Oil-Consumption and Ring-Pack Oil-Film-Thickness Measurements and their Correlation in a Reciprocating Engine

by

Daisuke Suzuki

B.S., Mechanical Engineering
GMI Engineering and Management Institute, June 1997

Submitted to the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

This thesis project consists of two phases. The first phase involves the development of measurement systems for engine oil-consumption and piston ring-pack oil-film-thickness of a four-cylinder gasoline engine. The second phase is the development of a methodology to correlate engine oil-consumption with piston ring-pack oil-film-thickness based on data obtained from a single-cylinder diesel engine.

The engine oil-consumption measurement is based on the Antex® sulfur dioxide (SO_2) detector system. To obtain real-time engine oil-consumption rates, other subsystem measurements are also necessary. This includes the intake airflow measurement, the fuel-consumption measurement, and the nitric oxides (NOx) measurement. A calibration methodology and a mathematical formula are also developed and employed for converting raw data into an oil-consumption rate. A Laser Induced Fluorescence (LIF) system has been developed at the Sloan Automotive Laboratory to measure the piston ring-pack oil-film-thickness. For the LIF raw data calibration, the machined scratch marks on a piston skirt-land are used and the temperature effect on the dye fluorescence intensity is taken into account.

In developing a methodology to correlate the oil-consumption with the piston ring-pack oil-film, the three computer models developed at the Sloan Automotive laboratory are implemented. The measured data of oil-film-thickness and the outputs from the computer models are used to estimate oil-consumption from each of the four theoretical oil-consumption mechanisms: inertial force, gas-flow-dragging, oil vaporization from cylinder-liner, and oil vaporization from ring-pack into gas-flow. The estimated oil-consumption rates agree with the actual rates within 30% error for mid-load and full-load conditions. The estimated oil-consumption rate also follows the same trend as the actual oil-consumption rate, which the oil-consumption rate increases as both the engine-load and the engine-speed increase. Considered for the single-cylinder diesel engine, the major contributors of the estimated oil consumption rates within the four mechanisms are from the oil vaporization from cylinder-liner and ring-pack.

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CHAPTER 1: INTRODUCTION

1.1. Technology Background of Engine Oil-Consumption

Since the ecology concern associated with engine emission was raised in the USA due to the Clean Air Act of 1970's, automobile manufacturers have been focusing on the development of low oil-consumption engines. The reduction of engine oil-consumption during operation results in lower vehicle operating cost, lower emission of hydrocarbons and particulate, longer catalyst life through the reduction of phosphorous, and higher vehicle quality from the customer's viewpoint [1]. In developing low oil-consumption engines, the automobile manufacturers have been doing extensive research on internal combustion engines to understand the mechanism behind engine oil-consumption.

Engine oil is consumed both externally and internally during engine operation. External consumption occurs when oil leaks through the gaskets of the valve cover, engine head, and oil pan due to the abrasion of the gaskets. On the other hand, internal oil-consumption occurs when oil enters the combustion chamber during lubrication processes. There are three systems that lead to engine oil-consumption internally: the power cylinder system, the engine overhead system, and the positive crankcase ventilation (PCV) system [1]. Through these systems, oil either leaks or is sent into the combustion chamber while oil lubricates the engine mechanisms. Since the focus of this thesis is only on the power cylinder system, only a brief explanation of the alternate mechanisms is below.

The power cylinder system is composed of the piston, the cylinder bore, and the piston ring-pack. As the piston reciprocates along the cylinder bore, the oil that is spread to the bore surface from the oil sump flows through the ring-packs to the combustion chamber. The purpose of this system is to provide a sufficient quantity of oil for lubricating the piston's movement while minimizing the friction between piston rings and the quantity of oil leakage to the combustion chamber. Secondly, the engine overhead system is composed of the valve stem seal, the valve stem, and the valve guide. The oil in the cylinder head leaks through the valve stem seal and passes along the valve guide and valve stem to the combustion chambers. Similar to the first system, oil is sent to the valve mechanism to reduce the friction of valve stem movement, which always involves a problem with oil leakage. Finally, the PCV system consists of the path supplying fresh air to the crankcase, the path venting the crankcase to the intake manifold, and the PCV valve. The PCV valve is located within the path between the crankcase and the intake manifold. When oil is spread within the engine block, oil is misted, and the mist is accumulated in the crankcase. The misted oil flows into the intake manifold through the PCV valve, then enters to the combustion chamber through the intake valve. When intake manifold pressure is low and blow-by is high, fresh air carries the misted oil to the combustion chamber. Unlike the two other systems that contribute to the oil-consumption, oil-consumption through the PCV system is not due to oil leakage;

however, oil is purposely sent to the combustion chamber to combust with fuel before it is released to the atmosphere.

During the past decade, the focus of the MIT lubrication consortium has been to understand the engine oil-consumption due to the power cylinder system, because this area is most vital area of engine lubrication mechanism. The engine oil-consumption contributions from each of the three systems vary in proportion differently depending on engine; however, in some engines, the oil-consumption from power cylinder system represents 80 to 90 % of total [1].

1.2. Previous Works

Laser Induced Fluorescence (LIF) has been employed at MIT to measure oil-film-thickness in the piston ring-pack due to its positive features such as high spatial resolution, and high frequency response. Since Hoult, Lux, Wong and Billian initially used a LIF system at the Sloan Automotive Laboratory [2], it has been developed by a number of people. Noordzij [3] and Tamai [4] did the most recent LIF measurements and the system modifications.

During the development of the LIF system, several different techniques were adapted to measure the oil-consumption rates of production engines at the Sloan Automotive Laboratory. The technique used in this thesis project is the Sulfur Dioxide (SO_2) detector that measures the sulfur concentration in the exhaust gas. Since lubricant oil contains sulfur as a part of compounds and is consumed with charged gas in the combustion chamber. As a part of this thesis, the development of the measurement technique for real-time oil-consumption by the new SO_2 detector system, manufactured by the Antex®, is discussed.

1.3. Project Objectives

The objectives of this thesis are as follows:

Phase 1: Based on a Four-cylinder Gasoline Engine

1) Implement the Antex® SO_2 detector system with subsystems and develop the procedure and mathematical equations to measure real-time engine oil-consumption rate at various steady-state engine-running conditions.

2) Implement a Laser Induced Fluorescence (LIF) system with subsystems and develop the data calibration procedure to measure piston ring-pack oil-film-thickness, cylinder and liner pressure, and liner temperature simultaneously with engine oil-consumption rate.

Phase 2: Based on a Single-cylinder Diesel Engine

1) Employee three computer models developed at the Sloan Automotive Laboratory to study piston ring-pack physical phenomena.

2) Develop a methodology to correlate the ring-pack oil-film-thickness to engine consumption at various engine-running conditions with the aid of the output of three computer models.

CHAPTER 2: LITERATURE REVIEW OF ENGINE OIL-CONSUMPTION AND THEORY OF OIL-CONSUMPTION MECHANISMS

Prior to the discussion of experimental systems and correlation methodology, literature survey on engine oil-consumption is done. The engine oil-consumption data of ten internal combustion engines are collected for observing tendencies of oil-consumption variation over different engine-running conditions (load and speed). The sources of data are from the past experiments at the Sloan automotive Laboratory [5][6] & [7], and technical literature [8][9][10][11][12] & [13]. Half of the engines are spark ignition engines, and the other half are compression ignition engines.

2.1. General Oil-Consumption Trends of Internal Combustion Engines

In order to observe the engine-speed effects on oil-consumption, the oil-consumption data are converted into the unit of mass per cycle. Since the bore size and cylinder number of each engine are different, mass per cycle based oil-consumption rates are divided by the engine displacement (μ g/cycle/displacement in liter), and the graph of the data is shown below, in Figure 2-1. From the graph, it is observed that engine oil-consumption rates are from 4 μg/cycle/liter to 440 μg/cycle/liter, and the average and standard deviation of 89 number of data points are 68.9 μg/cycle/liter and 66.8μg/cycle/liter, respectively.

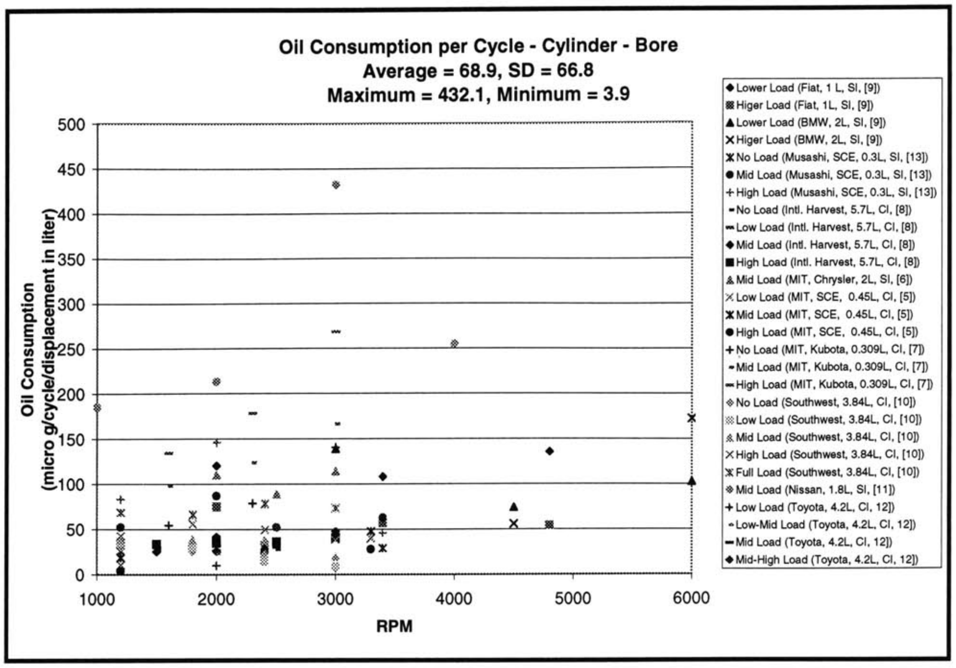

Figure 2-1 Oil-Consumption Rate of Ten Internal Combustion Engines

In addition, two other graphs of engine oil-consumption rate in the units of gram per hour per cylinder (g/h/cylinder), and micro gram per cycle per cylinder (μg/cycle/cylinder) are shown in Appendix A. The averages of oil-consumption rate in those units are 2.8 g/h/cylinder and 34.0 μg/cycle/cylinder, respectively.

2.2. Oil-Consumption Rate Comparison Among Different Engine-Running Conditions

The oil-consumption rates of individual engines at different engine-loads and engine-speeds were analyzed. Within the engine-load comparison, the oil-consumption rates of Kubota single-cylinder diesel engine (Figure 2-2), four-cylinder diesel engine at South

Research Institute (Figure 2-3), and Toyota six-cylinder diesel engine with turbo charger (Figure 2-4) show a clear increasing trend as engine-load gets higher. They all happen to be compression ignition engines.

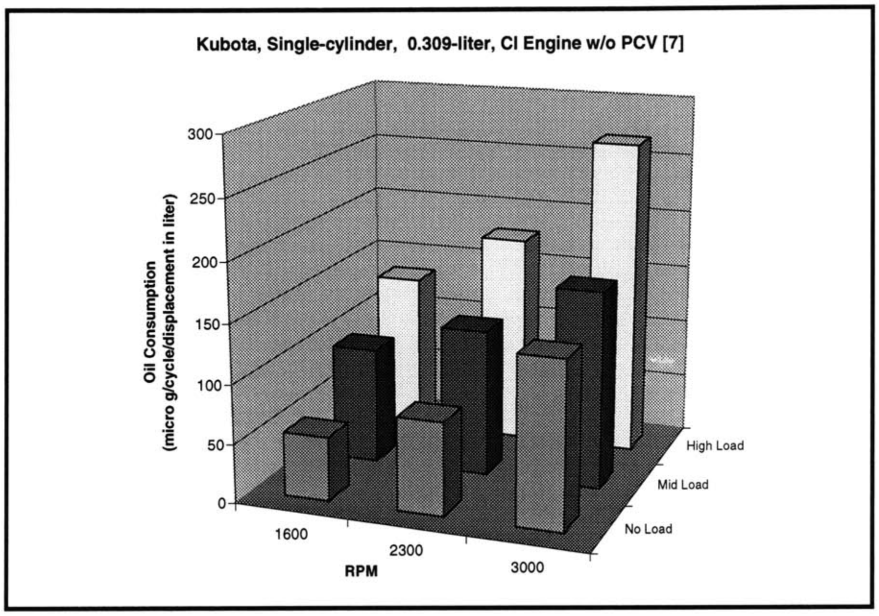

Figure 2-2 Kubota Engine Oil-Consumption

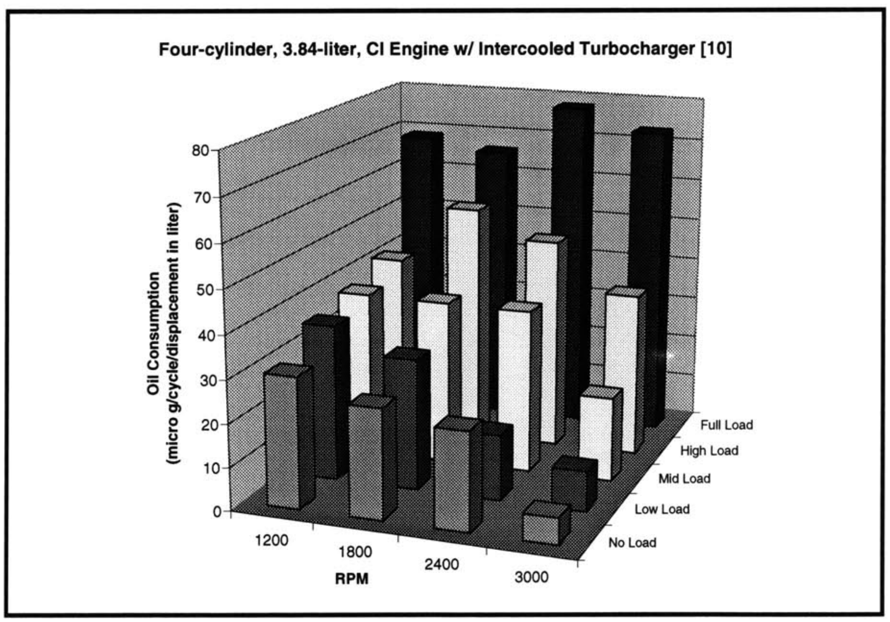

Figure 2-3 Four-Cylinder Diesel Engine Oil-Consumption Rate

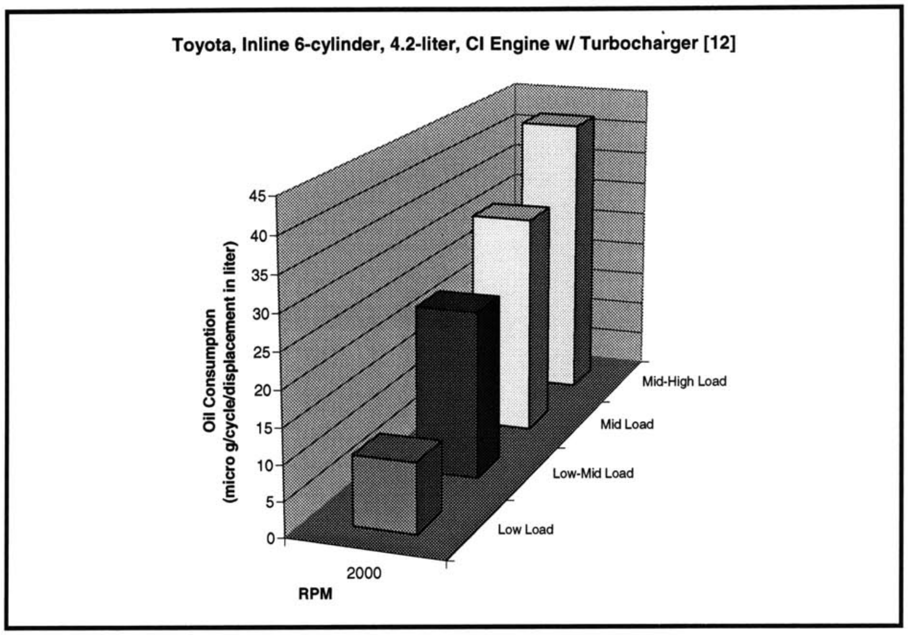

Figure 2-4 Toyota Engine Oil-Consumption Rate

Within the engine-speed comparison, the oil-consumption rates of Kubota single-cylinder diesel engine (Figure 2-1), and Ricardo single-cylinder diesel engine (Figure 2-5) indicate a clear increasing trend for higher engine-speed, and they also happen to be compression ignition engines. The oil-consumption rates of only the Kubota engine show a clear increasing trend for higher engine-load and engine-speed.

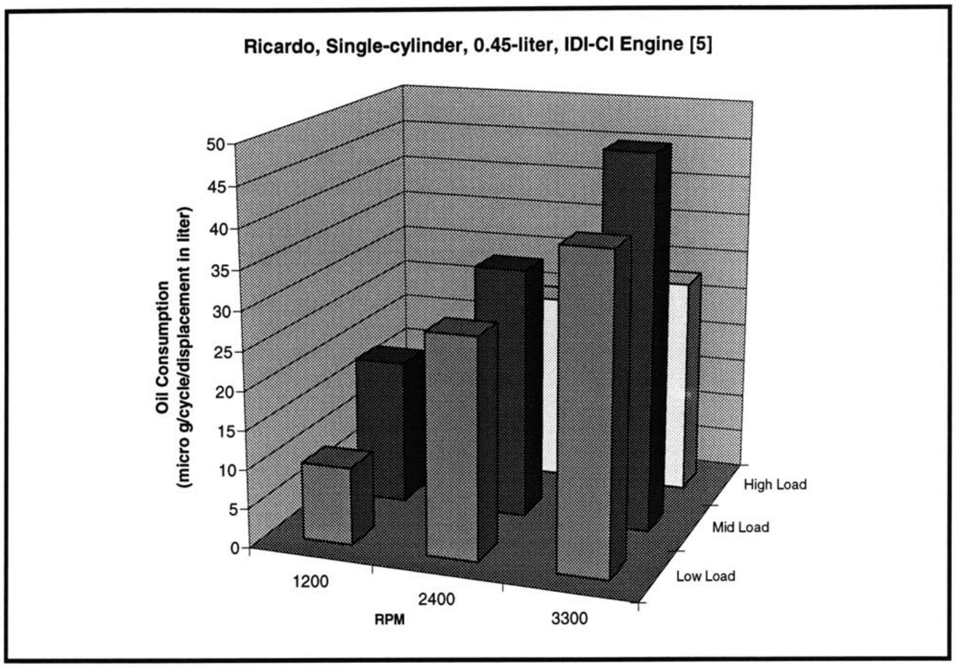

Figure 2-5 Ricardo Engine Oil-Consumption Rate

One trend is that oil-consumption rate reaches peak at mid-load or mid-speed condition, and it decreases as load or speed gets higher and lower (Figure 2-5 for load and Figure 2-6 & 7 for speed). On the other hand, there is a trend that the oil-consumption at mid-speed is lowest, and it increases as speed increases (Figure 2-8). The oil-consumption trend of a four-cylinder gasoline engine (Figure 2-9) is that the oil-consumption rate of higher load is higher at high engine-speed condition, but it is lower at low speed condition. The oil-consumption data of the rest two engines are included in the Appendix B.

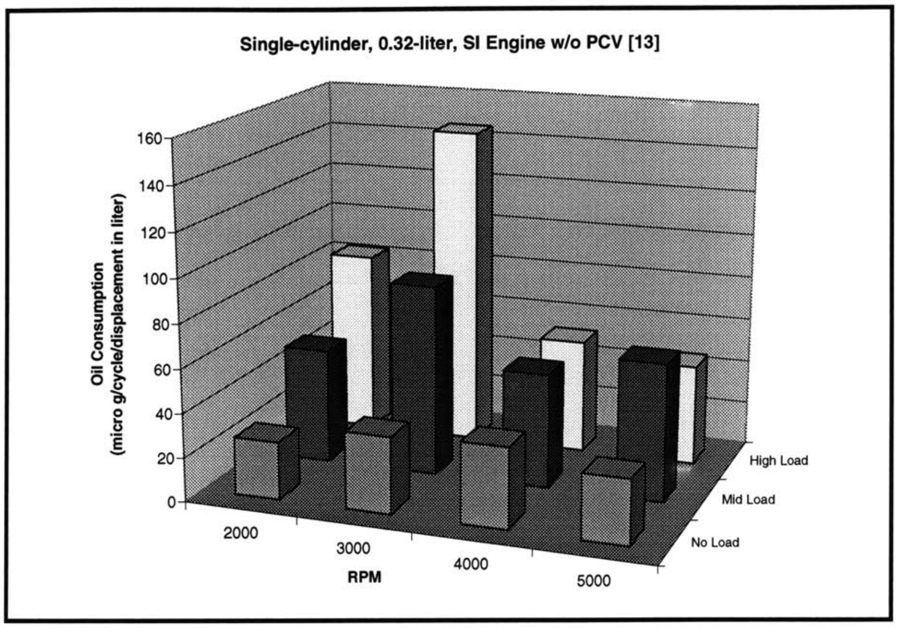

Figure 2-6 Single-Cylinder Engine Oil-Consumption Rate

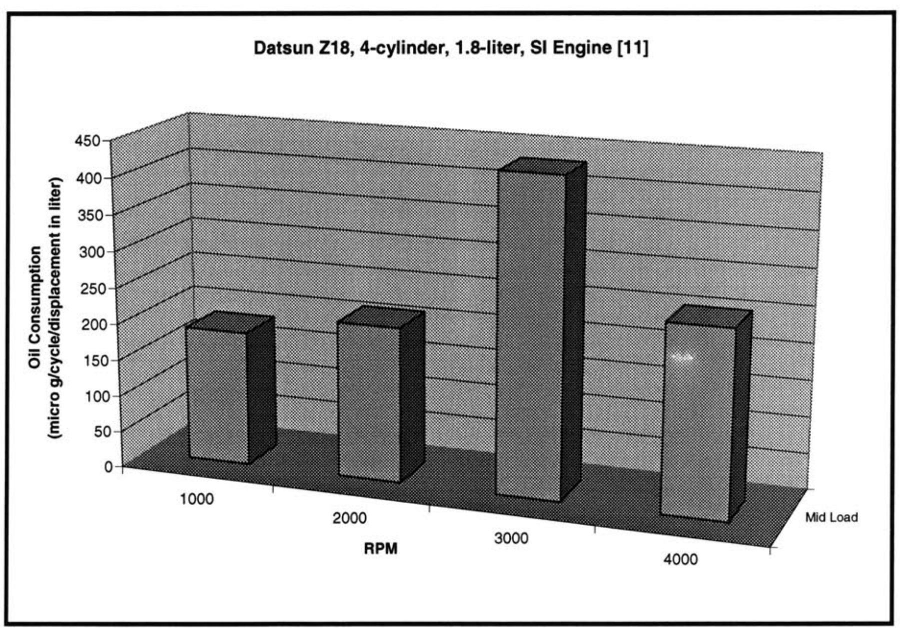

Figure 2-7 Datsun Engine Oil-Consumption Rate

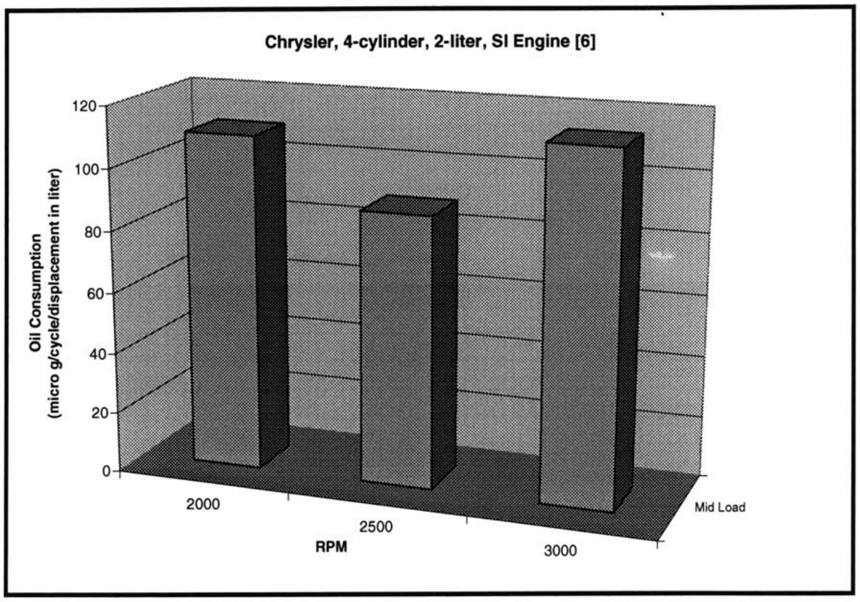

Figure 2-8 Chrysler Engine Oil-Consumption Rate

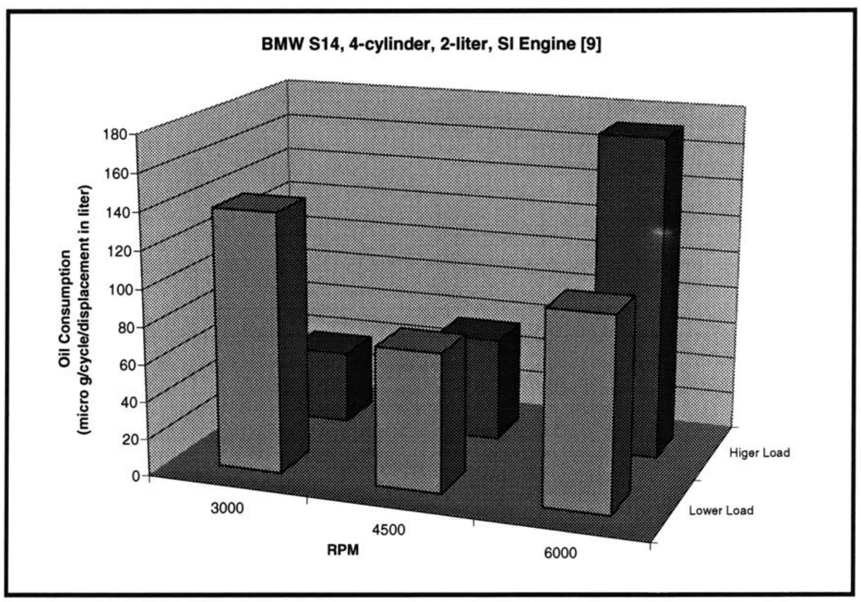

Figure 2-9 BMW Engine Oil-Consumption Rate

From the above observation of oil-consumption rate, it is found that the trends of engine oil-consumption rate differ depending on engine-running condition and engine type. Prior to the further investigation of the trends based on Kubota engine data in the following chapter, hypotheses of engine oil-consumption and oil-transport mechanisms in the power cylinder system are made. Based on the hypotheses, it is discussed which physical parameters of the engine may cause the variations in oil-consumption rate over different engine-running conditions.

2.3. Hypotheses of Engine Oil-Consumption and Oil-Transport Mechanisms

There are at least four mechanisms that are assumed to cause irreversible oil-removal from the system in a power cylinder: 1) inertial force, 2) gas-flow dragging, 3) oil vaporization from cylinder-liner, and 4) oil vaporization from ring-pack into gas-flow. In addition, three mechanisms are assumed to transport oil within the system: 1) inertial force, 2) gas-flow dragging, and 3) oil scraping and squeezing. The first two oil-consumption mechanisms take place only on the crown land. However, the fourth mechanism takes into account of the upper part of piston ring-pack. The oil-transport mechanisms deal with the oil that accumulates below the crown land.

The quantity of oil-consumption and oil-transport by each mechanism is a function of several parameters of combustion chamber condition, oil characteristics, gas-flow condition, and piston/liner/ring geometry. The sensitivity of the oil-consumption due to each mechanism differs by the combination of the parameters. The explanation of each of oil-consumption and oil-transport mechanisms is discussed below.

A. Oil-Consumption and Oil-Transport by Inertial Force

The source of inertial force is the combination of oil-film-thickness and piston acceleration. The inertial force is maximized when piston reaches the top dead center or the bottom dead center of cylinder-liner. At the end of either compression or exhaust strokes, any oil accumulated on the crown land becomes the direct source of oil-consumption as the oil is in liquid phase. The oil accumulated on the second land is transported into top ring groove when the top ring is lifted (end of exhaust stroke for Kubota engine case) by inertial force. The oil that flows into the bottom surface of groove moves up to the top surface of the groove by inertial force, gas dragging force, or ring squeezing motion. Once oil reaches the top surface of top ring groove, it is squeezed out as the top ring is lifted, or dragged by gas-flow onto crown (middle of expansion stroke for Kubota engine case).

The quantity of oil-transport by inertial force also depends on counter forces such as gas-flow dragging over piston lands, and the piston acceleration when piston reaches the bottom dead center. At the end of compression stroke, the high-speed gas stream drags oil on lands into the lower ring-packs, while oil is transported toward combustion chamber by inertial force. The balance of two forces then determines the quantity of transported oil. For the Kubota engine cases, inertial force effect always exceeds the gas-flow dragging effect.

The mechanism of oil-transport by inertial force is described with more detail in a later chapter with the actual data. Following is a description of the physical simple equation that determines the oil flow speed caused by the inertial force.

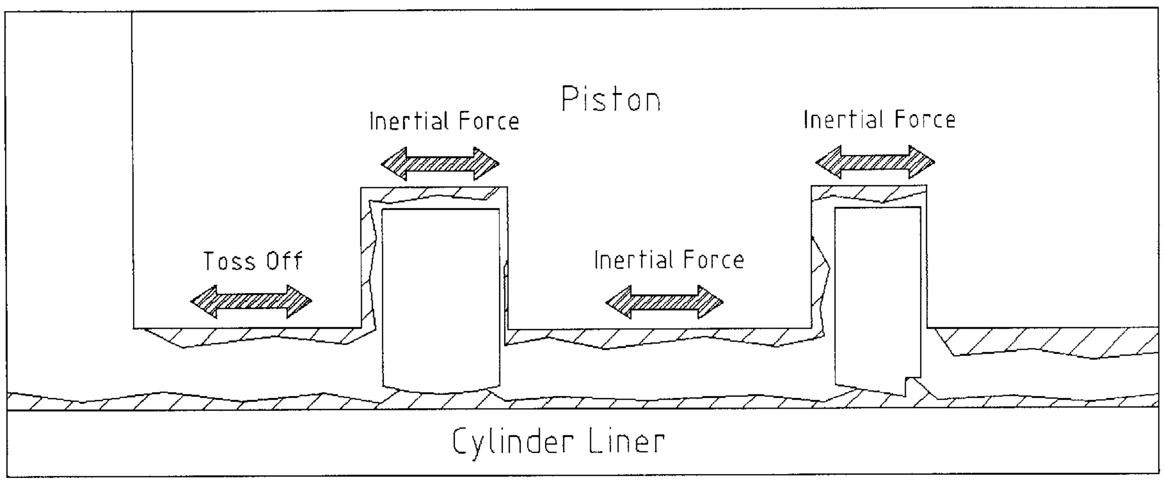

Figure 2-10 Oil-Consumption and Oil-Transport by Inertial Force

Inertial driven oil flow:

Oil flow speed due to the inertial force is described as:

$$v_{oil} \approx \frac{\rho_{oil} * a_{piston} * h_{oil}^{2}}{\mu_{oil}} \quad \cdots \text{Eq.2}-1 \quad [31]$$

Oil mass-flow rate (Eq.2-3) is the speed multiplied (Eq.2-1) by the oil cross-section area (Eq.2-2) and density:

$$A_{oil} = \pi * h_{oil} * D_{land} \cdots \text{Eq.2} - 2$$

$$M_{oil} = v_{oil} * A_{oil} * \rho_{oil}$$

$$= \frac{\rho_{oil}^{2} * a_{piston} * h_{oil}^{3} * \pi * D_{land}}{\mu_{oil}} \cdots \text{Eq.2} - 3$$

where v_{oil} : oil flow speed (m/s)
ρ_{oil} : oil density (kg/m^3)
a_{piston} : piston acceleration (m/s^2)
h_{oil} : oil-film-thickness (m)
μ_{oil} : oil absolute viscosity (Pa·s)
A_{oil} : oil cross-section area (m^2)
D_{land} : land diameter (m)
M_{oil} : oil mass-flow rate(kg/s)

Piston acceleration is a function of the square of engine-speed. As seen from the oil mass-flow rate equation, the oil-transport by inertial force is proportional to the cubic square of oil-film-thickness, the square of engine-speed and oil density, and inversely proportional to oil absolute viscosity. The oil density slightly decreases as oil temperature increases (higher load has higher piston temperature, so oil temperature is also higher), but the absolute viscosity decreases at much higher rate than oil density with the oil temperature increase [23]. Consequently, higher load and higher speed conditions produce more oil-transport by the inertial force.

B. Oil-Consumption and Oil-Transport by Gas-Flow Dragging

Since the speed of gas-stream in piston ring-pack is significantly high, it is assumed that the gas-stream drags oil from piston lands and grooves as the oil is in liquid phase. The gas-stream in the piston ring-pack mostly occurs during the end of compression stroke (negative effect to oil-consumption) and the beginning of expansion stroke (positive effect to oil-consumption). This is due to the high pressure in the combustion chamber when the piston is at that location. The oil-films on the crown land, the upper surface of top ring and top ring groove are the sources of direct oil-consumption by gas-flow dragging. The oil-film on the second land contributes to oil-transport into those areas. More detail of this mechanism is explained in the later chapter with the actual engine data.

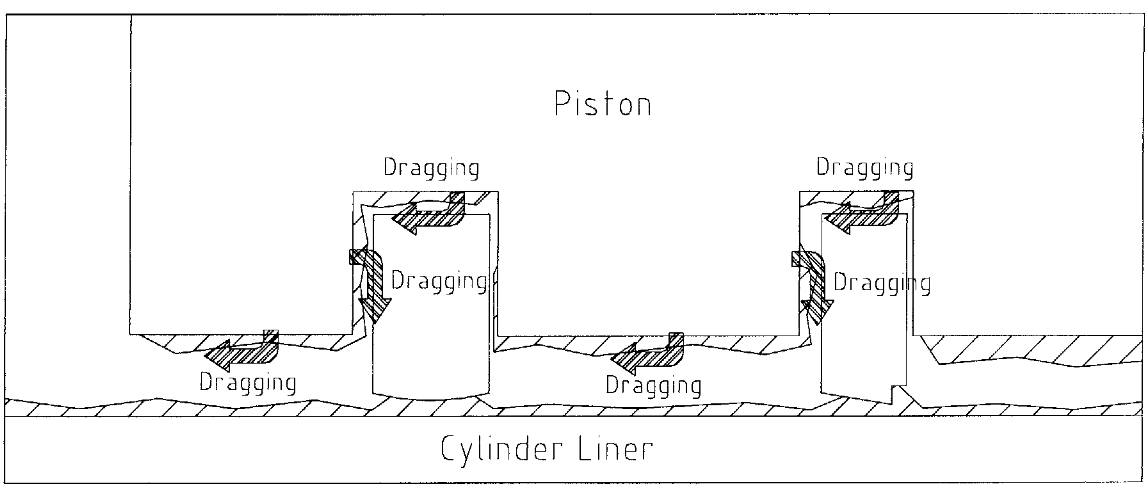

Figure 2-11 Oil-Consumption and Oil-Transport by Gas-Flow Dragging

The theoretical estimation of oil-consumption and oil-transport by gas-flow dragging is developed by the equations below. These equations are based on the shear-stress balancing equation between gas-flow and oil-flow and the laminar parabolic flow equation.

Gas-dragged oil flow:

$$\frac{dP}{dx} * \frac{h_{gas}}{2} = \mu_{oil} * \frac{dv_{oil}}{dy} \cdots \text{Eq.2-4} \quad \text{Shear-stress balance equation [31]}$$

$$V_{gas} = \frac{1}{12 * \mu_{gas}} * \frac{dP}{dx} * h_{gas}^{3} * \pi * D_{land} \cdots \text{Eq.2-5} \quad \text{Laminar parabolic equation [31]}$$

The average oil flow speed is when:

$$\frac{dv_{oil}}{dy} \approx \frac{v_{oil}}{\frac{1}{2} * h_{oil}} \cdots \text{Eq.2-6}$$

From the above three equations (Eq.2-4 through 2-6), the average oil flow speed is:

$$v_{oil} = 3 * V_{gas} * \frac{h_{oil}}{\mu_{oil}} * \frac{\mu_{gas}}{h_{gas}^{2}} * \frac{D_{land}}{\pi} \cdots \text{Eq.2-7}$$

Oil mass-flow rate (Eq.2-9) is the speed (Eq.2-7) multiplied by the oil cross-section area (Eq.2-8) and density

$$A_{oil} = \pi * h_{oil} * D_{land} \cdots Eq.2-8$$

$$M_{oil} = v_{oil} * A_{oil} * \rho_{oil} \cdots Eq.2-9$$

$$v_{oil} = \frac{\mu_{oil}}{\rho_{oi}l} \cdots Eq.2-10$$

where P: land pressure (Pa)
h_{gas}: thickness of the gas layer between the piston and the liner (m)
μ_{oil}: oil absolute viscosity (Pa·s)
v_{oil}: oil flow speed (m/s)
$v_{average\ oil}$: average oil flow speed (m/s)
V_{gas}: gas volume flow rate (m^3/s)
μ_{gas}: gas absolute viscosity (Pa·s)
D_{land}: piston land diameter (m)
A_{oil} : oil cross-section area (m^2)
M_{oil}: oil mass-flow rate (kg/s)
ρ_{oil}: oil density (kg/m^3)
ν_{oil}: oil kinematic viscosity (m^2/s)
h_{oil}: oil-film-thickness (m)
D_{land}: land diameter (m)

Oil mass-flow rate by the gas-flow dragging is a function of the square of oil height and the inverse square of gas height. It is also proportional to oil density, gas volume flow rate, and gas absolute viscosity, and inverse to oil absolute viscosity. As it was mentioned before, the oil absolute viscosity decreases as temperature increases, but the gas absolute viscosity increases; therefore, the quantity of oil-transport by gas-flow dragging increases as temperature increases. The kinematic viscosity is the absolute viscosity over the density (Eq.2-10). Referring to Figure 2-12, the Kinematic viscosity of engine oil decreases as temperature increases. Since the oil mass-flow rate is inversely proportional to the kinematic viscosity of oil, the oil-transport rate increases with the oil temperature. The gas-flow rate (blowby) is a function of pressure and temperature, but a consistent variation in gas-flow rate per cycle over different engine-running conditions is not observed from the Kubota engine data. Consequently, there is a high sensitivity of the oil-transport by gas-flow dragging due to engine-load condition.

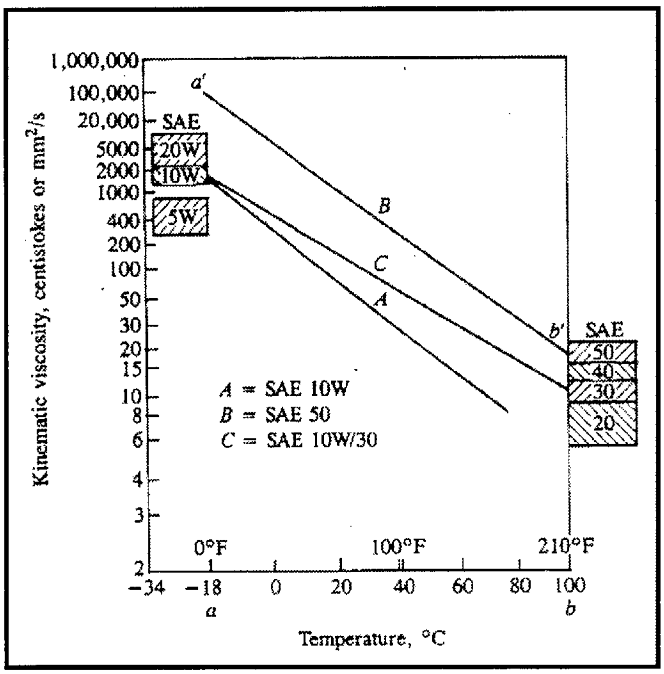

Figure 2-12 Engine Oil Kinematic Viscosity [26]

C. Oil-Transport by Ring Scraping and Squeezing

Ring dynamics (scraping and lifting/squeezing) is the third source of oil-transport when oil is in liquid phase. Ring-pack pressure, oil characteristics, and piston speed affect ring dynamics. Ring profile-geometry and ring dynamics (mainly twist) significantly influence oil accumulation in front of the ring, the minimum oil-film-thickness under the ring, and oil-film-thickness on the free liner. Oil accumulation in front of the ring, however, does not occur if the ring profile is sharp, and has little to do with the oil-film-thickness under the ring. Even if oil accumulates, the effect of engine-running condition on the quantity of oil accumulation is not obvious over various engine-running conditions because ring dynamic motions are very complicated phenomena.

Ring-lift is affected mostly by ring-pack pressure, but has little to do with other parameters that affect the friction between ring and cylinder-liner. For all Kubota engine cases, top ring-lift occurs during expansion, and it is seated back to the bottom groove during intake stroke. Even if the ring-pack pressures are different among engine-running conditions, the timing of ring-lift is always same for the Kubota engine case; therefore, oil-transport by ring squeezing does not vary among engine-running conditions.

The *FRICTION-OFT* computer model estimates the oil-film-thickness difference before and after a ring, which leads to oil accumulation in front of ring. Once the oil accumulation in front of ring is estimated, it is assumed that the oil quickly moves up to the top surface of ring and ring groove. On the other hand, the other model, *RINGPACK-OC*, estimates ring-lift at each crank angle for an entire cycle. As oil reaches the top surface of ring and ring groove, it is assumed that oil is squeezed out from groove.

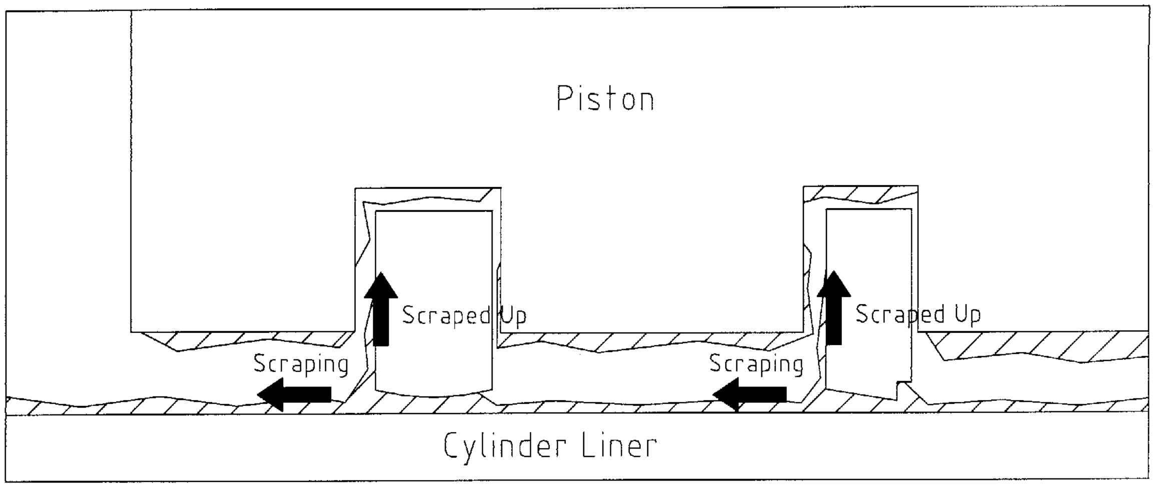

Figure 2-13 Oil-Transport by Ring Scraping

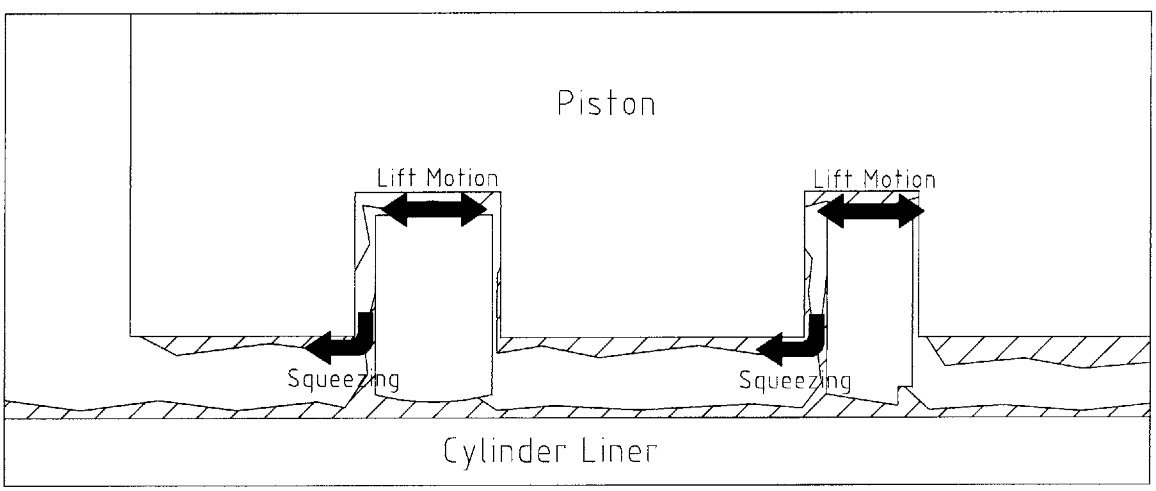

Figure 2-14 Oil-Transport by Ring Squeezing

D. Oil-Consumption by Cylinder-Liner Vaporization

To estimate the oil vaporization rate from the cylinder-liner, the computer model developed at the Sloan Automotive Laboratory is also used. As input data of this model, the cylinder-liner temperature is significantly important, because the oil vaporization rate exponentially increases as the temperature increases (higher engine-load condition has larger oil vaporization) [15]. Oil composition also has a large (but only linear) effect on the oil vaporization. Oil composition changes as oil is vaporized, but the oil-film-thickness changes only by the tenths of a micron. The scraping motion of the compression ring and scraper ring influences the compositions of the oil layer on the liner. The upper part of the oil layer, where oil control rings do not reach, has a slightly different composition from the lower portions. This part of oil layer has some influence on the total oil vaporization rate from cylinder-liner [15].

In addition to liner temperature and oil composition, the oil-film-thickness on the cylinder-liner affects the oil vaporization rate, only when the liner temperature is high enough. This influence is almost negligible when the liner temperature is low, which occurs at low or no engine-load conditions. At high and mid engine-load conditions, oil vaporization increases as engine-speed increases, because of a thicker oil-film on the free-liner of the cylinder.

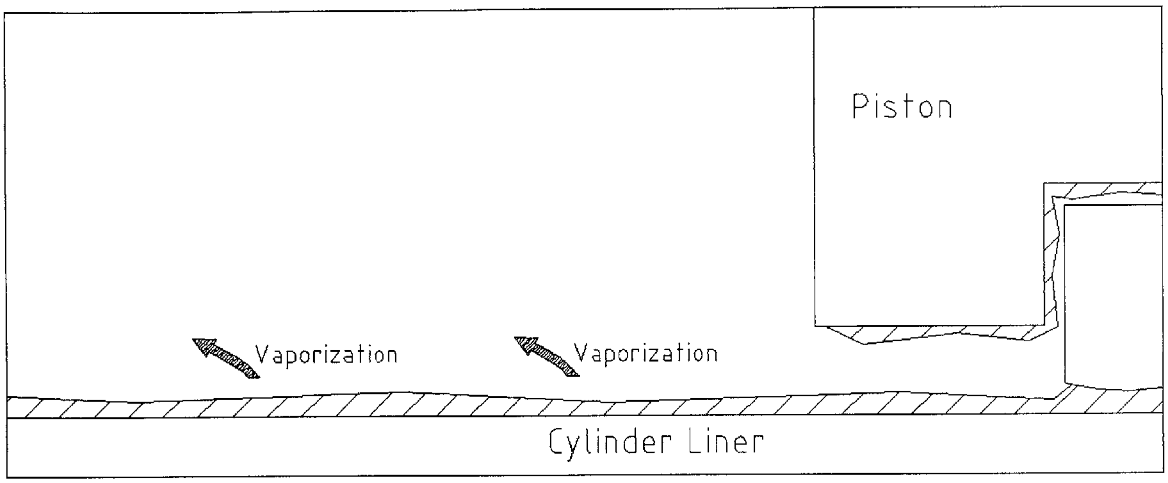

Figure 2-15 Oil-Consumption by Cylinder-Liner Vaporization

E. Oil-Consumption by Oil Vaporization from Ring-Pack into Gas-Flow

The final oil-consumption mechanism also involves oil vaporization from the ring-pack. Oil-consumption occurs as oil in the ring-pack is vaporized into gas, which then flows out (reverse blowby) during the expansion stroke. Oil vaporization quantity is a function of oil/land temperature, oil availability, and gas-flow rate. For the same reasons as cylinder-liner oil vaporization, oil vaporization in ring-pack gas is also sensitive to oil/land temperature; therefore, higher oil vaporization can be expected at higher engine-load conditions.

Oil vaporization quantity increases until the ring-pack gas saturates. Above the saturation point, more oil can remain in the gas as mist. The main source of oil vaporization is assumed to be the crown land and the upper surface of top ring and groove because of the higher temperature in these areas. In addition, since most reverse blowby comes from these areas (during the first quarter of expansion stroke for Kubota engine case), this oil contributes to the majority of the oil-consumption. Oil vaporization from the second land is significant when engine-load is high, because some amount of reverse blowby comes from this area during the second quarter of the expansion stroke. Oil in the other locations is also vaporized into gas, and the gas remains in the piston lands and crevices; however, the gas-flow rate and temperature of the area has small effect on the total oil-consumption due to oil-vaporization from ring-pack.

To obtain a good estimation of the oil-vaporization quantity in ring-pack gas, the time-based tracking of oil availability and supply to piston lands and crevices is necessary. By applying the gas-flow rate in each ring-pack region to the oil availability and supply, the total oil-consumption rate by oil vaporization from the ring-pack can be estimated. The time information of the gas-flow rate in the ring-pack can be estimated by implementing the *RINGPACK-OC* model. However the LIF measurements can be done at the several locations on the cylinder-liner, the one-dimensional oil-film data limits the time-resolution of the oil-film-thickness and oil-distribution in the ring-pack.

To simplify the estimation of oil-vaporization quantity in the ring-pack, only the oil accumulated on crown land and the upper surface of top ring and groove, which are measured at the certain cylinder-liner location (55 mm below top dead center for the Kubota engine), is taken into account with the corresponding temperatures. According to a Shell literature [16], the oil mass fraction in the ring-pack gas is estimated to be between 0.5 to 1.0% based on blowby rate. Since the gas-flow that flows out from ring-pack carries oil from ring-pack (positive flow of reverse blowby), the mass fraction needs to be adjusted based on the gas-flow rate. Once the mass fraction and the gas-flow rate is estimated, the oil-consumption rate due to oil vaporization from the ring-pack into gas-flow is calculated by multiplying the two parameters.

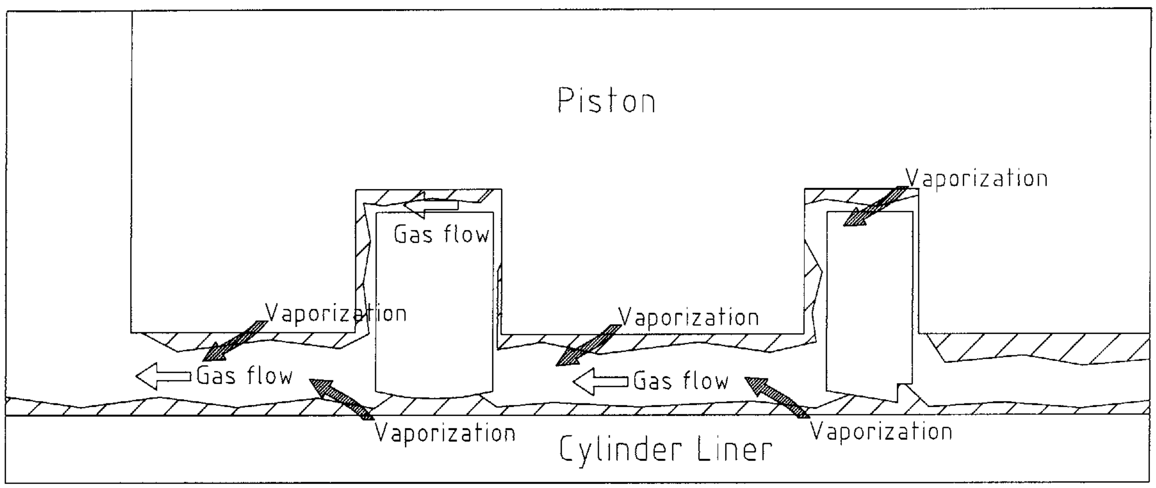

Figure 2-16 Oil-Consumption by Gas Vaporization in Ring-Pack

Table 2-1 summaries the effect of each oil-consumption mechanism to the total oil-consumption rates at different engine-running conditions and oil-film-thickness in ring-pack.

	Engine-load	**Engine-speed**	**Oil accumulation on land**
Inertial force	Sensitive	Highly Sensitive	Highly sensitive
Gas-flow dragging	Sensitive	Uncertain	Sensitive
Scraping and squeezing	Uncertain	Uncertain	Uncertain
Liner vaporization	Highly sensitive	Uncertain	Uncertain
Ring-pack gas-flow with oil vaporization	Highly sensitive	Uncertain	Sensitive

Table 2-1 The Sensitivity of Oil-Consumption Mechanism by Engine-Running Conditions and Oil Accumulation on Land

CHAPTER 3: DEVELOPMENT OF MEASURMENT SYSTEMS

Two systems are employed on a four-cylinder gasoline engine to measure engine oil-consumption and ring-pack oil-film-thickness, simultaneously. First, the system-setup and handling of the oil-consumption measurement system is discussed, and it is followed by the explanation of the ring-pack oil-film-thickness measurement system.

3.1. Oil-Consumption Measurement System

Figure 3-1 illustrates the oil-consumption (OC) measurement system that has been developed at the Sloan Automotive Laboratory.

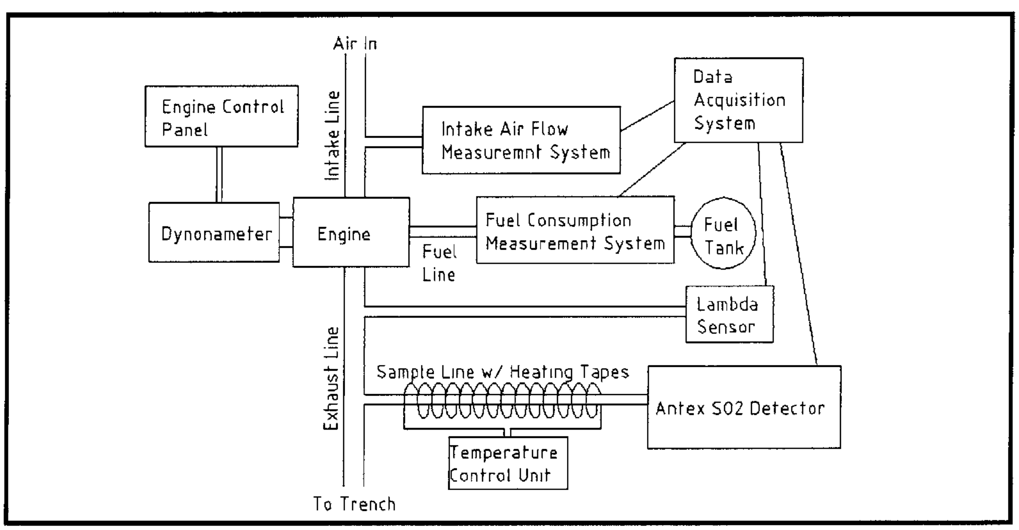

Figure 3-1 Oil-Consumption Measurement System

The system consists of nine subsystems: the Antex® sulfur dioxide (SO_2) detector system, a nitric oxides (NOx) measurement system, a sample line and its temperature control unit, an intake airflow measurement system, a fuel-consumption system, a lambda sensor, a data acquisition system, an engine control unit, and a dynamometer. The explanation of individual subsystem is described below.

A. Antex® SO2 Detector System

This instrument (Model R 6000 SE) measures the SO_2 concentration of sample gas as the gas flows through the detector [17]. Figure 3-2 illustrates the detail components of the system. As the exhaust or span gas enters the system, the gas is first pulled through the proportional valve and the first furnace tube by the pump. To compensate for minor difference in the gas pressure, the proportional valve is activated by a closed-loop control system to maintain a regulated absolute pressure (sub-atmosphere) for the pump to draw from. As the sample gas flows through the first furnace, the particles in the exhaust gas are combusted to become gas. Since some sulfur in the sample gas might be converted to SO_2 in the first furnace, and SO_2 can be retained by cold stainless steel, the stainless steel pump is heated up to 130 °C to minimize the retention of sulfur. The outlet of the pump is connected to the manual pressure regulator that maintains a constant pressure (manual recommendation: 0.48 bar (7 psi) by venting excess gas. The outlet of the pump is also connected to the restriction transfer tube that stabilizes the gas-flow. The constant gas pressure across the tube provides a constant flow to the second furnace tube.

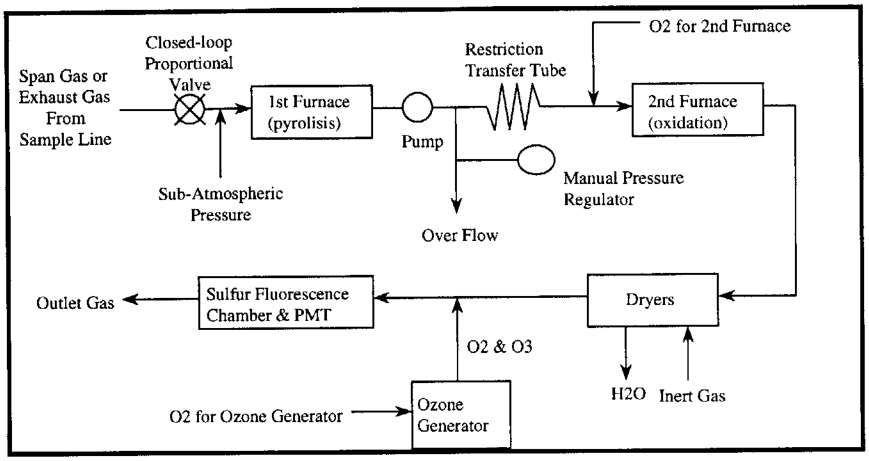

Figure 3-2 Antex® SO_2 Detector System

The regulated gas is mixed with excess oxygen before entering the second furnace tube that converts all compounds that were not converted in the first furnace tube to the permanent gases (CO_2 & SO_2). There are mainly two types of compounds of concern in the exhaust gas: sulfur compounds and hydrocarbons. After the sample gas flows through the second furnace tube, most sulfur compounds are converted to sulfur dioxide (SO_2), and most hydrocarbons are broken down to carbon dioxide (CO_2) and water. Excess water is removed by two membrane dryers (initially the system came with only one dryer) that is fed by inert gas (N_2). Nitric oxide (NO), which is one of the pollution gases in the exhaust gas, is known to affect the signal of SO_2 (100 ppm volume of NO is equivalent to a little over 1 ppm volume of SO_2 in sensitivity). Ozone gas (O_3) is therefore generated from the ozone generator and is fed to the sample gas to convert NO to NO_2. This is necessary to eliminate interference of the high level NO from low level sulfur analysis.

The ozonated gas then enters the sulfur fluorescence chamber where the gas is exposed to ultraviolet (UV) light. When excited by the proper wavelength of the UV light, SO_2 fluoresces and emits a specific wavelength of light. The filter within the chamber allows only the appropriate wavelength of light to reach the photomultiplier tube (PMT). The current that is proportional to the fluorescence signal of SO_2 is produced by the PMT, and is sent to the interface module that is initially calibrated with span gas and displays the concentration of SO_2 in ppm volume. The following graph illustrates the calibration curve and equation to convert the signal from SO_2 detector to SO_2 ppm volume.

