VIRTUAL MANUFACTURING ON THE WEB:
EXTRUSION DIE DESIGN

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Chapter 1

INTRODUCTION

1.1 Overview

A good design procedure should always be a precursor to the manufacturing of a quality product. Since the development of the extrusion process in the early eighteenth century, the extrusion process has not seen much of a change. Die design for extrusion processes has been the most difficult part. It has always relied on experimental trial-and-error methods and has depended on the knowledge and experience of the designer [1]. The industrial revolution over the last century has made it necessary for a process of die design that is less time-consuming and is cheaper for the highly competitive manufacturing industry.

Computer Aided Design (CAD) is a mechanism by which man and machine are combined into a problem solving team, which provides better solutions to the design problems in a multiple discipline domain [2]. Since the invention of the computer, Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) have been utilized in various fields of engineering and technology. For a very long time, the users of the CAD/CAM system have been engineers who have been specially trained for this purpose in that particular field. Two factors that limited the use of computer software for the design of dies were the accessibility to and the complexity of the software. The development of the Graphical User Interface system, where the user can interactively input or modify data and visualize the output on the computer screen, has reduced the
complexity issue to a great extent. Today, even a novice to the computer can use and appreciate the capability of the CAD system. Computer Aided Design has merged well with the manufacturing systems of the day. With the advancement in computer technology and the optimization of design techniques, CAD/CAM is faster and more accurate. The computer-aided solid modeling systems enable the designer to review and modify the design solutions in three-dimensions without needing to construct physical models and, thus, increase efficiency of the design process [3].

1.2 Internet

In recent years, the growth of the Internet and the exponential growth of the World Wide Web (www) have provided access to fast information transfer. Today it is possible for a person to study or publish information from the desktop of a very ordinary Personal Computer from home or place of work and reach millions of people around the world. The World Wide Web has emerged as an inexhaustible source of information and training.

1.3 Virtual Manufacturing

In manufacturing it is common that multiple facilities exist within the same company. Consequently, the design and the manufacturing plants might be located at different geographical locations hindering communication between the facilities within a company. During the manufacturing, planning, and development process, engineers in
one location might require information about the availability of equipment and scheduling capacity from their different facilities around the world. If a new product is to be manufactured, a company might need immediate information about machinery and scheduling problems in their other plants. An interface that combines the realism of Virtual Reality (VR) and the rapid information exchange capabilities of the Internet's sub-domain, World Wide Web, has the ability of bridging this gap that exists between the different stages of product development. This simplified VR model allows for a partial immersed "walkthrough" experience. It accurately reflects basic features of the shop floor machinery. Process plan verification is also possible due to the realistic models of the actual physical facilities and equipment familiar to the user. Other utilities, such as tooling control panel and machine operation instructions, provide extra functionality to the developed system.

The Virtual Manufacturing Project, an idea conceived by Mehta [4], would be a package available on the Internet for users around the world. The package will consist of modules that would allow the user to study, run, or analyze a manufacturing process interactively and in an immersive environment. The user will be able to give input in the form of manually keyed data on the browser and visualize the output as a three-dimensional model (environment). The project has been split into various modules and stages with each of these being done by a separate researcher. The project involves the following steps:

• Creation of a Web interface for the integration of the various modules
• Creating modules for the various manufacturing processes
• Converting the existing package like STREAM for shaped die design and SHEAR for shear die design to adapt to the Web
• Creating a module to view the output as a 3D model on the Web browser
• Creating an interface for the headgear and Data Glove to simulate an immersive environment.

1.4 Virtual Reality

Virtual Reality is a computer-generated interactive three-dimensional environment to simulate reality. Virtual Reality can take us into an imaginary world that appears remarkably similar to our own. To design a virtual reality system, one deals with concepts of spatial relationships and computer graphics which in turn are related to math, physics, art, and also human psychology. In the virtual or synthetic environments, one must take into account the laws of physics, like gravity, air resistance, and speed. To create and render models, one has to use mathematics and graphical concepts. The efforts made to create visualization media of complex data have already been the interest of researchers for several years. Virtual Reality has practically revolutionized the way one interprets certain complex data. Virtual Reality on the Web can be made possible by the use of tools like VRML (Virtual Reality Modeling Language). VRML is a language by itself and is governed by a specific syntax.
1.5 Java and CGI

Java and CGI are technologies that can be used to create an application that would reside on the Internet. Java is an Object Oriented Programming (OOP) language that can be used to create small applications called applets that reside on the Web and add functionality to the application. Java is similar to C++ in structure and syntax. The language was created by SUN systems, but as of this date there are many Java authoring tools, like Microsoft Visual J++ and Symantec Visual Café, etc. Java is one technology that has not been exploited to the maximum extent. Industry experts predict that it would probably be the only technology that would functionally surpass the hype it has created for itself [5].

CGI or Common Gateway Interface is a program written in C, C++, or PERL that can take in data from a remote user and processes the same before sending the results back to the user’s browser. It is a powerful tool that can be used for data exchange and manipulation on the Internet. The programs created in CGI must reside in a special directory called “cgi-bin” in order to obtain functionality. CGI code created for this thesis has been done using C language. The CGI code is responsible for most of the functions, including Data Input, Data Processing, Data Output, and also the VRML output that creates the virtual immersive environment.
1.6 Objective of the Thesis

The main objective of this thesis is to create a software package for the Internet that would let users around the world use the quality software available at Ohio University. The project as a whole would also involve the creation of new software to cover a few areas of manufacturing, like extrusion, rolling, forging, and drawing. This thesis focuses on the same aspects as the project, namely:

- Creation of a Web interface to bring together all the modules
- Creation of a package to design shaped dies for extrusion process
- Creation of a package to design shear dies for extrusion process
- Addition of a feeder plate module
- Addition of a drafting tool.

The creation of the package for the design of streamlined dies would involve the following steps:

- Creation of an interface for data acquisition from the user on the Web browser
- Sending the data provided by the user from his desktop to the program location
- Executing the program to output the result to files
- Output of the numerical data to the user’s computer
- Output of the 3D graphical data as a Virtual Reality Screen on the user's Desktop
• Converting the existing die design FORTRAN code to C to enable usage on the Web.

The tools used for accomplishing the above mentioned tasks are given below:

• HTML (Hyper Text Markup Language)
• CGI in C (Common Gateway Interface in C Language)
• JAVA (a programming language)
• VRML (Virtual Reality Modeling Language).
Virtual Manufacturing is the use of a desktop virtual reality system for the computer-aided design of components and processes for manufacture [4]. It offers unrivalled scope for creating and viewing three-dimensional engineering models, later to be passed to numerically-controlled machines for real manufacturing.

