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16. Abstract

Good ride quality, proper cross slope, and accurate material estimates are important for an overlay project. Currently there is not a method in Texas to accurately relate the condition of an existing roadway with the potential benefits of different overlay and milling strategies during the design phase or provide the appropriate information to the contractor. Many Districts have requested the use of the TxDOT inertial profilers to locate and measure potential grind and fill areas on paving projects prior to overlays. The Districts want to use a high-speed accurate instrument to survey the existing roadway without disrupting traffic This research develops a method which can integrate data from a scanning laser or multi-path profiles with a gyroscope and inertial profiler for viewing three-dimensional pavement surfaces for overlay and milling strategies.

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Using Profile Measurements to Locate and Measure Grind and Fill Areas to Improve Pavement Ride

Roger S. Walker, Ph.D., P.E

Emmanuel Fernando, Ph.D., P.E.

Eric Becker, MS CSE

Jareer Abdel Qader, MS-CE

Gerry Harrison

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ACKNOWLEDGMENTS

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Chapter 1 INTRODUCTION

1.1 REPORT OBJECTIVE AND BACKGROUND

Good ride quality, proper cross-slope, and accurate material estimates are important for an overlay project. Currently there is not a method in Texas to accurately relate the condition of an existing roadway with the potential benefits of different overlay and milling strategies during the design phase or provide the appropriate information to the contractor. Many Districts have requested the use of the TxDOT inertial profilers to locate and measure potential grind and fill areas on paving projects prior to overlays. The Districts want to use a high-speed accurate instrument to survey the existing roadway without disrupting traffic. Inertial profiles alone do not provide sufficient information to perform this task. During Project 0-1782, a scanning laser system was used for obtaining a transverse profile for rut measurements. The original objective of research Project 0-4463 was to investigate the integration of the scanning laser system and the inertial profiler for overlay and milling strategies. The project had several problems which resulted in a modified work plan and a one year extension. The problems were primarily caused by the inability to obtain scanning laser data from Project 5-1782.

1.2 PROJECT 0-1782

Project 0-1782 was initiated to investigate the possibility of using scanning laser technology for the measurement of rut depths that would alleviate some of the problems of the acoustic sensor systems now being used for this application. However, developing a working system for use of the scanning laser system on TxDOT vehicles was much harder than originally thought because of the noise on the scanning laser return signals as the laser beam is swept across the pavement.

During the project a functional system was developed based around the scanning laser, manufactured by Acuity Research Incorporated. During the first part of the project the Acuity scanning laser system was purchased and the system tested on several sections. During these tests it was noted that significant noise problems occurred with the laser system during the high-speed measurements. This noise appeared to be caused by the laser beam as it is swept across the pavement surface. Thus, much of the effort during the project was focused on developing a

means to distinguish the signal from the noise and to address a means by which measurements could be made at highway speeds. A multi-step procedure was developed which was found to reduce this noise. During the last year of the project the multi-step process was applied to each scan and used for rut measurements that were verified from measurements at the Ride/Rut Calibration facility and at sites in Austin and Granger, Texas (see Figure 1-1). In the Granger tests, the scanning laser rut readings were compared to other measuring methods, such as the straight edge and dip stick. This process and the results are discussed in detail in Report 0-1782-1.

With accurate transverse profile scans, it would be possible to integrate scanning laser data with longitudinal profile and gyroscope data, thus removing the vehicle's response, and then these signals could be used for overlay and milling strategies.

With the procedures developed from Project 0-1782 it was decided to try to use the system for project level data collection and an implementation project, Project 5-1782, was initiated in December 2002. About a year later, in the fall of 2003, Project 0-4463 was initiated to use scanning laser data to integrate with longitudinal inertial profile and gyroscope measurements to provide a pavement surface profile so that grind and fill information could be obtained. Problems, however, in implementing the scanning laser in Project 5-1782 had a direct effect on Project 0-4463.
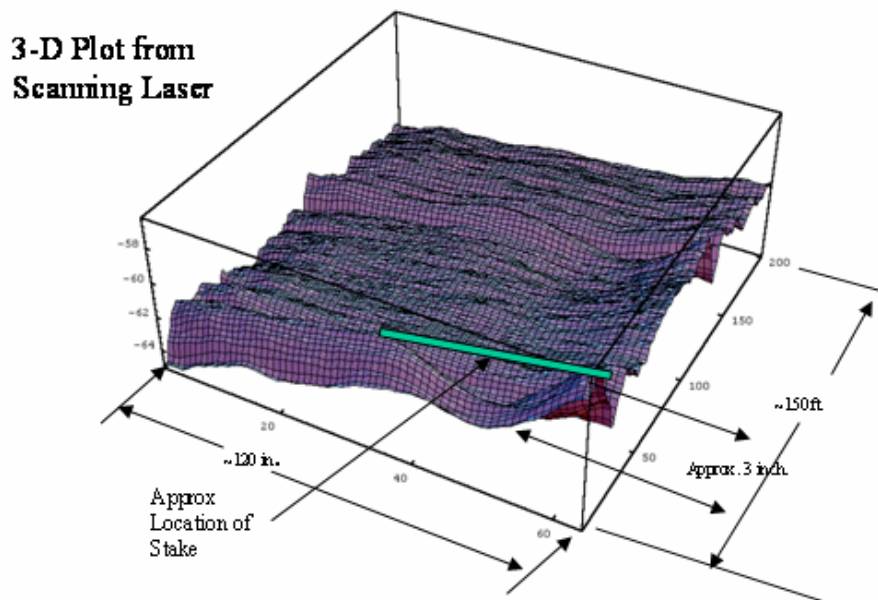
**Figure 1-1. Scanning Laser Measurements of Rutting Made on Decker Lane
in Austin, Texas.**

1.3 PROJECT 5-1782

The system developed in research Project 0-1782 and planned for use in Project 5-4385 was
based around the DOS system and Windows 3.1. TxDOT, however, was developing a vehicle
network system, the Texas Modular Vehicle (VNET), which was not directly compatible with
the program run in this manner. The implementation project would require modifying the
software so the system could integrate with the in-house VNET software for coordinating the
data collection activities in the Texas Modular Vehicle (TMV). The original implementation plan
called for the use of a TxDOT 'wrapper' program that would permit the use of the original
University of Texas at Arlington (UTA) multi-step data acquisition and processing software to
integrate with VNET.

These plans were changed during the first project meeting in January 2003. At this meeting
several key decisions were made by TxDOT project personnel that altered the original
implementation plans. It was decided that TxDOT project personnel would rewrite the scanning
laser data acquisition and processing software to work directly with VNET. A different method
of processing the scanning laser data was developed and implemented by TxDOT. The scanning

laser data were not available until the end of the implementation project, which then delayed their use in the integration with the inertial profile data in Project 0-4463 three-dimensional (3-D) surface measurements. When the data were available, the system was run over the simulated ruts at the Texas A&M Riverside Campus Ride/Rut Calibration facility but the results were not suitable for reliable estimates of determining potential areas for grind and fill applications. Figure 1-2 shows the profiler with the scanning laser in use at the Rut Calibration section and Figure 1-3 displays the resulting scanning laser data. As may be noted in Figure 1-3, the 3-D image has been rotated to provide a top view of the first two sets of rut beams and a part of the third set. The laser accurately picks up these beams of varying heights from 3 to 0.25 inches. However, the individual scans do not consistently record the heights correctly, with some positive and some negative, as noted by the yellow and blue colored beams in Figure 1-3. Researchers hoped that most of these problems would be corrected by TxDOT before the end of the project.

Figure 1-2. Rut Calibration Section.
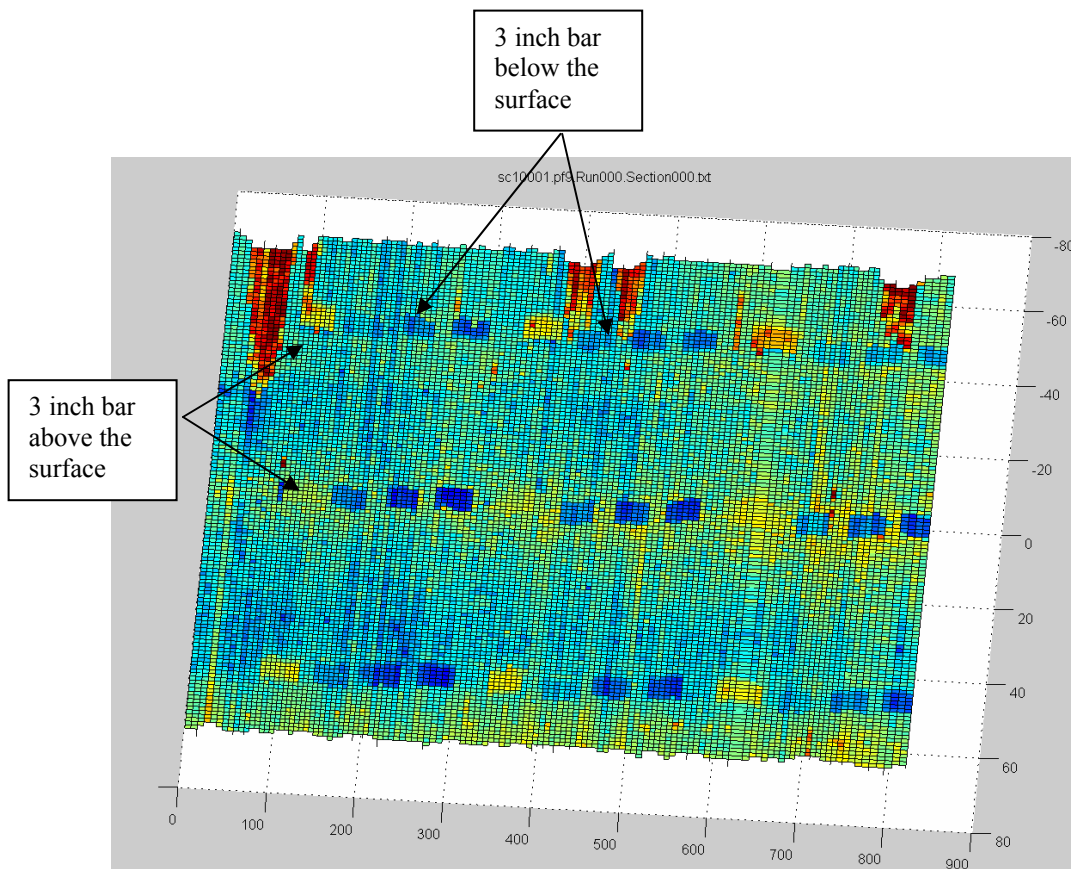
Figure 1-3. 3-D Display of Scanning Laser Readings Rotated for Top View.

A year's extension was requested so that the problems with the scanning laser system could be ironed out. Additionally, an extension was also needed for verification work on the program OVERLAY by Texas Transportation Institute (TTI) researchers on the project, as will be discussed. A one year extension was approved at the TxDOT Research Management Committee Meeting (RMC) meeting in June 2005.

1.4   REPORT COVERAGE

In the chapters which follow, the efforts and tasks performed during the project are discussed. Chapter 2 discusses the use of the OVERLAY program to simulate the overlay process. During the pre-proposal meeting for Project 0-4463 held in Austin in March 2003, TxDOT engineers identified an existing program written in a research project conducted in the early 1980s that predicts the surface profile with each successive overlay lift and estimates the amount of overlay

material needed during paving operations. Initial communications with a TxDOT pavement design engineer at the beginning of the project revealed that the computer program OVERLAY could potentially be used as a starting point for developing the software called for in the project. However, additional work was required to correct bugs in the program and to make modifications to this program so that it could be evaluated in the project.

Chapter 3 describes the development of a procedure for incorporating gyroscope data into the TxDOT profiling system. The gyroscope is a required sensor for providing a 3-D display of the pavement surface, providing the cross-slope of the pavement surface when integrated with the inertial reference profile. Chapter 4 provides details on the 3-D surface display program and procedures. The procedures and resulting program developed provide a means of integrating scanning laser data with the inertial reference profile and gyroscope data. When it became apparent that useable scanning laser data would not be obtained, the 3-D surface software was modified so that the capability of using displacement data from the five acoustic rut sensors, providing five 1-inch footprints, could be used for five of transverse profile readings. In Chapter 5, a procedure for computing grind and fill quantities from the 3-D surface profile of Chapter 4 is described.

At a project meeting in the fall of 2005, it was decided that a Compax3 linear actuator system be investigated, which when mounted on the front of the vehicle could provide laser readings across the pavement. The system could then be moved longitudinally from point to point down the road and the readings integrated with profile and gyroscope information to provide accurate 3-D surface profiles. The system was purchased and initial tests performed. Since the laser would scan across the pavement for each longitudinal position, this system was referred to as the static scanning laser system. The system developed and tested is described in Chapter 6.

The last chapter, Chapter 7, provides a summary of the report and recommendations. Appendixes included provide the instruction manual for using the 3-D surface and grind and fill software.

Chapter 2 VERIFICATION OF THE OVERLAY PROGRAM

2.1 INTRODUCTION

In a project conducted by the University of Texas at Austin in the early 1980s, researchers developed a computer program to simulate the change in surface profile with successive overlay lifts (Codas, Hudson, and Lee, 1983). The computer program *OVERLAY* used the surface profile measured with TxDOT's profilometer at that time along with geometric characteristics of the asphalt finisher to predict the compacted profile and the quantity of bituminous material to be placed on an overlay project. To the current authors' knowledge, the program was never verified nor implemented after its development in TxDOT Project 251. In view of the potential benefits that might be realized from using the program to determine overlay requirements and evaluate resurfacing alternatives given the existing pavement profile, this project undertook to verify the *OVERLAY* program by comparing its predictions with measured data taken on an overlaid section.

This task proved more difficult to conduct than initially planned since neither an executable copy of *OVERLAY* nor its source code was available. Researchers had to re-create the program from a listing of the source code provided in the report by Codas, Hudson, and Lee (1983). While researchers made every effort to reproduce the original program, no data were available from the earlier project with which to check the version generated from this work. Researchers note that the original program used profile data written on magnetic tape, which was the method for storing data in the profilometer TxDOT operated at the time the program was developed. Such tapes and the recording devices used at that time are no longer implemented. Thus, researchers focused on re-creating the methodology for simulating overlay smoothness as documented in the research report from the original project. Researchers wrote new code to read profile data based on TxDOT's current file format and added a couple of modifications to include a free-floating screed and an alternative compaction model. While researchers made every effort to maintain consistency with the original methodology on which *OVERLAY* was based, the verification

reported herein was conducted on the program as re-created in this project and not the original version.

2.2   DESCRIPTION OF THE OVERLAY SIMULATION

Figure 2-1 shows a schematic diagram of an asphalt finisher, the main components of which are the tractor unit and the screed. When the tow point of the finisher is subjected to a step-function disturbance, the *OVERLAY* program assumes that the screed traces the logarithmic curve illustrated in Figure 2-2. For a step disturbance H at the tow point, the response y is assumed to follow the Barber-Greene model given by:

$$y \;=\; H\left(1 - e^{-\frac{x}{L}}\right) \tag{1}$$

where x is the distance traveled by the screed and L is the length of the leveling arm from the tow point to the trailing edge of the screed. At a distance of $5L$, the screed has completed 99 percent of the adjustment induced by the step disturbance. In reality, the profile includes many step disturbances at multiples of the profile sampling interval. Thus, the tow point and the screed are affected by succeeding disturbances such that the adjustment caused by the previous disturbance is usually never completed. For this reason, the program models the response of the screed to a series of step disturbances. At any given distance, the step disturbance consists of the residual disturbance from the previous step plus the disturbance at the current step.

In most asphalt finishers, the smoothing action of the floating screed is enhanced by an automatic control system in which elevation readings from a reference (such as a ski or a stringline) are used to control the path of the tow point. The idea is that if the tow point is made to follow a smooth reference profile, the effects of irregularities on the surface being paved will be minimized, resulting in a smoother compacted surface. As originally developed, the *OVERLAY* program modeled two automatic screed control methods – the rigid ski and the stringline. A third option, the free-floating screed, was added to the program by researchers in the current project. These simulation methods are discussed in the following sections.

2.2.1 Rigid Ski Reference System

The rigid ski (Figure 2-3) is a beam that varies from about a foot to about 50 ft in length. It is guided in the horizontal plane by the asphalt finisher, but is designed to move freely in the vertical direction. The rigid ski typically tracks on a smooth curb or the finished pavement on an adjacent lane. A sensor targets the ski and provides elevation readings that are used to correct the tow point and provide adjustments at the screed end to level off the bumps and dips in the road profile to produce a smooth surface.

The mathematical model of the rigid ski reference system involves calculating the reference profile, the screed profile, and the final compacted profile. These calculations are done in the *OVERLAY* program as follows:
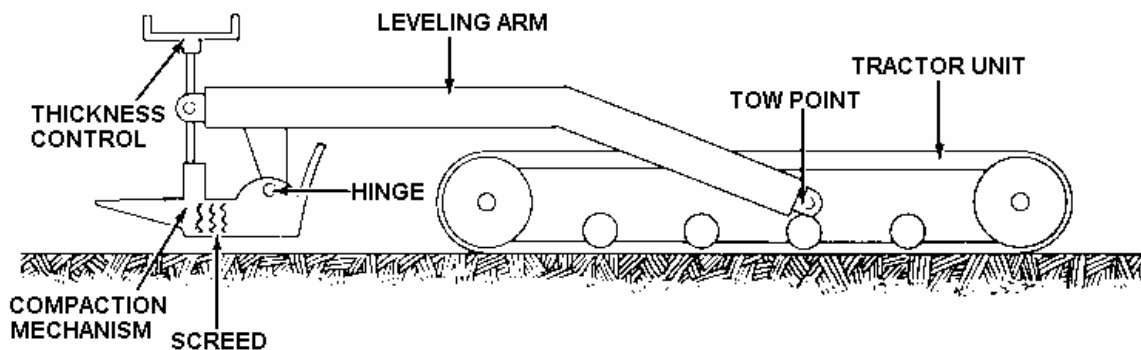
Figure 2-1. Schematic Diagram of Asphalt Finisher (from Barber-Greene Paving).
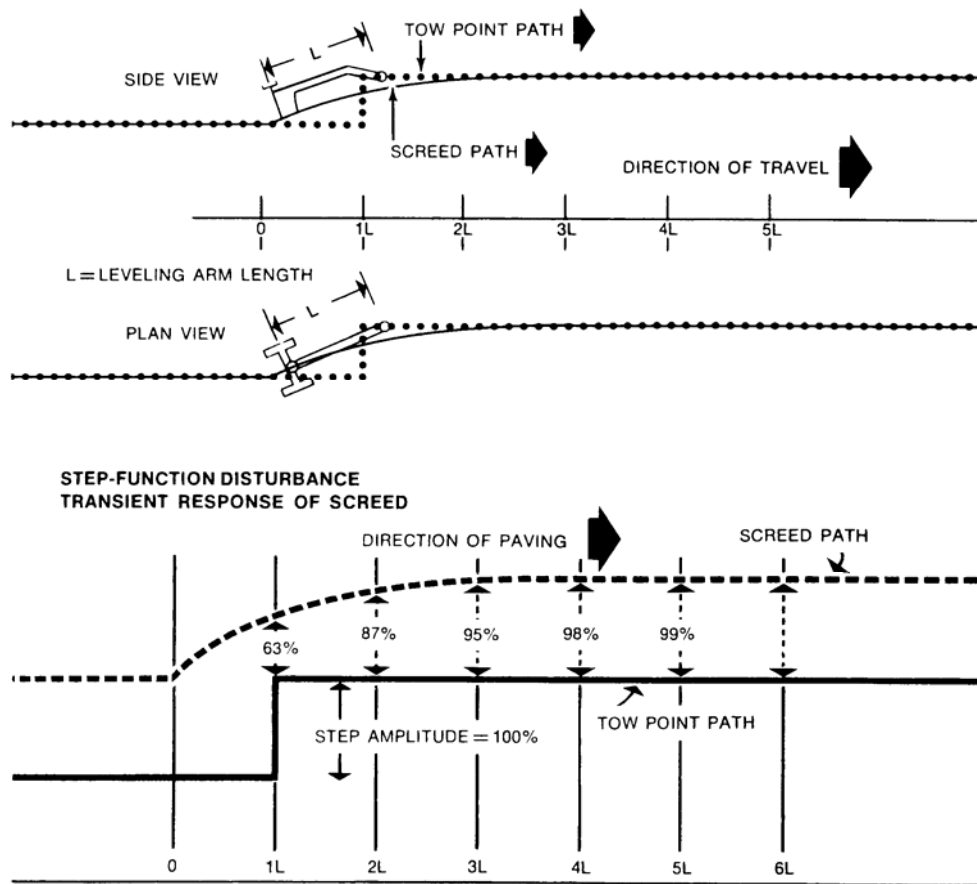
Figure 2-2. Assumed Screed Path in Simulation of Overlay Profile (from Barber-Greene Paving).

Figure 2-3. Illustration of a Rigid Ski.

- Algorithmically, the reference profile is determined by fitting a straight line through the two highest points of elevation in the current lift profile covered by the ski length, and calculating the elevation on that line at the sensor position. This calculation is done in sequence as the ski is moved point-to-point along the existing surface profile that is input to the program.

- The screed profile is calculated from the response of the screed to a single step disturbance according to Eq. (1).

- The final compacted profile may be determined using one of two options available in the program. The first option assumes equal compactive effort along the length of the mat being placed and is the option that was coded into the original program from TxDOT Project 251. In this option, the thickness of the compacted surface is computed based on the ratio of the uncompacted and compacted asphalt mix densities according to the following equation:

$$t_a = t_b \left(\frac{d_b}{d_a} \right) \tag{2}$$

where,

t_b, t_a =   lift thicknesses before and after compaction, and

d_b, d_a =   density of the asphalt concrete mix before and after compaction.

The second option, which researchers in the current project included with the program, assumes a sigmoidal relationship between the compaction ratio and the uncompacted thickness, t_u, given by the equation:

$$\frac{d_b}{d_a} = \beta_0 + \beta_1 \, e^{-\left(\frac{\beta_2}{t_u} \right)^{\beta_3}} \tag{3}$$

where β_0, β_1, β_2, and β_3 are coefficients of the sigmoidal model and the other terms are as defined previously. The alternative compaction model given by Eq. (3) considers the irregularities in the profile of the previous lift and differences in compactive effort that result at locations of bumps and dips.

2.2.2 Free-Floating Screed

The free-floating screed is used to model an asphalt finisher without a rigid ski or stringline reference. The screed, which traces the asphalt mat, is hinged to one end of the asphalt finisher arm at the tow point as illustrated in Figure 2-1. The tow point moves vertically as the asphalt finisher wheels encounter irregularities (e.g., bumps and dips) on the pavement surface. Researchers in the current project added the free-floating screed option to the program to handle operations where no reference systems are used. This option is a variant of the rigid ski system described previously. Specifically, the simulation using the free-floating screed assumes that the length between the asphalt finisher wheels (referred to as the wheel base) acts as a rigid ski.

Hence, in the mathematical modeling of the free-floating screed action, the algorithm for the rigid ski is implemented with the wheel base taken as the ski length to compute the vertical movement of the tow point given the surface profile elevations at the front and back wheels of the paving machine.

2.2.3 Stringline Reference

Stringlines are typically used in current practice for placement of Portland cement concrete pavements (Figure 2-4). The stringline is established along one side of the paving machine and is set to follow the desired profile of the finished slab or compacted surface for a hot-mix asphalt concrete pavement. A sensor connected to the laydown machine tracks the stringline and causes adjustments to be made as surface irregularities are encountered such that the final surface profile (as defined by the stringline) is maintained.

During this project, researchers encountered problems with the original program code simulating the stringline system. Consequently, new code was written to re-create the stringline method in the program evaluated by researchers.

2.3 VERIFICATION OF COMPUTER PROGRAM OVERLAY

Researchers verified the *OVERLAY* program re-created in this project on an existing pavement section located within the Texas A&M Riverside Campus. This section received a Type D hot-mix asphalt concrete overlay that the contractor placed in two 1½-inch lifts. Figure 2-5 shows the paver used for placing the overlay. This figure shows the placement of a 150-ft test section where no reference systems were used to verify the free floating screed option in the program. Another 150-ft section was placed where the contractor used the rigid ski shown in Figure 2-3 to test this particular reference system. Researchers evaluated these two methods, the free floating screed and the rigid ski, in this project. The stringline option was not tested as this method is not usually applied on asphalt concrete paving projects.

To verify the predictions from the computer program, researchers profiled the sections with the walking profiler (Figure 2-6) and the rod and level at three different stages:

Figure 2-4. Stringline Set-Up on a Concrete Paving Project.

Figure 2-5. Picture of Paver Used to Overlay Test Section.

Figure 2-6. Walking Profiler Used to Establish Reference Profiles.

- On the existing pavement surface prior to construction,

- After placement of the first lift, and

- After placement of the final lift.

Elevation measurements were taken at 9.5-inch intervals, corresponding to the foot length of the walking profiler. Rod and level measurements were taken at 95-ft intervals to correct the walking profiler data following the procedure described in TxDOT Test Method Tex-1001S. On the section placed with the free-floating screed, researchers profiled the right wheel path (relative to the direction of paving) consistent with the approach proposed by Codas, Hudson, and Lee (1983). On the section placed with the rigid ski, researchers profiled the path followed by the ski on the adjacent lane. The comparisons of the *OVERLAY* predictions with the reference data collected by researchers are presented in the following section.

2.3.1 Comparisons Based on Unfiltered Reference Profiles

The *OVERLAY* program was originally written to use data from TxDOT's profilometer in simulating the change in profile with successive overlay lifts. The program runs through a series of calculations that includes the thickness of the current lift in predicting the compacted profile. In essence, the previous lift is bumped up by the thickness of the current lift to predict its compacted profile. In view of this methodology, it is not correct to use inertial profile data to simulate the overlay profile since inertial profile data are by nature filtered and already exclude wavelengths beyond the cutoff specified during the data collection. During the course of this work, researchers verified that the predicted profile based on inertial profile measurements prior to construction is not the same as the profile generated by filtering the predicted profile from the program determined using the unfiltered or true reference profile before the overlay. Thus, researchers collected reference profile data with the walking profiler and rod and level to provide the proper input profiles to the program in the verification work performed in this project. The implication of this limitation is that practical applications (assuming that the program provides reasonable results) will not be feasible unless a reference profiler is developed that provides a more rapid method of collecting reference profiles on pavements.

Figures 2-7 to 2-10 compare the predicted profiles with the unfiltered reference data on the overlaid sections that researchers determined using the walking profiler and rod and level. The predictions shown are based on using the unfiltered reference data on the existing pavement in the simulations. Thus, the profile of the first lift is a function of the measured unfiltered profile of the existing pavement prior to construction. The program then uses this predicted profile to compute the profile of the second lift.

Researchers used the original and sigmoidal compaction models to predict the overlay profiles for the comparisons made. In terms of the sigmoidal model, the coefficients of Eq. (3) were initially backcalculated to achieve a good fit with the measured profile of the first lift on each 150-ft section. These coefficients were then used to predict the compacted profile of the second lift. From these backcalculations, researchers obtained the sigmoidal coefficients presented in Table 2-1.