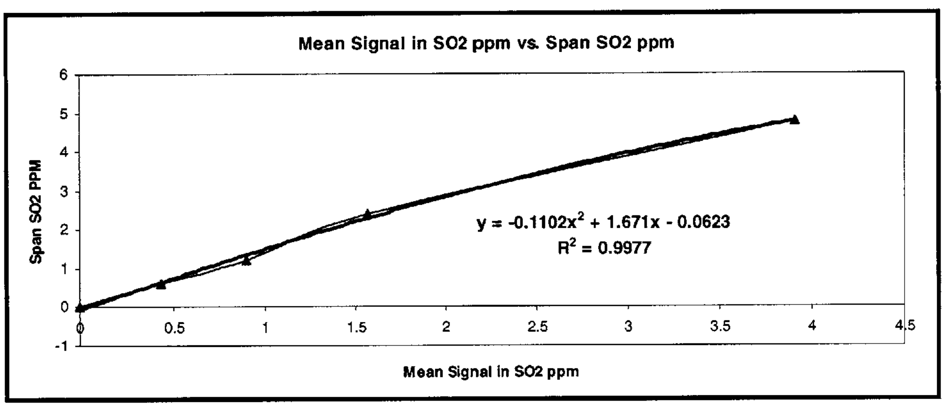

Figure 3-3 SO_2 Calibration Curve

The sensitivity of the detector is affected by the several factors: sample flow rate, ambient temperature, PMT high voltage, UV lamp, membrane dryer, ozone generator and NO. The higher the sample flow rate is the higher the sensitivity. The flow rate is, however, limited to the maximum of 800 cc/min (even at the higher pressure than 0.48

bar (7 psi) of the manual pressure regulator). The cooler ambient temperature increases the sensitivity; therefore, an air conditioner is installed in the system to keep low temperature for the sulfur fluorescence chamber and the PMT. The higher the PMT voltage the greater the signal sensitivity, but it also increases the background noise. The higher intensity of UV light increases the signal sensitivity; however, if the lamp is not appropriately positioned, it makes SO_2 signal as noise.

If the membrane dryer can not properly remove water from the sample gas, the sensitivity decreases. The inert gas in the dryer should have 2 to 3 times higher flow rate and less than 10 °C temperature than the sample gas to effectively remove water in the sample gas. The original SO_2 system was, therefore, modified by lowering the sample flow rate (set the pressure regulator at 0.34 bar (5 psi) instead of 0.48 bar (7 psi)), adding an extra dryer, and insulating the gas line around the dryer. As result, the SO_2 signal output reduction over a time was significantly reduced.

It is also important to flush the entire system with inert gas to keep the system dry while it is not running. This effectively prevents the inside of the fluorescence chamber from being corroded, which permanently reduces the SO_2 signal of the sample gas.

B. NOx Measurement System

The exhaust gas of an ordinary gasoline engine has a range of 3000 to 8000 ppm volume of NOx (over 90 % of NOx is NO). As it was mentioned previously that NO gas affects

SO_2 signal; therefore, the sufficient amount of ozone is necessary to convert all NO to NO_2 (the one molecular of ozone gas is used for the one molecular of NO). Too much ozone gas is not preferred because ozone gas attenuates the SO_2 signal intensity by absorbing UV light. Since the byproduct gas (NO_2) also attenuates the SO_2 signal intensity, and the NO concentration in the exhaust gas varies depending on the engine condition, the quantity of ozone should be set in the way that the variation of the ozone gas and NO_2 concentrations does not affect SO_2 signal. The original ozone generator (two cells) was replaced with the new generator (four cells) because it did not produce the sufficient amount of ozone.

From the experiment it was found that the attenuation of the SO_2 signal intensity is insignificant up to about 4000 ppm volume of the NOx in the exhaust gas. The attenuation effect of NOx varies depending on the flow rates of the sample gas, the oxygen for the second furnace and the ozone generator, which are hard to control precisely, and changed from time to time. It is, therefore, necessary to make the NOx attenuation curve that consists of the NOx attenuation of SO_2 signal intensity in the unit of SO_2 ppm volume as Y axis, and the corresponding concentration of NOx as X axis. The range of NOx concentration for the attenuation curve is chosen between 1600 and 8000 ppm, which is the NOx concentration range in the exhaust gas of ordinary gasoline engines.

Besides the NOx attenuation curve, a map of NOx concentrations in the exhaust gas at steady-state conditions of various engine-running conditions (loads and speeds) needs to be made. The mapping is done by using the NOx measurement instrument available at the Sloan Automotive Laboratory. Form the combination of NOx attenuation curve and NOx concentration map of the engine, the attenuation value in the unit of SO_2 ppm volume can be estimated at different steady-state engine conditions. It can be then added to the outcome of the SO_2 detector to estimate the true SO_2 volume concentration in the unit of ppm volume. Since the ozone generator in the Antex® system does not always produce the exactly same quantity of ozone, the NOx attenuation curve needs to be made every time when the SO_2 system is started for the new operation and calibrated with the span gas.

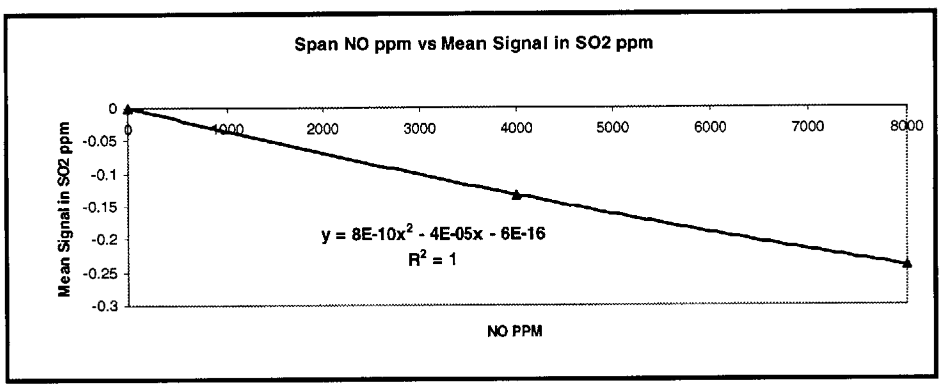

Figure 3-4 NOx Attenuation Curve

C. Exhaust Gas Sample Line and Temperature Control Unit

The exhaust gas contains several types of compounds that need to be kept as gas phase. A stainless steel tube, which intermediates between the Antex® SO_2 detector and the exhaust pipe line (before the catalytic converter), is, therefore, wrapped by heating tapes and thermal tapes to maintain high temperature of the sample gas-flow in the tube. This is not only to avoid plugging up the line by muddy compounds, but also to send as much sulfur as possible to the detector for the accurate measurement of oil-consumption. From the past experiments at the Sloan Automotive Laboratory, it was found that the ideal exhaust temperature should be about 500 °C to keep all sulfur compounds in gas phase; however, the practical highest temperature is only up to 300 °C before heating tapes are burned. This temperature can still keep above 90% of sulfur compounds as gas phase. In order to avoid burning heating tapes, the voltage sent to the heating tapes is controlled by the temperature control unit, which turns on/off the voltages power unit by referring to the sample gas temperature around the proportional valve.

D. Intake Airflow Measurement System

Besides the measurement of sulfur concentration in the exhaust gas, the simultaneous measurement of intake airflow rate is necessary to calculate oil-consumption rate. For the measurement, an intake airflow meter has been developed at the Sloan Automotive Laboratory. The principle of the system is that as intake air (laminar flow) flows through the critical orifice, it causes the air pressure drop. As the low-pressure sensor (160PC/164PC01D37) in the system measures the pressure difference before and after the orifice, and the accordance voltage regulated by the electric circuit is sent to the digital panel that indicates real-time airflow. The design for the electric circuit is based on the correlation factor of laminar flow meter between pressure drop and airflow rate, the pressure sensor sensitivity, and the digital panel specification. Prior to the experiment, the airflow meter needs to be calibrated.

E. Fuel-Consumption Measurement System

It was initially attempted to measure only fuel-consumption rate simultaneously with sulfur concentration of the exhaust gas for estimating oil-consumption rate. The accuracy of fuel or airflow rate directly corresponds to the one of oil-consumption rate. Since fuel rate of engine is much less than airflow rate, there is also less accuracy in fuel measurement. The response of the fuel rate is also slower than airflow rate to limit the transient measurement (although the SO_2 detector has a slower response). The data obtained by the fuel-consumption measurement system, however, can be used for making sure that the data of intake airflow rate and lambda sensor correspond to each other accurately. Figure 3-5 illustrates the configuration of the system.

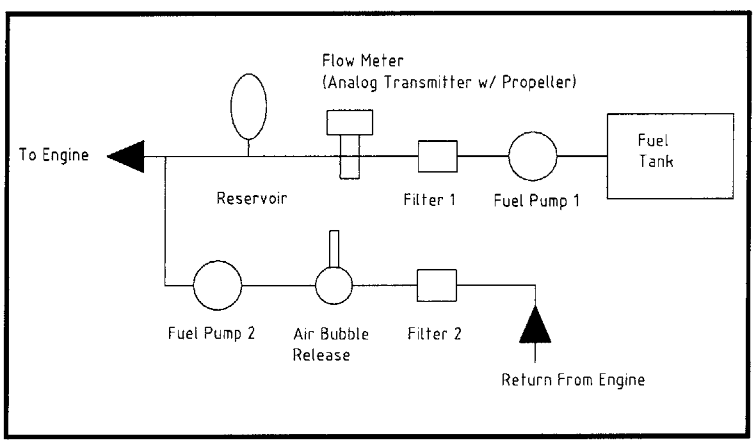

Figure 3-5 Fuel-Consumption Measurement System

F. Lambda Sensor

The parameter "lambda" is the air-fuel ratio of engine over air-fuel ratio of stoichiometric. The device called "Lambda Pro®" is capable to measure the lambda within the range between 0.55 to 1.75 and with the increment of 0.01. This device end is fixed to exhaust line near the sample gas is collected for the SO_2 detector.

G. Data Acquisition System for Oil-Consumption Measurement

The conventional way of oil-consumption measurement done at the Sloan Automotive Laboratory consists of two procedures: 1) take raw data and 2) analyze and validate raw data to convert it into oil-consumption rate. Since it takes time between the two procedures and each procedure is done at separate locations, it associates with errors during experiment. The errors are caused by 1) missing to capture useful information while engine is running and 2) being unable to restore hardware setup to repeat tests at exactly the same conditions.

The data acquisition system with LabView® program allows users to simultaneously measure and convert raw data into oil-consumption rate in real time. The appropriate data acquisition board (National Instruments®, PCI-MIO-16E-1), terminal junction box (SCB-68), PC (133 MHz) and cable (68-pin SH6868) are selected to take the raw data of the following parameters: oil-consumption rate, engine speed and load, fuel and intake airflow rates, intake manifold pressure, temperatures at the several locations of engine, lambda, and blowby. More detailed explanation can be obtained in the reference [18].

H. Other Remarks of Oil-Consumption Measurement

Since the SO_2 concentration of the exhaust gas is the primary parameter to estimate the oil-consumption rate, using the high sulfur concentrated engine oil is recommended. At the same time, the low sulfur content fuel should be used to reduce the SO_2 signal from other than engine oil. Tables 3-1 and 3-2 illustrate the specification of engine oil and fuel used for this experiment.

As it is shown in the table of engine oil specification, the sulfur weight % of oil decreases as temperature increases (or distillation % increases) and the time of engine run increases. Since the oil-consumption at the room temperature is concerned at this stage, and oil is replaced within less than 25 hours of engine run, the sulfur weight % at 100 °F should be used within somewhere between 1.51 wt.% (15100 ppm mass) and 1.43 wt.% (14300 ppm mass).

	High Sulfur Oil 10W-30		
Viscosity @ 100 F, CST	74.48		
SULFUR [%]	*1.51*		
Distillation	°C	°C	SULFUR WT %
IBP	288	160	
5 %	342	326	1.37
10 %	353	349	1.03
30 %	368	371	1.02
50 %	378	377	1.08
70 %	386	381	1.29
90 %	393	391	
EP	393	391	
% REC	34	34	
Properties after 12 hour run [1]			
Viscosity @ 38 °C, CST	61.42		
SULFUR [%]	*1.43*		

[1] Distillation after 12 hours of running time

Table 3-1 High Sulfur Oil Characteristics

	Low Sulfur Gasoline
Specific Gravity 60/60	0.7412
Reid Vapor pressure	8.9
Distillation	°C
IBP	
5 %	37
10 %	48
30 %	65
50 %	86
70 %	113
90 %	141
EP	207
Research Octane Number	94.7
Motor Octane Number	86.9
Antiknock Index	90.8
SULFUR [ppm]	**< 2**

Table 3-2 Low Sulfur Fuel Characteristics

3.2. Piston Oil-Film-Thickness Measurement System

For the measurement of piston/liner oil-film-thickness, the Laser Induced Fluorescence (LIF) system has been developed at the Sloan Automotive Laboratory. Figure 3-6 illustrates the schematic of the system. The following is a brief explanation of the system.

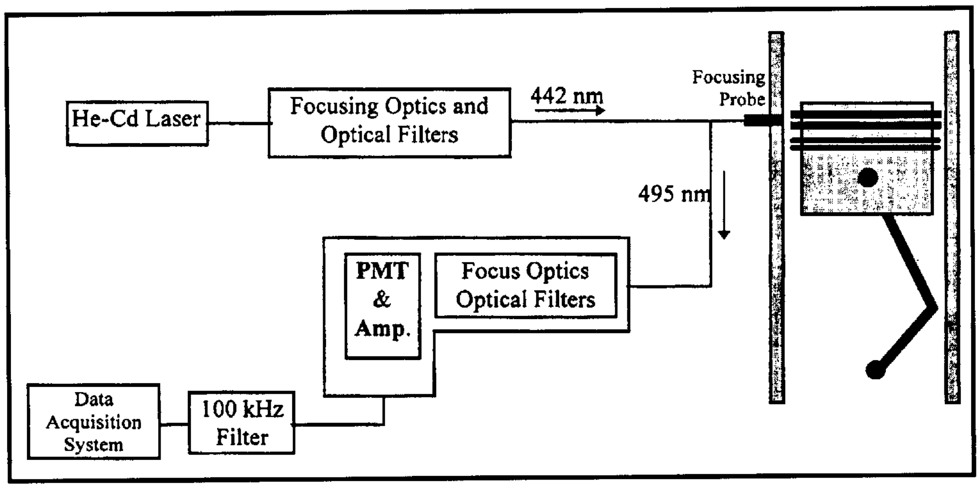

Figure 3-6 Laser Induced Fluorescence System

- He-Cd laser (442 nm wavelength) is generated and sent to a LIF focusing probe installed on engine block after it is focused and filtered.

- As the laser goes through two lenses in the probe, it is directed to engine oil through a silica window installed on cylinder-liner.

- When the laser hits engine oil, which is doped with the dye (C6 or C523 Coumarin-based, 0.15 g is mixed with 75 mil liter of Dichloromethane and 2 liters of engine oil), the dye is excited to emit the light of 495 nm.

- The incident light is then directed back to a bifurcated fiber optic cable through the probe. Before the incident light enters a photomultiplier tube(PMT) it is filtered by 495 nm filter and focused by two lenses.

- As the incident light hits the sensitive area of PMT, the PMT produces weak current signal, which is amplified by the amplifier for the data acquisition.

- A 100 kHz low-pass filter is used to eliminate the signal noise before the signal is sent to the data acquisition system.

- More detailed explanation of the system have been well documented in the references [3], [4], [19] & [20].

A. Remarks for Handling LIF System

- Turn on the He-Cd laser system and the power supply 30 minutes before the experiment, and after warm-up, measure the laser output by meter (Model 55PM). Previous users claim that the laser output should be about 14 mW; however, no more than 8 mW can be detected. This leads the laser output of 3mW maximum at the end of the cable.

- Prior to installing a focusing probe on the engine block during experiment, the LIF system and the engine should be run as if a typical data set is taken except the tip of focusing probe is covered. This data is used to determine the zero-offset value of LIF (the detailed explanation is covered in the next chapter).

- When installing a focusing probe to its sleeve make sure that output signal on oscilloscope is maximized; therefore, the noise is minimized.

- PMT input voltage by the amplifier should be set less than 700 volts in order to eliminate amplified noise (shown in Figure 3-7). The lower range of the voltage is determined by adjusting the peak LIF signal output through oscilloscope less than 10 volts. The signal greater than 10 volts will results in upper-bound signal saturation of the data acquisition system. The peak signal should be as close as to 10 volts in order to maximize the minimum signal resolution [4].

- The fluorescence intensity of the dye in engine oil decreases as engine oil temperature increases. Frequent adjustment of PMT input voltage is, therefore, necessary at different engine-running conditions.

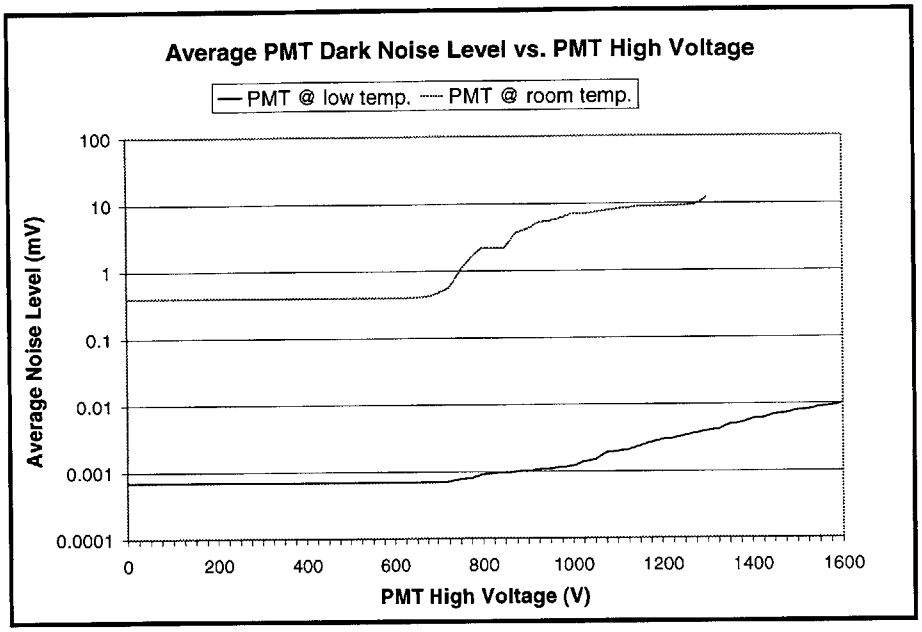

Figure 3-7 PMT Signal Noise vs. PMT Voltage *[4]

B. LIF Measurement Positions

Ideally, oil-film-thickness along stroke and around bore is measured to track all oil accumulation and supply in ring-pack. Since the liner near the TDC reaches high temperature and pressure during expansion stroke, there is a high chance that combustion residue and sludge might build up on a window and the bond might not be sustainable to the environment for a long engine operation. Accessibility to engine bore liner due to components, such as intake and exhaust manifolds, limits the location of the LIF measurement as well.

C. LIF Focusing Probe

The LIF focusing probe consists of a sleeve and a probe assembly. The probe assembly consists of probe housing, two glass lenses, and a spacer. The lenses and spacer are installed inside the housing, and the spacer is installed between lenses so that the laser can be focused through the lenses. The sleeve is screwed into the engine block and sealed by RTV Silicon. The probe assembly is then screwed into sleeve, but is adjustable to optimize the LIF signal.

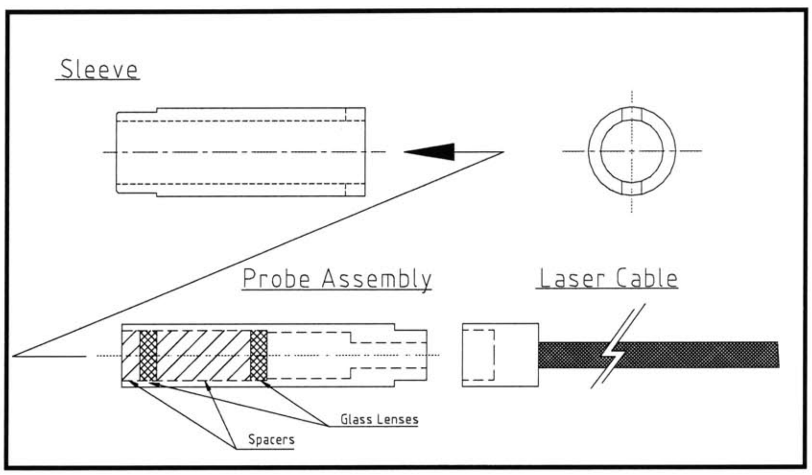

Figure 3-8 LIF Focusing Probe

D. Silica Window

Windows for the LIF measurement are ground from silica with a light transmission efficiency of over 90% at the laser and fluorescence wavelengths [4]. It is preferred to have an engine block without the honed finish-surface, so the manufacturer of the engine can hone after the windows are installed. For this project, since the surface of windows that is honed by the manufacturer was not acceptable, silica windows were redesigned for the honed bore liner.

To avoid breaking and scratching window surface by honing, only the 25 microns (1/1000") of protrusion is allowed from the bore surface after silica windows are installed with bond. The bond used to install windows is the combination of ECOBOND® 285 and Catalyst 24LV. This bond is selected for its excellent adhesion, thermal shock and impact resistance, excellent low temperature properties, and fast cure. The upper limit service temperature of the bond, which is 120 °C, limits the location of window on the bore liner and the engine operating temperature. The volume of the bond in the thickness of 12 microns (0.5/1000") should be taken into account for determining the window dimensions.

After the windows are honed (bore is also hone at the same time), the measurements of bore diameter, bore distortion, and window profile and recess are necessary. If the honed bore diameter exceeds the tolerance (60 micron in diameter for this engine), a piston and rings have to be replaced with larger ones. The bore distortion measurement is also important to ensure that piston rings fit well to the bore liner. The engine bore with the exceeded tolerance and distortion results in greater oil-consumption than the originally designed engine.

After honing, the silica windows are not allowed to protrude from the bore surface, and the window recession should be taken into account for offsetting the LIF data. If the depth of scratches on silica window surface exceeds more than a few microns, windows need to be re-honed until the smoother surface is accomplished. In order to measure the silica window surface with the cylinder-liner, the Talysurf® profilometer is used. The equipment is a tactile sensing instrument that uses a sharply pointed stylus to trace surface irregulars.

The flushness of silica windows with cylinder-liner was measured, and it was found that windows are not protruded from the cylinder wall. The surface roughness of all silica windows is within 5 microns, which is within the tolerance. The flushness of a window with cylinder-liner is illustrated in Figure 3-9.

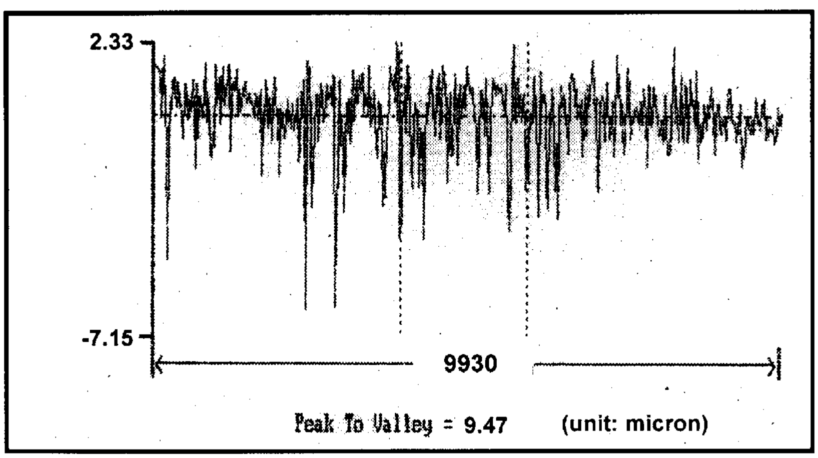

Figure 3-9 Roughness of Silica Window and Cylinder-Liner
(Silica window is between dashed lines)

The cylinder-liner surface of the different cylinder that is honed by the engine manufacturer is also measured, and the result is used to ensure that the newly honed surface of the silica windows and the cylinder-liner is within the tolerance of surface roughness. Since the scratch depths of the different cylinder wall are within 8 microns, which is larger than the one of silica windows, the newly honed surface of the silica windows and the cylinder-liner is acceptable.

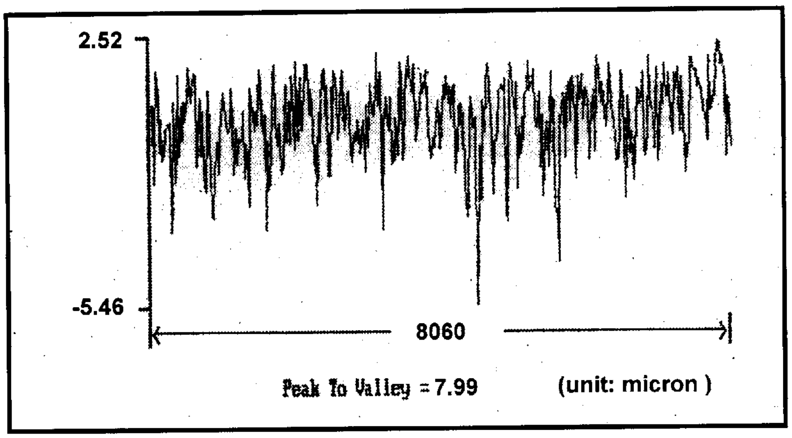

Figure 3-10 Roughness of the Different Cylinder-Liner

The profile measurement of the silica windows and the cylinder-liner is done at room temperature. Since thermal-expansion coefficients of the silica window, the engine block, and the glue are different from each other, the flushness is expected to be different when the engine is running. Besides the heat expansion, the wear rates of the silica window and the engine cylinder-liner by the piston rings are different. Another profile measurement is recommended after the completion of the experiment to ensure that the flushness is still tolerable.

E. 100 kHz Low-Pass Filter

The smallest sinusoidal-wave feature of the piston and ring-pack profiles is the edge of the oil control ring, the thickness of which is 0.57 mm, and the corresponding wavelength can be assumed to be twice of the thickness (1.14 mm). When the engine is running at the maximum speed (6000 rpm), the oil control ring passes by the silica windows that are installed 40 mm below TDC at the speed of about 26 m/s (the speed is slower at the windows installed 80 mm below TDC). At this speed, the absolute minimum sampling rate of 22.8 kHz (=(26 m/*s*) / (1.14 mm)) is required to trace the wavelength of oil control ring. To prevent signal aliasing, it is suggested by Nyquist criterion that the minimum sampling rate should be doubled (45.6 kHz). Since the frequency of the low-pass filter that is available at the Sloan Automotive Lab is 100 kHz, and the frequency is larger than the minimum sampling rate, this filter can remove the noise higher than 100kHz without eliminating the detailed feature of the LIF signal.

F. Data Acquisition System and Shaft Encoder

For the measurement of ring-pack oil-film-thickness, cylinder pressure, and ring-pack pressures, another data acquisition system is used. The 12-bit data acquisition board, Keithley Metrabyte® DAS-50, has an input range of +/- 10 volts with the maximum sampling rate of 1 MHz. The program installed in a 486-33 MHz IBM® Compatible PC needs to receive the trigger and clock signals to acquire the data signal.

To send the trigger and clock signals, a shaft encoder (BEI Model 25 Incremental optical encoder), which is connected to the end of the engine crankshaft by a coupling, is used. The shaft encoder sends one trigger signal and 2000 clock signals every revolution. The trigger signal is used for starting to run the data acquisition system, and the clock signals are used as timing for sampling the data. The maximum sampling rate of the LIF and pressure measurements equals to the clock signal rate that is 200 kHz, when the engine is running at the maximum of 6000 rpm. Since the maximum sampling rate of the data acquisition system is 1MHz, the maximum number of channels is limited to five when the data is taken at the maximum engine speed. The closest channel number that the data acquisition system can handle is, however, four. This constrains the number of parameters that can be simultaneously measured to four (ring-pack oil-film-thickness, one cylinder pressures, and two ring-pack pressures).

If more than one parameter needs to be measured, a multiple data-splitter device is required to acquire data in parallel. Since the fastest data-splitter available is slower than the maximum sampling rate (200 kHz), the data is taken sequentially, instead. When the data is taken sequentially at engine idling speed of 600 rpm, (the corresponding sampling rate is 20 kHz), the longest time-interval or time-duration between data points is 67 microseconds. This value is too small to be considered for losing the detailed features of the data; therefore, the sequential data acquisition is acceptable.

3.3. Cylinder Pressure, Ring-pack Pressure, Liner Temperature, and Blow-by Measurement System

A. Cylinder Pressure Measurement

The cylinder pressure of the cylinder 2 and 3 is measured sequentially with ring-pack oil-film-thickness. The pressure transducer used for this measurement is the Thermo COMP® Quartz Pressure Sensor Type 6061B, which has a water-cooled function to achieve the high sensitivity, the high natural frequency, and the excellent zero point stability. The end of transducer is connected to a dual mode amplifier (Kistler Type 5010). Since the maximum cylinder pressure is expected to be less than 100 bars, and the output voltage signal range is desired to be between 0 to 10 volts, the amplifier scale is set to be 10.

When a charge amplifier is used for the practical manner, the two most important factors for setting the amplifier are the time constant and the drift, and either one becomes the dominant factor. Since they are the negative effects to the amplified output signal, the careful selection of either one is necessary depending on the measurement situation.

When the time constant is long (slower rate), the drift becomes the dominant factor; therefore, on the other hand, the time constant becomes the dominant factor when it is shorter. The time constant is defined as the discharge time of an AC coupled circuit. As the time constant gets shorter, the faster decay of the amplified output occurs; therefore, the long time constant is preferred. On the other hand, the drift is defined as an undesirable change in output signal over time, which is not a function of the measured variable. As drift becomes the dominant factor, the amplified output drifts towards saturation at a certain rate. Since the time period of engine cycle is shorter than the drifting rate of the output signal, the drift becomes insignificant. This is why the time constant of the charge amplifier is set long, so the negative effect due to the time constant can be eliminated. Although the drifting within a cycle is insignificant, it is necessary to offset the pressure output signal every time the signal is analyzed. By assuming either that during exhaust stroke the cylinder pressure is atmospheric (1 bar), or that during intake stroke the cylinder pressure equals to the intake manifold pressure, the offset of pressure trace can be done.

B. Ring-Pack Pressure Measurement

There are two types of mass-flows that are assumed to significantly affect the oil-consumption, and they are the one coming from the piston skirt land into the crankcase and the other one coming from the piston crown land into the cylinder chamber. The one going into the crankcase is called blowby, and it is measured by a blowby meter installed in the EGR line of the engine. The other one coming through the crown land is called reverse blowby, and it can be estimated by using the *RINGPACK-OC* computer model. As input of the computer model, the ring-pack pressure needs to be measured to accurately estimate the gas-flow rate.

From past experience, it is known that the reverse blowby occurs between 0 to 90 crank angle degrees after TDC during expansion stroke. The locations of pressure transducers are, therefore, selected in the way that the pressure in the crown and second lands can be measured within the crank angle degrees. The figure below illustrates the measurement locations for ring-pack pressures, LIF and liner temperature, and the profile of the piston land/groove as the piston travel along the cylinder-liner.

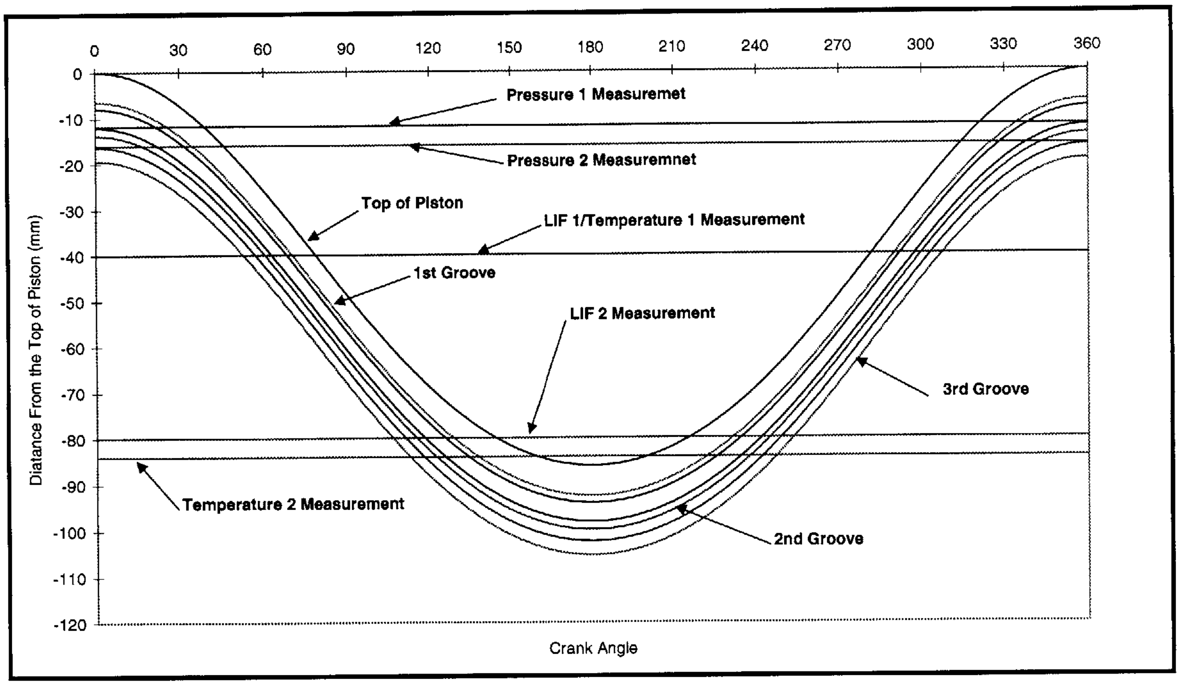

Figure 3-11 Measurement Locations and Piston Land/Groove Locations

The custom-made adapter is designed to isolate the water jacket while it mounts the pressure transducer with proper sealing on the combustion chamber. The pressure transducer used for the ring-pack pressure measurement is the Thermo COMP® Quartz

Pressure Sensor Type 6051B1. Unlike the one used for the cylinder pressure measurement, this transducer does not have a water-cooled feature because the cylinder wall does not get as high as the combustion chamber. The adapter for this pressure transducer is custom-designed, is screwed into the cylinder wall, and is fixed with the RTV Silicon Bond. The end of the pressure transducer is also connected to the same dual mode amplifier used for the cylinder pressure measurement, then the output of the amplifier is connected to the data acquisition system.

C. Liner Temperature Measurement

Two metal sheathed thermocouples (Omega® Type K Part # KMQSS-062U-6) are placed on the cylinder wall to measure the ring-pack temperature. Those thermocouples are fixed with a 1/32" Swagelock fitting and RTV silicon on the external surface of the cylinder wall. Since temperature gradient is slow over an engine cycle at the steady-state engine condition, the temperature is monitored by a temperature indicator (Omega® Model DP462), instead of the data is taken by the same data acquisition system used for the LIF and pressure measurements. To ensure the steady-state engine condition, the LIF data is taken after the temperatures indicate steady values.

The purpose of the temperature measurement is to calibrate the LIF signal to oil-film-thickness more precisely over a certain temperature range. As it was mentioned previously, the LIF signal is proportional to the fluorescence, and oil-film-thickens is proportional to the LIF signal. From the experimental data [21] it is shown that the fluorescence of dye in engine oil decreases when engine oil temperature increases, in other words, the change in dye temperature should be taken into account for calibrating the LIF signal to the oil-film-thickness. The more detailed explanation of the LIF calibration method is discussed in the next chapter.

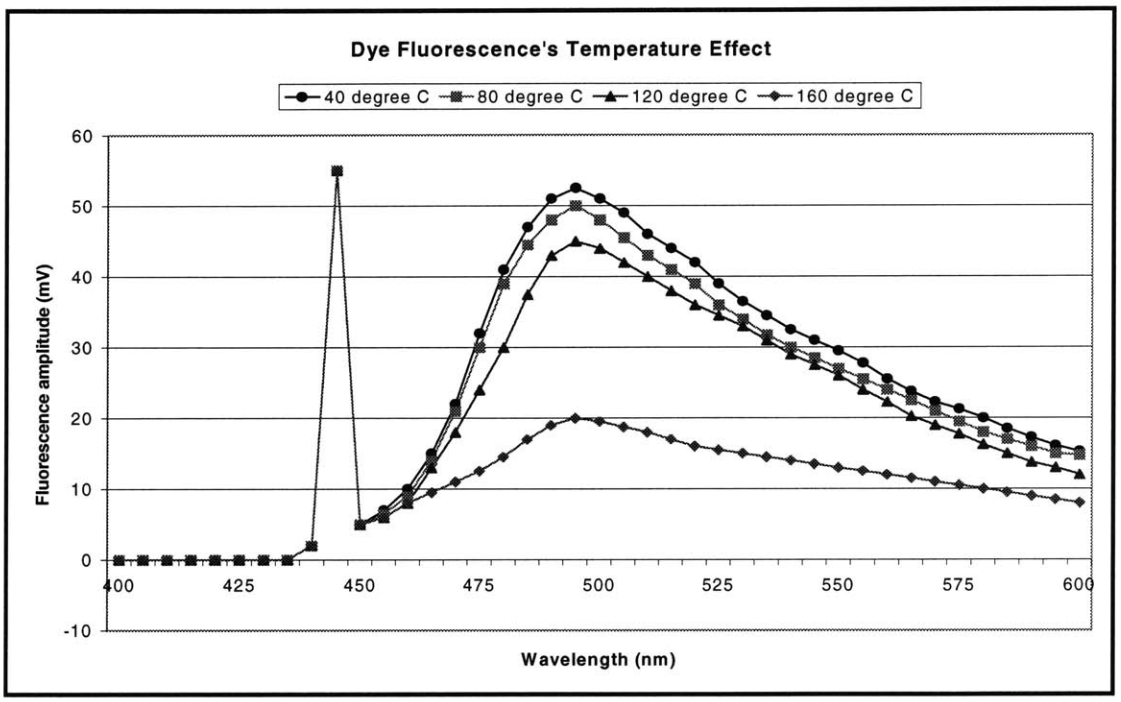

Figure 3-12 Fluorescence Amplitude verse Wavelength [21]

D. Blowby Measurement

A blowby meter (J-Tech® Model VB563AA) is employed on the engine to measure the volumetric flow-rate of blowby. This measured value can be used to verify the input and output of the RINGPCK-OC computer model that predicts the gas-flow rate in the ring-pack. Since the blowby, the reverse blowby, and other gas-flows significantly influence the engine oil-consumption [16.] & [23], the accurate measurement of them is important.

3.4. Steady-State Measurement Procedure

The test matrix for this project is designed to measure oil-consumption and ring-pack oil-film-thickness at various engine-loads and engine-speeds. Besides the measurements, ring-pack and cylinder pressures, cylinder-liner temperature, and blowby flow rate are simultaneously measured. The running-conditions of the engine are steady sate, and the range of engine load and speed is selected from no-load (idling) to the maximum load (wide-open throttle), and from 700 rpm (idling) to 6000 rpm (the maximum speed) respectively. The smaller the increments of engine-running conditions is, the better it is to see small changes in the data to correlate oil-consumption and ring-pack oil-film-thickness. However, since the LIF data is taken at four locations, the single increase in engine condition leads to the quadruple increase in data points.

The steady-state engine-running conditions can be obtained by monitoring the oil-consumption signal, the sample line temperature, and the cylinder-liner temperature. Since it usually take 10 to 15 minutes to obtain the steady sate condition of the engine, the frequent check of the measurement systems is required to assure good test data. During the oil-consumption measurement, the pressure in the manually-controlled pressure regulator, the zero SO_2 detector signal, and the oxygen flow rates to the second furnace and the ozone generator are unstable. These systems frequently need to be checked because they greatly affect the oil-consumption data. For the oil-film-thickness measurement, since four locations are measured during an engine-running condition, the adjustment of LIF focusing probe needs to be well done to acquire the high LIF signal. Overall, careful attention to the coolant and engine oil temperatures is necessary to avoid engine over-heating.

CHAPTER 4: DATA REDUCTION PROCEDURES

4.1. Oil-Consumption Data

Since the Antex® SO_2 detector is highly sensitive to setup conditions that constantly change, frequent calibration of the system is necessary. Once the system is stabilized and calibrated, the data should be collected while the engine is running at steady-state condition. It has been previously mentioned that the original signal from the SO_2 detector is attenuated by NO_X gas, so the SO_2 signal corresponding to the SO_2 volume concentration in the dried sample gas can be estimated by adding the NO_X attenuation value to the original signal.

After the SO_2 concentration in the dried sample gas is estimated, it needs to be converted into the SO_2 concentration in the wet sample gas (the exhaust gas from the engine). This requires the lambda value of the exhaust gas and the molar hydrogen-carbon ratio of fuel. Once the SO_2 concentration in the exhaust gas is calculated, the intake airflow rate of the engine, and the sulfur mass concentration of the fuel and the lubricant oil are used to estimate the engine oil-consumption rate. The following outline describes the procedure for evaluating the experimented data to obtain the oil-consumption rate.

A. Given

$[SO_{2\ Dry}]$: SO_2 volume concentration in the dried sample gas (ppm volume)

λ : Lambda of the exhaust gas ($A/F_{mixture} / A/F_{stoichiometric}$)

Y : Molar Hydrogen-Carbon ratio of fuel

*M*a : Intake airflow rate of engine (g/hr)

S_{fuel} : Sulfur mass concentration fraction in fuel

Ex. 0.2 ppm mass = $0.2*10^{-6}$

S_{oil} : Sulfur mass concentration fraction in oil

Ex. This should be between 0.0143 (old) and 0.0151 (new)

φ : Molar Nitrogen-Oxygen ratio of air = 3.773

MW_S : Molecular weight of sulfur (g/mole) = 32.06

MW_{SO2} : Molecular weight of SO_2 (g/mole) = 64.06

B. Assumptions

1. Air/Fuel mixture is completely burned either during the engine combustion or in the SO_2 detector
2. All hydrogen molecules are converted to H_2O in the SO_2 detector
3. H_2O is completely removed from the sample gas in the SO_2 detector
4. No effect of the EGR
5. All sulfur compounds are converted into SO_2 gas in the SO_2 detector

C. Calculations

First, calculate the SO_2 volume concentration in the exhaust gas (wet gas):

- $A/F_{stoichiometric}$: Air/Fuel ratio at stoichiometric

  $=[(4 + Y) * 34.56]/ (12.011 + 1.008 * Y)$ ··· Eq.4-1 [23]

  ϕ : Fuel/Air equivalence ratio = $1 / \lambda$ ··· Eq.4-2

  ε : Epsilon = $4 / (4 + Y)$ ··· Eq.4-3

- *Burned gas (the exhaust gas) compositions under 1700 K*: [23]

  H_2O : Molar ratio of H_2O to O_2 reactant

  Nb : Molar ratio of the burned gas to O_2 reactant

- *If $\phi \leq 1$ (lean fuel mixture):*

  $H_2O = 2 * (1 - \varepsilon) * \phi$ ··· Eq.4-4

  $Nb = (1 - \varepsilon) * \phi + 1 + \varphi$ ··· Eq.4-5

- *If $\phi > 1$(rich fuel mixture):*

  $H_2O = 2 * (1 - \varepsilon) * \phi$ ··· Eq.4-6   based on assumption 2

  $Nb = (2 - \varepsilon) * \phi + \varphi$ ··· Eq.4-7

From the above two parameters (H_2O and Nb):

- $[SO_{2\ Wet}]$: SO_2 volume concentration in the exhaust gas (wet gas) (ppm vol.)

  $= [SO_{2\ Dry}] * (1 - H_2O / Nb)$ ··· Eq.4-8 based on assumption 3

  where $[SO_{2\ Dry}]$: SO_2 volume concentration in the dried sample gas (ppm vol.)

- $\{SO_{2\ Wet}\}$: SO_2 volume concentration fraction in the exhaust gas

  $= [SO_{2\ Wet}]/10^6$ ··· Eq.4-9

Second, convert the SO_2 volume concentration fraction in the exhaust gas (Eq.4-9) into the SO_2 mass concentration fraction in the exhaust gas ($SO_{2\ Wet}$) (Eq.4-12). The mass and molecular weight of the fresh mixture or the exhaust gas are estimated below.

- m_{rp} : Mass of the fresh mixture or the exhaust gas per mole O_2 (g per mole O_2)

  $= 32 + 4 * \phi * (1 + 2 * \varepsilon) + 28.16 * \varphi$ ··· Eq.4-10

  from Heywood [23]

- MWb : Molecular weight of fresh mixture or exhaust gas (g/mole)

  $= m_{rp} / Nb$ ··· Eq.4-11

From the above parameters:

- $SO_{2\ Wet}$: SO_2 mass concentration fraction in the exhaust gas

  $= \{SO_{2\ Wet}\} * MW_{SO2} / MWb$ ··· Eq.4-12

Referred to Assumption 5, all sulfur atoms in the exhaust gas are reacted with oxygen to become SO_2. From the SO_2 mass concentration fraction in the exhaust gas, the sulfur mass concentration fraction in the exhaust gas can be expressed as follows:

- S_{Wet}: Sulfur mass concentration fraction in the exhaust gas

  $= SO_{2\ Wet} * MW_S / MW_{SO2}$ ··· Eq.4-13

Mass rate of sulfur in the exhaust gas (Eq.4-16) is estimated based on the above parameters and intake airflow rate.

- Mf : Fuel mass-consumption rate (g/hr)

  $= M\text{a} / (\lambda * A/F_{stoichiometric})$ ··· Eq.4-14

- Mrp : Mass rate of the fresh mixture or the exhaust gas of engine

  $= M\text{f} + M\text{a}$ ··· Eq.4-15

- $M_{S\text{-}Total\text{-}Exhaust}$: Mass rate of sulfur in the exhaust gas (g/hr)

  $= S_{Wet} * M\text{rp}$ ··· Eq.4-16

- $M_{S\text{-}Fuel}$: Mass rate of sulfur from fuel in the exhaust gas (g/hr)

  $= M\text{f} * S_{fuel}$ ··· Eq.4-17

Subtract the mass rate of sulfur from fuel (Eq.4-17) from the mass rate of sulfur in the exhaust gas (Eq.4-16) to estimate the mass rate of sulfur from oil (Eq.4-18).

- $M_{S\text{-}Oil}$: Mass rate of sulfur from oil in exhaust gas (g/hr)

$$= M_{S\text{-}Total\text{-}Exhaust} - M_{S\text{-}Fuel} \cdots \text{Eq.4-18}$$

Finally, the oil-consumption rate is estimated as:

OC : oil-consumption rate (g/hr) $= M_{S\text{-}Oil} / S_{oil} \cdots$ Eq.4-19

The following single equation of oil-consumption rate is derived from the above equations.

OC (g/cycle):

$$= \left\{ \frac{\left[\frac{[SO_{2Dry}]}{10^6} \times \left(1 - \frac{H_2O}{Nb}\right)\right] \times MWs}{\left[\frac{32 + \frac{4}{\lambda} \times \left[1 + \frac{8}{(4+Y)}\right] + 28.16 \times \varphi}{Nb}\right]} \times Ma \times \left[\left(\frac{\lambda \times (4+Y) \times 34.56}{12.011 + 1.008 \times Y}\right)^{-1} + 1\right] - \left[S_{Fuel} \times Ma \times \left(\frac{\lambda \times (4+Y) \times 34.56}{12.011 + 1.008 \times Y}\right)^{-1}\right] \right\} \times \frac{1}{S_{OIL}}$$

$\cdots$ Eq.4-20

- *If* $(1/\lambda) \le 1$:
  $H_2O = 2(1 - \varepsilon) * \phi$ $\cdots$ Eq.4-4
  $Nb = (1 - \varepsilon) * \phi + 1 + \varphi$ $\cdots$ Eq.4-5

- *If* $(1/\lambda) > 1$:
  $H_2O = 2(1 - \varepsilon) * \phi$ $\cdots$ Eq.4-6
  $Nb = (2 - \varepsilon) * \phi + \varphi$ $\cdots$ Eq.4-7

In grams per cycle base,

OC (g/cycle) :

$$= OC\ (g/hr) * \frac{1\,hr}{60\,min} * \frac{1}{RPM} * \frac{2\,revolution}{1\,cycle}$$

$$= \frac{OC\ (g/hr)}{RPM * 30} \cdots Eq.4-21$$

4.2. Oil-Film-Thickness and Pressures Data

The LIF and pressure data acquisition system takes 4000 data points per cycle per parameter. There is a cycle to cycle variation in the combustion chamber, even when an engine is running at steady state. To compensate for this variation, data should be taken for more than one cycle. Although the interval period of the variation is unknown, the data points are taken for every 10 consecutive cycles. The data acquisition system, therefore, takes 40,000 data points for each parameter. Through data processing, the data points are then averaged to determine an average-cycle model

After the data points are taken, each parameter is arrayed into a 10-column by 4000-row matrix by the "*SH2*", a FORTRAN based program. The matrix is then transformed into a Microsoft Excel spreadsheet to plot the graph below. Figure 4-1 shows the raw data plots of LIF and cylinder pressure, which are already shifted horizontally, so that the traces of LIF and pressure begin from the intake stroke and the LIF trace matches the piston profile.

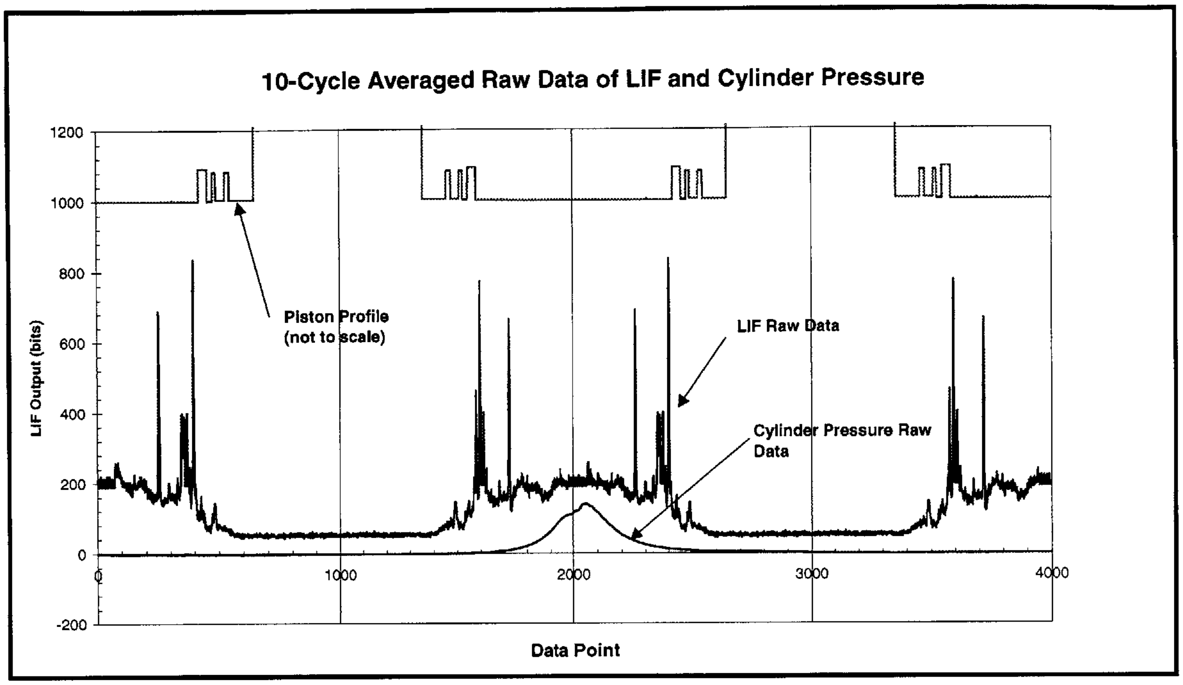

Figure 4-1 LIF and Pressure Raw Data

By examining the first 1000 data points of the LIF trace (during the intake stroke), it can been seen that the data acquisition starts recording the LIF and the cylinder pressure when the bottom of the piston skirt is above the silica window that is located 55 mm below top dead center (TDC). As the piston moves down the cylinder after approximately 250 points, the LIF spikes are traced corresponding to the oil-film in the piston regions. These spikes occur in sequence beginning with the piston scratch mark, followed by the oil control rings, the second (scraper) ring, and the top (compression) ring. About 600 data points after, which is the end of the crown land, the LIF system traces the free liner oil-film-thickness that is above the piston. This period continues until the piston comes back in front of the silica windows during the compression stroke. Oil-film-thickness is then recorded in the reverse order as seen during the intake stroke.

This tracing pattern continues in the same manner for the expansion and exhaust strokes. The cylinder pressure trace of the complete four strokes can be also seen as it reaches the peak value right after the 2000th data point, which corresponds to the beginning of the expansion stroke.

At this point, further data processing is necessary to precisely illustrate the traces of oil-film-thickness and cylinder pressure. The data processing consists of three steps: data shifting (horizontal shift), zero offsetting (vertical shift), and calibration.

A. Data Shift

Data shifting is necessary to horizontally shift the LIF and pressure traces so that they start at the beginning of a stroke. The intake stroke has been chosen as the first stroke, so some data points need to be subtracted from the 40,000 data points before they are converted into a matrix since the data acquisition triggering starts arbitrarily in a cycle. As the average from data points of a 10-consecutive-cycle is desired, it is necessary to take 11-consecutive-cycle data points. Once the exact number of subtracted data points is found, the data point subtraction is done by the *SH2* program.

To estimate the number of subtracted data points, first, LIF and pressure traces first need to be plotted on an Excel spreadsheet along with the piston profile without subtracting any data points. If the triggering does not start at the top dead center (TDC) of the intake stroke, the spikes of the LIF trace do not match with the piston profile (see Figure 4-2), and the cylinder pressure does not peak around the 2000th data point. Since the LIF spikes corresponding to the piston rings are hard discern, the spikes of the piston scratch mark are used for easy identification. The scratch marks on the piston are also used to calibrate the LIF trace to the oil-film-thickness.

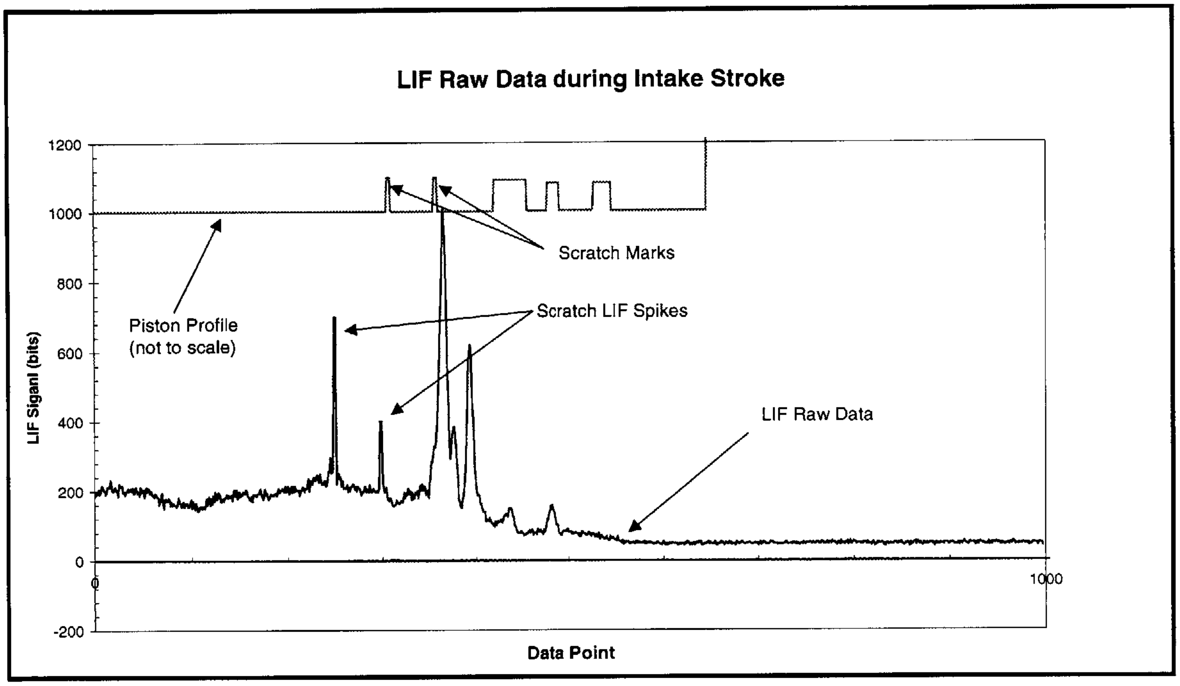

Figure 4-2 Unmatched LIF Raw Data Trace

If the scratch marks on the piston and their corresponding LIF spikes match perfectly after subtracting the "X' number of data points from Figure 4-2 and the cylinder pressure trace peaks out around the 2000th data point, the estimation of the subtracted number is determined to be "X". If the pressure does not reach the peak value but the trace matches perfectly, 2000 extra data points need to be added to "X". The determination of "X" is only necessary once unless the shaft encoder is readjusted on the engine crankshaft.

Under certain engine conditions, the LIF spike during some strokes does not match the corresponding piston scratch marks. This could be due to the mechanical error of the data acquisition system, piston secondary (piston tilt) motion, and crankshaft torsion. The data shift due to the piston secondary motion and the crankshaft torsion depends on the pressure within the cylinder and the lubricant behaviors in the piston ring-pack. To eliminate this mismatching, the data shifting of the LIF trace must be done for each stroke.

Once the LIF trace is shifted, it is necessary to convert the x-axis from the data point to the unit of distance since the primary interest of the LIF measurement is to observe the thickness and volume of the oil-film on the cylinder-liner. The distance is determined as the distance from the top of the piston to the silica window and is converted from the crank angle by the equation below. The increment of the data point is 0.18 degree crank angle.

$$D = W - R - L + R\cos\theta + (L^2 - (R * \sin\theta)^2)^{1/2} \quad \cdots \text{Eq.4-22}$$

where D: distance from the top of piston to silica window
W: window location from the top dead center
R: crank radius
L: connecting rod length
θ: crank angle (0.18 crank angle degree at the first data point which corresponds to the beginning of intake stroke)

It is important to precisely measure the length of each component to be able to precisely match the oil-film-thickness to the piston profile. Figure 4-3 is already data-shifted from the previous figure, and the x axis is converted to distance.

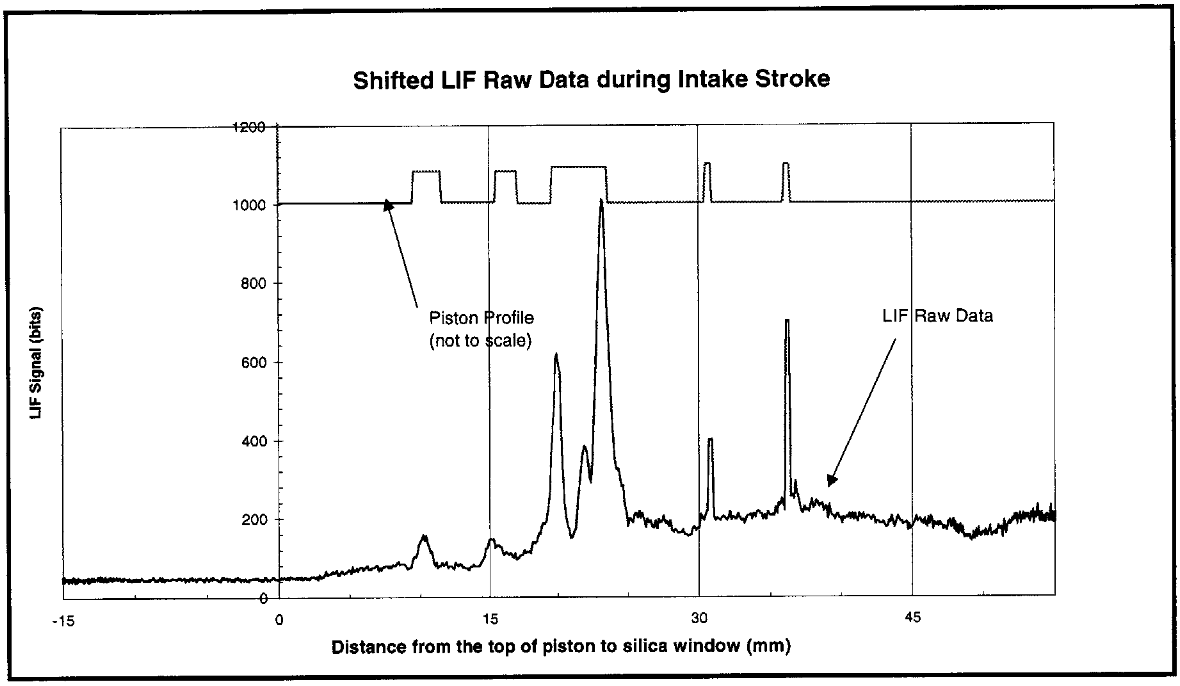

Figure 4-3 LIF Raw Data during Intake Stroke

B. Zero Offset

The zero offset is necessary to estimate the absolute oil-film-thickness by shifting the LIF trace vertically. The zero offset value depends on two factors. The first factor is the noise associated with the LIF system, and the second is the recess of the silica window.

As it was mentioned previously, the noise of the PMT is sensitive to the surrounding temperature of the PMT, and suddenly increases when the PMT voltage exceeds 700V. There is another source of noise, which is picked by the data acquisition system when data are taken. The low-pass filter connected between the PMT and the data acquisition system can reduce the noise frequency; however, the absolute noise value needs to be removed by the following method.

In order to determine the zero offset value due to noise, the data acquisition should be done by the normal procedure, except the tip of the laser cable should be covered by a black cap. This step needs to be done for all engine-running conditions because the PMT high voltage is adjusted for the engine conditions, and the noise is sensitive to the PMT high voltage value. Once the data for the zero offset and the LIF trace are taken, the zero offset value needs to be subtracted from the LIF trace.