The University of Bath [21] team is working on the virtual manufacturing project. The team believes that the technique is destined to become part of the next generation of CAD products and to be in routine use wherever quality manufacturing is to be found. The group has set up a system in a real engineering workshop so that one can see the full process in action. The computer and industrial-scale numerically controlled machines work together first to produce virtual components and then real components from metal blanks.

The computer system presents the user with a view of a virtual workshop complete with milling machine, choice of tools, a robot, and other items. This view is a fully-textured three-dimensional scene and may optionally be seen in stereo by wearing a special pair of spectacles. The spectacles have no physical connection to the computer so do not restrict movement. In addition, they allow the user to see the real world as well as the computer-generated world.
The Virtual Reality and Computer-Integrated Manufacturing Lab in the School of Mechanical and Materials Engineering at Washington State University [22] has been working on Virtual Manufacturing in the following areas:

- Three-dimensional calibration for virtual environments
- Assembly path planning using VR techniques
- Virtual assembly design environment
- Knowledge-based systems
- Virtual environments for ergonomic design
- Telerobotics.

ISR is a permanent institute of the University of Maryland [23] located within the A. James Clark School of Engineering. It is a National Science Foundation Engineering Research Center. The research team is working on the following topics:

- A simple virtual manufacturing tool ACIS to STEP file translator
- IMACS (Interactive Manufacturability Analysis and Critiquing System)
- OSPAM (Optimal Selection of Partners in Agile Manufacturing)
- Virtual factories.

The Manufacturing Engineering Laboratory (MEL)[24] at the National Institute of Standards and Technology serves as a central research laboratory for manufacturing infrastructure technology, measurements, and standards. They provide industry-needed manufacturing engineering tools, interface standards, manufacturing systems architectures, and traceability. For example, the industrial measurements of length, force,
mass, acoustics, vibration, and product data exchange ultimately rely on traceability to MEL.

To help manufacturers keep a lead in this race, MEL inaugurated a state-of-the art National Advanced Manufacturing Testbed (NAMT). Using the NAMT, research partners and NIST remotely access and share information, demonstrate manufacturing feasibility, and evaluate prototype standards. The NAMT provides the means to conduct distributed and virtual manufacturing research in advanced metrology, control, and interoperability technology. The results will create a new information technology-based manufacturing model.

Mitsubishi's researchers [25] use the CRAY J932se system to develop virtual manufacturing environments and study total effective manufacturing processes. The CRAY J932se supercomputer, which is the largest CRAY J90(TM) series system in Japan, is installed at Mitsubishi's Advanced Technology R&D Center at Amagasaki Works in the Hyogo prefecture.

Mitsubishi is one of the leaders in advanced virtual manufacturing research and the experts at the concern are confident that the vector-based processing power of the Cray(R) supercomputer combined with advanced visualization workstations from Silicon Graphics will help the company maintain its proven record of innovation.

These projects are still in the starting stages and currently there is still no package on the Web that would allow a user to interactively make a process plan or design a manufacturing system. Though the idea has been toyed with by various people, it has
been restricted to a single user environment on the desktop a single computer. Extensive search on the World Wide Web itself reveals that there is no program available on the Internet as yet. The search also reveals that work has been done on the creation of immersive Virtual Reality worlds available on the Internet, not for any practical application but only for visualization.

As such, one can conclude that there is no benchmark for creating an application for the Internet. The creation of this kind of a package is the focus of this thesis and is the first of its kind to open doors and set an example for many more that will appear later.
Chapter 3
EXTRUSION

3.1 History of Extrusion

Extrusion has an industrial history stretching back more than 160 years [6]. In the past 20 years, its economic importance has increased, primarily as a result of technological advances that have drawn on extensive practical experience and on numerous fundamental investigations into the extrusion process, tooling, and metal flow.

The development of the extrusion press from the first dimple lead press to the modern automatic extrusion plant represents a chapter in the history of metalworking. Several important dates mark the path to the versatile process used today for both nonferrous metals and steel [6]. A brief summary is given below:

1797: The first lead press was designed by S. Bramah (England).

1820: Thomas Burn (England) built the first hydraulic press for lead pipes [6]. This press contained the basic components of a modern tube press: container, changeable die, stems with attached dummy block, and a moving mandrel screwed to the stem.

1837: Introduction of a bridge die with a replaceable bridge and mandrel (J. and C. Hanson).

1840: W. Armstrong built the first hydraulic accumulator.

1867: First gas-heated two-part container (Hammon).

1870: Construction of an indirect lead press (Haines and Werms).
1879: First cable sheathing press for lead in which the lead was extruded directly onto the cable (Borell).


1894: A decisive step forward: Alexander Dick built a horizontal extrusion press for the Deutsche Delta Metallgesellschaft in Dusseldrof. This allowed high melting point alloys to be extruded for the first time. Special features of the press included a tilting container that was moved to the horizontal extrusion position. The oldest one designed, was initially of very low efficiency (25 to 30 extrusions in 10 hours). The one-piece container was another source of problem.

1896: Container constructed of several steel cylinders with a mixture of powdered graphite and borac between them (Nursery).


1917: Steel extruded for the first time in a 20 MN presses for the manufacture of steel clips.

1918: Twenty-four years after Dick’s patent, over 200 extrusion presses had been built.

1921: First experimental results on indirect extrusion published by R. Genders.

1925: Intensive research into flow patterns by Schweiguth Plankensteiner, Doernickel, Trockels, Hanser, Sachs and Siebel, which initiated new developments in press design, especially in tooling technology.

1927: First attempts to produce steel tubes in a Singer mechanical press.
1933: Mechanical tube press built by Mannesmann in Witten according to a patent by Singer for 12 MN capacity.

1927: Moving container and electric container heating.

1943: DEMAG-Hydraulic and Schloemann-SIEMAG built the first large-scale press installation with a capacity of 125 MN.

1945: Improvements in horizontal and vertical extrusion presses and auxiliary equipment, short-stroke presses, revolving presses, and compact presses. Extensive improvement of all moving parts; for example, horizontal die slide and rotating die holders to simplify die changing, internal pierce, and mandrel movement; automation of control systems; oil hydraulic drive, especially for aluminum extrusion.

1955: Development of techniques for extruding, steel and unusual metals including titanium, beryllium, zirconium, and uranium. Hydrostatic extrusion opened new possibilities for working difficult metals and alloys. Advances in tooling technology allowed complex hollow sections to be produced in aluminum. Automation of production with presses controlled by punch cards.

