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Numerical, Analytical, Experimental Study of Fluid Dynamic Forces in Seals

Volume 1—Executive Summary and Description of Knowledge-Based System

Wilbur Shapiro and Bharat Aggarwal
Mechanical Technology, Inc., Latham, New York

October 2004

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Prepared under Contract NAS3–25644

National Aeronautics and
Space Administration

Glenn Research Center

October 2004

Note that at the time of research, the NASA Lewis Research Center was undergoing a name change to the NASA John H. Glenn Research Center at Lewis Field. Both names may appear in this report.

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FOREWORD

The Computational Fluid Dynamics (CFD) computer codes and Knowledge-Based System (KBS) were generated under NASA contract NAS3-25644 originating from the Office of Advanced Concepts and Technology and administered through NASA-Lewis Research Center. The support of the Program Manager, Anita Liang, and the advice and direction of the Technical Monitor, Robert Hendricks, are gratefully appreciated. Major contributors to code development were:

- Dr. Bharat Aggarwal: KBS and OS/2 PC conversion of labyrinth seal code KTK
- Dr. Antonio Artiles: cylindrical and face seal codes ICYL and IFACE
- Dr. Mahesh Athavale and Dr. Andrzej Przekwas: CFD code SCISEAL
- Mr. Wilbur Shapiro: gas cylindrical and face seal codes GCYLT, GFACE, and seal dynamics code DYSEAL
- Dr. Jed Walowit: spiral groove gas and liquid cylindrical and face seal codes SPIRALG and SPIRALI.

The labyrinth seal code, KTK, was developed by Allison Gas Turbine Division of General Motors Corporation for the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. It is included as part of the CFD industrial codes package by the permission of the Air Force.

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1.0 SUMMARY

Advanced seals have been shown to result in significant enhancement of performance and life of turbomachinery. Consequently, NASA embarked on a five-year program (Contract NAS3 25644) to provide the U.S. aerospace industry with computer codes that would facilitate configuration selection and the design and application of advanced seals.

The program included four principal activities:

1. Development of SCISEAL, a scientific Computational Fluid Dynamics (CFD) code capable of producing full three-dimensional flow field information for a variety of cylindrical configurations. The code is used to enhance understanding of flow phenomena and mechanisms, to predict performance of complex situations, and to furnish accuracy standards for the industrial codes. SCISEAL also has the unique capability to produce stiffness and damping coefficients that are necessary for rotordynamic computations.
2. Generation of industrial codes for expeditious analysis, design, and optimization of turbomachinery seals. The industrial codes consist of a series of separate, stand-alone codes that were integrated by a Knowledge-Based System (KBS).
3. Production of a KBS that couples the industrial codes with a user-friendly Graphical User Interface (GUI) that can in the future be integrated with an expert system to assist in seal selection and data interpretation and provide design guidance.
4. Technology transfer via four multiday workshops at NASA facilities where the results of the program were presented and information exchanged among suppliers and users of advanced seals. A Peer Panel also met at the workshops to provide guidance and suggestions to the program.

The program has produced a wealth of computer codes that provide a solid foundation for analyzing and designing many of the advanced seals being contemplated for future air-breathing and space propulsion engines.

2.0 INTRODUCTION

NASA's advanced engine programs are aimed at progressively higher efficiencies, greater reliability, and longer life. Recent studies indicate that significant engine performance advantages and dramatic life extensions can be achieved through the use of advanced seals[1]. Advanced seals control leakage and lubricant and coolant flow, prevent entrance of contamination, inhibit the mixture of incompatible fluids, and assist in the control of rotor response.

Recognizing the importance and need of advanced seals, NASA, in 1990, embarked on a five-year program (Contract NAS3-25644) to provide the U.S. aerospace industry with computer codes that would facilitate configuration selection and the design and application of advanced seals.

The program included four principal activities:

1. Development of SCISEAL, a scientific Computational Fluid Dynamics (CFD) code capable of producing full three-dimensional flow field information for a variety of cylindrical configurations. The code is used to enhance understanding of flow phenomena and mechanisms, to predict performance of complex situations, and to furnish accuracy standards for the industrial codes. SCISEAL also has the unique capability to produce stiffness and damping coefficients that are necessary for rotordynamic computations.
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3. Production of a KBS that couples the industrial codes with a user-friendly Graphical User Interface (GUI) that can be appended to an expert system to assist in seal selection and data interpretation and provide design guidance.
4. Technology transfer via four multiday workshops at NASA facilities where the results of the program were presented and information exchanged among suppliers and users of advanced seals. A Peer Panel also met at the workshops to provide guidance and suggestions to the program.

This final report has been divided into separate volumes, as follows:

Volume 1: Executive Summary and Description of Knowledge-Based System
Volume 2: Description of Gas Seal Codes GCYLT and GFACE
Volume 3: Description of Spiral-Groove Codes SPIRALG and SPIRALI
Volume 4: Description of Incompressible Seal Codes ICYL and IFACE
Volume 5: Description of Seal Dynamics Code DYSEAL and Labyrinth Seal Code KTK
Volume 6: Description of Scientific CFD Code SCISEAL.

This Executive Summary volume provides general conclusions and recommendations, summarizes the codes, and describes the KBS that integrates the industrial codes by a user-friendly GUI.

3.0 GENERAL CONCLUSIONS

The program has produced a wealth of computer codes that provide a solid foundation for analyzing and designing many of the advanced seals being contemplated for future air-breathing and space propulsion engines. Air-breathing applications include:

- Turbine rim seals
- Turbine blade tip seals
- Compressor end seals
- Interstage seals
- Thrust balancing devices.

Space propulsion engine applications include:

- Helium buffer seals
- Liquid oxygen seals
- Damping seals
- Hydrogen seals
- Parallel and helical grooved cylindrical seals.

Applications are not limited to advanced engines. The codes can also be used to design seals for a variety of industrial machines such as boiler feed pumps and pipeline gas compressors.

The codes are designed to treat fluid-film seals, where a clearance exists between the rotating and stationary components. Leakage is inhibited by surface roughness, small but stiff clearance films, and viscous pumping devices, e.g., spiral grooves.

Since seals can introduce destabilizing influences to rotating shafts, which can result in significant problems, most of the codes produce dynamic stiffness and damping coefficients for subsequent insertion into rotordynamics analysis. Dynamic coefficients are determined not only by the industrial codes, but also by the computational fluid dynamics (CFD) code SCISEAL, which is the only known CFD code with this capability.

4.0 RECOMMENDATIONS

The industrial codes were written for a PC environment using OS/2 as an operating system. At the inception of the program, OS/2 appeared to be the logical extension of PC operating systems and was jointly supported by Microsoft and IBM. The advantages of OS/2 were clear : a 32-bit operating system as opposed to contemporary 16-bit systems; multi-tasking and multi-threading capabilities; safeguards against system crashes; and a graphical environment. Indeed, OS/2 has proven to be a very robust system, with excellent compilation capabilities and amenable to the development of a user-friendly GUI that was accomplished for the industrial codes. Unfortunately, the rupture between IBM and Microsoft has led to a proliferation of operating systems for PCs (Windows 3.1, Windows 95, Windows NT, OS/2 Warp), with the Windows systems being a significant majority. The prevalence of Windows systems is expected to continue because of preloading on new computers and external software production. Thus, wide dissemination of the codes, a principal objective, requires that the industrial codes be ported to the Windows systems. The industrial source codes were written in Fortran 77 and can be compiled on any operating system. Input for the original source codes is reasonably friendly in that variable names are included. However, for intermittent users who are the majority, GUI is far superior to Fortran input.

The scientific code SCISEAL is principally UNIX based, which is not a uniform operating system, and it is hardware dependent. It was developed for a Silicon Graphics workstation; variations have been compiled for Sun and Hewlett Packard.

To promote extensive code usage, which could lead to significant advances in seal technology, it is recommended that the codes be ported to additional operating systems. In particular, the industrial codes should be ported to Windows 95 and Windows NT, and the scientific code should be ported to IBM AIX, and DEC Alpha workstations and to Windows NT.

Software expires unless maintained and continually updated, and, unfortunately, there are no provisions for continuing this effort. Technical areas that could benefit by continuing this work include counterrotating seals, high-pressure gas seals, compliant seals, and contact face seals. Also, the present codes are very amenable to transition to fluid-film bearing technology, and all the codes could be coupled to rotordynamics codes. SCISEAL, which is presently limited to cylindrical seals, should be augmented to include face configurations.

It is therefore recommended that provisions be made to maintain and update the codes, and add the additional routines required to advance the state of the art in seal technology, bearing technology, and rotor bearing systems.

5.0 CODE DESCRIPTIONS

The scientific and industrial codes developed under the program are briefly described below.

5.1 Scientific Code

SCISEAL (scientific seals, CFD code) was developed to provide detailed flow information for a variety of existing and new types of turbomachinery seals. It is an advanced 3-D CFD code for solutions of the Navier-Stokes (N-S) flow equations. A pressure-based solution methodology is used to integrate the flow equations in a sequential manner. A variation of the SIMPLEC method is used to impose the velocity-pressure coupling. The flow domain is discretized using the finite-volume method, and a collocated variable arrangement is used to store the flow variables. An implicit, multi-domain capability allows the division of complex flow domains into suitable subdomains; this allows optimum use of computational cells, easier grid generation and improved grid quality. The current capabilities and the numerical and physical models include:

- Steady and time-accurate solutions of incompressible and compressible flows
- High-order spatial (3rd) and temporal (2nd) discretization schemes
- A variety of turbulence models: standard and Low-Re k-ε models, and a two-layer model for narrow seal passages and treatment of isotropic surface roughness
- Full range of boundary condition types, including seal specific conditions
- A moving grid algorithm for rotor tracking, variable fluid properties.

The code has two automated methods for calculating seal rotordynamic coefficients. For a nominally centered seal, a whirling rotor method is available, which uses the full N-S equations on whirling seals to generate the rotordynamic coefficients. For nominally eccentric seals, a small perturbation method is available. The rotor is perturbed about its nominal position, and the N-S equations are used to generate the equations for the perturbation variables. These are solved to yield the perturbation rotor loads and the rotordynamic coefficients. Both of these methods are set to handle cylindrical seals and similar geometries, and are available in the multi-domain mode.

5.2 Industrial Codes

GCYLT (gas, cylindrical, turbulent) analyzes a variety of cylindrical seals such as steps, tapers and hydrostatic geometries. The code is a Reynolds equation solver that considers laminar and turbulent flow in the film region. Principal usage is for low-clearance geometries that are effective in inhibiting leakage, such as floating ring and circumferentially sectored seals. The code produces the clearance and pressure distribution over a specified grid network, leakage along specified flow paths, interface loads, righting moments, viscous dissipation and frequency dependent stiffness and damping coefficients[2]. Plotting routines are also provided for visualizing the clearance and pressure distributions. Applications include seals for compressors, industrial gas turbines, jet engines, and helium buffer seals for space turbomachinery.

GFACE (gas face) attributes and capabilities are similar to those of GCYLT, but it was developed in polar coordinates rather than cylindrical coordinates, and it is limited to laminar flow. Plotting routines are also provided for visualizing the clearance and pressure distributions. Applications include seals for compressors, gas turbines, and jet engines.