The profile of the honed silica windows is measured to ensure that the window does not protrude from the cylinder-liner and that the recess and scratches of the window are within tolerance. The recess value should be subtracted from the LIF trace once the LIF trace is converted into the oil-film-thickness. The other consideration regarding the silica window surface is the depth of scratches. The scratch depth is usually between 2 to 5 microns, but it is not known through which scratch the laser beam penetrates to the ring-pack oil. Even if there is no window recess but the scratch depth is large, it is difficult to know how much should be subtracted from the oil-film-thickness due to the oil accumulation in the scratches.

On the other hand, the offset of the cylinder pressure and ring-pack pressure traces can be done after the calibration. There are two ways to offset the pressure traces. The first way is to offset the pressure traces during the intake stroke based on the intake manifold pressure. The second method is to offset the traces at the end of the exhaust stroke based on the atmospheric pressure. Offsetting pressure traces based on the exhaust stroke may cause potential errors because in particular circumstances the exhaust pressure will be higher than the atmospheric pressure due to the back pressure from the exhaust line.

C. Calibration

The purpose of the LIF calibration is to convert the voltage signal from the PMT into the actual oil-film-thickness usually as a micron measure. There are three methods that have been developed at the Sloan Automotive Laboratory to calibrate the LIF raw data: 1) upper skirt land machining mark method, 2) upper oil control ring profile method, and 3) upper skirt land piston scratch mark method.

These methods are chosen for because there is high chance of oil accumulation at the calibration areas and the calibration marks of the three methods never wear out. The detailed explanation of the first two methods is described in Tamai's thesis [4]. The drawbacks of these two methods are: 1) large time requirement and 2) low resolution of the LIF data. In addition to these drawbacks, the upper skirt land machining mark method required that the piston have machining marks on the skirt area. The upper oil control ring profile method has a problem associated with measuring the ring profile accurately. Even if the profile is measured accurately, the ring twist and the lift make it difficult to find a good correlation between the ring profile and the oil-film-thickness. Since it is hard to estimate the exact location and the twist angle of the rings, the accuracy of calibration decreases. For tow upper-skirt-land methods, when the piston tilts, matching the oil-film-thickness to the profile of the machining mark and the scratch mark also becomes more difficult, thus decreasing the accuracy of the calibration. The ring twisting and lifting however does not affect the accuracy of the two methods.

The method that requires the least calibration time and provides the highest accuracy is the upper-skirt-land scratch mark method. Figure 4-4 illustrates the machined scratch marks on the piston. In past experiments at the Sloan Automotive Laboratory, similar scratch marks were made by a chemical etching process [22]. It is difficult with this process to control the depth of the marks and to achieve a flat bottom surface that is crucial to the accuracy of the data LIF calibration.

Because the difference in the depth of the two scratch marks is used to determine the coefficient between the oil-film-thickness and the LIF data, at least two scratch marks in the piston axial line are necessary unless no machining mark on the skirt land. If the skirt land is flat, the depth of one scratch mark is used to estimate the calibration coefficient. The location of the scratch marks should be as close to the oil-control rings as possible because the oil accumulation around the region is high. The two scratch marks in the piston axial line should also be as close as possible, so that the temperature of the oil accumulated in the scratches are closer. The determination of the depth (25 microns ± 5) and the width (500 microns ± 50) of the scratch marks is described below.

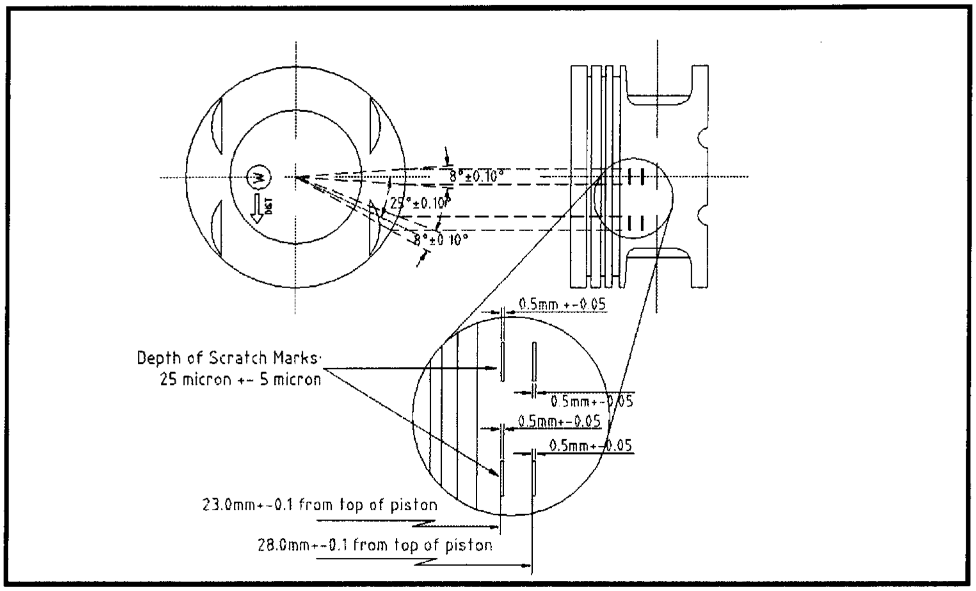

Figure 4-4 Piston Scratch Marks

It is known that the LIF fluorescence of the dye used for this experiment is proportional up to 80 to 100 microns of the oil-film-thickness [4]& [21]. Since the maximum gap height between the cylinder-liner and the upper-piston-skirt-land is about 70 microns, the depth of the scratch marks is limited to 30 microns.

The width of the scratch marks is determined based on the number of data points required to trace the scratch marks. Since the scratch marks could affect the oil motion on the piston skirt, the width, and the depth of the marks should be minimized. The interval distance of data points varies depending on the location of the silica window because the piston speed changes when it reciprocates along the cylinder-liner. The faster the piston speed is, the longer the interval distance; therefore, the lower the number of data points is taken within the scratch mark width. For example, when the engine speed is 3000 rpm, the 2,000-pulse per revolution shaft encoder sends clock signals to the data acquisition system to take data every 10 microseconds. At that engine-speed, the piston speed gets as high as 13.2 m/s when the lower scratch mark passes by the silica window that is located 80 mm below top dead center (based on the four-cylinder gasoline engine). From the clock signal rate of the data acquisition system (10 μs) and the maximum piston speed (13.2 m/*s*), the interval between data points is estimated to be 0.132 mm. In order to ensure that there are enough data points to trace the scratch marks (i.e. three points) the minimum width of the scratch marks becomes about 0.4 mm. Because of the availability of the tool to make the scratch marks, 0.5 mm = 500 microns is selected as the scratch width.

Once the scratch marks are made on the piston, profile measurement on the scratch marks is necessary because the accuracy of the scratch mark depth measurement directly affects on the accuracy of the oil-film-thickness calibration. The location of the scratch marks is also important to shift the LIF trace accurately along the piston profile. The following figure is the micro-geometric profile of scratch marks made on the center axis of the piston, and the difference of the two depths is measured to be 38.5 microns.

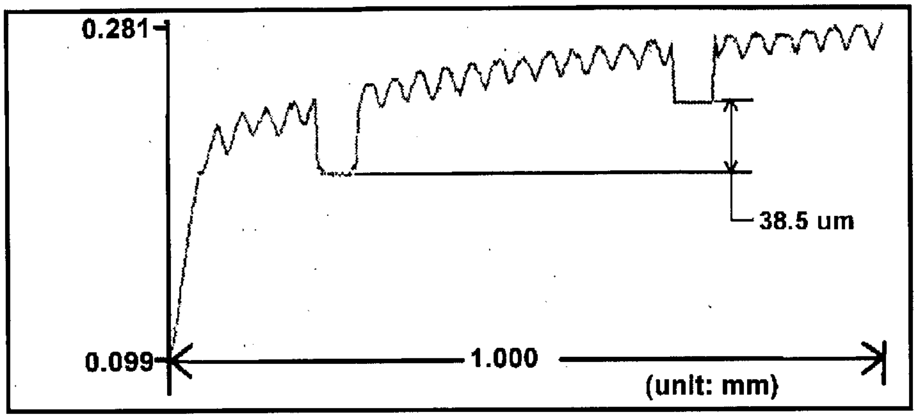

Figure 4-5 Scratch Marks on the Center Axial of Piston

By knowing the scratch depth difference, the shifted LIF trace can be calibrated after subtracting the noise signal. The LIF calibration should be done based on the single cycle trace rather than the 10-cycle averaged trace because there is the cycle to cycle variation. Among the four strokes, the maximum LIF spikes that correspond to the scratch marks should be used. The maximum LIF spikes usually occur during the intake stroke because the down motion of the piston collects more oil in the ring-pack. In addition, unlike the expansion stroke, there is no blowby in the piston ring-pack to drag the oil from the piston skirt land. Figure 4-6 is made after the previous LIF trace is subtracted by noise, calibrated based on the scratch marks, and offsetted by subtracting the window recess.

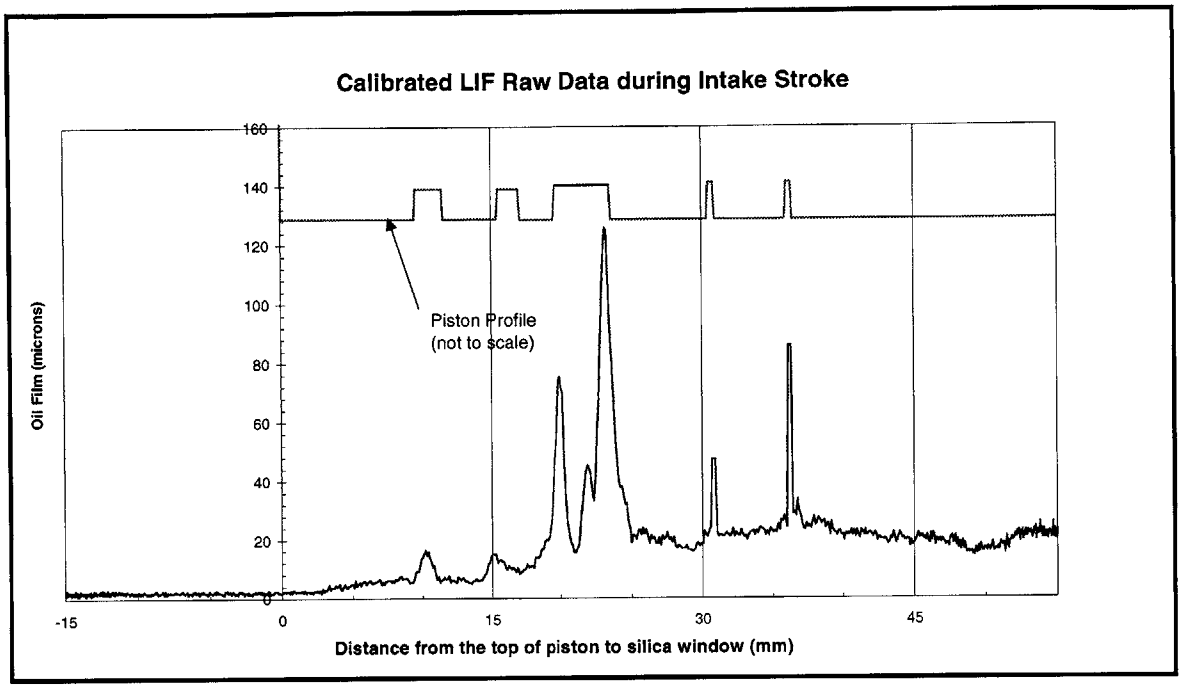

Figure 4-6 Calibrated LIF Trace

The intensity of the LIF signal, which is proportional to the fluorescence of the dye in the engine oil, decreases as the engine oil temperature increases. Since the engine oil has relatively high heat conductivity and the ring-pack oil-film-thickness is thin, the engine oil temperature is almost equivalent to the temperature of the piston lands, grooves, and cylinder-liner. The measurement of the engine oil temperature in the piston ring-pack is extremely difficult while the piston reciprocates in the cylinder; therefore, the following steps are used to estimate the engine oil temperature.

1) Assume that within the regions A, B, C and D in Figure 4-7, the same amount of oil accumulates on both the piston land and the cylinder-liner surfaces. Therefore, the temperature of the oil is the average of the piston land and the cylinder-liner temperatures.

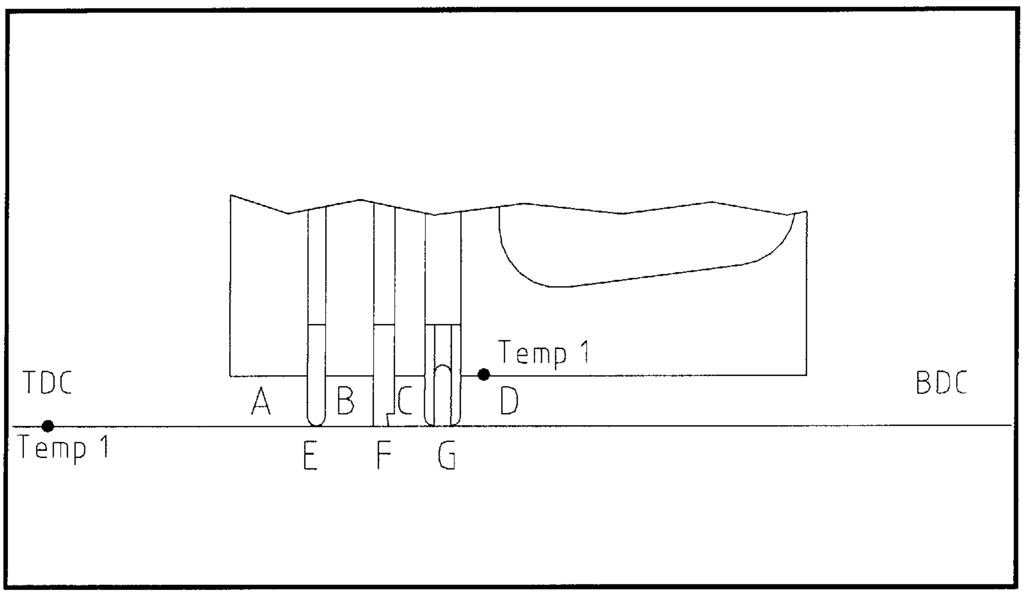

Figure 4-7 Piston Ring-Pack Regions

2) Assume that the temperature of the engine oil that accumulates on the ring surface and groove, like oil in regions E, F and G, is equal to the average of the groove and cylinder-liner temperatures.

3) Assume that the cylinder-liner temperature at the top dead center is equal to the upper skirt land temperature. This is a rough but reasonable assumption made by

independent studies [24] & [25]. The summary of the studies is included in Tamai's thesis [4].

4) The temperature distribution of the piston is estimated by using the above assumption and referring to Figure 4-8 of the piston temperature distribution in °C [23].

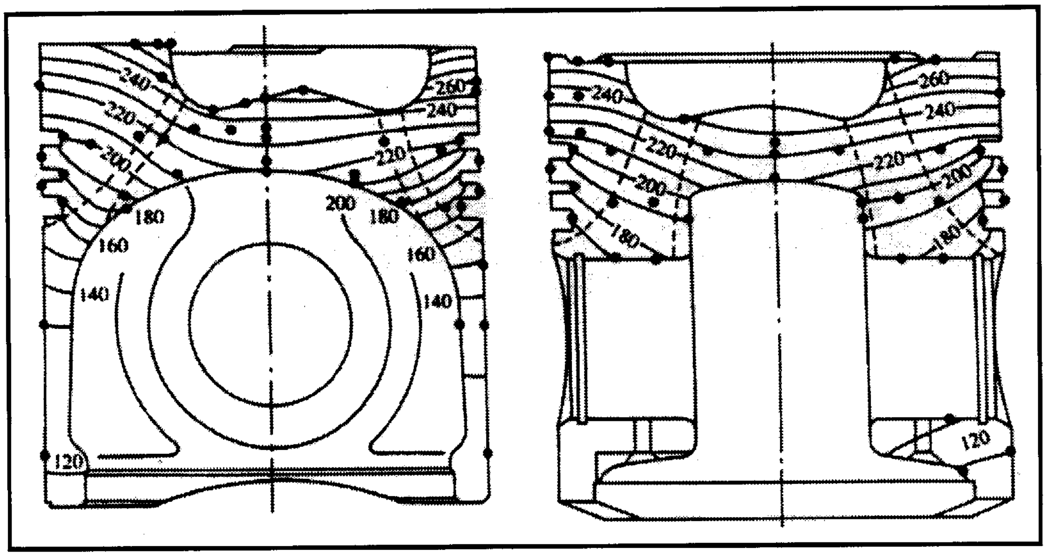

Figure 4-8 Piston Temperature Distribution (°C) [23]

5) There is no temperature difference within the piston at no load; therefore, any further oil-film-thickness calibration is unnecessary.

6) Assume that cylinder-liner temperature linearly decreases from the top dead center to the bottom dead center of the cylinder. From this assumption, the cylinder-liner

temperature at the silica windows can be estimated from the measured temperature data.

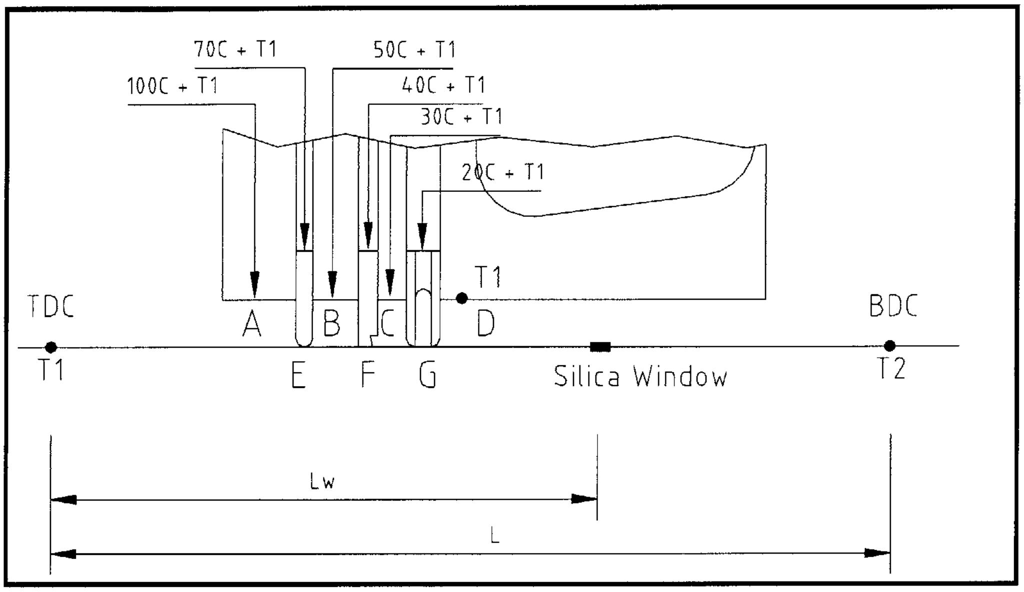

Figure 4-9 Temperature of Piston-Ring Regions

The cylinder-liner temperature at the silica window is:

$$T_{Window} = T1 - (T1-T2) * Lw/L \cdots \text{Eq.4-23}$$

The engine oil temperature in each region is:

$$T_{Region\ A} = (T_{Window} + 100\ °C + T1) / 2 \cdots \text{Eq.4-24}$$

$$T_{Region\ B} = (T_{Window} + 50\ °C + T1) / 2 \cdots \text{Eq.4-25}$$

$$T_{Region\ C} = (T_{Window} + 30\ °C + T1) / 2 \cdots \text{Eq.4-26}$$

$$T_{Region\ D} = (T_{Window} + T1) / 2 \cdots\cdots\cdots\cdots \text{Eq.4-27}$$

$$T_{Region\ E} = (T_{Window} + 70\ °C + T1) / 2 \cdots \text{Eq.4-28}$$

$$T_{Region\ F} = (T_{Window} + 40\ °C + T1) / 2 \cdots \text{Eq.4-29}$$

$$T_{\text{Region G}} = (T_{\text{Window}} + 20\ °C + T1) / 2 \cdots \text{Eq.4-30}$$

$$T_{\text{Free Liner}} = T_{\text{Window}} \cdots\cdots\cdots\cdots \text{Eq.4-31}$$

From the above temperature equations for each region and the LIF fluorescence intensity graph that is developed based on Figure 3-12, the LIF fluorescence intensity percentage at the oil temperature of 40 °C is estimated and plotted below.

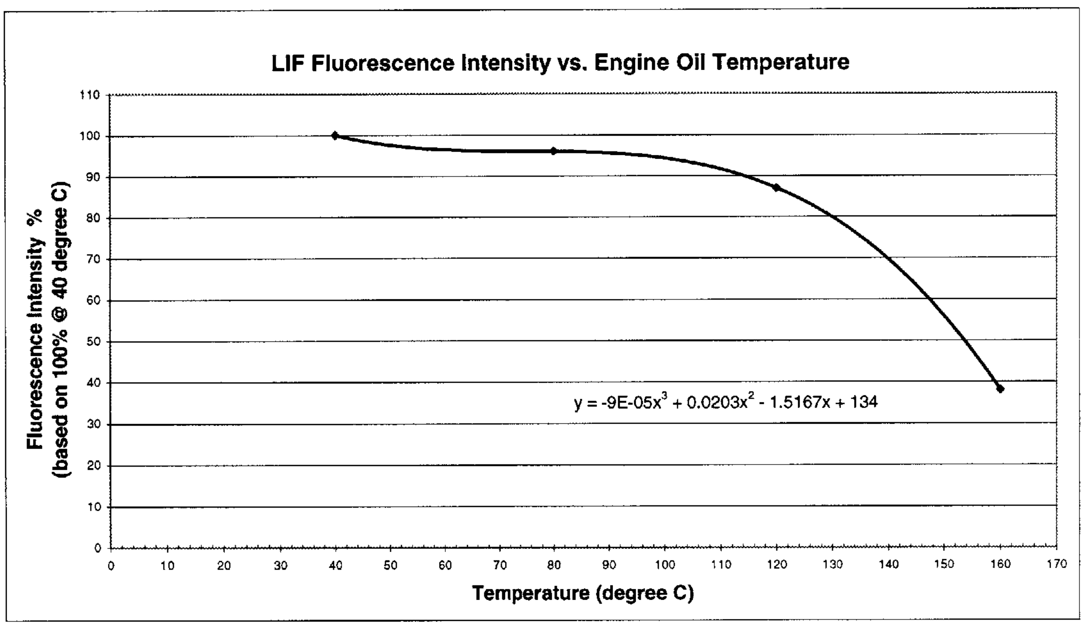

Figure 4-10 LIF Fluorescence Intensity based on 40 °C

Since the LIF trace is calibrated based on the oil accumulated on the upper skirt land region, the coefficient of LIF fluorescence needs to be estimated based on the temperature. Table 4-1 illustrates the example of the LIF fluorescence intensity and the coefficient at each region. The real oil-film-thickness in each region can be estimated by dividing the oil-film-thickness (calibrated LIF raw data) by the coefficient. Based on the data from the table, the calibrated LIF trace is adjusted and plotted in Figure 4-11.

Region in Piston Ring Pack	A	B	C	D	E	F	G	Free Liner	Scratch mark (T1)
Engine Oil Temp (°C)	140	115	105	90	125	110	100	75	105
LIF Fluorescence Intensity (%)	68	89	93	100	83	92	95	96	93
Coefficient of LIF Fluorescence	0.73	0.96	1.00	1.08	0.89	0.99	1.02	1.03	1.00

Table 4-1 LIF Fluorescence Intensity and Coefficient

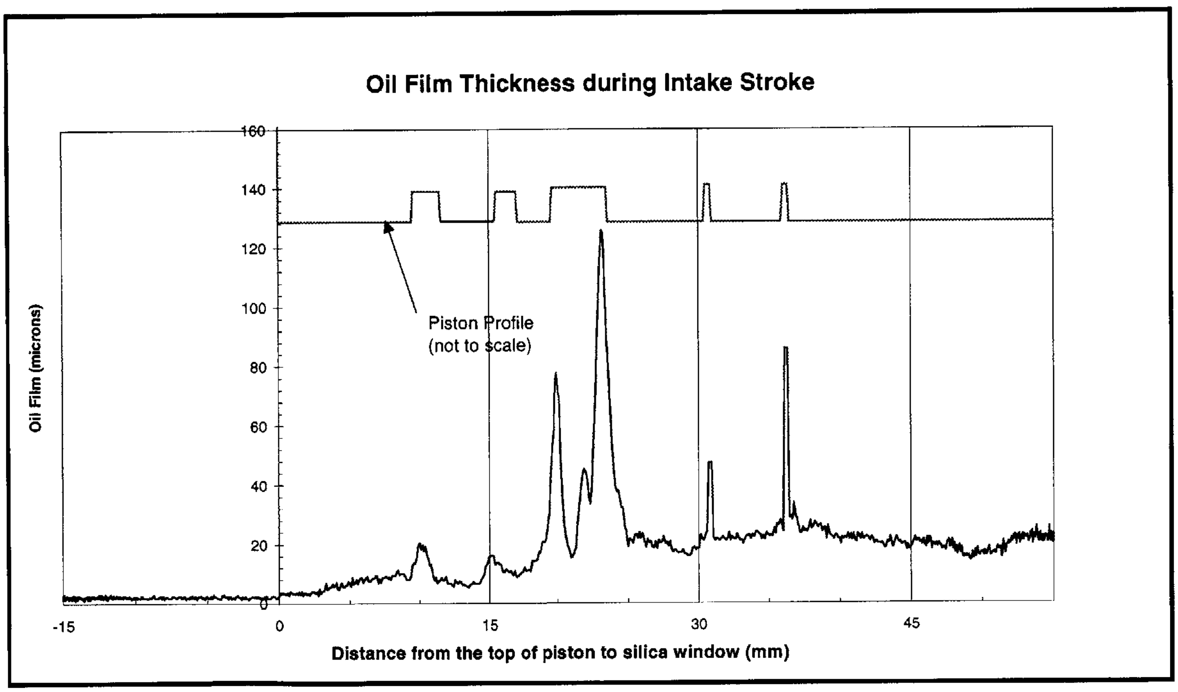

Figure 4-11 Oil-Film-Thickness @ Intake Stroke

CHAPTER 5: ANALYSIS OF OIL-CONSUMPTION AND OIL-FILM-THICKNESS INFORMATION

5.1. Oil-Consumption and Oil-Film-Thickness Data

For the development of a methodology to correlate engine-oil-consumption and piston-ring-pack oil-film-thickness, the data of the Kubota single-cylinder-diesel engine is used. Table 5-1 illustrates the specification and performance characteristics of the engine.

Make	Kubota
Model	EA300N
Type	Four-Stroke, IDI Diesel
Number of Cylinders	1
Bore	75 mm
Stroke	70 mm
Connecting Rod Length	110.1 mm
Crank Radius	35 mm
Displacement	0.309 liter
Compression Ratio	23:1
Cooling System	Water Cooled
Lubrication System	Trochoidal Pump (no filter)
Rated Brake Horsepower	4.48 kW @ 3000 rpm
Maximum Torque	15.2 Nm
Typical Application	Remote Power Generation

Table 5-1 Specifications and Performance-Characteristics of Kubota Engine

During the past decade this engine has been extensively used for the oil-consumption and ring-pack oil-film-thickness measurements at the Sloan Automotive Laboratory, because the engine is inexpensive and easy to modify for the experiments. Table 5-2 summarizes the Kubota engine experiments done by the past four graduate students and one researcher in the Sloan Automotive Laboratory.

Name	**Experiment & Analysis**
Mathew D. Bliven [26]	LIF measurement and OC ring rotation calculation for different engine oils and 2 and 3-piece OC rings
Richard M. Hartman [27]	Oil-consumption and LIF measurements for different engine oils Correlation of two data sets by comparing oil volume in piston-ring-pack at different engine-running conditions
Timothy Alan Cherry [28]	Blowby, land pressure, top-cylinder-liner temperature measurements for different engine oils when piston ring is pinned and no-pinned Verifying the *Gas Flow* computer model with experiment data
Byron Thomas Shaw III [29]	Blowby, land pressure, LIF and oil-consumption measurements Development of the Puddle Theory by the *Gas Flow* model
Mark Kiesel (visiting engineer)	LIF and oil-consumption measurements at nine engine-running conditions

Table 5-2 Kubota Engine Experiments

The engine-oil-consumption and ring-pack oil-film-thickness data used for the analysis in this thesis were taken by Mark Kiesel at nine engine-running conditions (three loads <0.7, 7 and 15 Nm> by three engine-speeds <1600, 2300 and 3000 rpm>). The 15W-40 multigrade oil was used with the original piston rings. The oil-consumption data of this engine has already been discussed in the Chapter 2. The LIF (oil-film-thickness) data were taken at 55 mm below top dead center. The data were shifted, offsetted, and calibrated according to the procedures described in the previous chapter. Since the noise data was not taken during the experiments, the data were offset by using the minimum oil-film-thickness under the top and second rings, and the free-liner oil-film-thickness, which are estimated by the *FRICTION-OFT* computer model. The accuracy of the oil-film-thickness outputs by the computer model has been proven by matching those outputs to the actual oil-film-thickness data of a single-cylinder gasoline engine by Casey [30]. For the temperature considerations for calibrating the LIF data, the top cylinder-liner temperature taken by Cherry [28] is used. The average oil-film-thickness of the piston lands at the nine engine-running conditions is shown in the table below.

	Condition *	16-n (μm)	16-m (μm)	16-f (μm)	23-n (μm)	23-m (μm)	23-f (μm)	30-n (μm)	30-m (μm)	30-f (μm)
Intake	Free liner avg.	0.6	0.6	0.1	0.7	0.7	0.3	0.6	0.6	0.3
stroke	Crown land avg.	2.6	4.0	9.2	1.5	3.9	5.4	3.0	5.7	5.9
	Second land avg.	5.1	3.9	8.4	3.7	8.6	4.7	4.1	11.1	5.2
	Third land avg.	40.9	26.0	10.7	14.2	6.0	7.9	29.3	17.3	17.4
	Skirt land avg.	24.8	21.5	22.5	24.7	23.8	21.4	24.7	19.8	19.8
Comp.	Free liner avg.	0.6	0.6	0.1	0.7	0.7	0.2	0.6	0.5	0.2
stroke	Crown land avg.	2.3	4.1	9.2	1.6	4.3	5.3	3.1	5.4	5.7
	Second land avg.	4.1	3.0	6.6	3.0	5.7	3.8	2.8	7.9	3.3
	Third land avg.	14.0	12.9	8.3	12.1	8.0	6.5	24.4	9.1	11.2
	Skirt land avg.	25.5	24.8	23.0	21.2	19.0	20.3	17.4	16.5	18.5
Expansion	Free liner avg.	0.8	0.7	1.0	0.9	0.8	0.9	1.2	0.8	0.8
stroke	Crown land avg.	2.9	5.9	10.1	2.1	4.7	5.5	3.3	6.2	5.9
	Second land avg.	4.2	4.9	10.0	3.3	5.4	3.3	2.7	7.9	3.2
	Third land avg.	48.6	44.6	16.4	22.2	14.6	8.7	28.8	10.5	11.3
	Skirt land avg.	21.8	20.0	26.1	20.5	20.9	18.9	21.1	18.7	18.9
Exhaust	Free liner avg.	0.8	0.7	0.9	1.0	0.8	0.4	1.3	0.9	0.9
stroke	Crown land avg.	2.5	4.3	9.6	1.7	4.7	5.9	3.8	6.8	6.8
	Second land avg.	4.0	3.2	7.7	3.3	6.3	3.6	3.4	8.5	3.6
	Third land avg.	11.1	9.7	6.4	9.2	6.8	4.5	27.9	8.8	10.2
	Skirt land avg.	43.8	41.2	36.4	36.0	30.2	29.2	25.6	24.4	25.8
4-stroke	Free liner avg.	0.7	0.7	0.5	0.8	0.7	0.5	0.9	0.7	0.5
average	Crown land avg.	2.6	4.6	9.5	1.7	4.4	5.5	3.3	6.0	6.1
	Second land avg.	4.3	3.7	8.2	3.3	6.5	3.9	3.2	8.8	3.8
	Third land avg.	28.6	23.3	10.4	14.4	8.8	6.9	27.6	11.4	12.5
	Skirt land avg.	29.0	26.9	27.0	25.6	23.5	22.5	22.2	19.8	20.8

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load

Table 5-3 Oil –Film-Thickness of Kubota Engine

5.2. Input and Output Data of Computer Models

Three computer models developed at the Sloan Automotive Laboratory are extensively utilized for the development of the correlation methodology. As mentioned earlier, the oil-film-thickness outputs from the *FRICTION-OFT* model are used to modify the piston ring-pack oil-film-thickness. The other outputs of the computer models are used as parameters to estimate the oil-consumption rate by the theoretical oil-consumption and oil-transport mechanisms described in the Chapter 2. Since most outputs are sensitive to the inputs, the accuracy of the outputs increases with the number of inputs. No data other than oil-consumption rate and the ring-pack oil-film-thickness are taken at the same time by Kiesel, but the other data of the same engine are available from prior experiments. Since the engine-running conditions of the experiments are slightly different from each other, the data are modified. Table 5-4 and 5-5 illustrate the available data from the past experiments, and adjusted data based on the engine-running conditions that are used by Kiesel.

	Motored				Fired @ 12.8 Nm			
Speed (rpm)	**1500**	**2000**	**2500**	**3000**	**1500**	**2000**	**2500**	**3000**
Blowby (l/min)	2.4	3.2	2.6	3.3	3.9	4.0	3.6	3.5
Max. second land pressure 20-35 ATDC @ expansion (bar)	14	14	12	9	24	19	17	14
Top cylinder-liner temperature (°C)	95	95	95	95	154	na	na	205

Table 5-4 Data of the Past Experiments of Kubota Engine

	No load (0.7 Nm)			Mid load (7 Nm)			Full load (15 Nm)		
Speed (rpm)	1600	2300	3000	1600	2300	3000	1600	2300	3000
Blowby (l/min)	2.4	2.7	3.3	3.2	3.3	3.4	3.9	3.8	3.6
Max. second land pressure 20-35 ATDC @ expansion (bar)	14	13	9	20	16	12	25	18	15
Top cylinder-liner temperature (°C)	95	95	95	135	135	155	155	175	205

Table 5-5 Adjusted Data for the Desired Engine-Running Conditions

In addition to the above data, the cylinder pressure data of the past experiments are also modified for each engine-running condition.

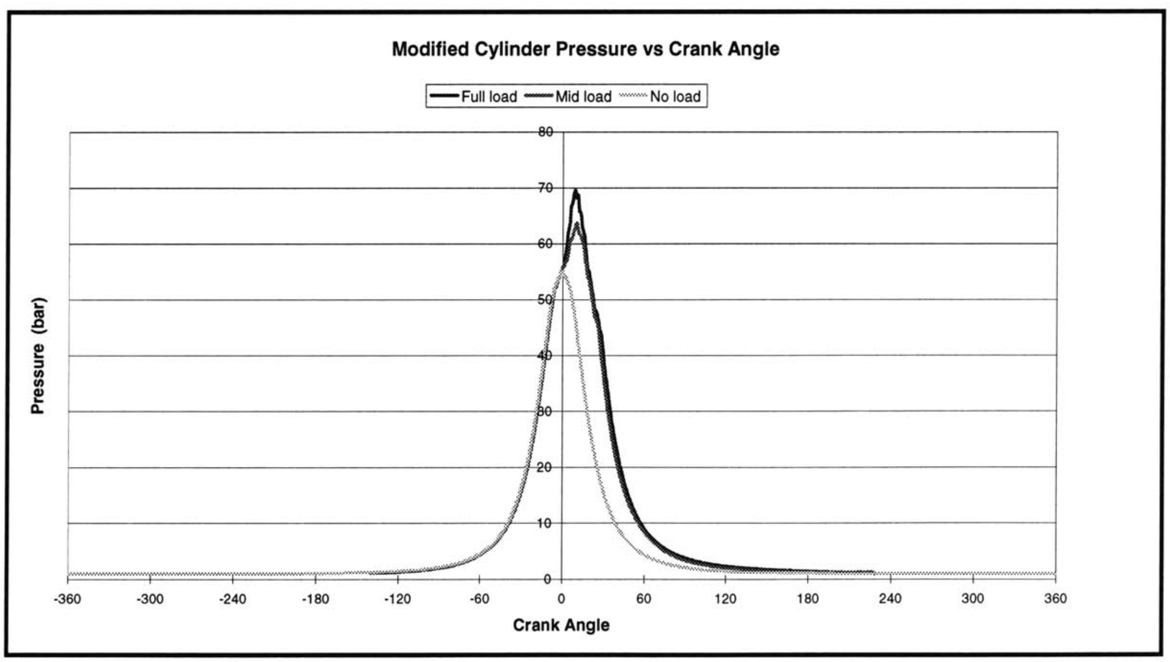

Figure 5-1 Adjusted Cylinder Pressure Traces of Kubota Engine

A. Inputs and Outputs of *RINGPACK-OC*

The *RINGPACK-OC* computer model is used to estimate the gas-mass-flow rate and the pressure of each region in the ring-pack, and the ring dynamic motions (ring-lift, force, moment, etc.) of each ring. The inputs such as the piston and ring geometry, the oil properties, the initial value of the pressure and the oil in the ring-pack are kept the same for all engine-running conditions. The inputs such as engine-speed, the temperature of lands and grooves, the gap size of the rings, and the reduction fraction of the volume in the grooves are changed, because the heat and the pressure in the ring-pack will significantly affect the value of these parameters.

Based on the top liner temperature, the temperatures of the piston lands, the ring grooves, and the cylinder-liner are determined by the same procedures used in the previous chapter. The table below summaries those temperatures at each condition.

	No load (0.7 Nm)			**Mid load (7 Nm)**			**Full load (15 Nm)**		
Speed (rpm)	**1600**	**2300**	**3000**	**1600**	**2300**	**3000**	**1600**	**2300**	**3000**
Crown land temp (°C)	95	95	95	240	240	260	260	280	310
Top groove temp (°C)	95	95	95	210	210	230	230	250	280
Second land temp (°C)	95	95	95	190	190	210	210	230	260
Second groove temp (°C)	95	95	95	180	180	200	200	220	250
Third land temp (°C)	95	95	95	170	170	190	190	210	240
Crankcase temp (°C)	95	95	95	110	110	130	130	150	180
Avg. liner temp (°C)	95	95	95	110	110	130	130	150	180

Table 5-6 Piton/groove/Liner Temperatures of the Kubota Engine

From the above temperature data, the fraction of the volume reduction in the groove is estimated for the top and second rings. Within the cavity between the groove and the back of ring, the volume reduction by the thermal expansion occurs because the ring expands to the opposite direction of the groove expansion. The size of the expansion is determined by the thermal coefficient of the ring material multiplied with the depth of ring, and the volume reduction is estimated as the expansion value divided by the gap between the groove and the ring. For the piston land and the cylinder-liner, it is assumed that there is no volume reduction change by the thermal expansion, because the bore diameter also increases. The table below is the volume reduction of the cavities at each engine condition.

	No load (0.7 Nm)			Mid load (7 Nm)			Full load (15 Nm)		
Speed (rpm)	**1600**	**2300**	**3000**	**1600**	**2300**	**3000**	**1600**	**2300**	**3000**
Volume reduction of top ring groove (%)	0.5	0.5	0.5	1.1	1.1	1.2	1.2	1.2	1.4
Volume reduction of second ring groove (%)	0.5	0.5	0.5	0.8	0.8	0.9	0.9	1.0	1.1

Table 5-7 Groove-Cavity Volume-Reduction by Thermal Expansion

After all parameters are adjusted according to the engine-running conditions, the computer model is executed based on the initial gap size of the top and second rings, 0.3 m and 0.5 m respectively. Then, the gap sizes are increased or decreased until that the computer-model-outputs of the blowby data and the second land pressure match the values measured. The gap size is that the gap size is larger at higher liner temperature conditions because the cylinder bore expands more. The blowby rate increases up to the certain value as the gap size increases; however, a larger gap size lowers the second land pressure. Iteration of the model were executed until an acceptable combination of the blowby and the second land pressure is obtained. Table 5-8 illustrates the estimated ring gap sizes, and the outputs of the second land pressure and the blowby rate. Since the blowby is more critical to the oil-consumption rate than the second land pressure, it is matched to within 5% error by adjusting the second land pressure value (the computer model estimation of the second land pressure is 30% less than the measured pressure in average).

	No load (0.7 Nm)			**Mid load (7 Nm)**			**Full load (15 Nm)**		
Speed (rpm)	**1600**	**2300**	**3000**	**1600**	**2300**	**3000**	**1600**	**2300**	**3000**
Blowby (l/min)	2.46	2.67	3.25	3.24	3.23	3.40	3.82	3.75	3.50
Max. second land pressure 20-35 ATDC @ expansion (bar)	8.5	7.0	5.4	12.7	11.0	9.1	16.0	13.9	12.9

Table 5-8 Blowby and Second Land Pressure of Kubota Engine from *RINGPACK-OC*

The other useful outputs of the *RINGPACK-OC* for oil-consumption estimation are ring-lift, ring-pack pressure, and gas-mass-flow rate (Appendix C). In depth analysis of these data with the oil-consumption mechanisms is discussed in the next section.

B. Inputs and Outputs of *FRICTION-OFT*

In general, the *FRICTION-OFT* computer model can be used to estimate the quantity of the oil-transported by the ring scraping motion, the minimum oil-film-thickness under rings, and the free liner oil-film-thickness. Some inputs of this model are the two output files of the *RINGPACK-OC*, "lift.dat" and "press.out", are used. In addition to these input files, the data of cylinder-liner temperatures and engine-speed are changed according to the engine-running conditions. Due to the smooth profile of the top ring in the Kubota engine, the oil scraping effect is not expected on the front and rear of the top ring. Therefore, in this analysis of this thesis, the *FRICTION-OFT* was used only to generate the film thickness information that was used to determine the uncertain "zero-offset" in the LIF data and execute the *Liner Vaporization Model.*

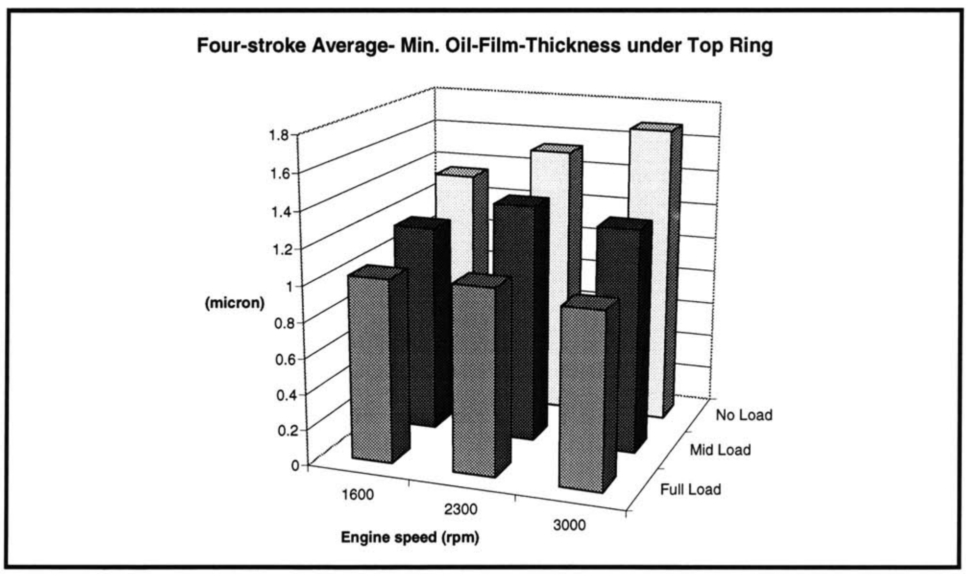

Figure 5-2 Four-Stroke Averaged Minimum Oil-Film-Thickness under the Top Ring of Kubota Engine from *FRICTION-OFT*

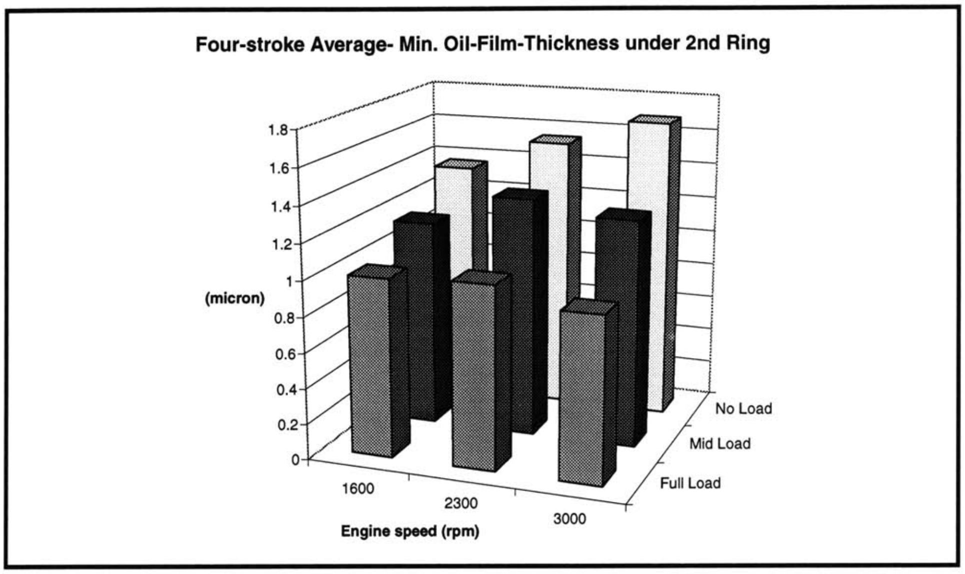

Figure 5-3 Four-Stroke Averaged Minimum Oil-Film-Thickness under the Second Ring of Kubota Engine from *FRICTION-OFT*

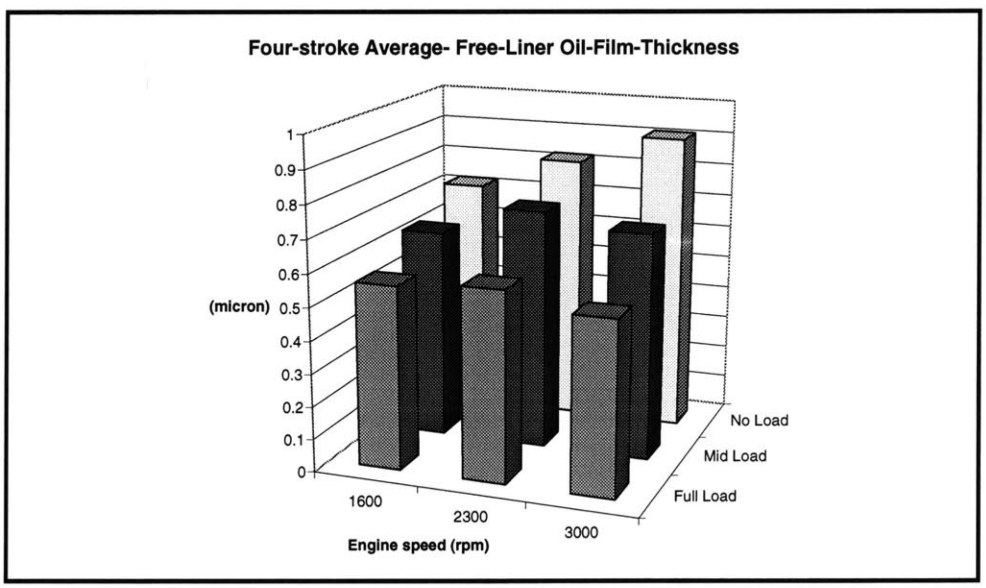

Figure 5-4 Four-Stroke Averaged Free-Liner Oil-Film-Thickness of Kubota Engine from *FRICTION-OFT*

Condition**	16-n	16-m	16-f	23-n	23-m	23-f	30-n	30-m	30-f
4-stroke average**	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)
Min. oil-film-thickness under top ring	1.35	1.17	1.03	1.53	1.34	1.04	1.69	1.26	0.98
Min. oil-film-thickness under second ring	1.36	1.16	1	1.54	1.34	1.02	1.69	1.27	0.92
Free liner oil-film-thickness	0.72	0.64	0.56	0.82	0.73	0.58	0.91	0.69	0.53

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load

**Since the above data are used to offset the LIF data, only the data that correspond to the LIF measurement points (55 mm below the top dead center) are used to estimate 4-stroke average values. For example, to estimate the 4-stroke average for the top ring, the output data when crank angle is 97, 263, -97 and –263 are used.

Table 5-9 Oil-Film-Thickness of Kubota Engine from *FRICTION-OFT*

By observing the data of the oil-film-thickness, it was found to increases as the engine-load decreases, and engine-speed increases. This can be explained by the steady-state Reynold's equation shown below.

$$\frac{\partial}{\partial X}\left(h^3\frac{\partial P}{\partial X}\right)=6*\mu*u\frac{\partial h}{\partial X}\quad \text{(Steady – State Reynold's Equation)} \cdots \text{Eq.5} - 1$$

By order of magnitude estimation

$$\frac{h^3 P}{X^2}\cong\frac{\mu*u*h}{X}\cdots \text{Eq.5}-2$$

$$P\cong\frac{\mu*u*X}{h^2}\cdots \text{Eq.5}-3$$

where P: oil pressure
μ: oil absolute viscosity
u: piston speed
h: oil-film-thickness
X: ring width

As the hydrodynamic motion of fluid, which is equal to the piston speed, increases, the oil-film has to increase to keep the fluid pressure constant. As the engine-load decreases, the liner temperature and the oil temperature decrease. The absolute viscosity of oil decreases with the temperature; therefore, in order to keep a constant fluid pressure, the oil-film-thickness has to increases as the oil viscosity increases.

C. Inputs and Outputs of *Liner Vaporization Model*

This computer model was recently developed at the Sloan Automotive Laboratory to help estimate the oil vaporization from the cylinder-liner. It has already been mentioned that the cylinder-liner oil-film-thickness and the oil composition have a large effect on the oil vaporization, when the cylinder-liner temperature is high. The oil-consumption data of the oil vaporization from cylinder-liner is illustrated in Figure 5-5. The oil-consumption was found to increase significantly when the engine load increases.

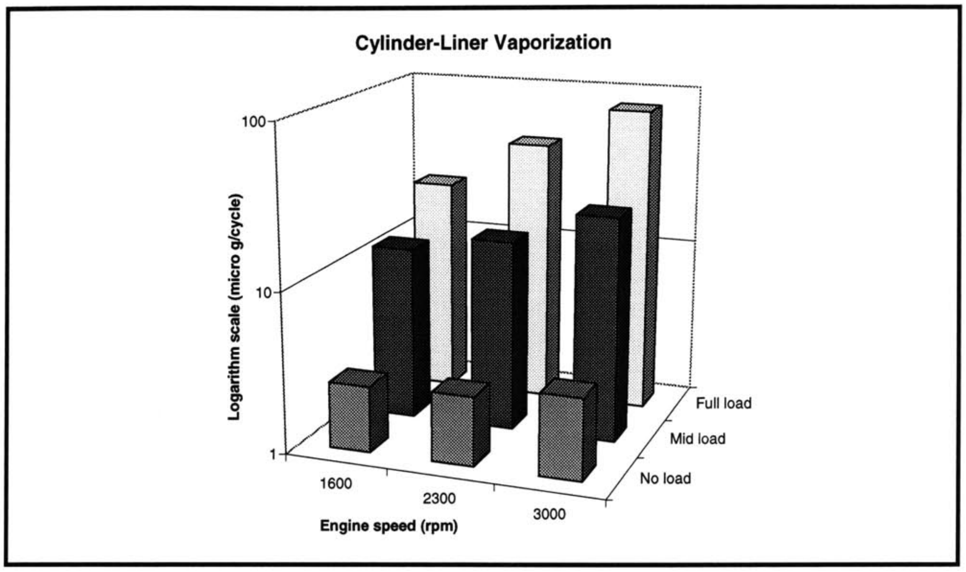

Figure 5-5 Oil Vaporization from Cylinder-Liner of Kubota Engine from *Liner Vaporization Model*

5.3. Correlation of Computer Model Outputs and Oil-Film-Thickness data to Oil-Consumption Rate

After the necessary output-data have been obtained from the three computer model, and attempt is made to correlate the data together with the LIF data to the oil-consumption rate. The correlation analysis is made difficult because the ring-pack oil-film-thickness is only observed as it passes over the silica window, which is installed 55 mm below top dead center (TDC). On the other hand, the pressure and the gas-flow in the ring-pack, and the ring-lift are predicted at every crank angle during one cycle. By the time the oil-film-thickness is observed, the important profile distribution of the oil might have passed. This becomes critical to the estimation of the oil-consumption and oil-transport during the compression and expansion strokes. During these periods, the large quantity of gas-flow blows through the ring-pack while the oil-transport by the inertial force is large at the end of the compression stroke. However, the oil-film-thickness is measured only before and after these series of oil-transport phenomena.

Another difficulty for the correlation analysis is that there is a large cycle to cycle variation in the data. To compensate for this, the oil-consumption is measured simultaneously with the oil-film-thickness, and the oil-film-thickness is averaged for every 10-cycle. However, the variation interval of oil-film-thickness might be larger than 10 cycles. From past oil-consumption and oil-film-thickness measurements at the Sloan Automotive Laboratory, the fluctuation of the former is about 10 minutes [5], and the latter is unpredictable. There are many sources that cause the fluctuation, and it is currently unclear what the main source is.

Based on the ring-lift and gas-flow trends, one engine cycle is divided into six periods: 1) 90 to 0 degree before top dead center during compression stroke, 2) 0 to 45 degrees after top dead center (ATDC) during expansion stroke, 3) 45 to 90 degrees ATDC during expansion stroke, 4) a few crank angles before bottom dead center (BBDC) during the expansion stroke, 5) a few crank angles before TDC during the exhaust stroke, and 6) 90 to 0 degree BBDC during intake stroke. For each period, the oil-consumption and oil-transport mechanisms by the inertial force and the gas-flow dragging are applied to estimate the oil-consumption and oil-transport rates around the crown land and the top ring groove. The oil-consumption estimation by the oil vaporization from the cylinder-liner and the ring-pack is done for the entire cycle. Since the compression ring of the

Kubota engine is too smooth to scrape the oil from the cylinder-liner, the oil-transport due to the oil scraping is not included. The equation below describes the total oil-consumption rate that consists of the oil-consumption rates from each oil-consumption and oil-transport mechanism.

$$OC_{\text{Total}} = \sum_{X=1}^{6} \left(OC_{\text{Gas-flow dragging @ Period X}} + OC_{\text{Inertial force @ Period X}} \right)$$
$$+ OC_{\text{Cylinder-liner oil-vaporization}} + OC_{\text{Rinng-pack gas oil-vaporization}} \cdots \text{Eq.5} - 4$$

where OC: oil-consumption rate

The computer model outputs (ring-pack gas-flow rates and pressures, ring-lift, and) of 2300 rpm at full-load are used to represent the oil-consumption and oil-transport mechanisms during each period.

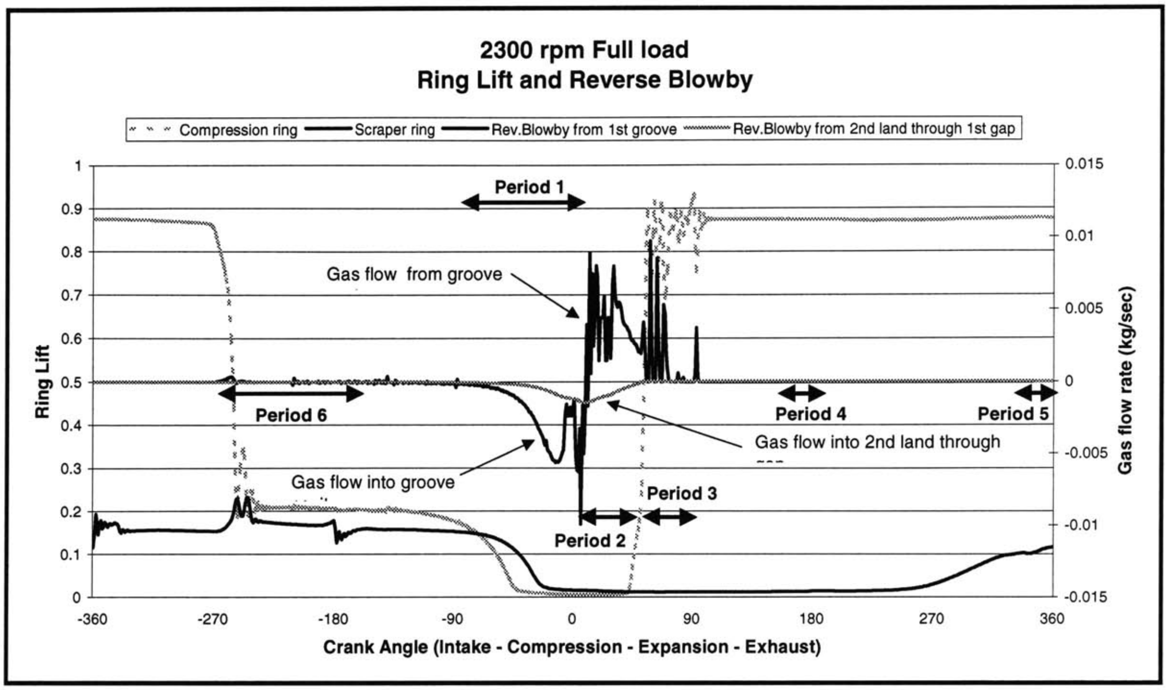

Figure 5-6 Ring-lift and Reverse Blowby Trace 1

Figure 5-6 illustrates the traces of gas-flow and ring-lift over one cycle (compression ring = top ring, scraper ring = second ring). During period 1, the gas flows into the second land through the top ring gap and into the top of ring groove (the ring is completely seated, so gas circulates within the groove cavity). The stream of gas can drag the oil from the crown land into the second land and the top groove cavity. The gas-flow into the groove cavity remains, and later flows back into the combustion chamber, so it has a positive effect to the oil-consumption. The gas flows through the top ring gap towards the crankcase (some remains in the lower ring-pack) forming the counter effect to the oil-consumption. It is, therefore, necessary to subtract the oil-transport quantity of the gas-flow into the gap from the gas-flow into the groove. At the same time, the high piston acceleration causes the oil toss-off from the crown land into the combustion chamber, which becomes a positive effect to the oil-consumption.

Since at least two types of the oil-consumption and oil-transport mechanisms occur during this period (gas-flow-dragging and inertial force), it is necessary to estimate the percentage of the oil on the crown land is transported by each type. Table 5-10 illustrates the crown land oil-transport quantities and their ratios over the sum of the two types at various engine speeds and loads.

The first three data columns of Table 5-10 show the engine speed effect on the quantities. To get the quantitative data, the same oil-film-thickness (10 microns) and land temperature (240 °C = mid load condition) are used. Different engine speeds (1600 rpm, 2300 rpm and 3000 rpm), maximum piston accelerations, and gas-flow rates are utilized. The following three data columns indicate the load effect, and the same oil-film-thickness (10 microns), and engine speed (1600 rpm), but the different land temperatures (no, mid and full loads conditions @ 1600 rpm), and gas-flow rates are used for the calculation. The piston speeds, and the land temperatures are referred to the engine speed and Table 5-6, respectively. The gas-flow rates are the outputs of the *RINGPACK-OC* models, which are the sum of the gas-flows from the crown land to the top groove and top ring gap during the period 1 and shown in Figure 5-7. Table 5-11 and 5-12 are the calculation sheets for oil-transport rates due to inertial force and gas-flow dragging.