3.2 Definition of Extrusion

Extrusion can be defined as the process of subjecting a material to compression so that it is forced to flow through a confined space past a suitable opening called the die. The metal is forced through the die and the crosssection of the die determines the shape properties of the resulting product. Extrusion may be done either on cold metal or on
heated metal. One of the analogies that can be offered to the process of extrusion is that of squeezing a tube of toothpaste. The metal billet is placed in the billet chamber and is forced by the ram through a die. The stress condition of the material is a triaxial one [7].

Hot extrusion is done to eliminate the cold working effects, reduce the force required, and reduce directional properties. Lead, brass, bronze, copper, aluminum, and some of the magnesium alloys are the most commonly extruded metals. Steel is not easily extrudable due to the following reasons:

- High yield strength
- Tendency to weld to the walls of the die chamber
- Requirement for heating to high temperatures like 2300 F
- Very high pressure required to deform steel plastically.

Good quality steel extrusions can be obtained by lubricating the surfaces of the billet chamber with materials such as phosphate salts or glass.

3.3 Dimensions and Shapes of Extrusions

Almost any shape can be extruded from non-ferrous metals. The intricacy in shape is limited only for material like steel. Non-ferrous metals are only slightly restricted in size. Extrusion of any shape that can be inscribed in a circle of thirty inches for non-ferrous materials and five inches for steel are possible. Theoretically, there is no limitation to the length of an extrusion. Extrusions can go to a length of one hundred feet.
The process of extrusion can create many shapes, such as those containing re-entrant angles and hollow sections that cannot be done in rolling.

Due to the comparatively low cost of extrusion dies (<$300) and the fact that the press required can be setup within a matter of minutes, it is possible to obtain small quantities of desired shape by extrusion more economically than by rolling.

### 3.4 Dimensional Tolerances

The dimensional tolerances of the process of extrusion are very good. For most shapes the tolerance of about ± 0.003 inch/inch is easily attainable. While products of extrusion possess a more uniform dense grain structure than other hot worked metals, they have rather marked directional properties. The usual lengths of extrusions go up to fifty feet. However, lengths of one hundred feet are attainable. The tolerances of the product depend mainly on the following factors:

- Material being extruded
- Temperature
- Error in straightness.

It is observed that maintaining a uniform crosssection over a large length is a big challenge for the extrusion industry.
3.5 Methods of Extrusion

Extrusion of metals can be classified under the following methods:

- Direct extrusion
- Indirect extrusion
- Impact extrusion.

3.5.1 Direct extrusion

Direct extrusion is a process where the flow of material through the die is in the direction of the movement of the ram that is used to force the material. Here the billet is moved forward relative to the wall of the container, thereby giving rise to high resistance from friction. Figure 3.1 illustrates the process of direct extrusion.

Figure 3.1: Direct extrusion
3.5.2 Indirect extrusion

Indirect extrusion is a process where the flow of the material through the die is in a direction opposite to the movement of the ram that is forcing the material to deform. Here there is no relative motion between the container and the billet and, therefore, the frictional force is minimal. Figure 3.2 illustrates the setup of an indirect extrusion process.

![Indirect Extrusion Diagram]

Figure 3.2: Indirect extrusion

3.5.3 Impact extrusion

Impact extrusion is a process where a single blow from the ram on the material causes the metal billet to be extruded between the die and the punch. This process is usually done cold and on low strength ductile materials such as lead, tin and aluminum. It is used to make collapsible tubes for toothpaste, shaving creme, and cans that are used to pack food. Figure 3.3 illustrates the impact extrusion procedure.
3.5.4 Extrusion of hollow shapes

Extrusion of hollow shapes is a modification of the regular type of extrusion. In the case of extrusion for hollow shapes, the equipment consists of a punch or a mandrel that pierces the metal to create the required cavity or hole. The cost of the equipment is comparatively higher in the case of extrusion of hollow shapes because of additional mandrel or punch. Figure 3.4 gives an illustration of the setup.

![Hollow Extrusion](image_url)

**Figure 3.3:** Impact extrusion

**Figure 3.4:** Hollow extrusion
3.6 Stress Analysis

Let us consider a metal particle that moves along a curved path during the extrusion process. Let \( D \) be the diameter of the billet and \( d \) the diameter of the extruded product. It is seen from the material flow that the particles at one crosssection on the billet will end up at different positions from the center on the extruded product. The surface metal flows slower than the metal at the center of the billet. Principal stresses will be initially equal but change once the particle starts flowing to the plastic zone. The stress component \( P_z \) will slowly become zero at the orifice. The analysis is very complex and, therefore, only a simplified analysis is presented below:

\[
W_{\text{ext}} = W_{\text{int}} = L \times l_0 = P_{av} \frac{D^2 \pi l_0}{4}
\]

\( W_{\text{ext}} \) = total extension work.

The internal work is due to the plastic deformation of the metal. If shear and friction are neglected, then the total energy required will be given as the specific deformation energy multiplied by the volume of metal deformed in transforming an element of the billet to a corresponding element in the bar. The strain in the \( Z \) direction can be written as

\[
E_z = \ln \left( \frac{L}{l_0} \right) = 2 \ln \left( \frac{D}{d} \right)
\]

Integrating for \( W_{\text{int}} \) required we get

\[
W_{\text{int}} = D^2 \pi l_0 \int \sigma_z \, d\varepsilon_z
\]

By equating this integral to the external energy under assumption of no losses we get average pressure
\[ P_{av} = i \sigma_z \, dz \]

It has been seen through analysis of extrusion systems that the actual internal energy is about fifty percent more than that assumed by the above equation. Therefore,

\[ P_{av} = 1.5 I \, \sigma \, d\varepsilon \]

The ratio of \( D^2/d^2 \) or \( A/a \) is called the extrusion ratio and determines the extent of uniform deformation. If the stress strain curve is given by the equation

\[ \sigma = E \varepsilon^m \]

then average pressure can be written as

\[ P_{av} = 1.5c/m+1 \varepsilon^{m+1} = 1.5c \, 2\ln(D/d)^{m+1}/m+1 \]

### 3.7 Effects of Friction

In case the wall friction is considered average, extrusion pressure can be calculated as

\[ P_{av} = P_{av} (1+4\mu z/D) \]

where \( z \) = billet length at any instant of the extrusion.

