CHAPTER 15 Use of Computers in Numerical Control Programming

OBJECTIVES Upon completion of this chapter, you will be able to:

- Describe the four ways computers are used in numerical control programming.
- Describe offline programming.
- Explain computer-aided programming.
- Describe the basic parts of a computer-aided programming system.
- Understand how the basic parts of an APT program work.
- Describe how CAD/CAM systems work.
- Describe a solid modeling systems and how they differ from CAD/CAM systems.

Computers are now commonplace on the shop floors. Prior to the PC revolution of the 1980s, computers for NC programming were limited to large companies. Today's inexpensive personal computers and software allow even the smallest NC shops to afford and use computers to help write NC programs. There are four ways computers and software are used to write NC programs:

1. Offline programming terminals.
2. Text-based programming using an NC programming language.
3. CAD/CAM programming.
4. Solid modeling systems.

This chapter will introduce these four methods. The purpose of this chapter is to make the student aware of the far reaching affect computers have on manufacturing not to teach CAD/CAM programming. There are many different brands of CAD/CAM systems on the market today, each requiring a textbook of its own to explain its operation.

OFFLINE PROGRAMMING TERMINALS

Technically speaking, all uses of computers to assist programming are offline-programming methods. *Offline programming* is performed away from the machine, not at the CNC computer keyboard. An offline-programming terminal usually refers to a computer that is used as a text editor for writing programs. This type of programming station does not “aid” the programmer but allows the program to be entered into the computer exactly as if it were being entered via the MDI console. The advantage is that one program may be written while another program is being run on the machine. The program being written is simply saved to a storage media, such as a computer disk, until needed at the control.

COMPUTER ASSISTED PROGRAMMING

As the name implies, computer-assisted programming involves the use of computers to help the programmer write an NC program. Computer-aided programming can be divided into three categories: language-based programming, referred to as *computer-aided programming;* computer aided manufacturing, called *CAM* or *CAD/CAM* programming; and solid modeling. These systems allow the programmer to program many NC controller types using a single programming system. Since a computer is used to generate the NC code, very complex part shapes can be programmed cost effectively. It is time consuming to manually calculate the coordinates for 4- and 5-axis CNC machines; few people posses the advanced math skills required to do so.

Types of Graphics Based Systems

Graphics-based programming systems are the most commonly used types of computer-based NC programming systems in use today. Graphics programming systems can be broken down into two basic categories: CAD/CAM systems and solid modeling systems.

CAD versus CAM

CAD stands for *computer aided design.* CAD programs are used for architectural or mechanical drawings. In the machine shop, mechanical drawings are used to communicate to manufacturing personnel what the finished part should look like, and to provide the dimensions and tolerances associated with the part. The most popular CAD program in use today is AutoCad, manufactured by AutoDesk Corporation. Examples of other CAD programs on the market include CADDS, Generic CAD, and Cad-Pack.

CAM stands for *computer aided manufacturing.* CAM programs are used by NC programmers to graphically define the tool paths associated with a part program and produce the NC code required by a machine control to manufacture the part. CAM programs represent the part as a "wireframe" image in either two or three dimensions. A wire-frame image is a skeletal view of the part as opposed to viewing the part as a solid object. Occasionally, a CAM program will include the capability to view, but not program, the part as a solid piece. This solid piece rendering looks like a photograph of the part.

Since the NC programmer needs to define auxiliary geometry during the course of programming, a CAM program by itself is often very limited. The CAM program must be combined with a CAD program to give the programmer the ability to add or edit the drawing file. An example of a CAM program currently on the market is AutoPro, manufactured by Intercim Corporation's NC division. AutoPro is a CAM module that runs inside of the popular AutoCad program, adding NC programming capability to the AutoCad program.

CAD/CAM stands for *computer aided design/computer aided manufacturing.* As the name implies, these systems have both the drawing engine and the NC programming engine combined into a single program. Most NC programming systems on the market are of this type. Some of the more popular CAD/CAM programs in use today include MasterCam, SurfCam, SmartCam, and Techsoft.