SPIRALG (spiral-groove gas) produces interface performance of spiral-groove cylindrical and face seals. The flow is assumed to be laminar, and isothermal and narrow groove theory is used, which characterizes the effects of grooves by a global pressure distribution without requiring computations on a groove-by-groove basis. The code produces forces, moments, film thickness, leakage, power loss and cross-coupled frequency-dependent stiffness and damping coefficients. Spiral-groove seals are finding wide application in pipeline compressors, laser gas circulators and computer disk drives, and they have also been developed for application to advanced air-breathing and space propulsion turbomachinery.

SPIRALI (Spiral-groove liquid (incompressible) seals) is based on the Hir's bulk flow model with the addition of spiral groove theory. Turbulence is treated with an extended form of the Hir's bulk flow model, generalized to include separate and arbitrary friction-factor Reynolds number relationships for each surface. Narrow groove theory is used to characterize the spiral groove geometries, which maintains the global representation. Geometries with film discontinuities such as parallel and multiple helical grooves, employ loss coefficients. Rough surfaces can be modeled by applying appropriate friction factor relationships. Output includes forces, moments, film thickness, leakage, power loss and cross-coupled stiffness and damping coefficients. Performance is confined to concentric operation. In addition to spiral-groove cylindrical and face seals, this code can treat axisymmetric variations in geometry, such as tapers and barrel shapes. Applications include spiral-groove seals, pressure breakdown bushings, wearing rings, damping seals and parallel and helical groove seals for high-pressure pumps and cryogenic turbomachines.

ICYL (liquid (incompressible) cylindrical) capabilities include 2-D incompressible, isoviscous turbulent flow in cylindrical geometries, rotation of rotor/and or housing, roughness of both rotor and housing and inertia pressure drops at inlets to the fluid film from the ends of the seal and from pressurized pockets. Inertia effects are incorporated by applying a Bernoulli relation at each boundary point and reducing the static pressure by the computed kinetic energy. Couette and Poiseuille turbulence and cavitation are included. Geometries such as steps, pockets, tapers, preloaded arcs and hydrostatic recesses can be treated. The code produces the pressure and clearance distributions, rotor position, forces and moments, pocket pressures and flows, and the cross-coupled dynamic coefficients (stiffness and damping). Applications include liquid hydrostatic and hydrodynamic seals for pumps, cryogenic machines, and miscellaneous machinery. Plotting routines are also provided.

IFACE (liquid (incompressible) face) has similar characteristics as ICYL, except it analyzes face seal or thrust configurations rather than cylindrical configurations.

DYSEAL (dynamics of seals). The dynamic response of seal rings to rotor motions is an important consideration in seal design. For contact seals, dynamic motions can impose significant increases in interfacial forces, resulting in high wear and reduction in useful life. For fluid-film seals, the rotor excursions are generally greater than the film thickness, and if the seal ring does not track, contact and failure may occur. The computer code DYSEAL can determine the tracking capability of fluid film seals and can be used for parametric variations in geometry to find acceptable configurations. For face seals, the code will determine response to rotor motions in five degrees of freedom, which are the three translations and two rotations about the center of gravity. The interface is represented by cross-coupled stiffness and damping coefficients that are determined from other codes. The effects of Coulomb friction of the secondary seals on seal ring response are included. Piston ring and O-ring secondary seals can be analyzed. The code can also determine response of floating ring seals. The floating-ring model permits two degrees of freedom for both the shaft and the ring, and is intended to determine seal ring response to an orbiting shaft. The secondary seal occurs between the ring and the wall and x-y Coulomb friction at that location is accounted for. The method of computation is a forward integration in time that provides absolute motions in all degrees of freedom. At every time step, friction is evaluated to determine whether motions continue or are halted.

KTK (knife-to-knife) calculates the leakage and pressure distribution through labyrinth seals based on a detailed knife-to-knife analysis. Input data are required to describe in detail the seal geometry and the environmental conditions affecting the leakage. Output is provided in the form of leakage flow and flow resistance characteristics, i.e., flow factor versus pressure ratio. In addition, an optimization feature is included which permits the user to identify global geometric constraints and allows the code to predict an optimum seal configuration based on minimum leakage. The labyrinth seal design model is an expansion of the knife-to-knife analyses reported in the literature. In such approaches, one-dimensional flow parameters in the knife throats are computed and linked together by a total pressure loss calculation. Flow coefficients are used for individual knives or groups of knives to account for the vena contracta in knife throats. Velocity head carry-over from upstream knives is accounted for by reducing the head loss between knives based on the flow expansion angle. The code basis used extensive empirical data produced by the Allison Engine Company under Air Force sponsorship[2].

User manuals[3 - 10] were generated to describe the theoretical basis of the codes and the methods to implement the FORTRAN versions.

6.0 DESCRIPTION OF KNOWLEDGE-BASED SYSTEM (KBS)

The function of the KBS is to provide user-friendly access to the industrial codes via pull down menus and dialog boxes that contain check box and radial button alternatives. Although the KBS is independent, perusal of the user manuals[3 - 10] will facilitate understanding of the input and output produced on the KBS.

6.1 System Executive

The CFD Executive Program integrates all components of the CFD industrial codes package. The individual codes are accessed through the executive. In addition, the executive provides utility functions such as browsing and printing output files created by the analysis programs, and plotting the data output by some of the industrial codes. The main screen is shown on Figure 1. There is a button for each of the seal categories for which codes are available. The individual codes are accessed by first clicking on the appropriate seal category to bring up the menu of individual codes in that category, and then clicking on a button to execute the desired code. Figure 2 shows the options in the Bushing and Ring Seal category.

6.2 Description of Menus

The file menu provides facilities to browse, print, and delete data files generated by the analysis codes. Figure 3 shows the File Selection Dialog used by all the programs to specify names of files. The files in the current directory, and, when appropriate, the names of subdirectories are listed in a listbox. To select a file name, you have to double click on a name in the file list box to select the file and then press the ACCEPT button. You can switch directories for which the files are listed in the file list box by double clicking on the directory name. When selecting a file to browse or an input data file to read, you may only select file listed in the listbox. When specifying the name of a file to be saved on disc, you may enter a name in the file name field or select a name listed in the listbox. If the file you specify already exists, you will be asked to confirm that you want to replace the existing file.

When the Browse File menu item is selected, the file selection dialog is displayed for you to select the name of the output file to browse. The file you select is then displayed in the Browse Dialog as shown in Figure 4. You can print the file being browsed by pressing the Print button.

The Help menu provides access to the on-line help. Context-sensitive help can also be accessed by pressing the F1 key or a Help button if one is available.

The File menu is used to save input data in a file and read data from a previously saved input file. Figure 5 shows the file menu selections available for each of the industrial codes. The input file selection dialog is displayed for you to specify the name of the input data file to be read or saved. Once the data has been read from a file, it can be changed using the normal input procedures. The main screen for the program displays the descriptive title for the current data set.

The Help menu is used to access the help system. Context sensitive help is available at all times by pressing the F1 key. Figure 6 shows the help menu selections available for each of the industrial codes. The help index is available for assistance with a specific topic such as an input variable.

The Analysis menu is used to begin an analysis after input data has been prepared. Figure 7 shows the analysis menu selections available for each of the industrial codes. When the Run Analysis menu item is selected, the file selection dialog is displayed for you to specify the name of the output file(s) that will be generated by the analysis code. An existing name may be selected from the file list, or a new name may be input at this time. If entering a new name, you only need to enter an eight-character file name. The program supplies the appropriate extension(s). The analytical program is then started as a separate process in its own window. The message "Analysis in progress..." is displayed in the program's main window until the analysis is completed. Once the analysis is running, the user interface is available for use. You may not, however, start another analysis while a previous one is in progress. Status messages from the analytical code that is running may be viewed by switching to the analytical-code window.

A batch mode which allows sequential execution of up to five test cases has been provided. When the Batch Mode menu item in the analysis menu is selected, the screen shown in Figure 8 is displayed to enter the input, output, and, if applicable, pressure file names for up to five cases. Only the file names and extensions need to be entered. A listbox containing the available input and output files is displayed at the bottom of the screen for viewing. The program will check to ensure that the input files you supplied exist. The names of the pressure files may be required for GCYL, GFACE, ICYL, and IFACE. The pressure files can be used as an initial guess of the pressure distribution to enhance convergence and speed.

The View menu in each program is used to browse program input, program output, and, if applicable, to plot data. Figure 9 shows the view menu selections available for each of the industrial codes. You are restricted to browsing and plotting files in the output file directories of the program you are using. The input view is based on current values entered by the user and is displayed in the format used by the analysis code.

The Input menu is used to input data. The menu items are essentially the same for each program. The input menu options for the GCYL code are shown in Figure 10. Selecting a menu item brings up a screen with the relevant input fields. The displayed input screen may hide or disable certain fields depending upon values that were entered on other input screens. The purpose of the input screens for each of the menu items is described below using GCYL as an example.

Analysis Options are used to define the scope of the analysis to be performed, and to define the title and units to be used for the input case. Figure 11 shows the Analysis Options screen with default values. Mutually exclusion options such as Calculate Stiffness are shown as radio buttons with the current choice highlighted. You can select only one of the options in a group of radio buttons. Other options such as boundary conditions allow several elements to be selected at the same time. These are shown as checkboxes. To get help on the choices available in an option, select the option and press the F1 key. The help screen for the Calculate Stiffness option is shown in Figure 12. The Analysis Options always contains an option to choose between SI and English units. The units displayed in the field labels and the numeric values will be automatically changed to the correct units. The SI and English units for frequently used quantities are as follows:

Description	SI Units	English Units
Lengths	m or mm	in.
Angular Velocity	rev/min or rad/s	rev/min or rad/s
Velocity	m/s	in./s
Forces	N	lb
Gas Constant	$m^2/s^2/°K$	$in.^2/s^2/°R$
Temperature	°K	°R
Density	kg/m^3	$lbm/in.^3$
Viscosity	Pa-s	$lb\text{-}s/in.^2$
Pressure	Pa	psia or psig
Entropy	J/Kg/°K	Btu/lbm/°R
Inertia	$Kg\text{-}m^2$	$lbm\text{-}ft^2$
Moments	N-m	in.-lb
Angles	deg or rad	deg or rad
Energy	J	ft-lb
Power	W	ft-lb/s
Stiffness	N/m	lb/in.

The Seal Geometry screen is used to specify seal dimensions as shown in Figure 13 with default values. The values are entered in the entry fields. If a field is not needed because of the analysis options selected, it is disabled to prevent you from entering data in that field.

The Operating Conditions screen is used to specify operating parameters such as speed, temperature, eccentricity, and pressures as shown in Figure 14 with default values.

The Seal Configuration screens are used to specify special features such as fluid sources, Rayleigh steps, spiral grooves, etc. These screens will, therefore, differ significantly from code to code. Figure 15 shows the screen for specifying flow line coordinates in GCYL. A flow line is a grid line with specified grid coordinate boundaries (X1, Y1) and (X2, Y2). The lines are specified as an array of starting and ending grid coordinates for the lines. Four sets of values in the array are displayed on the screen. You can scroll through the array using the scroll bar. When the number of lines is entered in the entry field and the cursor is moved to one of the fields in the array, the scroll bar will adjust its range to match the number of lines specified.