### 3.8 Types of Dies

- Solid shape
- Porthole
- Bridge
- Baffle or feeder plate
3.9 Considerations in Die Design

- Desired shape of the product
- Material
- Billet size
- Process capacity
- Extrusion ratio
- Number of die cavities
- Shrink factor
- Process tool
- Extrusion temperature
- Extrusion pressure
- Die material
- Heat treatment of die material

3.10 Types of Equipment Used

The classification of equipment on the basis of the type of force used to drive the ram is as follows:

- **Hydraulic press**: The force required to deform the metal plastically is done by hydraulic means.

- **Mechanical press**: The force required to deform the metal plastically is provided by mechanical means.
3.11 Advantages of Extrusion

- Uniform cross-sectional area over a long length.
- Low cost of dies making it economical to make small quantities of a shape.
- Good surface finish.

3.12 Limitations of Extrusion

- Most materials require high temperature and pressure, which makes the equipment costly.
- Die material should be able to withstand the load, high temperature, and wear.
- In the case of steel, the equipment is costlier due to the magnitude of temperature to which the metal must be heated. (2300 F).
- Indirect extrusion complicates the handling of the extruded parts.
- Extrusion is limited to only a few metals and cannot be done on any metal chosen.

3.13 Applications of Extrusion

- Helicopter blades
- Turbine blades
- Wing spans
- Columns used for creating structures
- Construction material.
Chapter 4

STREAM and SHEAR

4.1 Introduction to STREAM

STREAM, a software package for die design developed by Gunasekera [8] and modified by Mehta [9], is of great help in the design of extrusion dies. It offers eight types of predefined die shapes from which to choose. The limitation of this software package is that it is for the DOS system and the output is not compatible with any of the FEA software available. An improvement made to this software by Gosavi [10] has made it Windows compatible. The STREAM software can design the following die profiles:

- Straight converging die
- Convex extrusion type
- Concave extrusion type
- Parabolic
- Cubic streamlined
- Part conical and part streamlined
- Conical strain rate.

The STREAM package is designed to create the internal contour of a die given the output product geometry in the form of nodal data. It uses a mapping technique based on the Stoke’s theorem for the design of complex re-entry product sections. Mapping sections of the billet to corresponding sections of the product on a proportional area basis creates die design. The slab method is used to mathematically analyze the extrusion
process in order to determine the stresses on the workpiece and the forces involved. A
default cylindrical input billet is considered, and the mapping is done to generate the die
profile. There is no feature in the package where one can interactively view the die
contour. The output of the package was available in two formats listed below:

- AutoCAD drawing File
- Patran Sessions file.

The limitations of this software are listed below:

- The program is not user friendly.
- The code is in FORTRAN, which is outdated.
- The program cannot be put on the Web due to the above reason.

Force calculations are done using the slab method [11]. The slab method
comprises force balance on a thin slab (representative volume of the material) or section
of the deforming metal and yields fairly accurate solution to the problem. The concept
considers the metal flow through the die as numerous sections or slabs. Force balance of
each of these slabs would determine the stress. If the effect of back tension were taken
into consideration, the stresses would add up cumulatively towards exit section of the die
where the value of the stress obtained would be the value of the total extrusion force.

Siebel and Von Karnan first developed the Slab Method in 1924 and 1925 in
connection with rolling process. Sachs [12] was the first to investigate the slab method
for the drawing process.
The slab method predicts a load that is at least equal to or lower than the exact load needed to cause plastic flow. It entails a force balance on a slab of metal of differential thickness and is, hence, also called the free body equilibrium approach. The slab method is based on certain basic assumptions:

- The principal stresses do not vary on the planes perpendicular to the direction of the applied load.
- Although the effects of surface friction are included in the force balance, these do not influence the internal distortion of the metal or the orientation of the principal directions.
- Plane sections remain plane; thus the deformation is homogeneous in regard to the determination of induced strain.

In case of metal forming problems to obtain the actual forming loads, Thomsen [13] has suggested a factor of 1.5 to be multiplied to the loads predicted by the slab method.

4.2 Introduction to SHEAR

SHEAR is a program written in FORTRAN for the design of the shear dies for the extrusion process. The program takes input in the form of material and machine data and also the nodal data of the product geometry. The output is in the form of parameters that are essential for the design of extrusion processes using shear dies. The shear program
also gives the output of the number of product pieces that can be manufactured on the
machine with a set die diameter. It also provides the information on Dieland Required.

4.3 Conversion of PcSTREAM and SHEAR to C

PcSTREAM and SHEAR, which are still in FORTRAN, have become very complex and outdated. Moreover the functionality of this code on the Web is minimal, as FORTRAN code cannot be modified to interface as a CGI on the Internet. Therefore, the code had to be converted to C in order to use the specialties of this software on the Web. The conversion of the code to C language had to be done manually because of unavailability of FORTRAN to C converters. The conversion of code to C and embedding it as CGI was one of the major tasks.

Some of the aspects that had to be kept in mind during conversion of the code from FORTRAN to C are as follows:

- Removal of all interactive input and output statements
- Modifying the program to read the input from and write the output to a file
- Embedding HTML to display output on the Web browser
- Combining all the different FORTRAN programs to one C program
- To remove redundancy of statements by addition of a few statements
- Removal of “goto” statements to the best possible extent.
4.4 Web Setup and Design

A manipulation of all the tools and languages helps in the development of software packages on the Web. The basic interface, help screens, and Data acquisition forms are developed using HTML. The data transfer and processing at the location of the program is done by CGI written in C language. The output of numerical data is also done by CGI written in C. The graphical data is output as a VRML model on the users desktop, and this too is achieved through programs in C language. The drafting tool has been created in Java. The pop-up help screens have been created in JavaScript [5].

The creation of an application that would be accessible on a Web browser from any computer desktop around the world has its own challenges. One of the most important tasks in hand was to study, learn, and review all the available tools for programming on the Internet. After going through various tools it was decided to use the following tools to achieve the purpose of this thesis:

- Microsoft Visual J++
- Cosmo Create from SGI
- HTML for creating the Web interface
- HTML forms for input modules
- CGI using C for data transfer, data processing, and data output
- VRML for the creation of a virtual reality environment.
Regular input and output statements in C or Java cannot be used in the environment under consideration. Among the major requirements were

- Method of taking input from the remote user
- Writing the input data from the user to a data file
- Processing the data provided by the user
- Creating 3D VRML models from the results
- Putting the results on to the user screen.

To work around this problem, a HTML [14] form consisting of Textboxes, Select Menus, and Buttons was created which would act as the interface to collect data from the user. This could then be written to a data file on the server by a C program encoded with CGI statements.