Figure 2-7. Comparison of Predicted and Reference Profiles on Free-Floating Screed Section Based on Original Compaction Model.
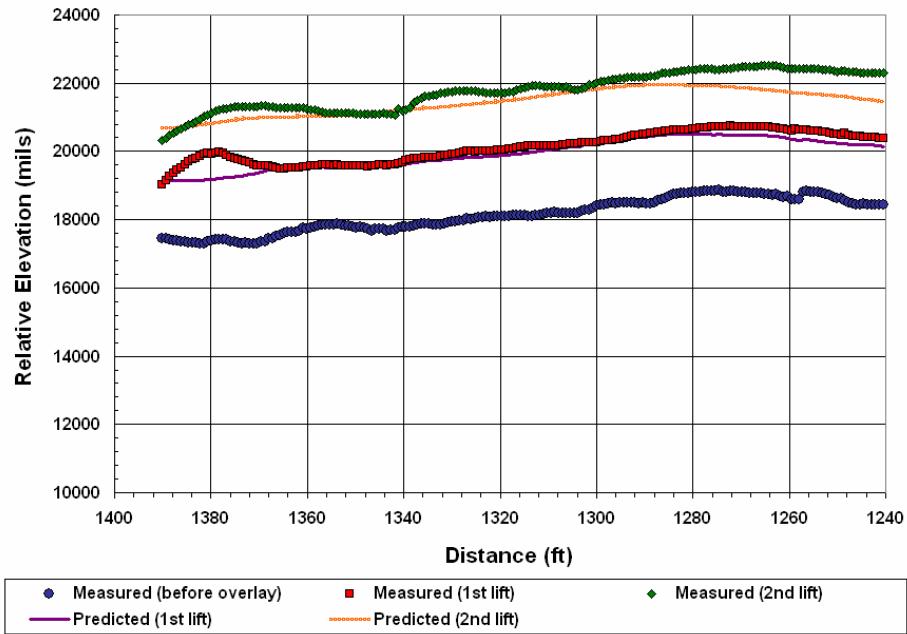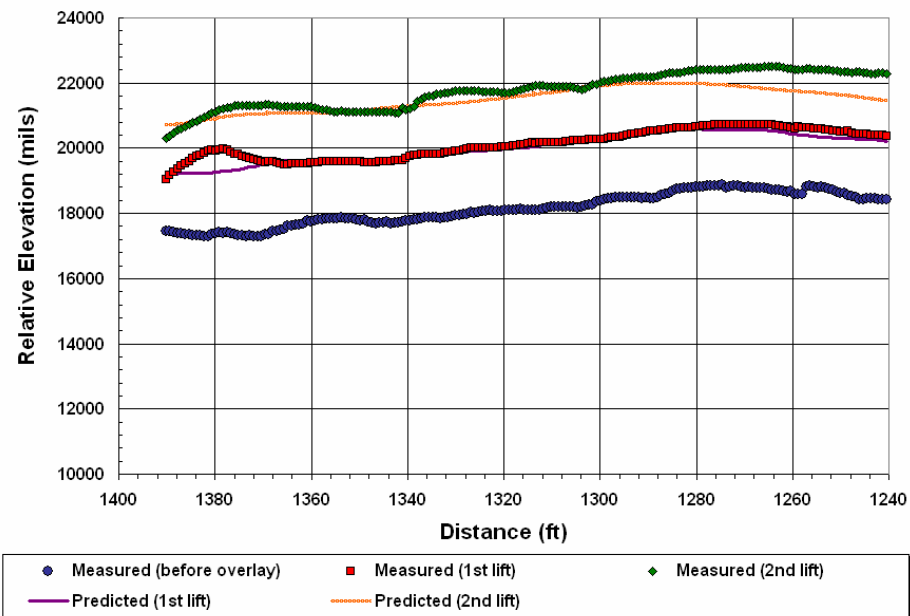

Figure 2-8. Comparison of Predicted and Reference Profiles on Free-Floating Screed Section Based on Sigmoidal Compaction Model.
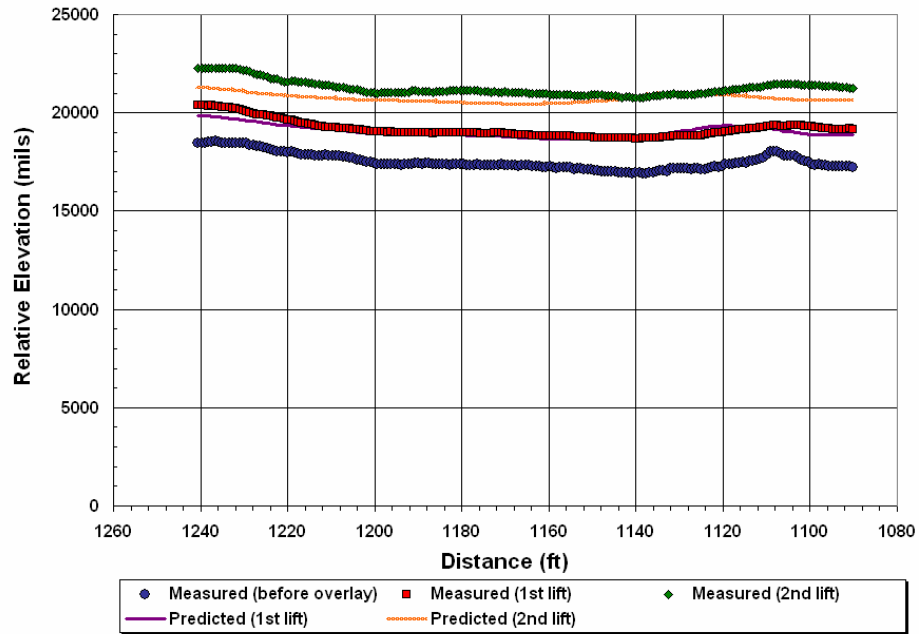
Figure 2-9. Comparison of Predicted and Reference Profiles on Rigid Ski Section Based on Original Compaction Model.
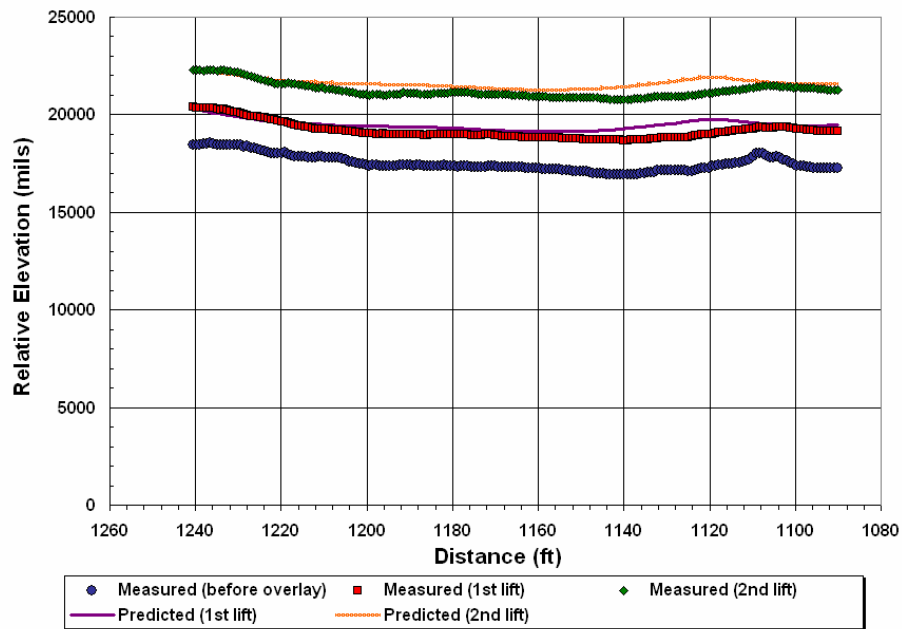

Figure 2-10. Comparison of Predicted and Reference Profiles on Rigid Ski Section Based on Sigmoidal Compaction Model.

Table 2-1. Sigmoidal Model Coefficients Backcalculated Based on Measured Reference Profiles for First Overlay Lift.

Screed Control Method	β_0	β_1	β_2	β_3
Free-Floating Screed	0.2	1.29	1000	1.0
Rigid Ski	0.2	1.00	1000	0.5

To quantify the accuracy of the predictions, researchers determined the average difference, and the average of the absolute differences between the predicted and measured profiles according to the following equations:

$$Average\,Difference \; = \; \frac{\sum_{i=1}^{n} \left(P_{predicted} - P_{measured} \right)}{n} \qquad (4)$$

$$Absolute\,Difference \; = \; \frac{\sum_{i=1}^{n} \left| P_{predicted} - P_{measured} \right|}{n} \qquad (5)$$

where,

$P_{predicted}$ = predicted profile elevation at a given location i,

$P_{measured}$ = measured profile elevation at location i, and

n = number of profile elevations.

Table 2-2 summarizes the statistics determined on each section. In terms of the error statistics, the sigmoidal compaction model generally had statistics that are closer to zero compared to the original compaction model. The only exception is with the simulated profile for the first lift on the rigid ski section, where the magnitudes of the error statistics are smaller for the original compaction model.

2.3.2 Comparisons Based on Smoothness Statistics Computed from Profiles

The results in Figures 2-7 to 2-10 show differences between predicted and measured profiles. In terms of assessing the program, researchers also computed the international roughness indices (IRIs) and compared these smoothness statistics to verify whether the program yields reasonable values. This analysis included the determination of IRIs based on predicted profiles where the filtered reference profiles for the existing surface were input to the program.

Table 2-2. Differences between Predicted and Reference Profiles.

Overlay Lift	Error Statistic (mils)	Free Floating		Rigid Ski	
		Sigmoidal	Original	Sigmoidal	Original
1	Average difference	-101	-188	303	-133
	Absolute difference	131	189	351	210
2	Average difference	-277	-333	383	-497
	Absolute difference	311	350	394	507

The fourth-order Butterworth filter implemented in TxDOT's profiler was used to filter the reference profiles measured with the walking profiler and rod and level. Researchers recognized that while this method of simulating the overlay profile is incorrect, it was of interest to verify how the IRIs from the predicted profiles compare with the IRIs computed from the filtered reference profiles of the final surface.

Table 2-3 compares the IRIs determined from this analysis. With respect to IRI, *OVERLAY* overpredicted the reduction in roughness with each successive lift. While both compaction models resulted in significantly lower IRIs compared to the corresponding statistics from the reference profiles, the sigmoidal model predicted IRIs that are generally closer to the reference values than the original compaction model.

To understand why the program underpredicts the IRIs, researchers compared the frequency spectra of the measured and predicted profiles for the floating-screed section. Figure 2-11 shows these comparisons. In this figure, the predicted frequency spectrum for the final lift is based on the sigmoidal compaction model. It is observed that the frequency spectrum associated with the predicted profile of the final surface has significantly lower amplitudes for frequencies above 0.01 cycles/ft. This finding indicates that the simulation significantly smooths the surface irregularities associated with these frequencies. Researchers surmise that this behavior is due to the deterministic nature of the exponential model given by Eq. (1), which is used in *OVERLAY* to predict the screed path. In reality, the screed will not precisely follow this exponential equation. This finding suggests that an alternative form of the model that considers the variability of the screed path will have to be investigated to come up with a program that more reasonably predicts the roughness of the overlay. This task is beyond the scope of this project, which simply aimed to verify the current program.

Table 2-3. Comparison of IRIs Computed from Predicted and Reference Profiles.

Simulation Method*	IRI (in/mile)					
	Original Surface	Predicted Lift 1**		Predicted Lift 2		Measured Lift 1	Measured Lift 2
Free floating (unfiltered)	138.8	S	45.8	S	28.4	128.5	152.1
		O	43.9	O	22.4		
Free floating (filtered)	138.7	S	89.3	S	76.3	121.5	151.1
		O	42.8	O	24.0		
Rigid ski (unfiltered)	164.9	S	58.6	S	59.8	78.4	97.7
		O	66.0	O	42.3		
Rigid ski (filtered)	161.8	S	75.7	S	78.9	78.4	97.7
		O	46.3	O	40.7		

*Unfiltered or filtered describes the original surface profile that is input to *OVERLAY*

**S refers to the sigmoidal compaction model while O refers to the original model
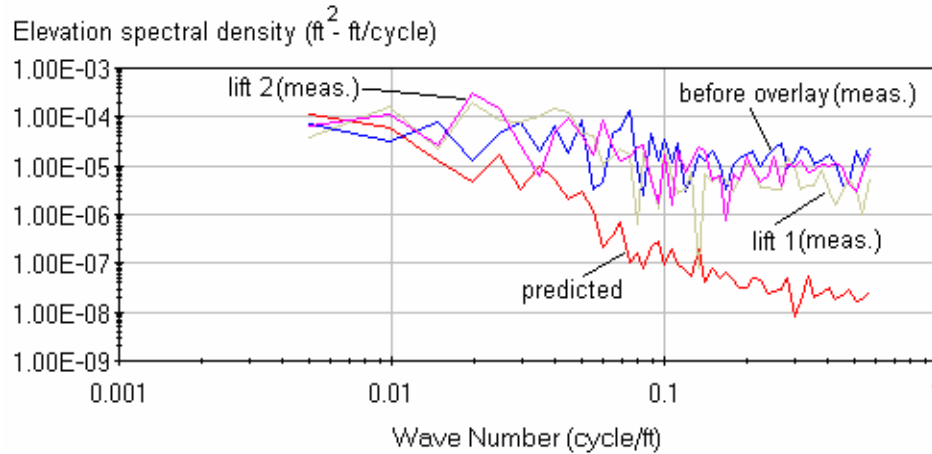
Figure 2-11. Comparison of Frequency Contents of Measured and Predicted Profiles on the Free-Floating Screed Section.

2.4   SUMMARY OF FINDINGS

Based on the comparisons presented, the following findings are noted:

- The predicted profiles from *OVERLAY* exhibit frequency contents that are appreciably different from the measured reference profiles. The elevation spectral densities associated with the predicted profiles are much lower, particularly at the higher frequencies.

- Differences in the frequency contents between predicted and measured profiles result in much lower predicted IRIs from the program compared to the corresponding statistics computed from the reference profiles.

- The simulation of overlay profiles based on the methodology used in *OVERLAY* needs to be based on unfiltered or true reference profiles. During the course of this work, researchers verified that the predicted profile based on inertial profile measurements prior to construction is not the same as the profile generated by filtering the predicted profile from the program determined using the unfiltered or true reference profile before the overlay.

- Relative to the original compaction model, the sigmoidal model generally gave predictions of the overlay profile that are closer to the corresponding reference profiles. This model also gave predictions of IRI that are generally closer to the corresponding reference statistics compared to the predictions from the original compaction model. However, researchers note that both methods significantly underpredict the IRI.

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- In view of the above findings, researchers are of the opinion that additional development work is needed in a couple of areas to make the *OVERLAY* program useful in practice:
  - A reference profiler will have to be developed that permits faster measurement of unfiltered reference profiles for program applications; and
  - An alternative form of the model for predicting the path traced by the screed needs to be investigated that considers the variability of the screed path to come up with a program that more reasonably predicts the roughness of the overlaid pavement.

Chapter 3 Gyroscope

In order to obtain an accurate surface profile, a measure of the pavement cross-slope would be needed. A gyroscope located in the middle of the rut bar was used for this measurement. The WinTK data collection program was then modified so that these readings could be synchronized and obtained directly with the inertial reference profile readings. Then by integrating the cross-slope measurements with the profile, the effect of the vehicle body on the gyroscope measurements could be removed. Solid-state gyroscopes can be used to measure the angle about an axis of rotation, in one, two, or even three dimensions. Generally, a vehicle in motion on a pavement has three axes (see Figure 3-1): the distance traveled, the elevation above the surface, and the transverse length perpendicular to the direction of travel.
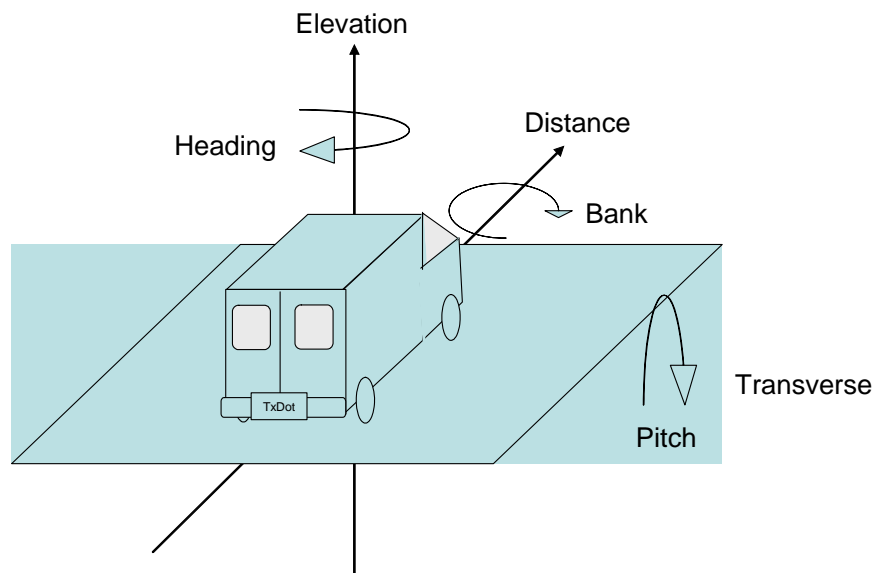

Figure 3-1. The Axes and Angles in Three Dimensions.

For this project, the desire was to find the angle of the vehicle with respect to transverse direction, or along the distance axis.

3.1 WATSON INDUSTRIES GYROSCOPES

Two different Watson Industries Gyroscopes were selected to be used in the research: the VRS-232 (two-dimensional) and the DMS-E604 (three-dimensional). Watson gyroscopes are solid-state gyroscopes with built-in circuitry that help in reducing the effects of the motion of the vehicle in the data produced by the unit.

Figure 3-2. The VRS-232 Vertical Reference System from Watson Industries.

The VRS-232 is a vertical reference system that reports the bank and the pitch of the vehicle it is mounted upon.

Figure 3-3. The DMS-E604 Vertical Reference System from Watson Industries.

The DMS-E604 is the dynamic measurement system, and the unit reports the bank, the pitch, and the heading. The DMS-E604 also has a Global Positioning System (GPS) antenna hookup to correct and ensure the gyroscope is true on its heading.

3.2   GETTING THE DATA INTO THE PROFILER SYSTEM

With the gyroscopes selected for use in the field, researchers had to devise a method of getting the gyroscope angles into the profiling system and WinTK software. This was done by using two free channels on the DT9803 analog to digital (A/D) converter to obtain the voltages representing the angles of inclination for the gyroscope for the pitch and the bank.

In the profiler, the A/D converter reports back to a buffer in which each row contains an entry of one of the channels in use. Inside the profiler, two averages are taken of the gyroscope reading. The first is the average readings based on each distance pulse found by a state machine, which gives one gyroscope reading per calculated profile point.

Table 3-1. Wiring the Gyroscope to the Profiler.

Reading	DT9803 Channel	DT9803 Pin	VRS-232 Pin	E604 Pin
Elevation (X-Axis)	9	4	6	15
Bank (Y-Axis)	10	6	7	14

Since one gyroscope reading per profile reading was considered to be too much information, a gyroscope limit interval was selected that is a multiple of the profile points. This limit is the number of profile distance readings it would take to measure the length of the vehicle. The average of these points is then computed (the second average). Figure 3-4 illustrates the program flow of adding the gyroscope processing into the WinTK profiler code.
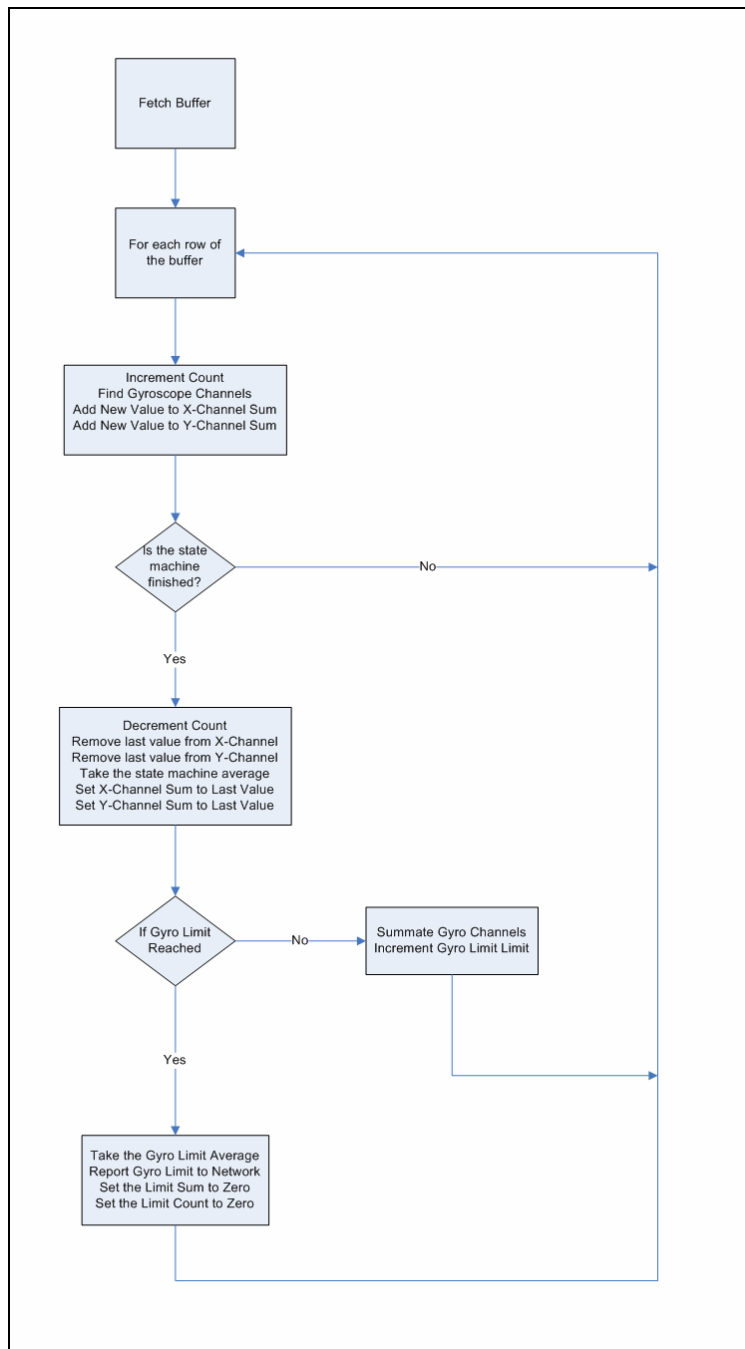
Figure 3-4. Adding Gyroscope to the Code.

Currently two configurations are settable for the gyroscope. The first is the ability to turn the gyroscope recording on and off, called GYROSCOPE. The second configuration is GYROCOUNT, that specifies the number of distance signals before reporting a reading. One argument is that the gyroscope should only be reported every 16 ft for the length of the van.

Table 3-2 Dictionary Entries for the Gyroscope.

Configuration Editor Key Word: **Configuration Tag used in CONFIG command:** GYROSCOPE **Use:** Gyroscope **Variable:** CDataCollectionOptions::m_bGyroscope **Units**: N/A **Type:** Boolean **Values:** {True, False} **Default:** True **Example:** "CONFIG GYROSCOPE TRUE\r\n" **Definition:** A switch to activate the Gyroscope reporting. If set to true, the system will report the elevation and bank of the vehicle every GYROCOUNT DMI signals.
Configuration Tag used in CONFIG command: GYROCOUNT **Use:** Gyroscope **Variable:** CDataCollectionOptions::m_iGyroCount **Units**: N/A **Type:** integer **Values:** positive integers greater than zero **Default:** 48 **Example:** "CONFIG GYROCOUNT 48 \r\n" **Definition:** The number of DMI counts that must occur before the system averages the result and reports the bank and elevation to the client.

3.3   GETTING DATA OUT OF THE PROFILER

The data generated by the gyroscope have two fields, the rotation about the transverse axis, which is the pitch of the vehicle, and the rotation about the distance axis, which is considered to be the bank of the vehicle. Each pair of values generated is the elevation followed by the bank of the vehicle for that reading in degrees.

"Elevation in Degrees:Bank in Degrees"

For example:
```
,20051208210502.630,20051208210503.400,7.19:7.23,7.24:7.21,....
```

Would be
,'Start Timestamp','Stop Timestamp','Elevation':'Bank','Elevation','Bank',....

3.4 EXPERIMENTS WITH THE GYROSCOPE

The gyroscope readings were tested both at walking speed using a test cart as well as using a vehicle.

3.4.1 Testing the Gyroscope by Cart

One question about the cross-slope was would the gyroscope produce a reasonable output that could be mirrored while going in the opposite direction. The 3-D gyroscope was placed on the 'push cart' used in Project 0-4385. In Project 0-4385, the two-dimensional gyroscope had already been found to provide accurate cross-slope information. Figure 3-5 illustrates the cross-slope readings obtained with the gyroscope as it is pushed in one direction on a pavement surface for about the first 772 ft. The cart was then turned 180 degrees and pushed back over the same section. Note that the cross-slope changes from a positive 1.8 degrees to negative 1.8 degrees as it is pushed in the other direction.
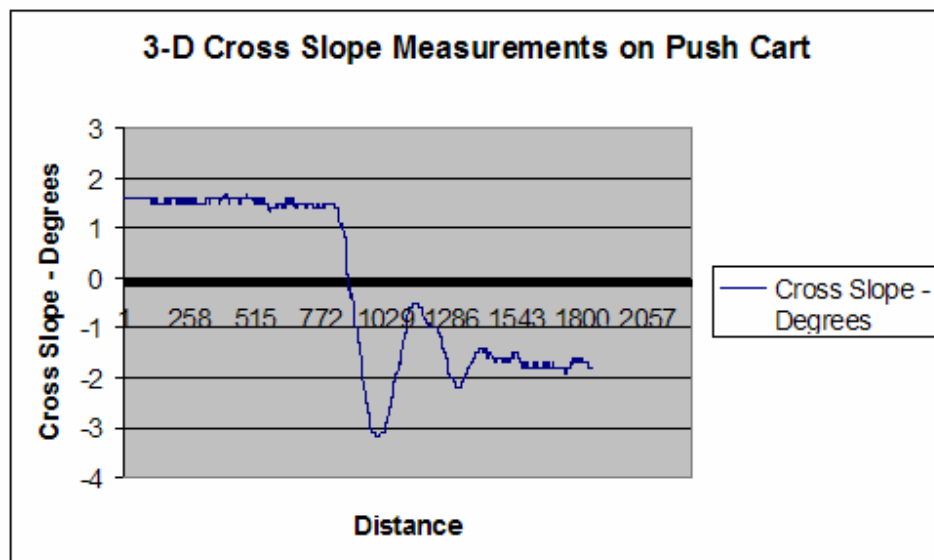
Figure 3-5. Cross Slope on Push Cart at Ride Section with 360 Degree Turn.

3.4.2 Testing the Gyroscope on Rut Section

The gyroscope was installed on a TxDOT profiler vehicle and runs were made on a section on Bull Creek road in Austin. Using the WinTK system, the results of the cross-slope readings on multiple runs were made as shown in Figure 3-6. The general trend or shape of the runs was similar, but the vehicle response will result in repeatability problems in the measurements. As will be discussed in Chapter 4, the gyroscope readings are integrated with the inertial reference profile, thus removing the vehicle response and these errors.
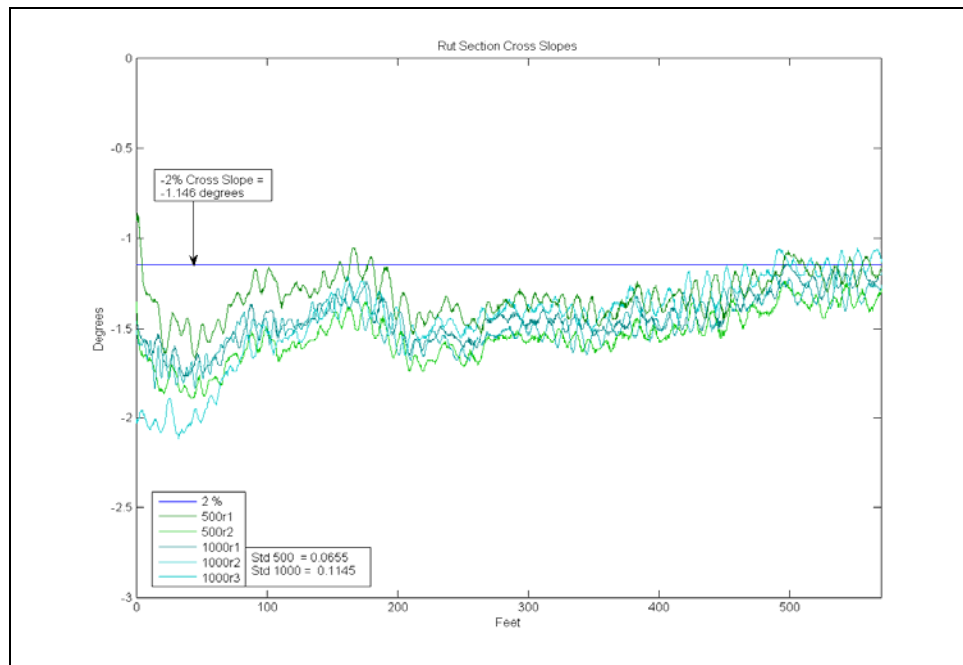
Figure 3-6. Cross-Slope Measurements on Rut Section Using Profiler.