Conditions*	16-m	23-m	30-m	16-n	16-m	16-f
Oil-Transport by Inertial force (Toss –off) (ug/cycle)	0.553	0.795	1.037	0.696	6.636	8.018
Oil-Transport by Gas-flow dragging (ug/cycle)	0.043	0.040	0.040	0.033	0.603	0.891
Sum (ug/cycle)	0.596	0.835	1.077	0.729	7.239	8.909
Toss-off Ratio	93%	95%	96%	95%	92%	90%
Gas-flow-dragging Ratio	7%	5%	4%	5%	8%	10%

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load

Table 5-10 Ratio of Oil-Transport by two Mechanisms

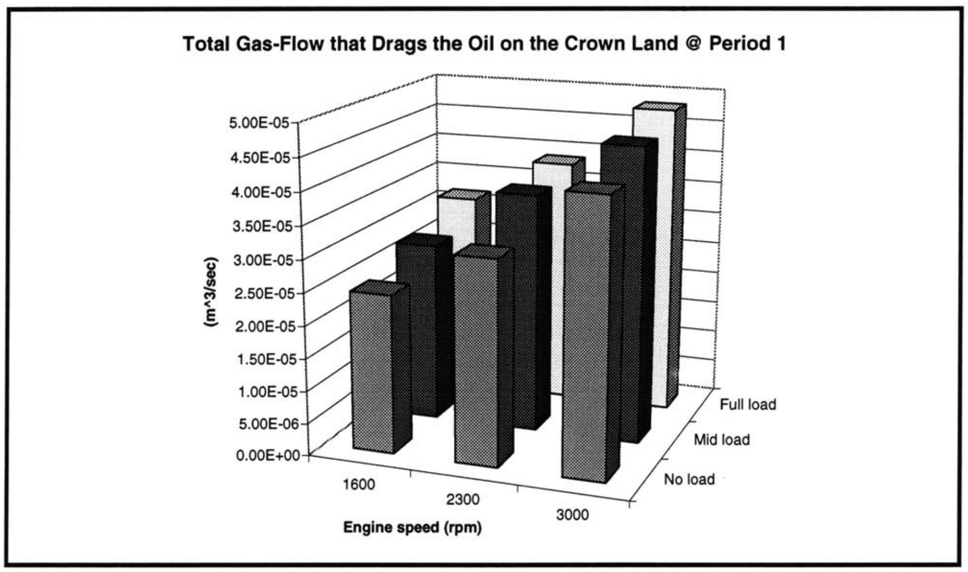

Figure 5-7 Gas-Flow Rate on the Crown Land during the Period 1

Conditions*	16-m	23-m	30-m	16-n	16-m	16-f
Engine speed (rpm)	1600	2300	3000	1600	1600	1600
Crown land temperature (°C)	240	240	240**	95	240	260
Piston Acceleration (m/s^2)	670	1385	2356	670	670	670
Oil density (kg/m^3)	748.6	748.6	748.6	840.0	748.6	736.0
Oil absolute viscosity (Pa s)	0.012	0.012	0.012	0.012	0.001	0.0008
Oil-film-thickness (um)	10.0	10.0	10.0	10.0	10.0	10.0
Oil-film-thickness (m)	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05
Average oil flow speed (m/s)	4.2E-03	8.6E-03	1.5E-02	4.7E-03	5.0E-02	6.2E-02
Oil volume flow rate (m^3/s)	9.8E-09	2.0E-08	3.5E-08	1.1E-08	1.2E-07	1.5E-07
Oil-transport rate (kg/s)	7.4E-06	1.5E-05	2.6E-05	9.3E-06	8.8E-05	1.1E-04
Oil-transport rate (ug/s)	7.4E+00	1.5E+01	2.6E+01	9.3E+00	8.8E+01	1.1E+02
Oil-transport rate (ug/cycle)	0.553	0.795	1.037	0.696	6.636	8.018

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load
** Actual crown land temperature at this condition is 260 °C

Table 5-11 Calculation for Oil-Transport Rate by Inertial force (Toss –off)

Conditions*	16-m	23-m	30-m	16-n	16-m	16-f
Crown land temperature (°C)	240	240	240**	95	240	260
Gas absolute viscosity (Pa s)	3.2E-05	3.2E-05	3.2E-05	2.2E-05	3.2E-05	3.4E-05
Gas height (m)	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04
Oil density (kg/m^3)	748.6	748.6	748.6	840.0	748.6	736.0
Oil absolute viscosity (Pa s)	0.012	0.012	0.012	0.012	0.001	0.0008
Oil-film-thickness (um)	10.0	10.0	10.0	10.0	10.0	10.0
Oil-film-thickness (m)	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05
Gas volume flow rate (m^3/s)	2.4E-05	3.2E-05	4.2E-05	2.4E-05	2.8E-05	3.2E-05
Average oil flow speed (m/s)	3.6E-04	4.8E-04	6.3E-04	2.5E-04	5.1E-03	7.6E-03
Oil volume flow rate (m^3/s)	8.5E-10	1.1E-09	1.5E-09	5.9E-10	1.2E-08	1.8E-08
Oil-transport rate (kg/s)	5.7E-07	7.7E-07	1.0E-06	4.4E-07	8.0E-06	1.2E-05
Oil-transport rate (ug/s)	5.7E-01	7.7E-01	1.0E+00	4.4E-01	8.0E+00	1.2E+01
Oil-transport rate (ug/cycle)	0.043	0.040	0.040	0.033	0.603	0.891

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load
** Actual crown land temperature at this condition is 260 °C

Table 5-22 Calculation for Oil-Transport Rate by Gas-Flow Dragging

Referring to Table 5-10, for all cases, the oil-transport amount by the gas-flow dragging is a small portion of the sum of two (less than equal to10%). Therefore, the oil-film-thickness reduction by the gas-flow dragging mechanism is insignificant compared to the case by the inertial force mechanism. Since the gas-flow into the top ring cavity occurs before the piston acceleration is maximized, the oil-film-thickness used for the oil-transport estimation by the inertial force can be the same as the one used for the estimation by the gas-flow dragging during the period 1. Until about 70 crank angle degrees before the top dead center (TDC) during period 1, any oil-consumption or oil-transport is not caused by the inertial force or the gas-flow dragging. The crown land oil-film-thickness that is measured at about 100 crank angle degrees before the TDC can be used as the oil-film input for the estimation of the oil-consumption and oil-transport quantities.

Since the top ring is seated on the groove during the period 1, the second land oil that is transported by the inertial force toward the combustion chamber stays behind the top ring. The oil accumulation behind the top ring becomes the potential source of oil-consumption during the later period.

During the period 2, the gas that flows into the top ring cavity during the period 1 comes back to the crown land after dragging more oil from the cavity and ring surface. It also drags more oil from the crown land. Meanwhile, the gas continues to flow into the second land through the top ring gas. Some part of gas that comes from the cavity flows into the gap; therefore, it is necessary to subtract the oil-transport quantity by the gas-flow into the gap from the value by the gas coming from the cavity to estimate the oil-consumption rate due to gas-flow dragging. The oil-film-thickness that is used for the estimation of the oil-consumption can be assumed to be equal to the thickness that is measured in front of the top ring during compression stroke. This is a reasonable assumption because the ring has been seated from the compression stroke to the end of the period 2, and no oil is transported from the rear of the top ring. Although the gas coming from the cavity can drag more oil from crown land to increases the oil-consumption quantity, it is assumed that all oil is dragged and tossed-off during the period 1.

On the second land, some oil has accumulated behind the top ring. However, a portion has been dragged toward the crankcase by the gas-flow through the gap.

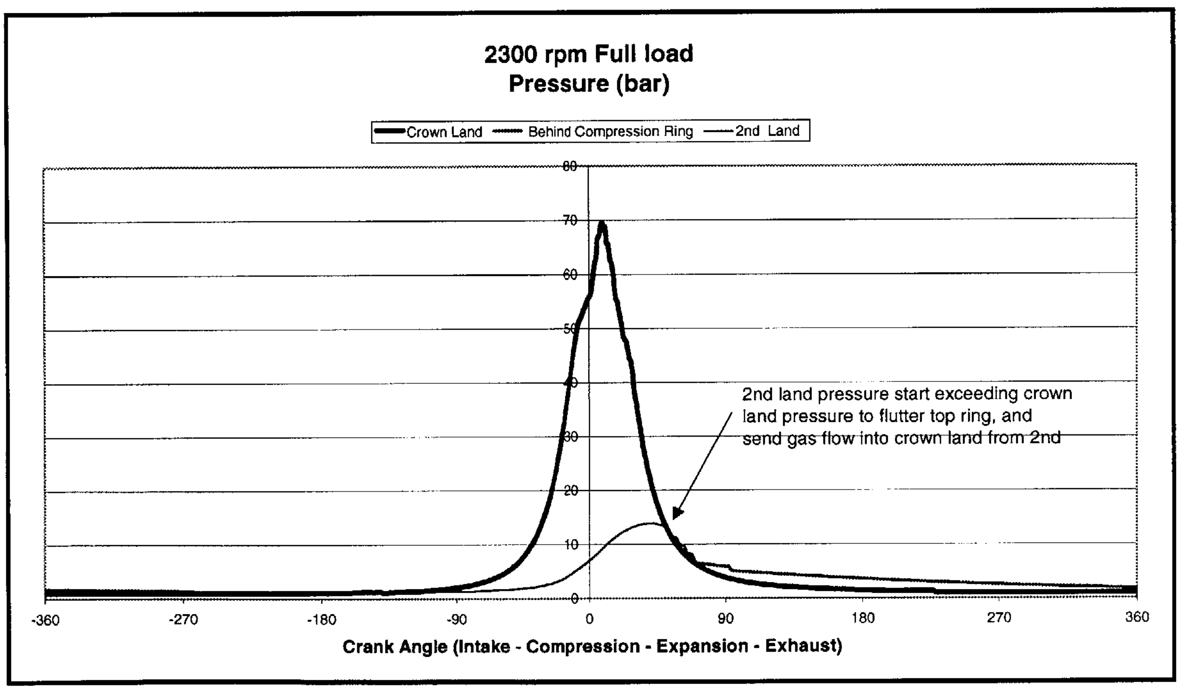

Figure 5-8 Ring-pack Pressure Trace 1

Figure 5-8 is the pressure trace of the crown land, behind the top ring, and the second land. The pressure behind the top ring follows crown land pressure (equal to the combustion chamber pressure) until the second land pressure exceeds the crown land pressure around 45 degrees ATDC during expansion stroke. When the second land pressure exceeds or starts exceeding the crown land pressure, which corresponds to the period 3, the top ring is lifted and flutters. In this period the gas flows into the crown land from the second land through the back of the top ring. This agrees with the gas-flow traces illustrated in Figure 5-9. This gas-flow drags the oil that remains in the top groove and accumulates on the second land and the back of the top ring. There might be plenty of oil at the back of the top ring due to oil-transport by the inertial motion during the period 1.

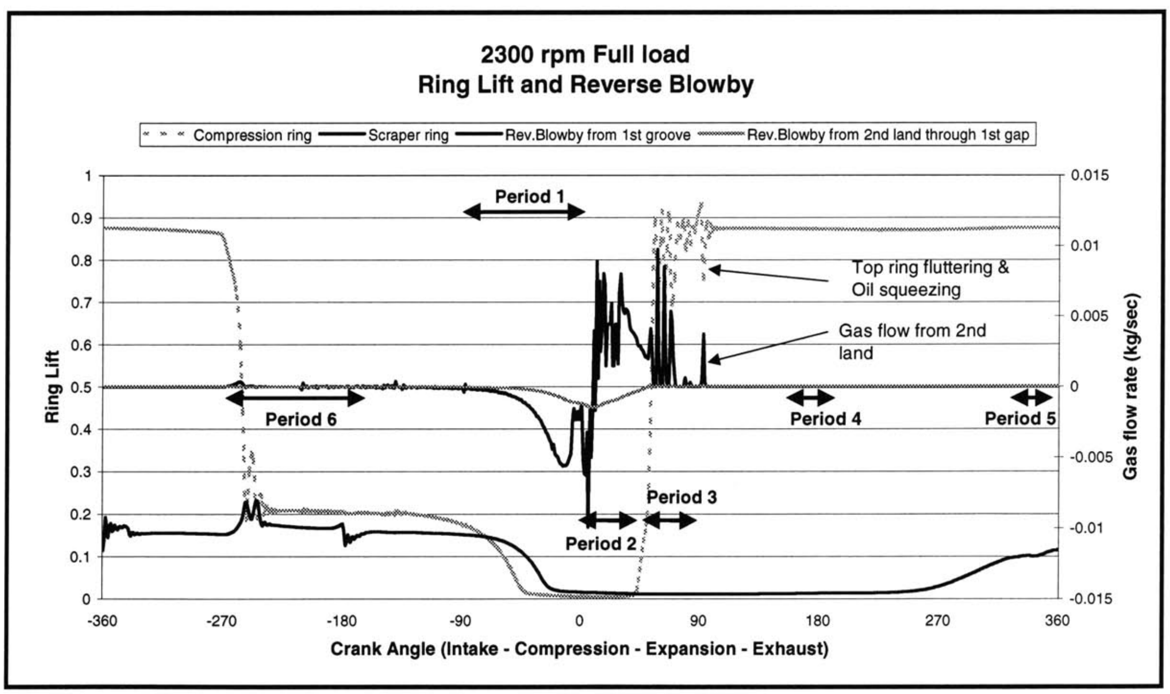

Figure 5-9 Ring-lift and Reverse Blowby Trace 2

The estimation of oil-film-thickness on the second land and behind the top ring is difficult because the oil-film-thickness is measured only before and after the first three periods (about 90 degrees before and after top dead center). During the period 1, the oil is accumulated behind the top ring by the inertial force. The gas that flows through the top ring gap during the period 1 and 2 drags a portion of the oil-film on the second land towards crankcase. During the period 3, the gas around the top ring flows only into the top groove from the second land. However, at the bottom of the second land, the gas flows into second ring gap (shown in Figure 5-10) during the same period when the gas flows from the second groove. This makes the estimation of oil-transport by gas-flow dragging on the second land extremely complicated. To simplify the calculation of oil-transport into the crown land through the groove, the second land oil-film-thickness measured during the compression stroke is used.

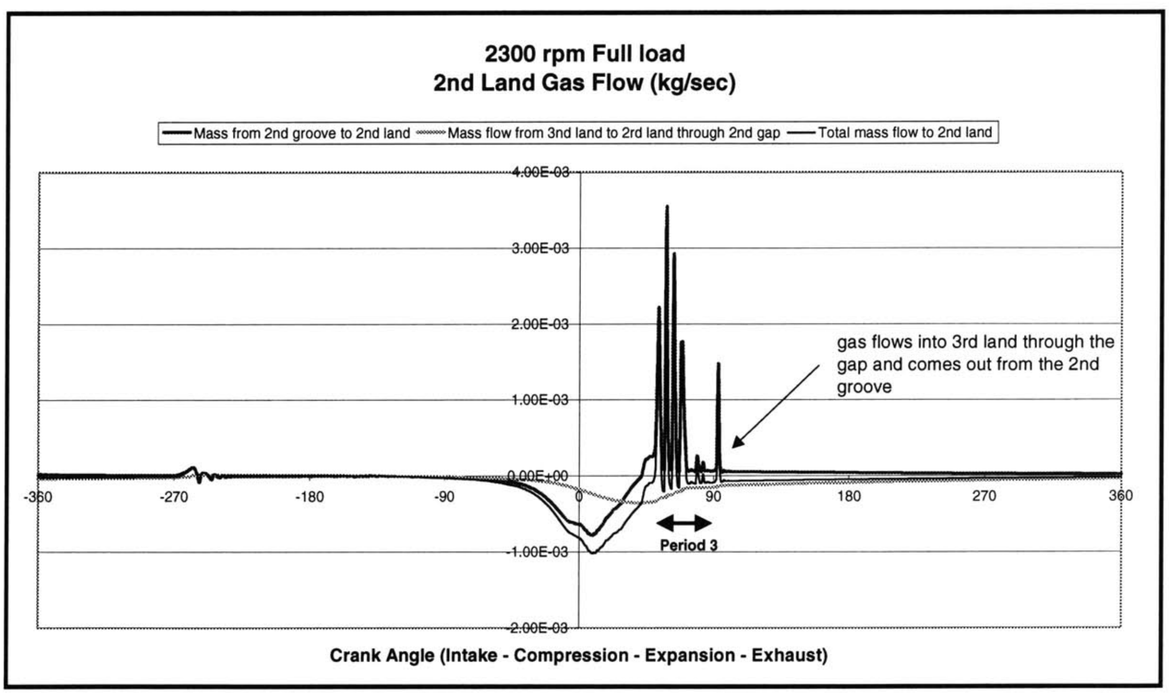

Figure 5-10 Gas-Flow Trace around Second Ring

During periods 4 and 5, the second land pressure that is higher than the crown land pressure keeps the top ring lifted. The inertial force in period 4 is the counter effect to the oil-consumption. However, the oil can not be transported to the top groove from the crown land because the top ring is fully lifted. Since the oil-film-thickness in the ring-pack is measured after period 4, it can be assumed that the oil that remains on the crown land is tossed-off. The oil on the second land is transported into the bottom surface of the top groove by the inertial force during period 5.

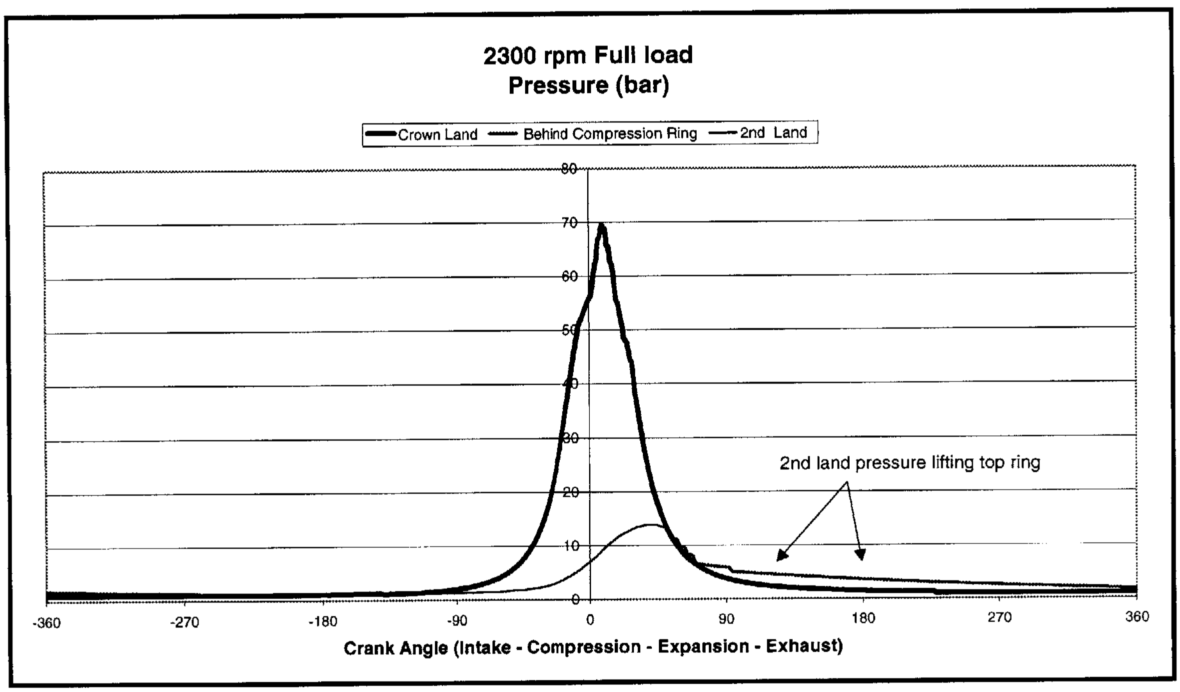

Figure 5-11 Ring-pack Pressure Trace 2

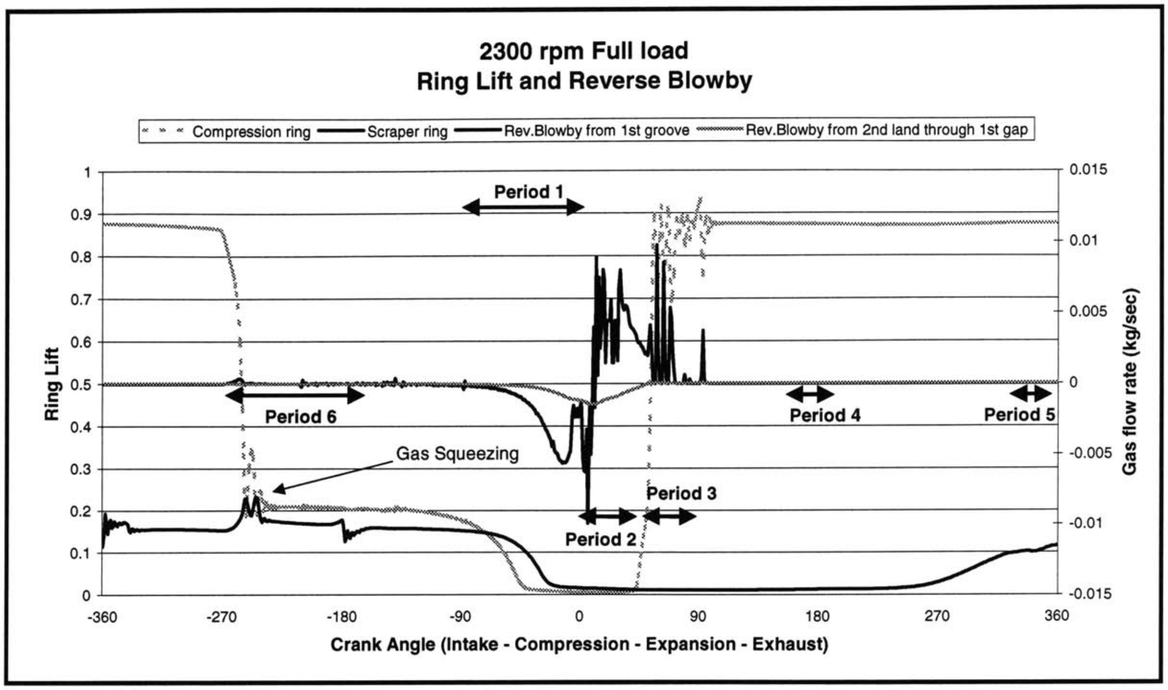

Figure 5-12 Ring-lift and Reverse Blowby Trace 3

Finally, at the beginning of period 6 (the middle of the intake stroke), the top ring swings back to the bottom of the groove by the pressure difference between the crown land and the second land. From the ring motion, the oil that is transported by the inertial force from the second land to the bottom surface of the top groove is squeezed. A portion of the oil goes back to the second land, and some goes to the top surface of top ring and groove. At the end of the period, the oil on the second land goes further down towards the second groove by the inertial force. During this period (like the period 4), there is no direct source of the oil-consumption; however, at periods 5 and 6, the significant quantity of oil can be transported on the top of top ring groove by the inertial force (period 5) and the ring squeezing (period 6).

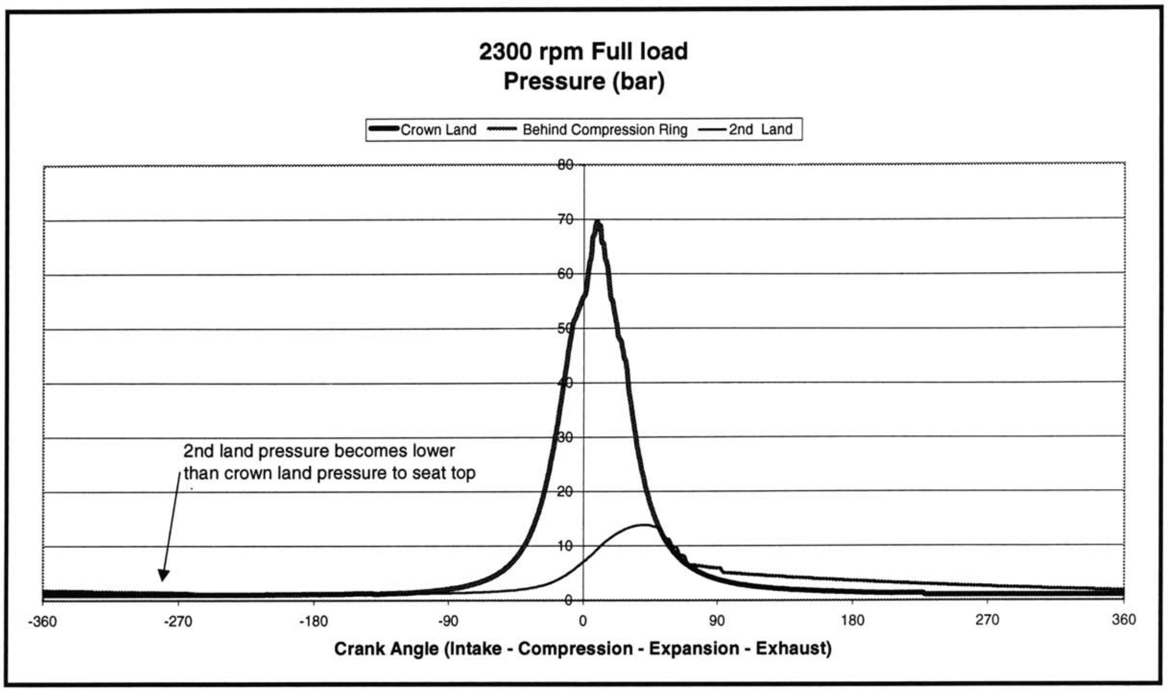

Figure 5-13 Ring-pack Pressure Trace 3

As mentioned earlier, the gas that blows from the crown land to the second land through the gap (ring-gap gas-flow) during periods 1 and 2 forms the negative effect to the oil-consumption. It is necessary to subtract the ring-gap gas-flow from the gas-flow that flows into and out of the top groove cavity to estimate the gas-flow that contributes to the oil-consumption.

Since the speed of each gas-flow that flow over the crown land during period 1 is significantly different (gas-flow blows into the gap is much faster), the size of the oiled-area on the crown land, which is dragged by those gas-flows is different as well. Figure 5-14 illustrates the size of the effective area that ring-gap gas-flow can drag the oil from the crown land. This area is found to be 6.4% of the total crown land area. The crown land oil that is available to the gas that blows into the top groove cavity is reduced by the area. In other word the volume-flow rate of the gas that flows into the top groove cavity during the period 1 is reduced by the percentage of the area.

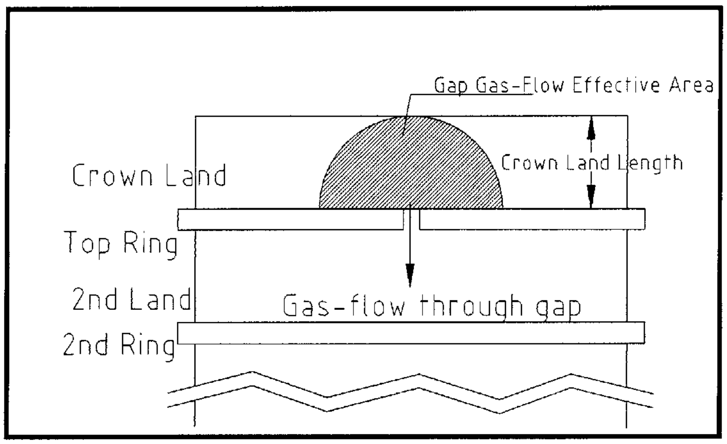

Figure 5-14 Effective Area of Gas-Flow through Top Ring Gap

Effective Area = $L^2 * \pi / 2$ Eq.5-5

Crown Land Area = $B * \pi * L$ Eq.5-6

Effective Area Ratio = $L / (2 * B) = 6.4\ \%$ ··· Eq.5-7

where L: Crown Land Length (9.6 mm)
B: Bore (75 mm)

For period 2, the effective area of the oil at the top of the top ring has the different ratio from the analysis of period 1. To simplification the calculation, the ratio is estimated by dividing the bottom line of the period 1effective area (2 * L) by the circumference of the piston (B * π) to be 8.1% (=2 * L / (B * π)). By the same reason as period 1, the gas-flow rate from the top groove cavity is reduced by the percentage.

Consequently, the sources of the oil-consumption by the inertial force and the gas-flow dragging during one cycle are summarized in the table below. The table indicates the oil-film-thickness, gas-flow rates, and maximum acceleration that are used to estimate the oil-consumption rate due to inertial force (toss-off) and gas-flow dragging during the selected periods.

Period	Mechanism	Oil-Film-Thickness	Other parameter
1	Gas-flow dragging	Crown land during compression stroke	(Gas-flow into top groove from crown land) – (Gas-flow into gap)* during the period 1
	Toss-off	Crown land during compression stroke	Maximum acceleration
2	Gas-flow dragging	Top of top ring during compression stroke	(Gas-flow from top groove into crown land) – (Gas-flow into gap)**during the period 2 ($P_{crown} > P_{second\ land}$)
3	Gas-flow dragging	Second land during compression stroke	Gas-flow into top groove from second land ($P_{second\ land} > P_{crown}$)
5	Toss-off	Crown land during exhaust stroke	Maximum acceleration

*The total gas-flow is estimated as the gas-flow into the top groove during the period multiplied by 0.936
**The total gas-flow is estimated as the gas-flow from the top groove during the period multiplied by 0.919

Table 5-13 Source of Oil-Consumption during Cycle

According to Table 5-13, Eq.5-4 becomes Eq.5-8.

$$OC_{\text{Estimated Total}} = OC_{\text{Gas-flow dragging @ Period 1,2 \& 3}} + OC_{\text{Inertial force (toss-off) @ Period 1 \& 5}}$$

$$+ OC_{\text{Cylinder-liner oil-vaporization}} + OC_{\text{Rinng-pack gas oil-vaporization}} \cdots \text{Eq.5} - 8$$

where OC: oil-consumption rate

Calculations of each of these four terms in Eq.5-8 are given in Chapter 6. Figures 5-15, 16 and 17 illustrate the gas-flow rates that contribute to the oil-consumption by the gas-flow dragging mechanism during periods 1, 2, and 3.

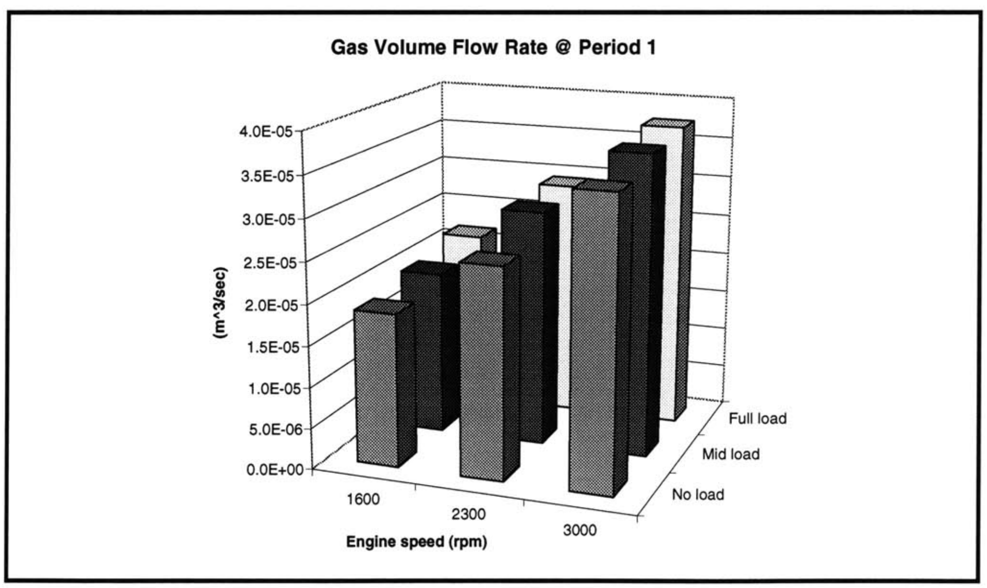

Figure 5-15 Gas-Flow Rate during the Period 1

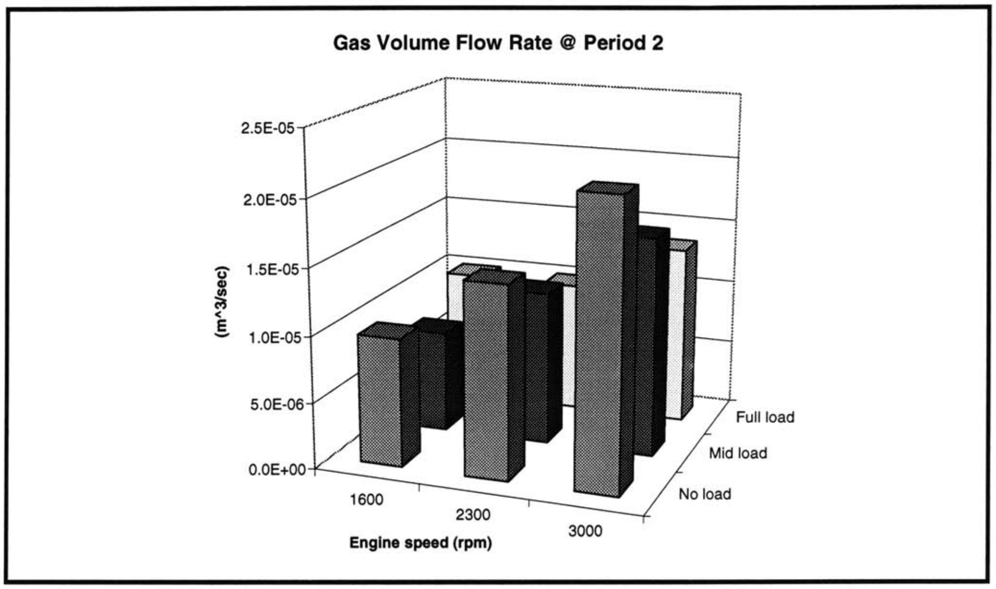

Figure 5-16 Gas-Flow Rate during the Period 2

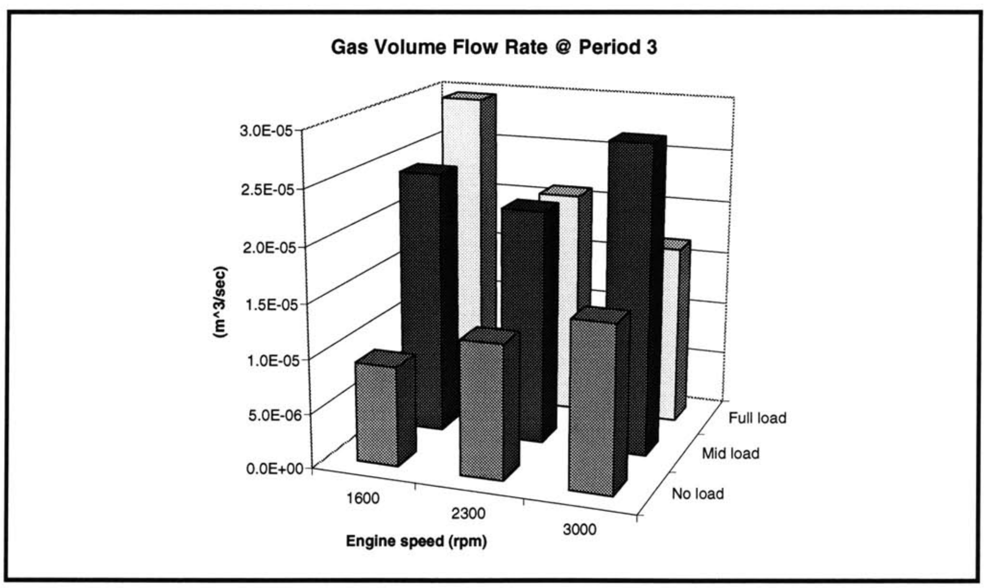

Figure 5-17 Gas-Flow Rate during the Period 3

In addition to the inertial force and gas-flow dragging mechanisms, the oil-consumption due to cylinder-liner vaporization and ring-pack vaporization needs to added to estimate the total oil-consumption rate. The oil-consumption due to the cylinder-liner vaporization is the direct output of the *Liner Vaporization Model* is shown in Figure 5-5.

For the ring-pack vaporization, the estimation of the oil mass fraction within the gas of ring-pack is necessary. As mentioned earlier, the mass fraction of oil in the ring-pack gas can be simplified as the fraction of oil-film-thickness on the crown land and the top groove, and the oil temperature. It is also mentioned earlier that the oil mass fraction in the ring-pack gas is between 0.5 and 1 % of blowby rate [16]. The blowby rate is the sum of the gas-mass-flow going into and coming out from the ring-pack, and it takes into account for the gas coming from combustion chamber, which does not carry any oil. Instead of using the blowby, the positive direction of the reverse blowby (one coming out from the crown land to the combustion chamber) is more appropriate for the estimation of the oil-consumption rate.

The following two figures (Figure 5-18 and 5-19) illustrate the blowby and the only positive direction reverse blowby rates. The average values of the blowby and the positive direction reverse blowby are 3,480 and 172,000 micro grams per cycle respectively. The positive direction reverse blowby is about 50 times larger than the blowby; therefore, the oil mass fraction in the ring-pack gas is adjusted to be between 0.01 and 0.02 % of the positive direction reverse blowby. From the crown land temperature and oil-film-thickness of all engine-running conditions, the oil mass fraction is selected from 0.002 and 0.015 %.

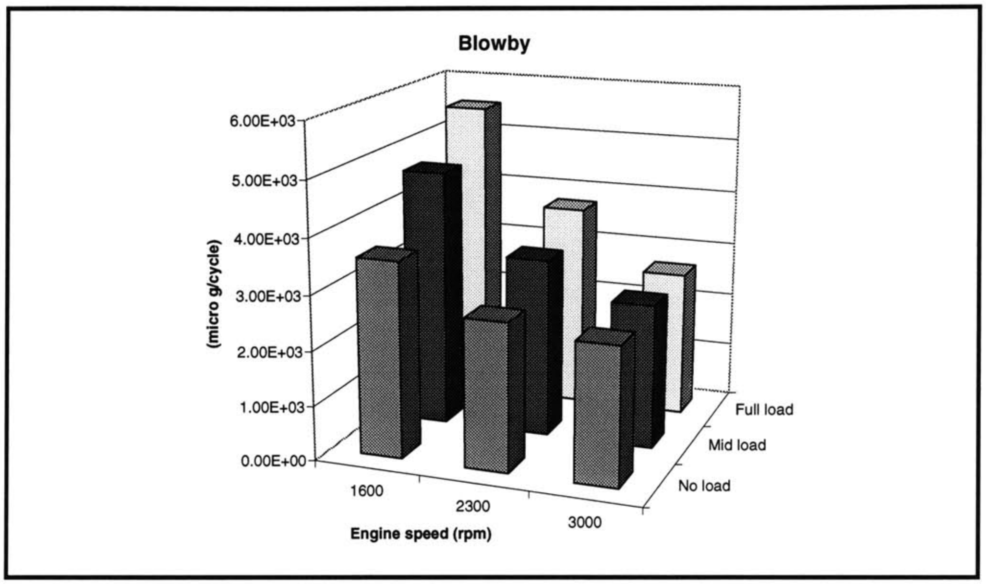

Figure 5-18 Blowby Rate

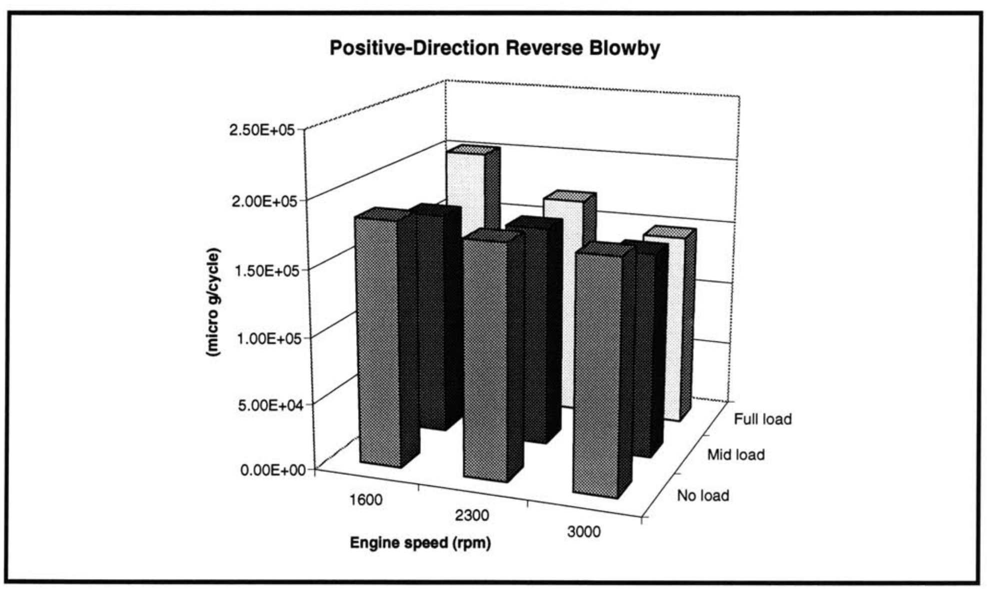

Figure 5-19 Positive Direction Reverse Blowby

CHAPTER 6: RESULTS OF CORRELATION ANALYSIS

Once all available data are acquired, the engine cycle is divided into six periods depending on the ring-pack gas-flows, ring-pack pressures, and ring lifts to estimate the oil-consumption rate by the inertial force and gas-flow dragging. The oil-consumption rates due to the cylinder-liner oil vaporization and the ring-pack oil vaporization are estimated for an entire cycle. Tables 6-1 through 6-4 are the calculation sheets to estimate the oil-consumption rate based on each mechanism.

Condition*	16-n	16-m	16-f	23-n	23-m	23-f	30-n	30-m	30-f
Avg. crown land oil-film-thickness (um)**	2.6	4.6	9.5	1.7	4.4	5.5	3.3	6.0	6.1
Crown land temp (°C)	95	240	260	95	240	280	95	260	310
Positive Reverse Blowby (ug/cycle)	1.85E +05	1.70E +05	2.02E +05	1.76E +05	1.67E +05	1.70E +05	1.73E +05	1.55E +05	1.48E +05
Oil mass fraction (%)	0.0020	0.0065	0.0080	0.0020	0.0065	0.0110	0.0030	0.0075	0.0150
Oil-consumption rate (ug/cycle)	3.69	11.07	16.17	3.52	10.87	18.73	5.20	11.64	22.19

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load
****Four-stroke average**

Table 6-1 Calculation for the Oil-Consumption due to Oil Vaporization from Ring-Pack into Gas-Flow

The oil-consumption rates of Table 6-1 are calculated by multiplying the positive reverse blowby rate by the oil mass fraction.

Condition*	16-n	16-m	16-f	23-n	23-m	23-f	30-n	30-m	30-f
Cylinder-liner oil-film-thickness (um)	0.72	0.64	0.56	0.82	0.73	0.58	0.91	0.69	0.53
TDC liner temp (°C)	95	135	155	95	135	170	95	155	205
BDC liner temp (°C)	95	105	125	95	105	140	95	125	175
Oil-consumption rate (ug/cycle)	2.58	12.03	22.5	2.68	15.23	45.1	3.19	24.5	80.5

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load

Table 6-2 Calculation for Oil-Consumption Rate due to Oil Vaporization from Cylinder-Liner

The oil consumption rates of Table 6-2 are the outputs of the *Liner Vaporization Model.*

Condition*	**p	16-n	16-m	16-f	23-n	23-m	23-f	30-n	30-m	30-f
Crown land temp (°C)		95	240	260	95	240	280	95	260	310
Piston Acceleration (m/s^2)		670	670	670	1385	1385	1385	2356	2356	2356
Oil density (kg/m^3)		840.0	748.6	736.0	840.0	748.6	***OB	840.0	736.0	***OB
Oil absolute viscosity (Pa s)		0.012	0.001	0.0008	0.012	0.001	***OB	0.012	0.0008	***OB
Oil-film-thickness (um)	1	2.3	4.1	9.2	1.6	4.3	***OB	3.1	5.4	***OB
Oil-film-thickness (m)	1	2.3E-06	4.1E-06	9.2E-06	1.6E-06	4.3E-06	***OB	3.1E-06	5.4E-06	***OB
Oil-film-thickness (um)	5	2.5	4.3	9.6	1.7	4.7	***OB	3.8	6.8	***OB
Oil-film-thickness (m)	5	2.5E-06	4.3E-06	9.6E-06	1.7E-06	4.7E-06	0.0E+00	3.8E-06	6.8E-06	0.0E+00
Average oil flow speed (m/s)	1	2.5E-04	8.4E-03	5.2E-02	2.6E-04	1.9E-02	0.0E+00	1.6E-03	6.3E-02	0.0E+00
	5	3.0E-04	9.2E-03	5.7E-02	3.0E-04	2.3E-02	0.0E+00	2.3E-03	1.0E-01	0.0E+00
Oil volume flow rate (m^3/s)	1	1.3E-10	8.1E-09	1.1E-07	1.0E-10	1.9E-08	0.0E+00	1.2E-09	8.1E-08	0.0E+00
	5	1.7E-04	9.3E-03	1.3E-01	1.2E-04	2.5E-02	0.0E+00	2.1E-03	1.6E-01	0.0E+00
Oil-consumption rate (kg/s)	1	1.1E-07	6.0E-06	8.3E-05	8.4E-08	1.4E-05	0.0E+00	1.0E-06	5.9E-05	0.0E+00
	5	2.1E-06	9.3E-06	1.0E-04	1.5E-06	2.5E-05	0.0E+00	2.5E-05	1.3E-04	0.0E+00
Total oil-consumption rate (kg/s) (p1+p5)		2.2E-06	1.5E-05	1.9E-04	1.5E-06	3.9E-05	0.0E+00	2.6E-05	1.9E-04	0.0E+00
Total oil-consumption rate (ug/s) (p1+p5)		2.2E+00	1.5E+01	1.9E+02	1.5E+00	3.9E+01	0.0E+00	2.6E+01	1.9E+02	0.0E+00
Total oil-consumption rate (ug/cycle) (p1+p5)		1.7E-01	1.2E+00	1.4E+01	8.1E-02	2.0E+00	0.0E+00	1.0E+00	7.5E+00	0.0E+00

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load
****p**: period *****OB**: oil is burned

Table 6-3 Calculation for Oil-Consumption Rate due to Inertial Force (Toss-Off)

The calculation of the oil-consumption rates of Table 6-3 is based on Eq.2-1 through 2-3.

Condition*	**p	16-n	16-m	16-f	23-n	23-m	23-f	30-n	30-m	30-f
Crown land temp (°C)	1	95	240	260	95	240	280	95	260	310
Top groove temp (°C)	2	95	210	230	95	210	250	95	230	280
Second land temp (°C)	3	95	190	210	95	190	230	95	210	260
Gas absolute viscosity (Pa s)	1	2.2E-05	3.2E-05	3.4E-05	2.2E-05	3.2E-05	3.5E-05	2.2E-05	3.4E-05	3.8E-05
	2	2.2E-05	3.0E-05	3.1E-05	2.2E-05	3.0E-05	3.3E-05	2.2E-05	3.1E-05	3.5E-05
	3	2.2E-05	2.8E-05	3.0E-05	2.2E-05	2.8E-05	3.1E-05	2.2E-05	3.0E-05	3.4E-05
Gas height (m)	1	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04
	2	2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04
	3	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04
Oil density (kg/m^3)	1	840.0	748.6	736.0	840.0	748.6	***OB	840.0	736.0	***OB
	2	840.0	767.5	754.9	840.0	767.5	742.3	840.0	754.9	***OB
	3	840.0	780.1	767.5	840.0	780.1	754.9	840.0	767.5	736.0
Oil absolute viscosity (Pa s)	1	0.012	0.001	0.0008	0.012	0.001	***OB	0.012	0.0008	***OB
	2	0.012	0.0015	0.0009	0.012	0.0015	0.00085	0.012	0.0009	0.0007
	3	0.012	0.004	0.0015	0.012	0.004	0.0009	0.012	0.0015	0.0008
Oil-film-thickness (um) / Oil-film-thickness (m)	1	2.3	4.1	9.2	1.6	4.3	***OB	3.1	5.4	***OB
		2.3E-06	4.1E-06	9.2E-06	1.6E-06	4.3E-06	***OB	3.1E-06	5.4E-06	***OB
	2	0.6	0.6	0.0	0.6	0.6	0.2	0.6	0.5	***OB
		5.5E-07	6.0E-07	2.0E-08	6.1E-07	6.2E-07	2.1E-07	6.0E-07	5.4E-07	***OB
	3	4.1	3	6.6	3	5.7	3.8	2.8	7.9	3.3
		4.1E-06	3.0E-06	6.6E-06	3.0E-06	5.7E-06	3.8E-06	2.8E-06	7.9E-06	3.3E-06
Gas volume flow rate (m^3/s)	1	1.9E-05	2.0E-05	2.2E-05	2.6E-05	2.9E-05	2.9E-05	3.5E-05	3.7E-05	3.8E-05
	2	9.9E-06	7.9E-06	1.0E-05	1.5E-05	1.2E-05	1.0E-05	2.2E-05	1.7E-05	1.4E-05
	3	9.2E-06	2.4E-05	3.0E-05	1.2E-05	2.2E-05	2.1E-05	1.5E-05	2.8E-05	1.7E-05
Average oil flow speed (m^3/s)	1	4.4E-05	1.5E-03	4.7E-03	4.3E-05	2.2E-03	0.0E+00	1.1E-04	4.7E-03	0.0E+00
	2	3.2E-06	2.9E-05	2.3E-06	5.3E-06	4.6E-05	2.6E-05	7.6E-06	1.0E-04	0.0E+00
	3	8.8E-05	6.5E-04	4.9E-03	8.7E-05	1.1E-03	3.5E-03	1.0E-04	5.6E-03	2.9E-03
Oil volume flow rate (m^3/s)	1	2.4E-11	1.4E-09	1.0E-08	1.7E-11	2.2E-09	0.0E+00	8.5E-11	6.0E-09	0.0E+00
	2	4.2E-13	4.2E-12	1.1E-14	7.5E-13	6.7E-12	1.3E-12	1.1E-12	1.3E-11	0.0E+00
	3	8.5E-11	4.6E-10	7.6E-09	6.1E-11	1.5E-09	3.1E-09	6.6E-11	1.0E-08	2.3E-09
Oil-consumption rate (kg/s)	1	1.8E-08	9.6E-07	6.8E-06	1.3E-08	1.5E-06	0.0E+00	6.4E-08	4.0E-06	0.0E+00
	2	3.2E-10	2.9E-09	7.3E-12	5.7E-10	4.7E-09	8.4E-10	8.1E-10	8.7E-09	0.0E+00
	3	6.4E-08	3.2E-07	5.3E-06	4.6E-08	1.0E-06	2.1E-06	5.0E-08	7.2E-06	1.5E-06
Total oil-consumption rate (kg/s) (p1+p2+p3)		8.2E-08	1.3E-06	1.2E-05	5.9E-08	2.5E-06	2.1E-06	1.1E-07	1.1E-05	1.5E-06
Total oil-consumption rate (ug/s) (p1+p2+p3)		8.2E-02	1.3E+00	1.2E+01	5.9E-02	2.5E+00	2.1E+00	1.1E-01	1.1E+01	1.5E+00
Total oil-consumption rate (ug/cycle) (p1+p2+p3)		6.18E-03	9.62E-02	9.07E-01	3.08E-03	1.32E-01	1.11E-01	4.54E-03	4.49E-01	6.07E-02

***16-n**: 1600 rpm No load, **23-m**: 2300 rpm Mid load, **30-f**: 3000 rpm Full load
**p: period ***OB: oil is burned

Table 6-4 Calculation for Oil-Consumption Rate due to Gas-Flow Dragging

The calculation of the oil-consumption rates of Table 6-4 is based on Eq.2-4 through 2-9.

Table 6-5 summaries the estimated oil-consumption rates based on each oil-consumption mechanism (from Table 6-1 to Table 6-4), and the estimated and measured total oil-consumption rates with % error. The % error is defined as below.

$$\% \text{ Error} = \frac{\left| OC_{\text{Estimated Total}} - OC_{\text{Measured Total}} \right|}{OC_{\text{Measured Total}}} * 100\% \quad \cdots \text{Eq.6-1}$$

where OC : oil-consumption rate

Speed (rpm)	1600			2300			3000		
Load	No	Mid	Full	No	Mid	Full	No	Mid	Full
Estimated total oil-consumption (1+2+3+4)	6.44	24.35	53.50	6.29	28.27	63.94	9.44	44.08	102.7 5
Toss-off (1)	0.17	1.15	13.92	0.08	2.04	0.00	1.04	7.49	0.00
Gas-flow-dragging (2)	0.01	0.10	0.91	0.00	0.13	0.11	0.00	0.45	0.06
Cylinder-liner vaporization (3)	2.58	12.03	22.50	2.68	15.23	45.10	3.19	24.50	80.50
Ring-pack gas-flow (4)	3.69	11.07	16.17	3.52	10.87	18.73	5.20	11.64	22.19
Measured total oil-consumption	16.80	30.30	41.50	24.30	38.20	55.00	43.30	51.40	82.90
Error (%)	62%	20%	29%	74%	26%	16%	78%	14%	24%

Unit: μg/cycle

Table 6-5: Estimated and Measured Oil-Consumption Rates with % Error

Table 6-6 is the fractions of oil-consumption rate due to each oil-consumption mechanism within the estimated total oil-consumption rate from Table 6-5.

Speed (rpm)	1600			2300			3000		
Load	No	Mid	Full	No	Mid	Full	No	Mid	Full
Estimated oil-consumption	6.44	24.35	53.50	6.29	28.27	63.94	9.44	44.08	102.75
Toss-off	2.6%	4.7%	26.0%	1.3%	7.2%	0.0%	11.0%	17.0%	0.0%
Gas-flow-dragging	0.2%	0.4%	1.7%	0.0%	0.5%	0.2%	0.0%	1.0%	0.1%
Cylinder-liner vaporization	40.1%	49.4%	42.1%	42.6%	53.9%	70.5%	33.8%	55.6%	78.3%
Ring-pack gas-flow	57.3%	45.5%	30.2%	56.0%	38.5%	29.3%	55.1%	26.4%	21.6%

Unit: μg/cycle for estimated oil-consumption

Table 6-6: Fraction of Estimated Oil-Consumption Rates

Figures 6-1 and 6-2 illustrate the trends of the estimated and measured total oil-consumption rates at various engine-running conditions.

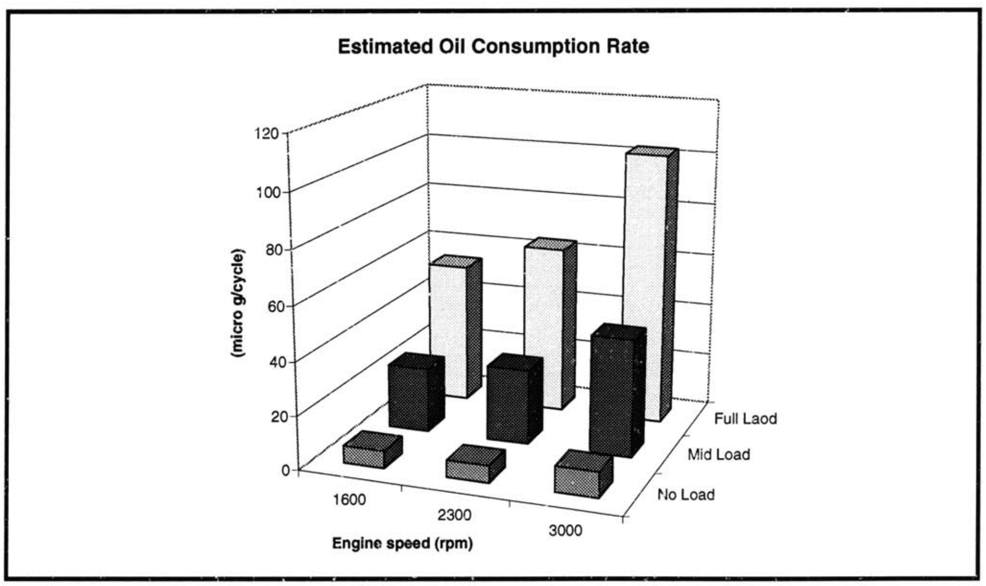

Figure 6-1Estimated Total Oil-Consumption Rate

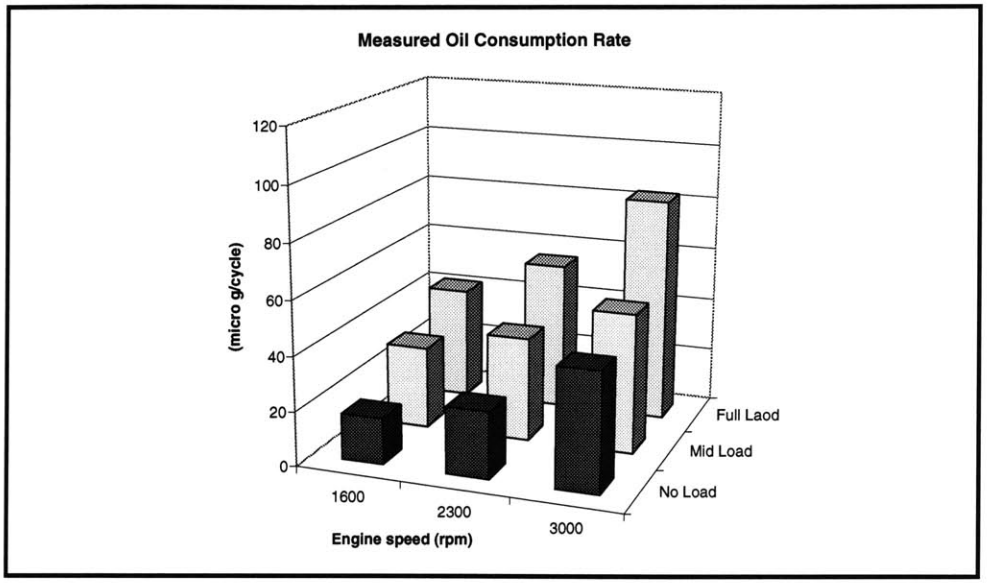

Figure 6-2 Measured Total Oil-Consumption Rate

CHAPTER 7: CONCLUSIONS

This thesis project consists of two phases. The first phase involves the development of measurement systems for engine oil-consumption and piston ring-pack oil-film-thickness of a four-cylinder gasoline engine. The second phase is the development of a methodology to correlate engine oil-consumption and piston ring-pack oil-film-thickness based on data obtained from a single-cylinder diesel engine.

7.1. Phase 1

The Antex® SO_2 detector system and the LIF system were conducted to measure real-time oil-consumption rate and piston ring-pack oil-film-thickness respectively. The data reduction procedures were developed for both systems to analyze the data. To improvement the ring-pack oil-film-thickness measurement, scratch marks were machined on the piston skirt land to simplify the data calibration procedure and increase the data calibration accuracy. The temperatures of the ring-pack regions were also taken into account for the LIF data calibration, which provides better oil-film-thickness estimation at higher than no–engine-load conditions.

7.2. Phase 2

The methodology to correlate the oil-consumption rate and the ring-pack oil-film-thickness of the Kubota single-cylinder engine has been studied. The analysis utilized three computer models (*RINGPACK-OC*, *FRICTION-OFT*, and *Liner Vaporization Model*) with input data sets from past experiments conducted on the same engine.

A. Contributions to Total Oil-Consumption

From this analysis for this engine (Table 6-6), it is seen that the major source of oil-consumption comes from the oil vaporization from cylinder-liner and in ring-pack. This value is between 70% to 99% of the total oil-consumption rate for all engine-running conditions. As engine-load increases, the cylinder-liner oil vaporization becomes the largest source of oil-consumption. From the 2300 rpm and 3000 rpm speed conditions analysis, the oil-consumption fractions due to the cylinder-liner oil vaporization increase from 42.6% to 70.5% and 33.8% to 78.3% respectively, as engine-load increases. On the other hand, oil-consumption fractions due to the gas-flow oil vaporization decrease from 56.0% to 29.3% and 55.1% to 21.6% for 2300 rpm and 3000 rpm respectively, as engine load increases. For the1600 rpm case, there is a clear decreasing trend of the oil-consumption fraction due to the gas-flow oil vaporization, which falls from 57.3% to 30.2% as the engine load increases. However, there is no inconsistency for the oil-consumption fraction due to the cylinder-liner oil vaporization.

The absolute value of engine oil-consumption due to both cylinder-liner oil vaporization and gas-flow oil vaporization increases as engine load increases. On the other hand, the fraction of oil-consumption rate due to the cylinder-liner oil vaporization increases, but the fraction due to the gas-flow oil vaporization decreases. Consequently it is concluded that the oil-consumption due to the cylinder-liner oil vaporization is more sensitive to the engine load (ring-packs and cylinder liner temperatures) than the oil-consumption due to the gas-flow oil vaporization

B. Total Oil-Consumption Rate Trends

From Table 6-5, the error between the actual and estimated oil-consumption rates, which is less than 30%, is acceptable at the mid-load and full-load conditions, At the no-load conditions, the error exceeds 60% (the actual one value larger than the estimated value). This error can be reduced if it is assumed that the major source of the oil mass fraction in the ring-pack gas-flow is from the oil-mist, rather than the oil-vaporization. Although there is a possibility that the oil mass fraction from the oil-mist is affected by the ring-pack temperature; the major source of mist might comes from the piston reciprocating motion. It can also be assumed that at the no-load conditions, the major source of the oil-consumption comes from other system such as EGR and valve train.

It is concluded that the estimated total oil-consumption rate follows the same trend as the measured oil-consumption rate. The estimated oil-consumption rate increases as both the engine-load and the engine-speed increase. This trend can be also seen for the estimated oil-consumption rate due to oil vaporization from the cylinder-liner and into the ring-pack gas-flow, especially among different engine loads. This trend agrees with the sensitivity analysis of the oil-consumption mechanism by the engine-running conditions (Table 2-1).

There are consistent trends in the oil-consumption rates due to inertial force (toss off) and gas-flow dragging only at mid-load conditions and 1600 rpm speed conditions. At the mid-load conditions, the oil-consumption rate due to inertial force increases as the engine speed increases. From the 1600 rpm speed conditions analysis, the oil-consumption rate due to the inertial force and the gas-flow dragging increases as the engine-load increases. For both mid-load and 1600 rpm speed conditions, the increasing trend of the oil-consumption rate also agrees with the sensitivity analysis of oil-consumption mechanism. At other load or speed conditions, there were no consistency that agrees with the sensitivity analysis. This could be due to the difference in the oil-film-thickness on crown land, which is assumed to be burned at high-load conditions.