The Core STREAM program or the core SHEAR program written in C would then read the data from the data file written previously, process the same, and write the output to various result files on the server. The file that consists of numerical statistics of the die geometry would be output on the users’ screen in the form of numerical data. Another C program embedded with CGI [15] would read the file that consists of the coordinates of the die geometry. This program would be output to a 3D VRML [16] model, which the user could interactively move and observe for a closer look at the die contour. Figure 4.1 illustrates the flowchart approach followed.
Figure 4.1: Flowchart for approach used
Case based output of results for the specific input can be done through scripting in CGI or in Java. Due to File I/O limitations in Java, CGI was chosen to do the job of displaying both numerical and graphical results on the users internet browser. To create an immersive environment for the user, VRML has been used for the graphical output.

The CGI program responsible for the creation of the 3D VRML model on the browser is a simple C program that reads coordinate data output by the core program and outputs VRML [17] syntax based on those coordinates so that the die contour appears as a visual 3D model. The programs responsible for output of stress, strain, and strainrate contour read an additional file with the requisite data of these parameters and create a color code for each section on the die contour.

The parameter values for various sections are read from a file and are divided by the maximum value of that parameter and scaled to a value of three. The values of the parameters now lie between zero and three. Based on this value, the Red, Green, and Blue (RGB) values for the section are set and the points on that section are displayed using the color.
Chapter 5

RESULTS

5.1 Achievements

The research has been successful in implementing the following objectives that had been set forth before commencement:

- Web based design
- Conversion of Stream to WebStream
- Conversion of Shear to WebShear
- Addition of feeder plate module to Shear
- Addition of drafting tool
- Post-processing results
- Die contour
- Stress, strain and strain rate contours
- File downloads.

The Web-based design has helped in making the package platform independent and browser independent. It provides easy worldwide access to anyone following the authentication norms.

Creation of WebStream and WebShear is complete, and the two packages have been totally implemented. The conversion of these packages from the original FORTRAN to base to a CGI script was a major challenge due to the length of the code.
The original FORTRAN code is outdated and cannot be used for implementation on the World Wide Web.

The feeder plate module added to WebShear helps the user in the design of a feeder plate. The module is based on creating a shaped die for the same product crosssection and dividing it into various sections along the length. The crosssectional areas of each of these sections and the percentage reduction with respect to the billet are calculated. The coordinates of the section at which the ratio of reduction is around 9:1 is considered for the feeder plate. The feeder plate module uses a special technique to calculate the crosssectional area at each section. The feeder plate is required in cases where the ratio of reduction from the billet to the final product is very large. The feeder plates appear as an intermediate die, thereby extruding in two stages.

A drafting tool has been added to the WebStream package to aid the user in drawing the product geometry. The tool outputs the nodal data of the product geometry that can then be entered in the WebStream nodal data form. The drafting tool has been created in Microsoft J++. It is a stand-alone Java Applet that appears as a pop-up screen when the user is going through the WebStream data input.

The post-processing modules have been written in C and have been designed to output the numerical results from the packages as 3D VRML worlds. The die, stress, strain, and the strainrate contours appear in the 3D format and provide the user with the capability to interact immersively and zoom, pan, and rotate the same.
5.2 WebShear Run

A sample run of WebShear has been illustrated below. Figure 5.1 displays a form wherein the type of geometry, machine, and the material can be chosen from the existing library. Figure 5.2 displays the numerical results.

![Figure 5.1: Shear input form](image-url)
Figure 5.2: Shear numerical results

Figure 5.3 displays the feeder plate crosssection and Figure 5.4 displays the shear die crosssection obtained from the WebShear program.
The results obtained from WebShear were downloaded and rendered in EMS using a programme written in Parametric Programming Language (PPL) for EMS. This language is very similar to C with embedded EMS commands. The following are some of the results obtained on EMS. Figure 5.5 shows the product and envelope geometry. Figure 5.6 shows the feeder plate and shear die (wireframe), and Figure 5.7 shows the feeder plate and shear die (3D Solid).
Figure 5.5: Product and envelope geometry

Figure 5.6: Feeder and shear die wireframe
5.3 WebStream Run

A sample run of WebStream was conducted to study the results obtained. Table 5.1 gives the material properties considered for the run.

<table>
<thead>
<tr>
<th>Table 5.1: Material Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Factor:</td>
</tr>
<tr>
<td>Yield Stress:</td>
</tr>
<tr>
<td>Strain Rate Factor:</td>
</tr>
<tr>
<td>Strain Rate Sensitivity Factor:</td>
</tr>
<tr>
<td>Activation Energy</td>
</tr>
</tbody>
</table>
Table 5.2 summarizes the other input parameters considered for the run which were as follows:

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billet Diameter</td>
<td>6 INCHES</td>
</tr>
<tr>
<td>Crossection of Product</td>
<td>NON CIRCULAR</td>
</tr>
<tr>
<td>Die Surface Definition</td>
<td>CUBIC STREAMLINED</td>
</tr>
<tr>
<td>Length of the Die</td>
<td>6 INCHES</td>
</tr>
<tr>
<td>Number of Sections for Analysis Across Die Length</td>
<td>15</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>14</td>
</tr>
</tbody>
</table>

Figure 5.8 illustrates the product geometry that has been considered for the sample run. The figure is that of a “H” section which must be extruded from a circular billet.

![H section diagram]

**Figure 5.8**: H section (crossection of the product)
The results obtained from the Webstream package are shown below. Figure 5.9 shows the internal die contour, figure 5.10 shows the stress contour for the die, figure 5.11 shows the strain contour for the die, and figure 5.12 illustrates the strain rate contour for the die. Figure 5.13 shows the shaped die obtained from rendering the coordinates obtained from WebStream in EMS using the program written in PPL. The program takes the electrode coordinates and creates a solid which is then subtracted from a cylinder of larger diameter to obtain the die itself.

**Figure 5.9**: Internal die contour
**Figure 5.10**: Stress contour of the die

**Figure 5.11**: Strain contour of the die
Figure 5.12: Strain rate contour of the die

Figure 5.13: Shaped die rendered on EMS
Chapter 6

CONCLUSIONS and RECOMMENDATIONS

6.1 Conclusions

The Stream and the Shear packages developed at the Russ College of Engineering and Technology at Ohio University are very elaborate packages that have been created on FORTRAN over the years. These packages do a very good job with the calculation of the die profile and other such data required for the manufacture of products using extrusion.