The Grid Definition screen used to define the grid used in the numerical solution is shown in Figure 16 with variable grids turned on for both axial and circumferential grids. The default is to turn off variable grids. The arrays used for variable grids are disabled if they are not required.

The Properties screen shown in Figure 17 is used to input seal fluid properties such as viscosity and specific heat ratio.

The Solution Control screen shown in Figure 18 is used to input information such as tolerance and number of iterations used to control the numeric solution.

The Set Defaults option is used to set values in all the screens to system defaults for the program.

Plotting routines are available to plot clearance and pressure distributions and to plot dynamic response for the dynamics code. Examples of film thickness and pressure plots are shown on Figures 19 and 20.

Further elaboration on the use of the KBS is found in Reference[11].

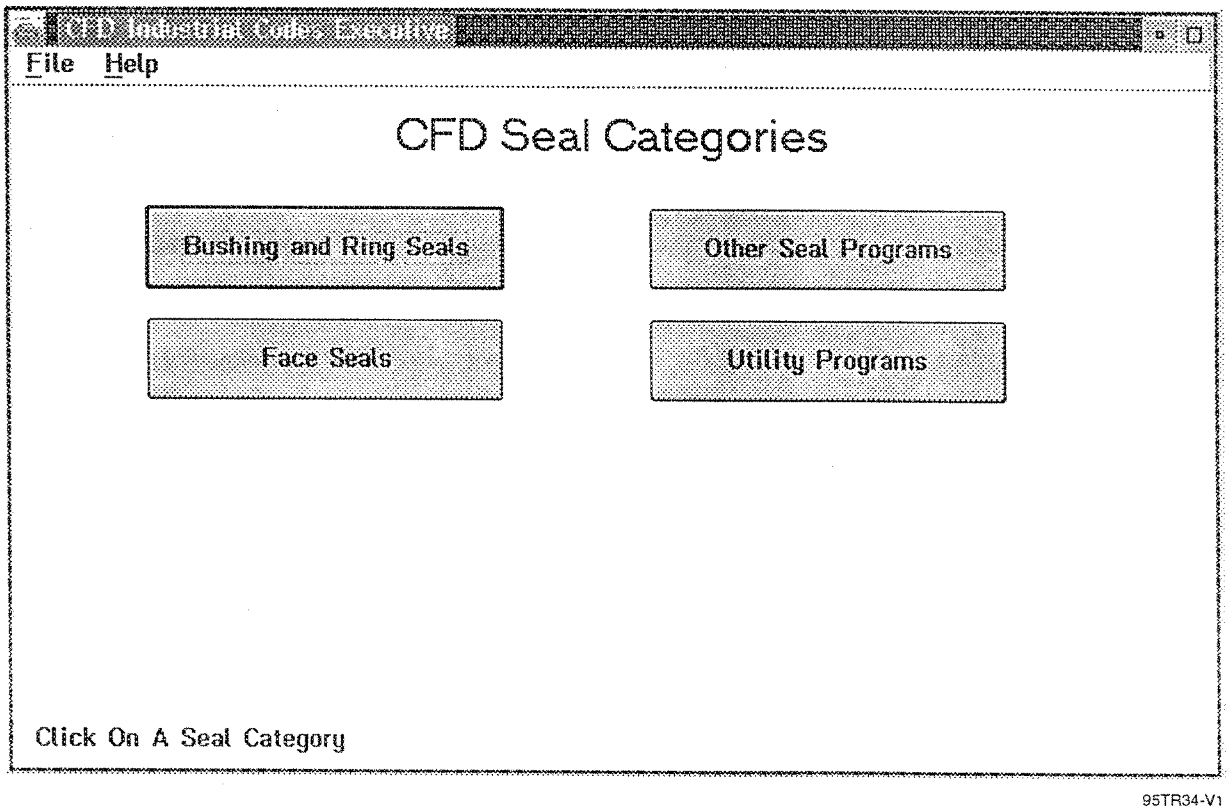

Figure 1. Main Menu Screen

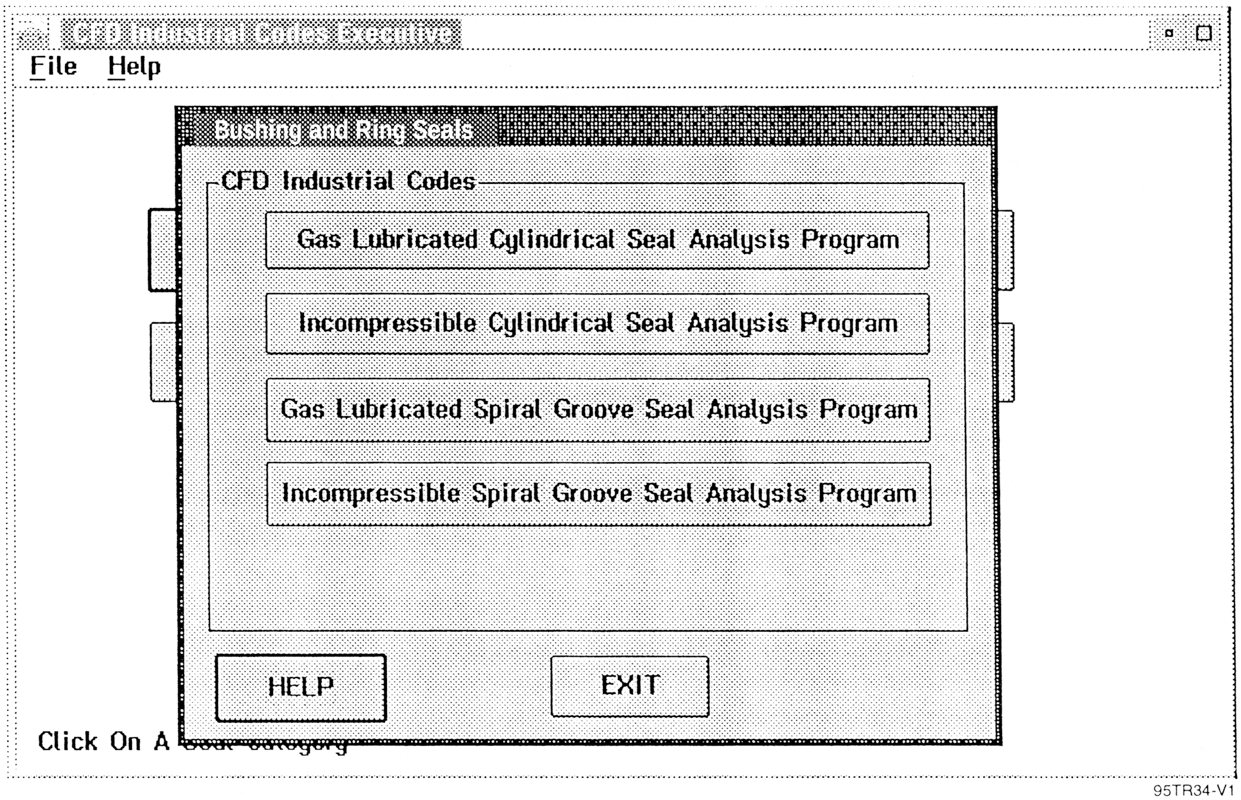

Figure 2. Bushing and Ring Seal Category

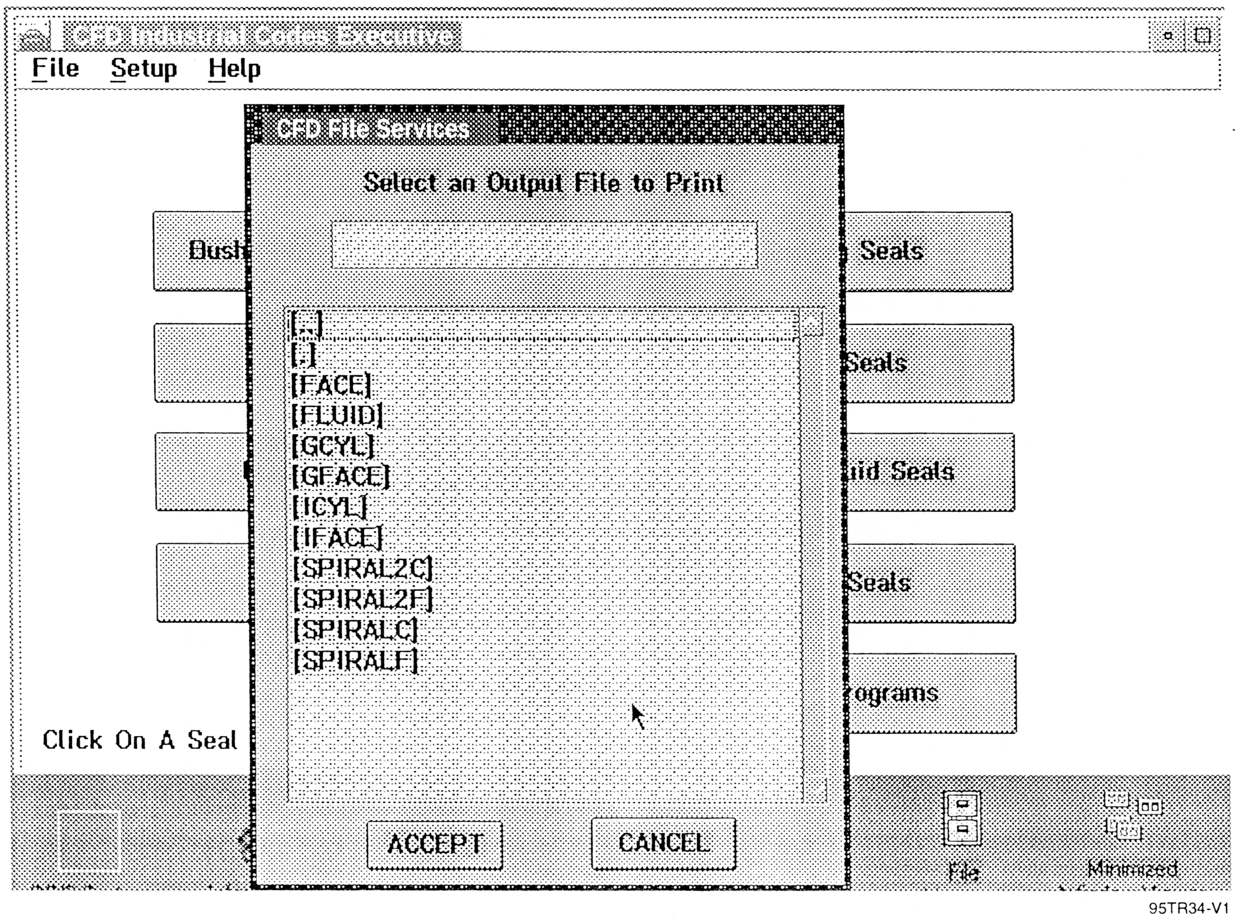

Figure 3. File Selection Utility

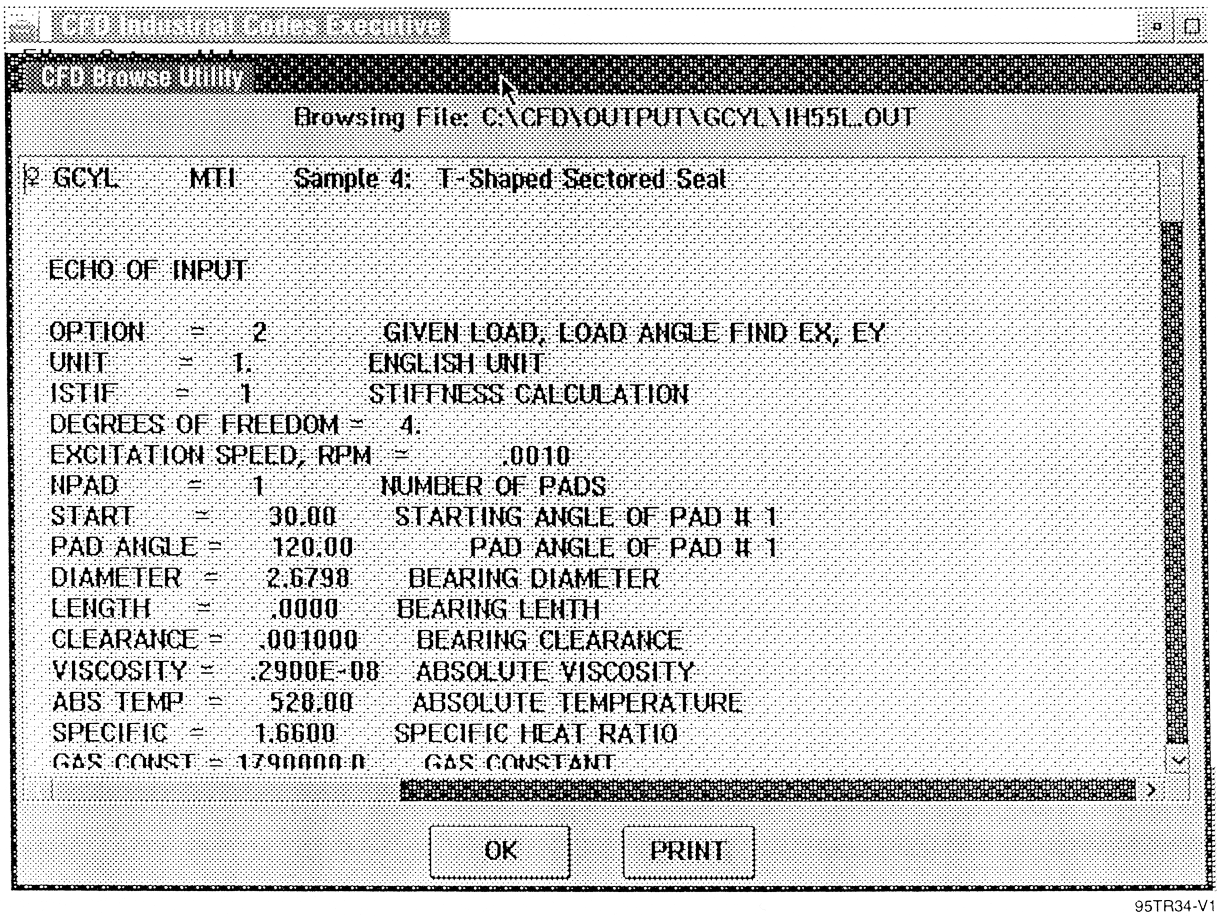

Figure 4. Browse Utility

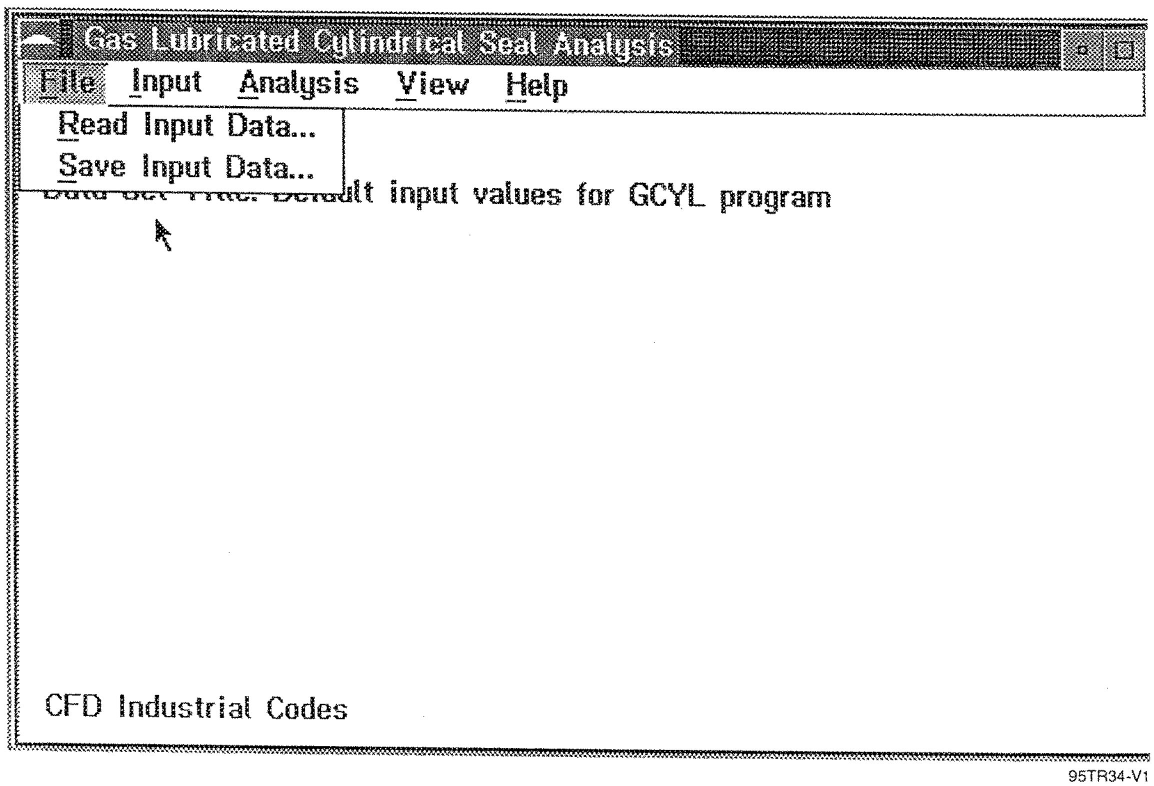

Figure 5. File Menu in Industrial Codes

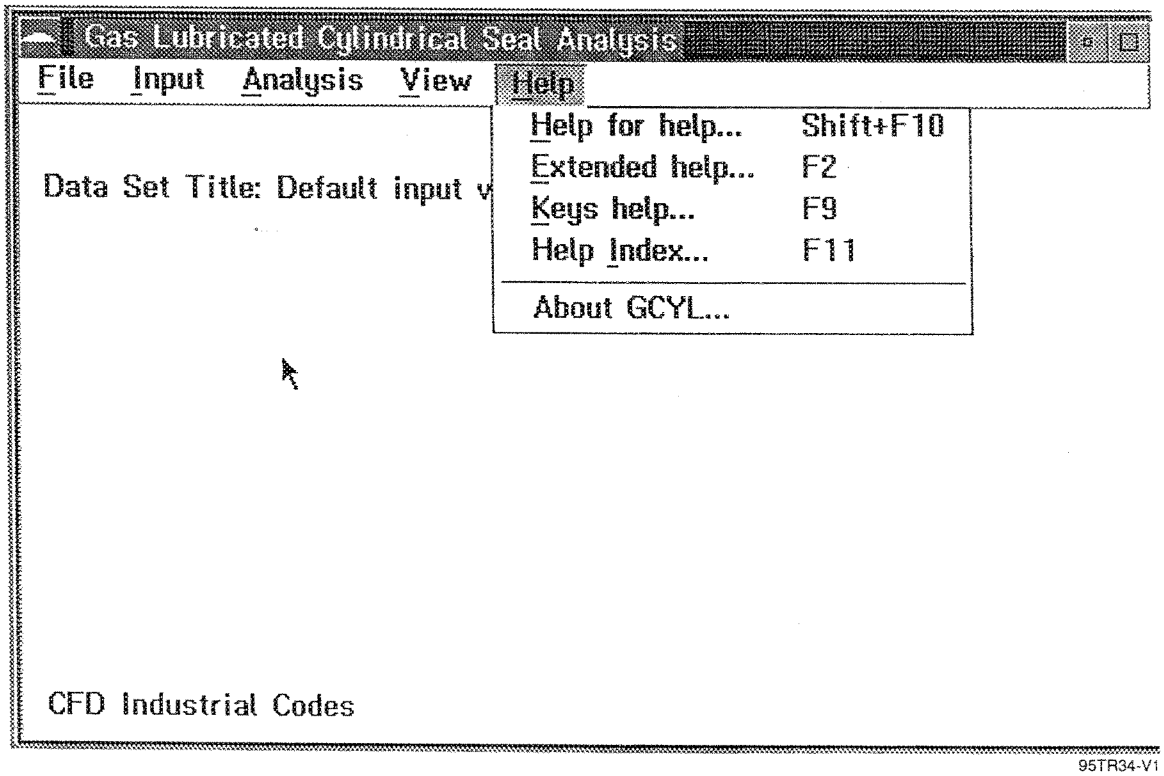