C. Oil-Consumption Analysis Methodology

To develop the correlation methodology, the hypotheses of oil-consumption and oil-transport mechanisms were made. These hypotheses are based on the effects of inertial force, gas-flow dragging, oil vaporization from cylinder liner, oil vaporization from ring-pack into gas-flow, and oil scraping and squeezing (Chapter 2). In the hypotheses, the oil-consumption rates of each mechanism were estimated based on the measured ring-pack oil-film-thickness information. This estimation required the utilization of the three computer models with the data sets from past experiments conducted on the same engine. These data sets, such as cylinder liner temperatures, blowby rates, and the second land pressures, were adjusted according to the engine-running conditions, at which the actual data of oil-consumption rates and oil-film-thickness were measured. Due to insufficient information, several input parameters for the computer models, such as the temperatures of the piston lands and grooves, the volume reduction fractions of the grooves, and the sizes of the ring gaps, are assumed.

Since one of the focuses of this thesis is to estimate the oil-consumption rates, the time based tracking of oil-transport rates within the piston ring-pack from the skirt land to the top of piston was not estimated. Therefore, the oil accumulations on the crown land, top ring groove, the second land, and cylinder liner, which were measured at the single location of the cylinder liner, were mainly used to estimate the total oil-consumption rates. In addition, due to the lack of the knowledge about oil-mist phenomena in the piston ring-pack, the oil-consumption rates due to the oil-mist were not taken into account for the calculation of the total oil-consumption rate.

This was the first attempt to correlate the oil-consumption rates with the piston ring-pack oil-film-thickness using the three computer models in the Slogan Automotive Laboratory. The correlation model gave reasonable results as the estimated oil-consumption rates matched the actual measured oil-consumption rates within the tolerable error.

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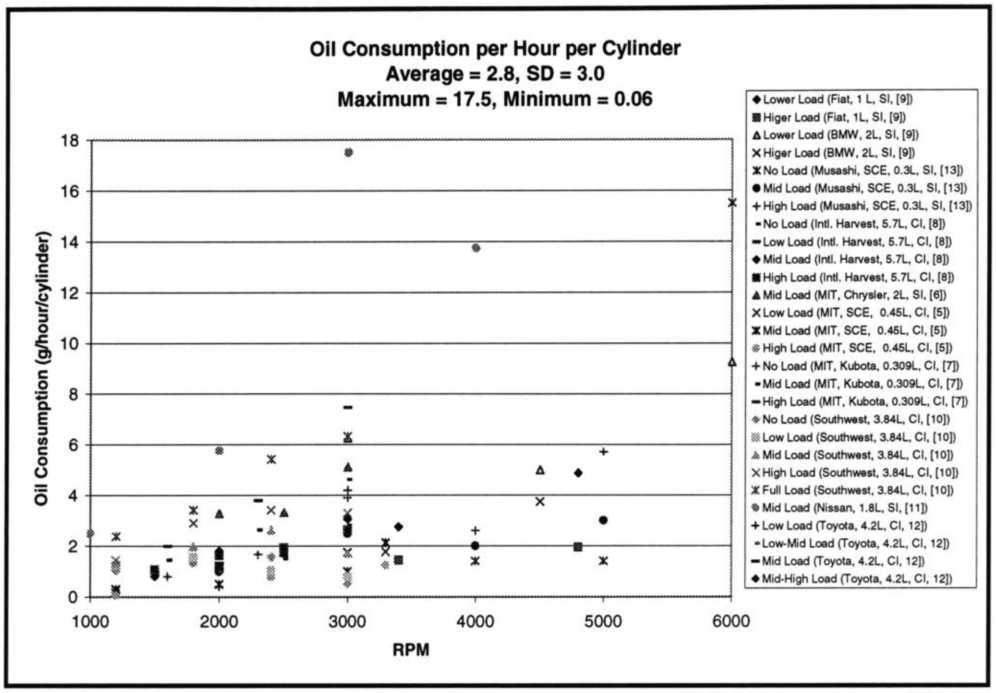
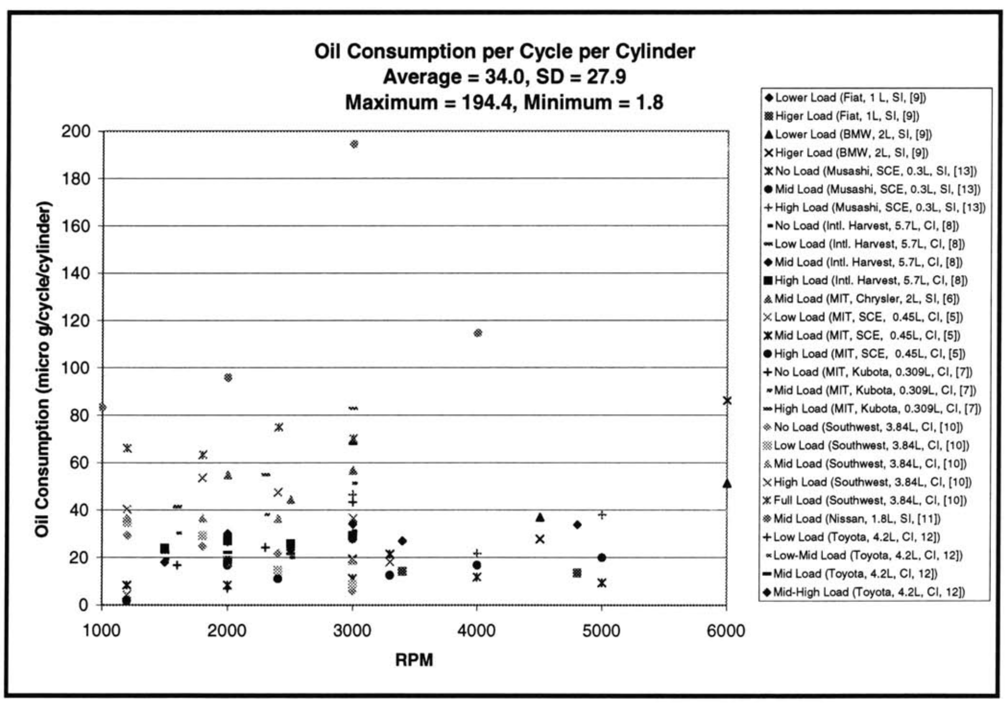
APPENDICES

Appendix A: Engine Oil-Consumption Data

A-1

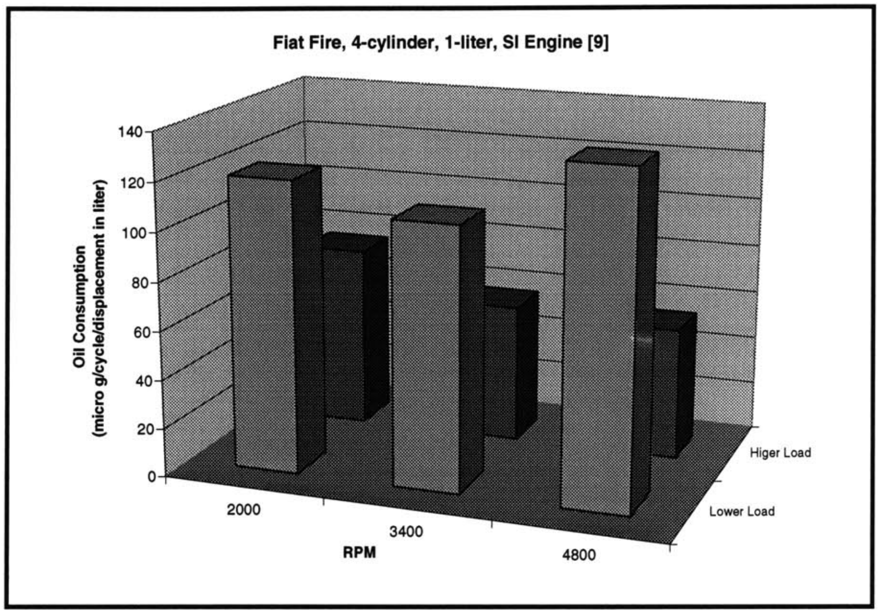


A-2

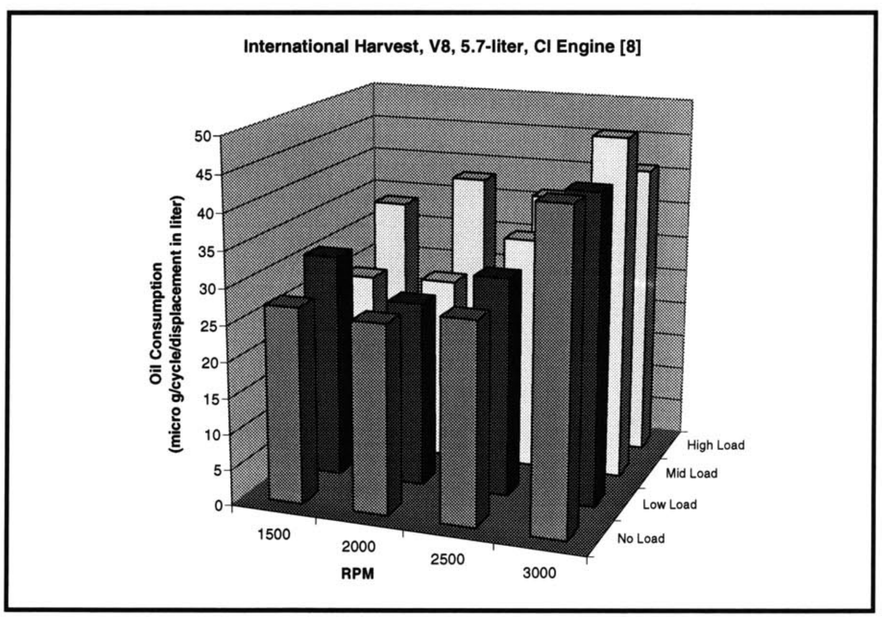


Appendix B: Engine Oil-Consumption Data of Individual Engines

B-1

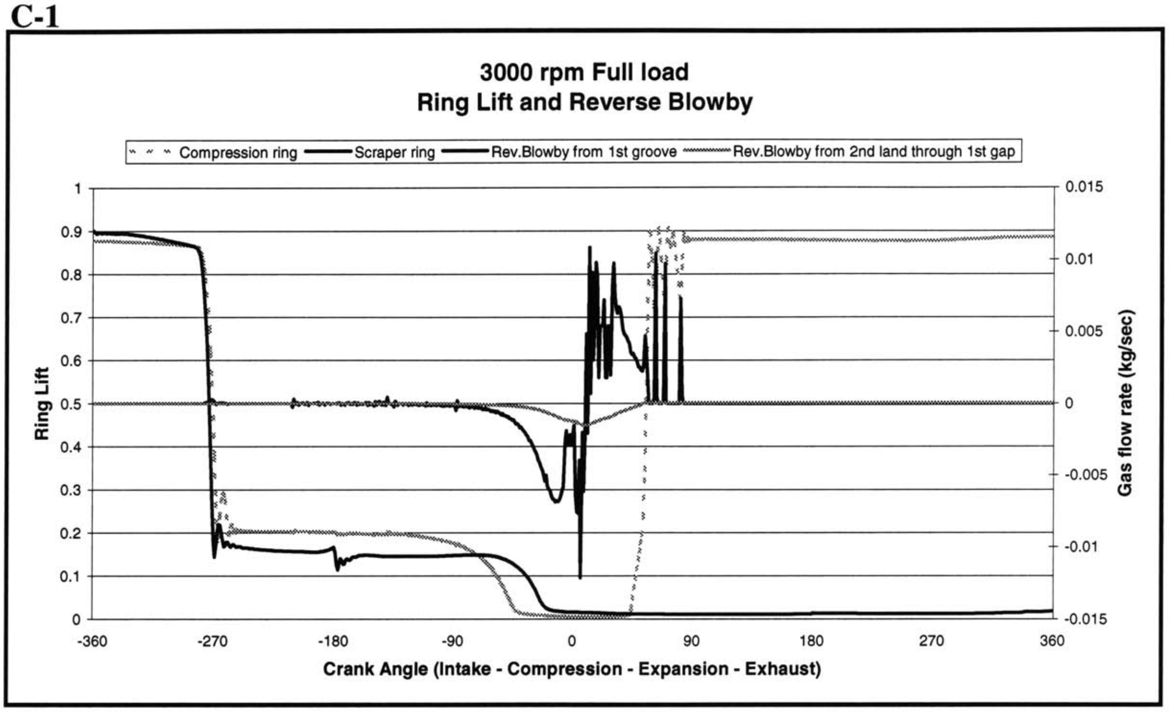


B-2

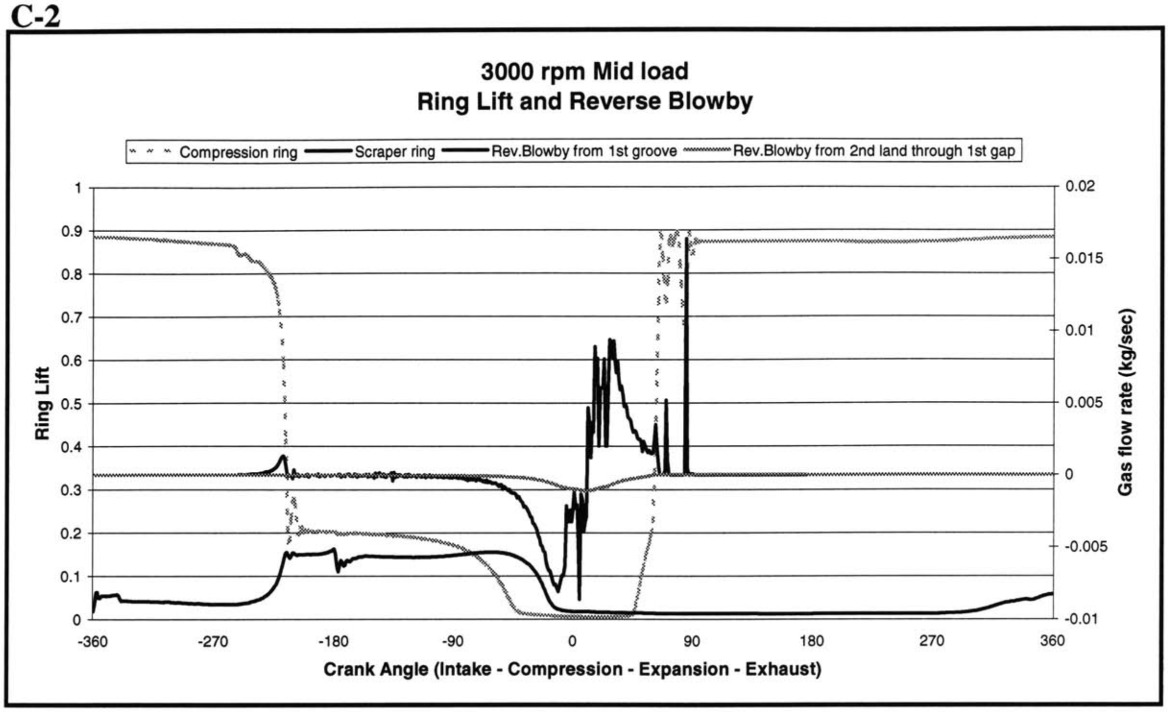


Appendix C: Outputs of *RINGPACK-OC*

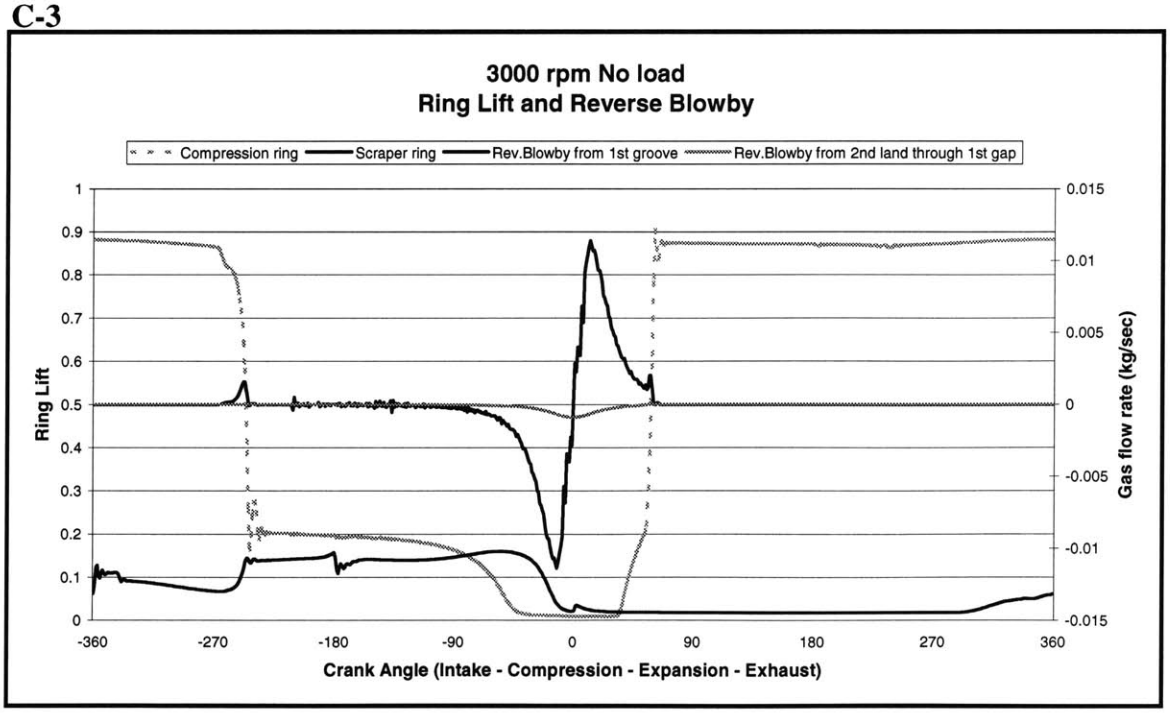
C-1



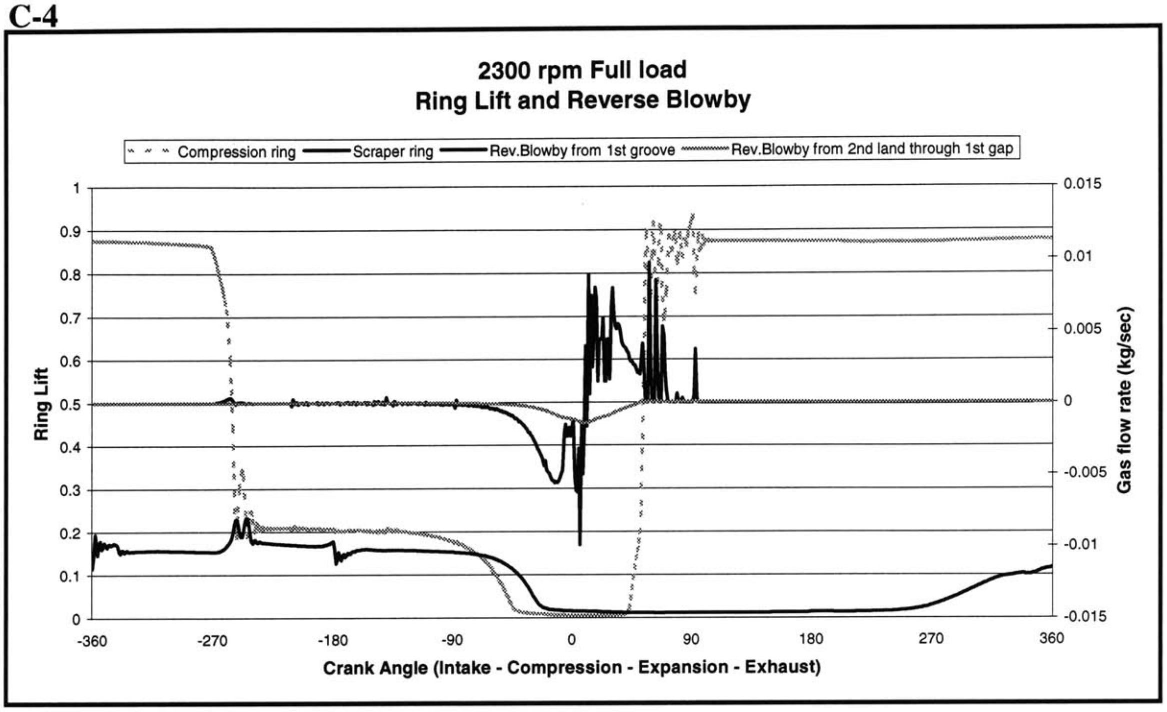
C-2


3000 rpm Mid load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-360
-270
-180
-90
0
90
180
270
360

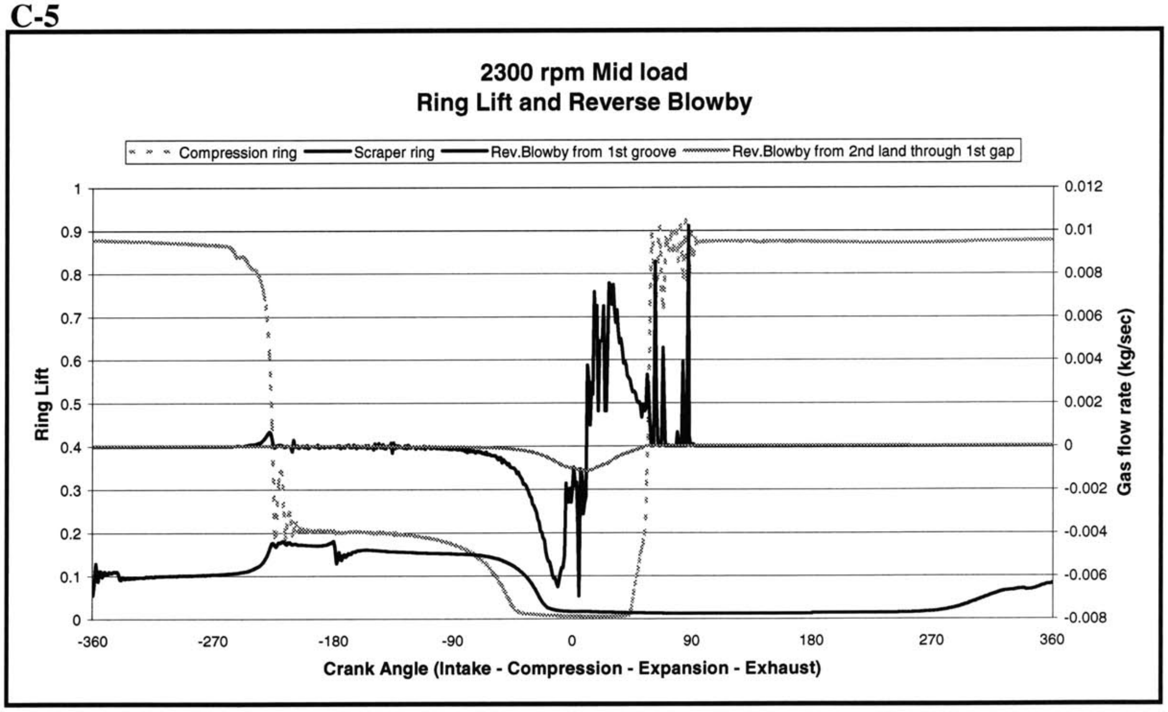
C-3


3000 rpm No load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-360
-270
-180
-90
0
90
180
270
360

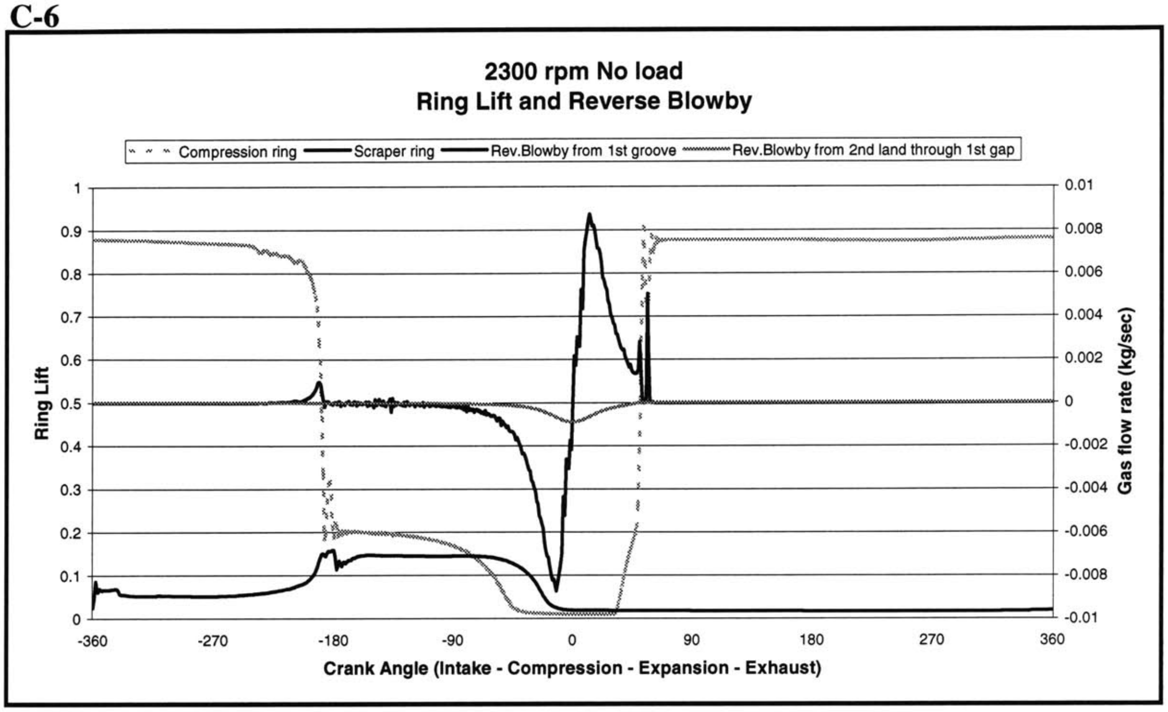
C-4


2300 rpm Full load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-360
-270
-180
-90
0
90
180
270
360

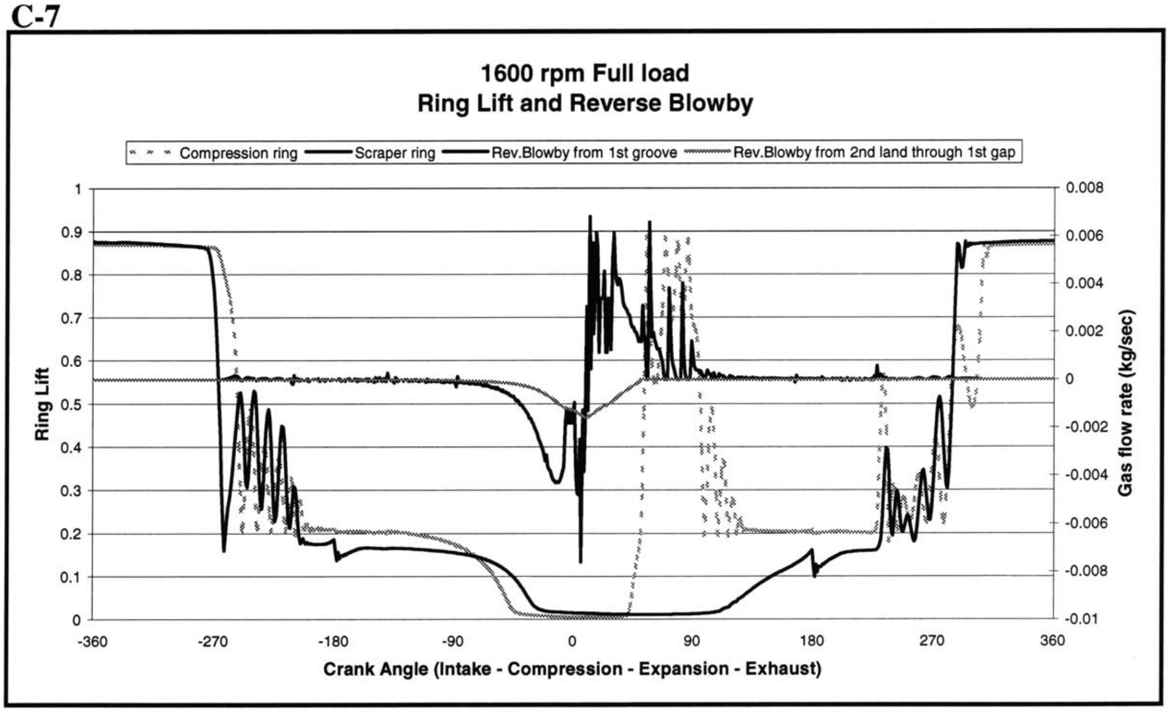
C-5


2300 rpm Mid load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-360
-270
-180
-90
0
90
180
270
360

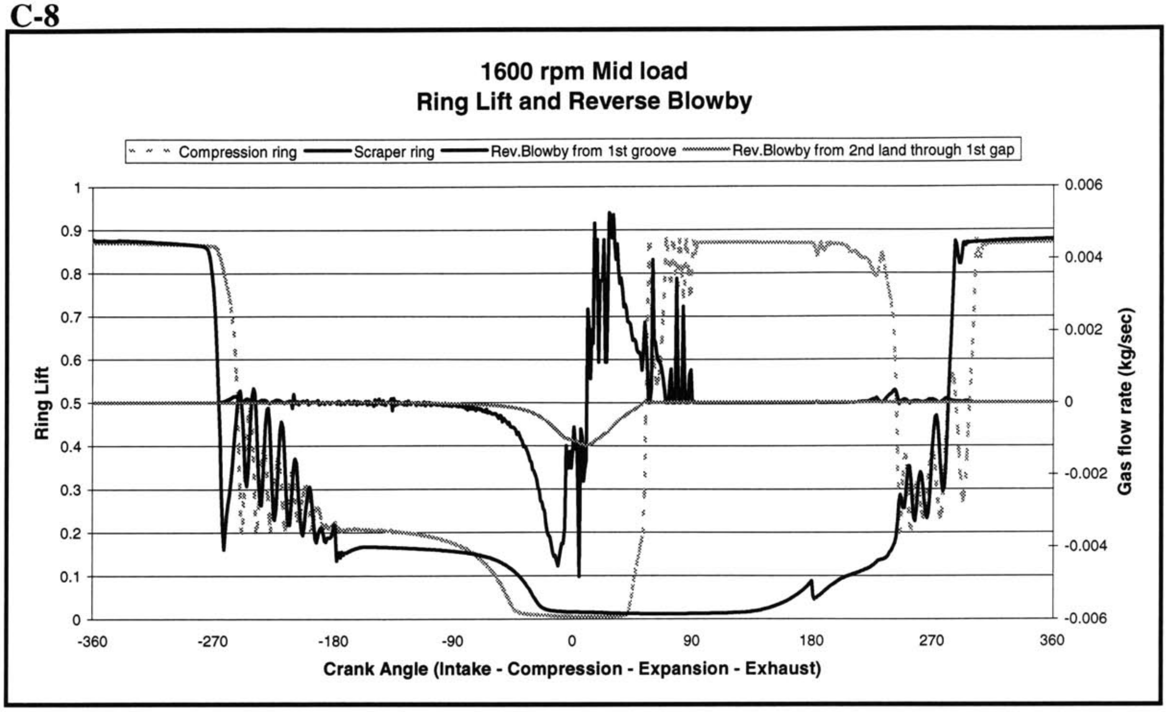
C-6


2300 rpm No load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-360
-270
-180
-90
0
90
180
270
360

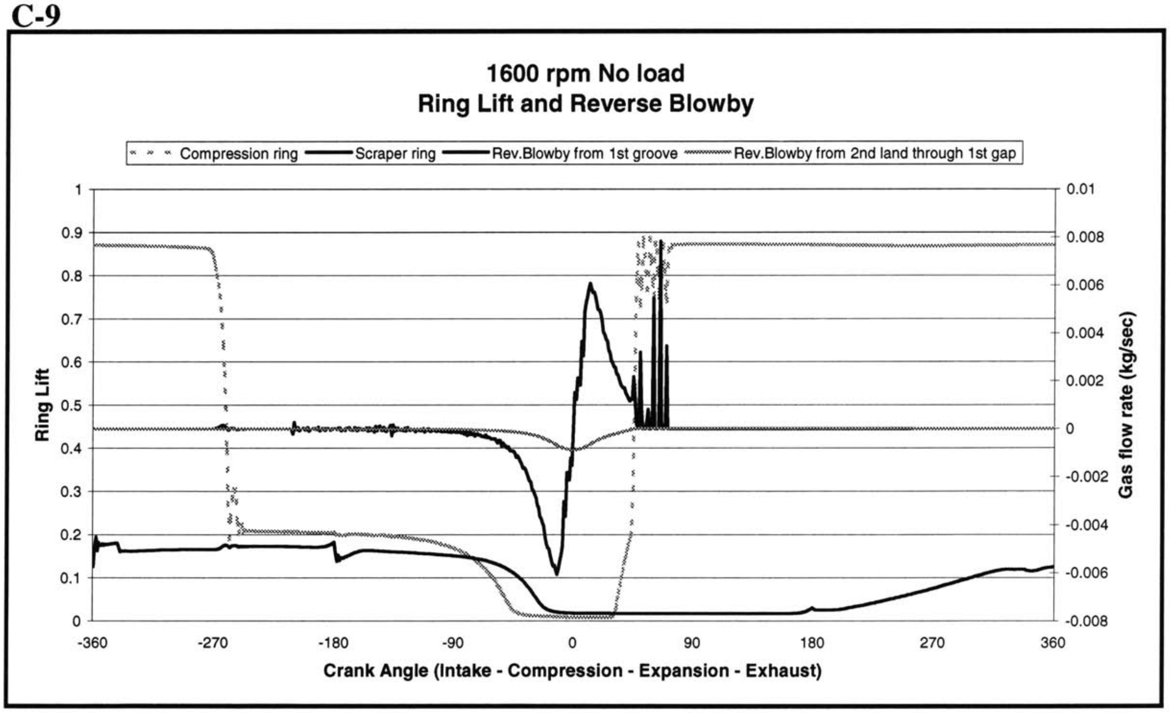
C-7


1600 rpm Full load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-360
-270
-180
-90
0
90
180
270
360

C-8

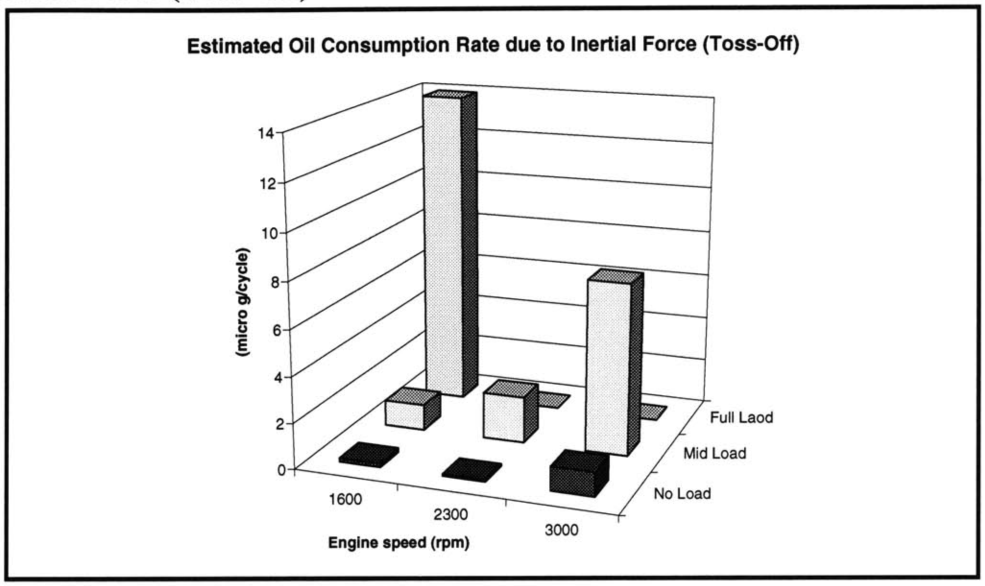

1600 rpm Mid load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-360
-270
-180
-90
0
90
180
270
360

C-9

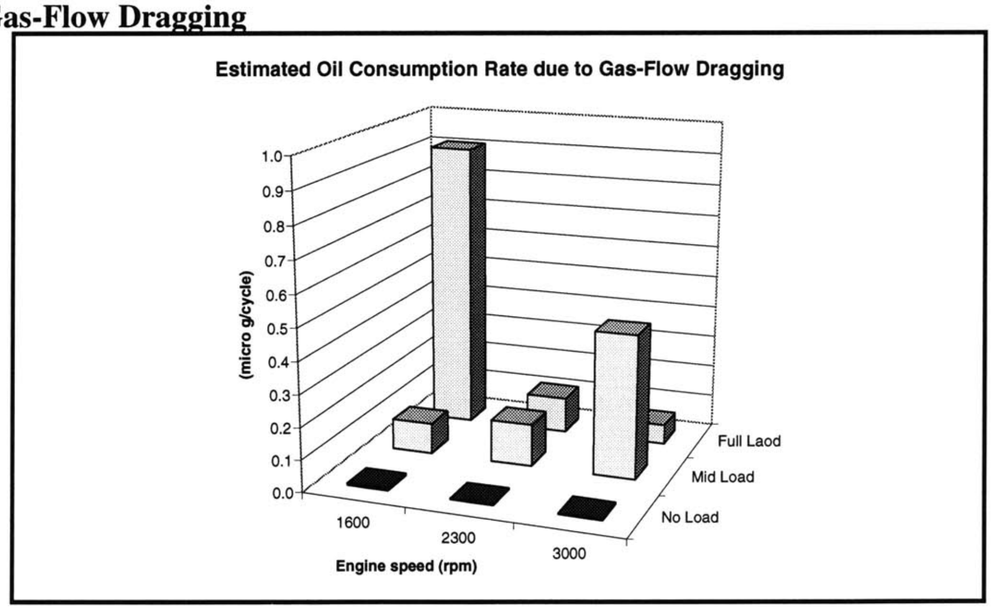

1600 rpm No load
Ring Lift and Reverse Blowby
Compression ring
Scraper ring
Rev.Blowby from 1st groove
Rev.Blowby from 2nd land through 1st gap
Ring Lift
Gas flow rate (kg/sec)
Crank Angle (Intake - Compression - Expansion - Exhaust)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-360
-270
-180
-90
0
90
180
270
360

Appendix D: Estimated Oil-Consumption Rate

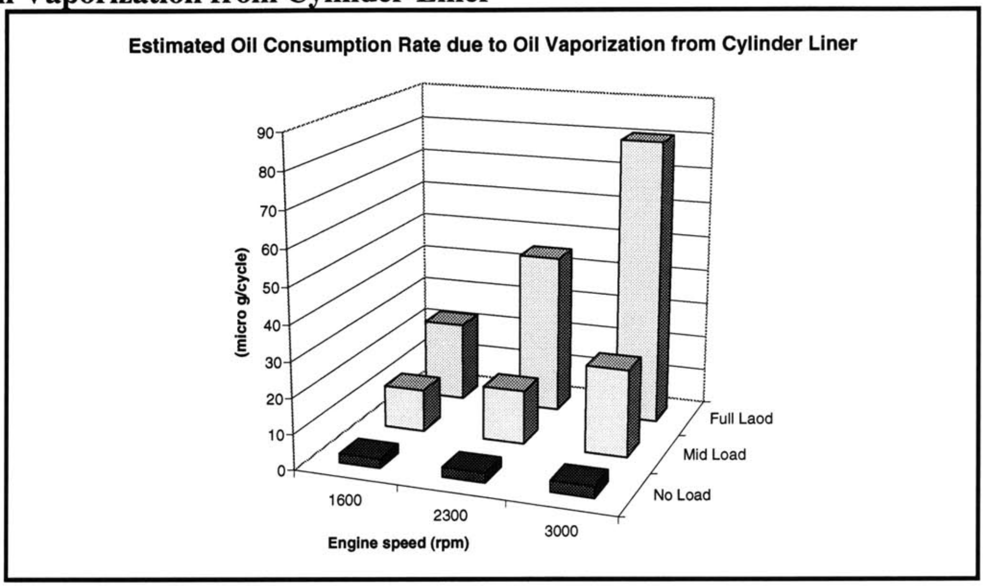
D-1: Inertial Force (Toss-Off)



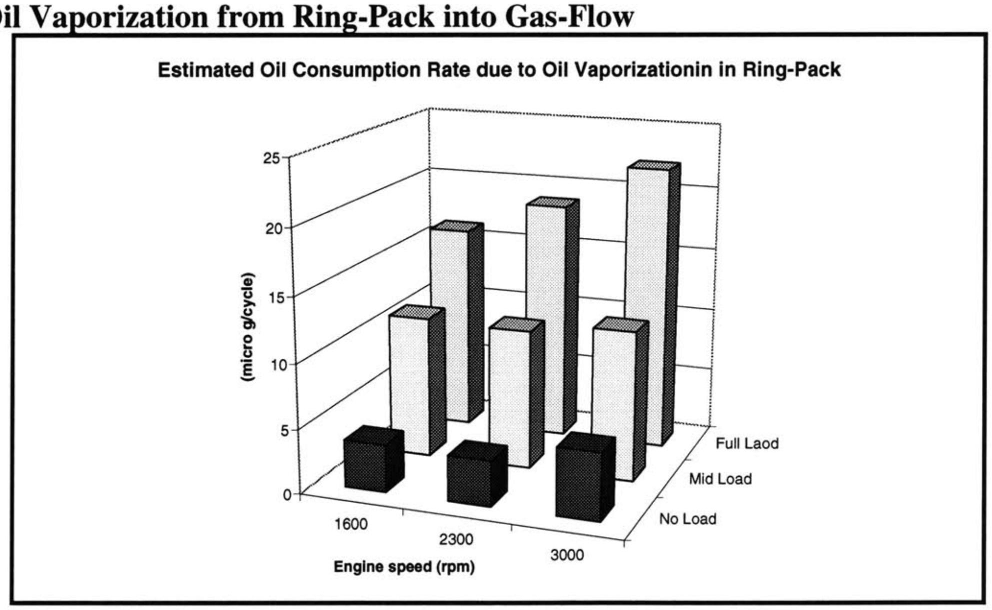
D-2: Gas-Flow Dragging



D-3: Oil Vaporization from Cylinder-Liner



D-4: Oil Vaporization from Ring-Pack into Gas-Flow



Appendix E: Input Files of *RINGPACK-OC*

1600 rpm-Full load condition

Input.dat:

```
&engine
 bore = 0.075, stroke = 0.070
 conrod = 0.110
 cp = 0
 dplug = 0
 ald1 = 9.6e-3
 rld1 = 37.35e-3
 rg1 = 33.25e-3
 sgmg1t = 4.e-7
 sgmg1b = 4.e-7
 ald2 = 3.90e-3
 rld2 = 37.35e-3
 rg2 = 33.25e-3
 hg2 = 1.58e-3
 gr2t_tilt = 0.00
 gr2b_tilt = 0.00
 sgmg2t = 4.e-7
 sgmg2b = 4.e-7
 ald3 = 2.4e-3
 rld3 = 37.35e-3
 rld4 = 36.35e-3
/
 &keystone
 thgt = 7.14
 thgb = 1.0
 hgi = 1.52e-3
 br_mea = 1.9e-3
 dr_mea = 0.5e-3
 df = 0.5e-3
 thrt = 7.33
 thrb = 0.8
/
 &ring
 alpi1 = 0.015
 gap1 = 0.306e-3
 dr1 = 3.3e-3
 ftan1 = 10
 rour1 = 6685.8
 sgmr1t = 3.e-7
 sgmr1b = 3.e-7
 alpi2 = 0.01
 ring2t_tilt = 0.0
 ring2b_tilt = 0.0
 br2 = 1.48e-3
 gap2 = 0.56e-3
 dr2 = 3.35e-3
 ftan2 = 13
 rour2 = 6486
 sgmr2t = 3.e-7
 sgmr2b = 3.e-7
 br3 = 4.0e-3
```

```
gap3 = 1.5e-3
/
&run
rpm = 1600
t1 = 260
t2 = 230
t3 = 210
t4 = 200
t5 = 190
t6 = 130
temp_liner = 130
ncycle = 2
/
&gas
runiv = 8314.3
wtmole = 29
gama = 1.4
/
&oildata
dens = 900
ok = 0.01147
temp1 = 2086.6
temp2 = 185.57
ho1t = 2.e-6
ho1b = 2.e-6
ho2t = 2.e-6
ho2b = 2.e-6
/
&rough
znugroove1 = 0.3
znugroove2 = 0.3
znuring1 = 0.3
znuring2 = 0.3
egroove1 = 0.76e+11
egroove2 = 0.76e+11
ering1 = 1.65e+11
ering2 = 1.1e+11
zp = 6.804
omega = 4
acc = 0.000044068
prk = 0.0001198
sfc = 0.1
cfct = 20.
/
&init
hr1 = 0.000050
hr2 = 0.000050
alpha1 = 0.00
alpha2 = 0.005
p2 = 101325
p3 = 121000
p4 = 150000
p5 = 151300
p6 = 120000
/
&ringcut
rcut1ul = 0.e-3
rcut1ud = 0.e-3
rcut1ll = 0
rcut1ld = 0
rcut2ul = 0
rcut2ud = 0
```

```
rcut2ll = 0.e-3
rcut2ld = 0.e-3
/
&landcut
cut2ul=0.15e-3
cut2ud=0.3e-3
cut2ml=0
cut2md=0
cut2ll=0.15e-3
cut2ld=0.3e-3
cut3ul=0.15e-3
cut3ud=0.3e-3
cut3ml=0
cut3md=0
cut3ll=0.15e-3
cut3ld=0.3e-3
/
&therm
thermld1=0.0
thermld2=0.0
thermld3=0.0
thermld4=0.0
thermgra1=0.0
thermgrr1=0.03
thermgra2=0.0
thermgrr2=0.03
distdata='n'
thermgap1=0.
thermgap2=0.
thermgap3=0
/
&oilfill
ofg1 = 0.1
ofg2 = 0.1
ofl2 = 0.2
ofl3 = 0.3
/
&oilblock
obgap1=0.
obgap2=0.
obgap3=0.
/
&side
ring1h=0.0
ring2h=0.0
ring3h=0.00000
/
&numerical
tol = 1.e-6
dth = 0.1
/
```

p1.dat:

-360	1.0133	-310	1.0133	-260	1.0133	-210	1.0617
-359	1.0133	-309	1.0133	-259	1.0133	-209	1.0722
-358	1.0133	-308	1.0133	-258	1.0133	-208	1.077
-357	1.0133	-307	1.0133	-257	1.0133	-207	1.0587
-356	1.0133	-306	1.0133	-256	1.0133	-206	1.0864
-355	1.0133	-305	1.0133	-255	1.0133	-205	1.084
-354	1.0133	-304	1.0133	-254	1.0133	-204	1.0848
-353	1.0133	-303	1.0133	-253	1.0133	-203	1.0774
-352	1.0133	-302	1.0133	-252	1.0133	-202	1.0914
-351	1.0133	-301	1.0133	-251	1.0133	-201	1.1005
-350	1.0133	-300	1.0133	-250	1.0133	-200	1.0829
-349	1.0133	-299	1.0133	-249	1.0133	-199	1.1135
-348	1.0133	-298	1.0133	-248	1.0133	-198	1.118
-347	1.0133	-297	1.0133	-247	1.0133	-197	1.1157
-346	1.0133	-296	1.0133	-246	1.0133	-196	1.1139
-345	1.0133	-295	1.0133	-245	1.0133	-195	1.1094
-344	1.0133	-294	1.0133	-244	1.0133	-194	1.1123
-343	1.0133	-293	1.0133	-243	1.0133	-193	1.1169
-342	1.0133	-292	1.0133	-242	1.0133	-192	1.0935
-341	1.0133	-291	1.0133	-241	1.0133	-191	1.1195
-340	1.0133	-290	1.0133	-240	1.0133	-190	1.1295
-339	1.0133	-289	1.0133	-239	1.0133	-189	1.126
-338	1.0133	-288	1.0133	-238	1.0133	-188	1.1215
-337	1.0133	-287	1.0133	-237	1.0133	-187	1.1441
-336	1.0133	-286	1.0133	-236	1.0133	-186	1.1399
-335	1.0133	-285	1.0133	-235	1.0133	-185	1.1347
-334	1.0133	-284	1.0133	-234	1.0133	-184	1.1351
-333	1.0133	-283	1.0133	-233	1.0133	-183	1.1499
-332	1.0133	-282	1.0133	-232	1.0133	-182	1.1472
-331	1.0133	-281	1.0133	-231	1.0133	-181	1.1487
-330	1.0133	-280	1.0133	-230	1.0133	-180	1.149
-329	1.0133	-279	1.0133	-229	1.0133	-179	1.1483
-328	1.0133	-278	1.0133	-228	1.0133	-178	1.1579
-327	1.0133	-277	1.0133	-227	1.0133	-177	1.1437
-326	1.0133	-276	1.0133	-226	1.0133	-176	1.1297
-325	1.0133	-275	1.0133	-225	1.0133	-175	1.1574
-324	1.0133	-274	1.0133	-224	1.0133	-174	1.162
-323	1.0133	-273	1.0133	-223	1.0133	-173	1.1662
-322	1.0133	-272	1.0133	-222	1.0133	-172	1.1883
-321	1.0133	-271	1.0133	-221	1.0133	-171	1.1818
-320	1.0133	-270	1.0133	-220	1.0133	-170	1.1778
-319	1.0133	-269	1.0133	-219	1.0133	-169	1.1566
-318	1.0133	-268	1.0133	-218	1.0133	-168	1.1712
-317	1.0133	-267	1.0133	-217	1.0133	-167	1.1807
-316	1.0133	-266	1.0133	-216	1.0133	-166	1.1986
-315	1.0133	-265	1.0133	-215	1.0133	-165	1.1793
-314	1.0133	-264	1.0133	-214	1.0133	-164	1.1751
-313	1.0133	-263	1.0133	-213	1.0133	-163	1.2041
-312	1.0133	-262	1.0133	-212	1.0818	-162	1.194
-311	1.0133	-261	1.0133	-211	1.1549	-161	1.2054

-160	1.2025	-110	1.5201	-60	4.5813	-10	48.079
-159	1.2168	-109	1.555	-59	4.7294	-9	49.961
-158	1.224	-108	1.5628	-58	4.9075	-8	51.74
-157	1.227	-107	1.6037	-57	5.0588	-7	53.432
-156	1.2116	-106	1.6135	-56	5.2395	-6	54.256
-155	1.2433	-105	1.641	-55	5.436	-5	54.81
-154	1.2278	-104	1.6569	-54	5.6575	-4	55.65
-153	1.2486	-103	1.6979	-53	5.8576	-3	56.49
-152	1.2493	-102	1.7083	-52	6.0948	-2	57.12
-151	1.2591	-101	1.7281	-51	6.3304	-1	57.96
-150	1.307	-100	1.7594	-50	6.5902	0	58.59
-149	1.2682	-99	1.8058	-49	6.8482	1	59.033
-148	1.2942	-98	1.8235	-48	7.1427	2	60.879
-147	1.2827	-97	1.8782	-47	7.4433	3	63.079
-146	1.24	-96	1.8833	-46	7.7733	4	65.309
-145	1.2531	-95	1.9237	-45	8.0962	5	66.462
-144	1.2754	-94	1.9475	-44	8.4641	6	69.994
-143	1.2502	-93	1.9947	-43	8.8703	7	70.578
-142	1.2784	-92	2.045	-42	9.2681	8	72.361
-141	1.3126	-91	2.0634	-41	9.7061	9	72.988
-140	1.1812	-90	2.0999	-40	10.19	10	71.578
-139	1.1752	-89	2.1475	-39	10.668	11	72.179
-138	1.1804	-88	2.2817	-38	11.192	12	69.014
-137	1.1937	-87	2.221	-37	11.751	13	68.805
-136	1.2031	-86	2.2791	-36	12.337	14	66.15
-135	1.2662	-85	2.3134	-35	12.974	15	65.267
-134	1.2226	-84	2.3593	-34	13.635	16	63.702
-133	1.212	-83	2.4157	-33	14.386	17	60.848
-132	1.2431	-82	2.4825	-32	15.135	18	58.275
-131	1.2471	-81	2.531	-31	15.952	19	57.75
-130	1.25	-80	2.5926	-30	16.807	20	56.175
-129	1.2516	-79	2.6543	-29	17.735	21	54.6
-128	1.2789	-78	2.736	-28	18.727	22	53.025
-127	1.2813	-77	2.809	-27	19.777	23	50.925
-126	1.2877	-76	2.8703	-26	20.926	24	50.4
-125	1.2897	-75	2.9306	-25	22.12	25	49.875
-124	1.32	-74	3.0209	-24	23.394	26	48.3
-123	1.3343	-73	3.0941	-23	24.748	27	46.725
-122	1.3383	-72	3.1792	-22	26.167	28	46.148
-121	1.3627	-71	3.2686	-21	27.743	29	43.803
-120	1.3655	-70	3.3502	-20	29.202	30	40.957
-119	1.3772	-69	3.4431	-19	30.884	31	38.788
-118	1.3798	-68	3.5589	-18	32.622	32	36.87
-117	1.4046	-67	3.6742	-17	34.387	33	35.033
-116	1.4336	-66	3.7637	-16	36.26	34	33.077
-115	1.4377	-65	3.8865	-15	38.2	35	31.166
-114	1.4515	-64	3.9982	-14	40.155	36	29.379
-113	1.4699	-63	4.1262	-13	42.155	37	27.879
-112	1.4846	-62	4.2808	-12	44.129	38	26.462
-111	1.5309	-61	4.4202	-11	46.121	39	25.082

40	23.738	90	4.0032	140	2.0003	190	1.4087
41	22.467	91	3.9308	141	1.9859	191	1.4002
42	21.256	92	3.8463	142	1.995	192	1.3973
43	20.229	93	3.7697	143	1.9635	193	1.3924
44	19.27	94	3.6908	144	1.9481	194	1.3942
45	18.318	95	3.6322	145	1.9342	195	1.3693
46	17.439	96	3.5577	146	1.912	196	1.3683
47	16.579	97	3.4946	147	1.8886	197	1.3617
48	15.796	98	3.4389	148	1.8975	198	1.3437
49	15.098	99	3.3766	149	1.8699	199	1.3399
50	14.405	100	3.3304	150	1.844	200	1.3441
51	13.769	101	3.2496	151	1.8475	201	1.318
52	13.155	102	3.2047	152	1.8201	202	1.3395
53	12.583	103	3.1316	153	1.8107	203	1.3329
54	12.05	104	3.0944	154	1.7942	204	1.3485
55	11.568	105	3.0587	155	1.7718	205	1.3428
56	11.065	106	2.9858	156	1.7684	206	1.312
57	10.668	107	2.9554	157	1.7507	207	1.3177
58	10.218	108	2.9127	158	1.7397	208	1.3433
59	9.8707	109	2.8943	159	1.7291	209	1.3311
60	9.4704	110	2.8141	160	1.7103	210	1.3206
61	9.1184	111	2.7877	161	1.6955	211	1.3224
62	8.7855	112	2.7524	162	1.6926	212	1.3182
63	8.4874	113	2.7042	163	1.7054	213	1.332
64	8.1853	114	2.6701	164	1.6724	214	1.3429
65	7.9056	115	2.6402	165	1.6616	215	1.3245
66	7.6521	116	2.6016	166	1.6561	216	1.331
67	7.3917	117	2.5853	167	1.711	217	1.3442
68	7.1593	118	2.5321	168	1.6314	218	1.3506
69	6.9328	119	2.5105	169	1.6258	219	1.3313
70	6.7411	120	2.4661	170	1.6274	220	1.3268
71	6.516	121	2.4505	171	1.6125	221	1.3379
72	6.3457	122	2.4286	172	1.5864	222	1.3367
73	6.1335	123	2.3983	173	1.5837	223	1.3532
74	5.966	124	2.3637	174	1.5702	224	1.3363
75	5.8041	125	2.3308	175	1.5522	225	1.3489
76	5.6261	126	2.3131	176	1.5453	226	1.2803
77	5.4836	127	2.2663	177	1.534	227	1.2765
78	5.3462	128	2.2411	178	1.5112	228	1.0133
79	5.1966	129	2.236	179	1.5137	229	1.0133
80	5.0586	130	2.1923	180	1.4963	230	1.0133
81	4.9287	131	2.1775	181	1.4938	231	1.0133
82	4.8247	132	2.1663	182	1.4841	232	1.0133
83	4.6867	133	2.1337	183	1.4759	233	1.0133
84	4.5947	134	2.1254	184	1.4557	234	1.0133
85	4.4717	135	2.0877	185	1.4575	235	1.0133
86	4.3925	136	2.0826	186	1.4629	236	1.0133
87	4.271	137	2.0593	187	1.4181	237	1.0133
88	4.1889	138	2.0294	188	1.4235	238	1.0133
89	4.0983	139	2.014	189	1.4115	239	1.0133

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-360.0	-6.252	-7.923	-5.814	-6.252	-7.924	-5.827	-19.989
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-358.0	6.253	8.343	7.574	6.253	8.234	6.692	22.171
-357.0	6.296	8.357	8.151	6.296	8.219	6.997	22.804
-356.0	6.293	8.350	8.436	6.293	8.163	7.042	23.079
-355.0	6.584	8.292	8.397	6.584	8.039	6.783	23.272
-354.0	6.572	8.281	8.065	6.572	7.980	6.249	22.918
-353.0	6.695	8.307	7.519	6.695	7.973	5.515	22.521
-352.0	6.812	8.232	6.851	6.812	7.829	4.675	21.895
-351.0	6.786	8.124	6.148	6.786	7.648	3.817	21.058
-350.0	6.770	8.020	5.476	6.770	7.475	3.007	20.266
-349.0	6.894	7.944	4.881	6.894	7.339	2.289	19.719
-348.0	6.758	7.931	4.386	6.758	7.277	1.685	19.076
-347.0	6.814	7.974	3.998	6.814	7.282	1.199	18.786
-346.0	6.751	8.069	3.714	6.751	7.351	.825	18.533
-345.0	6.893	8.123	3.522	6.893	7.374	.548	18.539
-344.0	6.792	8.169	3.409	6.792	7.387	.351	18.370
-343.0	6.855	8.143	3.359	6.855	7.308	.216	18.358
-342.0	6.871	8.039	3.357	6.871	7.131	.128	18.268
-341.0	6.883	4.591	3.389	6.883	3.500	.073	14.864
-340.0	6.821	2.191	3.444	6.821	1.114	.039	12.455
-339.0	6.889	1.861	3.511	6.889	.804	.020	12.262
-338.0	6.865	1.812	3.587	6.865	.727	.010	12.264
-337.0	6.898	1.737	3.667	6.898	.630	.005	12.303
-336.0	6.352	1.603	3.750	5.272	.490	.002	11.705
-335.0	7.213	1.449	3.833	6.356	.344	.001	12.494
-334.0	7.421	1.310	3.916	6.829	.222	.000	12.647
-333.0	7.340	1.206	3.999	6.875	.133	.000	12.545
-332.0	7.292	1.136	4.082	6.899	.076	.000	12.509
-331.0	6.951	1.095	4.163	6.951	.041	.000	12.210
-330.0	6.930	1.074	4.244	6.930	.021	.000	12.248
-329.0	6.862	1.067	4.324	5.587	.011	.000	12.253
-328.0	4.509	1.067	4.403	3.024	.005	.000	9.980
-327.0	2.789	1.073	4.482	1.339	.002	.000	8.343
-326.0	2.284	1.081	4.559	.858	.001	.000	7.924
-325.0	1.998	1.091	4.636	.599	.000	.000	7.725
-324.0	1.760	1.102	4.712	.391	.000	.000	7.573
-323.0	1.554	1.114	4.786	.225	.000	.000	7.454
-322.0	1.403	1.126	4.860	.114	.000	.000	7.389
-321.0	1.320	1.139	4.933	.054	.000	.000	7.392
-320.0	1.272	1.153	5.004	.023	.000	.000	7.429
-319.0	1.255	1.166	5.075	.010	.000	.000	7.495
-318.0	1.249	1.180	5.144	.004	.000	.000	7.572
-317.0	1.244	1.194	5.212	.001	.000	.000	7.650
-316.0	1.250	1.208	5.279	.000	.000	.000	7.736
-315.0	1.256	1.221	5.344	.000	.000	.000	7.822
-314.0	1.264	1.235	5.409	.000	.000	.000	7.908
-313.0	1.270	1.249	5.472	.000	.000	.000	7.991
-312.0	1.278	1.263	5.534	.000	.000	.000	8.074
-311.0	1.288	1.276	5.594	.000	.000	.000	8.158
-310.0	1.297	1.289	5.653	.000	.000	.000	8.240
-309.0	1.306	1.302	5.711	.000	.000	.000	8.320
-308.0	1.315	1.315	5.768	.000	.000	.000	8.398
-307.0	1.325	1.328	5.822	.000	.000	.000	8.475
-306.0	1.337	1.340	5.876	.000	.000	.000	8.553
-305.0	1.341	1.352	5.928	.000	.000	.000	8.621
-304.0	1.355	1.364	5.979	.000	.000	.000	8.698
-303.0	1.366	1.376	6.028	.000	.000	.000	8.769
-302.0	1.375	1.387	6.075	.000	.000	.000	8.837