Chapter 4 Three-Dimensional Development

One of the desired results of the project was a procedure of integrating the longitudinal and transverse profile readings with cross-slope. From this, a 3-D pavement surface image could be obtained and then graphics programs used for plotting. The images would also provide a means for determining grind and fill quantities. In order to obtain an appropriate surface image of the pavement, the movement of the vehicle must be removed from the cross-slope and transverse profile readings. Recall that the longitudinal profile already has the response of the vehicle removed and will thus provide a means of removing this response from the other two sensors.

If the data from the surface generated by a scanning system can be mapped to the profile wheel paths, then the three sets of data can be lined up and integrated. The angle of the two points of the profile, however, does not line up with the angle of the scanned pavement surface. If the Gyroscope data are available and are known, the inertial reading of the angle of the vehicle can be obtained. The three data values combined can then be used as the input to a three-dimensional analysis (Figure 4-1).
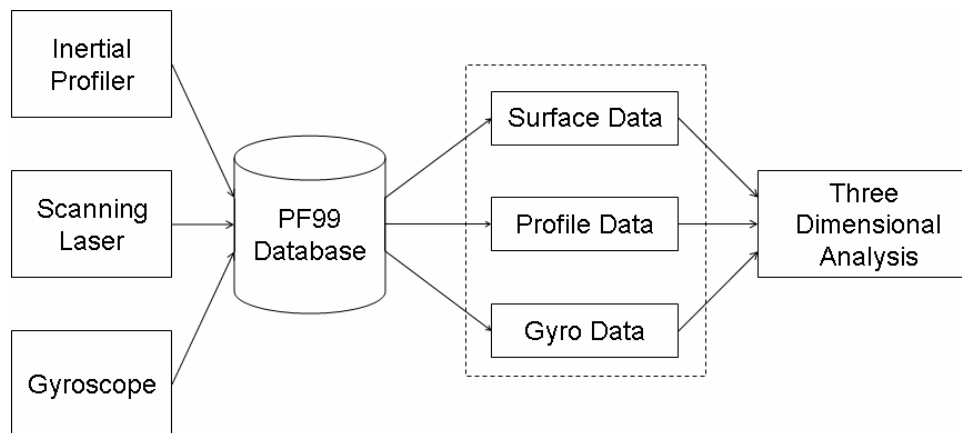
Figure 4-1. Combining Data to Perform the Analysis.

In addition to the scanning laser data, acoustic rut data can be used for a lower resolution surface for doing the three-dimensional analysis.

4.1   READING PF99 DATA

Before discussing the integration of the various signals in order to compute a surface image, it is necessary to examine how these signals are obtained from the data collection software. The data arrive for use with the system in a large set of data types stored in the VNET PF99 protocol. The data desired to be analyzed from each PF99 data file are embedded inside of this file and must first be extracted before use. Following are some terms used to denote the various tags associated with this data.

START

Each data section within the PF99 file has an entry labeled START that marks the beginning of the section. The analysis will search for and recognize where each section will start.

HEAD4

Within each data section some HEAD4 field exists that contains information about the section to be processed. The analysis takes this information to identify the data to be manipulated.

META1

The META1 field indicates that data describing either a rut or profile data collection are available. The procedure will read through the data and find the sampling interval by distance used for rut and profile.

RIDE

The RIDE tag beginning a line in the PF99 file indicates that the data set includes profile measurements that will be used for that section.

GYRO

The GYRO tag beginning a line in the PF99 file indicates that the data set includes gyroscope angle measurements that will be used for rotating the data in that section.

TPP0

The TPP0 tag indicates the transverse profile, or scanning laser, data stored within the section. The analysis takes this information as one source of the surface data.

RUTP0

The RUTP0 tag indicates the rut depth measurements marked across the path of the vehicle.

STOP

The STOP tag marks the end of each section. Once the three areas of data, the surface data, the profile, and the gyroscope angles, are all available, then the surface can be processed.

4.2   TRANSFORMING THE PF99 DATA

The three areas of data, the surface, the profile, and the gyroscope, all must be combined together in order to generate a surface for the grind and fill calculations. This has to be done in several stages. The profile and gyroscope data come from their PF99 data fields, and the surface data can be either the scanning laser or acoustic rut data. The first stage is to make certain that all the data have the same resolution, meaning that for every row of surface there is a matching profile and a matching gyroscope reading. The second stage is the rotation, which means the profile and the surface must be rotated to be the same angle as the gyroscope. The third stage is the combination, where each row of the rotated surface is offset to match each pair of the rotated profile.

4.2.1   Resolution

The data taken from the field are sampled at different intervals. The number of surface readings per kilometer is a different count than either the number of profile readings per kilometer or even the number of gyroscope readings per kilometer. Each sensor has a different resolution depending upon real-world conditions, such as the timing on the acoustic sensors. As a result, three different resolutions exist for the data: the surface, the profile, and the gyroscope.

Of the three data values, the backbone of the system is the surface data, which is a large two-dimensional array of points that represent an area. Using the surface as the standard resolution,

the gyroscope and profile data are interpolated to match the same resolution. Once all the data have been interpolated, the different data sets can be rotated.

4.2.2 Rotation

The angle of reference used for the analysis is the cross-slope, which is measured by the gyroscope readings. Each of the data types involved, both the profile and the target surface, must be rotated to match the gyroscope reading. To do this, a cross section of the data must be taken and the angle of that data determined. Once this angle is known, then the data can be rotated to match the cross-slope.

In each case, the angle can be found because of a set of known data. On each data set consisting of the profile, the scanning laser, and the acoustic rut the location of the wheel paths are known. If the distance D_w between the wheel paths is known, the angle θ' can be found by finding the arcsine of the difference in the elevations divided by the distance between the wheels (see Figure 4-2).

$$\theta' = \sin^{-1}\left(\frac{E_r - E_l}{D_w}\right)$$

Figure 4-2. Finding the Angle of the Data.

4.2.3 Rotating the Profile

For finding the angle of the profile and rotating it to be the same as the cross-slope, let there be some plane D_n that is at the same point along the distance axis. The two profile readings, the left wheel path and the right wheel path, intersect this plane at (T_l, E_l, D_n) and (T_r, E_r, D_n), respectively (see Figure 4-3).
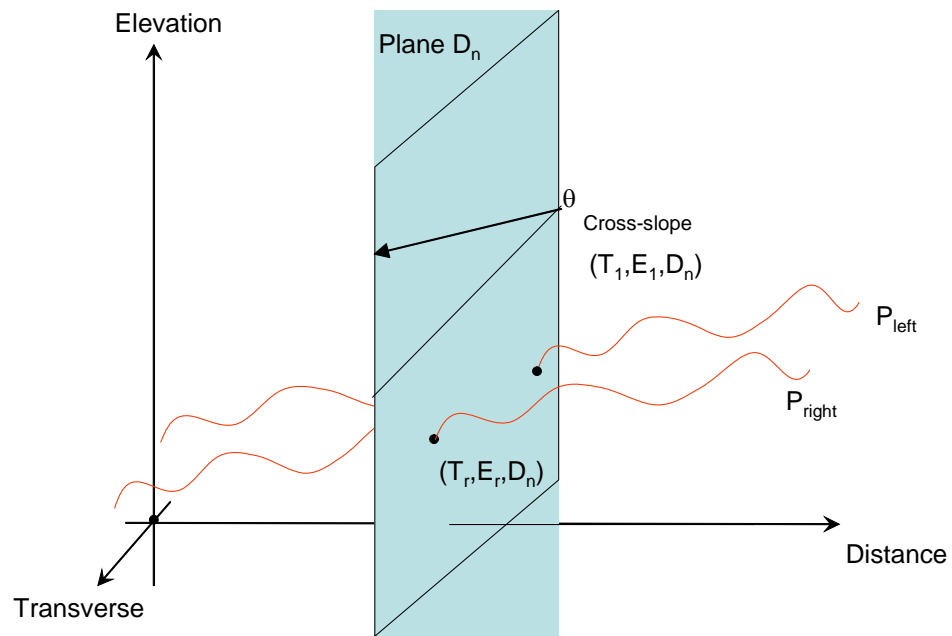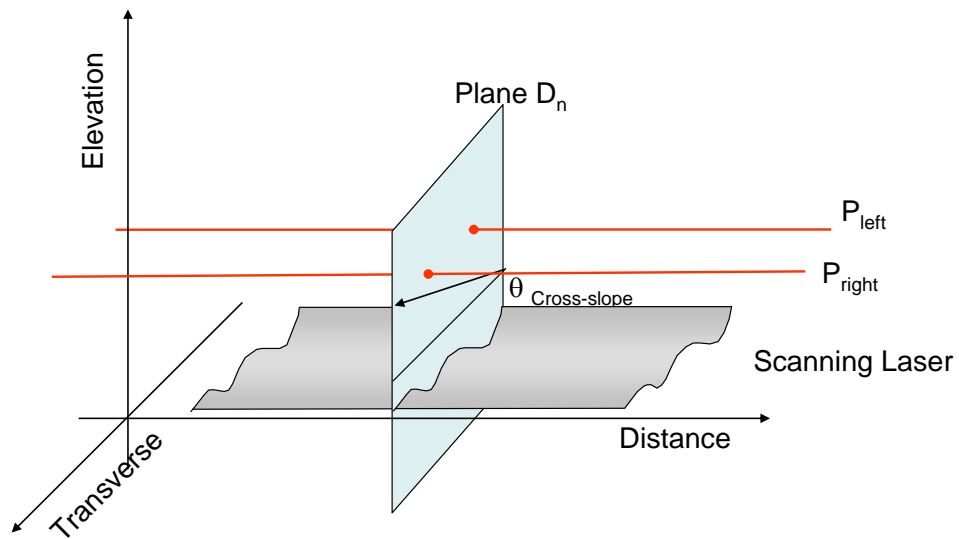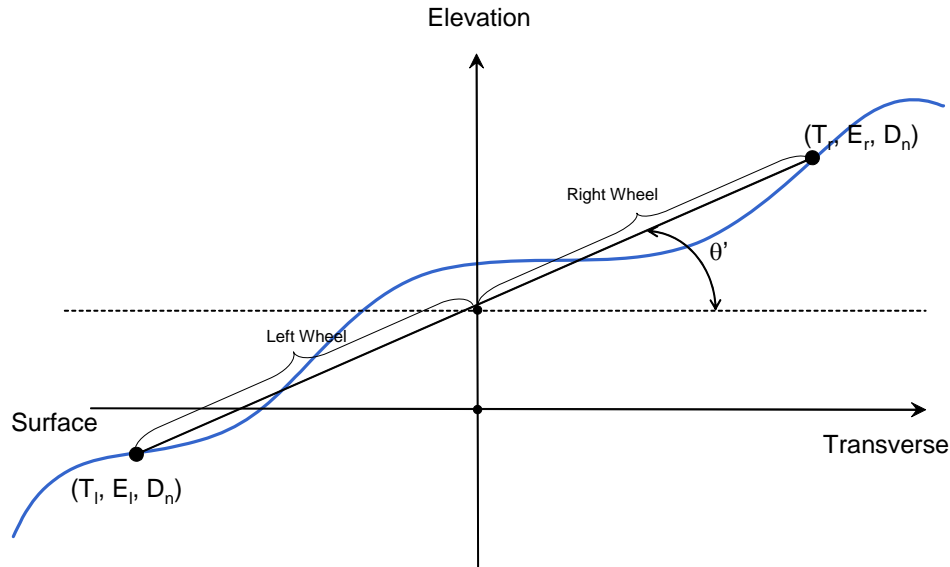
Figure 4-3. Taking a Slice of Profile.
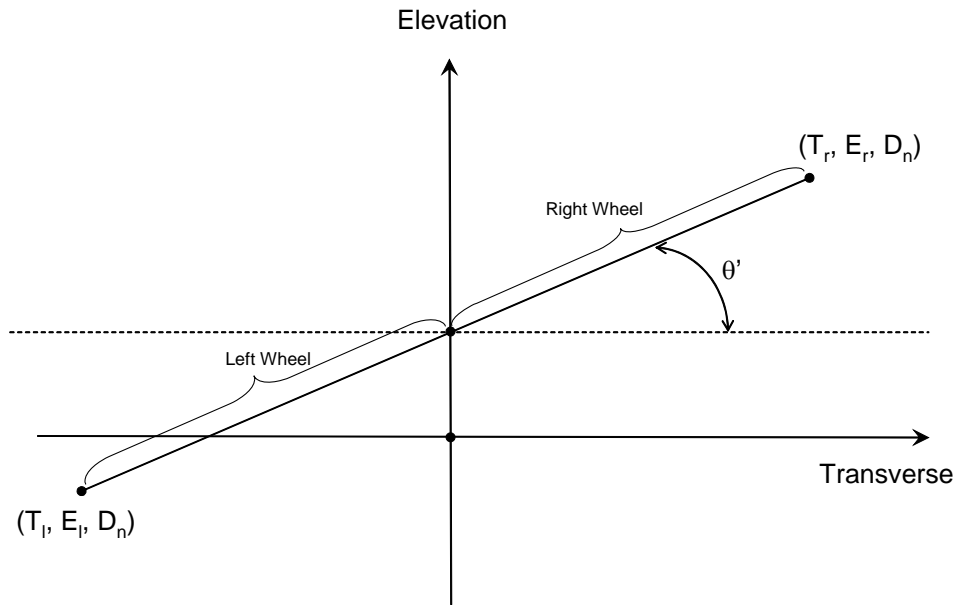
Figure 4-4. Rotating a Slice of Profile.

Now, a line segment connects the two profile points. If the distance D_w between the wheel paths is known, the angle θ' can be found by finding the arcsine of the difference in the elevations divided by the distance between the wheels.

Now that the cross-slope θ and the angle of the profile θ' are both known, the profile can be rotated about the midpoint until the profile angle matches the cross-slope (see Figure 4-4).

4.2.4 Rotating Scanning Laser Data

The same method used for finding the angle between the points of the two wheel paths of the profile can also be applied to the scanning laser data.

For finding the angle of the scanning laser data and rotating it to be the same as the cross-slope, let there be some plane D_n that is at the same point along the distance axis. A slice of data taken from the scanning laser data will now exist, and somewhere on this piece of data will be where the two wheel paths are touching the surface.

The two scanning laser readings, one at the left wheel path and one upon the right wheel path, intersect this plane at (T_l, E_l, D_n) and (T_r, E_r, D_n), respectively (see Figure 4-5).

Figure 4-5. Taking a Slice of Scanning Laser.

Figure 4-6. Rotating a Slice of Scanning Laser.

As with the profile, a line segment connects the two points of scanning laser data that intersect the two wheel paths. If the distance D_w between the wheel paths is known, the angle θ' can be found by finding the arcsine of the difference in the elevations divided by the distance between the wheels. Now that the cross-slope θ and the angle of the scanning laser θ' are both known, the scanning laser data can be rotated about the midpoint until the scanning laser angle matches the cross-slope (see Figure 4-6).

4.2.5 Rotating Acoustic Rut Data

Handling the acoustic rut data is similar to how the scanning laser data is manipulated. Again, the angle of the acoustic rut must be found and rotated to match the cross-slope. The acoustic rut data consist of five discrete points, two of which are set at the wheel paths of the vehicle.

Let there be some plane D_n that is at the same point along the distance axis. A slice of data taken from the acoustic rut data will now exist and the position of the right and left wheel path sensors are known. The left wheel path and the right wheel path acoustic rut data points intersect this plane at (T_l, E_l, D_n) and (T_r, E_r, D_n), respectively (see Figure 4-7).
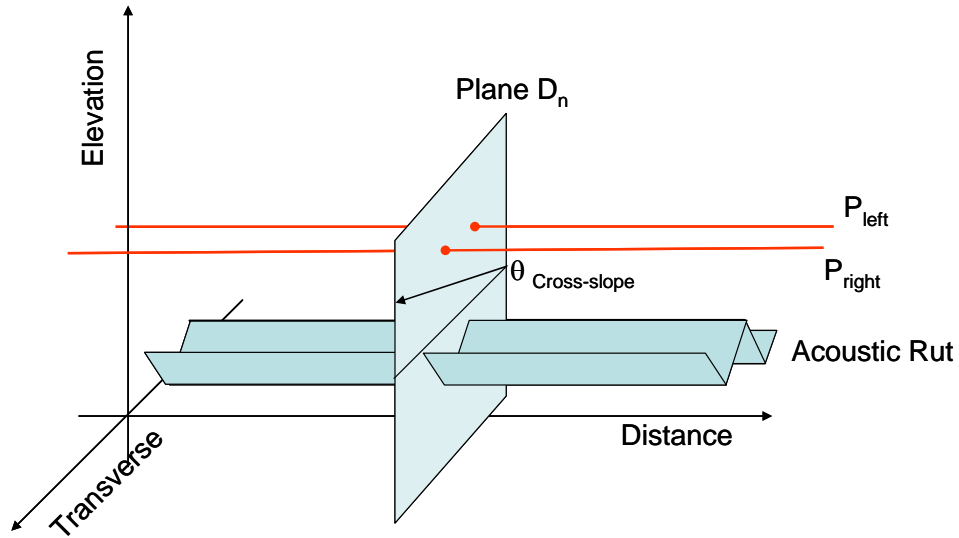
Figure 4-7. Taking a Slice of Acoustic Rut.
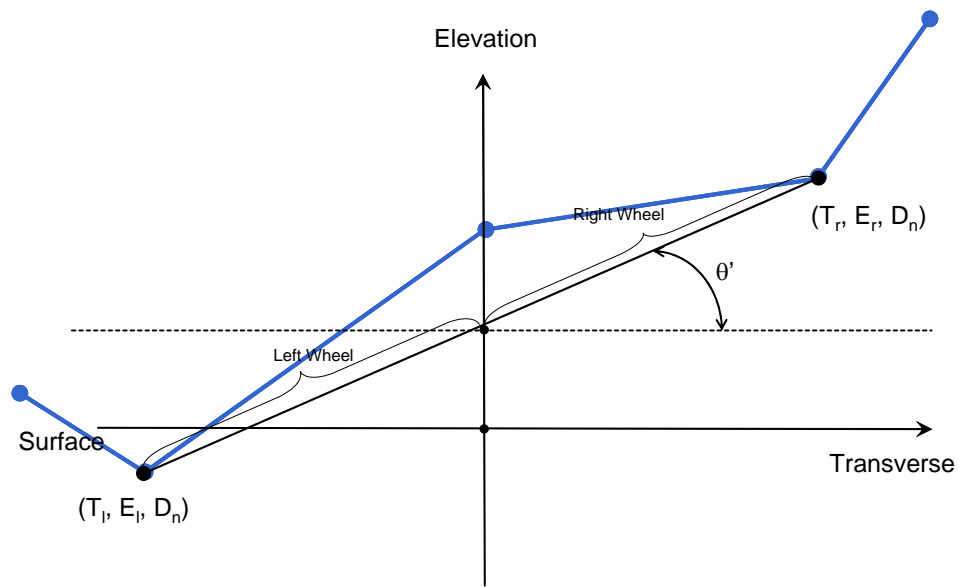
Figure 4-8. Rotating a Slice of Acoustic Rut.

As before, a line segment connects the two points of acoustic rut data that intersect at the two wheel paths. If the distance D_w between the wheel paths is known, the angle θ' can be found by finding the arcsine of the difference in the elevations divided by the distance between the wheels. Now that the cross-slope θ and the angle of the acoustic rut θ' are both known, the acoustic rut

data can be rotated about the midpoint until the acoustic rut angle matches the cross-slope (see Figure 4-8).

It should be noted that the same procedures could be done on other sensor data, such as laser rut displacements (instead of acoustic displacements), etc., to provide the 3-D surface image.

4.2.6 Offset

The surface data and the profile data are now all at the same angle as a cross-slope. Also, upon each of these two data sets is a matched pair of points that are a fixed distance apart. Given that they are at the same angle, the segments defined by the wheel paths are parallel.

So, for each slice of data across the surface that has been rotated to match a rotated profile, the data can be shifted by the difference of elevation between the profile and the surface at the wheel path (see Figures 4-9 and 4-10).
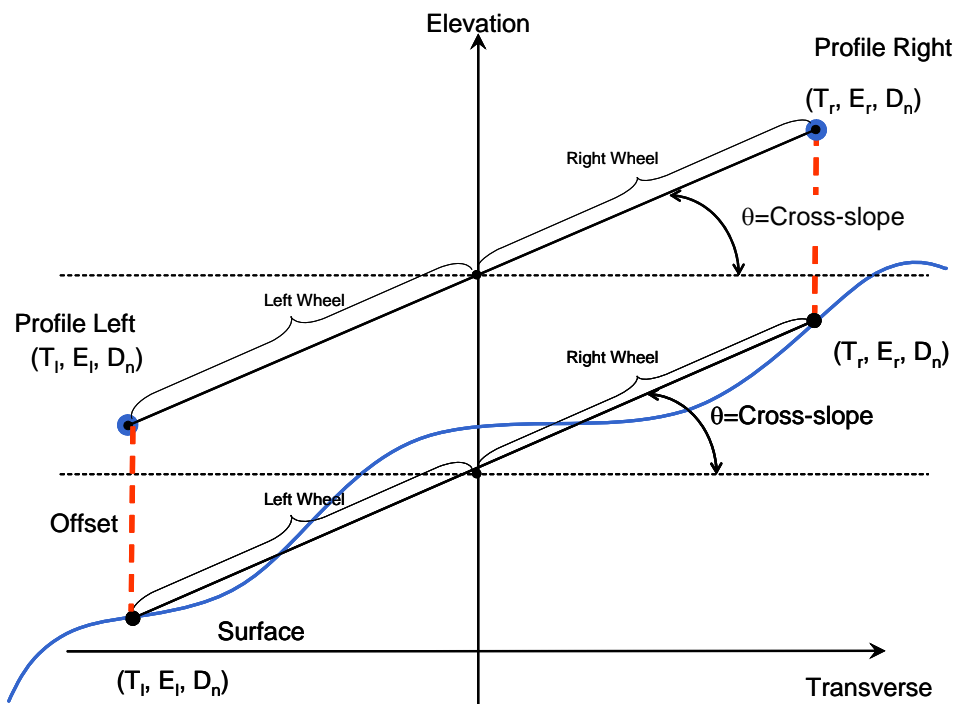
Figure 4-9. Offsetting the Rotated Scanning Laser to Match Rotated Profile.
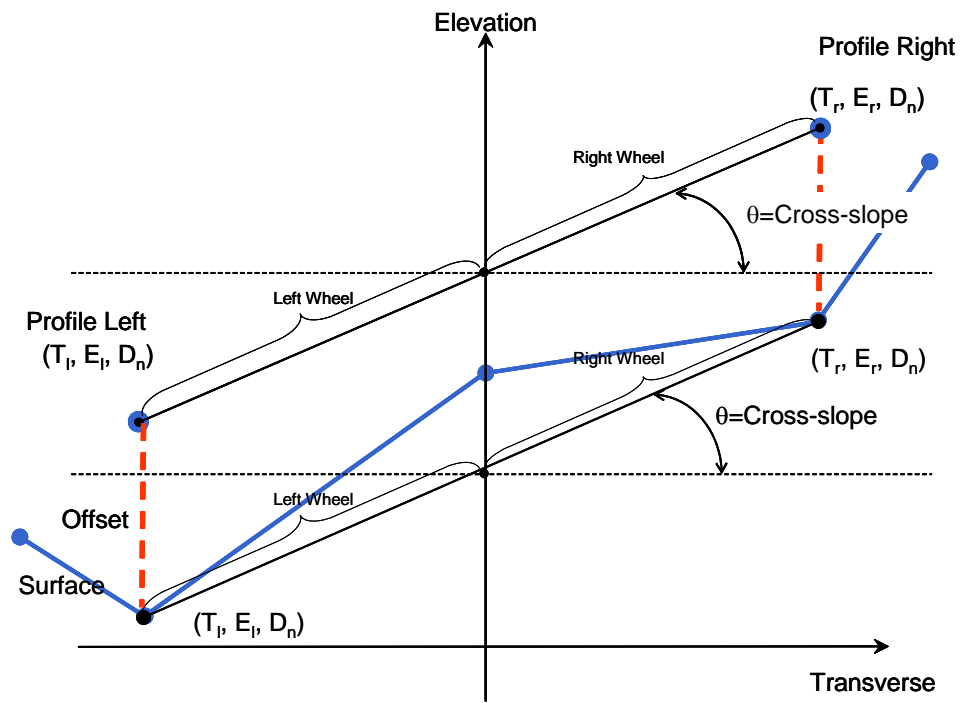
Figure 4-10. Offsetting the Rotated Acoustic Rut to Match Rotated Profile.

Chapter 5 Estimating Grind and Fill

In Chapter 4, a procedure is described for integrating the various sensor data in order to provide a 3-D image of the pavement surface. In this chapter, an approach and procedure are described where this image can be used in conjunction with a desired shape to compute the amount of grind or fill quantities needed in order to achieve this new shape. As noted, with the integrated sensors the created surface is independent of the motion of the vehicle. The surface has been pinned down to two profiles running along the wheel paths by using the cross-slope of the road. Now the surface has been staked out, the estimation of the grind and the fill can be performed.

5.1   DEFINING GRIND AND FILL

The idea of grind and fill suggests that a change to the current surface is desired. For example, the pavement surface may have some undesirable characteristic, such as a bump or dip. Suppose the desired surface is defined by a smooth plane at a 2 percent cross-slope. The estimation of the grind and the fill then is the difference between this surface, DS, and the surface, S, that has been found by the sensors. The difference between surfaces therefore is the amount of volume difference between the desired surface and the current surface.

If the desired surface, **DS,** was also based on the same dimensions as the current surface, then each location on the surfaces could be compared. This means that some volume could be found for each location on each surface that was one distance unit long, one transverse unit wide, and some difference between elevations high. These three values together would define a small volume. For cases where the desired surface is below the target surface, the result would be a negative volume. The grind required for a location on the surface would be where any positive volume was found between the desired surface and the target surface. The fill required for a location on the surface would be where any negative volume was found between the desired surface and the target surface.

5.1.1 The Mathematics of Grind and Fill

To find the estimation of grind and fill, the volume of each chunk of material needs to be bounded by some limits. For each section of the two surfaces, there can be some interval dD along the distance access that is the distance between readings for the surface scan.

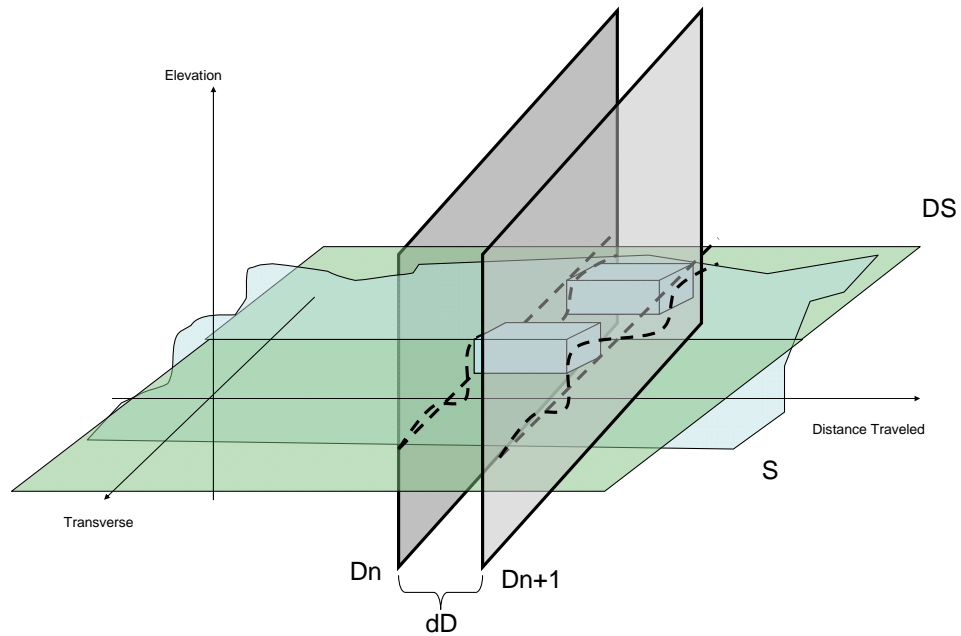This displacement dD gives one edge of the volume to be calculated (see Figures 5-1 and 5-2).