Figure 6. Help Menu in Industrial Codes

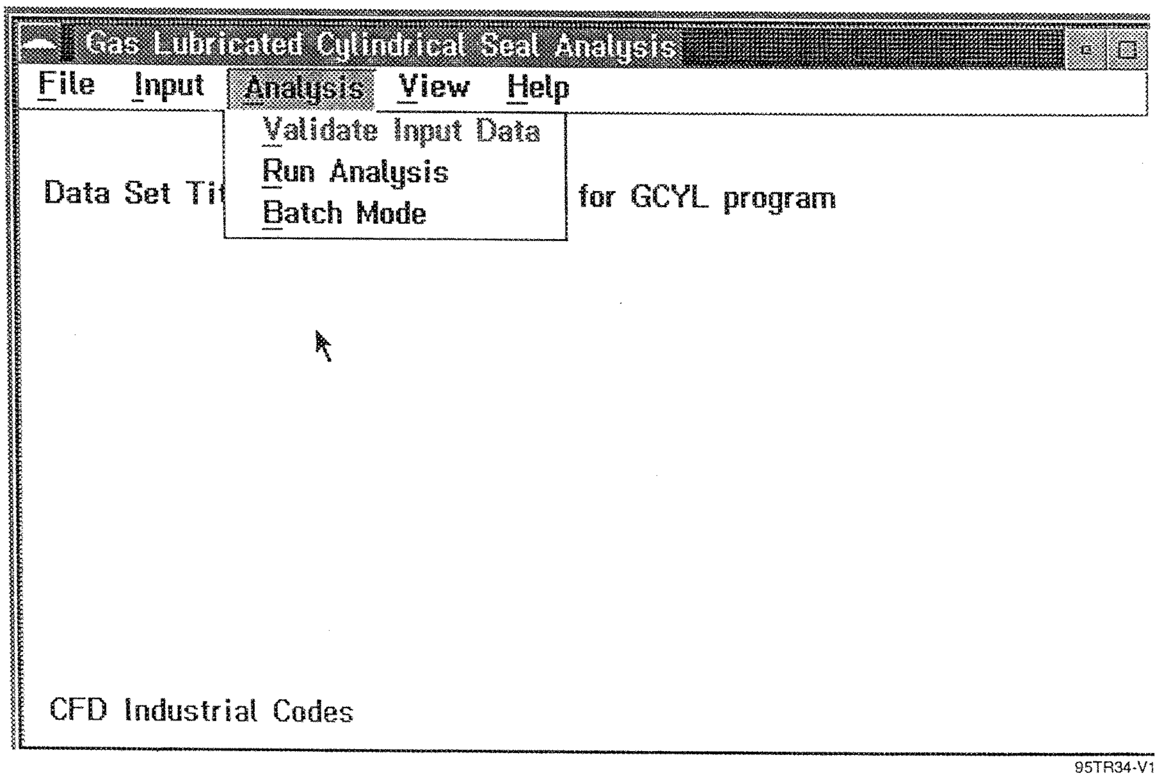

Figure 7. Analysis Menu in Industrial Codes

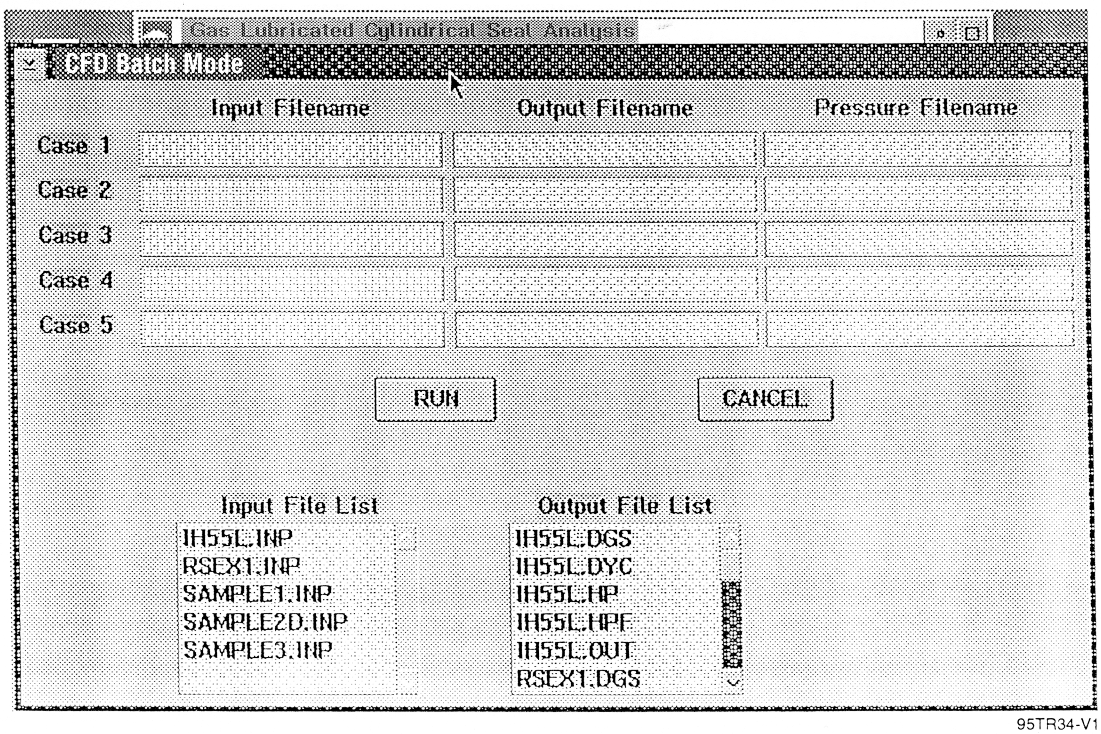

Figure 8. Batch Mode Analysis Input Screen

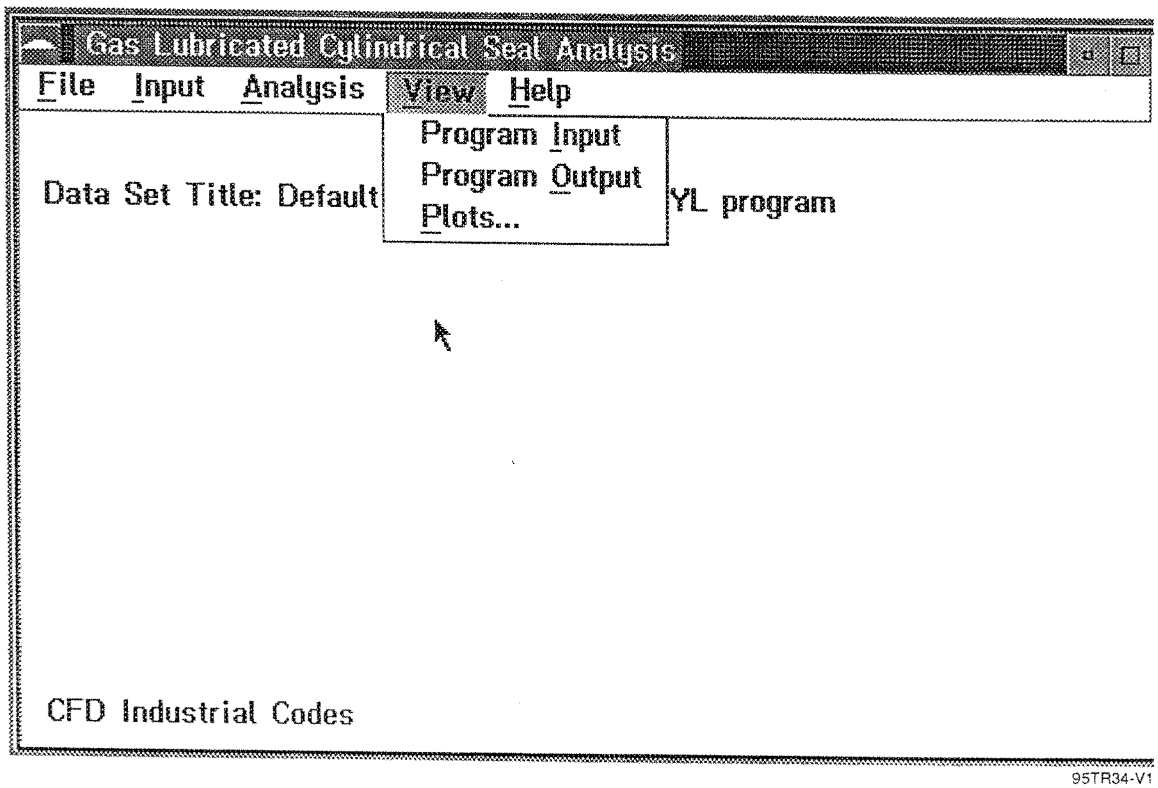

Figure 9. View Menu in Industrial Codes

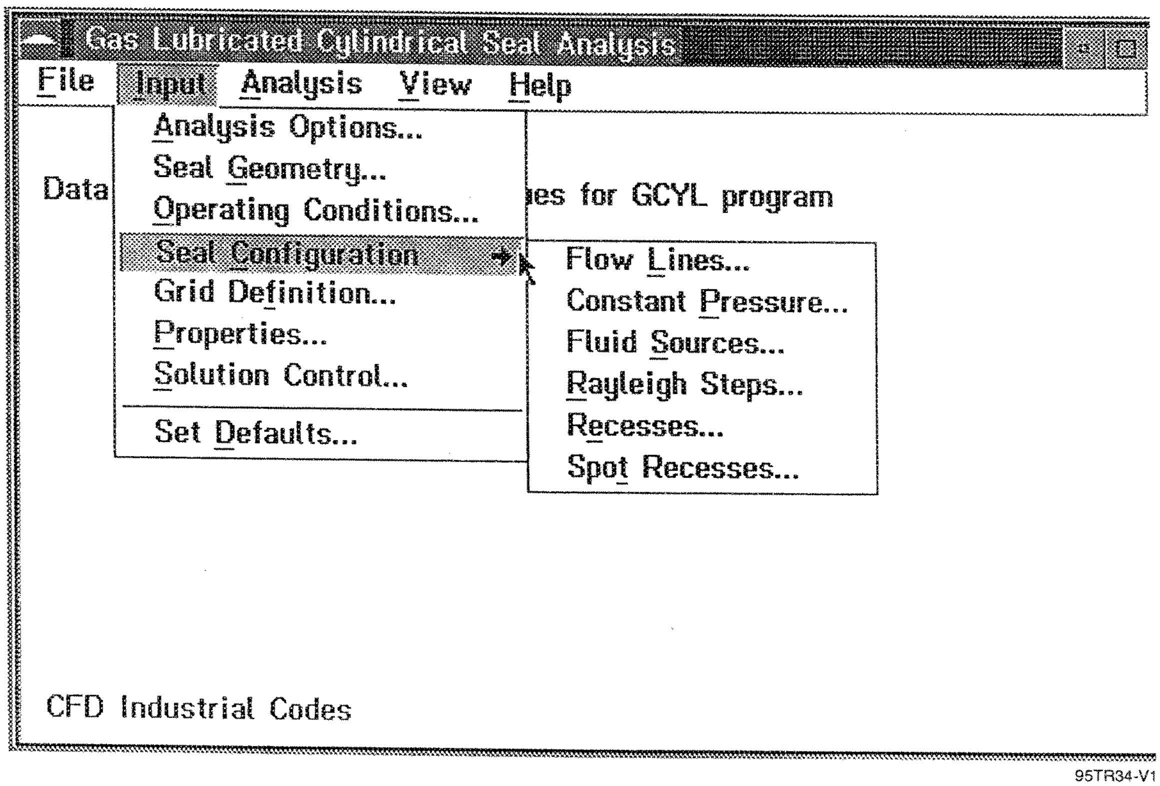

Figure 10. Main Screen and Input Menus for GCYL

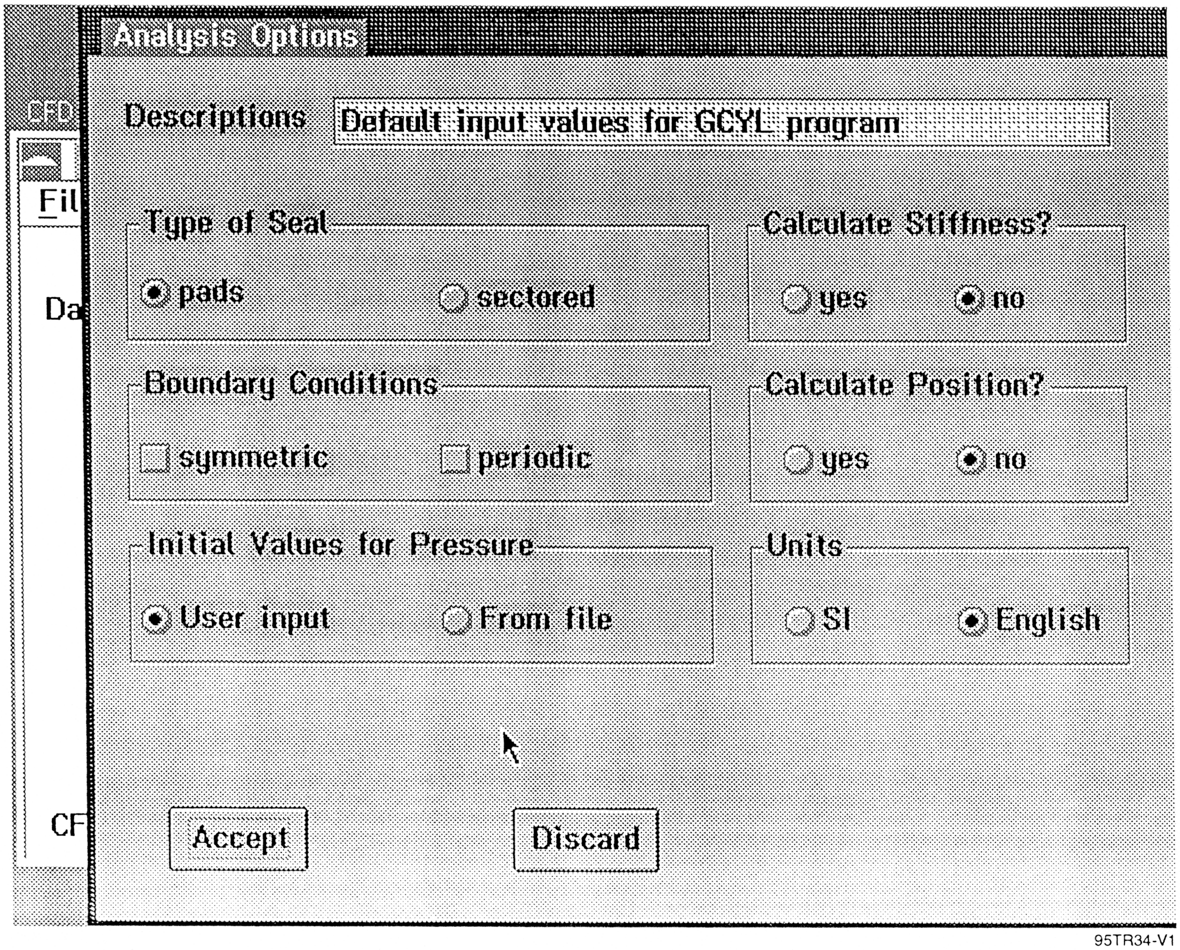

Figure 11. Analysis Options Screen for GCYL

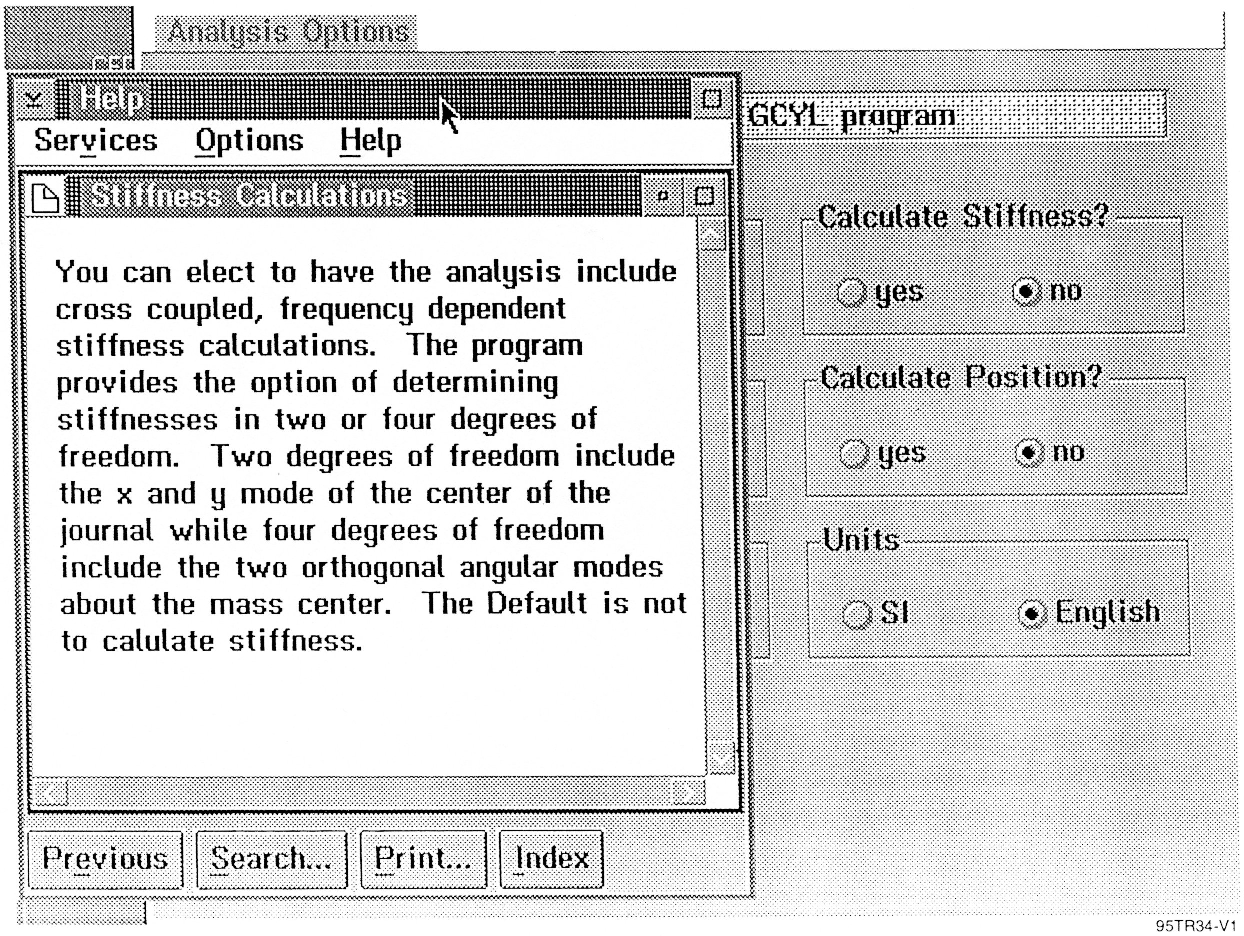

Figure 12. Context Sensitive Help

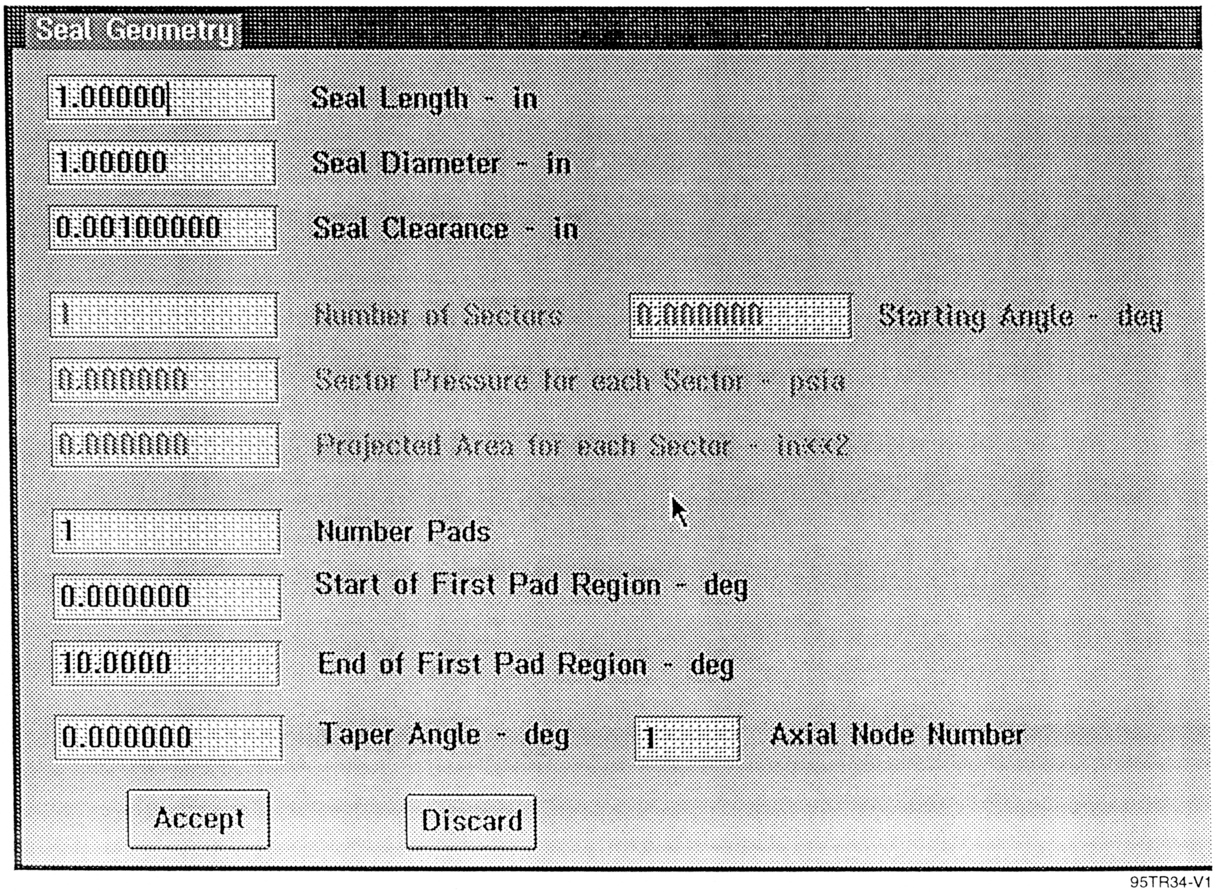

Figure 13. Seal Geometry Screen for GCYL

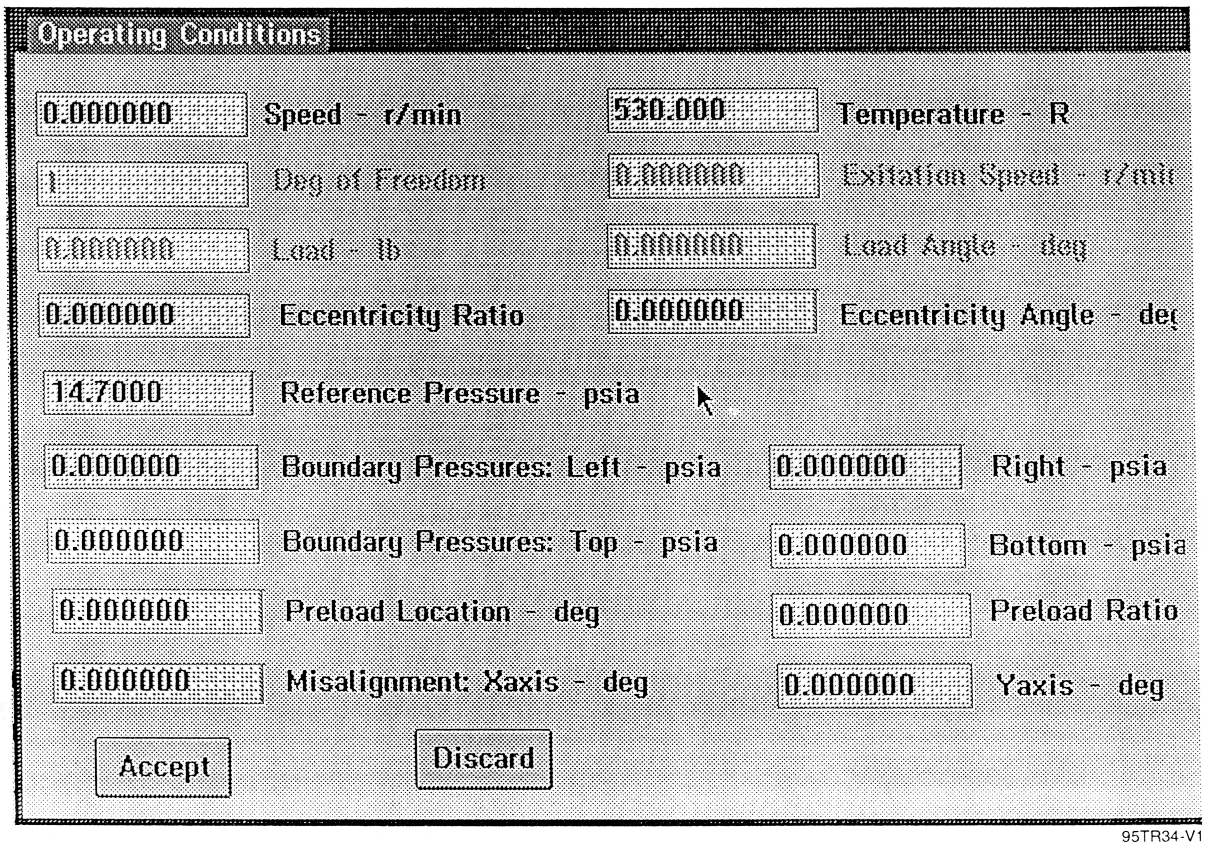

Figure 14. Operating Conditions Screen for GCYL