-301.0	1.384	1.398	6.122	.000	.000	.000	8.903
-300.0	1.389	1.409	6.166	.000	.000	.000	8.964
-299.0	1.400	1.419	6.209	.000	.000	.000	9.028
-298.0	1.406	1.429	6.250	.000	.000	.000	9.086
-297.0	1.414	1.438	6.290	.000	.000	.000	9.143
-296.0	1.424	1.448	6.328	.000	.000	.000	9.200
-295.0	1.433	1.456	6.365	.000	.000	.000	9.254
-294.0	1.439	1.465	6.400	.000	.000	.000	9.304
-293.0	1.445	1.473	6.433	.000	.000	.000	9.351
-292.0	1.449	1.481	6.465	.000	.000	.000	9.395
-291.0	1.458	1.488	6.495	.000	.000	.000	9.441
-290.0	1.464	1.495	6.523	.000	.000	.000	9.482
-289.0	1.470	1.502	6.549	.000	.000	.000	9.522
-288.0	1.475	1.508	6.574	.000	.000	.000	9.558
-287.0	1.478	1.514	6.597	.000	.000	.000	9.589
-286.0	1.482	1.519	6.619	.000	.000	.000	9.620
-285.0	1.486	1.524	6.639	.000	.000	.000	9.649
-284.0	1.489	1.529	6.657	.000	.000	.000	9.675
-283.0	1.493	1.533	6.673	.000	.000	.000	9.699
-282.0	1.495	1.537	6.687	.000	.000	.000	9.719
-281.0	1.499	1.540	6.700	.000	.000	.000	9.740
-280.0	1.502	1.543	6.711	.000	.000	.000	9.757
-279.0	1.498	1.546	6.721	.000	.000	.000	9.764
-278.0	1.501	1.548	6.728	.000	.000	.000	9.777
-277.0	1.503	1.549	6.734	.000	.000	.000	9.787
-276.0	1.508	1.550	6.739	.000	.000	.000	9.797
-275.0	1.493	1.551	6.741	.000	.000	.000	9.785
-274.0	1.504	1.552	6.742	.000	.000	.000	9.798
-273.0	1.505	1.552	6.741	.000	.000	.000	9.798
-272.0	1.503	1.551	6.738	.000	.000	.000	9.793
-271.0	1.497	1.550	6.734	.000	.000	.000	9.782
-270.0	1.500	1.549	6.728	.000	.000	.000	9.776
-269.0	1.497	1.547	6.720	.000	.000	.000	9.764
-268.0	1.493	1.545	6.711	.000	.000	.000	9.749
-267.0	1.492	1.542	6.700	.000	.000	.000	9.734
-266.0	1.487	1.539	6.687	.000	.000	.000	9.714
-265.0	1.483	1.536	6.673	.000	.000	.000	9.692
-264.0	1.477	1.532	6.657	.000	.000	.000	9.667
-263.0	1.474	1.528	6.640	.000	.000	.000	9.642
-262.0	1.470	1.523	6.621	.000	.000	.000	9.614
-261.0	1.465	1.518	6.600	.000	.000	.000	9.584
-260.0	1.459	1.513	6.578	.000	.000	.000	9.550
-259.0	1.449	1.507	6.555	.000	.000	.000	9.511
-258.0	1.445	1.501	6.529	.000	.000	.000	9.475
-257.0	1.436	1.494	6.503	.000	.000	.000	9.433
-256.0	1.429	1.487	6.475	.000	.000	.000	9.390
-255.0	1.423	1.480	6.445	.000	.000	.000	9.348
-254.0	1.411	1.472	6.414	.000	.000	.000	9.297
-253.0	1.404	1.464	6.382	.000	.000	.000	9.250
-252.0	1.397	1.456	6.348	.000	.000	.000	9.201
-251.0	1.387	1.448	6.313	.000	.000	.000	9.148
-250.0	1.376	1.440	6.276	.000	.000	.000	9.092
-249.0	1.366	1.432	6.238	.000	.000	.000	9.036
-248.0	1.359	1.424	6.199	.000	.000	.000	8.981
-247.0	1.349	1.415	6.158	.000	.000	.000	8.922
-246.0	1.337	1.406	6.116	.000	.000	.000	8.859
-245.0	1.327	1.396	6.073	.000	.000	.000	8.796
-244.0	1.317	1.386	6.029	.000	.000	.000	8.731
-243.0	1.306	1.376	5.983	.000	.000	.000	8.665
-242.0	1.294	1.366	5.936	.000	.000	.000	8.596
-241.0	1.285	1.355	5.888	.000	.000	.000	8.528
-240.0	1.271	1.344	5.839	.000	.000	.000	8.453

-239.0	1.257	1.333	5.788	.000	.000	.000	8.378
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-237.0	1.237	1.309	5.684	.000	.000	.000	8.230
-236.0	1.224	1.297	5.630	.000	.000	.000	8.151
-235.0	1.209	1.284	5.575	.000	.000	.000	8.068
-234.0	1.197	1.272	5.519	.000	.000	.000	7.987
-233.0	1.183	1.259	5.462	.000	.000	.000	7.903
-232.0	1.169	1.245	5.403	.000	.000	.000	7.817
-231.0	1.152	1.232	5.344	.000	.000	.000	7.728
-230.0	1.141	1.218	5.284	.000	.000	.000	7.643
-229.0	1.125	1.204	5.222	.000	.000	.000	7.551
-228.0	1.109	1.190	5.160	.000	.000	.000	7.458
-227.0	1.095	1.175	5.096	.000	.000	.000	7.367
-226.0	1.081	1.160	5.032	.000	.000	.000	7.273
-225.0	1.066	1.145	4.966	.000	.000	.000	7.177
-224.0	1.047	1.130	4.900	.000	.000	.000	7.077
-223.0	1.032	1.115	4.832	.000	.000	.000	6.979
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-220.0	.983	1.067	4.623	.000	.000	.000	6.673
-219.0	.965	1.051	4.551	.000	.000	.000	6.567
-218.0	.948	1.034	4.479	.000	.000	.000	6.461
-217.0	.932	1.017	4.405	.000	.000	.000	6.354
-216.0	.911	1.000	4.330	.000	.000	.000	6.241
-215.0	.895	.983	4.254	.000	.000	.000	6.132
-214.0	.877	.965	4.177	.000	.000	.000	6.020
-213.0	.856	.947	4.099	.000	.000	.000	5.902
-212.0	.839	.929	4.020	.000	.000	.000	5.788
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-210.0	.800	.893	3.858	.000	.000	.000	5.551
-209.0	.781	.874	3.775	.000	.000	.000	5.429
-208.0	.762	.855	3.691	.000	.000	.000	5.307
-207.0	.742	.835	3.605	.000	.000	.000	5.182
-206.0	.720	.816	3.519	.000	.000	.000	5.054
-205.0	.700	.796	3.430	.000	.001	.000	4.927
-204.0	.678	.776	3.341	.000	.001	.000	4.796
-203.0	.657	.757	3.250	.000	.002	.000	4.663
-202.0	.634	.737	3.157	.000	.003	.000	4.528
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-193.0	.428	.682	2.233	.001	.144	.001	3.344
-192.0	.410	.698	2.118	.001	.188	.001	3.226
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-188.0	.334	1.121	1.623	.026	.717	.009	3.078
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-186.0	.365	1.573	1.351	.122	1.239	.021	3.289
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-173.0	-3.661	-6.510	-2.086	-3.257	-6.131	-.478	-12.257
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-170.0	-2.154	-5.195	-2.816	-1.643	-4.683	-.696	-10.165
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-165.0	-.767	-2.846	-3.252	-.200	-2.203	-.478	-6.866
-164.0	-.683	-2.436	-3.280	-.109	-1.782	-.396	-6.399
-163.0	-.628	-2.049	-3.306	-.049	-1.390	-.318	-5.983
-162.0	-.614	-1.750	-3.334	-.023	-1.085	-.247	-5.698
-161.0	-.609	-1.464	-3.368	-.008	-.798	-.186	-5.441
-160.0	-.616	-1.226	-3.409	-.003	-.565	-.135	-5.252
-159.0	-.637	-1.100	-3.459	-.001	-.427	-.095	-5.196
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-156.0	-.674	-.726	-3.645	.000	-.086	-.026	-5.045
-155.0	-.697	-.685	-3.716	.000	-.046	-.016	-5.098
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-153.0	-.722	-.664	-3.921	.000	-.012	-.008	-5.307
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-151.0	-.757	-.676	-4.253	.000	-.003	-.023	-5.686
-150.0	-.776	-.687	-4.495	.000	-.001	-.064	-5.958
-149.0	-.795	-.699	-4.857	.000	.000	-.180	-6.351
-148.0	-.812	-.712	-5.438	.000	.000	-.452	-6.962
-147.0	-.832	-.729	-6.241	.000	.000	-.908	-7.802
-146.0	-.849	-.772	-6.960	.000	.000	-1.355	-8.581
-145.0	-.868	-.818	-7.102	.000	.000	-1.414	-8.787
-144.0	-.886	-.858	-6.699	.000	-.002	-1.079	-8.444
-143.0	-.904	-.892	-6.100	.000	-.005	-.618	-7.896
-142.0	-.923	-.914	-5.618	.000	-.007	-.270	-7.455
-141.0	-.940	-.924	-5.347	.000	-.007	-.090	-7.211
-140.0	-.958	-.918	-5.225	.000	-.004	-.022	-7.101
-139.0	-.974	-.913	-5.176	.000	-.002	-.004	-7.063
-138.0	-.991	-.911	-5.166	.000	.000	.000	-7.067
-137.0	-1.007	-.910	-5.177	.000	.000	.000	-7.094
-136.0	-1.024	-.912	-5.204	.000	.000	.000	-7.140
-135.0	-1.044	-.917	-5.257	.000	.000	.000	-7.218
-134.0	-1.056	-.923	-5.336	.000	.000	.000	-7.315
-133.0	-1.070	-.931	-5.435	.000	.000	.000	-7.436
-132.0	-1.087	-.941	-5.546	.000	.000	.000	-7.573
-131.0	-1.101	-.950	-5.655	.000	.000	.000	-7.706
-130.0	-1.116	-.961	-5.743	.000	.000	.000	-7.821
-129.0	-1.129	-.972	-5.797	.000	.000	.000	-7.899
-128.0	-1.145	-.984	-5.817	.000	.000	.000	-7.946
-127.0	-1.158	-.996	-5.814	.000	.000	.000	-7.968
-126.0	-1.173	-1.008	-5.807	.000	.000	.000	-7.988
-125.0	-1.185	-1.020	-5.818	.000	.000	.000	-8.023
-124.0	-1.200	-1.031	-5.837	.000	.000	.000	-8.068
-123.0	-1.214	-1.042	-5.862	.000	.000	.000	-8.118
-122.0	-1.226	-1.053	-5.892	.000	.000	.000	-8.170
-121.0	-1.239	-1.064	-5.924	.000	.000	.000	-8.227
-120.0	-1.251	-1.074	-5.959	.000	.000	.000	-8.284
-119.0	-1.262	-1.084	-5.995	.000	.000	.000	-8.342
-118.0	-1.274	-1.094	-6.032	.000	.000	.000	-8.401
-117.0	-1.286	-1.104	-6.070	.000	.000	.000	-8.460
-116.0	-1.299	-1.113	-6.108	.000	.000	.000	-8.520

-115.0	-1.310	-1.122	-6.146	.000	.000	.000	-8.578
-114.0	-1.321	-1.131	-6.183	.000	.000	.000	-8.635
-113.0	-1.332	-1.139	-6.220	.000	.000	.000	-8.692
-112.0	-1.344	-1.147	-6.256	.000	.000	.000	-8.747
-111.0	-1.357	-1.155	-6.292	.000	.000	.000	-8.803
-110.0	-1.365	-1.162	-6.326	.000	.000	.000	-8.853
-109.0	-1.376	-1.169	-6.360	.000	.000	.000	-8.905
-108.0	-1.385	-1.176	-6.392	.000	.000	.000	-8.953
-107.0	-1.397	-1.183	-6.423	.000	.000	.000	-9.003
-106.0	-1.406	-1.189	-6.453	.000	.000	.000	-9.047
-105.0	-1.415	-1.195	-6.481	.000	.000	.000	-9.091
-104.0	-1.423	-1.201	-6.509	.000	.000	.000	-9.132
-103.0	-1.434	-1.206	-6.534	.000	.000	.000	-9.175
-102.0	-1.441	-1.212	-6.559	.000	.000	.000	-9.212
-101.0	-1.448	-1.217	-6.582	.000	.000	.000	-9.248
-100.0	-1.457	-1.222	-6.604	.000	.000	.000	-9.283
-99.0	-1.467	-1.227	-6.624	.000	.000	.000	-9.318
-98.0	-1.473	-1.232	-6.642	.000	.000	.000	-9.347
-97.0	-1.482	-1.235	-6.659	.000	.000	.000	-9.377
-96.0	-1.486	-1.240	-6.675	.000	.000	.000	-9.401
-95.0	-1.493	-1.243	-6.689	.000	.000	.000	-9.425
-94.0	-1.499	-1.246	-6.701	.000	.000	.000	-9.446
-93.0	-1.506	-1.249	-6.712	.000	.000	.000	-9.466
-92.0	-1.513	-1.251	-6.721	.000	.000	.000	-9.485
-91.0	-1.517	-1.253	-6.729	.000	.000	.000	-9.498
-90.0	-1.521	-1.254	-6.734	.000	.000	.000	-9.510
-89.0	-1.527	-1.255	-6.739	.000	.000	.000	-9.520
-88.0	-1.540	-1.256	-6.741	.000	.000	.000	-9.536
-87.0	-1.535	-1.256	-6.742	.000	.000	.000	-9.532
-86.0	-1.539	-1.255	-6.741	.000	.000	.000	-9.535
-85.0	-1.541	-1.255	-6.739	.000	.000	.000	-9.535
-84.0	-1.545	-1.255	-6.735	.000	.000	.000	-9.534
-83.0	-1.549	-1.255	-6.729	.000	.000	.000	-9.532
-82.0	-1.553	-1.254	-6.721	.000	.000	.000	-9.528
-81.0	-1.554	-1.253	-6.712	.000	.000	.000	-9.519
-80.0	-1.557	-1.252	-6.701	.000	.000	.000	-9.510
-79.0	-1.559	-1.250	-6.688	.000	.000	.000	-9.497
-78.0	-1.563	-1.247	-6.673	.000	.000	.000	-9.483
-77.0	-1.565	-1.244	-6.657	.000	.000	.000	-9.466
-76.0	-1.565	-1.241	-6.639	.000	.000	.000	-9.445
-75.0	-1.565	-1.238	-6.619	.000	.000	.000	-9.422
-74.0	-1.567	-1.236	-6.598	.000	.000	.000	-9.400
-73.0	-1.567	-1.233	-6.575	.000	.000	.000	-9.375
-72.0	-1.568	-1.229	-6.550	.000	.000	.000	-9.347
-71.0	-1.569	-1.225	-6.524	.000	.000	.000	-9.318
-70.0	-1.567	-1.221	-6.495	.000	.000	.000	-9.283
-69.0	-1.567	-1.216	-6.466	.000	.000	.000	-9.249
-68.0	-1.568	-1.211	-6.434	.000	.000	.000	-9.212
-67.0	-1.568	-1.208	-6.401	.000	.000	.000	-9.176
-66.0	-1.565	-1.205	-6.366	.000	.000	.000	-9.136
-65.0	-1.565	-1.201	-6.329	.000	.000	.000	-9.095
-64.0	-1.563	-1.196	-6.291	.000	.000	.000	-9.050
-63.0	-1.562	-1.191	-6.251	.000	.000	.000	-9.003
-62.0	-1.561	-1.187	-6.210	.000	.000	.000	-8.958
-61.0	-1.559	-1.185	-6.167	.000	.000	.000	-8.911
-60.0	-1.558	-1.181	-6.122	.000	.000	.000	-8.861
-59.0	-1.555	-1.177	-6.076	.000	.000	.000	-8.808
-58.0	-1.554	-1.173	-6.028	.000	.000	.000	-8.755
-57.0	-1.551	-1.171	-5.978	.000	.000	.000	-8.699
-56.0	-1.547	-1.168	-5.928	.000	.000	.000	-8.643
-55.0	-1.544	-1.165	-5.877	.000	.000	.000	-8.586
-54.0	-1.542	-1.161	-5.826	.000	.000	.000	-8.529

-53.0	-1.537	-1.155	-5.775	.000	.000	.000	-8.467
-52.0	-1.534	-1.150	-5.723	.000	.000	.000	-8.407
-51.0	-1.529	-1.147	-5.670	.000	.000	.000	-8.346
-50.0	-1.525	-1.143	-5.616	.000	.000	.000	-8.284
-49.0	-1.520	-1.135	-5.561	.000	.000	.000	-8.216
-48.0	-1.517	-1.128	-5.504	.000	.000	.000	-8.149
-47.0	-1.513	-1.121	-5.447	.000	.000	.000	-8.081
-46.0	-1.510	-1.113	-5.388	-.001	.000	.000	-8.011
-45.0	-1.508	-1.105	-5.328	-.002	.000	.000	-7.942
-44.0	-1.509	-1.099	-5.267	-.004	.000	.000	-7.875
-43.0	-1.514	-1.113	-5.205	-.008	.000	.000	-7.832
-42.0	-1.525	-1.108	-5.141	-.016	.000	.000	-7.774
-41.0	-1.549	-1.112	-5.075	-.031	.000	.000	-7.736
-40.0	-1.593	-1.077	-5.009	-.060	.000	.000	-7.679
-39.0	-1.668	-1.073	-4.941	-.110	.000	.000	-7.682
-38.0	-1.789	-1.070	-4.876	-.195	-.001	.000	-7.736
-37.0	-1.975	-1.073	-4.846	-.331	-.002	.000	-7.895
-36.0	-2.239	-1.081	-4.823	-.538	-.004	.000	-8.143
-35.0	-2.594	-1.108	-4.722	-.831	-.007	.000	-8.424
-34.0	-3.044	-1.104	-4.623	-1.221	-.013	.000	-8.771
-33.0	-3.621	-1.129	-4.530	-1.738	-.025	.000	-9.280
-32.0	-4.398	-1.162	-4.444	-2.449	-.044	.000	-10.004
-31.0	-5.514	-1.229	-4.363	-3.489	-.081	.000	-11.106
-30.0	-6.877	-1.336	-4.286	-4.789	-.147	.000	-12.498
-29.0	-8.537	-1.482	-4.256	-6.400	-.249	.000	-14.276
-28.0	-10.286	-1.700	-3.401	-8.129	-.409	.000	-15.387
-27.0	-12.020	-1.998	-3.414	-9.866	-.640	.000	-17.432
-26.0	-13.763	-2.350	-3.490	-11.630	-.938	.000	-19.602
-25.0	-15.427	-2.776	-3.589	-13.332	-1.313	.000	-21.792
-24.0	-16.969	-3.289	-3.614	-14.926	-1.777	.000	-23.872
-23.0	-18.616	-3.869	-3.643	-16.628	-2.326	.000	-26.128
-22.0	-20.549	-4.455	-3.686	-18.619	-2.924	-.015	-28.691
-21.0	-22.788	-5.092	-3.802	-20.917	-3.576	-.112	-31.682
-20.0	-25.160	-5.814	-4.048	-23.357	-4.315	-.347	-35.022
-19.0	-27.834	-6.583	-4.388	-26.100	-5.108	-.695	-38.805
-18.0	-30.808	-7.351	-4.744	-29.147	-5.917	-1.090	-42.903
-17.0	-33.993	-8.113	-5.080	-32.409	-6.730	-1.494	-47.186
-16.0	-37.457	-8.962	-5.394	-35.954	-7.630	-1.898	-51.813
-15.0	-41.195	-9.885	-5.705	-39.775	-8.604	-2.315	-56.786
-14.0	-45.164	-10.860	-6.035	-43.828	-9.635	-2.760	-62.058
-13.0	-49.369	-11.877	-6.383	-48.122	-10.711	-3.238	-67.629
-12.0	-53.707	-12.931	-6.757	-52.549	-11.828	-3.751	-73.395
-11.0	-58.219	-14.025	-7.170	-57.152	-12.988	-4.313	-79.414
-10.0	-62.877	-15.162	-7.627	-61.901	-14.195	-4.930	-85.667
-9.0	-67.600	-16.344	-8.127	-66.715	-15.450	-5.601	-92.071
-8.0	-72.350	-17.572	-8.668	-71.556	-16.754	-6.325	-98.590
-7.0	-77.088	-18.844	-9.247	-76.385	-18.106	-7.100	-105.179
-6.0	-82.064	-20.160	-9.860	-81.450	-19.504	-7.923	-112.084
-5.0	-87.498	-21.517	-10.504	-86.973	-20.946	-8.791	-119.519
-4.0	-91.618	-22.928	-11.173	-91.180	-22.446	-9.700	-125.720
-3.0	-95.416	-24.391	-11.852	-95.058	-23.999	-10.639	-131.658
-2.0	-99.789	-25.869	-12.485	-99.517	-25.570	-11.583	-138.142
-1.0	-105.114	-27.283	-13.013	-104.931	-27.088	-12.489	-145.410
.0	-111.399	-28.498	-13.273	-111.337	-28.465	-13.278	-153.170
1.0	119.325	30.229	14.254	119.323	30.155	13.690	163.809
2.0	122.172	30.878	14.689	122.159	30.747	13.815	167.739
3.0	127.074	31.683	14.538	126.990	31.452	13.405	173.295
4.0	126.151	32.182	13.827	126.016	31.853	12.454	172.160
5.0	124.007	32.303	12.704	123.773	31.856	11.101	169.013
6.0	120.108	32.104	11.350	119.780	31.536	9.531	163.562
7.0	113.235	31.695	9.931	112.809	31.009	7.911	154.861
8.0	108.152	31.149	8.569	107.616	30.349	6.367	147.870

9.0	99.599	30.504	7.340	98.963	29.595	4.977	137.442
10.0	93.472	29.765	6.285	92.723	28.749	3.782	129.522
11.0	84.844	28.948	5.419	83.999	27.831	2.795	119.212
12.0	77.240	28.073	4.737	76.291	26.856	2.006	110.051
13.0	68.505	27.166	4.223	67.468	25.851	1.399	99.894
14.0	59.910	26.199	3.855	58.787	24.790	.945	89.964
15.0	52.812	25.169	3.609	51.603	23.670	.618	81.590
16.0	45.591	24.121	3.461	44.306	22.534	.391	73.173
17.0	39.323	23.054	3.390	37.960	21.381	.238	65.768
18.0	34.172	21.961	3.376	32.736	20.210	.140	59.509
19.0	29.221	20.685	3.400	27.721	18.880	.079	53.306
20.0	25.114	19.319	3.450	23.550	17.438	.042	47.883
21.0	21.765	18.164	3.516	20.146	16.220	.022	43.445
22.0	18.365	17.047	3.590	16.698	15.045	.010	39.002
23.0	15.929	15.874	3.670	14.234	13.824	.005	35.473
24.0	13.543	14.728	3.751	11.803	12.638	.002	32.022
25.0	14.659	13.585	3.834	12.884	11.459	.001	32.078
26.0	16.601	12.480	3.917	14.937	10.331	.000	32.998
27.0	17.349	11.404	4.000	15.916	9.235	.000	32.753
28.0	16.274	10.383	4.082	15.063	8.205	.000	30.739
29.0	14.715	9.319	4.164	13.646	7.146	.000	28.197
30.0	13.256	8.368	4.244	12.266	6.195	.000	25.868
31.0	11.672	7.408	4.324	10.762	5.266	.000	23.405
32.0	10.125	6.669	4.404	9.318	4.521	.000	21.198
33.0	8.801	6.085	4.482	8.114	3.933	.000	19.368
34.0	7.456	5.549	4.560	6.960	3.402	.000	17.565
35.0	6.051	5.012	4.636	6.051	2.883	.000	15.699
36.0	6.300	4.338	4.712	6.300	2.272	.000	15.349
37.0	6.342	3.728	4.786	6.342	1.723	.000	14.856
38.0	6.636	3.290	4.860	5.052	1.332	.000	14.786
39.0	7.453	3.015	4.933	5.706	1.081	.000	15.401
40.0	7.223	2.786	5.004	5.284	.882	.000	15.013
41.0	6.803	2.593	5.075	4.704	.717	.000	14.470
42.0	6.429	2.432	5.144	4.215	.582	.000	14.004
43.0	6.051	2.290	5.212	3.756	.467	.000	13.554
44.0	5.523	2.167	5.279	3.195	.370	.000	12.969
45.0	5.000	2.061	5.344	2.636	.290	.000	12.406
46.0	4.334	1.971	5.409	1.979	.224	.000	11.714
47.0	3.859	1.896	5.472	1.522	.170	.000	11.227
48.0	3.492	1.835	5.534	1.176	.128	.000	10.860
49.0	3.237	1.786	5.594	.935	.094	.000	10.618
50.0	3.038	1.748	5.653	.752	.069	.000	10.440
51.0	2.863	1.720	5.711	.596	.049	.000	10.293
52.0	2.744	1.699	5.768	.491	.035	.000	10.210
53.0	2.641	1.684	5.822	.403	.024	.000	10.147
54.0	2.545	1.673	5.876	.323	.016	.000	10.094
55.0	2.510	1.666	5.928	.290	.011	.000	10.104
56.0	2.364	1.662	5.979	.189	.007	.000	10.004
57.0	2.344	1.659	6.028	.170	.004	.000	10.031
58.0	2.258	1.658	6.075	.114	.003	.000	9.991
59.0	2.219	1.658	6.122	.087	.002	.000	9.998
60.0	2.187	1.658	6.166	.066	.001	.000	10.011
61.0	2.161	1.658	6.209	.048	.000	.000	10.028
62.0	2.138	1.659	6.250	.035	.000	.000	10.048
63.0	2.123	1.660	6.290	.025	.000	.000	10.073
64.0	2.107	1.661	6.328	.018	.000	.000	10.096
65.0	2.097	1.662	6.365	.012	.000	.000	10.123
66.0	2.088	1.663	6.400	.008	.000	.000	10.151
67.0	2.080	1.663	6.433	.006	.000	.000	10.176
68.0	2.074	1.664	6.465	.004	.000	.000	10.202
69.0	2.067	1.664	6.495	.002	.000	.000	10.226
70.0	2.061	1.664	6.523	.001	.000	.000	10.248

71.0	2.057	1.664	6.549	.001	.000	.000	10.270
72.0	2.051	1.663	6.574	.001	.000	.000	10.289
73.0	2.045	1.663	6.597	.000	.000	.000	10.305
74.0	2.041	1.661	6.619	.000	.000	.000	10.321
75.0	2.035	1.656	6.639	.000	.000	.000	10.330
76.0	2.029	1.651	6.657	.000	.000	.000	10.336
77.0	2.023	1.646	6.673	.000	.000	.000	10.341
78.0	2.016	1.640	6.687	.000	.000	.000	10.344
79.0	2.007	1.634	6.700	.000	.000	.000	10.342
80.0	2.001	1.629	6.711	.000	.000	.000	10.341
81.0	1.993	1.623	6.721	.000	.000	.000	10.336
82.0	1.985	1.616	6.728	.000	.000	.000	10.329
83.0	1.977	1.610	6.734	.000	.000	.000	10.321
84.0	1.969	1.603	6.739	.000	.000	.000	10.311
85.0	1.960	1.597	6.741	.000	.000	.000	10.298
86.0	1.951	1.590	6.742	.000	.000	.000	10.282
87.0	1.941	1.583	6.741	.000	.000	.000	10.265
88.0	1.931	1.575	6.738	.000	.000	.000	10.245
89.0	1.920	1.568	6.734	.000	.000	.000	10.222
90.0	1.911	1.560	6.728	.000	.000	.000	10.199
91.0	1.900	1.552	6.720	.000	.000	.000	10.173
92.0	1.889	1.544	6.711	.000	.000	.000	10.144
93.0	1.877	1.536	6.700	.000	.000	.000	10.113
94.0	1.864	1.527	6.687	.000	.000	.000	10.079
95.0	1.852	1.518	6.673	.000	.000	.000	10.043
96.0	1.840	1.509	6.657	.000	.000	.000	10.006
97.0	1.827	1.500	6.640	.000	.000	.000	9.967
98.0	1.813	1.491	6.621	.000	.000	.000	9.925
99.0	1.800	1.482	6.600	.000	.000	.000	9.882
100.0	1.786	1.472	6.578	.000	.000	.000	9.836
101.0	1.773	1.462	6.555	.000	.000	.000	9.790
102.0	1.759	1.452	6.529	.000	.000	.000	9.741
103.0	1.744	1.442	6.503	.000	.000	.000	9.688
104.0	1.731	1.431	6.475	.000	.000	.000	9.637
105.0	1.714	1.421	6.445	.000	.000	.000	9.580
106.0	1.698	1.410	6.414	.000	.000	.000	9.522
107.0	1.683	1.399	6.382	.000	.000	.000	9.464
108.0	1.667	1.388	6.348	.000	.000	.000	9.403
109.0	1.653	1.377	6.313	.000	.000	.000	9.342
110.0	1.636	1.365	6.276	.000	.000	.000	9.277
111.0	1.619	1.354	6.238	.000	.000	.000	9.211
112.0	1.603	1.342	6.199	.000	.000	.000	9.143
113.0	1.584	1.330	6.158	.000	.000	.000	9.072
114.0	1.566	1.318	6.116	.000	.000	.000	9.001
115.0	1.549	1.306	6.073	.000	.000	.000	8.928
116.0	1.531	1.294	6.029	.000	.000	.000	8.854
117.0	1.514	1.282	5.983	.000	.000	.000	8.779
118.0	1.495	1.269	5.936	.000	.000	.000	8.700
119.0	1.478	1.257	5.888	.000	.000	.000	8.622
120.0	1.459	1.244	5.839	.000	.000	.000	8.541
121.0	1.440	1.231	5.788	.000	.000	.000	8.459
122.0	1.421	1.218	5.737	.000	.000	.000	8.376
123.0	1.403	1.205	5.684	.000	.000	.000	8.291
124.0	1.383	1.192	5.630	.000	.000	.000	8.204
125.0	1.362	1.179	5.575	.000	.000	.000	8.116
126.0	1.344	1.165	5.519	.000	.000	.000	8.028
127.0	1.320	1.152	5.462	.000	.000	.000	7.933
128.0	1.306	1.138	5.403	.000	.000	.000	7.848
129.0	1.284	1.125	5.344	.000	.000	.000	7.753
130.0	1.264	1.111	5.284	.000	.000	.000	7.659
131.0	1.244	1.098	5.222	.000	.000	.000	7.565
132.0	1.224	1.085	5.160	.000	.000	.000	7.469

133.0	1.201	1.072	5.096	.000	.000	.000	7.370
134.0	1.182	1.059	5.032	.000	.000	.000	7.273
135.0	1.161	1.046	4.966	.000	.000	.000	7.173
136.0	1.140	1.033	4.900	.000	.000	.000	7.072
137.0	1.119	1.019	4.832	.000	.000	.000	6.970
138.0	1.097	1.005	4.763	.000	.000	.000	6.866
139.0	1.075	.991	4.694	.000	.000	.000	6.760
140.0	1.055	.977	4.623	.000	.000	.000	6.655
141.0	1.033	.961	4.551	.000	.000	.000	6.545
142.0	1.011	.944	4.479	.000	.000	.000	6.434
143.0	.989	.928	4.405	.000	.000	.000	6.321
144.0	.967	.911	4.330	.000	.000	.000	6.208
145.0	.944	.894	4.254	.000	.000	.000	6.092
146.0	.922	.876	4.177	.000	.000	.000	5.976
147.0	.900	.858	4.099	.000	.000	.000	5.857
148.0	.877	.839	4.020	.000	.000	.000	5.736
149.0	.855	.820	3.939	.000	.000	.000	5.614
150.0	.831	.800	3.858	.000	.000	.000	5.489
151.0	.808	.780	3.775	.000	.000	.000	5.363
152.0	.785	.760	3.691	.000	.000	.000	5.236
153.0	.763	.740	3.605	.000	.000	.000	5.108
154.0	.739	.720	3.519	.000	.001	.000	4.977
155.0	.716	.701	3.430	.000	.002	.000	4.847
156.0	.692	.683	3.341	.000	.004	.000	4.715
157.0	.668	.666	3.250	.000	.008	.000	4.583
158.0	.644	.654	3.157	.000	.015	.000	4.455
159.0	.620	.648	3.063	.000	.029	.000	4.331
160.0	.596	.655	2.966	.000	.053	.000	4.218
161.0	.571	.682	2.868	.000	.092	.000	4.121
162.0	.546	.734	2.768	.000	.155	.000	4.048
163.0	.521	.817	2.666	.001	.246	.000	4.004
164.0	.497	.936	2.562	.002	.375	.000	3.995
165.0	.488	1.096	2.455	.002	.544	.000	4.040
166.0	.469	1.294	2.346	.006	.784	.000	4.108
167.0	.501	1.502	2.233	.002	1.049	.001	4.236
168.0	.508	1.726	2.118	.080	1.316	.001	4.352
169.0	.515	1.976	2.000	.116	1.627	.002	4.491
170.0	.539	2.215	1.878	.168	1.896	.003	4.632
171.0	.586	2.540	1.752	.246	2.267	.006	4.878
172.0	.620	2.821	1.623	.301	2.579	.009	5.064
173.0	.808	3.175	1.489	.527	2.964	.014	5.472
174.0	.976	3.551	1.351	.730	3.371	.021	5.878
175.0	1.179	4.034	1.197	.971	3.886	.031	6.410
176.0	1.468	4.517	1.026	1.300	4.399	.044	7.011
177.0	1.903	5.189	.841	1.786	5.100	.060	7.933
178.0	2.355	5.964	.641	2.294	5.907	.080	8.959
179.0	2.907	6.764	.421	2.915	6.748	.101	10.092
180.0	3.393	7.673	.122	3.503	7.714	.122	11.188
181.0	-4.319	-9.205	-.473	-4.128	-9.124	-.146	-13.996
182.0	-4.663	-9.224	-.771	-4.450	-9.133	-.180	-14.658
183.0	-4.026	-8.769	-1.074	-3.818	-8.635	-.222	-13.870
184.0	-3.229	-8.271	-1.325	-2.968	-8.096	-.272	-12.826
185.0	-3.276	-7.703	-1.573	-2.972	-7.484	-.331	-12.552
186.0	-3.199	-7.301	-1.826	-2.852	-7.032	-.400	-12.326
187.0	-2.881	-6.791	-2.086	-2.493	-6.477	-.478	-11.758
188.0	-2.533	-6.303	-2.349	-2.106	-5.946	-.562	-11.185
189.0	-2.209	-5.769	-2.598	-1.745	-5.374	-.640	-10.576
190.0	-1.958	-5.234	-2.816	-1.461	-4.806	-.696	-10.007
191.0	-1.717	-4.722	-2.984	-1.190	-4.262	-.716	-9.423
192.0	-1.456	-4.266	-3.093	-.908	-3.778	-.690	-8.814
193.0	-1.137	-3.804	-3.165	-.587	-3.290	-.631	-8.106
194.0	-.996	-3.378	-3.216	-.417	-2.838	-.558	-7.590

195.0	-.874	-3.017	-3.252	-.287	-2.447	-.478	-7.143
196.0	-.769	-2.707	-3.280	-.173	-2.109	-.396	-6.756
197.0	-.703	-2.438	-3.306	-.099	-1.808	-.318	-6.447
198.0	-.715	-2.188	-3.334	-.082	-1.526	-.247	-6.237
199.0	-.674	-1.835	-3.368	-.036	-1.157	-.186	-5.877
200.0	-.857	-1.501	-3.409	-.117	-.824	-.135	-5.767
201.0	-.652	-1.276	-3.459	-.003	-.598	-.095	-5.387
202.0	-.660	-1.039	-3.515	-.001	-.377	-.064	-5.214
203.0	-.670	-.924	-3.578	.000	-.261	-.042	-5.172
204.0	-.682	-.798	-3.645	.000	-.148	-.026	-5.125
205.0	-.702	-.736	-3.716	.000	-.087	-.016	-5.154
206.0	-.711	-.693	-3.802	.000	-.046	-.009	-5.206
207.0	-.724	-.675	-3.923	.000	-.023	-.008	-5.323
208.0	-.742	-.672	-4.059	.000	-.011	-.010	-5.472
209.0	-.759	-.676	-4.211	.000	-.005	-.017	-5.646
210.0	-.774	-.685	-4.382	.000	-.002	-.031	-5.842
211.0	-.791	-.696	-4.574	.000	-.001	-.058	-6.061
212.0	-.808	-.709	-4.779	.000	.000	-.099	-6.297
213.0	-.826	-.739	-4.953	.000	.000	-.136	-6.518
214.0	-.845	-.781	-5.045	.000	.000	-.140	-6.670
215.0	-.863	-.823	-5.051	.000	-.001	-.106	-6.737
216.0	-.880	-.864	-5.008	.000	-.003	-.058	-6.752
217.0	-.897	-.901	-4.962	.000	-.007	-.022	-6.760
218.0	-.914	-.937	-4.930	.000	-.011	-.006	-6.780
219.0	-.932	-.974	-4.934	.000	-.019	-.001	-6.840
220.0	-.949	-.960	-4.956	.000	-.013	.000	-6.866
221.0	-.965	-.940	-4.987	.000	-.005	.000	-6.892
222.0	-.981	-.927	-5.024	.000	-.001	.000	-6.932
223.0	-.999	-.920	-5.066	.000	.000	.000	-6.984
224.0	-1.014	-.919	-5.110	.000	.000	.000	-7.043
225.0	-1.031	-.921	-5.158	.000	.000	.000	-7.109
226.0	-1.046	-.925	-5.215	.000	.000	.000	-7.186
227.0	-1.060	-.932	-5.283	.000	.000	.000	-7.275
228.0	-1.077	-.941	-5.361	.000	.000	.000	-7.379
229.0	-1.093	-.950	-5.438	.000	.000	.000	-7.481
230.0	-1.107	-.960	-5.501	.000	.000	.000	-7.568
231.0	-1.124	-.970	-5.543	.000	.000	.000	-7.637
232.0	-1.136	-.981	-5.575	.000	.000	.000	-7.692
233.0	-1.150	-.992	-5.615	.000	.000	.000	-7.757
234.0	-1.164	-1.004	-5.657	.000	.000	.000	-7.825
235.0	-1.179	-1.015	-5.700	.000	.000	.000	-7.895
236.0	-1.192	-1.027	-5.744	.000	.000	.000	-7.963
237.0	-1.205	-1.039	-5.788	.000	.000	.000	-8.033
238.0	-1.221	-1.051	-5.833	.000	.000	.000	-8.104
239.0	-1.234	-1.062	-5.878	.000	.000	.000	-8.174
240.0	-1.247	-1.074	-5.922	.000	.000	.000	-8.242
241.0	-1.260	-1.085	-5.966	.000	.000	.000	-8.310
242.0	-1.273	-1.096	-6.009	.000	.000	.000	-8.378
243.0	-1.284	-1.107	-6.052	.000	.000	.000	-8.443
244.0	-1.296	-1.117	-6.093	.000	.000	.000	-8.506
245.0	-1.308	-1.128	-6.134	.000	.000	.000	-8.570
246.0	-1.322	-1.138	-6.174	.000	.000	.000	-8.634
247.0	-1.333	-1.149	-6.213	.000	.000	.000	-8.695
248.0	-1.344	-1.159	-6.251	.000	.000	.000	-8.754
249.0	-1.356	-1.169	-6.287	.000	.000	.000	-8.812
250.0	-1.366	-1.178	-6.323	.000	.000	.000	-8.867
251.0	-1.379	-1.188	-6.357	.000	.000	.000	-8.923
252.0	-1.388	-1.197	-6.390	.000	.000	.000	-8.974
253.0	-1.397	-1.205	-6.421	.000	.000	.000	-9.023
254.0	-1.408	-1.214	-6.452	.000	.000	.000	-9.074
255.0	-1.417	-1.222	-6.480	.000	.000	.000	-9.120
256.0	-1.425	-1.231	-6.508	.000	.000	.000	-9.164

257.0	-1.438	-1.238	-6.534	.000	.000	.000	-9.210
258.0	-1.446	-1.246	-6.559	.000	.000	.000	-9.250
259.0	-1.456	-1.253	-6.582	.000	.000	.000	-9.291
260.0	-1.464	-1.260	-6.603	.000	.000	.000	-9.328
261.0	-1.481	-1.267	-6.624	.000	.000	.000	-9.371
262.0	-1.480	-1.274	-6.642	.000	.000	.000	-9.395
263.0	-1.486	-1.279	-6.659	.000	.000	.000	-9.425
264.0	-1.494	-1.285	-6.675	.000	.000	.000	-9.454
265.0	-1.502	-1.291	-6.689	.000	.000	.000	-9.482
266.0	-1.509	-1.296	-6.701	.000	.000	.000	-9.506
267.0	-1.516	-1.301	-6.712	.000	.000	.000	-9.529
268.0	-1.523	-1.305	-6.721	.000	.000	.000	-9.550
269.0	-1.531	-1.310	-6.729	.000	.000	.000	-9.570
270.0	-1.536	-1.314	-6.734	.000	.000	.000	-9.585
271.0	-1.541	-1.318	-6.739	.000	.000	.000	-9.597
272.0	-1.547	-1.322	-6.741	.000	.000	.000	-9.610
273.0	-1.551	-1.326	-6.742	.000	.000	.000	-9.620
274.0	-1.556	-1.330	-6.741	.000	.000	.000	-9.627
275.0	-1.562	-1.333	-6.739	.000	.000	.000	-9.634
276.0	-1.565	-1.336	-6.735	.000	.000	.000	-9.635
277.0	-1.569	-1.339	-6.729	.000	.000	.000	-9.636
278.0	-1.578	-1.341	-6.721	.000	.000	.000	-9.640
279.0	-1.576	-1.343	-6.712	.000	.000	.000	-9.631
280.0	-1.580	-1.345	-6.701	.000	.000	.000	-9.625
281.0	-1.582	-1.346	-6.688	.000	.000	.000	-9.616
282.0	-1.588	-1.348	-6.673	.000	.000	.000	-9.609
283.0	-1.588	-1.349	-6.657	.000	.000	.000	-9.594
284.0	-1.591	-1.350	-6.639	.000	.000	.000	-9.580
285.0	-1.593	-1.349	-6.619	.000	.000	.000	-9.562
286.0	-1.596	-1.349	-6.598	.000	.000	.000	-9.543
287.0	-1.597	-1.349	-6.575	.000	.000	.000	-9.521
288.0	-1.599	-1.349	-6.554	.000	.000	.000	-9.502
289.0	-1.600	-1.348	-6.535	.000	.000	.000	-9.484
290.0	-1.603	-1.348	-6.517	.000	.000	.000	-9.468
291.0	-1.603	-1.347	-6.500	.000	.000	.000	-9.451
292.0	-1.607	-1.347	-6.483	.000	.000	.000	-9.436
293.0	-1.608	-1.346	-6.464	-.001	.000	.000	-9.418
294.0	-1.610	-1.344	-6.444	-.001	.000	.000	-9.398
295.0	-1.612	-1.343	-6.422	-.002	.000	.000	-9.377
296.0	-1.613	-1.341	-6.399	-.003	.000	.000	-9.353
297.0	-1.620	-1.339	-6.374	-.006	.000	.000	-9.332
298.0	-1.624	-1.338	-6.347	-.009	.000	.000	-9.308
299.0	-1.632	-1.336	-6.318	-.014	.000	.000	-9.286
300.0	-1.643	-1.334	-6.287	-.020	-.001	.000	-9.264
301.0	-1.656	-1.333	-6.254	-.030	-.001	.000	-9.244
302.0	-1.671	-1.331	-6.220	-.040	-.001	.000	-9.222
303.0	-1.700	-1.329	-6.185	-.059	-.002	.000	-9.215
304.0	-1.743	-1.329	-6.148	-.088	-.004	.000	-9.221
305.0	-1.786	-1.330	-6.111	-.116	-.006	.000	-9.226
306.0	-1.870	-1.332	-6.071	-.174	-.008	.000	-9.273
307.0	-1.912	-1.335	-6.031	-.210	-.012	.000	-9.277
308.0	-1.969	-1.340	-5.988	-.259	-.018	.000	-9.298
309.0	-2.031	-1.346	-5.943	-.314	-.024	.000	-9.321
310.0	-2.105	-1.357	-5.897	-.378	-.033	.000	-9.358
311.0	-2.201	-1.377	-5.849	-.463	-.047	.000	-9.427
312.0	-2.328	-1.398	-5.800	-.574	-.064	.000	-9.525
313.0	-2.511	-1.430	-5.749	-.735	-.087	.000	-9.689
314.0	-2.782	-1.467	-5.696	-.978	-.116	.000	-9.945
315.0	-3.165	-1.499	-5.641	-1.328	-.144	.000	-10.304
316.0	-3.637	-1.535	-5.584	-1.782	-.177	.000	-10.756
317.0	-4.105	-1.572	-5.527	-2.258	-.212	.000	-11.204
318.0	-4.536	-1.608	-5.469	-2.717	-.250	.000	-11.614

319.0	-4.991	-1.657	-5.411	-3.214	-.296	.000	-12.059
320.0	-5.468	-1.719	-5.350	-3.765	-.355	.000	-12.537
321.0	-5.955	-1.774	-5.286	-4.351	-.423	.000	-13.015
322.0	-6.060	-1.924	-5.218	-4.516	-.559	.000	-13.201
323.0	-6.357	-2.050	-5.146	-4.914	-.675	-.001	-13.553
324.0	-6.773	-2.248	-5.070	-5.517	-.854	-.002	-14.092
325.0	-6.955	-2.479	-4.992	-5.955	-1.075	-.002	-14.425
326.0	-6.912	-2.764	-4.910	-6.200	-1.349	-.004	-14.586
327.0	-6.304	-3.005	-4.826	-6.304	-1.587	-.005	-14.135
328.0	-6.300	-3.295	-4.750	-6.300	-1.879	-.008	-14.345
329.0	-6.283	-3.553	-4.677	-6.283	-2.150	-.012	-14.512
330.0	-6.291	-3.870	-4.606	-6.291	-2.479	-.019	-14.767
331.0	-6.281	-4.169	-4.538	-6.281	-2.797	-.029	-14.988
332.0	-6.279	-4.352	-4.479	-6.279	-3.014	-.045	-15.110
333.0	-6.283	-4.500	-4.428	-6.283	-3.186	-.070	-15.212
334.0	-6.280	-4.809	-4.385	-6.280	-3.522	-.104	-15.474
335.0	-6.296	-5.037	-4.350	-6.296	-3.780	-.149	-15.683
336.0	-6.265	-5.314	-4.321	-6.265	-4.095	-.203	-15.900
337.0	-6.294	-5.493	-4.302	-6.294	-4.315	-.269	-16.088
338.0	-6.276	-5.747	-4.289	-6.276	-4.608	-.346	-16.312
339.0	-6.266	-6.388	-4.281	-6.266	-5.308	-.432	-16.936
340.0	-6.308	-7.004	-4.278	-6.308	-5.994	-.527	-17.590
341.0	-6.291	-7.425	-4.273	-6.291	-6.494	-.628	-17.989
342.0	-6.285	-7.861	-4.263	-6.285	-7.024	-.730	-18.410
343.0	-6.292	-8.171	-4.252	-6.292	-7.433	-.836	-18.715
344.0	-6.289	-8.391	-4.243	-6.289	-7.760	-.950	-18.923
345.0	-6.304	-8.438	-4.237	-6.304	-7.881	-1.071	-18.979
346.0	-6.283	-8.478	-4.237	-6.283	-8.028	-1.203	-18.999
347.0	-6.304	-8.452	-4.241	-6.304	-8.023	-1.344	-18.997
348.0	-6.294	-8.417	-4.251	-6.294	-7.998	-1.496	-18.961
349.0	-6.297	-8.321	-4.268	-6.297	-7.894	-1.662	-18.886
350.0	-6.301	-8.218	-4.299	-6.301	-7.801	-1.847	-18.818
351.0	-6.285	-8.055	-4.350	-6.285	-7.645	-2.057	-18.690
352.0	-6.310	-7.906	-4.429	-6.310	-7.518	-2.302	-18.645
353.0	-6.300	-7.795	-4.540	-6.300	-7.438	-2.586	-18.635
354.0	-6.312	-7.795	-4.685	-6.312	-7.476	-2.916	-18.792
355.0	-6.300	-7.628	-4.868	-6.300	-7.334	-3.294	-18.796
356.0	-6.309	-7.684	-5.088	-6.309	-7.444	-3.725	-19.081
357.0	-6.299	-7.747	-5.334	-6.299	-7.557	-4.209	-19.380
358.0	-6.292	-7.889	-5.570	-6.292	-7.755	-4.735	-19.750
359.0	-6.296	-7.846	-5.763	-6.296	-7.764	-5.281	-19.905
360.0	-6.252	-8.087	-5.788	-6.252	-8.088	-5.801	-20.127

face1.dat:

```
0.95e-3 0.95e-3
0 0 20
0 0 20
0 0
```

face2.dat:

```
0.4e-3 0.6e-3
0 -0.005 12.5
0 0.03 5
0.48e-3 0
```

Appendix F: Input Files of *FRICTION-OFT*

1600 rpm-Full load condition

ring.dat:

```
&inp
 rpm = 1600
 conrod = .110
 rcr = .035
 bore = .075
 h0 = 3.e-6
 fcxu = 0.3
 fcxl = 0.2
 fsxu = 0.3
 fsxl = 0.1
 hlnr = 0.25e-6
 /
 &ocr
 ftano = 44.
 dos = 0.0024
 faceo='coeo.dat'
 /
 &scr
 ftans = 13.
 dsc = 0.0039
 faces='coes.dat'
 /
 &com
 ftanc = 10.
 dcc = 0
 facec='coec.dat'
 /
 &rough
 sigma_liner = 0.15e-6
 znu_liner = 0.3
 e_liner = 1.211e+11
 sigma_1st = 0.15e-6
 znu_1st = 0.3
 e_1st = 1.685e+11
 sfc_1st = 0.1
 sigma_2nd = 0.15e-6
 znu_2nd = 0.3
 e_2nd = 1.211e+11
 sfc_2nd = 0.1
 sigma_oc = 0.15e-6
 znu_oc = 0.3
 e_oc = 1.685e+11
 sfc_oc = 0.1
 zp = 6.804
 omega = 4
 acc = 0.000044068
 prk = 0.0001198
 cfct = 10.
 /
 &oilv
 zk = 0.0352
```

```
temp1 = 1658.88
temp2 = 163.54
rho = 850
hlratio = 0.493
bta1 = 2.43
bta2 = 0.0218
zm0 = 1
/
&tliner
ttdc=155
tbdc=125
/
&weight
wth = 1.
wtx = 1.
/
&numofcycle
ncycle = 2
/
```

press.out:

-360.0	1.01325	1.18780	1.18783	1.19852	1.19853
-359.0	1.01325	1.18829	1.18832	1.19851	1.19865
-358.0	1.01325	1.18875	1.18877	1.19865	1.19857
-357.0	1.01325	1.18917	1.18919	1.19868	1.19874
-356.0	1.01325	1.18955	1.18957	1.19875	1.19873
-355.0	1.01325	1.18990	1.18991	1.19879	1.19881
-354.0	1.01325	1.19022	1.19023	1.19883	1.19883
-353.0	1.01325	1.19050	1.19052	1.19887	1.19888
-352.0	1.01325	1.19077	1.19078	1.19890	1.19891
-351.0	1.01325	1.19100	1.19102	1.19894	1.19894
-350.0	1.01325	1.19122	1.19123	1.19896	1.19897
-349.0	1.01325	1.19142	1.19143	1.19899	1.19899
-348.0	1.01325	1.19159	1.19160	1.19901	1.19902
-347.0	1.01325	1.19175	1.19176	1.19903	1.19904
-346.0	1.01325	1.19190	1.19191	1.19905	1.19905
-345.0	1.01325	1.19203	1.19203	1.19907	1.19907
-344.0	1.01325	1.19215	1.19215	1.19908	1.19909
-343.0	1.01325	1.19225	1.19226	1.19910	1.19910
-342.0	1.01325	1.19235	1.19235	1.19911	1.19911
-341.0	1.01325	1.19243	1.19243	1.19914	1.19911
-340.0	1.01325	1.19251	1.19251	1.19914	1.19914
-339.0	1.01325	1.19258	1.19258	1.19914	1.19914
-338.0	1.01325	1.19264	1.19264	1.19915	1.19915
-337.0	1.01325	1.19269	1.19270	1.19915	1.19915
-336.0	1.01325	1.19274	1.19275	1.19916	1.19916
-335.0	1.01325	1.19279	1.19279	1.19916	1.19917
-334.0	1.01325	1.19283	1.19283	1.19917	1.19917
-333.0	1.01325	1.19286	1.19287	1.19917	1.19918
-332.0	1.01325	1.19290	1.19290	1.19918	1.19918
-331.0	1.01325	1.19293	1.19293	1.19918	1.19918
-330.0	1.01325	1.19295	1.19295	1.19918	1.19919
-329.0	1.01325	1.19297	1.19298	1.19919	1.19919
-328.0	1.01325	1.19300	1.19300	1.19919	1.19919
-327.0	1.01325	1.19302	1.19302	1.19919	1.19920
-326.0	1.01325	1.19303	1.19304	1.19919	1.19920

-325.0	1.01325	1.19305	1.19305	1.19920	1.19920
-324.0	1.01325	1.19306	1.19306	1.19920	1.19920
-323.0	1.01325	1.19307	1.19307	1.19920	1.19920
-322.0	1.01325	1.19308	1.19309	1.19920	1.19920
-321.0	1.01325	1.19309	1.19310	1.19920	1.19921
-320.0	1.01325	1.19310	1.19310	1.19920	1.19921
-319.0	1.01325	1.19311	1.19311	1.19920	1.19921
-318.0	1.01325	1.19312	1.19312	1.19920	1.19921
-317.0	1.01325	1.19312	1.19312	1.19920	1.19921
-316.0	1.01325	1.19313	1.19313	1.19921	1.19921
-315.0	1.01325	1.19313	1.19314	1.19921	1.19921
-314.0	1.01325	1.19314	1.19314	1.19921	1.19921
-313.0	1.01325	1.19314	1.19314	1.19921	1.19921
-312.0	1.01325	1.19315	1.19315	1.19921	1.19921
-311.0	1.01325	1.19315	1.19315	1.19921	1.19921
-310.0	1.01325	1.19315	1.19315	1.19921	1.19921
-309.0	1.01325	1.19316	1.19316	1.19921	1.19921
-308.0	1.01325	1.19316	1.19316	1.19921	1.19921
-307.0	1.01325	1.19316	1.19316	1.19921	1.19921
-306.0	1.01325	1.19316	1.19316	1.19921	1.19921
-305.0	1.01325	1.19316	1.19316	1.19921	1.19921
-304.0	1.01325	1.19317	1.19317	1.19921	1.19921
-303.0	1.01325	1.19317	1.19317	1.19921	1.19922
-302.0	1.01325	1.19317	1.19317	1.19921	1.19922
-301.0	1.01325	1.19317	1.19317	1.19921	1.19922
-300.0	1.01325	1.19317	1.19317	1.19921	1.19922
-299.0	1.01325	1.19317	1.19317	1.19921	1.19922
-298.0	1.01325	1.19317	1.19317	1.19921	1.19922
-297.0	1.01325	1.19317	1.19317	1.19921	1.19922
-296.0	1.01325	1.19317	1.19317	1.19921	1.19922
-295.0	1.01325	1.19317	1.19318	1.19921	1.19922
-294.0	1.01325	1.19317	1.19318	1.19921	1.19922
-293.0	1.01325	1.19318	1.19318	1.19921	1.19922
-292.0	1.01325	1.19318	1.19318	1.19921	1.19922
-291.0	1.01325	1.19318	1.19318	1.19921	1.19922
-290.0	1.01325	1.19318	1.19318	1.19921	1.19922
-289.0	1.01325	1.19318	1.19318	1.19921	1.19922
-288.0	1.01325	1.19318	1.19318	1.19921	1.19922
-287.0	1.01325	1.19318	1.19318	1.19921	1.19922
-286.0	1.01325	1.19318	1.19318	1.19921	1.19922
-285.0	1.01325	1.19318	1.19318	1.19921	1.19922
-284.0	1.01325	1.19318	1.19318	1.19921	1.19922
-283.0	1.01325	1.19318	1.19318	1.19921	1.19922
-282.0	1.01325	1.19318	1.19318	1.19921	1.19922
-281.0	1.01325	1.19318	1.19318	1.19921	1.19922
-280.0	1.01325	1.19318	1.19318	1.19921	1.19922
-279.0	1.01325	1.19318	1.19318	1.19921	1.19922
-278.0	1.01325	1.19318	1.19318	1.19921	1.19922
-277.0	1.01325	1.19318	1.19319	1.19920	1.19922
-276.0	1.01325	1.19319	1.19319	1.19919	1.19923
-275.0	1.01325	1.19319	1.19319	1.19917	1.19925
-274.0	1.01325	1.19319	1.19319	1.19910	1.19928
-273.0	1.01325	1.19316	1.19316	1.19902	1.19935
-272.0	1.01325	1.19304	1.19303	1.19896	1.19949
-271.0	1.01325	1.19271	1.19269	1.19892	1.19969
-270.0	1.01325	1.19209	1.19206	1.19882	1.19992
-269.0	1.01325	1.19118	1.19114	1.19843	1.20000
-268.0	1.01325	1.19008	1.19006	1.19748	1.20003
-267.0	1.01325	1.18911	1.18913	1.19565	1.20010
-266.0	1.01325	1.18803	1.18807	1.19242	1.20039
-265.0	1.01325	1.18559	1.18561	1.18747	1.20143
-264.0	1.01325	1.18028	1.18025	1.18039	1.20390

-263.0	1.01325	1.17148	1.17146	1.17082	1.20727
-262.0	1.01325	1.16351	1.16423	1.16451	1.19859
-261.0	1.01325	1.16170	1.16302	1.16446	1.18087
-260.0	1.01325	1.15728	1.15893	1.16092	1.17892
-259.0	1.01325	1.14919	1.15134	1.15413	1.18105
-258.0	1.01325	1.13823	1.14108	1.14499	1.18002
-257.0	1.01325	1.12472	1.12856	1.13412	1.17444
-256.0	1.01325	1.10854	1.11383	1.12192	1.16424
-255.0	1.01325	1.08945	1.09695	1.10881	1.14961
-254.0	1.01325	1.06786	1.07875	1.09558	1.13191
-253.0	1.01325	1.04613	1.06225	1.08388	1.11430
-252.0	1.01325	1.02876	1.05361	1.07655	1.10122
-251.0	1.01325	1.01838	1.06045	1.07689	1.09723
-250.0	1.01325	1.01332	1.08841	1.08846	1.10657
-249.0	1.01325	1.01237	1.12240	1.11211	1.13129
-248.0	1.01325	1.01376	1.11522	1.12366	1.15447
-247.0	1.01325	1.01461	1.10745	1.11728	1.16927
-246.0	1.01325	1.01741	1.08748	1.09848	1.17884
-245.0	1.01325	1.02087	1.06057	1.07151	1.17295
-244.0	1.01325	1.02217	1.04366	1.05369	1.14596
-243.0	1.01325	1.02228	1.03846	1.04988	1.10885
-242.0	1.01325	1.02146	1.03808	1.05222	1.08467
-241.0	1.01325	1.01924	1.04082	1.05662	1.07902
-240.0	1.01325	1.01627	1.05083	1.06405	1.08402
-239.0	1.01325	1.01345	1.07471	1.07711	1.09810
-238.0	1.01325	1.01221	1.10732	1.09908	1.12463
-237.0	1.01325	1.01362	1.10689	1.11252	1.15618
-236.0	1.01325	1.01407	1.10055	1.10556	1.18192
-235.0	1.01325	1.01524	1.08755	1.09176	1.19482
-234.0	1.01325	1.01695	1.07120	1.07600	1.18525
-233.0	1.01325	1.01811	1.05947	1.06537	1.15792
-232.0	1.01325	1.01825	1.05513	1.06303	1.12349
-231.0	1.01325	1.01729	1.05661	1.06621	1.10065
-230.0	1.01325	1.01551	1.06438	1.07268	1.09732
-229.0	1.01325	1.01370	1.08129	1.08405	1.10762
-228.0	1.01325	1.01267	1.10412	1.10105	1.12889
-227.0	1.01325	1.01314	1.11673	1.11705	1.15832
-226.0	1.01325	1.01367	1.11259	1.11569	1.18632
-225.0	1.01325	1.01413	1.10370	1.10589	1.19975
-224.0	1.01325	1.01521	1.09065	1.09336	1.19560
-223.0	1.01325	1.01660	1.07789	1.08175	1.17848
-222.0	1.01325	1.01749	1.06852	1.07385	1.15240
-221.0	1.01325	1.01736	1.06478	1.07183	1.12578
-220.0	1.01325	1.01628	1.06713	1.07477	1.11045
-219.0	1.01325	1.01470	1.07654	1.08181	1.11101
-218.0	1.01325	1.01331	1.09331	1.09378	1.12428
-217.0	1.01325	1.01274	1.11156	1.10921	1.14794
-216.0	1.01325	1.01323	1.11911	1.11957	1.17754
-215.0	1.01325	1.01362	1.11408	1.11541	1.19886
-214.0	1.01325	1.01401	1.10534	1.10661	1.19966
-213.0	1.01325	1.01491	1.09533	1.09739	1.19221
-212.0	1.08176	1.07585	1.09303	1.09355	1.17558
-211.0	1.15493	1.14715	1.11402	1.10937	1.16277
-210.0	1.06172	1.06783	1.13732	1.13246	1.16717
-209.0	1.07216	1.07144	1.15077	1.14953	1.18462
-208.0	1.07699	1.07711	1.14354	1.14509	1.19798
-207.0	1.05869	1.06058	1.13596	1.13689	1.20003
-206.0	1.08638	1.08467	1.12865	1.12886	1.19998
-205.0	1.08398	1.08434	1.12888	1.12815	1.19636
-204.0	1.08484	1.08451	1.13790	1.13623	1.18992
-203.0	1.07736	1.07732	1.15098	1.14866	1.19191
-202.0	1.09137	1.09071	1.15211	1.15218	1.19759