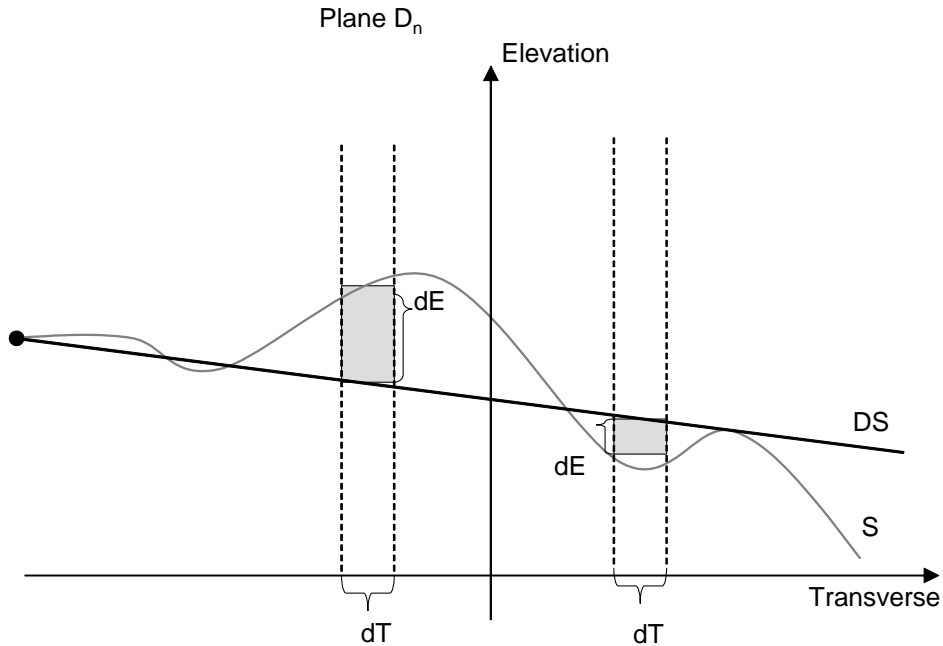**Figure 5-1. Desired Surface Cutting across Target Surface Bound by a Distance Interval.**

Figure 5-2. Cross Section of the Intersection of the Two Surfaces.

Now, the distance along the transverse axis of the surface is also a fixed interval dT that represents the second edge of the volume. The base of the volume will be some rectangle dT*dD.

The third element in the volume will be the value that is the difference in the elevation, some value dE where the TS is subtracted from the DS. Either the DS is higher than the TS, or the TS is higher than the DS. By multiplying dE*dT*dD, the volume for this area of the surface can be found. A positive value indicates that the surface at this point has to be removed (or a grind area), and a negative value at this point would indicate a pit that would have to be filled.

If a record is kept or if the volume was positive and negative at that point, then a total grind and a total fill per row of the surface can be found. In turn, the sum of all the grinds for each row and the sum of all the fills for each row will result in the total grind and fill for the entire surface.

5.1.2 Sample Case: The Dome

An example case for the grind and fill would be a dome surface intersected with some desired plane. All the volume above the plane will have to be ground down, and all the volume below the plane will be a fill (see Figures 5-3).
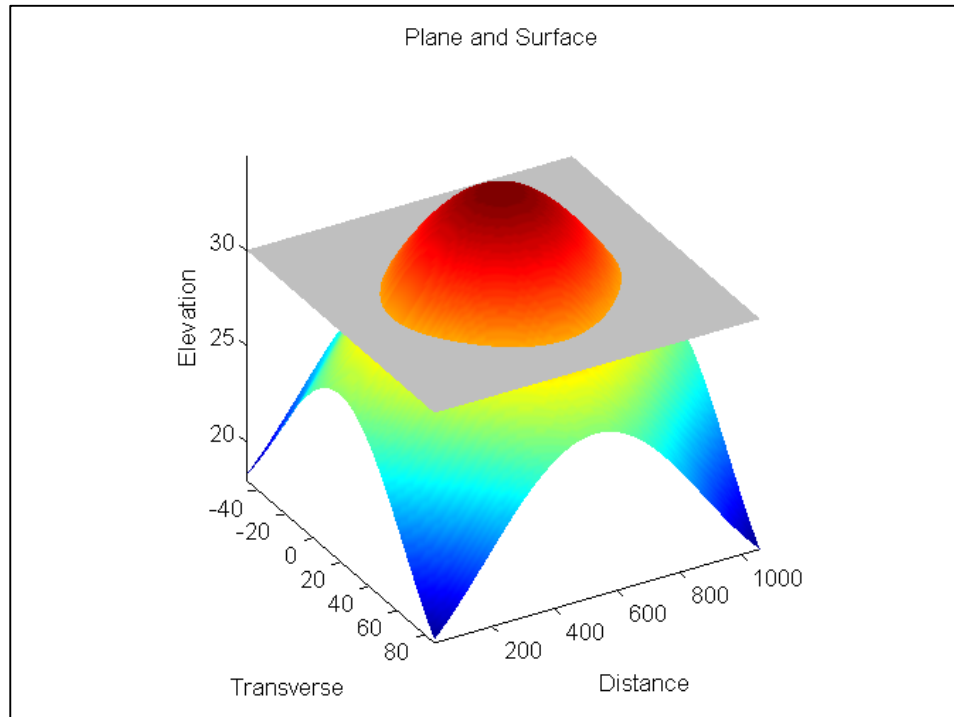
Figure 5-3. Desired Surface Intersecting a Dome.
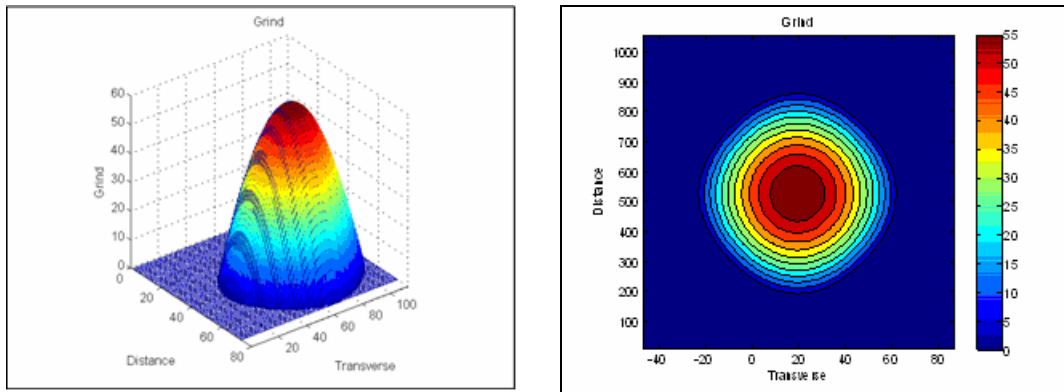
Figure 5-4. Volume Found for Grind.

The top of the dome sliced by the desired surface would have some positive volume difference between the dome and the desired surface. This difference can be measured and recorded, allowing a contour graph to be created, as shown in Figure 5-4.
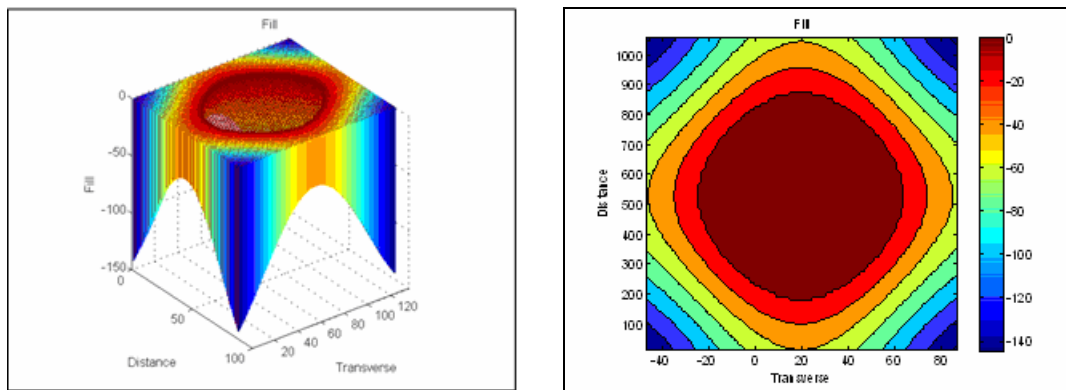
Figure 5-5. Volume Found for Fill.

The sloping sides of the dome below the desired surface results in a negative difference between the desired surface and the target surface. This negative volume surface becomes the area for fill. The negative volume also can be charted as a contour graph, as shown in Figure 5-5.

Chapter 6 The Static Scanning Laser

During the final stages of the project, when it became apparent that reliable scanning laser data would not be obtainable, a meeting was held with the project director and project personnel and a method for measuring accurate transverse data using a laser moving along a bar in front of a vehicle was discussed. The system would be used for verifying the program OVERLAY during the overlay construction project. A Compax3 system with the linear actuator was purchased along with a SLS Selcom laser to provide transverse measurements for connective longitudinal points along the road. The system was given the name static scanning laser measuring system, since for the measurements the vehicle would be stopped at each point while the transverse measurements taken as the laser is scanned across pavement. Cross-slope measurements would also be taken at each longitudinal point.

6.1 BUILDING THE STATIC SCANNING LASER

The static scanning laser system consists of both hardware and software components, which are discussed in the following sections.

6.1.1 Hardware System

The hardware used in this project can be split into three parts: motor control, data collection, and the interface circuit

6.1.1.1 Motor Controller System

The first part is motor controller system, which is responsible of movements and locating the laser sensor to the desired location. It consists of the Compax3 system with the linear actuator (BLMA 120). The motor part, which is mainly a bar of 14-ft length, is shown in Figure 6-1 installed on the front of a truck.

Figure 6-1. Linear Actuator Motor.

6.1.1.2 Data Collection

The second component provides a means for collecting the data from the sensors. It consists of the sensors (laser and gyroscope shown in Figure 6-2), data translation module, and the laptop.
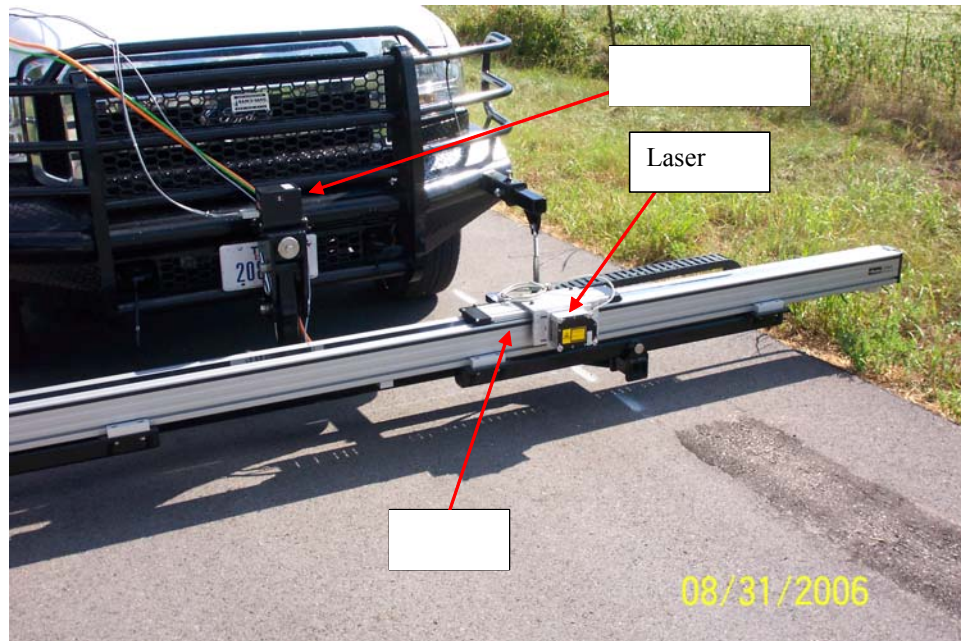
Figure 6-2. Laser and Gyroscope Sensors.

6.1.1.3   Interface Circuit

The third component of the system is an interface circuit for communication between the first two parts. Its main task is converting voltage levels between the two subsystems (converting voltage from TTL level [0-5 V] to Compax3 logic level [0-24 V]).
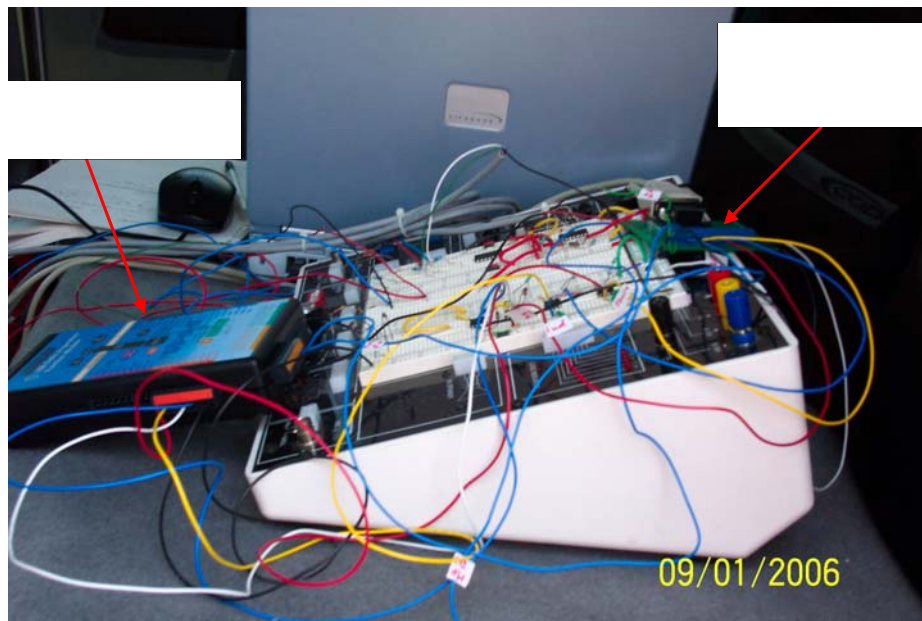
Figure 6-3. Data Translation Card and Interface Circuit.
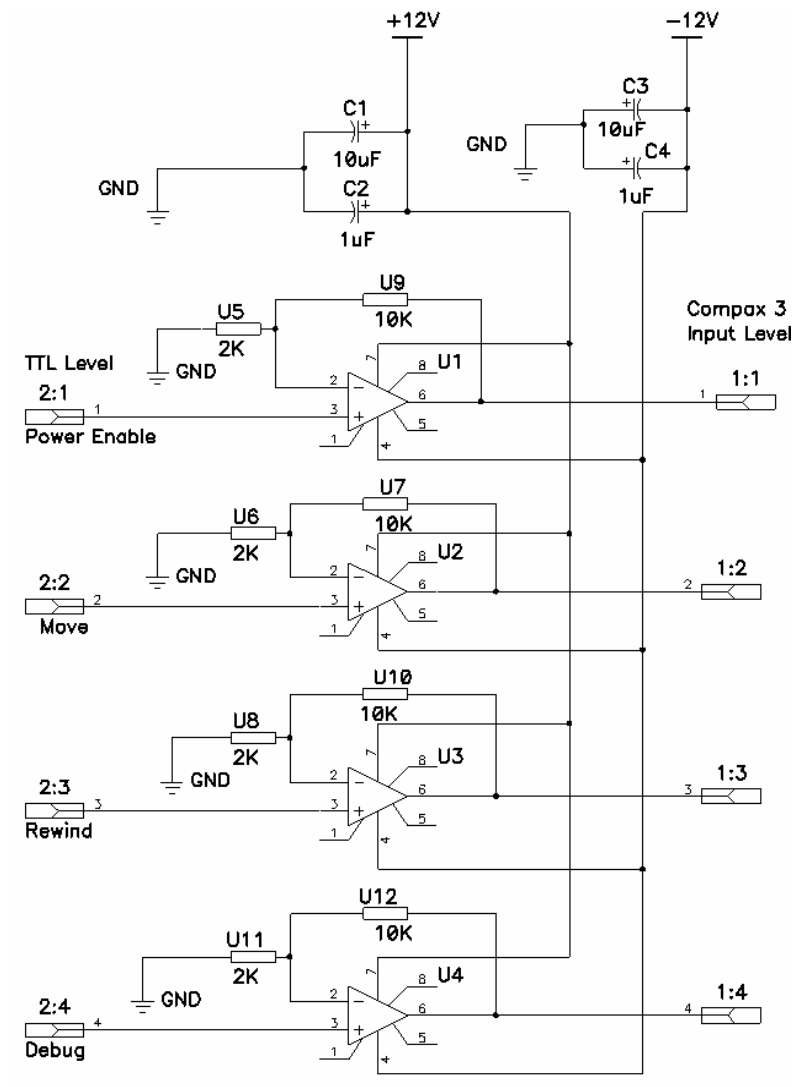
Figure 6-4. Interface Circuit.

Figures 6-3 and 6-4 show the interface circuit between Compax3 and the data translation card.

6.2   CONTROLLING THE STATIC SCANNING LASER

There are two programs used that are required for the system. The first one is the program that runs in the Compax3 and is responsible for sending and receiving control signals to and from the laptop. It is also used for initiating the appropriate commands for the motor in order to move to a new location or rewinding it to its original location.

The other program (called *gui_interface_v3*) runs in the laptop and its purpose is to provide a user interface to the system, exchanging control signals with the Compax3 system, and collecting data from the sensors through the data translation module. This is illustrated in Figure 6-5
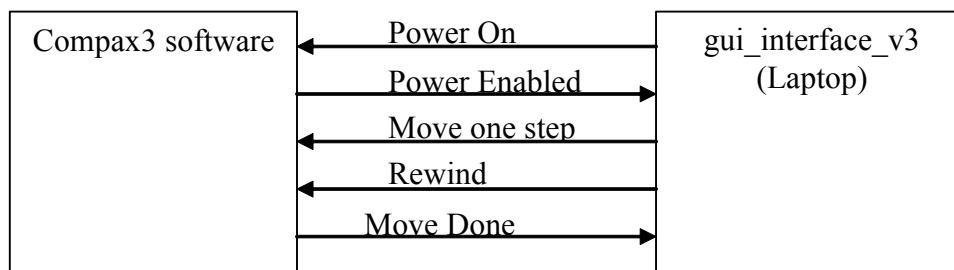
Figure 6-5. The Control Signals Transferred between the Two Programs.

Table 6-1. Control Signals.

Power On	Turns on the motor and is sent by the *gui_interface_v3* program to the Compax3.
Power Enabled	Acknowledgment for the power on signal sent from Compax3 telling that the motor is on.
Move one step	Control signal to let the motor move to the next step (move 1 inch).
Rewind	Move the motor back to its original location. (Usually initiated when the system done from collecting data from a location.)
Move Done	Acknowledgment to either the Move one step or Rewind commands telling that the motor finishes its movement and now it's on the desired new location.

6.2.1 Gui_interface_v3 program

The interface program is a Matlab program (Figure 6-6) that runs on the laptop and it is the only program that the user will operate to communicate with the system. Figure 6-7 shows the program when it first runs. A file is automatically created with a name in the form of **'LA_profiler-*date-time*.txt'** in order to save the sensor readings in it.

To operate the system the user should first set the end point specifying the transverse measurement length for each longitudinal position. Once the end points are defined and the 'End Point' button is pressed, the start button will be activated and the system is ready to collect data (Figure 6-8)

For the program, the user can choose to run it in one of two modes:

1. Automatic Control mode: the user only hits the start button and the program collects the data and automatically moves the motor along the bar until the specified end is reached.

2. Manual Control Mode: the user selects the commands to power on the motor, read the data, move the motor 1 inch, or rewind the motor. This is done by using the control buttons on the left side of the program interface (see Figure 6-9).

START

Create new file with name
(LA_profiler-*date-time*.txt)

Set End Point

START button pressed

Move One inch

Read data from laser and
Gyroscope (Read 1000
times and take the average)

Display Data and save it in
the file

End Point reached

Stop and Move to
the next location
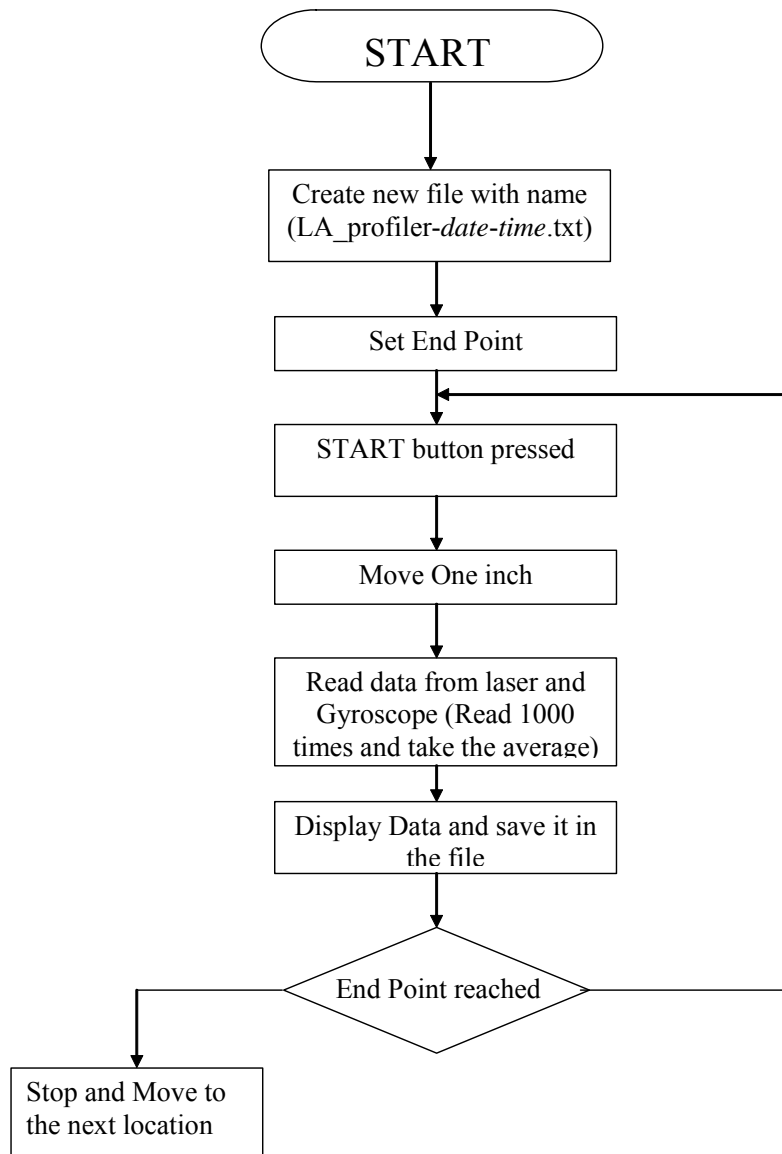
Figure 6-6. A Flowchart for the Matlab Program (Automatic Mode).
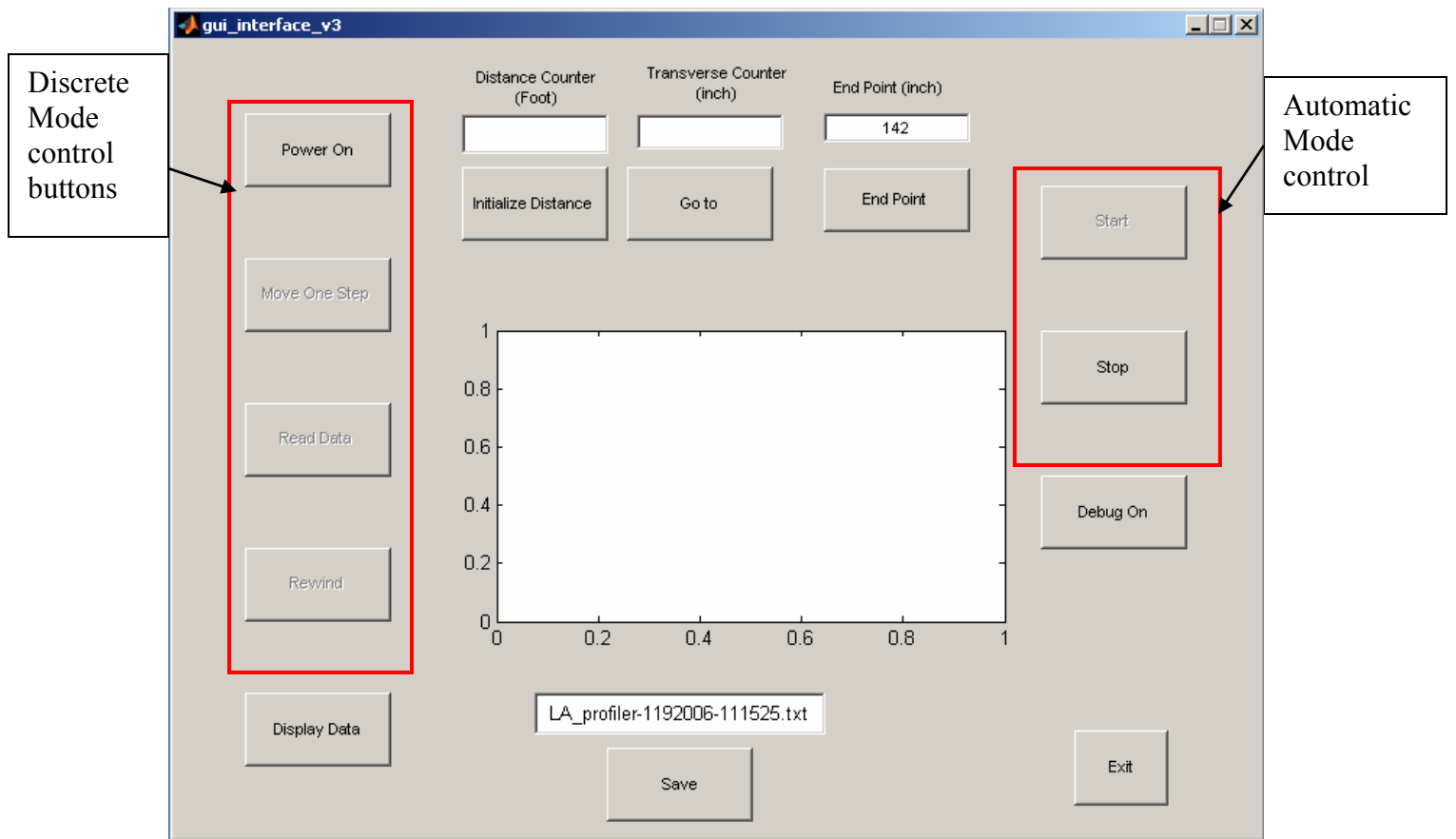
Figure 6-7. The Matlab Interface Program Window.
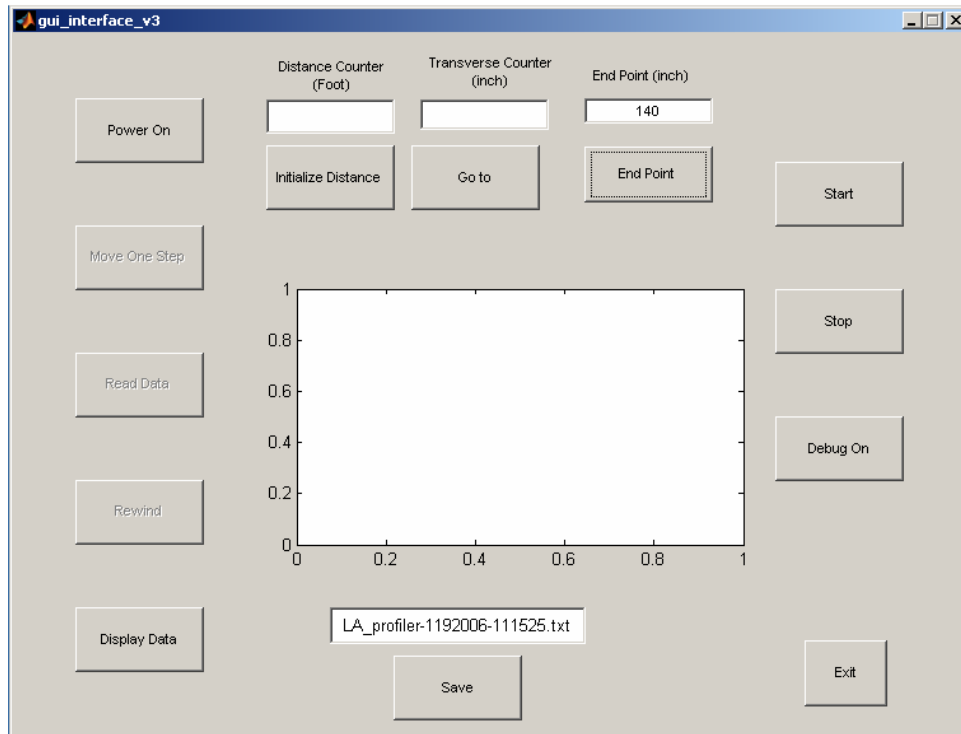
Figure 6-8. Selecting the Length of the Data Segment (Determining the End Point).