This thesis has been successful in converting the existing FORTRAN code to C language and implementing it on the World Wide Web for access all over the world with a Web browser. The thesis has been helpful in removing the redundancy in the existing software and modifying it to meet today's standards. The implementation on the Web has been successful and has been well received by users. The package developed under the scope of this thesis is a small part of a huge virtual manufacturing project and has been the first big step towards a full-blown Web-based virtual manufacturing package.

The implementation of the package is an intelligent combination of various tools like HTML, JavaScript, CGI and many other Web tools to bring together the great ability of packages like Stream and Shear with fast information transfer and easy accessibility on the World Wide Web. The user would be able to view the profile or download the result files to his computer from the result page provided on the package. The package provides
the capability of moving back-and-forth and observing the results after changing a small portion or the whole of the input data.

The visualization of the results, such as the die contour, stress contour, strain contour, and the strain rate contour, are now available as 3D interactive VRML models rather than the old 2D representations which were tough to analyze and understand for a first-time user. The visualization of 3D models for the stress, strain, and strainrate contours is a totally new addition to the software, and the implementation has been successful.

The addition of the feeder plate design module to the Shear program on the Web allows the user to design feeder plates for the product in cases where the reduction from the billet to the product using just a shear die is too large. The feeder plate design module is a totally new addition to the existing program.

The output of the Web packages created is in the form of 3D VRML models which provide a better understanding of a profile to the user than a 2D Drawing in AutoCAD or any other package.

The WebStream and the WebShear packages are among the first applications created for the Web. Therefore, there is a great deal of improvement that could be implemented with advancements in technology and software.
6.2 Recommendations

This thesis is part of a very huge project called virtual manufacturing. The project as a whole would provide an expert system that will be able to define a process of manufacturing that should be followed for production based on the product geometry input. The system in its full-blown version will cover all the manufacturing areas. The Internet forms a very broad platform and provides easy access to users all over the world. In order for the expert system to work efficiently, the next step should be to incorporate other processes, such as drawing and rolling.

The existing facility is for the designs of shaped and shear dies for extrusion only. The system should also concentrate on other aspects of the extrusion process. The incorporation of drafting tools to the package could help the user input the geometry graphically rather than with numerical node data.

In developing the algorithm for displaying the stress, strain, and the strainrate contours as 3D models under VRML, only the red, green, and blue regions of the spectrum have been exploited. It is recommended that a combination of the same should be used to get more shades to represent the levels of the respective parameters to better illustrate the results.
REFERENCES


20. URL: http://www.bath.ac.uk/~ensrit/vman.html.


22. URL: http://www.isr.umd.edu/Labs/CIM/vm/.


APPENDICES

Appendix A: Listing of HTML form used to collect data

<HTML>
<HEAD>
<TITLE>Data Input Module</TITLE>
<SCRIPT LANGUAGE = "JavaScript">
<! --
WinOpt="TOOLBAR=NO,LOCATION=NO,DIRECTORIES=NO,STATUS=NO,MEN
UBAR=NO,SCROLLBARS=NO,RESIZABLE=NO,COPYHISTORY=YES,WIDTH=400,HEIGHT=425"
var win;

win = window.open("http://Webme.ent.ohiou.edu/vm/mmform.html", "w", winOpt);

function chunits()
{
if(document.dimdat.UNITX.selectedIndex==0)
win=window.open("http://Webme.ent.ohiou.edu/vm/mmform.html","w",winOpt);
if(document.dimdat.UNITX.selectedIndex==1)
win=window.open("http://Webme.ent.ohiou.edu/vm/mmform.html","w",winOpt);
if(document.dimdat.UNITX.selectedIndex==2)
win=window.open("http://Webme.ent.ohiou.edu/vm/mmform.html","w",winOpt);
}
//-->
</SCRIPT>
</HEAD>

<BODY ALINK="green" VLINK="red" LINK="blue" BGColor=white TEXT=black>
<P>
<P>
<IMG SRC="gifs/dimodule.gif">
<HR>
<P>
<CENTER>

<form NAME = "dimdat" METHOD=POST ACTION = "http://www.ent.ohiou.edu/cgi-bin/me/getdimdat" >

</form>
"
<table>
<thead>
<tr>
<th><strong>Number of Sections Along The Die Length</strong></th>
<th>&lt;input type=&quot;text&quot; name=&quot;NUMBER_OF_SECTIONS&quot; size=&quot;4&quot;&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of The Die</strong></td>
<td>&lt;input type=&quot;text&quot; name=&quot;LENGTH_OF_DIE&quot; size=&quot;4&quot;&gt;</td>
</tr>
<tr>
<td><strong>Diameter of The Billet</strong></td>
<td>&lt;input type=&quot;text&quot; name=&quot;DIAMETER_OF_BILLET&quot; size=&quot;4&quot;&gt;</td>
</tr>
<tr>
<td><strong>Number of Nodes</strong></td>
<td>&lt;input type=&quot;text&quot; name=&quot;NUMBER_OF_NODES&quot; size=&quot;4&quot;&gt;</td>
</tr>
</tbody>
</table>

**Die Surface Definition**
- Straight Converging Die
- Cubic Streamline Die
- Convex - Extrusion Type
- Concave - Drawing Type
- Parabolic
- Third Order Area Basis Streamline
- Conical / Streamlined

**Units**
- Meters
- Modified Imperial Units
- Modified S I Units
<TR>
<TD ALIGN=RIGHT> <B>Input Type</B></TD>
<TD>
<SELECT NAME="input">
<Option SELECTED VALUE="msn">Manual Input
<Option VALUE="dfile">Data File Input
<Option VALUE="draw">Drawing Input
</SELECT>
</TD>
</TR>
</TABLE>
<P ALIGN="RIGHT">
<INPUT TYPE="RESET" NAME="clear" VALUE="Clear All Data"></P>
<P ALIGN="RIGHT">
<INPUT TYPE="SUBMIT" NAME="run" VALUE="Save Data" onclick="win.close()"></P>
</FORM>
</CENTER>
<HR>
</BODY>
</HTML>
Appendix B: Listing of CGI program to collect data and store it as a file

```c
#include <stdio.h>
#include <string.h>
#include <stdlib.h>

/** Convert a two-char hex string into the char it represents **/

char x2c(char *what) {
    register char digit;
    digit = (what[0]>='A' ? ((what[0] & 0xdf) - 'A')+10 : (what[0] - '0'));
    digit *= 16;
    return(digit);
}

/** Reduce any %xx escape sequences to the characters they represent **/

void unescape_url(char *url) {
    register int i,j;
    for(i=0,j=0; url[j]; ++i,++j) {
        if((url[i] = url[j]) == '%' ) {
            url[i] = x2c(&url[j+1]) ;
            j+= 2 ;
        }
    }
    url[i] = '\0' ;
}

/** Read the CGI input and place all name/val pairs into list. **/
/** Returns list containing name1, value1, name2, value2, ... , NULL **/

char **getcgivars() {
    register int i ;
    char *request_method ;
    int content_length ;
    char *cgiinput ;
    char **cgivars ;
```
char **pairlist;
int paircount;
char *nvpair;
char *eqpos;