-201.0	1.10052	1.10004	1.15202	1.15174	1.19511
-200.0	1.08289	1.08398	1.15600	1.15537	1.19364
-199.0	1.11351	1.11147	1.16077	1.15969	1.19633
-198.0	1.11798	1.11776	1.16463	1.16431	1.19581
-197.0	1.11574	1.11588	1.16633	1.16591	1.19586
-196.0	1.11386	1.11395	1.16959	1.16910	1.19676
-195.0	1.10938	1.10969	1.17126	1.17100	1.19653
-194.0	1.11230	1.11209	1.17377	1.17331	1.19695
-193.0	1.11692	1.11666	1.17585	1.17555	1.19726
-192.0	1.09350	1.09497	1.17715	1.17698	1.19727
-191.0	1.11949	1.11790	1.17879	1.17841	1.19745
-190.0	1.12950	1.12888	1.18190	1.18148	1.19788
-189.0	1.12602	1.12626	1.18275	1.18262	1.19795
-188.0	1.12147	1.12171	1.18461	1.18429	1.19805
-187.0	1.14407	1.14275	1.18632	1.18606	1.19833
-186.0	1.13993	1.14018	1.18768	1.18749	1.19837
-185.0	1.13472	1.13503	1.18891	1.18873	1.19851
-184.0	1.13508	1.13506	1.19009	1.18992	1.19864
-183.0	1.14988	1.14902	1.19146	1.19125	1.19871
-182.0	1.14718	1.14735	1.19249	1.19239	1.19884
-181.0	1.14874	1.14865	1.19348	1.19334	1.19887
-180.0	1.14898	1.14898	1.19448	1.19440	1.19896
-179.0	1.14826	1.14823	1.19242	1.19210	1.20170
-178.0	1.15792	1.15739	1.19036	1.19023	1.19814
-177.0	1.14370	1.14450	1.19344	1.19335	1.19690
-176.0	1.12968	1.13050	1.19205	1.19198	1.19998
-175.0	1.15737	1.15578	1.19407	1.19389	1.19736
-174.0	1.16199	1.16175	1.19471	1.19464	1.19989
-173.0	1.16619	1.16595	1.19522	1.19510	1.19909
-172.0	1.18829	1.18708	1.19654	1.19643	1.19930
-171.0	1.18178	1.18215	1.19687	1.19682	1.19969
-170.0	1.17780	1.17802	1.19760	1.19755	1.19939
-169.0	1.15664	1.15786	1.19769	1.19772	1.19972
-168.0	1.17117	1.17034	1.19815	1.19807	1.19962
-167.0	1.18073	1.18021	1.19862	1.19861	1.19972
-166.0	1.19856	1.19757	1.19923	1.19912	1.19985
-165.0	1.17932	1.18041	1.19924	1.19931	1.19982
-164.0	1.17512	1.17534	1.19937	1.19935	1.19987
-163.0	1.20413	1.20254	1.19999	1.19986	1.19999
-162.0	1.19403	1.19460	1.19990	1.19996	1.19997
-161.0	1.20543	1.20480	1.20037	1.20026	1.20000
-160.0	1.20252	1.20269	1.20051	1.20055	1.20001
-159.0	1.21679	1.21601	1.20127	1.20112	1.20002
-158.0	1.22403	1.22365	1.20201	1.20192	1.20003
-157.0	1.22696	1.22680	1.20280	1.20269	1.20006
-156.0	1.21160	1.21244	1.20279	1.20284	1.20006
-155.0	1.24326	1.24158	1.20387	1.20364	1.20007
-154.0	1.22783	1.22867	1.20415	1.20417	1.20009
-153.0	1.24856	1.24745	1.20517	1.20495	1.20010
-152.0	1.24935	1.24932	1.20582	1.20576	1.20013
-151.0	1.25912	1.25860	1.20682	1.20663	1.20014
-150.0	1.30703	1.30465	1.20859	1.20827	1.20019
-149.0	1.26823	1.27023	1.20921	1.20921	1.20019
-148.0	1.29421	1.29288	1.21064	1.21034	1.20022
-147.0	1.28269	1.28330	1.21128	1.21123	1.20024
-146.0	1.24003	1.24227	1.21115	1.21122	1.20023
-145.0	1.25310	1.25241	1.21126	1.21120	1.20024
-144.0	1.27535	1.27422	1.21187	1.21175	1.20025
-143.0	1.25023	1.25155	1.21179	1.21186	1.20025
-142.0	1.27843	1.27697	1.21254	1.21236	1.20027
-141.0	1.31258	1.31090	1.21373	1.21353	1.20029
-140.0	1.18124	1.18853	1.21126	1.21196	1.20022

-139.0	1.17524	1.17553	1.20892	1.20915	1.20017
-138.0	1.18043	1.18017	1.20661	1.20703	1.20014
-137.0	1.19374	1.19299	1.20494	1.20514	1.20009
-136.0	1.20306	1.20256	1.20356	1.20378	1.20008
-135.0	1.26624	1.26296	1.20506	1.20472	1.20011
-134.0	1.22263	1.22499	1.20495	1.20512	1.20010
-133.0	1.21196	1.21251	1.20482	1.20480	1.20010
-132.0	1.24305	1.24142	1.20534	1.20522	1.20012
-131.0	1.24714	1.24693	1.20603	1.20593	1.20012
-130.0	1.24999	1.24984	1.20670	1.20659	1.20014
-129.0	1.25155	1.25147	1.20730	1.20721	1.20015
-128.0	1.27886	1.27746	1.20850	1.20827	1.20018
-127.0	1.28127	1.28116	1.20948	1.20935	1.20020
-126.0	1.28769	1.28736	1.21061	1.21042	1.20022
-125.0	1.28968	1.28958	1.21155	1.21141	1.20024
-124.0	1.32003	1.31853	1.21311	1.21283	1.20028
-123.0	1.33425	1.33358	1.21460	1.21438	1.20031
-122.0	1.33833	1.33813	1.21612	1.21588	1.20034
-121.0	1.36274	1.36159	1.21790	1.21760	1.20038
-120.0	1.36550	1.36537	1.21949	1.21926	1.20041
-119.0	1.37722	1.37667	1.22124	1.22095	1.20045
-118.0	1.37984	1.37972	1.22277	1.22255	1.20049
-117.0	1.40463	1.40350	1.22472	1.22440	1.20053
-116.0	1.43364	1.43236	1.22686	1.22652	1.20058
-115.0	1.43769	1.43752	1.22887	1.22858	1.20062
-114.0	1.45152	1.45091	1.23099	1.23066	1.20067
-113.0	1.46989	1.46910	1.23319	1.23285	1.20072
-112.0	1.48462	1.48400	1.23546	1.23511	1.20076
-111.0	1.53094	1.52903	1.23830	1.23783	1.20083
-110.0	1.52011	1.52058	1.24051	1.24022	1.20088
-109.0	1.55496	1.55354	1.24343	1.24294	1.20094
-108.0	1.56283	1.56253	1.24588	1.24554	1.20101
-107.0	1.60367	1.60207	1.24909	1.24857	1.20107
-106.0	1.61347	1.61310	1.25183	1.25145	1.20114
-105.0	1.64105	1.63999	1.25509	1.25458	1.20121
-104.0	1.65688	1.65629	1.25807	1.25764	1.20129
-103.0	1.69793	1.69643	1.26165	1.26110	1.20136
-102.0	1.70826	1.70790	1.26484	1.26439	1.20144
-101.0	1.72813	1.72742	1.26833	1.26780	1.20152
-100.0	1.75943	1.75834	1.27187	1.27134	1.20161
-99.0	1.80579	1.80422	1.27589	1.27529	1.20171
-98.0	1.82354	1.82295	1.27966	1.27913	1.20180
-97.0	1.87815	1.87638	1.28414	1.28346	1.20191
-96.0	1.88332	1.88317	1.28801	1.28749	1.20200
-95.0	1.92368	1.92241	1.29255	1.29187	1.20211
-94.0	1.94748	1.94676	1.29675	1.29617	1.20222
-93.0	1.99468	1.99326	1.30159	1.30089	1.20233
-92.0	2.04505	2.04359	1.30648	1.30579	1.20247
-91.0	2.06339	2.06287	1.31130	1.31065	1.20258
-90.0	2.09989	2.09886	1.31636	1.31563	1.20271
-89.0	2.14753	2.14623	1.32162	1.32089	1.20285
-88.0	2.28174	2.27832	1.32835	1.32736	1.20304
-87.0	2.22102	2.22265	1.33292	1.33242	1.20314
-86.0	2.27906	2.27755	1.33923	1.33829	1.20329
-85.0	2.31339	2.31256	1.34457	1.34387	1.20348
-84.0	2.35930	2.35817	1.35087	1.35001	1.20359
-83.0	2.41569	2.41436	1.35696	1.35613	1.20381
-82.0	2.48247	2.48094	1.36369	1.36279	1.20396
-81.0	2.53103	2.52995	1.37027	1.36940	1.20415
-80.0	2.59263	2.59129	1.37731	1.37638	1.20434
-79.0	2.65425	2.65296	1.38446	1.38352	1.20454
-78.0	2.73601	2.73435	1.39217	1.39116	1.20476

-77.0	2.80901	2.80758	1.40000	1.39899	1.20498
-76.0	2.87029	2.86913	1.40804	1.40702	1.20521
-75.0	2.93058	2.92947	1.41624	1.41520	1.20545
-74.0	3.02091	3.01930	1.42504	1.42392	1.20570
-73.0	3.09406	3.09280	1.43390	1.43281	1.20596
-72.0	3.17921	3.17779	1.44330	1.44213	1.20623
-71.0	3.26858	3.26715	1.45297	1.45179	1.20653
-70.0	3.35024	3.34897	1.46297	1.46176	1.20682
-69.0	3.44308	3.44168	1.47339	1.47213	1.20714
-68.0	3.55890	3.55724	1.48447	1.48314	1.20748
-67.0	3.67424	3.67265	1.49601	1.49465	1.20784
-66.0	3.76367	3.76249	1.50772	1.50637	1.20819
-65.0	3.88650	3.88493	1.52026	1.51881	1.20858
-64.0	3.99824	3.99687	1.53304	1.53160	1.20899
-63.0	4.12615	4.12465	1.54664	1.54511	1.20941
-62.0	4.28084	4.27911	1.56101	1.55940	1.20989
-61.0	4.42025	4.41876	1.57590	1.57429	1.21036
-60.0	4.58127	4.57962	1.59174	1.59003	1.21087
-59.0	4.72940	4.72796	1.60790	1.60621	1.21141
-58.0	4.90750	4.90585	1.62550	1.62364	1.21197
-57.0	5.05876	5.05743	1.64309	1.64130	1.21258
-56.0	5.23949	5.23796	1.66216	1.66022	1.21318
-55.0	5.43602	5.43446	1.68163	1.67974	1.21391
-54.0	5.65755	5.65587	1.70281	1.70071	1.21454
-53.0	5.85756	5.85614	1.72448	1.72248	1.21533
-52.0	6.09484	6.09321	1.74781	1.74558	1.21609
-51.0	6.33040	6.32889	1.77190	1.76972	1.21695
-50.0	6.59025	6.58867	1.79773	1.79542	1.21783
-49.0	6.84818	6.84670	1.82442	1.82208	1.21876
-48.0	7.14274	7.14114	1.85276	1.85034	1.21975
-47.0	7.44331	7.44178	1.88228	1.87982	1.22079
-46.0	7.77330	7.77172	1.91320	1.91069	1.22187
-45.0	8.09621	8.09474	1.94534	1.94280	1.22301
-44.0	8.46406	8.46247	1.97900	1.97640	1.22419
-43.0	8.87028	8.86862	2.01443	2.01177	1.22548
-42.0	9.26809	9.26655	2.05174	2.04902	1.22680
-41.0	9.70613	9.70451	2.09107	2.08828	1.22825
-40.0	10.18998	10.18827	2.13277	2.12991	1.22971
-39.0	10.66829	10.66669	2.17690	2.17398	1.23132
-38.0	11.19171	11.19004	2.22360	2.22061	1.23301
-37.0	11.75058	11.74889	2.27316	2.27009	1.23477
-36.0	12.33661	12.33492	2.32572	2.32259	1.23665
-35.0	12.97399	12.97224	2.38155	2.37835	1.23862
-34.0	13.63502	13.63330	2.44090	2.43763	1.24067
-33.0	14.38563	14.38378	2.50413	2.50079	1.24289
-32.0	15.13514	15.13338	2.57150	2.56808	1.24521
-31.0	15.95190	15.95009	2.64326	2.63977	1.24766
-30.0	16.80686	16.80505	2.71975	2.71619	1.25027
-29.0	17.73454	17.73269	2.80135	2.79770	1.25309
-28.0	18.72720	18.72532	2.88843	2.88469	1.25617
-27.0	19.77670	19.77482	2.98133	2.97750	1.25958
-26.0	20.92572	20.92377	3.08050	3.07656	1.26335
-25.0	22.12028	22.11836	3.18627	3.18223	1.26752
-24.0	23.39433	23.39241	3.29899	3.29485	1.27211
-23.0	24.74772	24.74579	3.41908	3.41484	1.27716
-22.0	26.16693	26.16501	3.54690	3.54256	1.28270
-21.0	27.74329	27.74128	3.68314	3.67869	1.28876
-20.0	29.20210	29.20033	3.82767	3.82315	1.29540
-19.0	30.88375	30.88183	3.98090	3.97629	1.30263
-18.0	32.62202	32.62014	4.14357	4.13887	1.31051
-17.0	34.38670	34.38489	4.31581	4.31105	1.31908
-16.0	36.25989	36.25807	4.49798	4.49316	1.32839

-15.0	38.19993	38.19814	4.69053	4.68564	1.33850
-14.0	40.15479	40.15308	4.89357	4.88864	1.34946
-13.0	42.15513	42.15345	5.10717	5.10221	1.36131
-12.0	44.12899	44.12742	5.33124	5.32626	1.37408
-11.0	46.12108	46.11956	5.56562	5.56065	1.38782
-10.0	48.07897	48.07754	5.81013	5.80516	1.40255
-9.0	49.96083	49.95951	6.06423	6.05930	1.41831
-8.0	51.74013	51.73892	6.32720	6.32232	1.43508
-7.0	53.43217	53.43105	6.59830	6.59348	1.45288
-6.0	54.25563	54.25510	6.87390	6.86924	1.47162
-5.0	54.81000	54.80964	7.15038	7.14591	1.49111
-4.0	55.65000	55.64947	7.42802	7.42369	1.51123
-3.0	56.49000	56.48948	7.70765	7.70344	1.53199
-2.0	57.12000	57.11961	7.98843	7.98437	1.55338
-1.0	57.96000	57.95949	8.27054	8.26659	1.57537
.0	58.59000	58.58962	8.55378	8.54996	1.59799
1.0	59.03264	59.03237	8.83687	8.83318	1.62119
2.0	60.87856	60.87750	9.12449	9.12080	1.64503
3.0	63.07892	63.07769	9.42201	9.41831	1.66986
4.0	65.30907	65.30787	9.73048	9.72677	1.69596
5.0	66.46214	66.46154	10.04581	10.04217	1.72341
6.0	69.99423	69.99246	10.37362	10.36988	1.75224
7.0	70.57847	70.57818	10.70976	10.70614	1.78273
8.0	72.36139	72.36052	11.04988	11.04630	1.81457
9.0	72.98834	72.98804	11.39316	11.38969	1.84771
10.0	71.57826	71.57895	11.72852	11.72529	1.88174
11.0	72.17884	72.17855	12.05753	12.05439	1.91616
12.0	69.01417	69.01577	12.37215	12.36933	1.95076
13.0	68.80523	68.80534	12.67242	12.66972	1.98490
14.0	66.15000	66.15141	12.95816	12.95571	2.01855
15.0	65.26658	65.26706	13.22888	13.22657	2.05135
16.0	63.70246	63.70332	13.48751	13.48536	2.08335
17.0	60.84789	60.84953	13.72730	13.72538	2.11435
18.0	58.27500	58.27655	13.94567	13.94395	2.14391
19.0	57.75000	57.75032	14.15143	14.14978	2.17193
20.0	56.17500	56.17598	14.34691	14.34539	2.19877
21.0	54.60000	54.60101	14.52908	14.52768	2.22440
22.0	53.02500	53.02604	14.69809	14.69682	2.24877
23.0	50.92500	50.92645	14.85212	14.85099	2.27177
24.0	50.40000	50.40037	14.99572	14.99464	2.29333
25.0	49.87500	49.87537	15.13378	15.13275	2.31370
26.0	48.30000	48.30114	15.26239	15.26146	2.33298
27.0	46.72500	46.72618	15.37845	15.37763	2.35098
28.0	46.14821	46.14865	15.48593	15.48515	2.36764
29.0	43.80269	43.80457	15.58120	15.58056	2.38302
30.0	40.95732	40.95976	15.65705	15.65657	2.39670
31.0	38.78804	38.79001	15.71472	15.71436	2.40833
32.0	36.87005	36.87187	15.75744	15.75718	2.41787
33.0	35.03299	35.03483	15.78644	15.78627	2.42540
34.0	33.07731	33.07938	15.80161	15.80154	2.43100
35.0	31.16571	31.16787	15.80286	15.80290	2.43469
36.0	29.37929	29.38143	15.79092	15.79105	2.43651
37.0	27.87900	27.88090	15.76717	15.76738	2.43654
38.0	26.46201	26.46390	15.73242	15.73271	2.43491
39.0	25.08186	25.08380	15.68660	15.68697	2.43168
40.0	23.73788	23.73988	15.62949	15.62995	2.42689
41.0	22.46655	22.46856	15.56103	15.56157	2.42057
42.0	21.25628	21.25836	15.47426	15.47503	2.41258
43.0	20.22866	20.23066	15.34709	15.34818	2.40184
44.0	19.27022	19.27230	15.19315	15.19433	2.38751
45.0	18.31783	18.32016	15.02663	15.02793	2.37024
46.0	17.43863	17.44103	14.85677	14.85809	2.35076

47.0	16.57921	16.58186	14.67812	14.67953	2.32973
48.0	15.79631	15.79901	14.49839	14.49982	2.30748
49.0	15.09797	15.10065	14.31566	14.31712	2.28446
50.0	14.40532	14.40831	14.12366	14.12527	2.26068
51.0	13.76926	13.77266	13.89951	13.90183	2.23556
52.0	13.15518	13.16595	13.34192	13.34941	2.20047
53.0	12.58288	12.60173	12.60762	12.61280	2.13977
54.0	12.04960	12.11949	12.11927	12.12331	2.07535
55.0	11.56837	11.88970	11.88783	11.88878	2.02092
56.0	11.06545	11.80241	11.80445	11.80509	1.98320
57.0	10.66813	11.55484	11.57087	11.58200	1.95360
58.0	10.21778	10.37091	10.38893	10.39722	1.89422
59.0	9.87072	9.91661	9.92752	9.93181	1.82867
60.0	9.47039	9.51125	9.52572	9.53057	1.77560
61.0	9.11840	9.15043	9.16350	9.16790	1.73076
62.0	8.78551	8.81601	8.82779	8.83207	1.69252
63.0	8.48743	8.51710	8.52602	8.52997	1.65943
64.0	8.18530	8.22219	8.22979	8.23388	1.63013
65.0	7.90562	7.95068	7.95575	7.95957	1.60357
66.0	7.65213	7.71195	7.71469	7.71807	1.58000
67.0	7.39165	7.49845	7.49959	7.50260	1.55940
68.0	7.15929	7.35101	7.35005	7.35174	1.54246
69.0	6.93281	7.28196	7.28138	7.28222	1.53102
70.0	6.74108	7.22871	7.22954	7.23030	1.52328
71.0	6.51596	7.17756	7.17898	7.17964	1.51615
72.0	6.34570	6.92372	6.93892	6.95021	1.50908
73.0	6.13352	6.37344	6.38582	6.39384	1.48443
74.0	5.96605	6.08365	6.08832	6.09251	1.45750
75.0	5.80406	5.90781	5.90979	5.91279	1.43806
76.0	5.62612	5.76984	5.77054	5.77302	1.42437
77.0	5.48364	5.67561	5.67486	5.67634	1.41459
78.0	5.34621	5.62342	5.62245	5.62333	1.40831
79.0	5.19662	5.58083	5.58142	5.58222	1.40407
80.0	5.05859	5.54200	5.54310	5.54388	1.40079
81.0	4.92872	5.50340	5.50492	5.50564	1.39754
82.0	4.82466	5.33258	5.35879	5.37322	1.39385
83.0	4.68673	4.88126	4.88703	4.89272	1.37434
84.0	4.59465	4.73752	4.73753	4.73986	1.35882
85.0	4.47175	4.67284	4.67166	4.67280	1.35036
86.0	4.39254	4.63508	4.63491	4.63571	1.34589
87.0	4.27103	4.60188	4.60276	4.60354	1.34312
88.0	4.18888	4.57007	4.57151	4.57222	1.34064
89.0	4.09828	4.48775	4.49676	4.50390	1.33820
90.0	4.00318	4.18421	4.19343	4.19964	1.32782
91.0	3.93082	4.02002	4.02474	4.02848	1.31677
92.0	3.84633	3.90892	3.91267	3.91567	1.30887
93.0	3.76974	3.81477	3.81869	3.82138	1.30300
94.0	3.69084	3.72452	3.73006	3.73277	1.29810
95.0	3.63219	3.64853	3.65522	3.65733	1.29383
96.0	3.55775	3.56957	3.58474	3.58698	1.29017
97.0	3.49464	3.49954	3.53077	3.53213	1.28702
98.0	3.43891	3.43978	3.51477	3.51460	1.28516
99.0	3.37660	3.37741	3.52434	3.52506	1.28501
100.0	3.33043	3.33223	3.45797	3.46083	1.28351
101.0	3.24964	3.25514	3.34894	3.35340	1.27972
102.0	3.20472	3.21018	3.22443	3.22804	1.27434
103.0	3.13160	3.13923	3.14368	3.14632	1.26986
104.0	3.09444	3.09741	3.09634	3.09772	1.26688
105.0	3.05873	3.06188	3.06339	3.06458	1.26503
106.0	2.98577	2.99467	3.01196	3.01422	1.26315
107.0	2.95536	2.95744	2.97658	2.97744	1.26123
108.0	2.91265	2.91333	2.96828	2.96810	1.26025

109.0	2.89426	2.89419	2.98065	2.98111	1.26040
110.0	2.81413	2.81685	2.92666	2.92941	1.25942
111.0	2.78769	2.79007	2.85070	2.85392	1.25667
112.0	2.75243	2.75561	2.77674	2.77955	1.25308
113.0	2.70417	2.70782	2.72119	2.72334	1.25047
114.0	2.67007	2.67217	2.68365	2.68502	1.24871
115.0	2.64018	2.64119	2.66253	2.66317	1.24781
116.0	2.60161	2.60189	2.65950	2.65924	1.24749
117.0	2.58531	2.58571	2.65360	2.65509	1.24748
118.0	2.53210	2.53412	2.60430	2.60668	1.24570
119.0	2.51048	2.51172	2.55659	2.55879	1.24325
120.0	2.46614	2.46821	2.51496	2.51688	1.24187
121.0	2.45049	2.45109	2.48358	2.48487	1.24058
122.0	2.42856	2.42880	2.46712	2.46764	1.24035
123.0	2.39827	2.39883	2.45892	2.45988	1.24028
124.0	2.36370	2.36498	2.42333	2.42539	1.23828
125.0	2.33075	2.33194	2.38768	2.38947	1.23701
126.0	2.31311	2.31363	2.35886	2.36024	1.23623
127.0	2.26634	2.26757	2.33793	2.33900	1.23552
128.0	2.24109	2.24173	2.31803	2.31935	1.23503
129.0	2.23601	2.23623	2.28967	2.29133	1.23365
130.0	2.19234	2.19363	2.26367	2.26512	1.23290
131.0	2.17754	2.17798	2.23888	2.24038	1.23210
132.0	2.16631	2.16665	2.21360	2.21512	1.23111
133.0	2.13369	2.13470	2.18870	2.19025	1.23036
134.0	2.12540	2.12564	2.16437	2.16586	1.22945
135.0	2.08775	2.08896	2.14001	2.14161	1.22868
136.0	2.08264	2.08277	2.11643	2.11791	1.22780
137.0	2.05932	2.06008	2.09318	2.09477	1.22710
138.0	2.02939	2.03036	2.06981	2.07136	1.22621
139.0	2.01397	2.01447	2.04731	2.04886	1.22551
140.0	2.00026	2.00071	2.02505	2.02660	1.22473
141.0	1.98592	1.98639	2.00334	2.00489	1.22400
142.0	1.99505	1.99473	1.98324	1.98461	1.22334
143.0	1.96354	1.96460	1.96320	1.96475	1.22270
144.0	1.94812	1.94862	1.94370	1.94512	1.22197
145.0	1.93425	1.93472	1.92480	1.92624	1.22142
146.0	1.91198	1.91274	1.90611	1.90755	1.22076
147.0	1.88864	1.88945	1.88727	1.88877	1.22013
148.0	1.89753	1.89720	1.87018	1.87149	1.21957
149.0	1.86991	1.87089	1.85291	1.85435	1.21902
150.0	1.84398	1.84489	1.83564	1.83705	1.21838
151.0	1.84751	1.84737	1.81938	1.82069	1.21790
152.0	1.82012	1.82111	1.80299	1.80441	1.21734
153.0	1.81072	1.81104	1.78720	1.78852	1.21680
154.0	1.79419	1.79480	1.77153	1.77291	1.21632
155.0	1.77180	1.77263	1.75596	1.75733	1.21576
156.0	1.76842	1.76854	1.74105	1.74235	1.21530
157.0	1.75072	1.75139	1.72629	1.72764	1.21481
158.0	1.73971	1.74012	1.71197	1.71327	1.21433
159.0	1.72913	1.72953	1.69797	1.69927	1.21389
160.0	1.71026	1.71098	1.68410	1.68541	1.21342
161.0	1.69548	1.69604	1.67043	1.67174	1.21297
162.0	1.69263	1.69273	1.65740	1.65864	1.21254
163.0	1.70543	1.70494	1.64538	1.64653	1.21215
164.0	1.67244	1.67374	1.63292	1.63421	1.21172
165.0	1.66159	1.66200	1.62090	1.62209	1.21129
166.0	1.65612	1.65634	1.60918	1.61038	1.21094
167.0	1.71095	1.70885	1.59955	1.60047	1.21062
168.0	1.63136	1.63459	1.58785	1.58923	1.21027
169.0	1.62579	1.62597	1.57722	1.57827	1.20984
170.0	1.62740	1.62735	1.56658	1.56777	1.20964

171.0	1.61249	1.61308	1.55642	1.55754	1.20917
172.0	1.58637	1.58746	1.54580	1.54702	1.20894
173.0	1.58374	1.58384	1.53576	1.53688	1.20856
174.0	1.57017	1.57075	1.52574	1.52692	1.20825
175.0	1.55220	1.55296	1.51580	1.51698	1.20789
176.0	1.54526	1.54556	1.50613	1.50729	1.20760
177.0	1.53404	1.53452	1.49664	1.49781	1.20722
178.0	1.51123	1.51223	1.48702	1.48827	1.20685
179.0	1.51367	1.51356	1.47798	1.47912	1.20663
180.0	1.49630	1.49708	1.46888	1.47013	1.20628
181.0	1.49379	1.49376	1.45495	1.45566	1.21972
182.0	1.48406	1.48455	1.44248	1.44344	1.20487
183.0	1.47585	1.47618	1.43925	1.44013	1.20476
184.0	1.45565	1.45658	1.42707	1.42807	1.20828
185.0	1.45746	1.45735	1.42170	1.42251	1.20320
186.0	1.46291	1.46268	1.41367	1.41454	1.20652
187.0	1.41808	1.42014	1.40547	1.40649	1.20418
188.0	1.42353	1.42327	1.39842	1.39928	1.20461
189.0	1.41154	1.41211	1.39040	1.39135	1.20458
190.0	1.40873	1.40885	1.38369	1.38454	1.20389
191.0	1.40022	1.40062	1.37650	1.37740	1.20421
192.0	1.39728	1.39741	1.36987	1.37070	1.20372
193.0	1.39237	1.39261	1.36341	1.36426	1.20370
194.0	1.39423	1.39413	1.35737	1.35813	1.20354
195.0	1.36935	1.37054	1.35093	1.35183	1.20336
196.0	1.36828	1.36832	1.34481	1.34559	1.20327
197.0	1.36174	1.36206	1.33877	1.33959	1.20310
198.0	1.34365	1.34453	1.33257	1.33342	1.20295
199.0	1.33988	1.34006	1.32656	1.32737	1.20275
200.0	1.34407	1.34386	1.32120	1.32192	1.20264
201.0	1.31797	1.31928	1.31501	1.31594	1.20254
202.0	1.33951	1.33844	1.31017	1.31076	1.20239
203.0	1.33285	1.33320	1.30525	1.30598	1.20236
204.0	1.34850	1.34772	1.30127	1.30177	1.20222
205.0	1.34276	1.34305	1.29718	1.29779	1.20216
206.0	1.31200	1.31353	1.29258	1.29326	1.20204
207.0	1.31770	1.31741	1.28838	1.28894	1.20194
208.0	1.34328	1.34204	1.28511	1.28554	1.20190
209.0	1.33108	1.33168	1.28168	1.28220	1.20180
210.0	1.32061	1.32112	1.27830	1.27878	1.20172
211.0	1.32243	1.32234	1.27509	1.27554	1.20165
212.0	1.31815	1.31837	1.27201	1.27246	1.20157
213.0	1.33201	1.33132	1.26946	1.26980	1.20153
214.0	1.34291	1.34238	1.26725	1.26756	1.20148
215.0	1.32453	1.32543	1.26477	1.26515	1.20141
216.0	1.33103	1.33071	1.26265	1.26293	1.20137
217.0	1.34421	1.34358	1.26087	1.26112	1.20133
218.0	1.35056	1.35026	1.25937	1.25958	1.20129
219.0	1.33132	1.33226	1.25749	1.25779	1.20125
220.0	1.32676	1.32698	1.25574	1.25599	1.20119
221.0	1.33785	1.33731	1.25431	1.25451	1.20117
222.0	1.33674	1.33680	1.25291	1.25313	1.20114
223.0	1.35316	1.35237	1.25199	1.25210	1.20112
224.0	1.33631	1.33713	1.25065	1.25089	1.20109
225.0	1.34887	1.34825	1.24984	1.24992	1.20107
226.0	1.28033	1.28384	1.24728	1.24779	1.20101
227.0	1.27651	1.27668	1.24516	1.24541	1.20095
228.0	1.01325	1.03084	1.23586	1.23779	1.20072
229.0	1.01325	1.01607	1.20972	1.21512	1.20011
230.0	1.01325	1.02768	1.14520	1.15810	1.19427
231.0	1.01325	1.03693	1.07296	1.08466	1.18185
232.0	1.01325	1.03316	1.04424	1.05018	1.16070

233.0	1.01325	1.02917	1.03784	1.04261	1.13448
234.0	1.01325	1.02553	1.03882	1.04497	1.11068
235.0	1.01325	1.01917	1.04639	1.05129	1.10233
236.0	1.01325	1.01277	1.07366	1.06782	1.11661
237.0	1.01325	1.01287	1.10100	1.09743	1.15740
238.0	1.01325	1.01414	1.08434	1.08753	1.19638
239.0	1.01325	1.01440	1.07170	1.07301	1.19965
240.0	1.01325	1.01455	1.06693	1.06750	1.18764
241.0	1.01325	1.01406	1.07288	1.07235	1.16763
242.0	1.01325	1.01312	1.08827	1.08582	1.15597
243.0	1.01325	1.01257	1.10917	1.10502	1.16029
244.0	1.01325	1.01349	1.11305	1.11380	1.17729
245.0	1.01325	1.01363	1.10934	1.11018	1.19271
246.0	1.01325	1.01383	1.10427	1.10485	1.19803
247.0	1.01325	1.01404	1.09982	1.10026	1.19537
248.0	1.01325	1.01406	1.09867	1.09886	1.18842
249.0	1.01325	1.01382	1.10162	1.10132	1.18156
250.0	1.01325	1.01347	1.10788	1.10698	1.17914
251.0	1.01325	1.01321	1.11558	1.11428	1.18217
252.0	1.01325	1.01315	1.12207	1.12086	1.18872
253.0	1.01325	1.01326	1.12526	1.12450	1.19495
254.0	1.01325	1.01343	1.12481	1.12459	1.19768
255.0	1.01325	1.01372	1.12155	1.12188	1.19701
256.0	1.01325	1.01425	1.11590	1.11694	1.19358
257.0	1.01325	1.01508	1.10760	1.10951	1.18718
258.0	1.01325	1.01595	1.09745	1.10016	1.17836
259.0	1.01325	1.01633	1.08814	1.09123	1.16853
260.0	1.01325	1.01596	1.08328	1.08622	1.15823
261.0	1.01325	1.01505	1.08514	1.08730	1.14942
262.0	1.01325	1.01401	1.09357	1.09422	1.14711
263.0	1.01325	1.01327	1.10580	1.10488	1.15463
264.0	1.01325	1.01305	1.11691	1.11563	1.16983
265.0	1.01325	1.01320	1.12259	1.12207	1.18638
266.0	1.01325	1.01349	1.12205	1.12237	1.19604
267.0	1.01325	1.01398	1.11656	1.11780	1.19628
268.0	1.01325	1.01515	1.10609	1.10893	1.18986
269.0	1.01325	1.01722	1.08973	1.09500	1.17620
270.0	1.01325	1.01923	1.07119	1.07912	1.15464
271.0	1.01325	1.02001	1.05765	1.06831	1.12646
272.0	1.01325	1.01954	1.05107	1.06448	1.10202
273.0	1.01325	1.01819	1.05001	1.06508	1.09102
274.0	1.01325	1.01643	1.05497	1.06928	1.09104
275.0	1.01325	1.01468	1.06755	1.07738	1.09859
276.0	1.01325	1.01338	1.08676	1.08988	1.11310
277.0	1.01325	1.01294	1.10526	1.10520	1.13377
278.0	1.01325	1.01317	1.11557	1.11705	1.15651
279.0	1.01325	1.01362	1.11688	1.12002	1.17555
280.0	1.01325	1.01464	1.10912	1.11392	1.18403
281.0	1.01325	1.01760	1.08919	1.09805	1.17604
282.0	1.01325	1.02221	1.06128	1.07545	1.14835
283.0	1.01325	1.02527	1.04186	1.06043	1.10627
284.0	1.01325	1.02658	1.03373	1.05670	1.07568
285.0	1.01325	1.02711	1.03060	1.05948	1.06745
286.0	1.01325	1.02719	1.02916	1.06746	1.07110
287.0	1.01325	1.02657	1.02783	1.07937	1.08082
288.0	1.01325	1.02507	1.02600	1.09377	1.09446
289.0	1.01325	1.02443	1.02563	1.10707	1.11030
290.0	1.01325	1.02449	1.02603	1.11953	1.12248
291.0	1.01325	1.02459	1.02668	1.12992	1.13229
292.0	1.01325	1.02442	1.02716	1.13806	1.13947
293.0	1.01325	1.02321	1.02652	1.14495	1.14530
294.0	1.01325	1.02130	1.02520	1.15111	1.15174

295.0	1.01325	1.01970	1.02432	1.15637	1.15759
296.0	1.01325	1.01848	1.02379	1.16104	1.16141
297.0	1.01325	1.01760	1.02347	1.16460	1.16517
298.0	1.01325	1.01699	1.02312	1.16760	1.16806
299.0	1.01325	1.01660	1.02250	1.17003	1.17032
300.0	1.01325	1.01638	1.02148	1.17192	1.17224
301.0	1.01325	1.01629	1.02014	1.17345	1.17362
302.0	1.01325	1.01632	1.01876	1.17460	1.17479
303.0	1.01325	1.01648	1.01766	1.17551	1.17561
304.0	1.01325	1.01686	1.01713	1.17619	1.17629
305.0	1.01325	1.01764	1.01734	1.17674	1.17680
306.0	1.01325	1.01921	1.01863	1.17718	1.17724
307.0	1.01325	1.02255	1.02183	1.17758	1.17764
308.0	1.01325	1.02846	1.02920	1.17803	1.17811
309.0	1.01325	1.03582	1.03645	1.17859	1.17868
310.0	1.01325	1.04266	1.04302	1.17921	1.17931
311.0	1.01325	1.04891	1.04896	1.17986	1.17996
312.0	1.01325	1.05493	1.05543	1.18053	1.18064
313.0	1.01325	1.06114	1.06139	1.18123	1.18134
314.0	1.01325	1.06697	1.06734	1.18194	1.18205
315.0	1.01325	1.07270	1.07299	1.18265	1.18276
316.0	1.01325	1.07822	1.07853	1.18336	1.18347
317.0	1.01325	1.08356	1.08384	1.18407	1.18417
318.0	1.01325	1.08873	1.08901	1.18476	1.18486
319.0	1.01325	1.09373	1.09399	1.18544	1.18554
320.0	1.01325	1.09855	1.09881	1.18611	1.18620
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322.0	1.01325	1.10772	1.10795	1.18738	1.18747
323.0	1.01325	1.11206	1.11228	1.18799	1.18808
324.0	1.01325	1.11624	1.11646	1.18858	1.18866
325.0	1.01325	1.12028	1.12048	1.18915	1.18923
326.0	1.01325	1.12416	1.12436	1.18970	1.18978
327.0	1.01325	1.12789	1.12808	1.19023	1.19030
328.0	1.01325	1.13149	1.13167	1.19073	1.19081
329.0	1.01325	1.13494	1.13511	1.19122	1.19129
330.0	1.01325	1.13825	1.13842	1.19169	1.19176
331.0	1.01325	1.14143	1.14159	1.19214	1.19220
332.0	1.01325	1.14447	1.14463	1.19257	1.19263
333.0	1.01325	1.14739	1.14754	1.19298	1.19303
334.0	1.01325	1.15018	1.15032	1.19337	1.19342
335.0	1.01325	1.15284	1.15298	1.19374	1.19379
336.0	1.01325	1.15539	1.15551	1.19410	1.19414
337.0	1.01325	1.15781	1.15793	1.19443	1.19448
338.0	1.01325	1.16012	1.16023	1.19475	1.19480
339.0	1.01325	1.16232	1.16242	1.19506	1.19510
340.0	1.01325	1.16440	1.16450	1.19535	1.19539
341.0	1.01325	1.16638	1.16648	1.19562	1.19566
342.0	1.01325	1.16826	1.16835	1.19588	1.19592
343.0	1.01325	1.17003	1.17012	1.19612	1.19616
344.0	1.01325	1.17171	1.17179	1.19635	1.19639
345.0	1.01325	1.17329	1.17337	1.19657	1.19660
346.0	1.01325	1.17478	1.17485	1.19677	1.19680
347.0	1.01325	1.17618	1.17625	1.19696	1.19699
348.0	1.01325	1.17750	1.17756	1.19714	1.19716
349.0	1.01325	1.17873	1.17879	1.19731	1.19733
350.0	1.01325	1.17989	1.17994	1.19746	1.19748
351.0	1.01325	1.18097	1.18102	1.19761	1.19763
352.0	1.01325	1.18197	1.18202	1.19774	1.19776
353.0	1.01325	1.18291	1.18296	1.19787	1.19788
354.0	1.01325	1.18378	1.18382	1.19798	1.19800
355.0	1.01325	1.18459	1.18463	1.19809	1.19811
356.0	1.01325	1.18534	1.18537	1.19819	1.19820

357.0	1.01325	1.18603	1.18606	1.19828	1.19830
358.0	1.01325	1.18667	1.18670	1.19837	1.19838
359.0	1.01325	1.18726	1.18729	1.19845	1.19846
360.0	1.01325	1.18780	1.18783	1.19852	1.19853

lift.out:

-360.0	.86938E+00	.87718E+00	.49354E+02	.31441E+02
-359.0	.86968E+00	.87555E+00	.49734E+02	.32748E+02
-358.0	.86967E+00	.87480E+00	.49737E+02	.32958E+02
-357.0	.86961E+00	.87542E+00	.49761E+02	.32795E+02
-356.0	.86963E+00	.87491E+00	.49750E+02	.32933E+02
-355.0	.86963E+00	.87528E+00	.49763E+02	.32832E+02
-354.0	.86961E+00	.87496E+00	.49767E+02	.32915E+02
-353.0	.86960E+00	.87516E+00	.49774E+02	.32864E+02
-352.0	.86960E+00	.87497E+00	.49780E+02	.32911E+02
-351.0	.86958E+00	.87509E+00	.49785E+02	.32875E+02
-350.0	.86957E+00	.87495E+00	.49790E+02	.32909E+02
-349.0	.86956E+00	.87502E+00	.49798E+02	.32887E+02
-348.0	.86955E+00	.87489E+00	.49799E+02	.32922E+02
-347.0	.86951E+00	.87490E+00	.49813E+02	.32920E+02
-346.0	.86951E+00	.87477E+00	.49810E+02	.32958E+02
-345.0	.86948E+00	.87473E+00	.49827E+02	.32968E+02
-344.0	.86945E+00	.87463E+00	.49834E+02	.32996E+02
-343.0	.86943E+00	.87458E+00	.49843E+02	.33007E+02
-342.0	.86941E+00	.87452E+00	.49854E+02	.33020E+02
-341.0	.86938E+00	.87515E+00	.49866E+02	.32740E+02
-340.0	.86935E+00	.87556E+00	.49874E+02	.32539E+02
-339.0	.86932E+00	.87546E+00	.49888E+02	.32548E+02
-338.0	.86929E+00	.87542E+00	.49898E+02	.32555E+02
-337.0	.86926E+00	.87530E+00	.49913E+02	.32582E+02
-336.0	.86925E+00	.87525E+00	.49904E+02	.32587E+02
-335.0	.86917E+00	.87514E+00	.49953E+02	.32606E+02
-334.0	.86915E+00	.87507E+00	.49968E+02	.32616E+02
-333.0	.86911E+00	.87495E+00	.49981E+02	.32638E+02
-332.0	.86907E+00	.87485E+00	.49995E+02	.32658E+02
-331.0	.86903E+00	.87473E+00	.49999E+02	.32685E+02
-330.0	.86899E+00	.87461E+00	.50015E+02	.32713E+02
-329.0	.86894E+00	.87448E+00	.50029E+02	.32744E+02
-328.0	.86893E+00	.87434E+00	.49966E+02	.32775E+02
-327.0	.86885E+00	.87420E+00	.49933E+02	.32808E+02
-326.0	.86877E+00	.87406E+00	.49934E+02	.32842E+02
-325.0	.86873E+00	.87391E+00	.49941E+02	.32877E+02
-324.0	.86864E+00	.87376E+00	.49960E+02	.32913E+02
-323.0	.86862E+00	.87361E+00	.49960E+02	.32949E+02
-322.0	.86853E+00	.87345E+00	.49986E+02	.32987E+02
-321.0	.86847E+00	.87329E+00	.49997E+02	.33024E+02
-320.0	.86841E+00	.87313E+00	.50012E+02	.33063E+02
-319.0	.86834E+00	.87296E+00	.50035E+02	.33102E+02
-318.0	.86829E+00	.87279E+00	.50054E+02	.33142E+02
-317.0	.86822E+00	.87262E+00	.50074E+02	.33182E+02
-316.0	.86816E+00	.87244E+00	.50095E+02	.33223E+02
-315.0	.86809E+00	.87226E+00	.50116E+02	.33264E+02
-314.0	.86803E+00	.87208E+00	.50138E+02	.33305E+02
-313.0	.86796E+00	.87190E+00	.50159E+02	.33347E+02
-312.0	.86789E+00	.87171E+00	.50181E+02	.33390E+02
-311.0	.86782E+00	.87152E+00	.50203E+02	.33432E+02
-310.0	.86775E+00	.87133E+00	.50226E+02	.33475E+02
-309.0	.86768E+00	.87114E+00	.50248E+02	.33518E+02

-308.0	.86760E+00	.87094E+00	.50271E+02	.33562E+02
-307.0	.86753E+00	.87074E+00	.50293E+02	.33606E+02
-306.0	.86746E+00	.87054E+00	.50316E+02	.33649E+02
-305.0	.86738E+00	.87034E+00	.50339E+02	.33694E+02
-304.0	.86730E+00	.87014E+00	.50362E+02	.33738E+02
-303.0	.86723E+00	.86993E+00	.50385E+02	.33782E+02
-302.0	.86715E+00	.86972E+00	.50408E+02	.33826E+02
-301.0	.86707E+00	.86951E+00	.50431E+02	.33870E+02
-300.0	.86698E+00	.86930E+00	.50454E+02	.33915E+02
-299.0	.86690E+00	.86908E+00	.50477E+02	.33959E+02
-298.0	.86682E+00	.86887E+00	.50500E+02	.34003E+02
-297.0	.86674E+00	.86865E+00	.50522E+02	.34046E+02
-296.0	.86665E+00	.86843E+00	.50545E+02	.34090E+02
-295.0	.86656E+00	.86820E+00	.50568E+02	.34134E+02
-294.0	.86647E+00	.86798E+00	.50590E+02	.34177E+02
-293.0	.86639E+00	.86775E+00	.50613E+02	.34220E+02
-292.0	.86629E+00	.86751E+00	.50635E+02	.34263E+02
-291.0	.86620E+00	.86728E+00	.50657E+02	.34305E+02
-290.0	.86611E+00	.86704E+00	.50679E+02	.34347E+02
-289.0	.86601E+00	.86679E+00	.50701E+02	.34389E+02
-288.0	.86592E+00	.86654E+00	.50723E+02	.34430E+02
-287.0	.86582E+00	.86629E+00	.50744E+02	.34471E+02
-286.0	.86572E+00	.86602E+00	.50765E+02	.34512E+02
-285.0	.86561E+00	.86575E+00	.50786E+02	.34552E+02
-284.0	.86551E+00	.86547E+00	.50806E+02	.34591E+02
-283.0	.86540E+00	.86517E+00	.50826E+02	.34630E+02
-282.0	.86528E+00	.86485E+00	.50846E+02	.34668E+02
-281.0	.86516E+00	.86451E+00	.50866E+02	.34705E+02
-280.0	.86504E+00	.86413E+00	.50886E+02	.34742E+02
-279.0	.86491E+00	.86368E+00	.50904E+02	.34778E+02
-278.0	.86477E+00	.86314E+00	.50923E+02	.34813E+02
-277.0	.86463E+00	.86240E+00	.50941E+02	.34844E+02
-276.0	.86447E+00	.86119E+00	.50960E+02	.34868E+02
-275.0	.86429E+00	.85868E+00	.50976E+02	.34875E+02
-274.0	.86409E+00	.85324E+00	.50995E+02	.34875E+02
-273.0	.86387E+00	.84294E+00	.51010E+02	.34878E+02
-272.0	.86357E+00	.82604E+00	.51027E+02	.34881E+02
-271.0	.86316E+00	.80100E+00	.51042E+02	.34885E+02
-270.0	.86252E+00	.76649E+00	.51056E+02	.34889E+02
-269.0	.86133E+00	.72159E+00	.51063E+02	.34892E+02
-268.0	.85868E+00	.66494E+00	.51064E+02	.34896E+02
-267.0	.85342E+00	.59607E+00	.51070E+02	.34898E+02
-266.0	.84511E+00	.51463E+00	.51092E+02	.34899E+02
-265.0	.83459E+00	.42115E+00	.51115E+02	.34901E+02
-264.0	.82292E+00	.31862E+00	.51135E+02	.34904E+02
-263.0	.81057E+00	.21505E+00	.51152E+02	.34865E+02
-262.0	.79738E+00	.15960E+00	.51166E+02	.30922E+02
-261.0	.78344E+00	.19820E+00	.51174E+02	.35822E+02
-260.0	.76923E+00	.23461E+00	.51181E+02	.34851E+02
-259.0	.75454E+00	.26108E+00	.51188E+02	.34777E+02
-258.0	.73843E+00	.28411E+00	.51195E+02	.34933E+02
-257.0	.71933E+00	.30933E+00	.51201E+02	.34949E+02
-256.0	.69517E+00	.33981E+00	.51208E+02	.34955E+02
-255.0	.66335E+00	.37600E+00	.51215E+02	.34974E+02
-254.0	.62076E+00	.41600E+00	.51222E+02	.34988E+02
-253.0	.56394E+00	.45634E+00	.51230E+02	.34992E+02
-252.0	.49004E+00	.49247E+00	.51238E+02	.34982E+02
-251.0	.39901E+00	.51841E+00	.51234E+02	.34947E+02
-250.0	.29757E+00	.52570E+00	.51209E+02	.34879E+02
-249.0	.20569E+00	.50413E+00	.50252E+02	.34834E+02
-248.0	.21790E+00	.45284E+00	.51909E+02	.34945E+02
-247.0	.27566E+00	.38805E+00	.51281E+02	.34972E+02

-246.0	.34564E+00	.33031E+00	.51233E+02	.35014E+02
-245.0	.41273E+00	.30590E+00	.51230E+02	.35029E+02
-244.0	.46242E+00	.33057E+00	.51224E+02	.35028E+02
-243.0	.48636E+00	.39055E+00	.51219E+02	.34985E+02
-242.0	.48165E+00	.45574E+00	.51218E+02	.34937E+02
-241.0	.44797E+00	.50481E+00	.51217E+02	.34919E+02
-240.0	.38716E+00	.52908E+00	.51214E+02	.34902E+02
-239.0	.30556E+00	.52404E+00	.51198E+02	.34862E+02
-238.0	.21841E+00	.48490E+00	.51093E+02	.34826E+02
-237.0	.20870E+00	.41349E+00	.50711E+02	.34921E+02
-236.0	.25499E+00	.33183E+00	.51049E+02	.34949E+02
-235.0	.30719E+00	.27073E+00	.51170E+02	.34930E+02
-234.0	.35444E+00	.25685E+00	.51201E+02	.34906E+02
-233.0	.38680E+00	.29472E+00	.51205E+02	.34945E+02
-232.0	.39791E+00	.36280E+00	.51203E+02	.34928E+02
-231.0	.38553E+00	.43002E+00	.51200E+02	.34882E+02
-230.0	.35081E+00	.47452E+00	.51194E+02	.34853E+02
-229.0	.29893E+00	.48666E+00	.51177E+02	.34827E+02
-228.0	.24098E+00	.46260E+00	.51117E+02	.34810E+02
-227.0	.20214E+00	.40417E+00	.49037E+02	.34839E+02
-226.0	.22499E+00	.32698E+00	.51156E+02	.34891E+02
-225.0	.26416E+00	.25984E+00	.51163E+02	.34854E+02
-224.0	.30744E+00	.22821E+00	.51175E+02	.34780E+02
-223.0	.34495E+00	.24331E+00	.51183E+02	.34818E+02
-222.0	.36868E+00	.29564E+00	.51183E+02	.34871E+02
-221.0	.37351E+00	.36197E+00	.51180E+02	.34859E+02
-220.0	.35776E+00	.41817E+00	.51176E+02	.34825E+02
-219.0	.32344E+00	.44825E+00	.51165E+02	.34800E+02
-218.0	.27694E+00	.44524E+00	.51138E+02	.34779E+02
-217.0	.22978E+00	.40827E+00	.51067E+02	.34779E+02
-216.0	.20458E+00	.34468E+00	.49668E+02	.34810E+02
-215.0	.22540E+00	.27539E+00	.50996E+02	.34810E+02
-214.0	.25984E+00	.22532E+00	.51120E+02	.34717E+02
-213.0	.29869E+00	.21221E+00	.51144E+02	.34665E+02
-212.0	.32675E+00	.23749E+00	.51105E+02	.34732E+02
-211.0	.31338E+00	.28023E+00	.51053E+02	.34727E+02
-210.0	.24928E+00	.30822E+00	.51087E+02	.34703E+02
-209.0	.19633E+00	.30410E+00	.47433E+02	.34701E+02
-208.0	.22622E+00	.27261E+00	.51156E+02	.34726E+02
-207.0	.25532E+00	.23123E+00	.51106E+02	.34680E+02
-206.0	.27562E+00	.19426E+00	.51085E+02	.34567E+02
-205.0	.27419E+00	.17681E+00	.51077E+02	.33976E+02
-204.0	.25052E+00	.18390E+00	.51056E+02	.34677E+02
-203.0	.21188E+00	.18862E+00	.50980E+02	.34525E+02
-202.0	.20802E+00	.17965E+00	.50548E+02	.34375E+02
-201.0	.22143E+00	.17540E+00	.50928E+02	.33808E+02
-200.0	.22152E+00	.17985E+00	.50982E+02	.34436E+02
-199.0	.21297E+00	.17626E+00	.50993E+02	.33942E+02
-198.0	.20584E+00	.17544E+00	.50038E+02	.33833E+02
-197.0	.21152E+00	.17649E+00	.50984E+02	.34003E+02
-196.0	.20753E+00	.17496E+00	.50420E+02	.33758E+02
-195.0	.21021E+00	.17505E+00	.50889E+02	.33778E+02
-194.0	.20951E+00	.17502E+00	.50790E+02	.33777E+02
-193.0	.20879E+00	.17437E+00	.50667E+02	.33672E+02
-192.0	.21128E+00	.17458E+00	.50932E+02	.33711E+02
-191.0	.21276E+00	.17467E+00	.50955E+02	.33734E+02
-190.0	.20694E+00	.17456E+00	.50284E+02	.33720E+02
-189.0	.20979E+00	.17451E+00	.50833E+02	.33716E+02
-188.0	.20920E+00	.17512E+00	.50730E+02	.33829E+02
-187.0	.20798E+00	.17538E+00	.50522E+02	.33882E+02
-186.0	.20827E+00	.17609E+00	.50579E+02	.34016E+02
-185.0	.20882E+00	.17713E+00	.50677E+02	.34203E+02

-184.0	.20893E+00	.17813E+00	.50698E+02	.34384E+02
-183.0	.20839E+00	.17965E+00	.50617E+02	.34651E+02
-182.0	.20864E+00	.18138E+00	.50670E+02	.34945E+02
-181.0	.20927E+00	.18353E+00	.50800E+02	.35288E+02
-180.0	.20932E+00	.18617E+00	.50818E+02	.35641E+02
-179.0	.20572E+00	.16130E+00	.49954E+02	.31120E+02
-178.0	.20389E+00	.13703E+00	.49495E+02	.26441E+02
-177.0	.20426E+00	.15605E+00	.49563E+02	.30154E+02
-176.0	.20423E+00	.14151E+00	.49540E+02	.27310E+02
-175.0	.20315E+00	.14842E+00	.49283E+02	.28684E+02
-174.0	.20290E+00	.14885E+00	.49222E+02	.28762E+02
-173.0	.20307E+00	.14721E+00	.49273E+02	.28454E+02
-172.0	.20286E+00	.15165E+00	.49242E+02	.29326E+02
-171.0	.20359E+00	.15055E+00	.49436E+02	.29117E+02
-170.0	.20420E+00	.15316E+00	.49593E+02	.29631E+02
-169.0	.20547E+00	.15443E+00	.49901E+02	.29884E+02
-168.0	.20531E+00	.15550E+00	.49879E+02	.30097E+02
-167.0	.20512E+00	.15759E+00	.49845E+02	.30506E+02
-166.0	.20462E+00	.15859E+00	.49734E+02	.30705E+02
-165.0	.20556E+00	.16013E+00	.49962E+02	.31006E+02
-164.0	.20592E+00	.16153E+00	.50046E+02	.31281E+02
-163.0	.20468E+00	.16254E+00	.49756E+02	.31479E+02
-162.0	.20511E+00	.16362E+00	.49861E+02	.31688E+02
-161.0	.20465E+00	.16443E+00	.49750E+02	.31846E+02
-160.0	.20476E+00	.16515E+00	.49777E+02	.31986E+02
-159.0	.20414E+00	.16558E+00	.49623E+02	.32069E+02
-158.0	.20386E+00	.16594E+00	.49556E+02	.32142E+02
-157.0	.20371E+00	.16649E+00	.49515E+02	.32248E+02
-156.0	.20437E+00	.16629E+00	.49681E+02	.32212E+02
-155.0	.20304E+00	.16658E+00	.49343E+02	.32268E+02
-154.0	.20370E+00	.16638E+00	.49515E+02	.32230E+02
-153.0	.20279E+00	.16638E+00	.49278E+02	.32232E+02
-152.0	.20286E+00	.16621E+00	.49299E+02	.32200E+02
-151.0	.20234E+00	.16607E+00	.49161E+02	.32176E+02
-150.0	.20058E+00	.16585E+00	.48692E+02	.32135E+02
-149.0	.20204E+00	.16556E+00	.49084E+02	.32080E+02
-148.0	.20101E+00	.16557E+00	.48806E+02	.32084E+02
-147.0	.20162E+00	.16519E+00	.48971E+02	.32013E+02
-146.0	.20313E+00	.16517E+00	.49362E+02	.32009E+02
-145.0	.20279E+00	.16505E+00	.49275E+02	.31985E+02
-144.0	.20178E+00	.16475E+00	.49012E+02	.31928E+02
-143.0	.20280E+00	.16467E+00	.49279E+02	.31911E+02
-142.0	.20164E+00	.16460E+00	.48973E+02	.31899E+02
-141.0	.20038E+00	.16431E+00	.48636E+02	.31844E+02
-140.0	.20554E+00	.16444E+00	.49952E+02	.31868E+02
-139.0	.20625E+00	.16520E+00	.50111E+02	.32010E+02
-138.0	.20539E+00	.16514E+00	.49908E+02	.31995E+02
-137.0	.20502E+00	.16556E+00	.49827E+02	.32074E+02
-136.0	.20435E+00	.16571E+00	.49666E+02	.32100E+02
-135.0	.20182E+00	.16557E+00	.49017E+02	.32074E+02
-134.0	.20359E+00	.16536E+00	.49478E+02	.32036E+02
-133.0	.20397E+00	.16561E+00	.49569E+02	.32083E+02
-132.0	.20281E+00	.16543E+00	.49276E+02	.32048E+02
-131.0	.20252E+00	.16530E+00	.49200E+02	.32024E+02
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-129.0	.20241E+00	.16512E+00	.49171E+02	.31991E+02
-128.0	.20135E+00	.16504E+00	.48893E+02	.31977E+02
-127.0	.20130E+00	.16483E+00	.48878E+02	.31937E+02
-126.0	.20102E+00	.16474E+00	.48804E+02	.31921E+02
-125.0	.20104E+00	.16459E+00	.48811E+02	.31893E+02
-124.0	.19983E+00	.16445E+00	.48482E+02	.31866E+02
-123.0	.19940E+00	.16422E+00	.48367E+02	.31824E+02