When the user presses the 'Start' button the system will begin data collection in accordance to the following steps:

1.   Move the motor 1 inch

2.   Read data from sensors

3.   Display the data read (as shown in the flow diagram in Figures 6-6)

4.   Save data in a file

5.   If end point reached then the motor should be rewind to the original point; otherwise, go to step 1.
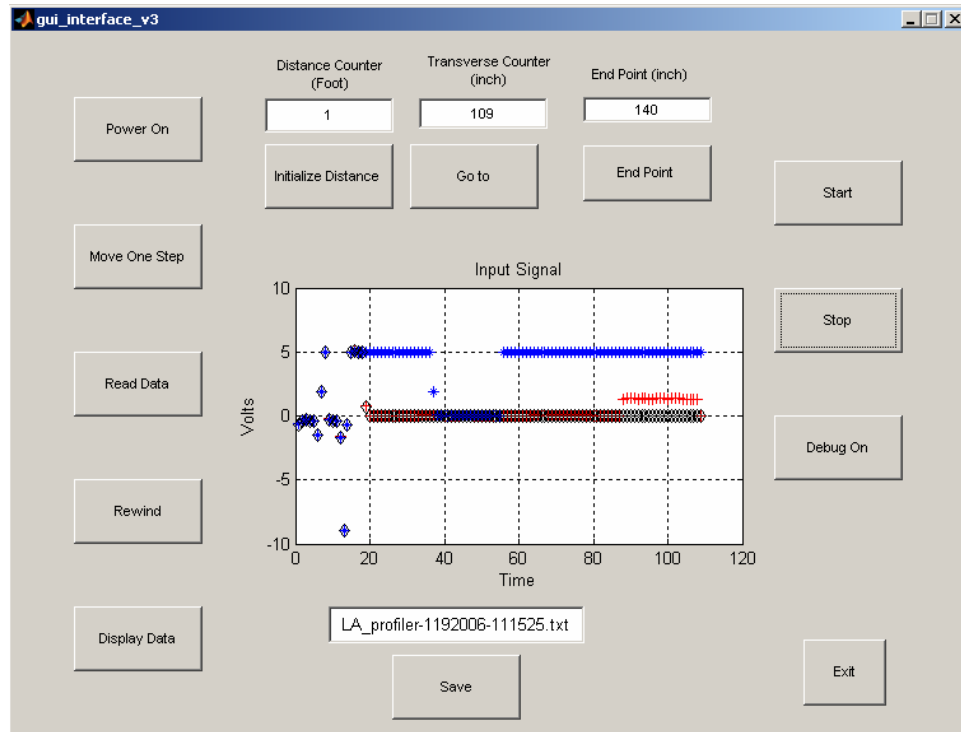
Figure 6-9. The Data Collected and the Transverse Counter Are Displayed for Every Inch while Collecting Data.

6.3 TESTING THE STATIC SCANNING LASER

The data were collected from three different sections with different bump depths, as in Figures 6-10 through 6-13 The data collected from each section represent 27 different locations 9.5 inches apart. The locations are predetermined on the sections, as in Figure 6-14.
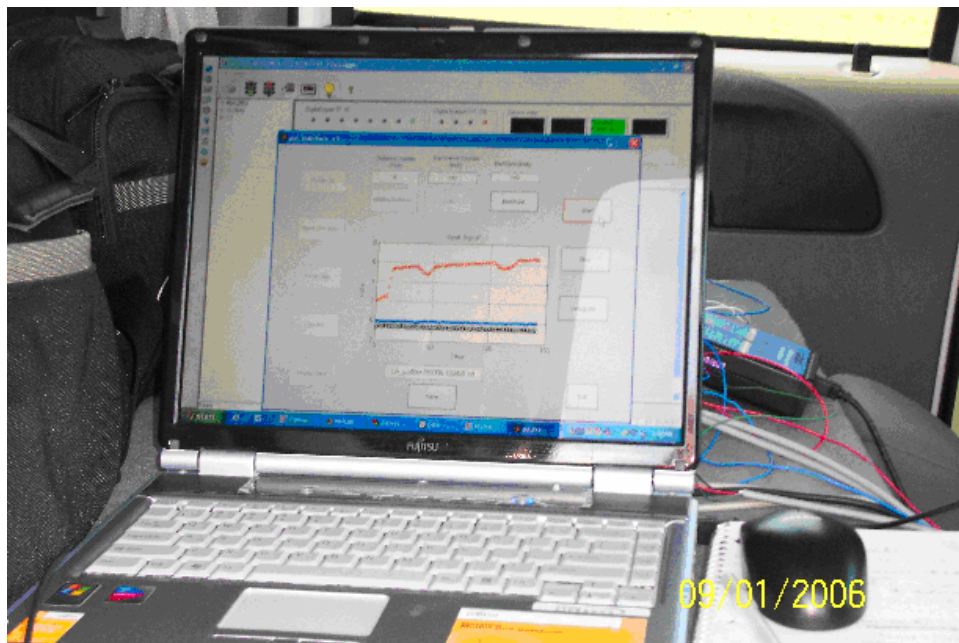
Figure 6-10. Displaying Data Collected from One of the Test Locations.

Figure 6-11. Section 1.

Figure 6-12. Section 2.

Figure 6-13. Section 3.
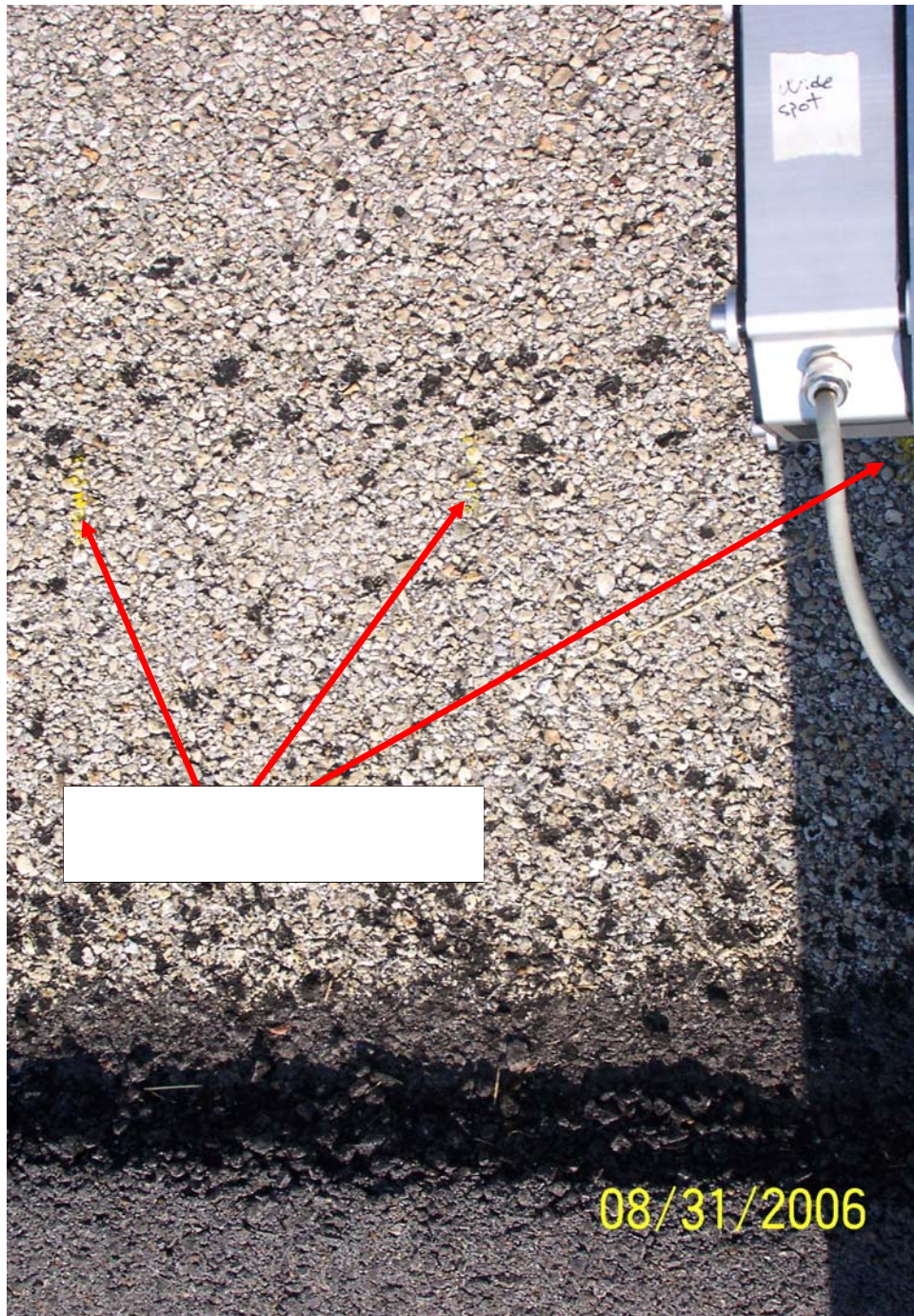
Figure 6-14. Preset Locations (9.5 inches apart).

6.4   RESULTS FROM THE STATIC SCANNING LASER

After the tests with the static scanning laser were complete, a sample file was given to be processed as a transverse profile data set. Data from the divide (see Figure 6-15) at section two was taken and processed as a three-dimensional image (see Figures 6-16 through 6-18).

Figure 6-15. Section 2 Dividing Line Marker.
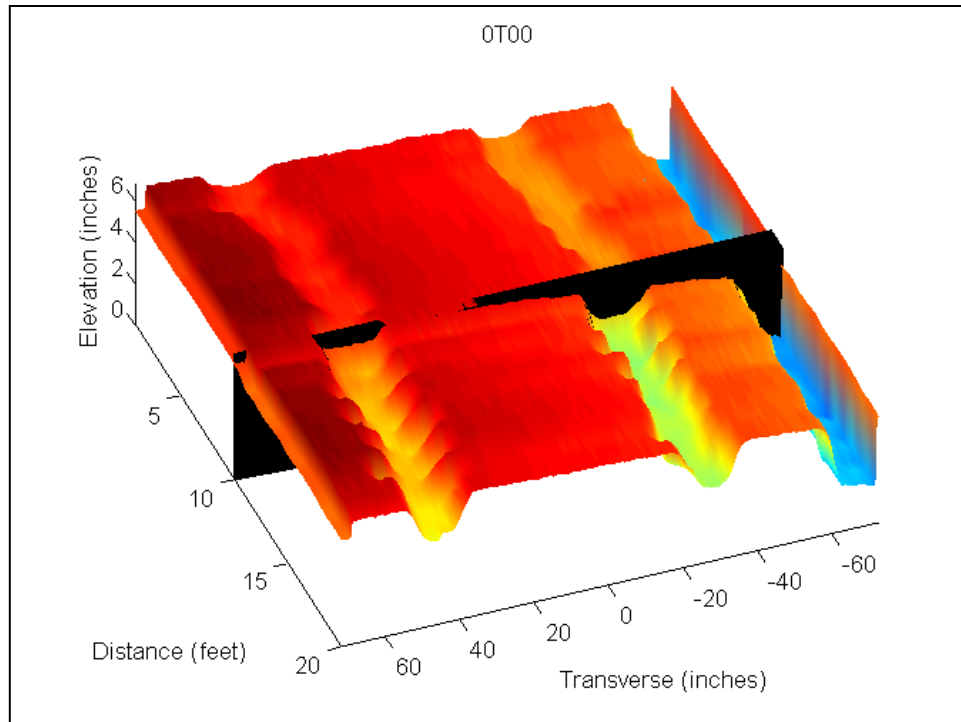
Figure 6-16. Looking Down on the Section 2 Divide Marker.
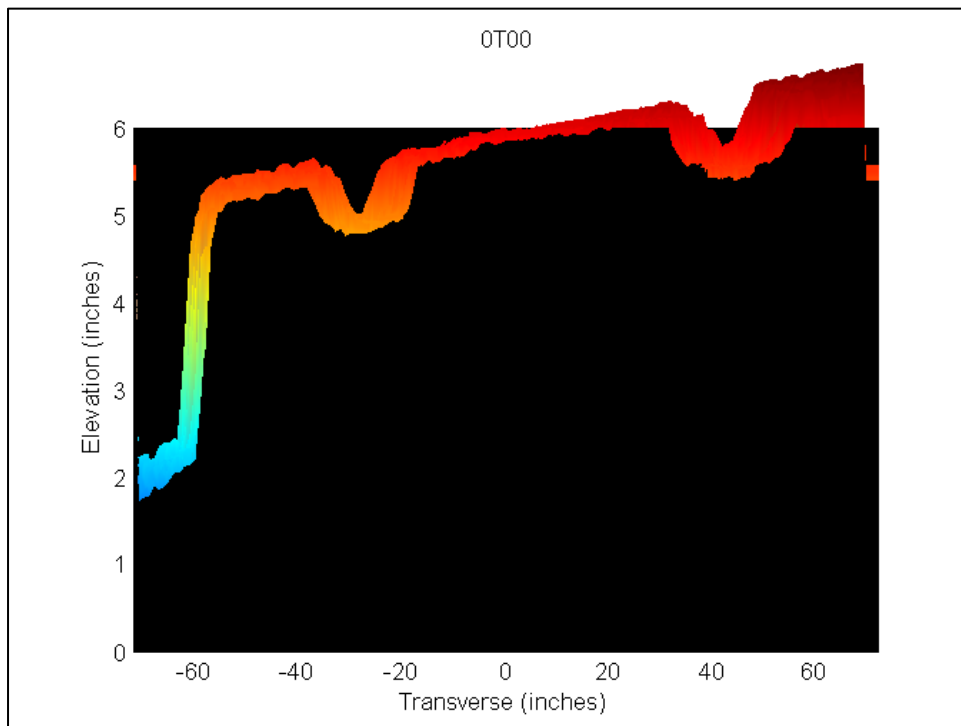
Figure 6-17. Looking on the 1 inch and 1/2 inch Side of the Divide.
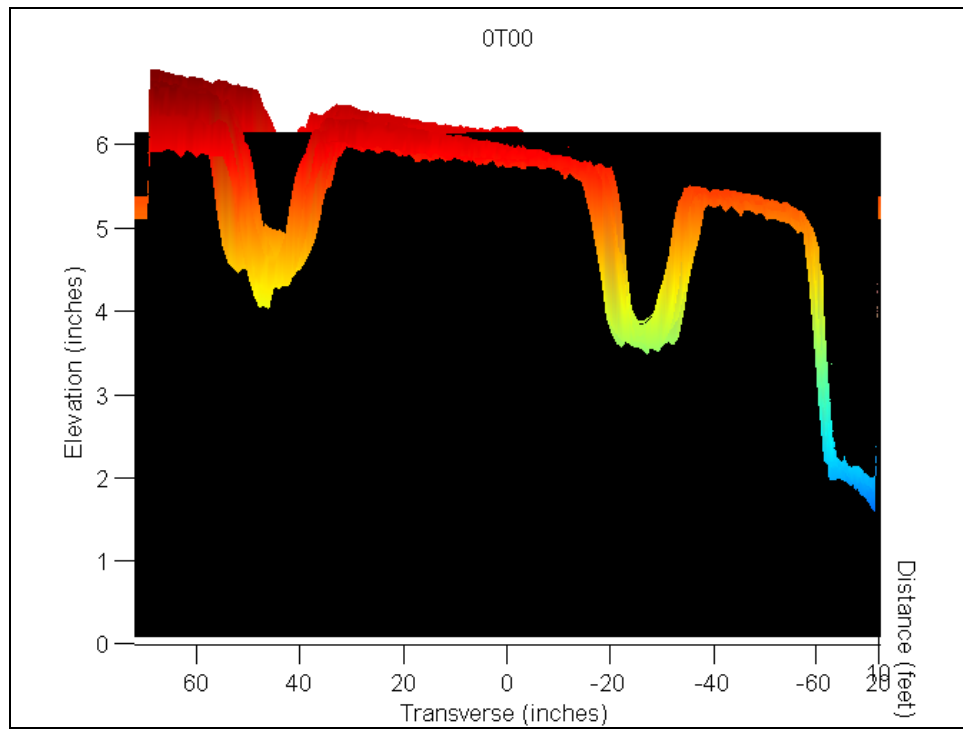
Figure 6-18. Looking at the 1 inch and 1 1/2 inch Side of the Divide.

6.5 FUTURE WORK FOR THE STATIC SCANNING LASER

The static scanning laser system was purchased during the last part of the project. Because of this only a simple program was developed to test the concept, although it does provide the surface display data in the PF99 format. From the results of this usage, as illustrated by the 3-D surface displays in Figures 6-13 to 6-18, a more user friendly program could be developed. The 3-D Surface Display program (Described in Chapter 4) can read the data from the static scanning laser program but does not provide for its integration with the gyroscope and longitudinal profile. Future work would be to provide the integration capability with the other sensors and to make the software more user friendly. The static scanning laser system, when integrated with gyroscope data and longitudinal profile, would provide a very accurate but slow speed surface profile measurement system.

A second requirement of the static scanning laser was the need for an interface circuit to buffer the voltage between the Compax3 controller and the data translation board. The Compax 3 circuitry relies on a 24 V signal, while the data translation board relies on a 5 V signal. Researchers could not find an off the shelf product able to handle this interface requirement. This buffer was done using the circuit design shown in Figure 6-4. Figure 6-19 provides a circuit board design that could be used for implementing the circuit. A board with this capability would be needed for implementation or extensive usage.
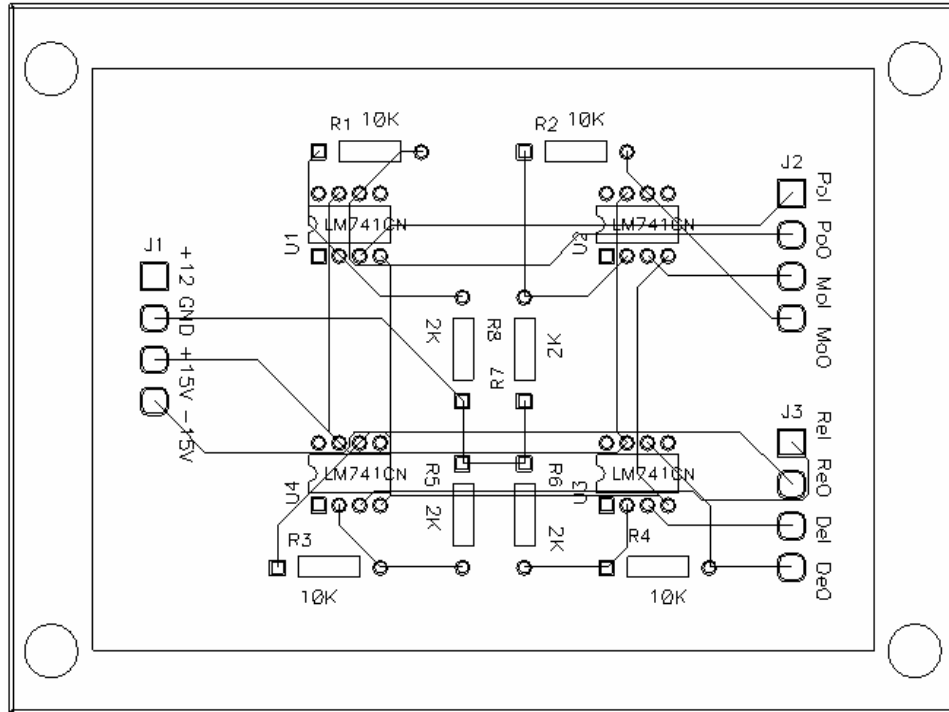
Figure 6-19. Proposed Interface Circuit Board.

Chapter 7 Summary

The original objective of this project was to investigate the integration of the scanning laser system, the inertial profiler, and the gyroscope for overlay and milling strategies. The lack of adequate scanning laser data prevented the expected progress in achieving this goal; however, a number of very useful results occurred including the capability for developing and using grind and fill strategies. A procedure was developed for using the gyroscope sensor in the current TxDOT profilers for providing a cross-slope capability. When integrated with the inertial profile data in the 3-D surface program, the vehicle response is removed, yielding accurate pavement cross-slope measurements. A 3-D surface profile graphics program was developed and discussed in the report. The transformed data from combining scanning laser or other transverse sensor data with inertial reference longitudinal profile and gyroscope data can be sent to a grind and fill module and used for modeling the results of different overlay strategies.

As noted in Chapter 1, when it became apparent that useable scanning laser data would not be obtained, the 3-D surface software was modified so that the capability of using displacement data from the five acoustic rut sensors, providing five transverse acoustic displacement readings, could be used for transverse profile readings. Software was developed which could be used for either scanning laser data or acoustic rut displacement data for 3-D surface pavement surface profile. A procedure was developed and is implemented in this software for integrating the transverse data with inertial reference profile and gyroscope data from the TxDOT profilers. This integration procedure synchronizes the profile and gyroscope data with the transverse profile data to provide a pavement surface image with the vehicle response removed. This provides a very powerful package or analysis tool for accurate 3-D surface profile. The software is compliant with the TxDOT in-house VNET protocol and reads the profile, gyroscope, and transverse profile sensor data directly from the VNET PF99 files.

An additional useful result is in the development of a program which will read the 3-D image to provide a means of determining grind and fill quantities when passing a plane over, under, or

inside of the 3-D surface image. The user enters the parameters for the angle, height, and longitudinal positions. The software is written in MatLab, providing a rich set of tools for later modification to this module for simulating different desired pavement surfaces and overlay strategies. The software can further be modified to allow additional laser displacement readings, or multi-path inertial profile readings, thereby providing additional surface resolution. The instruction manuals for reading and integrating the PF99 VNET data for use with the 3-D surface display and the grind and fill programs are given in the Appendixes.

The 3-D surface and grind and fill software is ready for implementation, but will likely require tuning or other changes as it is used. It is recommended that the implementation include a task so that the software can be evaluated on selected projects. A separate project could be used to expand the capability of including other transverse measurement systems, such as the static scanning laser discussed in Chapter 6 or laser rut displacements. These additional sensor systems are illustrated by the dotted lines in the program flow diagram in Figure 7-1.

The OVERLAY program was developed and evaluated. Additional development work is needed in a couple of areas to make the *OVERLAY* program useful in practice:

- A reference profiler will have to be developed that permits faster measurement of unfiltered reference profiles for program applications; and
- An alternative form of the model for predicting the path traced by the screed needs to be investigated that considers the variability of the screed path to come up with a program that more reasonably predicts the roughness of the overlaid pavement.
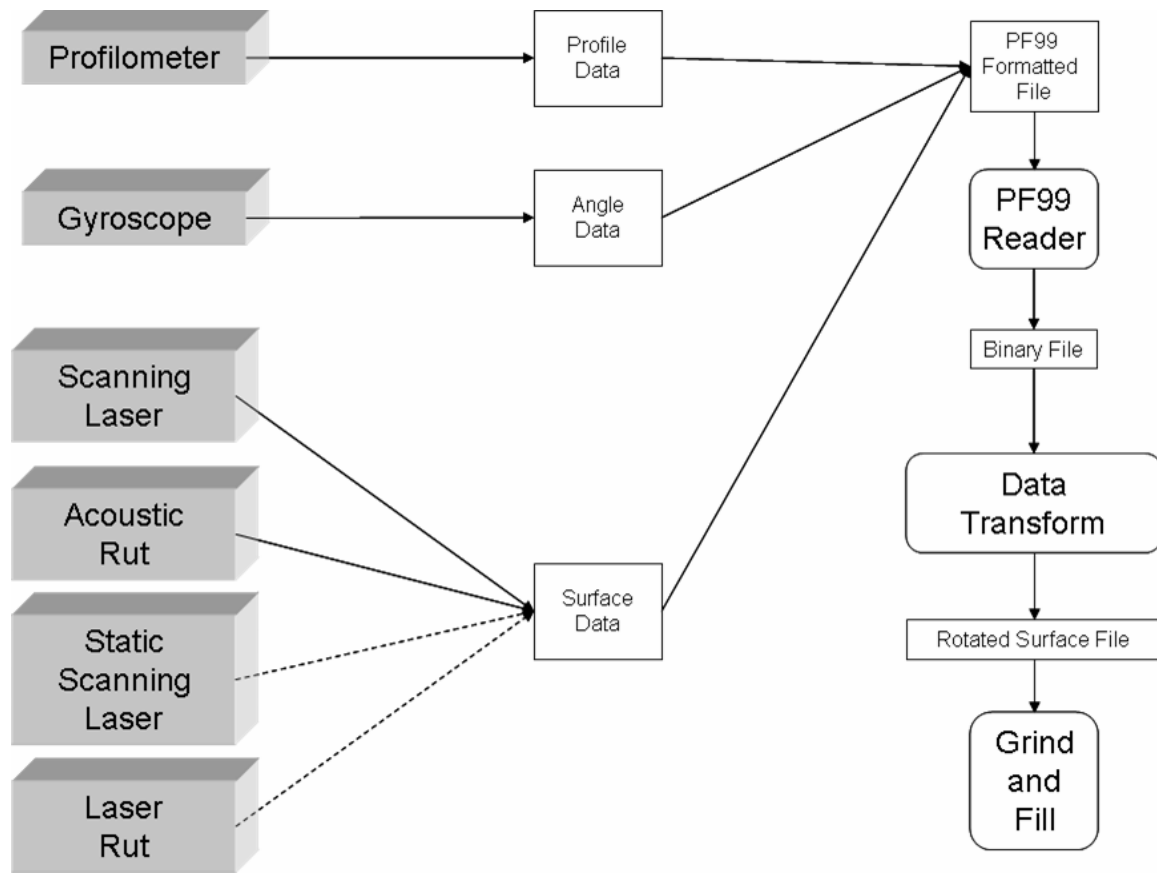
Figure 7-1. Program Data Flow.

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Barber-Greene Paving. *Principles of the Asphalt Finisher*. Page 6900, Release 106, Aurora, Ill.

