateral loads that may accelerate wear on the cylinder walls are lessened by a cam roller follower. A slotted groove on the piston will keep the roller follower properly aligned. The weight of the piston is a significant factor to consider. The piston weight is reduced by a two bushing arrangement to reduce the piston diameter from 5 to 3/4 in.. The weight is further compensated by a stopper and return spring that assist in accelerating the piston downward upon completion of its stroke. This is necessary to insure the follower is in constant contact with the cam surface. Deflections are minimal and the unit is slightly overdesigned for possible use with even higher peak injection pressures in future research.

4.3 PRESSURE MEASUREMENT AND FUEL ATOMIZATION

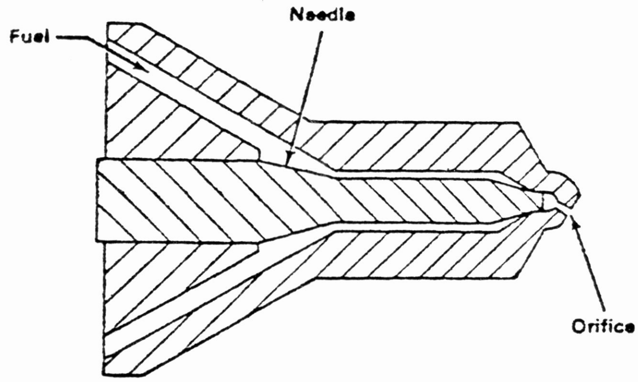
The measurement of pressurized fuel and atomization of the particles is the third major subdivision of the apparatus. Upon leaving the injection pump, the fuel is highly pressurized. The pulsating pressures resulting from the injector pump must be evaluated by a highly responsive device that can record the pressure curve of an injection stroke. First, to avoid rapid oscillation of injection pressures, the pressurized fuel line is 3 feet in length. This provides singulation of the injection stroke pressures. Second, to capture the instantaneous atomization pressure an

AVL strain gage pressure transducer is placed adjoining the fuel nozzle holder. The transduced voltage reading is then recorded on a calibrated oscilliscope screen for determination of the pressure level. An adapter to the transducer allows for easy installation into the fuel line. Transducers with a nominal pressure rating of 17,000 psi are recommended. The temperature range of operation is +14 to +194 °F. The unit will measure static pressure and have quick response to dynamic loading for peak pressures up to 150 percent of the nominal rating.

A type T (copper-constantan) thermocouple is fastened to the fuel line immediately upstream to the pressure transducer. The dissapation of heat from the fuel to the tubing will give an accurate reading of fuel temperature prior to atomization.

The Bendix HCL nozzle holder spray tips are designed to give three seperate pressure levels. Using the spray nozzle tip as the method to restrict flow and increase peak pressures will be achieved by reducing the nozzle diameter while keeping speed, temperature, and flow rate constant. Apparatus peak pressure levels are set for 6,000, 10,000 and 14,000 psi. These levels will produce data on the effect of injection pressure versus particle size.

The nozzle spray tips will impart a one directional flow to the fluid for simplification of the particle measurement scheme. The single orifice type of spray tip nozzle, illustrated in Figure 8, will be used.



4.4 MEASUREMENT OF THE ATOMIZED PARTICLES

The measurement of the atomized particles is the final function of the apparatus. The PDPS-11c Particle Measurement System employs a 2-dimensional optical array imaging probe to determine the number of differently sized particles and their size and speed. The instrument employs 64 active photodiode elements in an array and takes image slices at rates up to 5 million per second when a particle passes through. The data is then converted into useful results such as the Sauter Mean Diameter, particle velocity, and the percentage of droplet sizes present. The system configuration includes a color CRT display, a printer/plotter for hard copy output, two mini cassette transports for loading programs or logging data, and an automatic image slice rate generator for 2-dimensional probes. The system is highly flexible by measuring particles from 19 to 1675 microns at velocities up to 50 meters per second.

The sampling area is a laser beam 1 cent.in diameter and 6.1 cent. long. Only particles that completely pass through the beam are counted.

The smallest sampling rate is one per second. Since the smallest sampling period is substantially longer than the injection pulse, a time average sample of the spray must be taken. Time average of the spray in one sampling area will give average readings of the particle size present. As the sampling area is moved to a different region, more samples may be taken, until finally, data from other sections will compose the entire atomization pattern of fuel spray. Particle velocities will help determine relative penetration characteristics of the fuels.

A wind screen to reduce ambient air movement encloses the spray chamber. This will give a better approximation to the actual atomization pattern present. A gathering pan encloses the bottom of the wind screen to collect the atomized fuel.