-122.0	.19920E+00	.16407E+00	.48310E+02	.31797E+02
-121.0	.19839E+00	.16388E+00	.48087E+02	.31761E+02
-120.0	.19832E+00	.16365E+00	.48069E+02	.31719E+02
-119.0	.19791E+00	.16353E+00	.47953E+02	.31696E+02
-118.0	.19793E+00	.16331E+00	.47960E+02	.31656E+02
-117.0	.19699E+00	.16316E+00	.47696E+02	.31629E+02
-116.0	.19606E+00	.16291E+00	.47434E+02	.31581E+02
-115.0	.19591E+00	.16270E+00	.47393E+02	.31542E+02
-114.0	.19550E+00	.16253E+00	.47275E+02	.31511E+02
-113.0	.19492E+00	.16228E+00	.47110E+02	.31465E+02
-112.0	.19444E+00	.16209E+00	.46973E+02	.31429E+02
-111.0	.19282E+00	.16184E+00	.46509E+02	.31382E+02
-110.0	.19339E+00	.16155E+00	.46675E+02	.31328E+02
-109.0	.19204E+00	.16142E+00	.46283E+02	.31304E+02
-108.0	.19211E+00	.16106E+00	.46309E+02	.31236E+02
-107.0	.19045E+00	.16090E+00	.45824E+02	.31206E+02
-106.0	.19051E+00	.16055E+00	.45845E+02	.31141E+02
-105.0	.18934E+00	.16035E+00	.45502E+02	.31104E+02
-104.0	.18916E+00	.16004E+00	.45452E+02	.31045E+02
-103.0	.18759E+00	.15978E+00	.44989E+02	.30997E+02
-102.0	.18757E+00	.15946E+00	.44988E+02	.30935E+02
-101.0	.18680E+00	.15923E+00	.44746E+02	.30893E+02
-100.0	.18602E+00	.15891E+00	.44530E+02	.30831E+02
-99.0	.18435E+00	.15859E+00	.44036E+02	.30771E+02
-98.0	.18402E+00	.15825E+00	.43942E+02	.30707E+02
-97.0	.18208E+00	.15794E+00	.43364E+02	.30648E+02
-96.0	.18230E+00	.15754E+00	.43433E+02	.30571E+02
-95.0	.18076E+00	.15728E+00	.42972E+02	.30523E+02
-94.0	.18042E+00	.15685E+00	.42874E+02	.30440E+02
-93.0	.17865E+00	.15654E+00	.42343E+02	.30382E+02
-92.0	.17733E+00	.15610E+00	.41950E+02	.30297E+02
-91.0	.17673E+00	.15572E+00	.41772E+02	.30225E+02
-90.0	.17570E+00	.15537E+00	.41462E+02	.30158E+02
-89.0	.17428E+00	.15491E+00	.41038E+02	.30070E+02
-88.0	.16969E+00	.15442E+00	.39658E+02	.29977E+02
-87.0	.17248E+00	.15387E+00	.40500E+02	.29870E+02
-86.0	.16989E+00	.15371E+00	.39717E+02	.29839E+02
-85.0	.16990E+00	.15298E+00	.39724E+02	.29698E+02
-84.0	.16774E+00	.15271E+00	.39068E+02	.29648E+02
-83.0	.16663E+00	.15213E+00	.38736E+02	.29534E+02
-82.0	.16420E+00	.15163E+00	.37999E+02	.29437E+02
-81.0	.16306E+00	.15111E+00	.37656E+02	.29336E+02
-80.0	.16102E+00	.15055E+00	.37035E+02	.29228E+02
-79.0	.15935E+00	.14998E+00	.36530E+02	.29117E+02
-78.0	.15671E+00	.14938E+00	.35728E+02	.29000E+02
-77.0	.15466E+00	.14872E+00	.35103E+02	.28871E+02
-76.0	.15279E+00	.14809E+00	.34534E+02	.28749E+02
-75.0	.15112E+00	.14742E+00	.34024E+02	.28618E+02
-74.0	.14833E+00	.14671E+00	.33173E+02	.28479E+02
-73.0	.14631E+00	.14594E+00	.32557E+02	.28329E+02
-72.0	.14365E+00	.14521E+00	.31743E+02	.28185E+02
-71.0	.14114E+00	.14437E+00	.30975E+02	.28019E+02
-70.0	.13870E+00	.14354E+00	.30227E+02	.27857E+02
-69.0	.13600E+00	.14267E+00	.29400E+02	.27685E+02
-68.0	.13253E+00	.14172E+00	.28335E+02	.27498E+02
-67.0	.12915E+00	.14071E+00	.27297E+02	.27298E+02
-66.0	.12662E+00	.13968E+00	.26518E+02	.27095E+02
-65.0	.12292E+00	.13862E+00	.25380E+02	.26885E+02
-64.0	.11988E+00	.13745E+00	.24441E+02	.26651E+02
-63.0	.11599E+00	.13630E+00	.23240E+02	.26423E+02
-62.0	.11157E+00	.13498E+00	.21877E+02	.26160E+02
-61.0	.10756E+00	.13362E+00	.20636E+02	.25890E+02

-60.0	.10283E+00	.13221E+00	.19173E+02	.25609E+02
-59.0	.99023E-01	.13068E+00	.17992E+02	.25302E+02
-58.0	.93372E-01	.12915E+00	.16236E+02	.24995E+02
-57.0	.89739E-01	.12740E+00	.15112E+02	.24645E+02
-56.0	.84188E-01	.12576E+00	.13381E+02	.24316E+02
-55.0	.78911E-01	.12385E+00	.11746E+02	.23932E+02
-54.0	.72807E-01	.12191E+00	.98296E+01	.23541E+02
-53.0	.67488E-01	.11987E+00	.81744E+01	.23130E+02
-52.0	.61125E-01	.11769E+00	.61670E+01	.22689E+02
-51.0	.55437E-01	.11537E+00	.43671E+01	.22220E+02
-50.0	.48525E-01	.11297E+00	.21944E+01	.21734E+02
-49.0	.42713E-01	.11041E+00	.35084E+00	.21214E+02
-48.0	.36197E-01	.10777E+00	-.17339E+01	.20678E+02
-47.0	.30558E-01	.10494E+00	-.35520E+01	.20103E+02
-46.0	.25612E-01	.10205E+00	-.51687E+01	.19512E+02
-45.0	.21919E-01	.99004E-01	-.63898E+01	.18891E+02
-44.0	.19074E-01	.95852E-01	-.73491E+01	.18247E+02
-43.0	.16936E-01	.92478E-01	-.80829E+01	.17555E+02
-42.0	.15409E-01	.88944E-01	-.86130E+01	.16830E+02
-41.0	.14264E-01	.85122E-01	-.90179E+01	.16042E+02
-40.0	.13372E-01	.81175E-01	-.93387E+01	.15229E+02
-39.0	.12683E-01	.77012E-01	-.95887E+01	.14367E+02
-38.0	.12132E-01	.72551E-01	-.97909E+01	.13442E+02
-37.0	.11680E-01	.67945E-01	-.99587E+01	.12484E+02
-36.0	.11305E-01	.63103E-01	-.10099E+02	.11473E+02
-35.0	.10988E-01	.58109E-01	-.10219E+02	.10425E+02
-34.0	.10717E-01	.53095E-01	-.10321E+02	.93674E+01
-33.0	.10481E-01	.48116E-01	-.10411E+02	.83095E+01
-32.0	.10274E-01	.43318E-01	-.10489E+02	.72814E+01
-31.0	.10091E-01	.38895E-01	-.10558E+02	.63234E+01
-30.0	.99190E-02	.34986E-01	-.10625E+02	.54664E+01
-29.0	.97276E-02	.31677E-01	-.10706E+02	.47306E+01
-28.0	.95203E-02	.28944E-01	-.10798E+02	.41129E+01
-27.0	.93022E-02	.26722E-01	-.10897E+02	.36021E+01
-26.0	.90764E-02	.24934E-01	-.11002E+02	.31841E+01
-25.0	.88462E-02	.23495E-01	-.11109E+02	.28412E+01
-24.0	.86148E-02	.22326E-01	-.11219E+02	.25578E+01
-23.0	.83847E-02	.21372E-01	-.11329E+02	.23221E+01
-22.0	.81585E-02	.20590E-01	-.11438E+02	.21255E+01
-21.0	.79376E-02	.19941E-01	-.11547E+02	.19600E+01
-20.0	.77264E-02	.19396E-01	-.11651E+02	.18188E+01
-19.0	.75267E-02	.18935E-01	-.11751E+02	.16975E+01
-18.0	.73391E-02	.18541E-01	-.11845E+02	.15928E+01
-17.0	.71653E-02	.18203E-01	-.11932E+02	.15021E+01
-16.0	.70059E-02	.17910E-01	-.12011E+02	.14228E+01
-15.0	.68605E-02	.17653E-01	-.12083E+02	.13528E+01
-14.0	.67286E-02	.17425E-01	-.12147E+02	.12907E+01
-13.0	.66095E-02	.17223E-01	-.12204E+02	.12354E+01
-12.0	.65022E-02	.17043E-01	-.12254E+02	.11859E+01
-11.0	.64055E-02	.16881E-01	-.12298E+02	.11416E+01
-10.0	.63181E-02	.16734E-01	-.12336E+02	.11017E+01
-9.0	.62393E-02	.16600E-01	-.12370E+02	.10658E+01
-8.0	.61681E-02	.16478E-01	-.12398E+02	.10333E+01
-7.0	.61037E-02	.16364E-01	-.12423E+02	.10034E+01
-6.0	.60473E-02	.16245E-01	-.12442E+02	.97055E+00
-5.0	.59989E-02	.16117E-01	-.12454E+02	.93299E+00
-4.0	.59562E-02	.15980E-01	-.12463E+02	.89087E+00
-3.0	.59174E-02	.15835E-01	-.12469E+02	.84443E+00
-2.0	.58822E-02	.15685E-01	-.12473E+02	.79408E+00
-1.0	.58496E-02	.15530E-01	-.12477E+02	.74040E+00
.0	.58192E-02	.15371E-01	-.12481E+02	.68413E+00
1.0	.57901E-02	.15264E-01	-.12460E+02	.65944E+00

2.0	.57513E-02	.15190E-01	-.12426E+02	.65581E+00
3.0	.57187E-02	.15111E-01	-.12402E+02	.64791E+00
4.0	.56912E-02	.15026E-01	-.12385E+02	.63588E+00
5.0	.56678E-02	.14935E-01	-.12372E+02	.61966E+00
6.0	.56475E-02	.14839E-01	-.12362E+02	.59986E+00
7.0	.56254E-02	.14738E-01	-.12360E+02	.57795E+00
8.0	.56012E-02	.14631E-01	-.12362E+02	.55389E+00
9.0	.55766E-02	.14519E-01	-.12368E+02	.52758E+00
10.0	.55580E-02	.14403E-01	-.12368E+02	.49905E+00
11.0	.55424E-02	.14282E-01	-.12368E+02	.46841E+00
12.0	.55317E-02	.14159E-01	-.12364E+02	.43582E+00
13.0	.55228E-02	.14033E-01	-.12359E+02	.40161E+00
14.0	.55147E-02	.13906E-01	-.12355E+02	.36603E+00
15.0	.55070E-02	.13779E-01	-.12350E+02	.32944E+00
16.0	.54998E-02	.13652E-01	-.12345E+02	.29215E+00
17.0	.54912E-02	.13527E-01	-.12337E+02	.25451E+00
18.0	.54817E-02	.13403E-01	-.12321E+02	.21694E+00
19.0	.54744E-02	.13282E-01	-.12301E+02	.17968E+00
20.0	.54704E-02	.13163E-01	-.12279E+02	.14291E+00
21.0	.54734E-02	.13048E-01	-.12250E+02	.10696E+00
22.0	.54839E-02	.12937E-01	-.12217E+02	.72147E-01
23.0	.55092E-02	.12829E-01	-.12174E+02	.38664E-01
24.0	.55209E-02	.12726E-01	-.12154E+02	.66656E-02
25.0	.55300E-02	.12627E-01	-.12140E+02	-.23767E-01
26.0	.55617E-02	.12533E-01	-.12106E+02	-.52568E-01
27.0	.56034E-02	.12442E-01	-.12070E+02	-.79661E-01
28.0	.56218E-02	.12357E-01	-.12054E+02	-.10500E+00
29.0	.56964E-02	.12275E-01	-.12005E+02	-.12862E+00
30.0	.58116E-02	.12198E-01	-.11943E+02	-.15048E+00
31.0	.59176E-02	.12125E-01	-.11894E+02	-.17058E+00
32.0	.60266E-02	.12057E-01	-.11848E+02	-.18894E+00
33.0	.61473E-02	.11992E-01	-.11801E+02	-.20557E+00
34.0	.62973E-02	.11932E-01	-.11747E+02	-.22056E+00
35.0	.64716E-02	.11875E-01	-.11688E+02	-.23403E+00
36.0	.66750E-02	.11823E-01	-.11621E+02	-.24614E+00
37.0	.68863E-02	.11773E-01	-.11551E+02	-.25700E+00
38.0	.71436E-02	.11727E-01	-.11466E+02	-.26671E+00
39.0	.74993E-02	.11684E-01	-.11343E+02	-.27489E+00
40.0	.80676E-02	.11643E-01	-.11135E+02	-.28121E+00
41.0	.93570E-02	.11605E-01	-.10651E+02	-.28585E+00
42.0	.14532E-01	.11569E-01	-.88166E+01	-.28894E+00
43.0	.30096E-01	.11536E-01	-.37012E+01	-.29052E+00
44.0	.51995E-01	.11505E-01	.32529E+01	-.29062E+00
45.0	.75639E-01	.11476E-01	.10653E+02	-.28938E+00
46.0	.97725E-01	.11449E-01	.17507E+02	-.28697E+00
47.0	.12039E+00	.11424E-01	.24490E+02	-.28355E+00
48.0	.14054E+00	.11401E-01	.30644E+02	-.27926E+00
49.0	.15888E+00	.11380E-01	.36176E+02	-.27423E+00
50.0	.17729E+00	.11360E-01	.41552E+02	-.26869E+00
51.0	.20003E+00	.11340E-01	.44774E+02	-.26317E+00
52.0	.30473E+00	.11322E-01	.45074E+02	-.25760E+00
53.0	.48517E+00	.11303E-01	.45283E+02	-.25153E+00
54.0	.68064E+00	.11285E-01	.45542E+02	-.24495E+00
55.0	.88812E+00	.11267E-01	.41633E+02	-.23804E+00
56.0	.85789E+00	.11250E-01	.55178E+02	-.23126E+00
57.0	.73944E+00	.11234E-01	.50368E+02	-.22456E+00
58.0	.64120E+00	.11217E-01	.48033E+02	-.21451E+00
59.0	.59124E+00	.11203E-01	.47016E+02	-.19942E+00
60.0	.56063E+00	.11192E-01	.46939E+02	-.18076E+00
61.0	.54680E+00	.11188E-01	.47064E+02	-.15803E+00
62.0	.54718E+00	.11189E-01	.47226E+02	-.13232E+00
63.0	.55990E+00	.11197E-01	.47377E+02	-.10528E+00

64.0	.58374E+00	.11208E-01	.47532E+02	-.77920E-01
65.0	.61866E+00	.11224E-01	.47675E+02	-.50724E-01
66.0	.66467E+00	.11241E-01	.47802E+02	-.25050E-01
67.0	.72416E+00	.11259E-01	.47927E+02	-.14597E-02
68.0	.80347E+00	.11275E-01	.48002E+02	.18411E-01
69.0	.88495E+00	.11283E-01	.42480E+02	.31989E-01
70.0	.85211E+00	.11288E-01	.57438E+02	.41861E-01
71.0	.80566E+00	.11292E-01	.73397E+02	.51177E-01
72.0	.72947E+00	.11300E-01	.35495E+02	.62066E-01
73.0	.68726E+00	.11412E-01	.47003E+02	.11699E+00
74.0	.69275E+00	.11491E-01	.48510E+02	.15431E+00
75.0	.71708E+00	.11540E-01	.48746E+02	.17705E+00
76.0	.75486E+00	.11580E-01	.48836E+02	.19503E+00
77.0	.80857E+00	.11610E-01	.48868E+02	.20801E+00
78.0	.87449E+00	.11626E-01	.47575E+02	.21510E+00
79.0	.86425E+00	.11638E-01	.50350E+02	.22040E+00
80.0	.79259E+00	.11650E-01	.80554E+02	.22538E+00
81.0	.72153E+00	.11662E-01	.10835E+03	.23036E+00
82.0	.66462E+00	.11713E-01	.65437E+02	.24804E+00
83.0	.70057E+00	.11955E-01	.53594E+02	.32037E+00
84.0	.76220E+00	.12039E-01	.50226E+02	.34475E+00
85.0	.83217E+00	.12076E-01	.49507E+02	.35543E+00
86.0	.88173E+00	.12097E-01	.43930E+02	.36134E+00
87.0	.83160E+00	.12117E-01	.63277E+02	.36676E+00
88.0	.76639E+00	.12136E-01	.87272E+02	.37207E+00
89.0	.70456E+00	.12187E-01	.60548E+02	.38582E+00
90.0	.68317E+00	.12446E-01	.52579E+02	.45259E+00
91.0	.67886E+00	.12618E-01	.50320E+02	.49556E+00
92.0	.67076E+00	.12747E-01	.49885E+02	.52776E+00
93.0	.65116E+00	.12870E-01	.49840E+02	.55822E+00
94.0	.61593E+00	.13001E-01	.49870E+02	.59075E+00
95.0	.56178E+00	.13126E-01	.49901E+02	.62168E+00
96.0	.48606E+00	.13258E-01	.49946E+02	.65458E+00
97.0	.39031E+00	.13371E-01	.49979E+02	.68266E+00
98.0	.28201E+00	.13403E-01	.49984E+02	.69008E+00
99.0	.19539E+00	.14109E-01	.47138E+02	.66615E+00
100.0	.22845E+00	.14139E-01	.50416E+02	.69807E+00
101.0	.30783E+00	.14205E-01	.50178E+02	.74331E+00
102.0	.39539E+00	.14457E-01	.50132E+02	.84982E+00
103.0	.45859E+00	.14857E-01	.50150E+02	.99195E+00
104.0	.48901E+00	.15192E-01	.50162E+02	.11029E+01
105.0	.48377E+00	.15444E-01	.50181E+02	.11812E+01
106.0	.44519E+00	.15961E-01	.50230E+02	.13210E+01
107.0	.37768E+00	.16427E-01	.50237E+02	.14400E+01
108.0	.28456E+00	.17079E-01	.50245E+02	.14665E+01
109.0	.19342E+00	.18085E-01	.46617E+02	.17539E+01
110.0	.22391E+00	.18127E-01	.51117E+02	.17793E+01
111.0	.28844E+00	.18628E-01	.50444E+02	.19333E+01
112.0	.34349E+00	.21001E-01	.50352E+02	.25106E+01
113.0	.36967E+00	.23166E-01	.50359E+02	.30014E+01
114.0	.36137E+00	.25046E-01	.50370E+02	.34207E+01
115.0	.31788E+00	.26142E-01	.50381E+02	.36629E+01
116.0	.24614E+00	.26701E-01	.50368E+02	.37680E+01
117.0	.19292E+00	.27464E-01	.46410E+02	.39162E+01
118.0	.22878E+00	.28968E-01	.50340E+02	.42794E+01
119.0	.26250E+00	.32971E-01	.50438E+02	.51507E+01
120.0	.27880E+00	.35664E-01	.50455E+02	.57293E+01
121.0	.27394E+00	.38529E-01	.50458E+02	.63425E+01
122.0	.24313E+00	.39684E-01	.50451E+02	.65885E+01
123.0	.19878E+00	.40019E-01	.48104E+02	.66597E+01
124.0	.21423E+00	.42920E-01	.50922E+02	.72755E+01
125.0	.23160E+00	.46620E-01	.50539E+02	.80587E+01

126.0	.23439E+00	.48758E-01	.50498E+02	.85090E+01
127.0	.22116E+00	.50960E-01	.50473E+02	.89724E+01
128.0	.20520E+00	.52362E-01	.49775E+02	.92665E+01
129.0	.20954E+00	.55171E-01	.50528E+02	.98554E+01
130.0	.20982E+00	.57785E-01	.50479E+02	.10402E+02
131.0	.20732E+00	.59865E-01	.50209E+02	.10836E+02
132.0	.20746E+00	.62524E-01	.50256E+02	.11391E+02
133.0	.20723E+00	.64792E-01	.50209E+02	.11863E+02
134.0	.20692E+00	.67279E-01	.50171E+02	.12380E+02
135.0	.20708E+00	.69578E-01	.50193E+02	.12857E+02
136.0	.20677E+00	.72037E-01	.50153E+02	.13366E+02
137.0	.20611E+00	.74222E-01	.50012E+02	.13819E+02
138.0	.20701E+00	.76662E-01	.50203E+02	.14323E+02
139.0	.20628E+00	.78896E-01	.50057E+02	.14784E+02
140.0	.20609E+00	.81128E-01	.50025E+02	.15245E+02
141.0	.20562E+00	.83367E-01	.49923E+02	.15706E+02
142.0	.20437E+00	.85435E-01	.49638E+02	.16131E+02
143.0	.20485E+00	.87347E-01	.49756E+02	.16524E+02
144.0	.20471E+00	.89492E-01	.49723E+02	.16965E+02
145.0	.20449E+00	.91307E-01	.49674E+02	.17337E+02
146.0	.20466E+00	.93188E-01	.49715E+02	.17723E+02
147.0	.20489E+00	.95059E-01	.49773E+02	.18106E+02
148.0	.20374E+00	.96837E-01	.49494E+02	.18469E+02
149.0	.20422E+00	.98440E-01	.49615E+02	.18797E+02
150.0	.20459E+00	.10029E+00	.49704E+02	.19175E+02
151.0	.20377E+00	.10190E+00	.49506E+02	.19503E+02
152.0	.20423E+00	.10350E+00	.49621E+02	.19830E+02
153.0	.20397E+00	.10521E+00	.49557E+02	.20177E+02
154.0	.20403E+00	.10670E+00	.49575E+02	.20479E+02
155.0	.20432E+00	.10836E+00	.49644E+02	.20817E+02
156.0	.20385E+00	.10988E+00	.49532E+02	.21127E+02
157.0	.20397E+00	.11136E+00	.49562E+02	.21427E+02
158.0	.20383E+00	.11292E+00	.49529E+02	.21743E+02
159.0	.20371E+00	.11435E+00	.49499E+02	.22033E+02
160.0	.20391E+00	.11587E+00	.49550E+02	.22342E+02
161.0	.20398E+00	.11743E+00	.49568E+02	.22657E+02
162.0	.20354E+00	.11900E+00	.49459E+02	.22974E+02
163.0	.20250E+00	.12056E+00	.49193E+02	.23290E+02
164.0	.20336E+00	.12218E+00	.49416E+02	.23620E+02
165.0	.20330E+00	.12408E+00	.49400E+02	.24004E+02
166.0	.20311E+00	.12586E+00	.49353E+02	.24365E+02
167.0	.20044E+00	.12768E+00	.48649E+02	.24733E+02
168.0	.20338E+00	.12935E+00	.49426E+02	.25071E+02
169.0	.20300E+00	.13163E+00	.49325E+02	.25531E+02
170.0	.20280E+00	.13325E+00	.49281E+02	.25859E+02
171.0	.20280E+00	.13545E+00	.49279E+02	.26304E+02
172.0	.20371E+00	.13752E+00	.49515E+02	.26721E+02
173.0	.20347E+00	.13960E+00	.49459E+02	.27140E+02
174.0	.20391E+00	.14196E+00	.49577E+02	.27617E+02
175.0	.20439E+00	.14442E+00	.49703E+02	.28112E+02
176.0	.20466E+00	.14712E+00	.49778E+02	.28654E+02
177.0	.20514E+00	.15003E+00	.49911E+02	.29241E+02
178.0	.20623E+00	.15365E+00	.50187E+02	.29969E+02
179.0	.20632E+00	.15710E+00	.50227E+02	.30660E+02
180.0	.20718E+00	.16082E+00	.50445E+02	.31405E+02
181.0	.19905E+00	.12083E+00	.48196E+02	.23191E+02
182.0	.19891E+00	.98088E-01	.48160E+02	.18617E+02
183.0	.19930E+00	.12782E+00	.48269E+02	.24660E+02
184.0	.20080E+00	.10887E+00	.48688E+02	.20805E+02
185.0	.20012E+00	.12314E+00	.48504E+02	.23724E+02
186.0	.20000E+00	.12139E+00	.48480E+02	.23357E+02
187.0	.20152E+00	.12254E+00	.48882E+02	.23600E+02

188.0	.20156E+00	.12811E+00	.48903E+02	.24719E+02
189.0	.20198E+00	.12739E+00	.49020E+02	.24582E+02
190.0	.20207E+00	.13192E+00	.49047E+02	.25498E+02
191.0	.20242E+00	.13329E+00	.49145E+02	.25774E+02
192.0	.20247E+00	.13558E+00	.49164E+02	.26235E+02
193.0	.20278E+00	.13798E+00	.49254E+02	.26718E+02
194.0	.20255E+00	.13962E+00	.49196E+02	.27048E+02
195.0	.20349E+00	.14170E+00	.49442E+02	.27465E+02
196.0	.20336E+00	.14326E+00	.49410E+02	.27776E+02
197.0	.20350E+00	.14475E+00	.49450E+02	.28074E+02
198.0	.20395E+00	.14627E+00	.49561E+02	.28376E+02
199.0	.20396E+00	.14797E+00	.49566E+02	.28713E+02
200.0	.20335E+00	.14976E+00	.49408E+02	.29071E+02
201.0	.20443E+00	.15103E+00	.49683E+02	.29320E+02
202.0	.20329E+00	.15245E+00	.49397E+02	.29602E+02
203.0	.20340E+00	.15334E+00	.49428E+02	.29775E+02
204.0	.20247E+00	.15415E+00	.49188E+02	.29934E+02
205.0	.20263E+00	.15490E+00	.49232E+02	.30080E+02
206.0	.20359E+00	.15544E+00	.49476E+02	.30185E+02
207.0	.20329E+00	.15614E+00	.49400E+02	.30320E+02
208.0	.20203E+00	.15645E+00	.49073E+02	.30379E+02
209.0	.20238E+00	.15681E+00	.49166E+02	.30447E+02
210.0	.20262E+00	.15725E+00	.49229E+02	.30532E+02
211.0	.20246E+00	.15753E+00	.49186E+02	.30585E+02
212.0	.20245E+00	.15788E+00	.49185E+02	.30651E+02
213.0	.20179E+00	.15812E+00	.49009E+02	.30696E+02
214.0	.20124E+00	.15820E+00	.48865E+02	.30709E+02
215.0	.20184E+00	.15836E+00	.49023E+02	.30740E+02
216.0	.20148E+00	.15854E+00	.48929E+02	.30772E+02
217.0	.20090E+00	.15858E+00	.48774E+02	.30779E+02
218.0	.20052E+00	.15868E+00	.48672E+02	.30797E+02
219.0	.20123E+00	.15875E+00	.48861E+02	.30809E+02
220.0	.20130E+00	.15903E+00	.48878E+02	.30861E+02
221.0	.20084E+00	.15931E+00	.48757E+02	.30915E+02
222.0	.20077E+00	.15947E+00	.48739E+02	.30945E+02
223.0	.20008E+00	.15967E+00	.48551E+02	.30985E+02
224.0	.20071E+00	.15976E+00	.48721E+02	.31001E+02
225.0	.20010E+00	.15996E+00	.48555E+02	.31040E+02
226.0	.20286E+00	.16010E+00	.49288E+02	.31064E+02
227.0	.20284E+00	.16058E+00	.49279E+02	.31155E+02
228.0	.21664E+00	.16115E+00	.50979E+02	.31259E+02
229.0	.28489E+00	.16404E+00	.50908E+02	.31794E+02
230.0	.39069E+00	.17109E+00	.50944E+02	.33030E+02
231.0	.49159E+00	.18646E+00	.50916E+02	.34187E+02
232.0	.55430E+00	.22897E+00	.50890E+02	.34173E+02
233.0	.56677E+00	.29618E+00	.50886E+02	.34211E+02
234.0	.52701E+00	.36063E+00	.50889E+02	.34227E+02
235.0	.43669E+00	.39717E+00	.50893E+02	.34198E+02
236.0	.30239E+00	.39190E+00	.50873E+02	.34146E+02
237.0	.18058E+00	.33886E+00	.42800E+02	.34139E+02
238.0	.23755E+00	.25873E+00	.51481E+02	.34201E+02
239.0	.28922E+00	.20102E+00	.50995E+02	.33992E+02
240.0	.31171E+00	.19443E+00	.50891E+02	.33924E+02
241.0	.30261E+00	.23043E+00	.50866E+02	.34100E+02
242.0	.26629E+00	.27487E+00	.50838E+02	.34127E+02
243.0	.21407E+00	.29834E+00	.50746E+02	.34107E+02
244.0	.20694E+00	.28822E+00	.50224E+02	.34132E+02
245.0	.23455E+00	.25614E+00	.50678E+02	.34120E+02
246.0	.25925E+00	.22278E+00	.50800E+02	.34058E+02
247.0	.27606E+00	.20357E+00	.50831E+02	.33984E+02
248.0	.28190E+00	.20408E+00	.50837E+02	.33984E+02
249.0	.27649E+00	.21817E+00	.50831E+02	.34029E+02

250.0	.26254E+00	.23392E+00	.50815E+02	.34054E+02
251.0	.24524E+00	.24163E+00	.50787E+02	.34058E+02
252.0	.23113E+00	.23720E+00	.50754E+02	.34049E+02
253.0	.22600E+00	.22244E+00	.50737E+02	.34024E+02
254.0	.23263E+00	.20325E+00	.50753E+02	.33972E+02
255.0	.24999E+00	.18706E+00	.50786E+02	.33899E+02
256.0	.27437E+00	.18020E+00	.50817E+02	.33902E+02
257.0	.30069E+00	.18608E+00	.50837E+02	.33903E+02
258.0	.32316E+00	.20666E+00	.50848E+02	.33985E+02
259.0	.33613E+00	.23954E+00	.50851E+02	.34056E+02
260.0	.33548E+00	.27913E+00	.50848E+02	.34099E+02
261.0	.32015E+00	.31670E+00	.50841E+02	.34103E+02
262.0	.29308E+00	.34168E+00	.50827E+02	.34087E+02
263.0	.26134E+00	.34600E+00	.50798E+02	.34074E+02
264.0	.23478E+00	.32823E+00	.50752E+02	.34074E+02
265.0	.22302E+00	.29502E+00	.50717E+02	.34077E+02
266.0	.23128E+00	.25924E+00	.50739E+02	.34060E+02
267.0	.25841E+00	.23425E+00	.50787E+02	.34026E+02
268.0	.29869E+00	.22977E+00	.50825E+02	.34022E+02
269.0	.34394E+00	.25093E+00	.50844E+02	.34068E+02
270.0	.38451E+00	.29721E+00	.50849E+02	.34121E+02
271.0	.41160E+00	.36050E+00	.50847E+02	.34128E+02
272.0	.41990E+00	.42515E+00	.50844E+02	.34100E+02
273.0	.40780E+00	.47646E+00	.50842E+02	.34080E+02
274.0	.37677E+00	.50730E+00	.50839E+02	.34067E+02
275.0	.33163E+00	.51549E+00	.50832E+02	.34050E+02
276.0	.28163E+00	.50037E+00	.50810E+02	.34028E+02
277.0	.24036E+00	.46301E+00	.50761E+02	.34027E+02
278.0	.22207E+00	.40947E+00	.50712E+02	.34054E+02
279.0	.23532E+00	.35303E+00	.50742E+02	.34084E+02
280.0	.27952E+00	.31188E+00	.50803E+02	.34099E+02
281.0	.34662E+00	.30347E+00	.50839E+02	.34120E+02
282.0	.42367E+00	.33844E+00	.50845E+02	.34153E+02
283.0	.49733E+00	.41239E+00	.50835E+02	.34130E+02
284.0	.55982E+00	.50501E+00	.50826E+02	.34081E+02
285.0	.60873E+00	.59957E+00	.50822E+02	.34072E+02
286.0	.64403E+00	.69178E+00	.50820E+02	.34088E+02
287.0	.66654E+00	.78291E+00	.50819E+02	.34110E+02
288.0	.67731E+00	.87107E+00	.50818E+02	.33415E+02
289.0	.67754E+00	.86773E+00	.50819E+02	.33968E+02
290.0	.66884E+00	.83450E+00	.50819E+02	.33675E+02
291.0	.65306E+00	.81485E+00	.50819E+02	.34301E+02
292.0	.63218E+00	.81708E+00	.50820E+02	.34294E+02
293.0	.60813E+00	.84385E+00	.50820E+02	.34180E+02
294.0	.58261E+00	.87627E+00	.50821E+02	.32089E+02
295.0	.55722E+00	.86381E+00	.50821E+02	.34539E+02
296.0	.53362E+00	.86486E+00	.50822E+02	.34030E+02
297.0	.51357E+00	.87192E+00	.50822E+02	.33139E+02
298.0	.49880E+00	.86771E+00	.50821E+02	.33988E+02
299.0	.49099E+00	.87099E+00	.50820E+02	.33360E+02
300.0	.49160E+00	.86957E+00	.50818E+02	.33665E+02
301.0	.50187E+00	.87070E+00	.50815E+02	.33440E+02
302.0	.52288E+00	.87058E+00	.50812E+02	.33468E+02
303.0	.55561E+00	.87092E+00	.50807E+02	.33409E+02
304.0	.60107E+00	.87119E+00	.50800E+02	.33350E+02
305.0	.66039E+00	.87132E+00	.50793E+02	.33334E+02
306.0	.73481E+00	.87163E+00	.50781E+02	.33268E+02
307.0	.82558E+00	.87173E+00	.50772E+02	.33247E+02
308.0	.87263E+00	.87196E+00	.48188E+02	.33195E+02
309.0	.84579E+00	.87207E+00	.50372E+02	.33170E+02
310.0	.84054E+00	.87227E+00	.50678E+02	.33125E+02
311.0	.85897E+00	.87241E+00	.50699E+02	.33091E+02

312.0	.86747E+00	.87259E+00	.50151E+02	.33050E+02
313.0	.86541E+00	.87274E+00	.50530E+02	.33013E+02
314.0	.86696E+00	.87291E+00	.50252E+02	.32972E+02
315.0	.86708E+00	.87306E+00	.50189E+02	.32935E+02
316.0	.86678E+00	.87322E+00	.50224E+02	.32895E+02
317.0	.86716E+00	.87338E+00	.50094E+02	.32857E+02
318.0	.86697E+00	.87354E+00	.50107E+02	.32819E+02
319.0	.86715E+00	.87369E+00	.50030E+02	.32780E+02
320.0	.86711E+00	.87384E+00	.49998E+02	.32741E+02
321.0	.86715E+00	.87399E+00	.49947E+02	.32702E+02
322.0	.86722E+00	.87416E+00	.49920E+02	.32656E+02
323.0	.86730E+00	.87431E+00	.49881E+02	.32612E+02
324.0	.86733E+00	.87448E+00	.49839E+02	.32562E+02
325.0	.86739E+00	.87465E+00	.49807E+02	.32509E+02
326.0	.86752E+00	.87479E+00	.49784E+02	.32455E+02
327.0	.86781E+00	.87494E+00	.49775E+02	.32402E+02
328.0	.86789E+00	.87508E+00	.49756E+02	.32348E+02
329.0	.86802E+00	.87522E+00	.49727E+02	.32296E+02
330.0	.86810E+00	.87536E+00	.49708E+02	.32240E+02
331.0	.86820E+00	.87549E+00	.49684E+02	.32186E+02
332.0	.86828E+00	.87561E+00	.49663E+02	.32143E+02
333.0	.86836E+00	.87573E+00	.49642E+02	.32104E+02
334.0	.86844E+00	.87585E+00	.49622E+02	.32052E+02
335.0	.86851E+00	.87596E+00	.49602E+02	.32007E+02
336.0	.86859E+00	.87606E+00	.49584E+02	.31960E+02
337.0	.86865E+00	.87616E+00	.49565E+02	.31920E+02
338.0	.86872E+00	.87625E+00	.49548E+02	.31877E+02
339.0	.86877E+00	.87630E+00	.49532E+02	.31798E+02
340.0	.86883E+00	.87630E+00	.49515E+02	.31724E+02
341.0	.86888E+00	.87629E+00	.49500E+02	.31669E+02
342.0	.86893E+00	.87625E+00	.49486E+02	.31611E+02
343.0	.86898E+00	.87619E+00	.49472E+02	.31569E+02
344.0	.86902E+00	.87618E+00	.49460E+02	.31531E+02
345.0	.86906E+00	.87622E+00	.49447E+02	.31514E+02
346.0	.86911E+00	.87630E+00	.49436E+02	.31493E+02
347.0	.86914E+00	.87640E+00	.49425E+02	.31484E+02
348.0	.86917E+00	.87652E+00	.49415E+02	.31472E+02
349.0	.86920E+00	.87664E+00	.49406E+02	.31470E+02
350.0	.86923E+00	.87676E+00	.49397E+02	.31466E+02
351.0	.86926E+00	.87688E+00	.49390E+02	.31472E+02
352.0	.86928E+00	.87699E+00	.49383E+02	.31475E+02
353.0	.86930E+00	.87706E+00	.49376E+02	.31478E+02
354.0	.86932E+00	.87711E+00	.49371E+02	.31470E+02
355.0	.86934E+00	.87716E+00	.49366E+02	.31481E+02
356.0	.86935E+00	.87721E+00	.49362E+02	.31468E+02
357.0	.86936E+00	.87720E+00	.49358E+02	.31462E+02
358.0	.86937E+00	.87718E+00	.49356E+02	.31446E+02
359.0	.86938E+00	.87717E+00	.49354E+02	.31451E+02
360.0	.86938E+00	.87718E+00	.49354E+02	.31441E+02

Appendix G: Input Files of *Liner Vaporization Model*

1600 rpm-Full load condition

maininput.inp:

```
simpleInput:          .TRUE.
simpleInputFileName:   CycleSim.out
readInitSpecMassFrac:  .TRUE.
variableOilTemp:       .TRUE.
variableSC:           .TRUE.
incDepletion:         .TRUE.
changeThick:          .TRUE.
incHeatOfVap:         .TRUE.
incRingInfluece:      .TRUE.
fullOutput:           .TRUE.
startCrankAngle:      -360.D0
endCrankAngle:        360.D0
varTempStepScale:     0.8D0
minCrankAngStep:      0.1D0
outputCrankAngStep:   5.0D0
PrExp:               0.33333333D0
HTConst:              0.035D0
HTExp:               0.8D0
lenCrownLand:         0.01D0
posOilUpdate:         -0.035D0
```

oilprops.inp:

```
twoZones: .TRUE.
NumSpec: 10
BP: 588.1D0
610.0D0
626.3D0
636.6D0
655.3D0
671.5D0
689.6D0
713.1D0
744.8D0
795.2D0
SpecMassFracTop: 0.0179D0
0.0268D0
0.0446D0
0.0893D0
0.0893D0
0.0893D0
0.1339D0
0.1339D0
0.1785D0
0.1967D0
SpecMassFracDefault: 0.0179D0
0.0268D0
0.0446D0
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0.0893D0
0.0893D0
0.0893D0
0.1339D0
0.1339D0
0.1785D0
0.1967D0
EvapScConst: 2.5D0
alphaOil: 0.8D-7
kOil: 130.D-3
densOil: 850.D0

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCC Comments CCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

Oil: Unspecified 15w40
Model: 4th Model for this oil

EvapScConst is ignored if variableSC is set to TRUE in maininpt.inp.

alphaOil is ignored if the fully transient temperature model is not used (which is the default state of the vaporization model right now).

loft.dat:

```
 .000   .4542  .4623
 .076   .0789  .0789
 .153   .0721  .0723
 .229   .0740  .0741
 .306   .0758  .0760
 .382   .0757  .0758
 .458   .0791  .0793
 .535   .0789  .0790
 .611   .0805  .0807
 .687   .0811  .0813
 .764   .0823  .0824
 .840   .0840  .0841
 .917   .0855  .0856
 .993   .0863  .0864
1.069   .0874  .0875
1.146   .0894  .0896
1.222   .0914  .0915
1.298   .0918  .0920
1.375   .0915  .0917
1.451   .0944  .0946
1.528   .0959  .0961
1.604   .0973  .0975
1.680   .0982  .0984
1.757   .0993  .0995
1.833   .1008  .1010
1.909   .1018  .1020
1.986   .1031  .1034
2.062   .1046  .1048
2.139   .1061  .1064
2.215   .1076  .1079
2.291   .1084  .1087
2.368   .1105  .1107
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2.597	.1136	.1139
2.673	.1146	.1149
2.750	.1156	.1159
2.826	.1168	.1171
2.902	.1180	.1183
2.979	.1191	.1194
3.055	.1203	.1206
3.131	.1215	.1218
3.208	.1227	.1230
3.284	.1238	.1242
3.361	.1253	.1257
3.437	.1264	.1267
3.513	.1276	.1280
3.590	.1289	.1293
3.666	.1294	.1298
3.742	.1316	.1319
3.819	.1329	.1333
3.895	.1340	.1344
3.972	.1347	.1798
4.048	.1360	.1802
4.124	.1369	.1815
4.201	.1377	.1838
4.277	.1384	.1852
4.353	.1398	.1873
4.430	.1409	.1902
4.506	.1419	.1923
4.583	.1429	.1946
4.659	.1443	.1971
4.735	.1472	.1998
4.812	.1488	.2029
4.888	.1501	.2046
4.964	.1512	.2076
5.041	.1534	.2112
5.117	.1562	.2128
5.194	.1577	.2127
5.270	.1586	.2157
5.346	.1600	.2178
5.423	.1623	.2200
5.499	.1640	.2214
5.575	.1655	.2240
5.652	.1671	.2286
5.728	.1689	.2300
5.805	.1721	.2321
5.881	.1746	.2342
5.957	.1770	.2362
6.034	.1791	.2383
6.110	.1810	.2403
6.186	.1851	.2423
6.263	.1883	.2463
6.339	.1920	.5212
6.416	.1930	.5079
6.492	.1955	.5060
6.568	.1996	.5060
6.645	.2032	.5064
6.721	.2062	.5065
6.797	.2089	.5060
6.874	.2117	.5045
6.950	.2149	.5024
7.027	.2178	.4994
7.103	.2204	.4958

7.179	.2230	.4917
7.256	.2256	.4867
7.332	.2288	.4814
7.409	.2313	.4757
7.485	.2338	.4696
7.561	.2363	.4636
7.638	.2389	.4569
7.714	.2416	.4498
7.790	.2442	.4426
7.867	.2470	.4356
7.943	.2499	.4281
8.020	.2526	.4209
8.096	.2552	.4137
8.172	.2580	.4060
8.249	.2594	.3987
8.325	.2626	.3917
8.401	.2654	.3848
8.478	.2680	.3781
8.554	.2704	.3717
8.631	.2696	.3657
8.707	.2733	.3601
8.783	.2762	.3552
8.860	.2786	.3505
8.936	.2807	.3463
9.012	.2824	.3428
9.089	.2808	.3396
9.165	.2837	.3371
9.242	.2861	.3349
9.318	.2879	.3333
9.394	.2892	.3321
9.471	.2903	.3312
9.547	.2911	.3308
9.623	.2884	.3306
9.700	.2914	.3308
9.776	.2933	.3313
9.853	.2943	.3319
9.929	.2948	.3328
10.005	.2947	.3339
10.082	.2969	.3351
10.158	.2938	.3365
10.234	.2919	.3379
10.311	.2907	.3395
10.387	.2900	.3412
10.464	.2896	.3429
10.540	.2820	.3447
10.616	.2873	.3466
10.693	.2901	.3484
10.769	.2913	.3502
10.845	.2914	.3522
10.922	.2904	.3541
10.998	.2887	.3561
11.075	.2832	.3580
11.151	.2838	.3599
11.227	.2835	.3619
11.304	.2825	.3638
11.380	.2808	.3659
11.456	.2789	.3678
11.533	.2717	.3697
11.609	.2724	.3716
11.686	.2722	.3734
11.762	.2713	.3753
11.838	.2699	.3772

11.915	.2684	.3789
11.991	.2665	.3807
12.067	.2621	.3825
12.144	.2617	.3843
12.220	.2610	.3861
12.297	.2602	.3877
12.373	.2591	.3895
12.449	.2579	.3912
12.526	.2568	.3928
12.602	.2546	.3945
12.678	.2542	.3961
12.755	.2538	.3977
12.831	.2534	.3993
12.908	.2530	.4009
12.984	.2526	.4024
13.060	.2522	.4040
13.137	.2515	.4053
13.213	.2514	.4063
13.289	.2514	.4083
13.366	.2515	.4094
13.442	.2515	.4104
13.519	.2516	.4124
13.595	.2517	.4134
13.671	.2522	.4153
13.748	.2521	.4163
13.824	.2522	.4182
13.901	.2524	.4192
13.977	.2525	.4202
14.053	.2530	.4220
14.130	.2533	.4230
14.206	.2546	.4248
14.282	.2546	.4257
14.359	.2547	.4266
14.435	.2550	.4284
14.512	.2552	.4293
14.588	.2555	.4302
14.664	.2561	.4319
14.741	.2565	.4327
14.817	.2580	.4345
14.893	.2580	.4353
14.970	.2581	.4361
15.046	.2584	.4377
15.123	.2586	.4385
15.199	.2590	.4393
15.275	.2598	.4409
15.352	.2618	.4417
15.428	.2616	.4433
15.504	.2616	.4440
15.581	.2617	.4448
15.657	.2622	.4463
15.734	.2626	.4471
15.810	.2631	.4478
15.886	.2656	.4493
15.963	.2656	.4501
16.039	.2656	.4508
16.115	.2657	.4523
16.192	.2659	.4530
16.268	.2662	.4537
16.345	.2671	.4551
16.421	.2676	.4558
16.497	.2686	.4565
16.574	.2690	.4579

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16.726	.2692	.4592
16.803	.2694	.4605
16.879	.2696	.4612
16.956	.2699	.4619
17.032	.2701	.4631
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17.185	.2713	.4644
17.261	.2721	.4657
17.337	.2724	.4663
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17.490	.2734	.4682
17.567	.2738	.4688
17.643	.2796	.4694
17.719	.2772	.4700
17.796	.2740	.4711
17.872	.2731	.4717
17.948	.2727	.4723
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18.178	.2751	.4745
18.254	.2790	.4756
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18.407	.2771	.4768
18.483	.2766	.4773
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19.170	.2978	.4837
19.247	.2984	.4842
19.323	.2982	.4847
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20.316	.2976	.4930
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20.851	.3109	.4971
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21.156	.3143	.4993
21.233	.3133	.4997
21.309	.3149	.5001

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21.538	.3194	.5019
21.615	.3201	.5023
21.691	.3209	.5027
21.767	.3223	.5035
21.844	.3210	.5039
21.920	.3234	.5043
21.996	.3256	.5047
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22.226	.3317	.5063
22.302	.3328	.5067
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23.218	.3485	.5124
23.295	.3497	.5128
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23.753	.3536	.5156
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23.906	.3432	.5163
23.982	.3402	.5166
24.059	.3383	.5170
24.135	.3390	.5177
24.211	.3409	.5180
24.288	.3438	.5184
24.364	.3543	.5187
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24.593	.3443	.5200
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27.266	.4224	.5324
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27.954	.4358	.5353
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28.183	.4514	.5360
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28.336	.4227	.5368
28.412	.4180	.5370
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28.794	.4397	.5385
28.870	.4294	.5387
28.947	.4221	.5389
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29.099	.4142	.5396
29.176	.4152	.5399
29.252	.4176	.5401
29.329	.4214	.5403
29.405	.4263	.5405
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29.634	.4766	.5414
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29.787	.5062	.5418
29.863	.5208	.5423
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30.092	.5125	.5429
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30.321	.5100	.5438
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30.551	.5066	.5444
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30.780	.4995	.5452

30.856	.4998	.5454
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31.238	.4993	.5465
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31.391	.4966	.5469
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31.543	.4989	.5475
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31.773	.5000	.5481
31.849	.5004	.5484
31.925	.5004	.5486
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32.078	.4998	.5490
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32.231	.5022	.5495
32.307	.5028	.5497
32.384	.5032	.5498
32.460	.5035	.5500
32.536	.5037	.5502
32.613	.5011	.5505
32.689	.5026	.5507
32.765	.5037	.5508
32.842	.5047	.5510
32.918	.5054	.5512
32.995	.5065	.5515
33.071	.5067	.5517
33.147	.5068	.5518
33.224	.5068	.5520
33.300	.5044	.5522
33.376	.5056	.5523
33.453	.5073	.5526
33.529	.5079	.5528
33.606	.5084	.5529
33.682	.5088	.5531
33.758	.5091	.5532
33.835	.5096	.5535
33.911	.5132	.5537
33.987	.5111	.5538
34.064	.5095	.5540
34.140	.5085	.5541
34.217	.5076	.5544
34.293	.5077	.5545
34.369	.5081	.5547
34.446	.5089	.5548
34.522	.5099	.5550
34.598	.5175	.5553
34.675	.5129	.5554
34.751	.5097	.5555
34.828	.5076	.5556
34.904	.5067	.5558
34.980	.5077	.5560
35.057	.5094	.5562
35.133	.5117	.5563
35.210	.5266	.5564
35.286	.5235	.5566
35.362	.5208	.5568
35.439	.5207	.5570
35.515	.5214	.5571

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35.668	.5249	.5573
35.744	.5307	.5576
35.821	.5372	.5577
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35.973	.5441	.5579
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36.126	.5539	.5583
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36.279	.5598	.5585
36.355	.5625	.5586
36.432	.5636	.5588
36.508	.5664	.5590
36.584	.5688	.5591
36.661	.5708	.5592
36.737	.5725	.5593
36.813	.5752	.5595
36.890	.5762	.5596
36.966	.5772	.5597
37.043	.5781	.5598
37.119	.5743	.5599
37.195	.5789	.5601
37.272	.5804	.5602
37.348	.5814	.5603
37.424	.5820	.5604
37.501	.5824	.5606
37.577	.5822	.5607
37.654	.5818	.5608
37.730	.5834	.5609
37.806	.5815	.5610
37.883	.5784	.5612
37.959	.5772	.5613
38.035	.5763	.5614
38.112	.5755	.5615
38.188	.5744	.5616
38.265	.5742	.5617
38.341	.5587	.5618
38.417	.5672	.5619
38.494	.5741	.5620
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38.646	.5868	.5622
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38.799	.5894	.5624
38.876	.5884	.5625
38.952	.5811	.5626
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39.105	.5832	.5627
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39.334	.5836	.5633
39.410	.5830	.5633
39.487	.5821	.5634
39.563	.6156	.5635
39.639	.5899	.5636
39.716	.5696	.5637
39.792	.5538	.5639
39.868	.5339	.5639
39.945	.5289	.5640
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40.098	.5270	.5643
40.174	.5282	.5645
40.250	.5396	.5646

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40.403	.5583	.5647
40.479	.5719	.5648
40.556	.5771	.5647
40.632	.5814	.5647
40.709	.5848	.5647
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40.861	.5876	.5646
40.938	.5905	.5645
41.014	.5930	.5645
41.090	.5968	.5646
41.167	.5982	.5646
41.243	.5993	.5647
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41.396	.5977	.5648
41.472	.5996	.5649
41.549	.6012	.5650
41.625	.6024	.5650
41.702	.6040	.5652
41.778	.6044	.5652
41.854	.6046	.5653
41.931	.6045	.5654
42.007	.5984	.5654
42.083	.6016	.5655
42.160	.6039	.5656
42.236	.6070	.5657
42.313	.6079	.5657
42.389	.6083	.5657
42.465	.6083	.5658
42.542	.6073	.5659
42.618	.6087	.5658
42.694	.6060	.5659
42.771	.6036	.5659
42.847	.5998	.5660
42.924	.5984	.5661
43.000	.5972	.5661
43.076	.5955	.5662
43.153	.5949	.5662
43.229	.5932	.5653
43.305	.5938	.5658
43.382	.5946	.5666
43.458	.5948	.5669
43.535	.5948	.5671
43.611	.5946	.5673
43.687	.5944	.5673
43.764	.5940	.5673
43.840	.5910	.5679
43.916	.5929	.5670
43.993	.5945	.5664
44.069	.5955	.5658
44.146	.5965	.5652
44.222	.5965	.5650
44.298	.5961	.5650
44.375	.5553	.5646
44.451	.5748	.5651
44.527	.5912	.5656
44.604	.6147	.5664
44.680	.6224	.5666
44.757	.6273	.5669
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45.673	.6149	.5671
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45.826	.5665	.5671
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46.131	.5603	.5670
46.208	.5601	.5670
46.284	.5609	.5669
46.360	.5618	.5669
46.437	.5630	.5668
46.513	.5663	.5668
46.590	.5684	.5667
46.666	.5708	.5667
46.742	.5754	.5667
46.819	.5787	.5667
46.895	.5816	.5667
46.971	.5860	.5666
47.048	.5876	.5666
47.124	.5890	.5666
47.201	.5908	.5666
47.277	.5954	.5666
47.353	.5919	.5666
47.430	.5905	.5666
47.506	.5893	.5666
47.582	.5876	.5665
47.659	.5871	.5665
47.735	.5867	.5665
47.812	.5923	.5666
47.888	.5898	.5666
47.964	.5854	.5666
48.041	.5839	.5666
48.117	.5828	.5666
48.193	.5815	.5666
48.270	.5812	.5666
48.346	.5813	.5666
48.423	.5697	.5666
48.499	.5801	.5666
48.575	.5957	.5666
48.652	.6008	.5666
48.728	.6043	.5666
48.805	.6072	.5666
48.881	.6068	.5665
48.957	.5850	.5666
49.034	.5947	.5666
49.110	.6024	.5666
49.186	.6125	.5666
49.263	.6151	.5666
49.339	.6160	.5666
49.416	.6145	.5666
49.492	.6238	.5666
49.568	.6068	.5666
49.645	.5928	.5666
49.721	.5728	.5667

49.797	.5662	.5667
49.874	.5587	.5667
49.950	.5574	.5667
50.027	.5628	.5664
50.103	.5624	.5666
50.179	.5623	.5667
50.256	.5627	.5668
50.332	.5632	.5668
50.408	.5647	.5668
50.485	.5657	.5668
50.561	.5714	.5667
50.638	.5703	.5665
50.714	.5687	.5661
50.790	.5683	.5659
50.867	.5681	.5657
50.943	.5683	.5655
51.019	.5687	.5654
51.096	.5696	.5653
51.172	.5707	.5652
51.249	.5722	.5650
51.325	.5728	.5650
51.401	.5735	.5648
51.478	.5737	.5647
51.554	.5731	.5647
51.630	.5734	.5646
51.707	.5736	.5644
51.783	.5736	.5644
51.860	.5735	.5642
51.936	.5734	.5642
52.012	.5731	.5641
52.089	.5725	.5637
52.165	.5721	.5638
52.241	.5718	.5638
52.318	.5713	.5638
52.394	.5711	.5638
52.471	.5706	.5637
52.547	.5704	.5636
52.623	.5697	.5630
52.700	.5697	.5630
52.776	.5697	.5630
52.852	.5696	.5629
52.929	.5694	.5627
53.005	.5693	.5625
53.082	.5704	.5624
53.158	.5689	.5619
53.234	.5683	.5616
53.311	.5674	.5611
53.387	.5670	.5609
53.463	.5665	.5605
53.540	.5664	.5603
53.616	.5664	.5598
53.693	.5663	.5597
53.769	.5662	.5595
53.845	.5661	.5592
53.922	.5660	.5590
53.998	.5658	.5587
54.074	.5658	.5584
54.151	.5656	.5581
54.227	.5655	.5578
54.304	.5653	.5576
54.380	.5651	.5572
54.456	.5649	.5571

54.533	.5688	.5569
54.609	.5652	.5565
54.685	.5638	.5563
54.762	.5617	.5559
54.838	.5610	.5558
54.915	.5602	.5555
54.991	.5540	.5526
55.067	.5567	.5536
55.144	.5610	.5551
55.220	.5637	.5561
55.296	.5646	.5563
55.373	.5654	.5565
55.449	.5648	.5594
55.526	.5643	.5577
55.602	.5634	.5549
55.678	.5626	.5530
55.755	.5622	.5523
55.831	.5614	.5515
55.908	.5605	.5513
55.984	.5601	.5514
56.060	.5590	.5516
56.137	.5581	.5518
56.213	.5577	.5519
56.289	.5569	.5520
56.366	.5566	.5523
56.442	.5561	.5523
56.519	.5552	.5522
56.595	.5545	.5522
56.671	.5539	.5521
56.748	.5536	.5521
56.824	.5530	.5523
56.900	.5526	.5521
56.977	.5524	.5521
57.053	.5520	.5519
57.130	.5516	.5518
57.206	.5513	.5517
57.282	.5519	.5517
57.359	.5511	.5516
57.435	.5505	.5516
57.511	.5500	.5515
57.588	.5498	.5514
57.664	.5497	.5513
57.741	.5492	.5506
57.817	.5496	.5508
57.893	.5499	.5508
57.970	.5500	.5508
58.046	.5501	.5505
58.122	.5494	.5500
58.199	.5497	.5498
58.275	.5498	.5495
58.352	.5499	.5493
58.428	.5498	.5488
58.504	.5498	.5487
58.581	.5498	.5483
58.657	.5494	.5479
58.733	.5490	.5474
58.810	.5487	.5468
58.886	.5484	.5463
58.963	.5516	.5457
59.039	.5479	.5452
59.115	.5465	.5450
59.192	.5445	.5446

59.268	.5433	.5442
59.344	.5357	.5439
59.421	.5414	.5435
59.497	.5453	.5429
59.574	.5477	.5425
59.650	.5489	.5419
59.726	.5505	.5408
59.803	.5484	.5407
59.879	.5467	.5404
59.955	.5454	.5399
60.032	.5443	.5394
60.108	.5431	.5385
60.185	.5426	.5380
60.261	.5421	.5375
60.337	.5416	.5370
60.414	.5411	.5363
60.490	.5416	.5373
60.566	.5406	.5355
60.643	.5398	.5340
60.719	.5391	.5328
60.796	.5386	.5319
60.872	.5382	.5316
60.948	.5378	.5310
61.025	.5374	.5304
61.101	.5371	.5299
61.177	.5368	.5294
61.254	.5361	.5287
61.330	.5361	.5283
61.407	.5360	.5278
61.483	.5358	.5274
61.559	.5356	.5269
61.636	.5359	.5256
61.712	.5351	.5257
61.788	.5343	.5255
61.865	.5338	.5252
61.941	.5414	.5238
62.018	.5360	.5236
62.094	.5320	.5234
62.170	.5284	.5227
62.247	.5273	.5221
62.323	.5214	.5161
62.399	.5268	.5196
62.476	.5319	.5225
62.552	.5337	.5230
62.629	.5347	.5315
62.705	.5330	.5217
62.781	.5320	.5171
62.858	.5311	.5139
62.934	.5301	.5107
63.011	.5294	.5109
63.087	.5287	.5109
63.163	.5278	.5108
63.240	.5272	.5106
63.316	.5266	.5105
63.392	.5260	.5101
63.469	.5255	.5097
63.545	.5247	.5091
63.622	.5244	.5092
63.698	.5237	.5082
63.774	.5232	.5077
63.851	.5226	.5069
63.927	.5262	.5074

64.003	.5219	.5059
64.080	.5193	.5048
64.156	.5183	.5042
64.233	.5145	.5034
64.309	.5178	.5033
64.385	.5208	.5030
64.462	.5229	.5015
64.538	.5216	.5016
64.614	.5199	.5014
64.691	.5184	.5009
64.767	.5177	.5011
64.844	.5170	.4998
64.920	.5159	.4982
64.996	.5150	.4970
65.073	.5142	.4956
65.149	.5137	.4954
65.225	.5129	.4948
65.302	.5141	.4932
65.378	.5121	.4929
65.455	.5105	.4923
65.531	.5094	.4915
65.607	.5073	.4890
65.684	.5084	.4893
65.760	.5089	.4889
65.836	.5083	.4905
65.913	.5077	.4868
65.989	.5071	.4841
66.066	.5067	.4799
66.142	.5052	.4802
66.218	.5039	.4799
66.295	.5029	.4815
66.371	.5024	.4788
66.447	.5016	.4759
66.524	.5009	.4842
66.600	.5000	.4751
66.677	.4992	.4708
66.753	.4949	.4553
66.829	.4964	.4649
66.906	.4968	.4692
66.982	.4996	.4698
67.058	.4956	.4691
67.135	.4935	.4683
67.211	.4910	.4676
67.288	.4904	.4652
67.364	.4902	.4597
67.440	.4887	.4604
67.517	.4874	.4601
67.593	.4858	.4613
67.669	.4850	.4574
67.746	.4857	.4547
67.822	.4831	.4530
67.899	.4805	.4509
67.975	.4791	.4493
68.051	.4779	.4481
68.128	.4771	.4457
68.204	.4745	.4440
68.280	.4746	.4431
68.357	.4711	.4407
68.433	.4681	.4403
68.510	.4666	.4370
68.586	.4654	.4388
68.662	.4626	.4314

68.739	.4611	.4197
68.815	.4571	.4252
68.891	.4529	.4257
68.968	.4540	.4228
69.044	.4488	.4183
69.121	.4314	.4099
69.197	.4432	.4090
69.273	.4381	.4066
69.350	.4280	.4022
69.426	.4340	.4227
69.503	.4098	.3268
69.579	.4051	.3890
69.655	.4040	.3813
69.732	.3824	.3677
69.808	.3688	.3510
69.884	.3396	.3581
69.961	.0000	.0000

In addition, the same "ring.dat" file from the *FRICTION-OFT* is used for the *Liner Vaporization Model.*