Codas, S. D., W. R. Hudson, and C. E. Lee. *Development of a Computer Program (OVERLAY) to Simulate Laydown and Compaction of Asphalt Pavements*. Research Report 251-2, Center for Transportation Research, The University of Texas at Austin, Austin, Tex., 1983

Walker, Roger S., 5-1782-01-S Project 5-1782-01: Implementation of the Real-Time Transverse Pavement Profile Measurement System

The MathWorks Inc., MATLAB Mathematics Version 7, June 2004

The MathWorks Inc., MATLAB Graphics Version 7, June 2004

APPENDIX A CONNECTION PIN SUMMARY

PIN Summary for Connecting to Data Translation Module

DMS-B604 Gyroscope

25-Pin Male Connector

Pin	Description
1	Power Ground
2	+10 or +30 VDC
3	User Input
4	User Input
5	User Input
6	User Input
7	Steady Turn
8	Break Test
9	Ready
10	Initialization Command
11	Velocity Input
12	Signal Ground
13	Reference Command
14	Bank (Analog)
15	Elevation (Analog)
16	Heading (Analog)
17	X Axis Acceleration (Analog)
18	Y Axis Acceleration (Analog)
19	Z Axis Acceleration (Analog)
20	Forward Acceleration (Analog)
21	Lateral Acceleration (Analog)
22	Vertical Acceleration (Analog)
23	Roll Rate (Analog)
24	Pitch Rate (Analog)
25	Yaw Rate (Analog)

9-Pin Female Connector

Pin	Description
1	No Connection
2	TXD
3	RXD
4	No Connection
5	Signal Ground
6	No Connection
7	No Connection
8	No Connection
9	No Connection

Connect Gyroscope to DMS-B604 to a DT9803

Gryoscope Pin	Gyroscope Description	DT9803 Pin	DT9803 Description
25-Pin Male 14	Bank (X) Angle	Purple Pin 4	Channel 9
25-Pin Male 15	Elevation (Y) Angle	Purple Pin 6	Channel 10
25-Pin Male 16	Pitch (Z) Angle	Purple Pin 8	Channel 11
25-Pin Male 23	Roll (X) Rate	Blue Pin 10	Channel 12
25-Pin Male 24	Pitch (Y) Rate	Blue Pin 12	Channel 13
25-Pin Male 25	Yaw (Z) Rate	Blue Pin 14	Channel 14
25-Pin Male 2	Power Ground	Blue Pin 17	Isolated Analog Ground

APPENDIX B INSTRUCTION MANUAL FOR USING THE 3-D SURFACE PROFILE AND GRIND AND FILL SOFTWARE

The 3-D Surface Profile and Grind and Fill Software consists of three stand-alone programs. The first is the PF99 VNET data file reader. This program reads the PF99 data file generated from a project or network level data collection TMV run and breaks out the appropriate inertial reference profile, gyroscope sensor, scanning laser transverse profile, or rut displacement data and generates separate files suitable for the 3-D graphics and grind and fill programs. The second program, Data Transform program, takes the *.bin file from the PF99 reader and transforms it into data files that can be used with the Grind and Fill program. It additionally provides a 3-D surface profile display which reads the sensor data selected to provide a 3-D image of this data. The user may select a specified viewing angle or rotation. The user may also select or deselect specific sensors and reprocess the display. The third program provides cut and fill quantities after passing a plane over, under, or through the 3-D surface profile image. The user can specify the plane longitudinal starting point, angle of entry, and height. For each selection, the resulting volume computations are provided for the fill or cut quantities. Additionally the program will plot the resulting 3-D surface profile for the cut or fill areas. This package will allow the user to model and view various overlay, cut, or fill strategies.
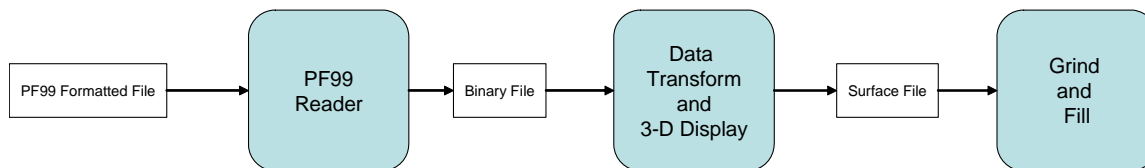
Flow of Data between the Three Programs

B.1 THE PF99 READER

The first program is the PF99 reader program, which will take a file with a PF99 format and extract a section of data to be processed.
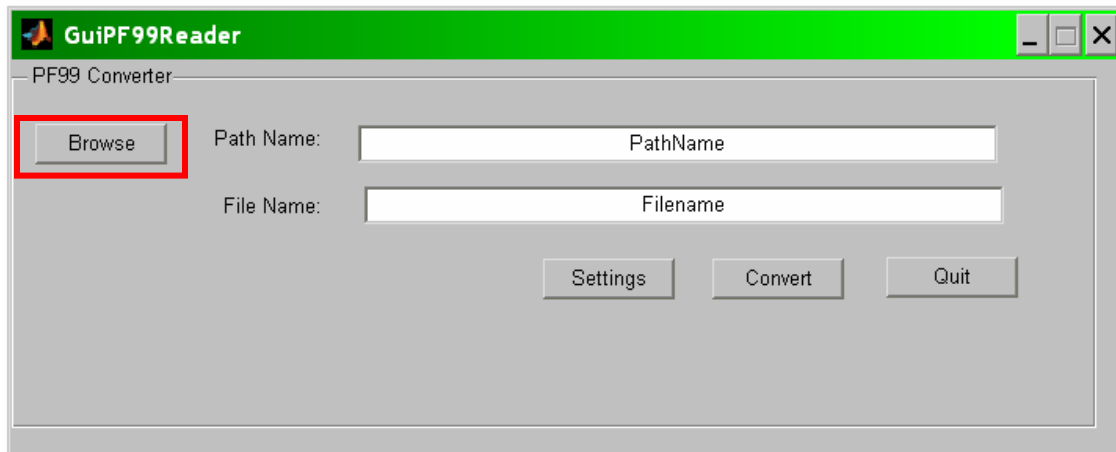
The first step in running the 4463 programs is to run PF99 reader. When the program first executes, the dialog box above appears. The next step is then to click **Browse**.
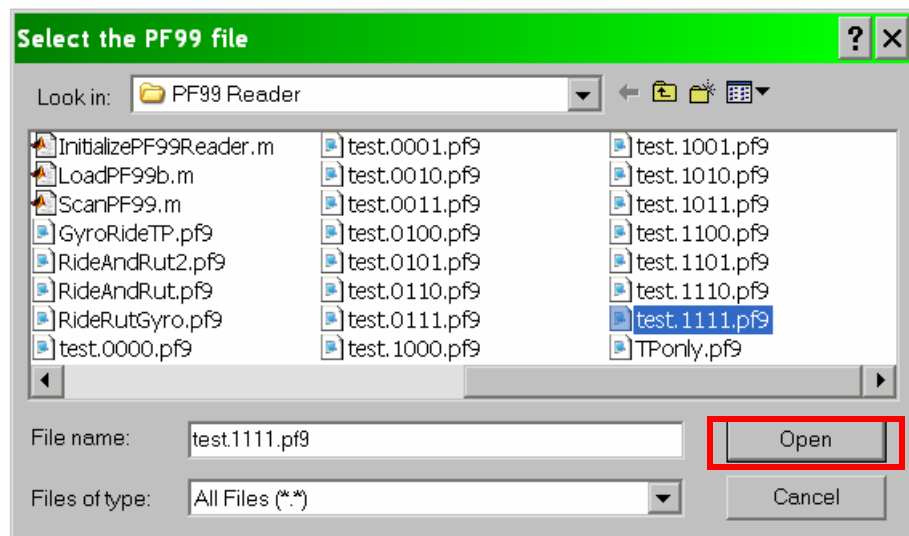
When Browse is selected, a file dialog box pops up. Select the file that is to be processed, and click **Open**. The file will now be selected.
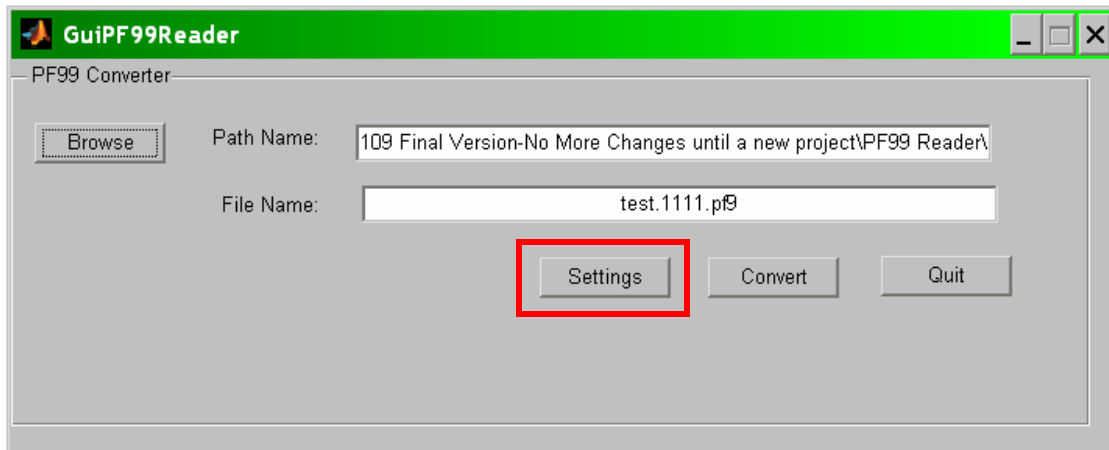
Now that the file has been selected, the settings need to be checked. Click **Settings**.
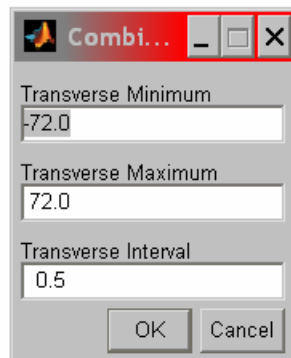
The Select button opens the Combination Settings dialog, which contains the sweep for the Transverse Profile. The data will have to be sorted and interpolated to be a fixed interval between readings.
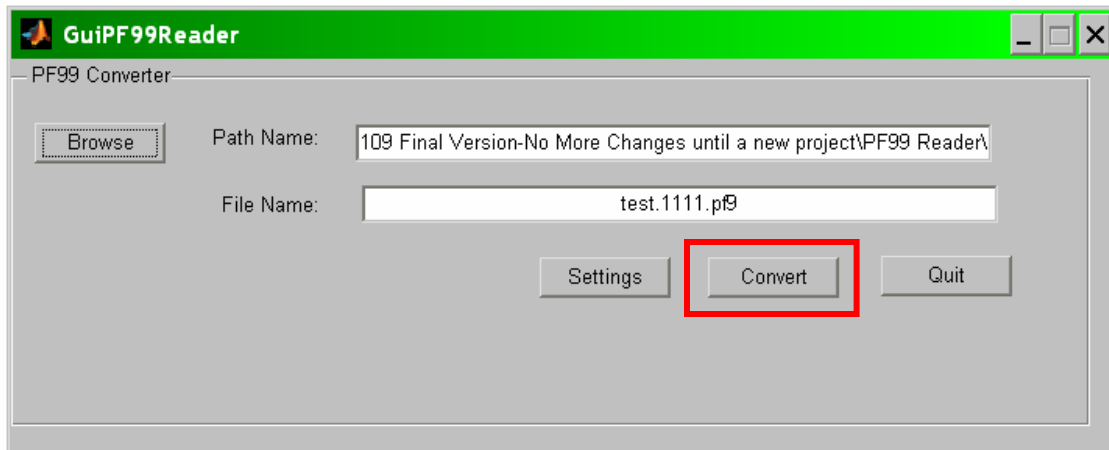
Next, the **Convert** button should be clicked. The PF99 reader will begin scanning the file to see what sections are stored within the PF99 files.
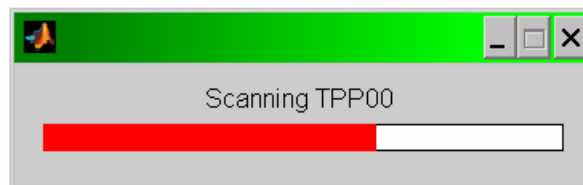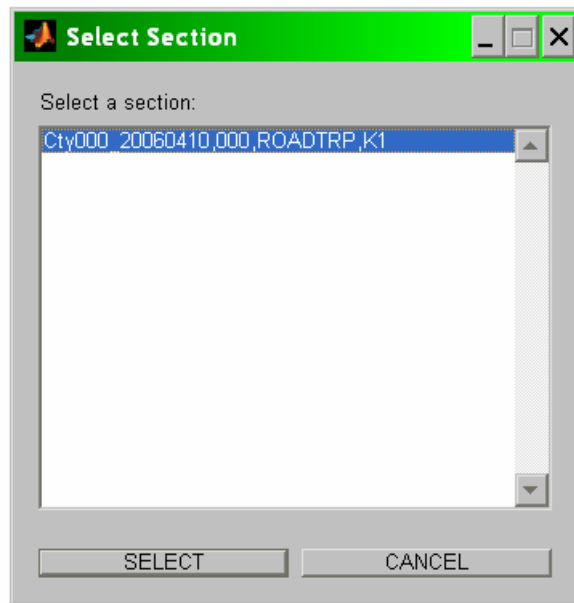
One or more sections within the PF99 file will be displayed, and the user can then select the section to be processed. Once selected, the distance stored in the section will be prompted to the user.
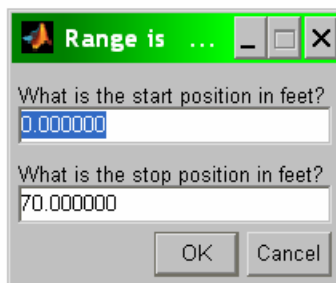
The user will enter the start position and the stop position to be processed.
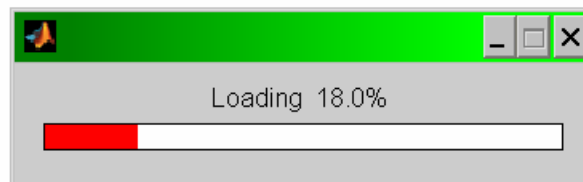
Now that the data set and the location of the data are known, the data for that section will be loaded into the program memory for processing.
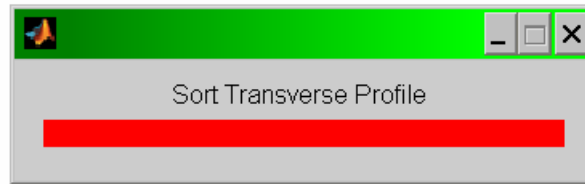
Once loaded, the data will go though several processing steps, converting the data into the target file.
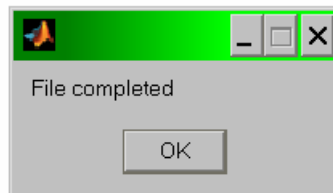
Once complete, the program will add '.bin' to the end of the original file, and the program is finished.

B.2 DATA TRANSFORM AND 3-D DISPLAY

The second program is the Data Transform program, which will take a file generated by the PF99 reader and turn it into a set of surface files.

Transforming the Data
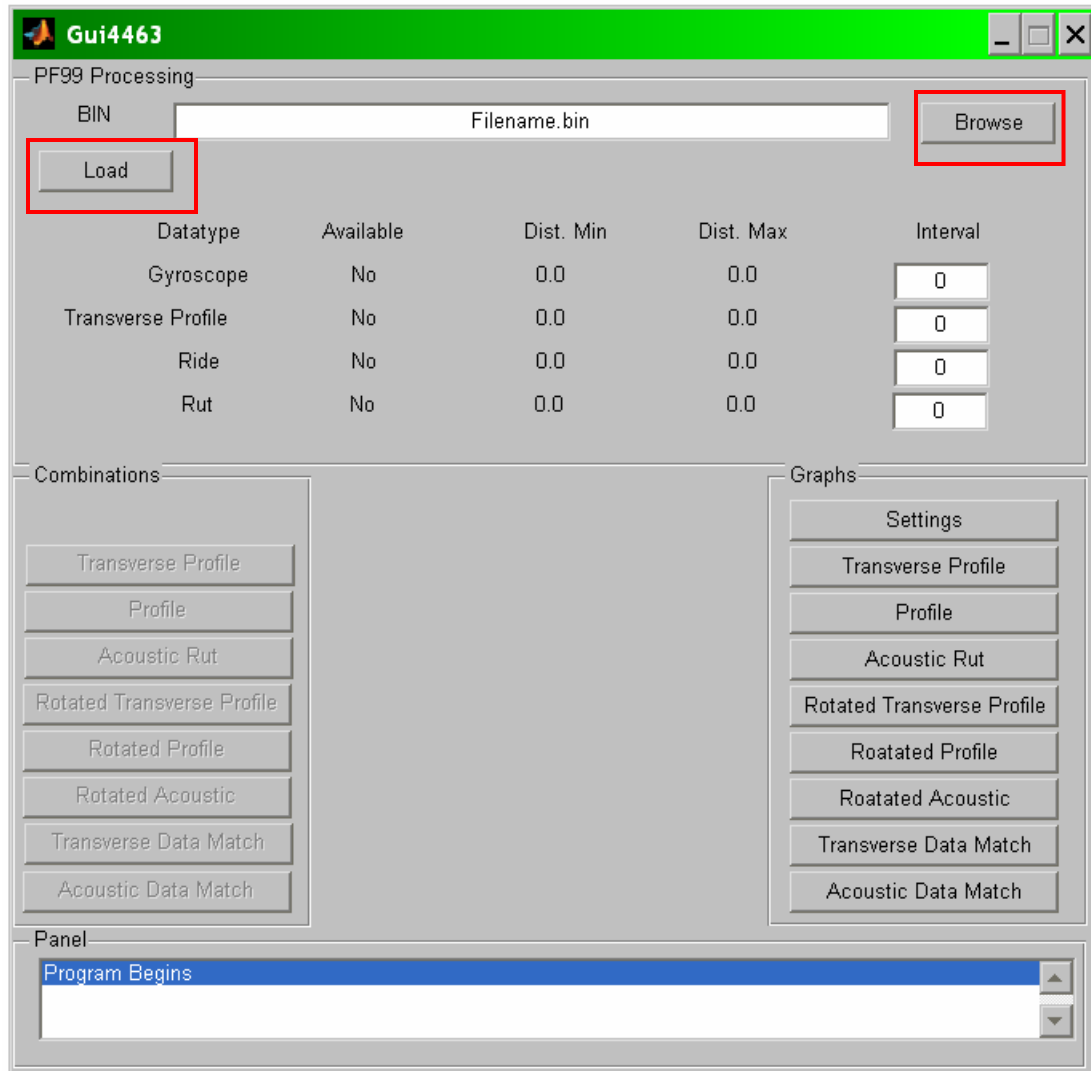
The Data Transform program takes the *.bin file from the PF99 reader and transforms it into data files that can be used with the Grind and Fill program. The first step is to select a file by clicking the **Browse** button on the dialog box.
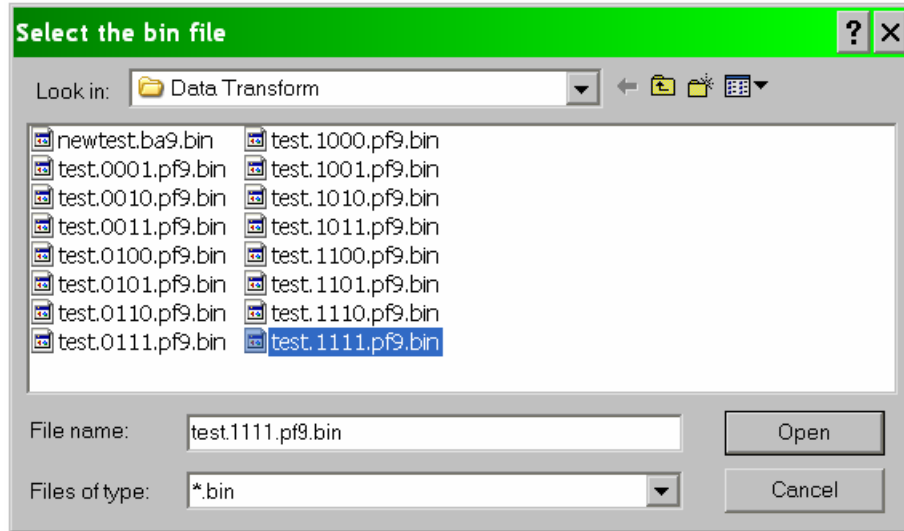
Then, select a *.bin file that was created by the PF99 reader. Once this has been done, select the **Load** button to finish getting the data. The status window will update with the data available, the minimum distance, the maximum distance, and the distance interval. The distance interval may also be altered in this box if it is not read from the data file.
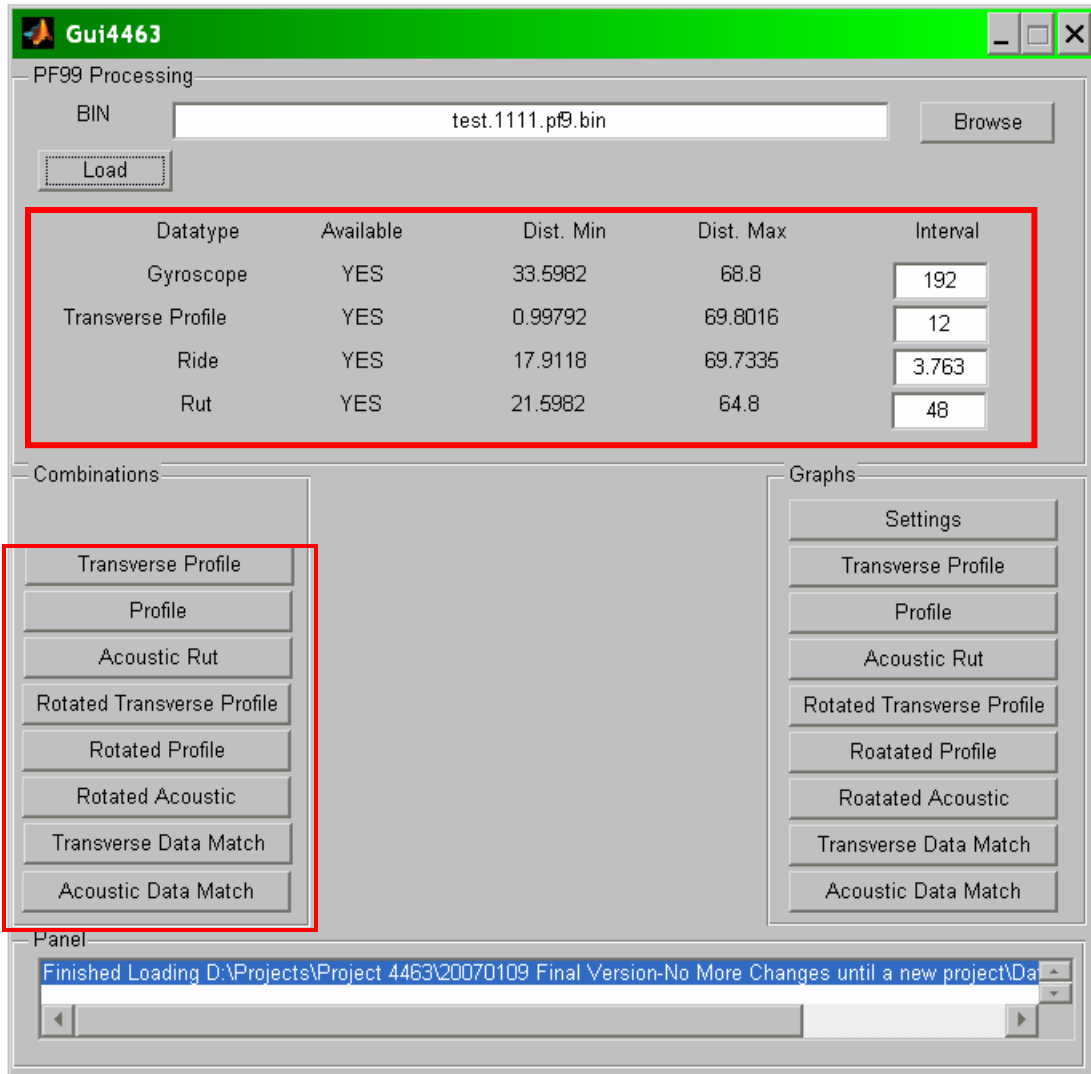
When the data is loaded, the summary of what data is available will appear on the top half of the dialog box. Given that certain data is available, the **Combination** box on the lower left side will activate various buttons as displayed in the table below. Each button will activate only if all the data needed is available.

Combinations Available from Loaded Data

	Transverse Profile Button	Profile Button	Acoustic Rut Button	Rotated Transverse Profile Button	Rotated Profile Button	Rotated Acoustic Rut Button	Transverse Data Match Button	Acoustic Data match Button
Transverse Profile Data	X			X			X	
Profile Data		X			X		X	X
Acoustic Rut Data			X			X		X
Gyroscope Data				X	X	X	X	X

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Each of these combinations produces an additional file, which has yet another extension added to describe the contents of the file. If the data type is in the file, the appropriate letter is assigned; otherwise, the character '0' is put in as a placeholder.

	Gyroscope	Transverse Profile	Profile	Acoustic Rut
Filename.bin	G	T	P	R

Defining the extension of the transformed files

- If Scanning Laser data is present, the **Transverse Profile** combination button will activate. This option will read the information from the status box and the stored data to create a *.0T00 file. The *.0T00 file can be used to graph the surface in three dimensions.

- If Profile data is present, the **Profile** combination button will activate. This option will read the information from the status box and the stored data to create a *.00P0 file. The *.00P0 file can be used to graph the profile in three dimensions.

- If Acoustic Rut data is present, the **Acoustic Rut** combination button will activate. This option will read the information from the status box and the stored data to create a *.000R file. The *.000R file can be used to graph the acoustic rut in three dimensions

- If Gyroscope data and Transverse Profile data are available, the **Rotated Transverse Profile** combination button will activate. This option will read the information from the status box and the stored data to create at *.GT00 file. The *.GT00 file can be used to graph the rotated transverse profile in three dimensions.

- If Gyroscope data and Profile data are available, the **Rotated Profile** combination button will activate. This option will read the information from the status box and the stored data to create a *.G0P0 file. The *.G0P0 file can be used to graph the rotated profile in three dimensions.

- If Gyroscope data and Acoustic Rut data are available, the **Rotated Acoustic** button will activate. This option will read the information from the status box and the stored data to created a *.G00R file. The *.G00R file can be used to graph the rotated acoustic rut in three dimensions

- If Gyroscope data and Transverse Profile data and Profile Data are all available, then the **Transverse Data Match** combination button will activate. This option will create a *.GTP0 file. The GTP0 file can be used to graph the combination of the profile and the transverse laser rotated to the same angle. This Transverse Data Match file is also one of the valid inputs for the Grind and Fill program.

- If Gyroscope data and Acoustic Rut data and Profile data are all available, then the **Acoustic Data Match** combination button will activate. This option will crate a *.G0PR file. The *.G0PR file can be used to graph the combination of the profile and the acoustic rut rotated to the same angle. This Acoustic Data Match file is also one of the valid inputs for the Grind and Fill program.