/** Depending on the request method, read all CGI input into cgiinput **/
/** (really should produce HTML error messages, instead of exit()ing) **/

request_method= getenviron("REQUEST_METHOD");
if (!strcmp(request_method, "GET")) {
    cgiinput = strdup(getenv("QUERY_STRING"));
}
else if (!strcmp(request_method, "POST")) {
    /* strcasecmp() is not supported in Windows-- use strcmpi() instead */
    if (strcasecmp(getenv("CONTENT_TYPE"), "application/x-www-form-urlencoded")) {
        printf("getcgivars(): Unsupported Content-Type.
M)
        exit(1);
    }
    if (!content_length = atoi(getenv("CONTENT_LENGTH"))) {
        printf("getcgivars(): No Content-Length was sent with the POST request.
U)
        exit(1);
    }
    if ( !cgiinput = (char *) malloc(content_length+1)) {
        printf("getcgivars(): Could not malloc for cgiinput.
"
        exit(1);
    }
    if (!fread(cgiinput, content_length, 1, stdin)) {
        printf("Couldn't read CGI input from STDOUT.
fl)
        exit(1);
    }
    cgiinput[content_length]=\0' ;
}
else {
    printf("getcgivars(): unsupported REQUEST_METHOD\n") ;
    exit(1);
}

/** Change all plusses back to spaces **/

for(i=0; cgiinput[i]; i++) if(cgiinput[i] == '+') cgiinput[i] = ' ';
/** First, split on "&" to extract the name-value pairs into pairlist **/

pairlist = (char **) malloc(256 * sizeof(char **));
paircount = 0;
nvpair = strtok(cgiinput, "&") ;
while (nvpair) {
    pairlist[paircount++] = strdup(nvpair);
    if (! (paircount % 256))
        pairlist = (char **) realloc(pairlist, (paircount + 256) * sizeof(char **));
    nvpair = strtok(NULL, "&") ;
}
pairlist[paircount] = 0; /* terminate the list with NULL */

/** Then, from the list of pairs, extract the names and values **/

cgivars = (char **) malloc((paircount * 2 + 1) * sizeof(char **));
for (i = 0; i < paircount; i++) {
    if (eqpos = strchr(pairlist[i], '=')) {
        *eqpos = '\0' ;
        unescape_url(cgivars[i*2+1] = strdup(eqpos+1)) ;
    } else {
        unescape_url(cgivars[i*2+1] = strdup("")) ;
    }
    unescape_url(cgivars[i*2] = strdup(pairlist[i])) ;
}
cgivars[paircount*2] = 0; /* terminate the list with NULL */

/** Free anything that needs to be freed **/

free(cgiinput) ;
for (i = 0; pairlist[i]; i++) free(pairlist[i]) ;
free(pairlist) ;

/** Return the list of name-value strings **/

return cgivars ;

}
void main() {
    char **cgivars;
    int i, numno = 0;
    FILE *f;

    f = fopen("temp/pcsdata.dat","w");

    /** First, get the CGI variables into a list of strings **/
    cgivars = getcgivars();

    /** Print the CGI response header, required for all HTML output. **/
    /** Note the extra \n, to send the blank line. **/
    printf("Content-type: text/html\n\n");

    /** Finally, print out the complete HTML response page. **/
    printf("<html>");
    printf("<head><title>Web Stream Input Check </title></head>\n");
    printf("<body bgcolor=black text=silver link=blue alink=green vlink=red>\n");
    printf("<IMG SRC="http://Webme.ent.ohiou.edu/stream/gifs/pceuin.gif">\n");
    printf("<p><IMG SRC="http://Webme.ent.ohiou.edu/stream/gifs/modocont.gif">\n");
    printf("<HR>");
    printf("<ul>");

    /** Print the CGI variables sent by the user. Note the list of **/
    /** variables alternates names and values, and ends in NULL. **/
    fprintf(f,"NONCIRCULAR\n");
    for (i = 0; cgivars[i]; i += 2) {
        printf("<li>[%s] = [%s]\n", cgivars[i], cgivars[i+1]);
        fprintf(f,"\%s\n", cgivars[i+1]);
        if(!strcmp(cgivars[i], "NUMBER_OF_NODES")) numno = atoi(cgivars[i+1]);
    }

    printf("</ul>\n");
    printf("</hr>");
    printf(" The number of nodes: %d\n", numno);
printf("<A Href="http://www.ent.ohiou.edu/cgi-bin/me/nodeform">"");
printf("<img SRC="http://Webme.ent.ohiou.edu/stream/gifs/continue.gif""");
printf("Align=right Border=0></A>");

printf("<A Href="http://Webme.ent.ohiou.edu/stream/dimform.html">"");
printf("<img SRC="http://Webme.ent.ohiou.edu/stream/gifs/back.gif""");
printf("Align=right Border=0></A>");

printf("</body>\n") ;
printf("</html>\n") ;

/** Free anything that needs to be freed **/ 

for (i=0; cgivars[i]; i++) free(cgivars[i]) ;
free(cgivars) ;
fclose(f);
exit(0) ;
Appendix C: Listing of CGI program used to output the die shapes in VRML

```c
#include<stdio.h>
#include<stdlib.h>

void main(void)
{
    FILE *f;
    int i=0,imax;
    float x[500],y[500],z[500];

    f=fopen("temp/diefig.dat","r");

    /** open “diefig.dat” and read the die coordinates **/
    while(fscanf(f, "%f%f%f", &x[i], &y[i], &z[i]) == 3)
    {
        i++;
    }
    imax=i;

    fclose(f);

    /** Print the VRML header **/
    printf("Content-type: x-world/x-vrml%c%c",10,10);
    printf("#VRML V1.0 ascii%c",10);
    printf("DEF Viewer Info { string "examiner" }");
    printf("Coordinate3 { point[");

    /** Output the coordinates read from a file and output it in a specific manner **/
    /** output the coordinates as point in space in virtual reality world **/
    for(i=0;i<imax;i++){
        if (i<imax-1) printf("%.3f %.3f %.3f",x[i],y[i],z[i]);
        else printf("%.3f %.3f %.3f",x[i],y[i],z[i]);
    } printf("] } PointSet{ startIndex 1 }");

    /** Create a Indexed Face Set of all the points in space **/
```
printf("IndexedFaceSet{ coordIndex[");
for(i=0;i<imax;i++)
    if (i<(imax-1)) printf("%d, ",i);
    else printf("%d}\",i);
}
Appendix D: Web Stream Users Manual

1. Start Netscape Navigator or Microsoft Internet Explorer from the Start menu.

2. Open Location http://Webme.ent.ohiou.edu/vm.
3. Enter the Login and Password for authentication.

4. The following introduction screen would appear. Click Continue.
5. Click on a requisite die design package (e.g., Stream).