5. LIMITATIONS OF THE APPARATUS

1. Temperature of the fuel oils must be carefully guarded. The transducer can serve in a maximum surrounding temperature of 194 F. If higher values are needed, they should be simulated by using blends with less viscous fuels to lower the viscosity level appropriately.
2. Tolerances within the pumping chamber must be guarded against fuels which lie below the 50 saybolt-second viscosity level. High viscosity levels will inhibit self-lubrication of the fuel pump, causing severe damage to the unit in a short time period.
3. The particle measurement system cannot be adapted to measurement in highly pressurized surroundings or give fractional second

sampling periods. High speed photography is one solution to the latter problem of sampling the near instantaneous fluctuations in a jet stream pattern.

6. RECOMMENDATIONS FOR FURTHER STUDY

This apparatus has been designed for future work in testing plant oils as alternate diesel fuels. Knowledge of the atomization characteristics of plant oils at various levels of pressure and temperature may lead to better long-term engine performance tests and acceptance of plant oils as a fuel source. The apparatus is currently designed for measuring peak pressures up to 10,000 psi and temperature levels up to 194 F. The AVL pressure transducer is the limiting factor in both cases. A transducer that withstands higher pressures and temperatures would enable the study of 15,000 psi peak pressures and 280 F temperatures.

7. CONCLUSIONS

An apparatus has been designed to effectively study the degree and distribution pattern of atomized plant oil fuels. The relationship of a pulsating fuel jet to steady state atomization theory has been found to give reasonable accuracy in earlier test systems. This apparatus will simulate a wide variety of conditions including fuel temperature, injection pressure, nozzle orifice diameter, and mass flow rate. The resulting atomization data will be used to draw conclusions of the most effective and significant parameters to control in achieving optimum spray patterns of plant oil fuels.

8. LIST OF MATERIALS

A. Fuel Storage and Transfer

5 gallon metal container

10 micron Fram fuel filter

12-802 Holly fuel transfer pump

1/4 in. Tryron tubing (4 ft.)

1/8 in. stainless tubing (2 ft.)

300 W (1/2 x 72 in.) heating tape

band heater

B. Fuel Injection and Drive

Bendix FCX-19 fuel injector pump #10-84899-40

Test Cam L-8645-TC

Dayton 5 HP 676K electric motor

Cam Follower Assembly

Camrol bearing follower CYR-2 3/4-S

2 - Fafnir RCJ- 2 in. bearings

Bunting oil-filled bushing P-77-8

Bunting oil-filled bushing P-301-24

Spring, Assoc. Spring Co. #C1225-135-1500

1/2 in. x 2 ft. x 2 ft. of 4340 CR steel

6 in. dia. x 12 in. length solid 4340 CR steel

14 - 1/2 x 3/4 in. fine threaded bolts

Motor Drive Stand

18 ft. of 1/4 in. L-shaped steel

3.0 pitch dia. * 2-A sheave with SH Bushing

10.6 pitch dia. * 2-A sheave with SDS Bushing

2 - A * 75 Torque-Flex belts

4 in. dia. idler pulley

18 in. long 2 3/4 in. dia. shaft

C. Pressure Measurement and Fuel Atomization

L-39011 high pressure fuel line

Type T copper-constantan thermocouple

micro-volt meter

AVL Pressure Transducer 31DP 1200 E - 2,0

30 DP.01.21

30 DP.01.35

30 ZD.02

trace oscilliscope

Bendix HCL 335 Nozzle Holder #10-39632-26

orifice type spray tips; 133030

133040

133050

D. Measurement of the Atomized Particles

4 ft. x 6 ft. 1/8 in. galvanized sheet metal

PDPS-11c Particle Measurement System

fuel gathering pan

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Appendix A

DESIGN EQUATIONS

Belt drive selection

Specifications; center distance 24 in.

service factor 1.3

belt life 400-800 hrs.

design horsepower 5 Hp.

$$HP = \frac{Q_f\ (rpm)}{5252}$$; where Q = torque in pound feet.

Allowable Tension Ratio; $R = e^{1.5123}$ basis of Effective Pull.

Tight Side Tension; $$T_t = \frac{1.25 * \text{Effective Pull}}{G}$$

Minor design considerations illustrated in the Gates Belt Design Book.