Displaying the Data
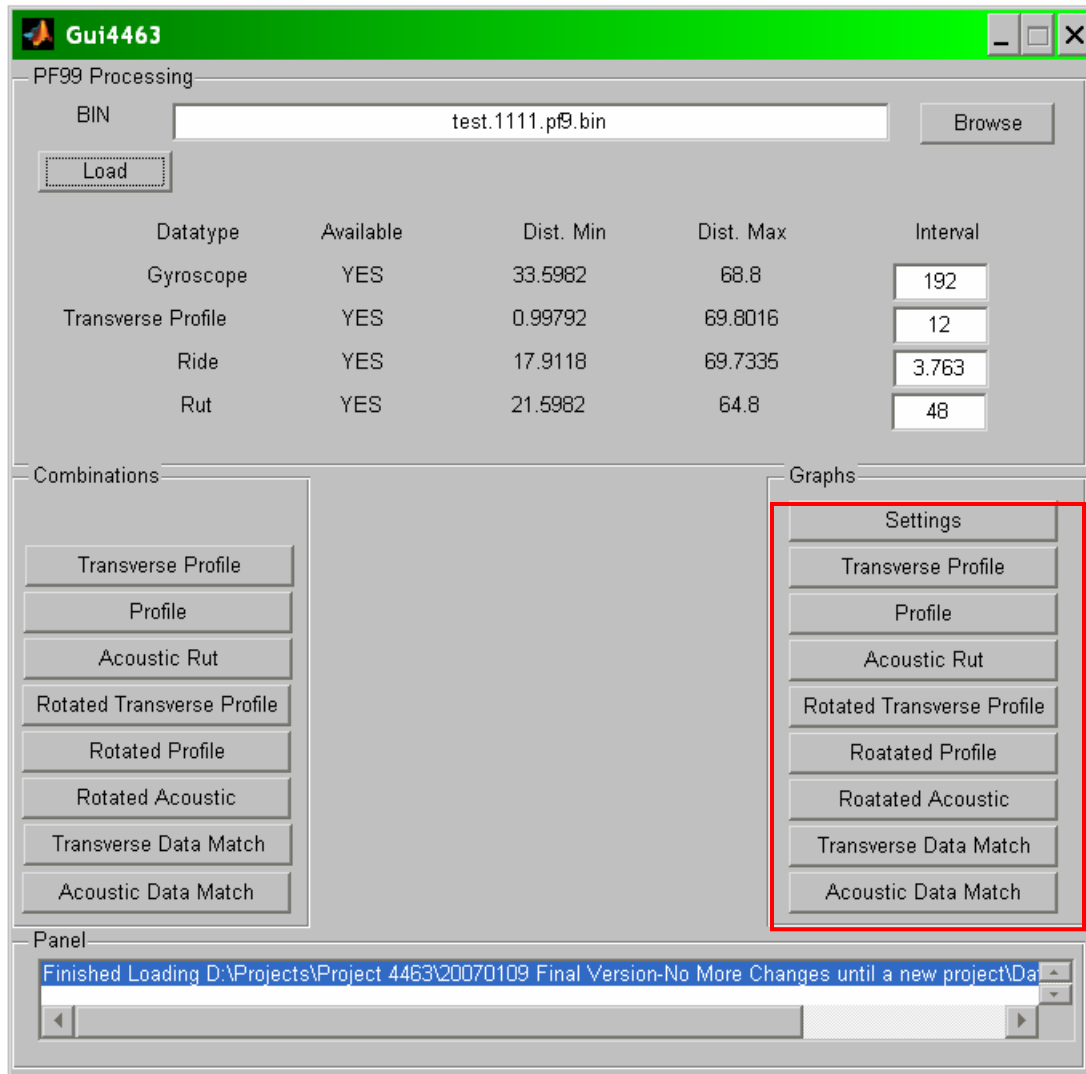
The other section of the Data Transform program is the graphical control box. These buttons control the display of graphs of data generated by the combination boxes. These are always active, and can display previously generated files.
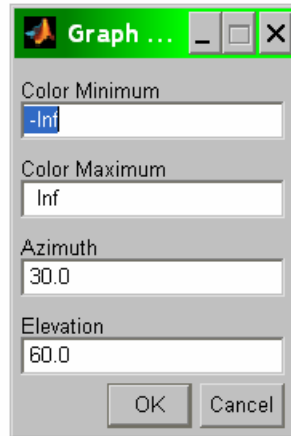
The first button is the **Settings** button, which opens a Graph Options dialog box for use with the Matlab display engine. The colors visible on the graph go from some minimum in the elevation plane to some maximum in the elevation plane. The defaults are '-inf' for negative infinity and 'inf' for positive infinity. The next two co-ordinates are the rotation of the plane of the graph, and the height of the view above the graph.
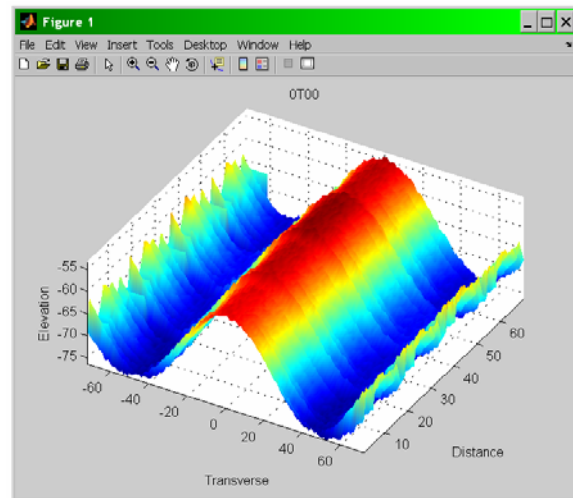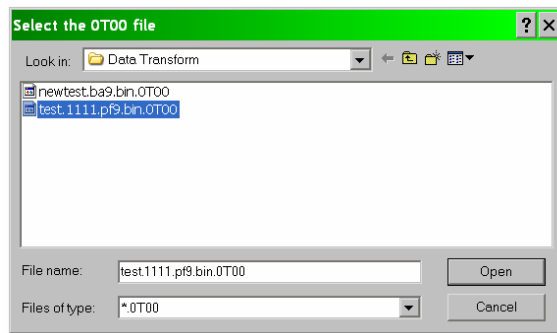
To see the Transverse Profile, click that button and select a *.0T00 file. The system will then display a graph showing the surface at the azimuth and elevation specified.
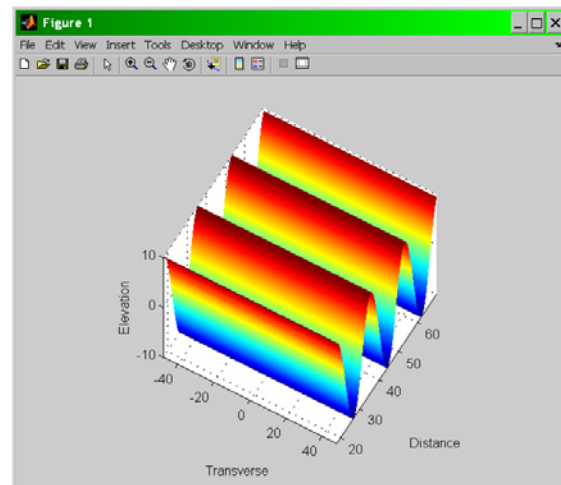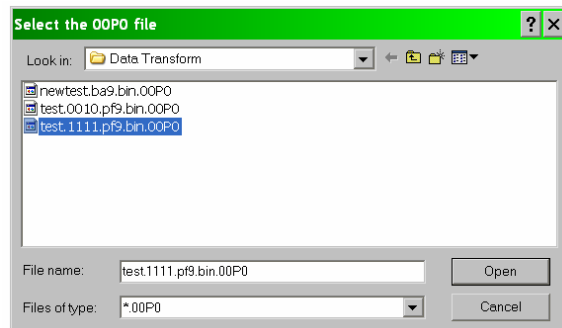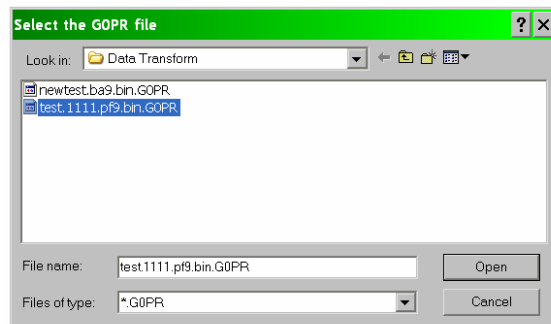

To see the Profile, click that button and select a *.00P0 file. The system will then display a graph showing the surface.
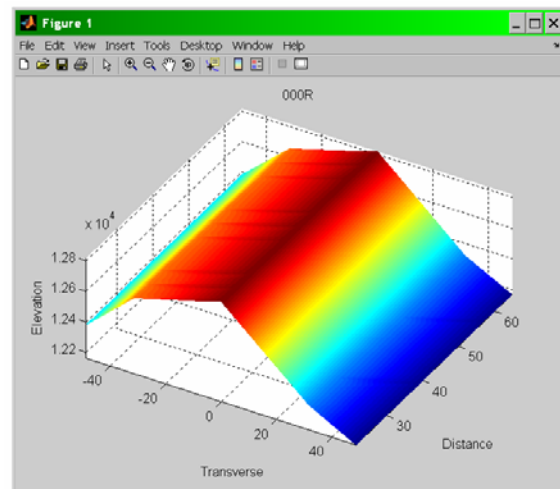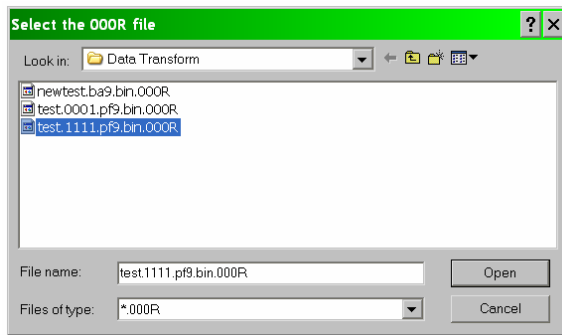
To see the Acoustic Rut Profile, click that button and select a *.000R file. The system will then display a graph showing the surface.
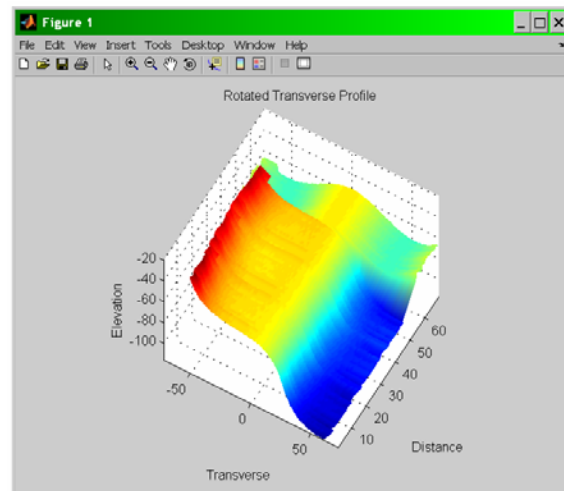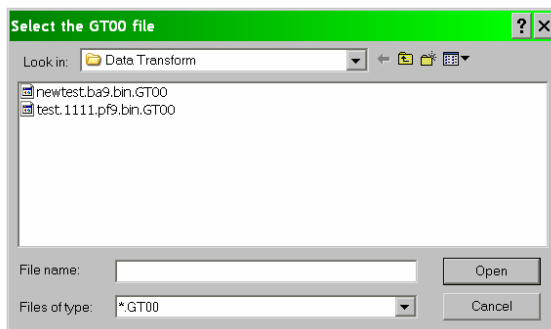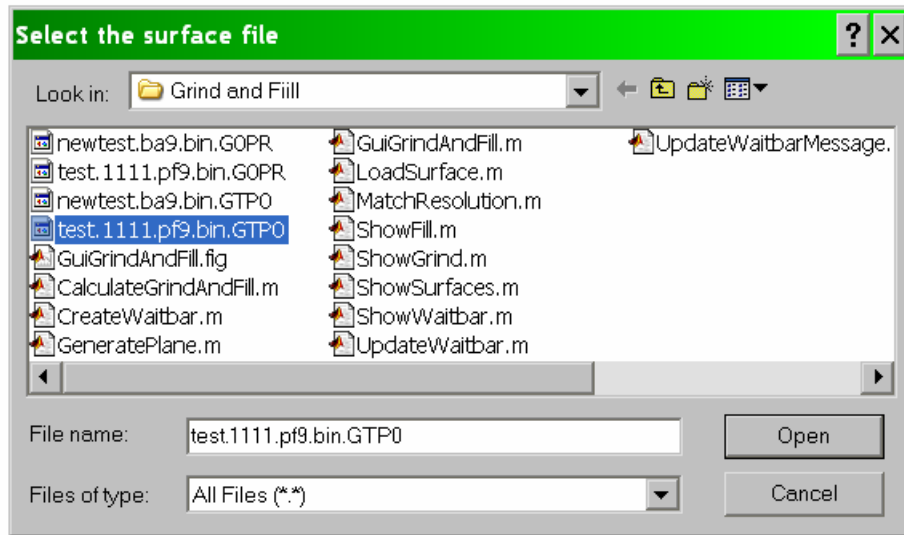

To see the Rotated Transverse Profile, click that button and select a *.GT00 file. The system will then display a graph showing the surface.
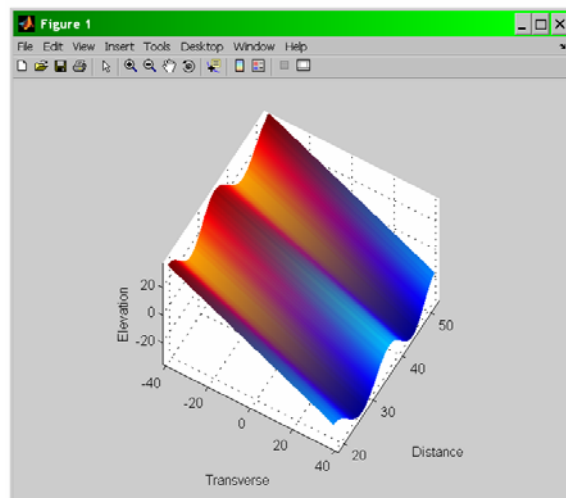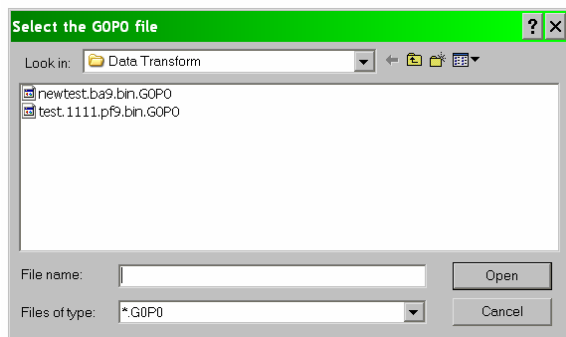
To see the Rotated Profile, click that button and select a *.G0P0 file. The system will then display a graph showing the surface.
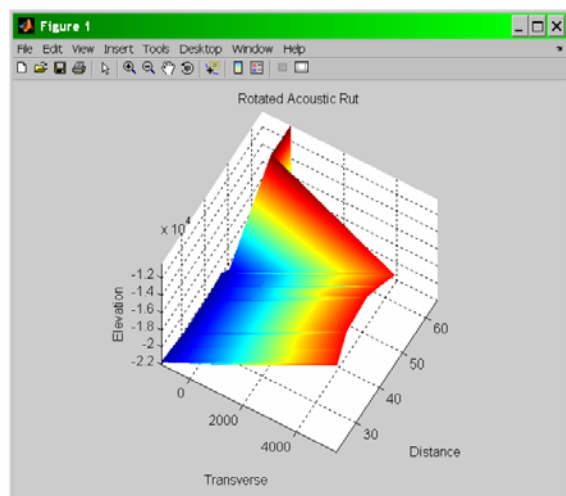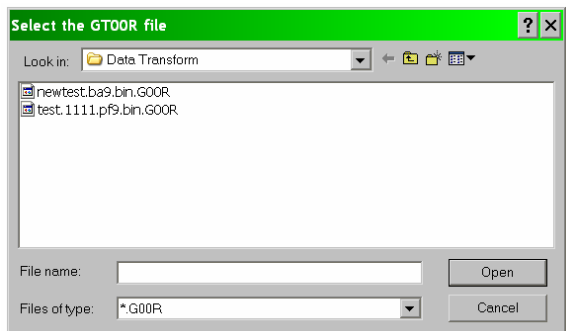
To see the Rotated Acoustic Rut, click that button and select a *.G00R file. The system will then display a graph showing the surface.
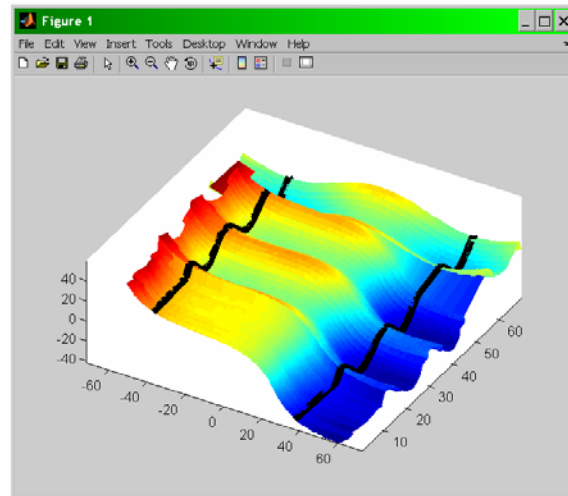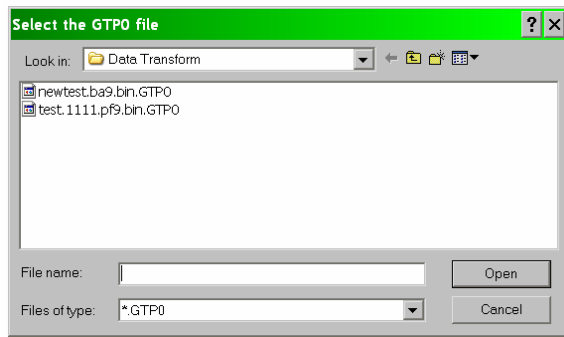
To see the Transverse Profile Data Match, click that button and select a *.GTP0 file. The system will then display a graph showing the surface.
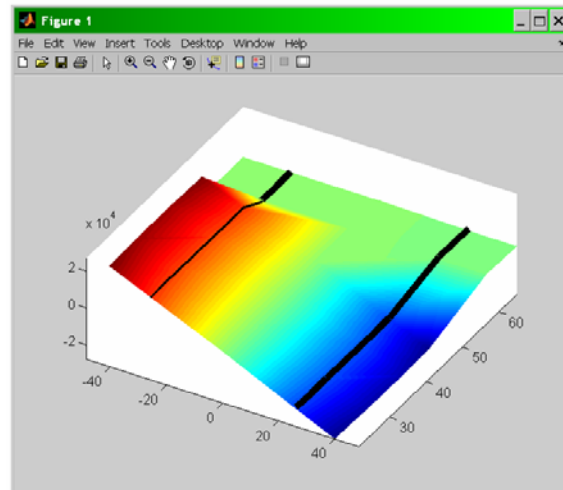
To see the Acoustic Rut Data Match, click that button and select a *.GTP0 file. The system will then display a graph showing the surface.

B.3 GRIND AND FILL

The Grind and Fill tool takes the differences between a surface and a plane in order to determine how much volume must be changed across the surfaces by grinding down a pavement or filling in a depression. The first surface is a target surfaces generated by the Data Transform tool, which contains a transverse data reading or an acoustic data reading that has been rotated and matched to the profile. The second surface is a user defined plane that is at a given angle.

Loading the Surface
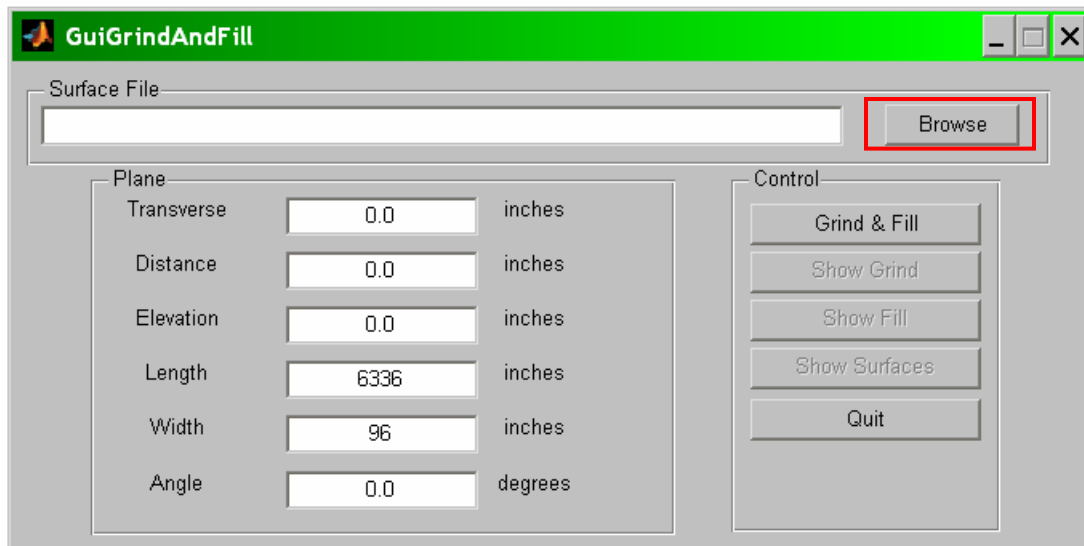
When the tool begins, the first step is to load the Data Match file from the Data Transform tool into the Grind and Fill. The **Browse** button needs to be selected.

Select the surface file

Look in: 📁 Grind and Fiill

- 📄 newtest.ba9.bin.G0PR
- 📄 test.1111.pf9.bin.G0PR
- 📄 newtest.ba9.bin.GTP0
- 📄 test.1111.pf9.bin.GTP0
- 📄 GuiGrindAndFill.fig
- 📄 CalculateGrindAndFill.m
- 📄 CreateWaitbar.m
- 📄 GeneratePlane.m
- 📄 GuiGrindAndFill.m
- 📄 LoadSurface.m
- 📄 MatchResolution.m
- 📄 ShowFill.m
- 📄 ShowGrind.m
- 📄 ShowSurfaces.m
- 📄 ShowWaitbar.m
- 📄 UpdateWaitbar.m
- 📄 UpdateWaitbarMessage.

File name: test.1111.pf9.bin.GTP0   **Open**

Files of type: All Files (*.*)   **Cancel**

Now, the surface selection dialog box opens. Either a *.GTP0 or a *.GOPR file will need to be selected. A Transverse Profile Data Match file is marked *.GTP0, and an Acoustic Rut Data Match file is marked *.G0PR.

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Defining a Desired Surface as a Plane
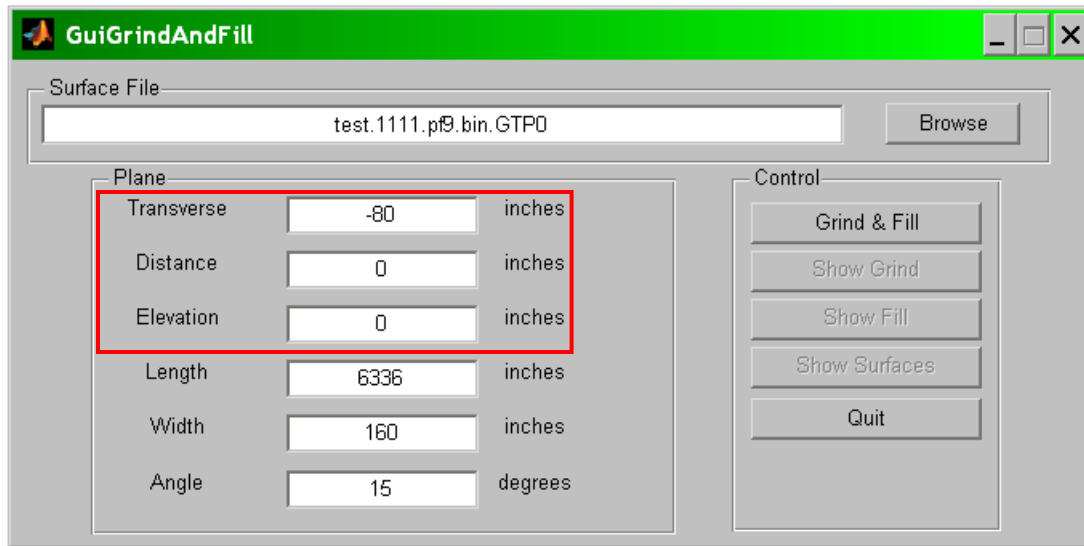
Now that the file has been selected, the Plane definition panel must be filled in with the correct coordinates. The first three fields, Transverse, Distance, and Elevation, describe the starting location of the plane.
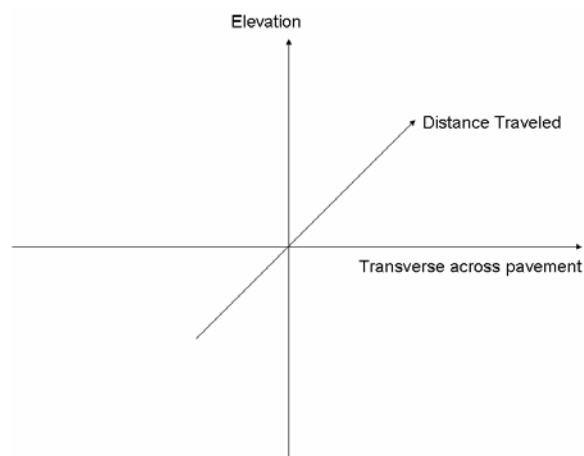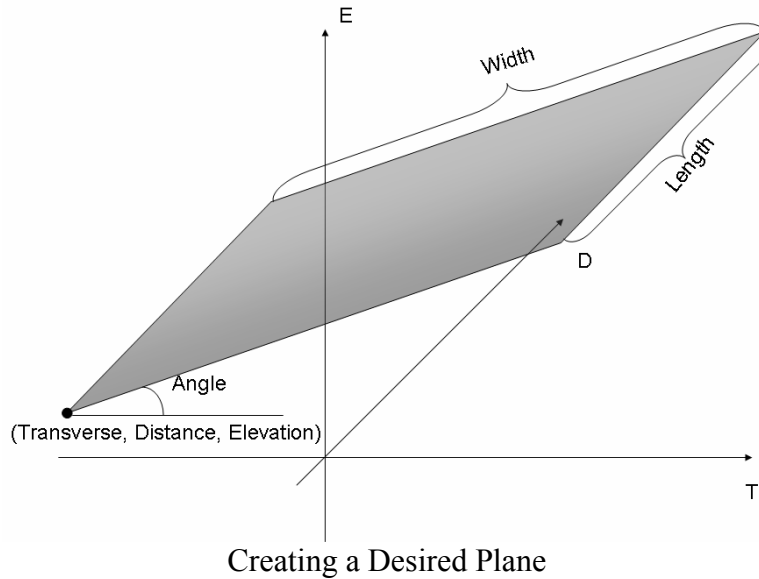

Defining the Axes in 3-Dimensions
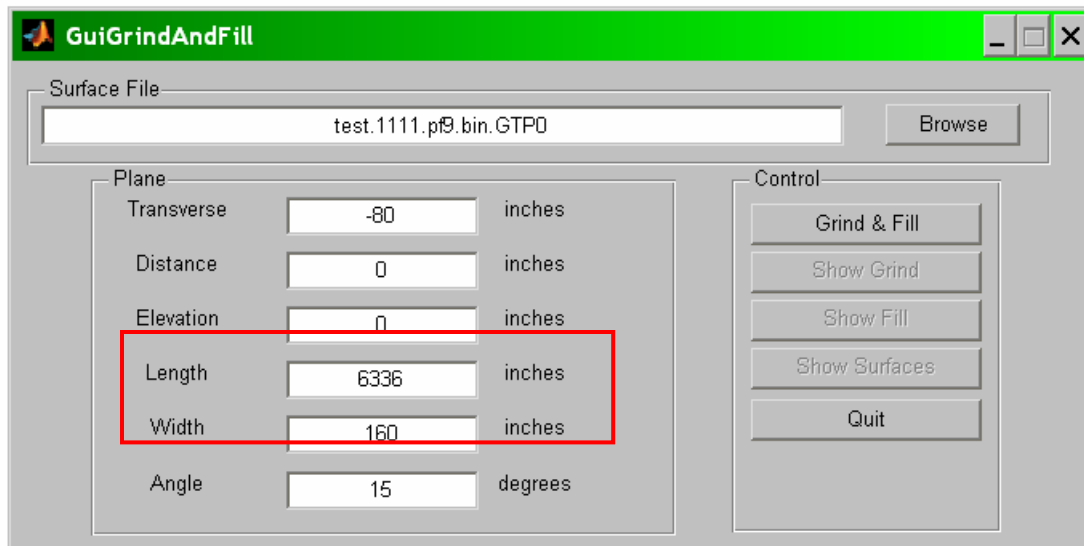
The plane then has some length in the distance direction, and some width in the transverse direction.
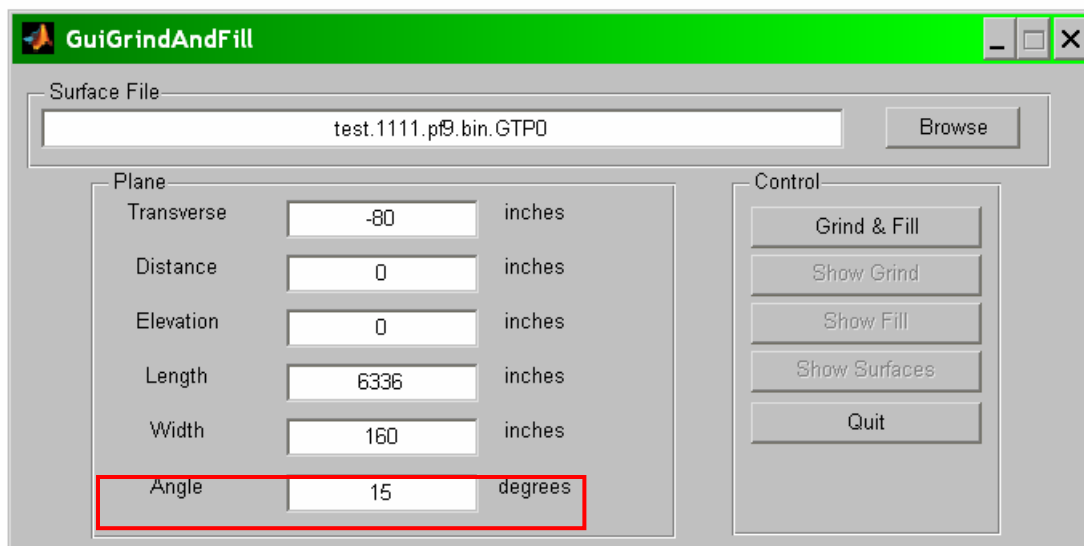
Finally, the plane is set at some angle with respect to the transverse direction.

Creating a Desired Plane

Calculating Grind and Fill

Once the plane has been defined, the Grind and Fill button can be selected. At this time, a "waitbar" will appear on the screen to show the user the system is still processing. At the end of the calculations, a Grind and Fill complete box will appear.
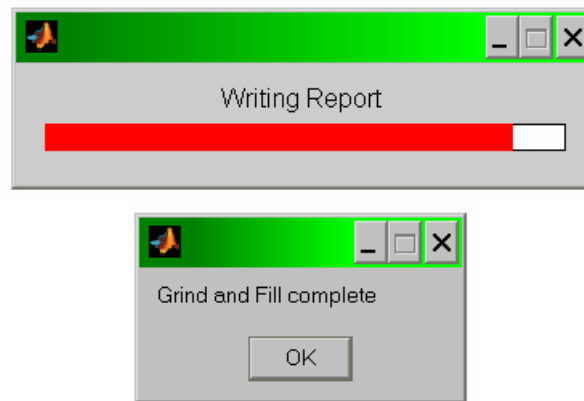

Once the Grind and Fill calculation is complete, the remaining buttons on the main dialog box will become active and a report of the data will be displayed.