6. Browse through the start and introduction screens by clicking Continue.
7. Click on the requisite choice (e.g., Extrusion).

Requirements

Netcape Navigator 3.0 & above or Microsoft Internet Explorer 3.0 & above

and

Cosmo VRML Plugin

8. Click on the die portion of the VRML model for die design module.
9. The following screen shows the types of dies that stream can handle.

Web Stream Can Design The Following Types Of Dies

- Straight Converging Dies
- Convex - Extrusion Type
- Concave Drawing Type
- Parabolic
- Cubic Streamline
- Third Order Area Basis Streamline
- Conical Streamlined
- Constant Strain Rate

10. Enter machine and material data in the form.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESS 1</td>
<td>ALLOY 2</td>
</tr>
<tr>
<td>Press Capacity</td>
<td>4000</td>
</tr>
<tr>
<td>Max Die Diameter</td>
<td>10</td>
</tr>
<tr>
<td>Container Length</td>
<td>45</td>
</tr>
<tr>
<td>Ram Speed</td>
<td>21</td>
</tr>
<tr>
<td>Max Ram Stroke</td>
<td>95</td>
</tr>
</tbody>
</table>
11. Enter data required as per the details required.

12. Check your data and click Continue to move on.
13. Input node data and click on Save Node Data to move on.

14. Check the node data and click Continue to move on.
15. Input offset and other parameters and click on Save Data.

16. Check the offset and parameter data and click Continue to run Web Stream.
17. The preview page gives options to view the various 3D outputs of Web Stream.

18. The billet to product mapping is shown below. Click Back for previous page.
19. The results page with various view and download options.

20. The die contour is displayed as a 3D VRML world.
21. Stress contour displayed as a 3D model.

22. Downloading data file. Type in path in window and save the file.
Appendix E: Web Shear Users Manual

1. Start Netscape Navigator or Microsoft Internet Explorer from the Start menu.

2. Open location http://webme.ent.ohiou.edu/vm.

---

Headlines from ABCNews.com

- Share, access, and connect: Communicator 4.01 for Windows NT.
- Please let us know what you think... customer survey.
- Experience integrated HTML editing and improved performance with Netscape Visual JavaScript Preview Release 2 - now available for download.
- Download the beta version of Netscape Messaging Server 3.0 for Windows NT.
- Netscape and software.net unveil Netscape Software Depot by software.net, an online service reselling software from Netscape developers.
- More news...

---

Feeling lost on the Web? Netscape Guide by Yahoo! gives you quick and easy access to the most popular information on the Web.
3. Enter the Login and Password for authentication.

4. The following introduction screen would appear. Click Continue.

Virtual Manufacturing is the use of a desktop Virtual Reality system for Computer Aided Design of Components and Manufacturing Processes. It offers Unrivaled scope for creating and viewing three dimensional engineering models, to be passed later on to numerically controlled machines for manufacture.

This Package aims to create an interface that combines the realism of virtual reality and the rapid information exchange capabilities of the Internet sub-domain known as the World Wide Web with intricate mathematical calculations involved in the mechanical design of components and processes.

Developed by

CAD CAM Group
Department of Mechanical Engineering
Russ College of Engineering & Technology
Ohio University
5. Click on the requisite choice (e.g., Extrusion).

Requirements

Netscape Navigator 3.0 & above or Microsoft Internet Explorer 3.0 & above

and

Cosmo VRML PlugIn

6. Click on the die portion of the VRML model for die design module.
7. Click on a requisite die design package (e.g., Shear).

8. Browse through the following introduction screen and click Continue.

Web Shear Has the following Salient Features

- Circular / Non Circular Profiles of the Product
- Machine Library / Custom Machine
- Material Library / Custom Material
- Preview of Input and Product Geometry
- Force Calculation Results

10. Input data as required and click Save Data.
11. Check your data and move on.

12. Input node data of the product geometry.
13. Check node data and move on.

14. Preview page: Select geometry to view and verify and move on.
15. Study numerical results page and click Continue to move on.

RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Radius of the CircumCircle</td>
<td>1.58</td>
</tr>
<tr>
<td>The Area of the Geometry</td>
<td>2.00</td>
</tr>
<tr>
<td>The Perimeter of the Geometry</td>
<td>5.66</td>
</tr>
<tr>
<td>The geometric centre is given by X</td>
<td>0.00</td>
</tr>
<tr>
<td>The geometric centre is given by Y</td>
<td>-0.00</td>
</tr>
<tr>
<td>DILAND</td>
<td>0.38</td>
</tr>
<tr>
<td>The Number of Holes That Fit the Billet Diameter</td>
<td>9</td>
</tr>
<tr>
<td>The minimum number of Holes for Press Capacity</td>
<td>9</td>
</tr>
<tr>
<td>The Maximum Number of Holes that fit the Given Length Multiple</td>
<td>25</td>
</tr>
<tr>
<td>Billet Length</td>
<td>50.00 (inches)</td>
</tr>
<tr>
<td>Billet Diameter</td>
<td>20.00 (inches)</td>
</tr>
<tr>
<td>Container Diameter</td>
<td>20.00 (inches)</td>
</tr>
<tr>
<td>Equivalent Butt Length</td>
<td>2.00 (inches)</td>
</tr>
<tr>
<td>Extrusion Speed</td>
<td>1.10 (ft/min)</td>
</tr>
<tr>
<td>Maximum Runout Length</td>
<td>1008.00 (inches)</td>
</tr>
<tr>
<td>Length of Each Piece</td>
<td>275.00 (inches)</td>
</tr>
<tr>
<td>Loss of Per Runout</td>
<td>11.00 (inches)</td>
</tr>
<tr>
<td>Specific Weight of Material</td>
<td>0.10 (lbs/cuin)</td>
</tr>
</tbody>
</table>

16. Click on the choices on the results page to view geometry or download result files.