Design of the Follower Assembly

Shear Stress and Shear Deflection Due to a Lateral Load.

$$\tau_{xz} = \frac{V\ dx}{I}\int_{z_1}^{c} z\ dA \quad \text{and} \quad w_s\left(x = \frac{L}{2}\right) = \int_{o}^{L/2} \gamma_o\ dx = \frac{3PL}{8AG}$$

Deflection Due to Torque

$$G = \frac{\tau}{\gamma} \quad \text{where } k_t = \frac{T}{\phi} = \frac{GJ}{L} \quad \text{(lb-in./rad)}$$

Damped Free Vibrations

$$+\!\downarrow \sum F = ma: \quad w - k(\delta_{st} + x) - c\dot{x} = m\ddot{x}$$

Critical Damping

$$\frac{x_m}{P_m/k} = \frac{x_m}{\delta_m} = \frac{1}{\sqrt{[1 - (w/p)^2]^2 + 2(c/c_c)(w/p)^2}}$$

Kinetic Energy

$1/2\ mv^2 = 1/2\ kx^2$ where k = spring constant

Second Order Differential Equations for Spring Constant

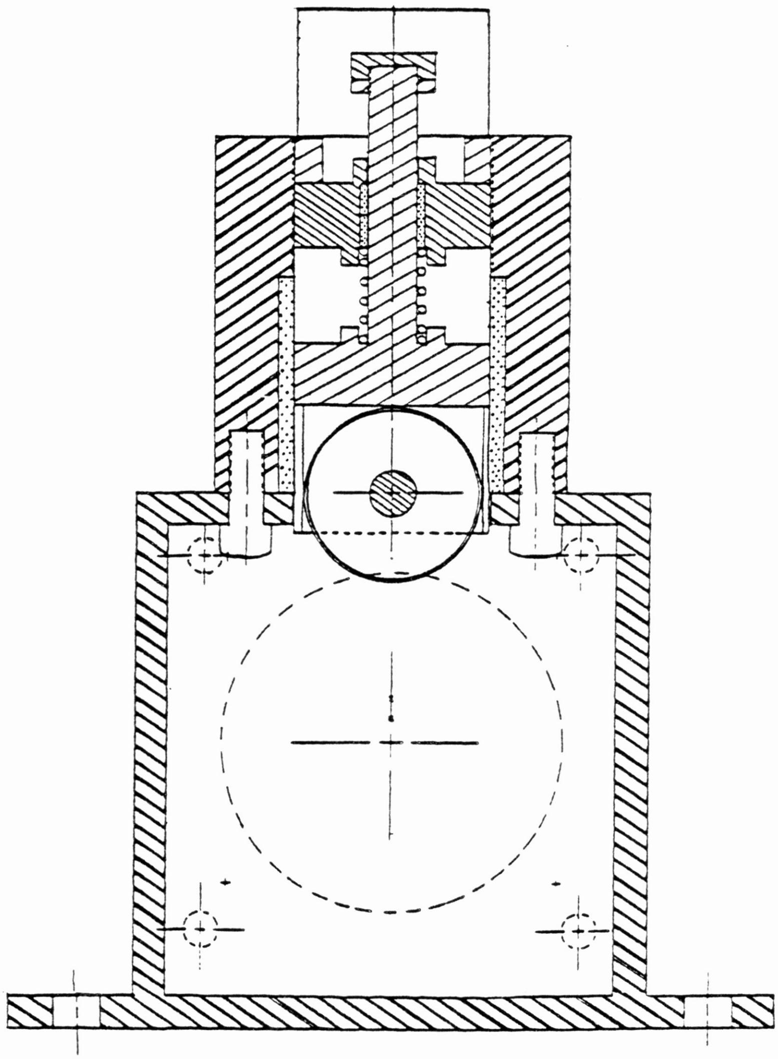
$m\ddot{u} + ku = F(t) = P_m \sin wt$

k was found to equal 113 $\frac{\text{lb.}}{\text{in.}}$

Appendix B

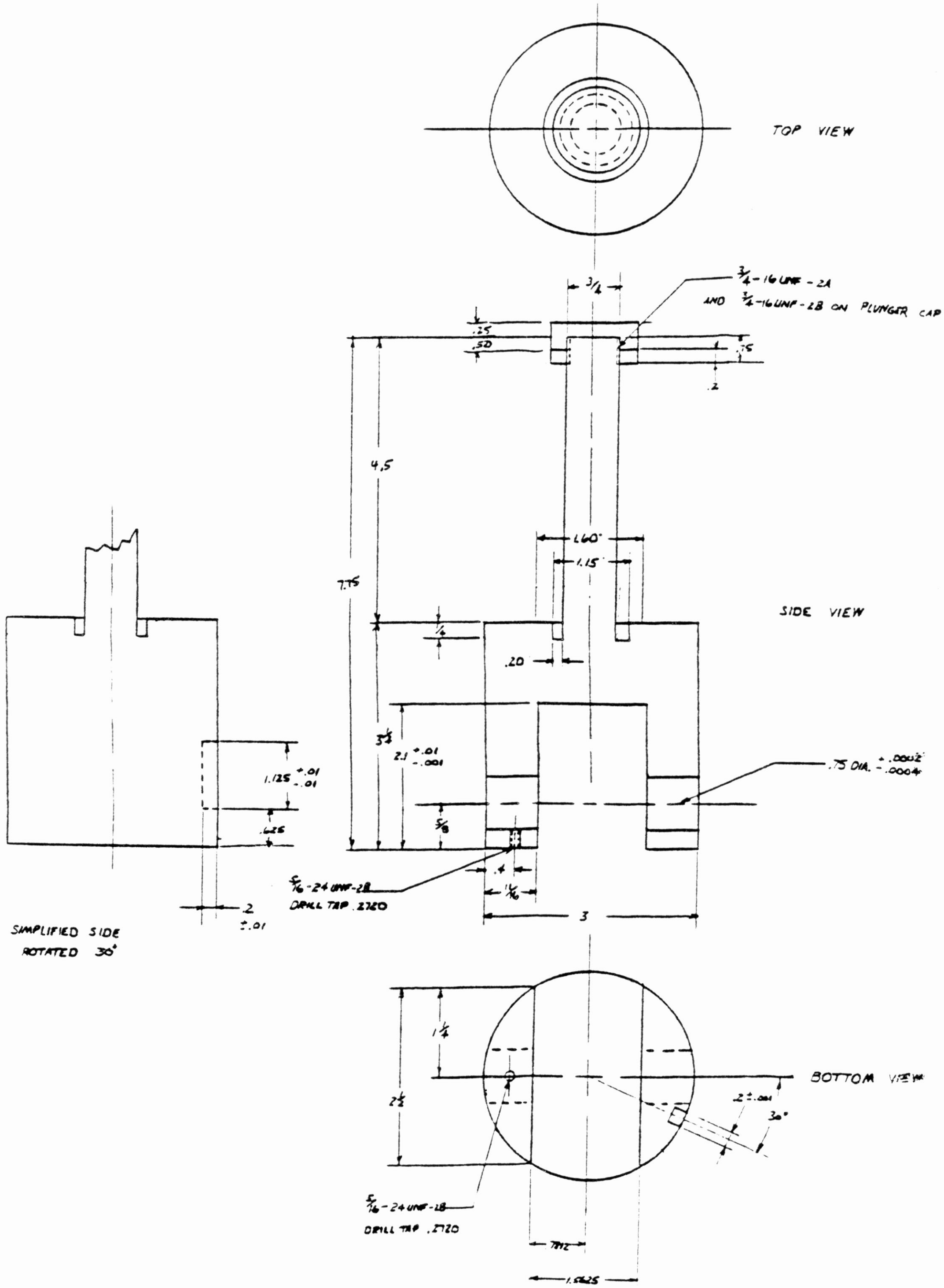
APPARATUS DRAWINGS

CROSS SECTION OF THE CAM FOLLOWER ASSEMBLY

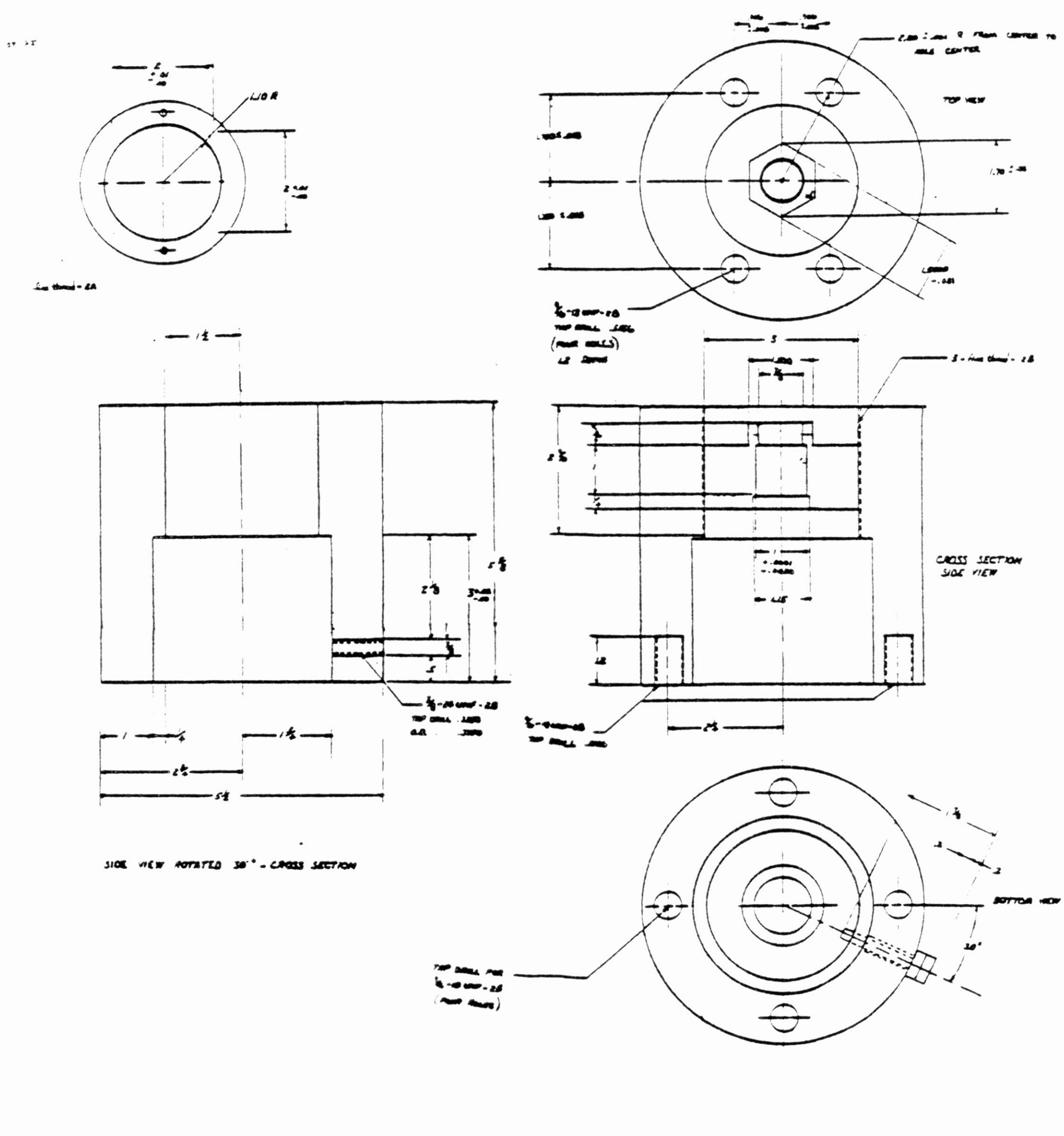


SIDE VIEW

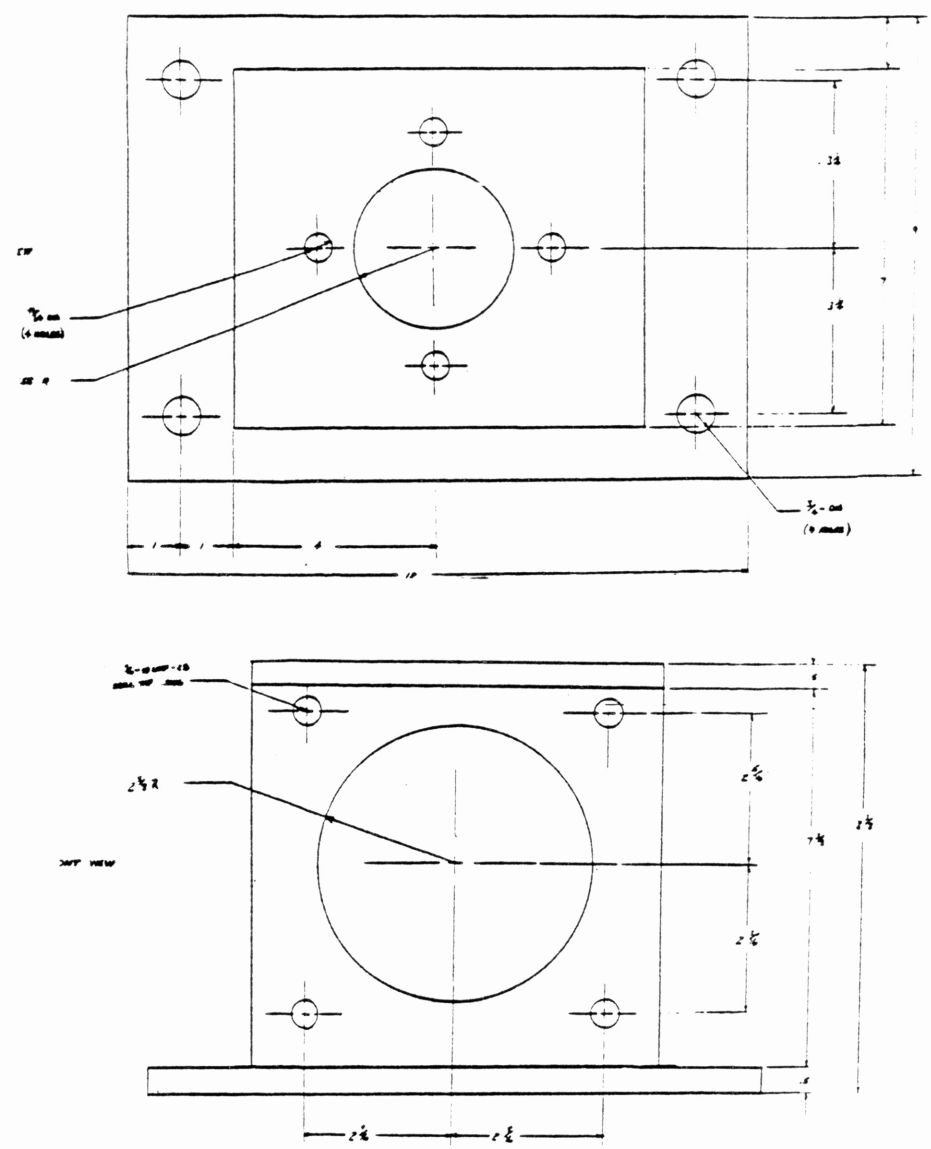