Total volume of the surface: 151006.43 cubic inches
Total volume of the plane: 527494.88 cubic inches
Total difference of the volumes: -376488.45 cubic inches
Total Volume to Grind: 121423.89 cubic inches
Total Volume to Fill: 497912.34 cubic inches
Total Volume Difference: 376488.45 cubic inches

Three graphs are now also available to be shown to the user. The Grind map, the Fill map, and the representation of the two surfaces, the plane and the Data Match surface.
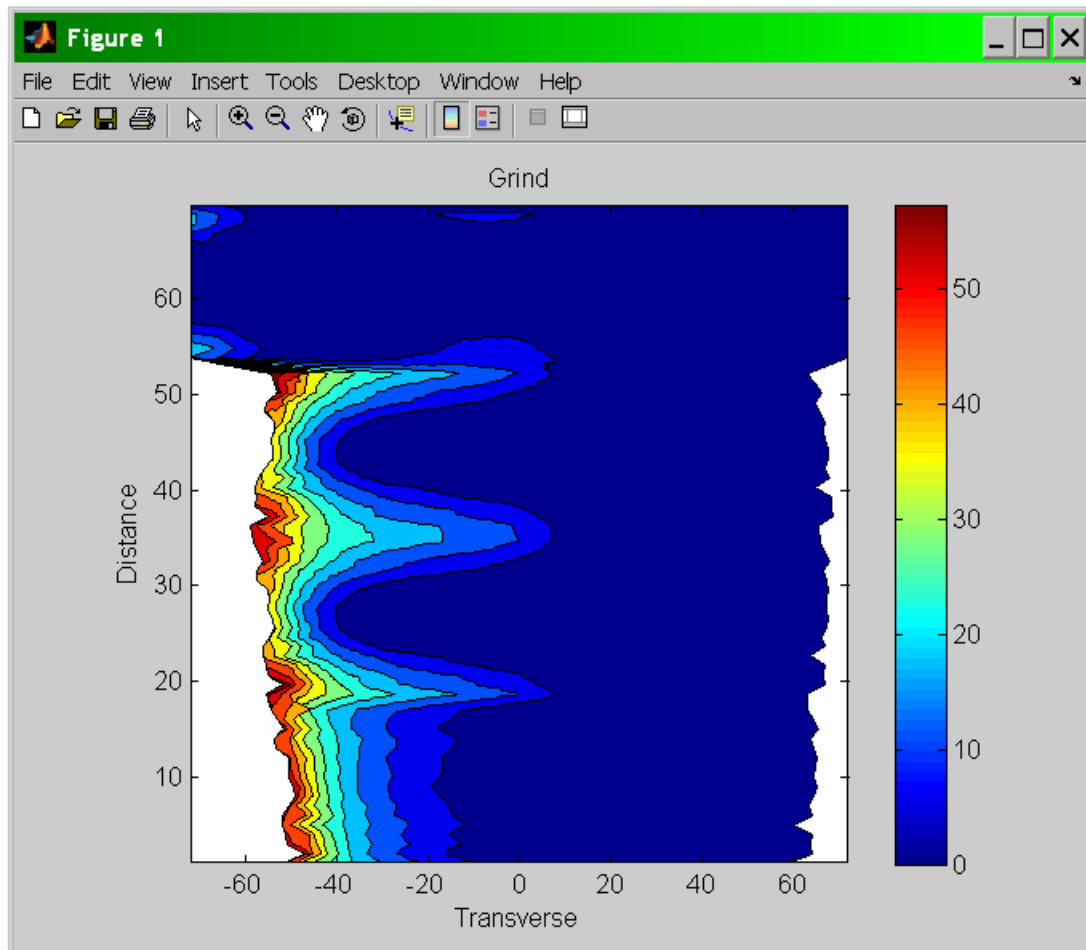
The Grind Map shows where the surface would have to be ground down to be the same surface as the desired plane.
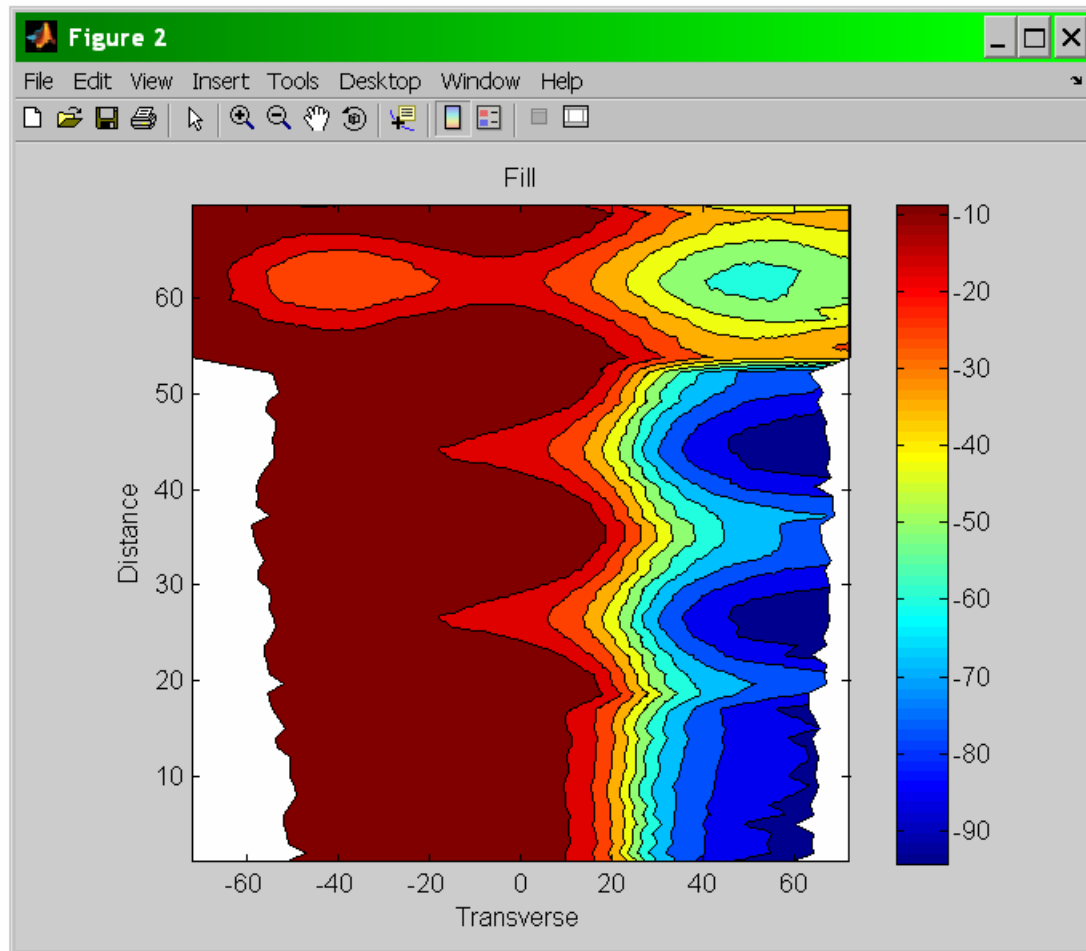
The Fill Map shows the amount of material that needs to be added in order to bring the surface up to the desired plane.
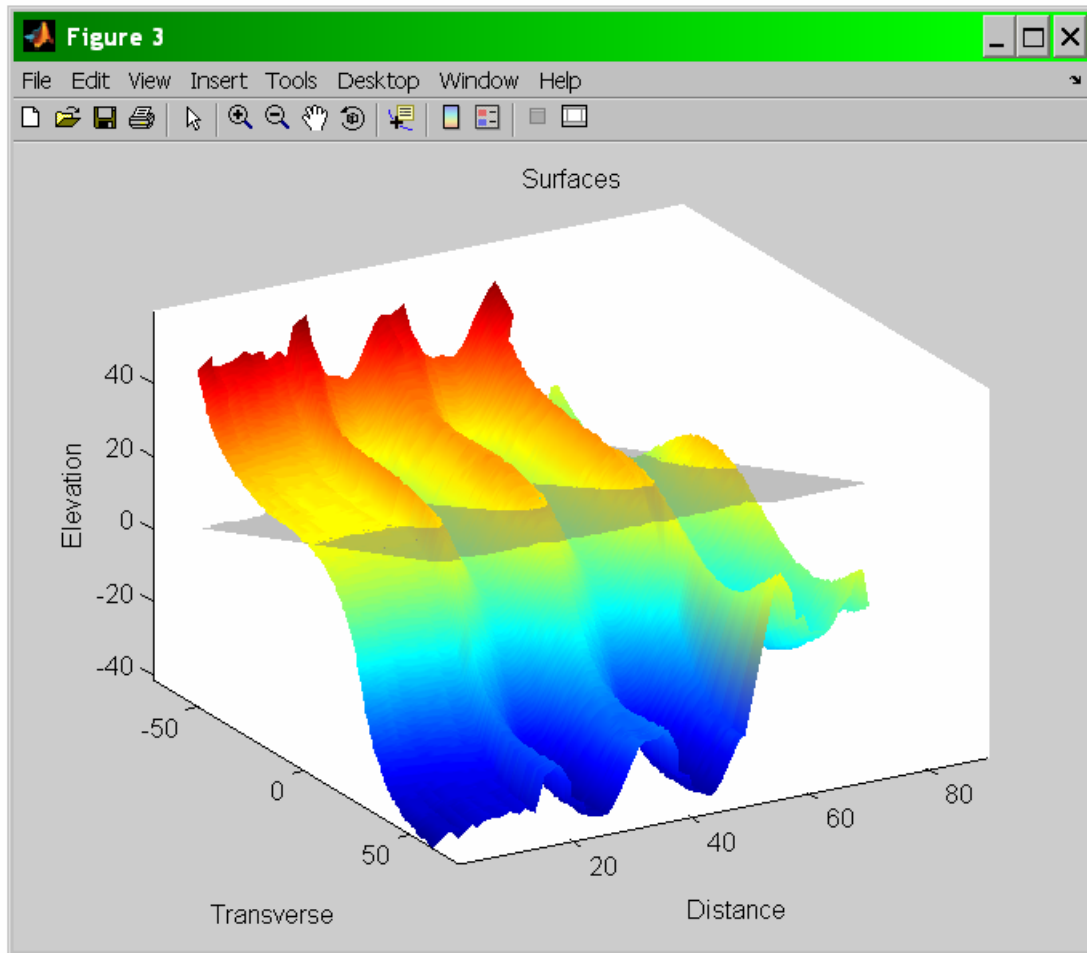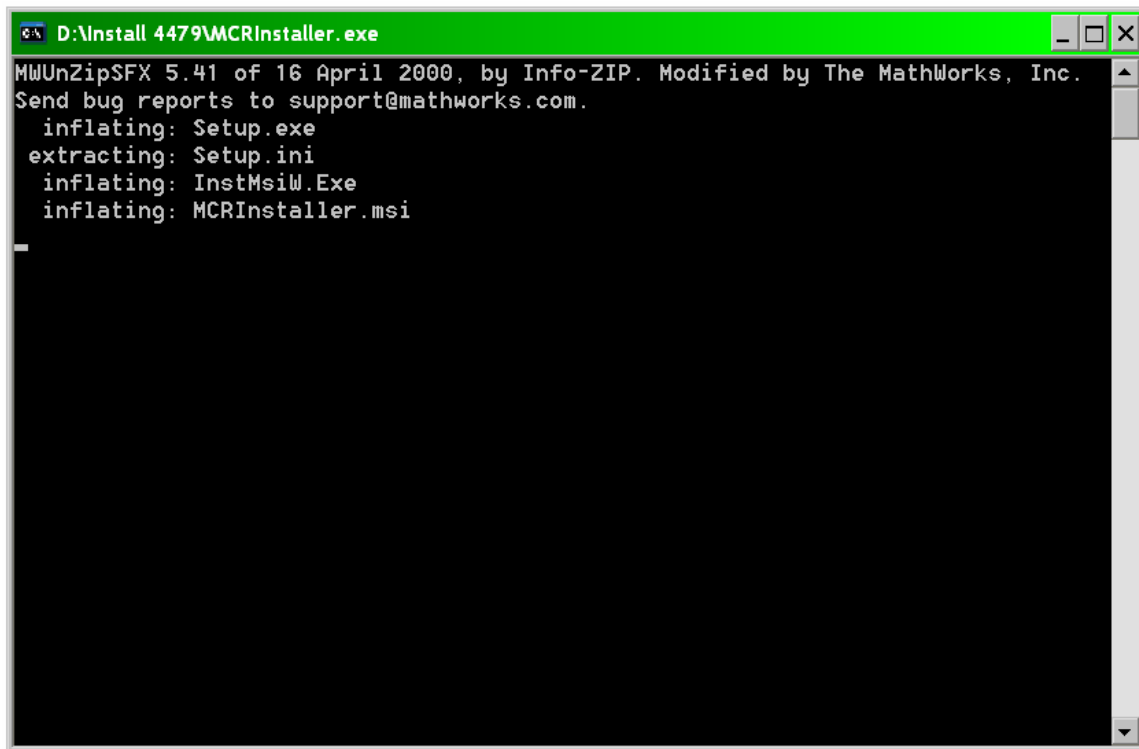
The final image is the comparison of the surface and the plane. In this case, the desired plane displays in a transparent gray.

APPENDIX C MATLAB RUNTIME COMPONENT

Appendix C provides the method of installing the 3-D Display and Grind and Fill Program described in Appendix B. Following are a list of the steps needed for installing this software.

Matlab provides a library for its internal routines to be used in deployment of software that comes with the Matlab Compiler Toolbox.

Make a directory on your hard disk, and copy the MCRInstaller.exe program to that directory. Next, execute the installer and the following command window will appear.

```
D:\Install 4479\MCRInstaller.exe                                    _ □ ×
MWUnZipSFX 5.41 of 16 April 2000, by Info-ZIP. Modified by The MathWorks, Inc.
Send bug reports to support@mathworks.com.
  inflating: Setup.exe
 extracting: Setup.ini
  inflating: InstMsiW.Exe
  inflating: MCRInstaller.msi
```
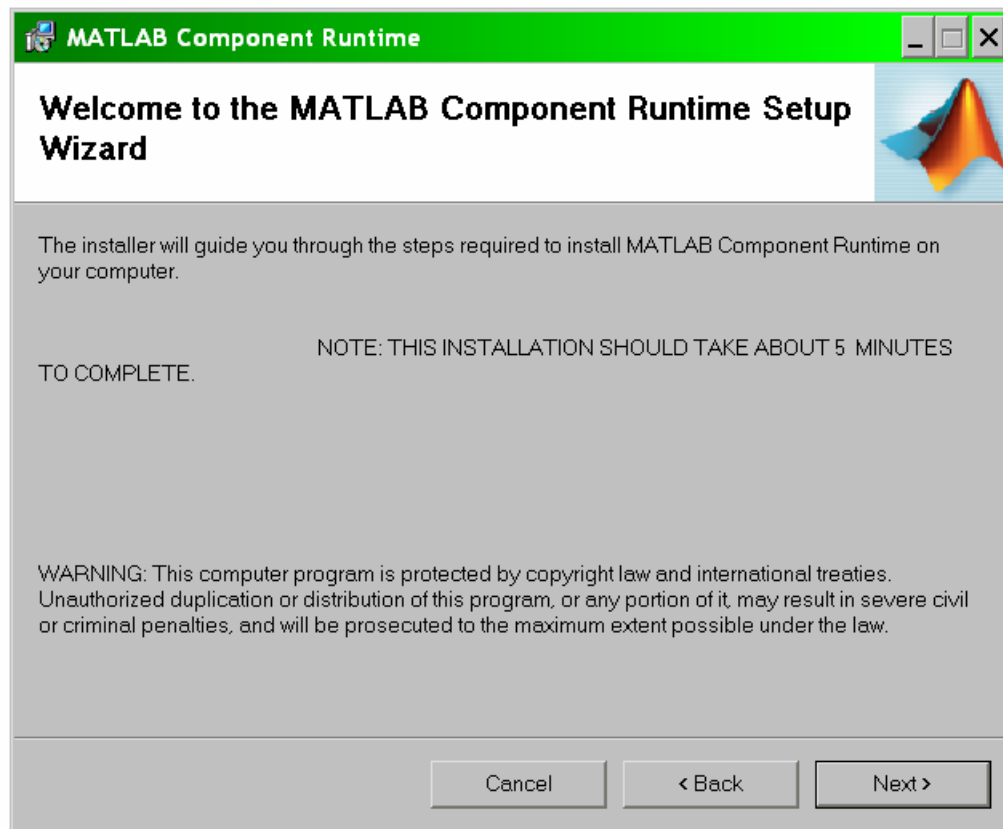
A few seconds after this window opens, the installation program will begin. The Windows Installer screen below opens up as the system gets ready to install.
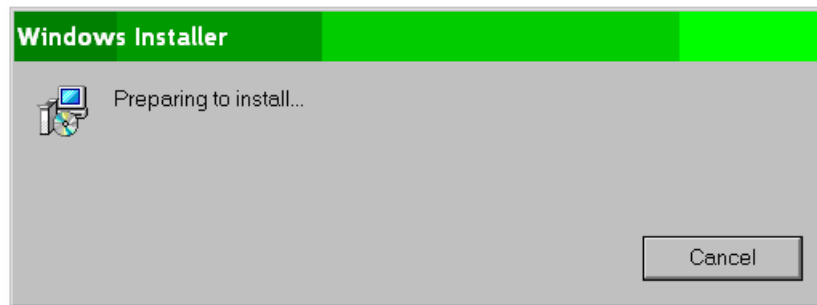
Next, the following splash screen will appear, and prompts the user to click next to install the Runtime Component. Click **Next** to continue.
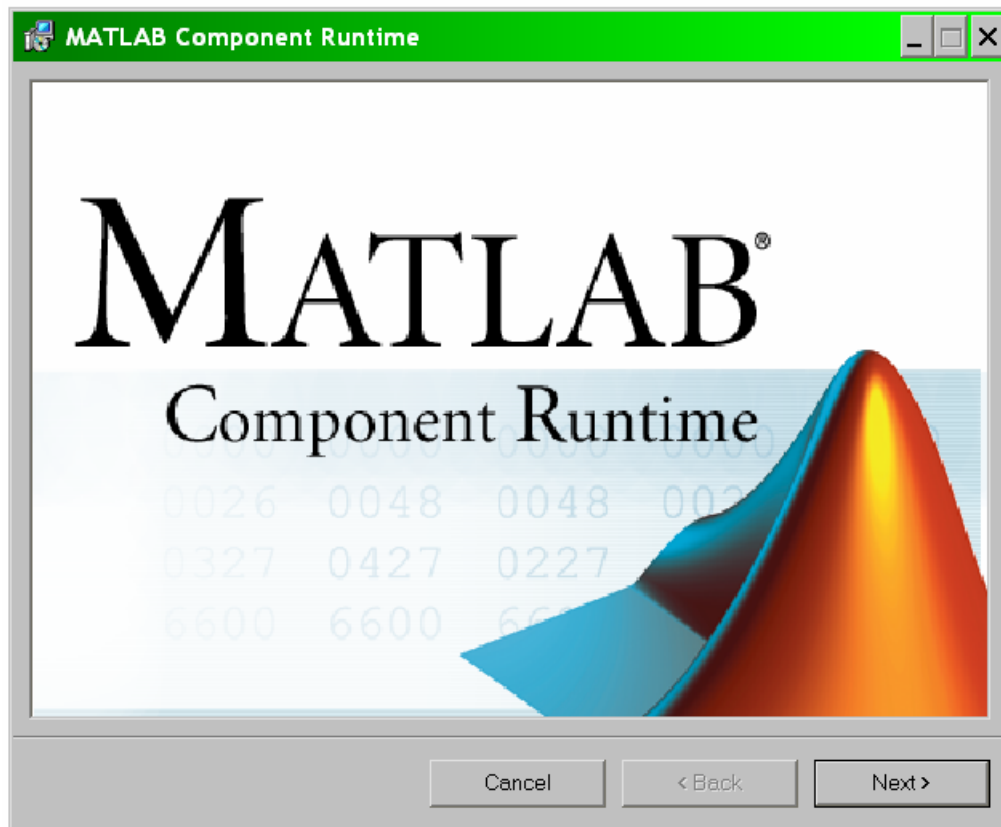
The next screen is the warning screen. Simply click **Next** to continue.

The following dialog is the installation folder dialog, which allows the user to install the runtime component on a different drive, or for specific accounts. For this project, the default folder was selected and the component was made available to everyone's account on the computer.
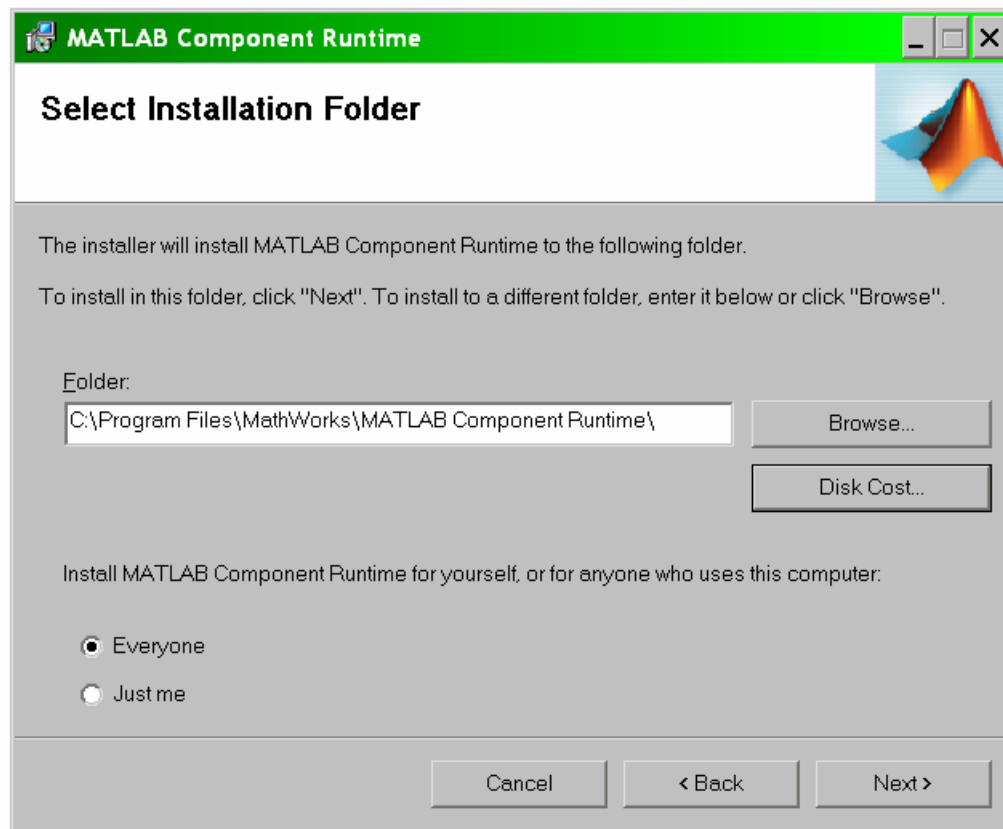
Then, the Confirmation screen appears, which gives the user one last chance to exit before proceeding with the final installation.
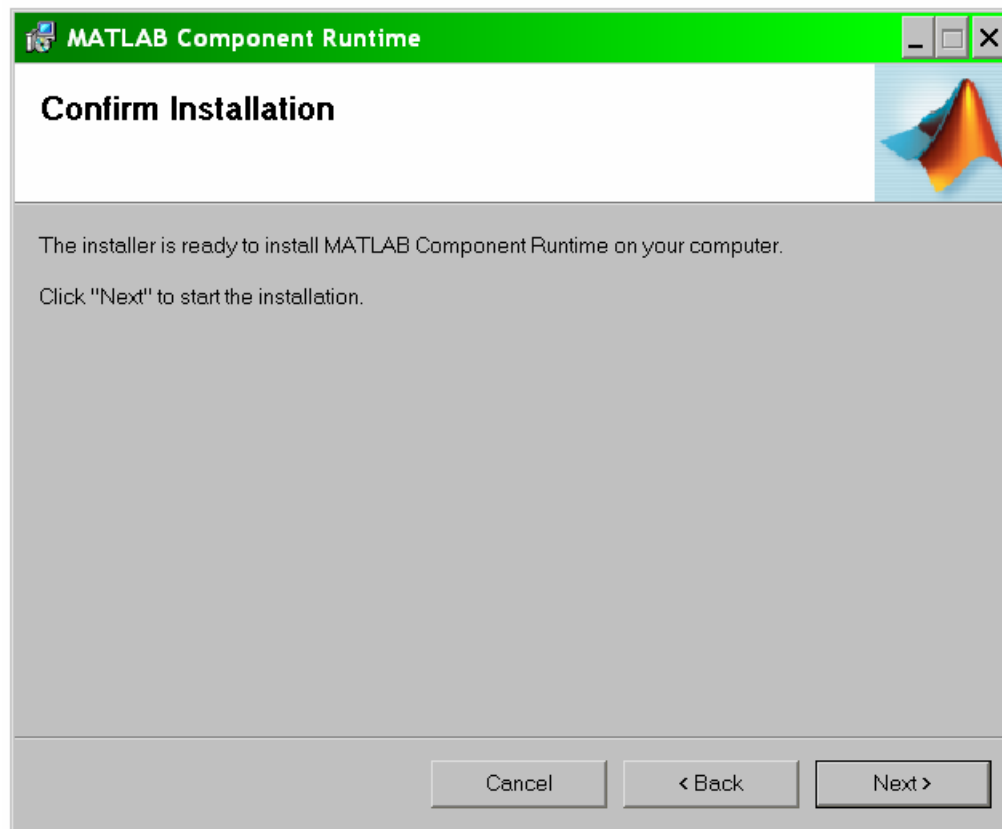
Now, the progress screen activates, and remains activated for about five minutes. It is recommended that the computer be left alone for a period of about five minutes while the program finishes its installation. The progress bar will fill up multiple times during the installation.
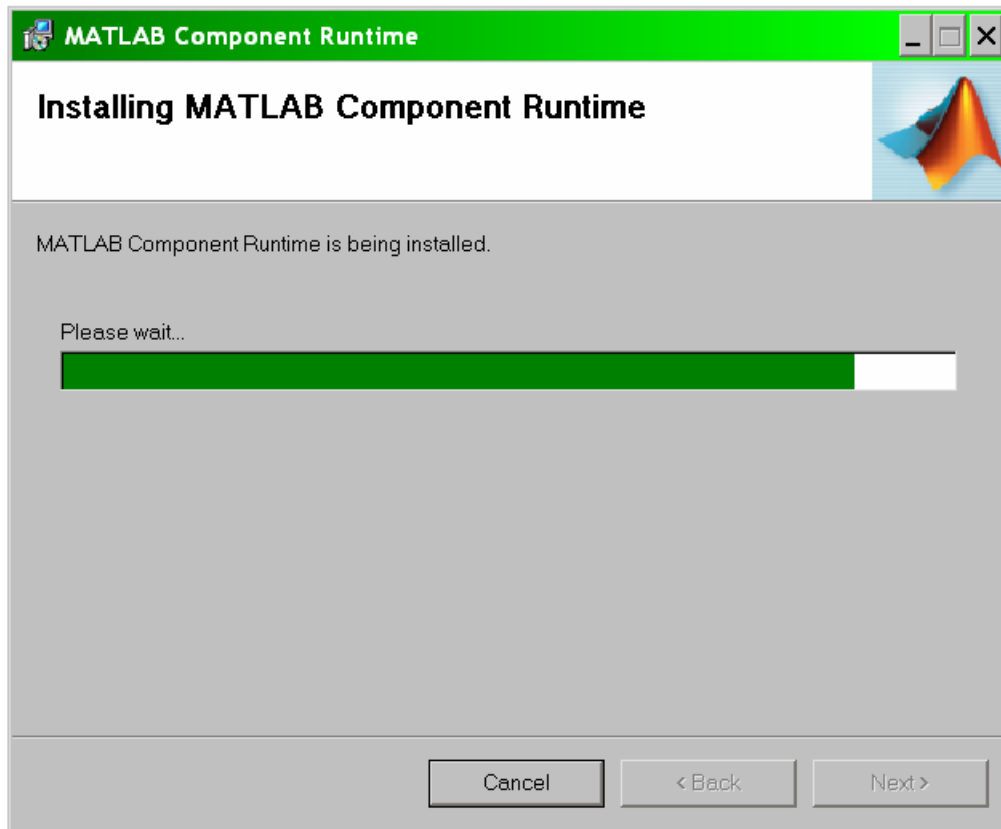
The final screen is the completion dialog, and then the installation is done.