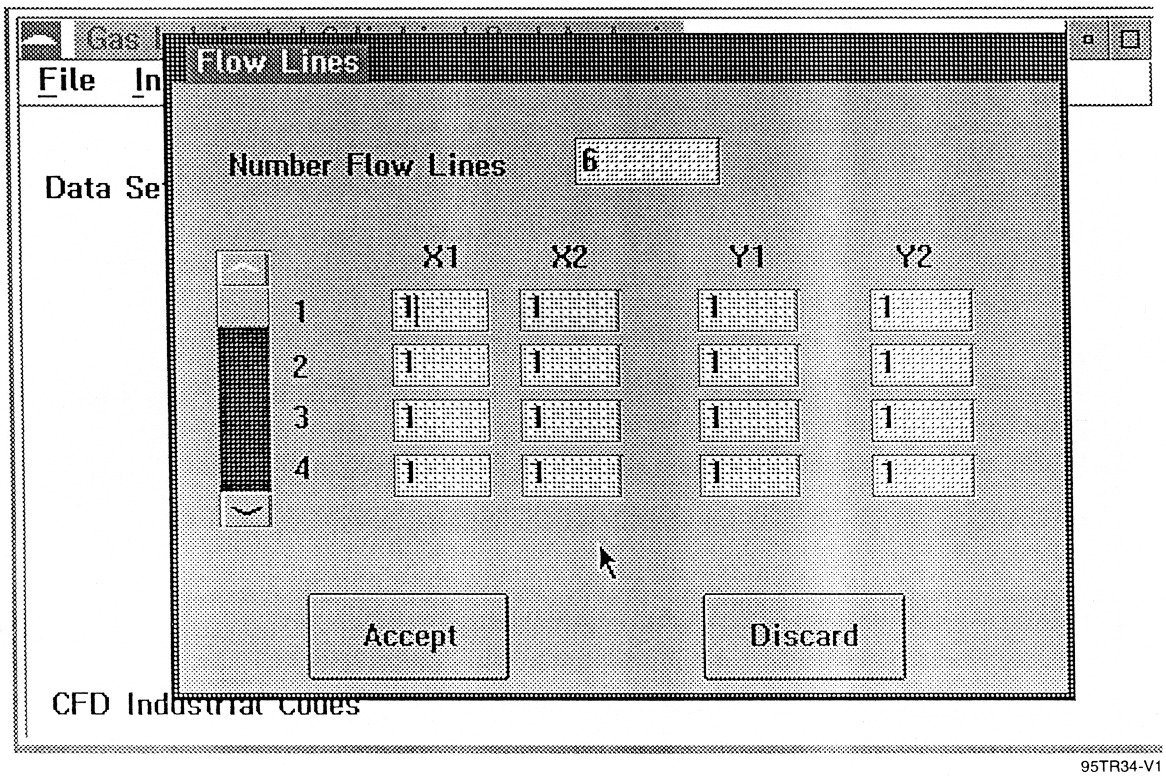

Figure 15. Seal Configuration Screen for GCYL

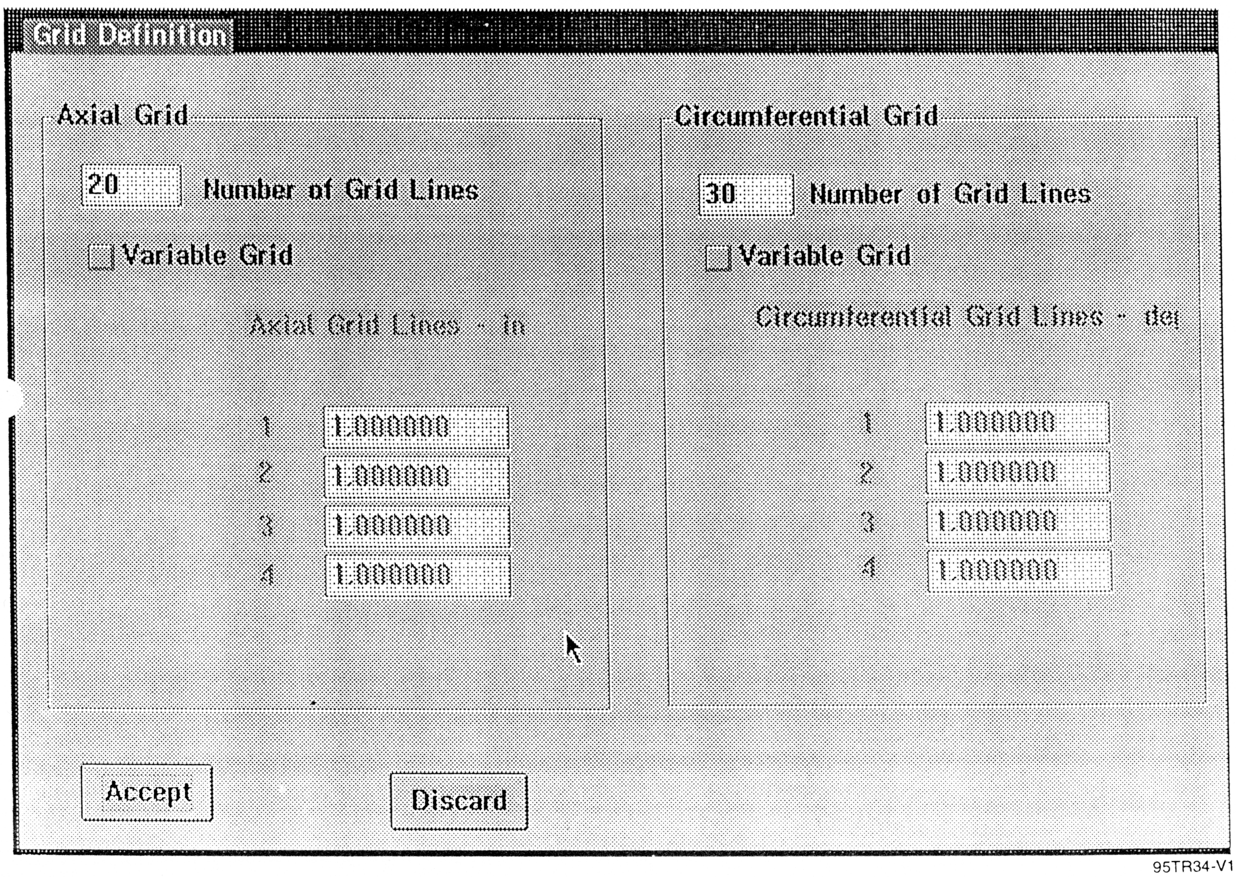

Figure 16. Grid Definition Screen for GCYL

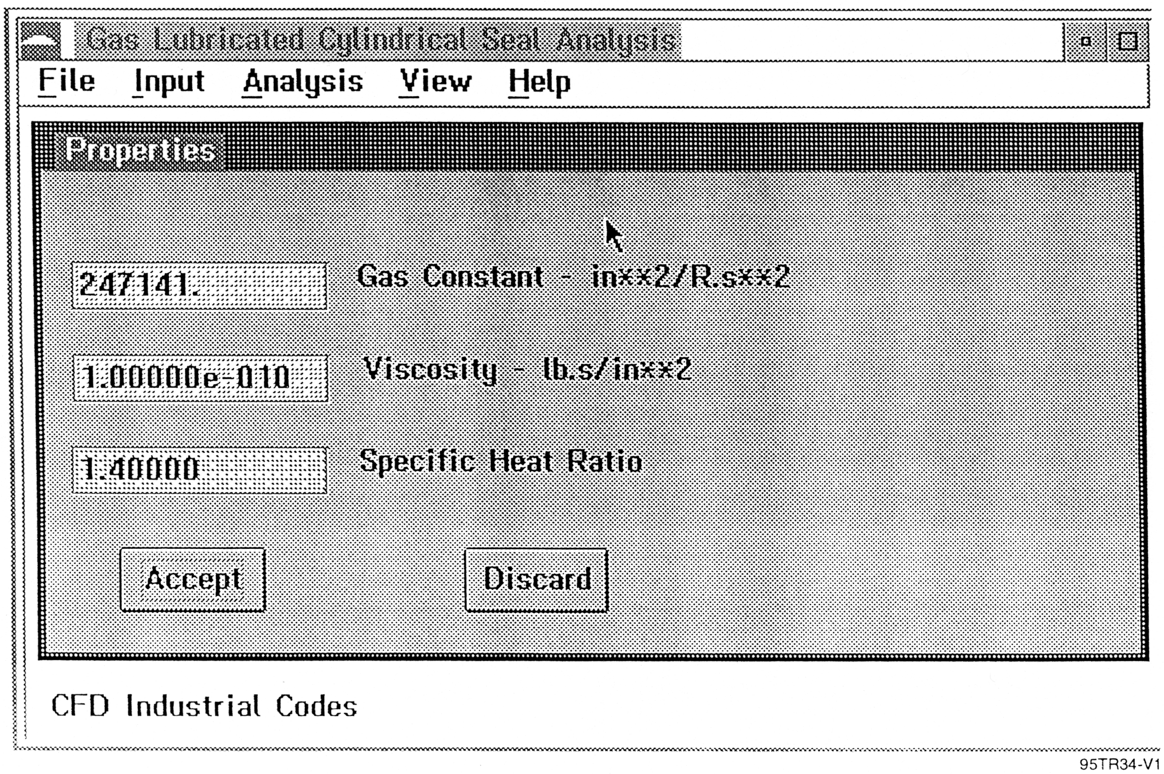

Figure 17. Seal Fluid Properties Screen for GCYL

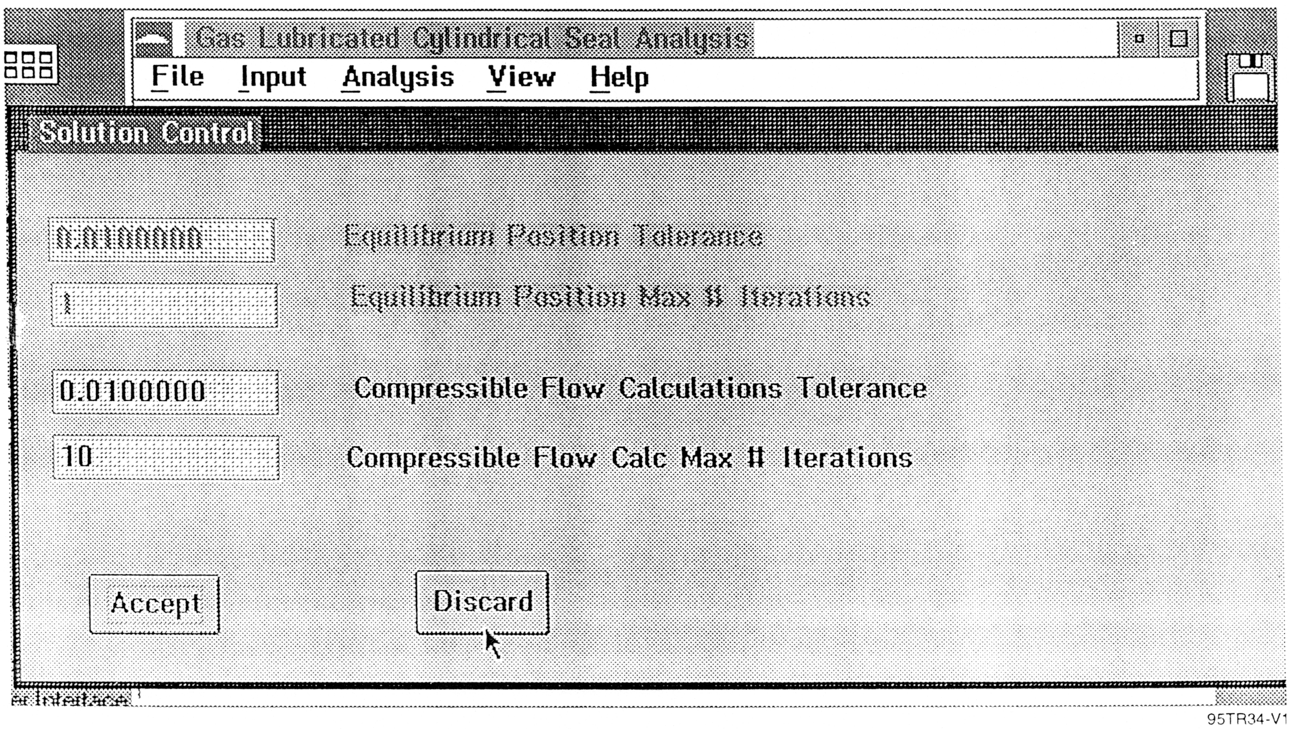

Figure 18. Solution Control Screen for GCYL

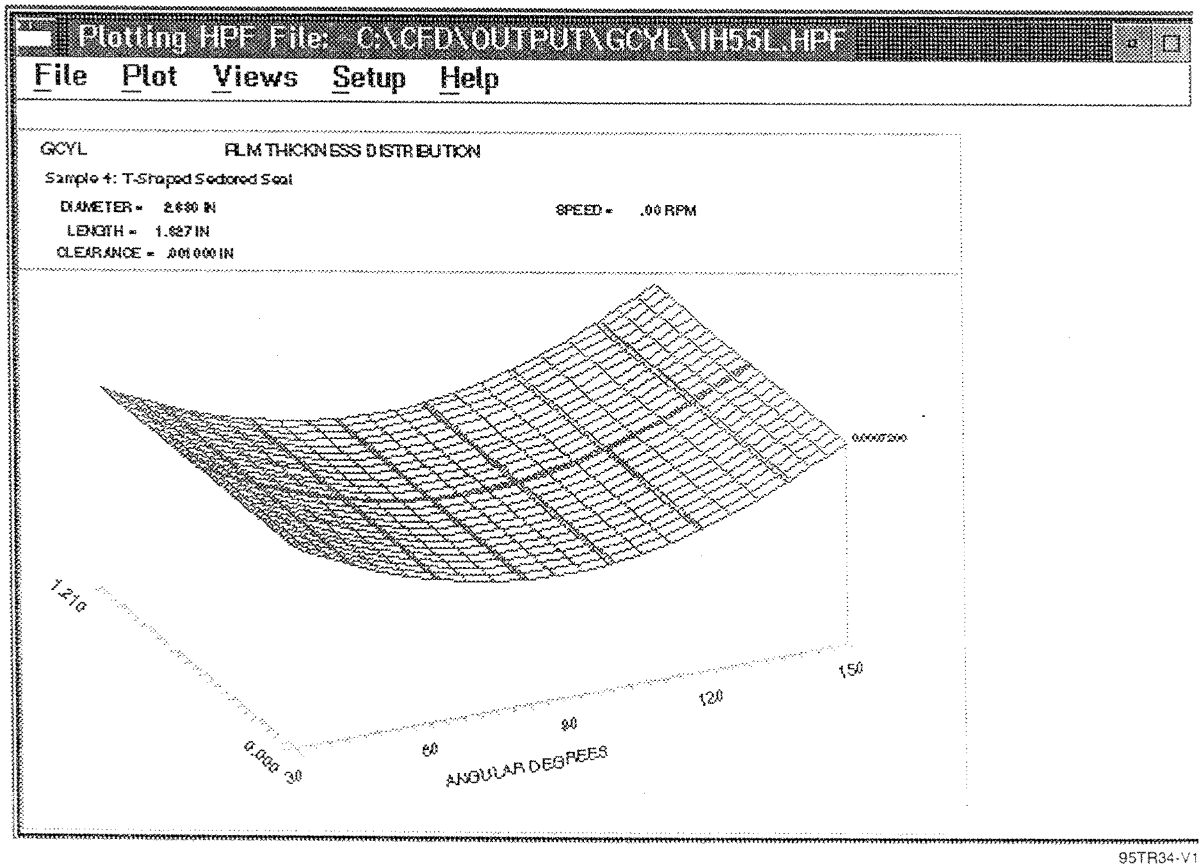

Figure 19. PLOT4DPM - Film Thickness Plot

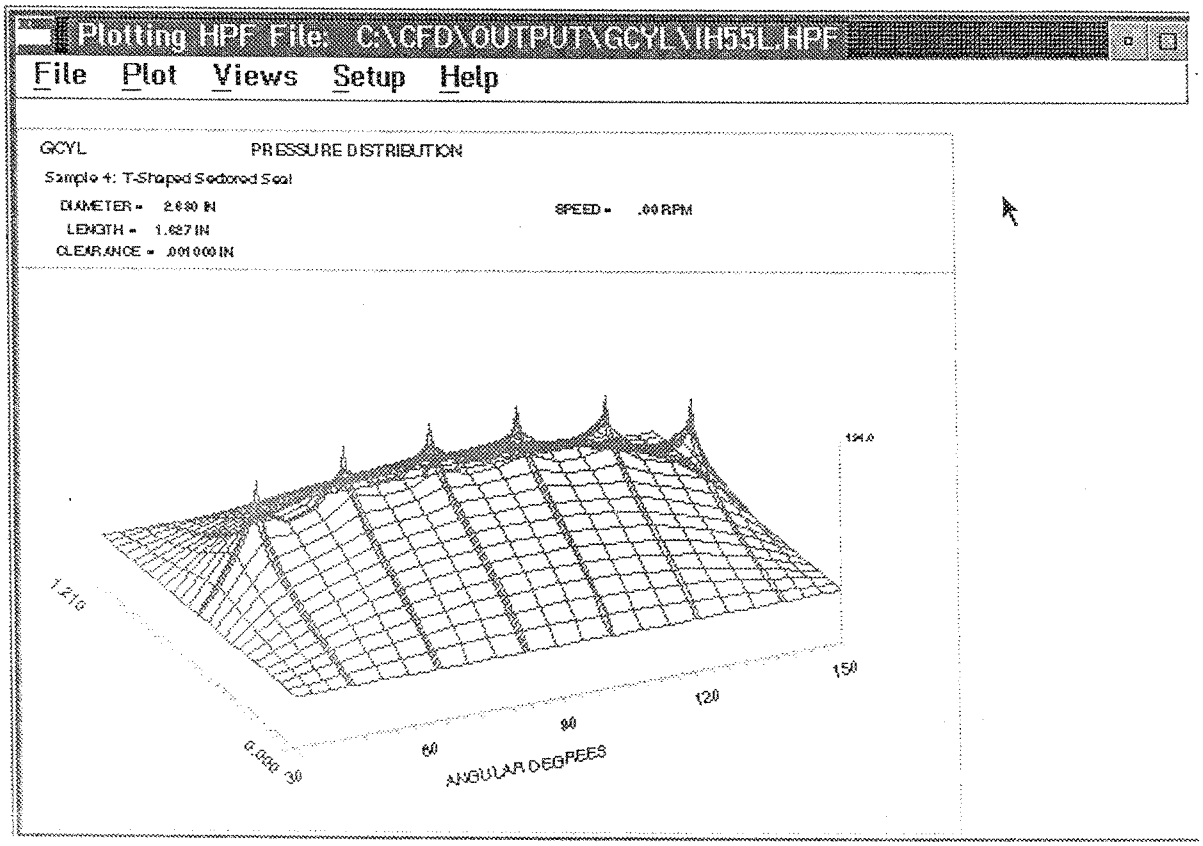

Figure 20. PLOT4DPM - Pressure Distribution Plot

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Wilbur Shapiro and Bharat Aggarwal

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13. ABSTRACT ***(Maximum 200 words)***
The objectives of the program were to develop computational fluid dynamics (CFD) codes and simpler industrial codes for analyzing and designing advanced seals for air-breathing and space propulsion engines. The CFD code SCISEAL is capable of producing full three-dimensional flow field information for a variety of cylindrical configurations. An implicit multidomain capability allows the division of complex flow domains to allow optimum use of computational cells. SCISEAL also has the unique capability to produce cross-coupled stiffness and damping coefficients for rotordynandc computations. The industrial codes consist of a series of separate stand-alone modules designed for expeditious parametric analyses and optimization of a wide variety of cylindrical and face seals. Coupled through a Knowledge-Based System (KBS) that provides a user-friendly Graphical User Interface (GUI), the industrial codes are PC based using an OS/2 operating system. These codes were designed to treat film seals where a clearance exists between the rotating and stationary components. Leakage is inhibited by surface roughness, small but stiff clearance films, and viscous pumping devices. The codes have demonstrated to be a valuable resource for seal development of future air-breathing and space propulsion engines.

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