PISTON ASSEMBLY



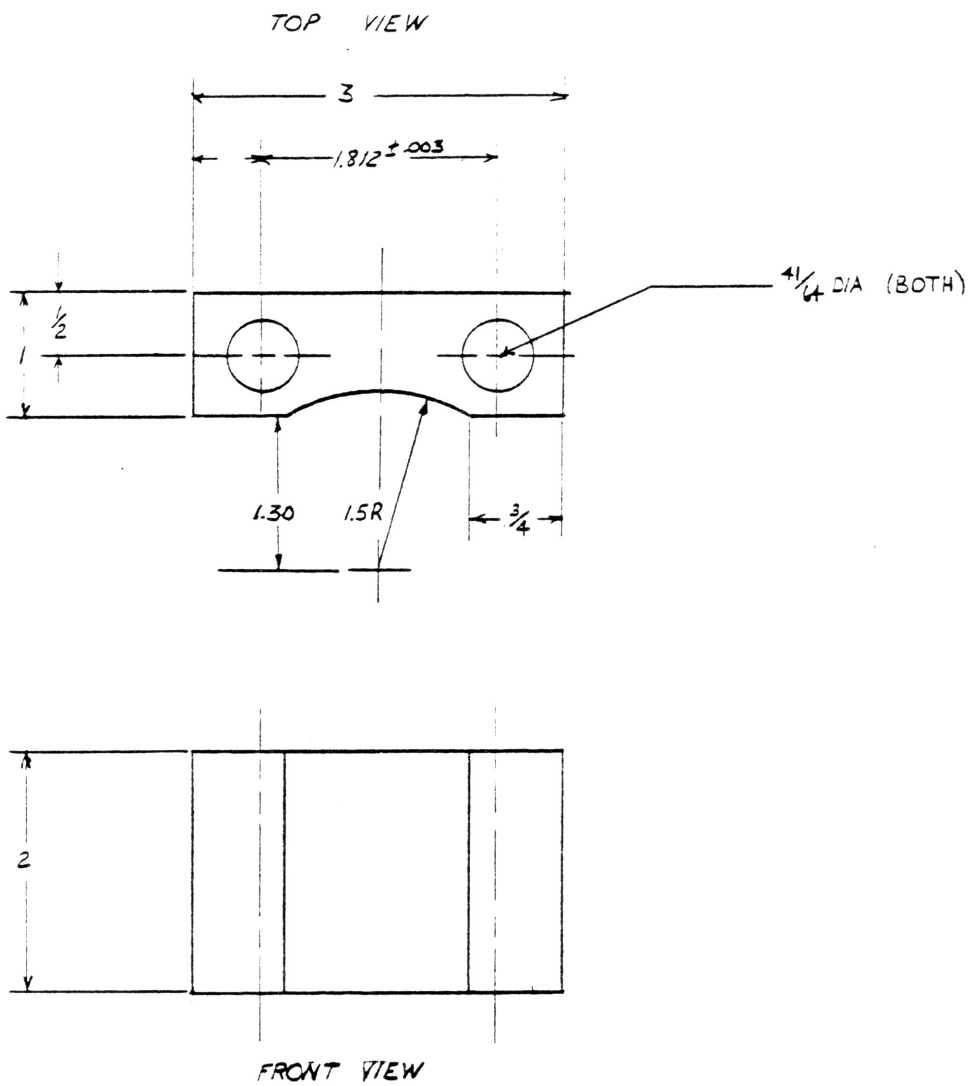
CYLINDER/STOPPER ASSEMBLY



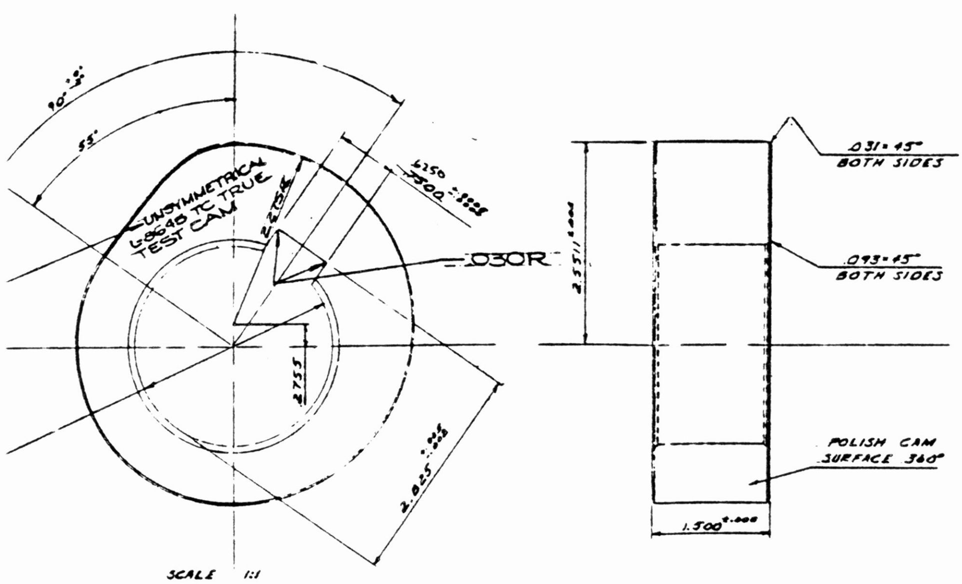
CAM HOUSING



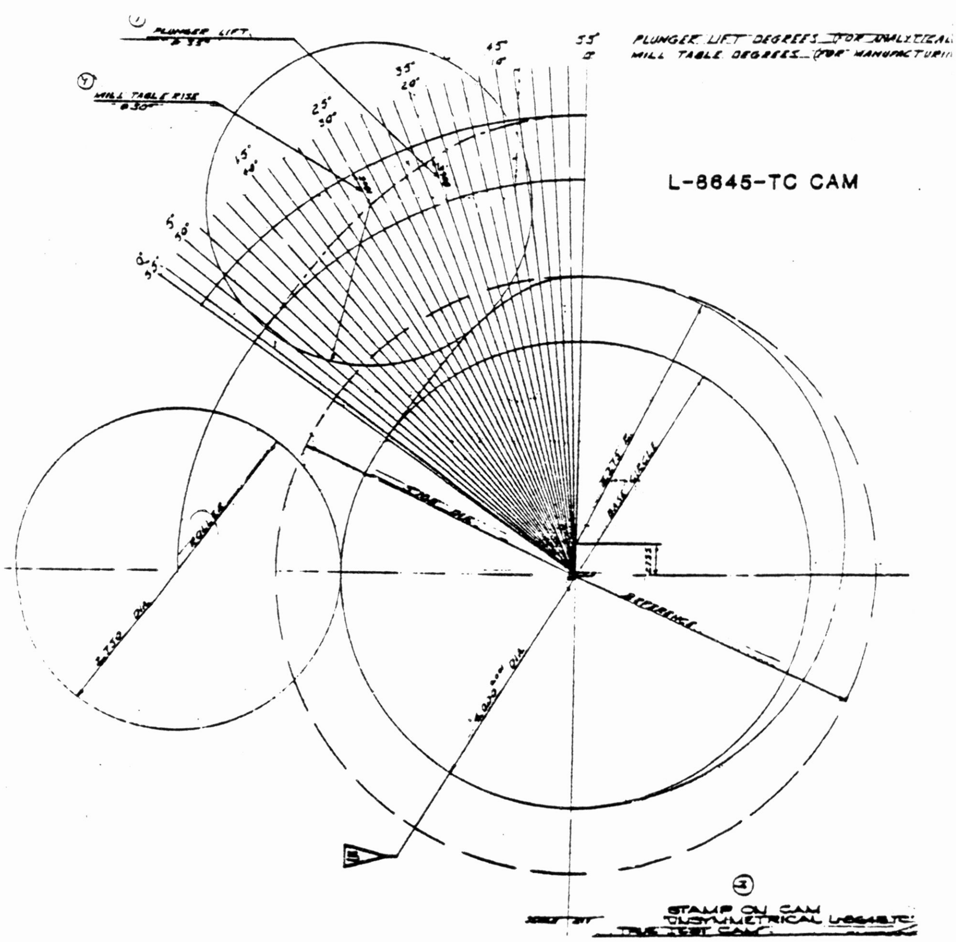
FUEL PUMP MOUNTING BLOCKS



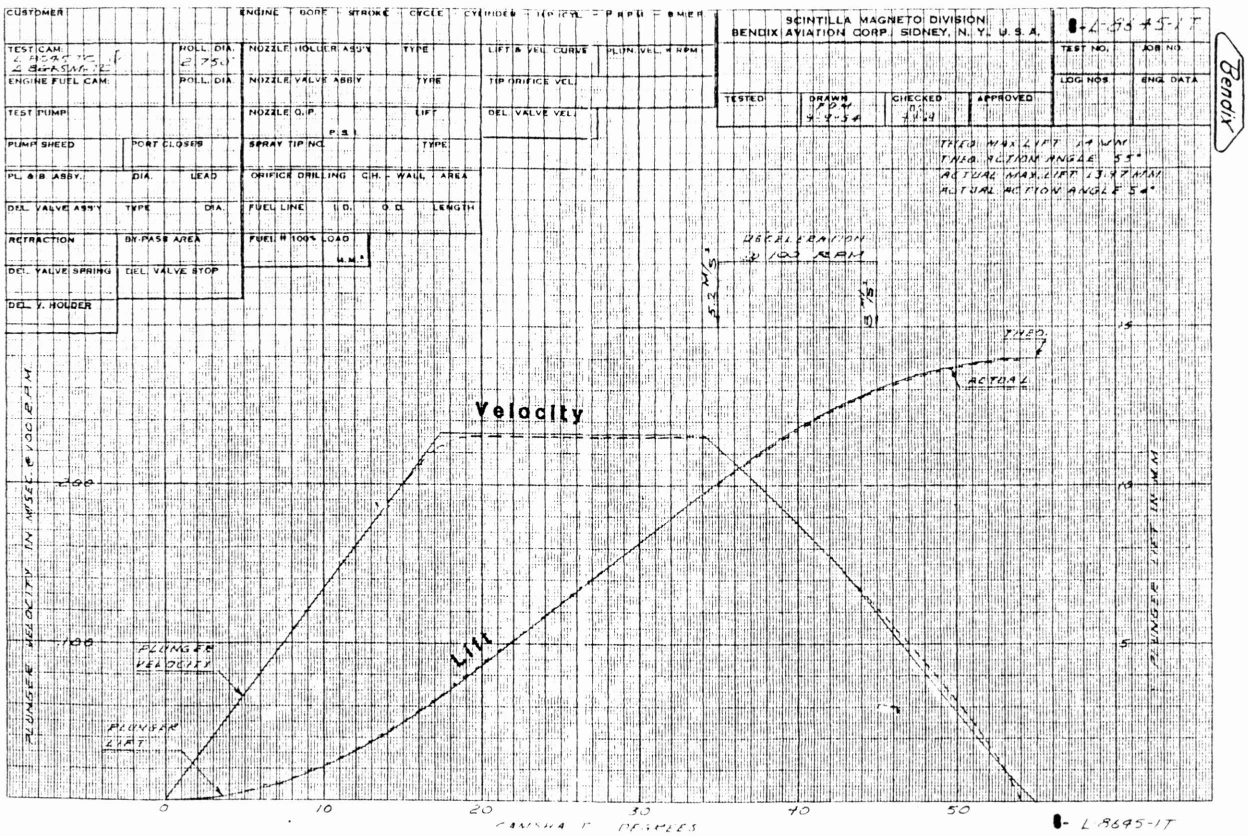
THE L-8645-TC CAM



THE CAM PROFILE



CAM VELOCITY AND PLUNGER LIFT CURVES



Appendix C

VITA

James William Boenig attended Judson High School in Converse, Texas, graduating in May 1979. He entered Texas A&M University in August 1979. While at Texas A&M, James served as president of the Texas A&M Student Branch of the American Society of Agricultural Engineers (ASAE) and chairman of the Student Agricultural Council. He served as committee chairman and member of various student organizations and honor societies and was selected for inclusion in the 1983 edition of Who's Who Among Students in American Universities and Colleges. In May 1983, he graduated "Summa Cum Laude" with a 3.93 GPR, receiving a B. S. degree in Agricultural Engineering. His address is Box 150, Converse, Texas 78109.