How Computer Assisted Programming Systems Work

All programming systems are really two systems working together. The programming system itself is called the processor. The APT language is a text-based processing system. MasterCam, SurfCam, and Autopro are examples of CAD/CAM processing systems. Pro/Engineer is an example of a solid modeling processing system. The purpose of the programming system (programming processor) is to take the programmer's specified information and convert it into a file called a *centerline data file (CL file).* The CL file contains the cutter centerline locations of the NC program along with commands indicating when to turn the spindle on or off, turn the coolant on or of, turn on cutter diameter compensation, and so on.

The second system is called the postprocessor. The job of the postprocessor is to convert the CL file's information into the tape commands that the NC control needs. Most NC shops have a variety of NC controls. While only one processor, for example MasterCam, may be in use in a given shop, a separate postprocessor is required for each machine control.

Regardless of what type of programming system is used (computer-aided, CAD/CAM, or Solid Modeling), each system works in the same basic way that is illustrated in Figure 15-1. First, the NC programmer creates a source file. This file, or collection of files, contains the part geometry, the tool

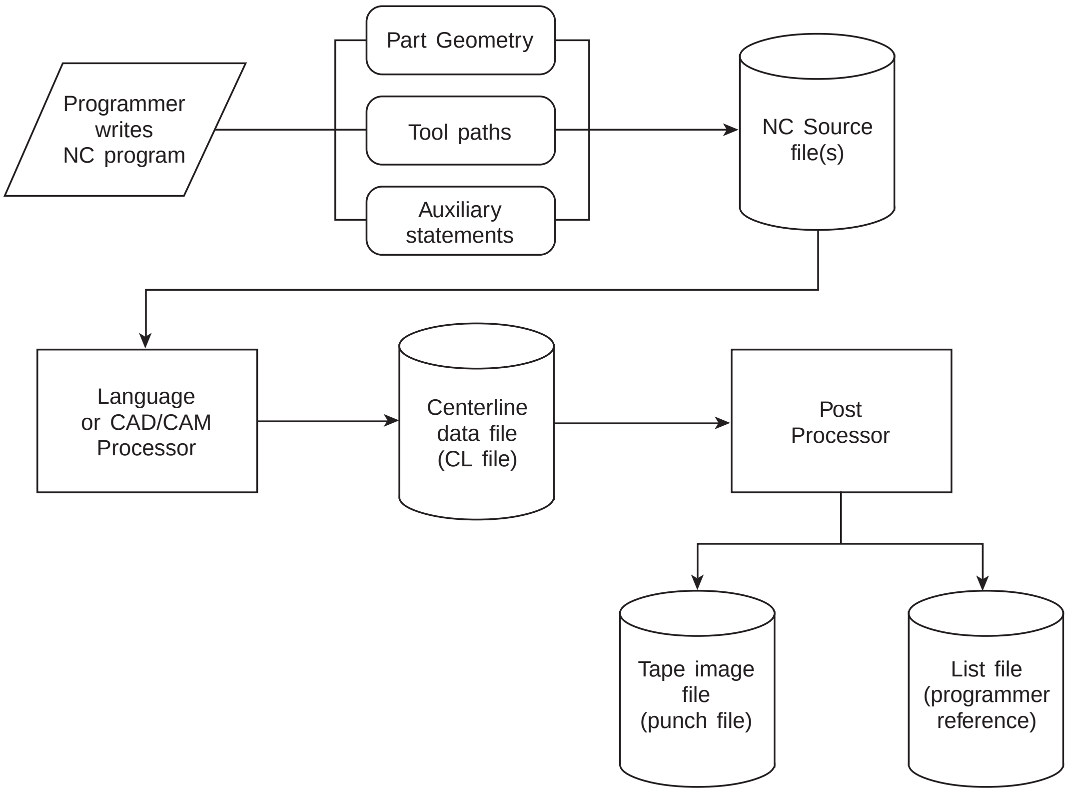

FIGURE 15-1
Flow diagram of a computer-aided or CAD/CAM system

paths to be developed, and any auxiliary statements (turning on or off the spindle, coolant, and so on). The NC programming system then processes this information into a CL file. Lastly, the postprocessor converts the CL file into the final tape image file that will be loaded into the NC control.

COMPUTER-AIDED PROGRAMMING LANGUAGES

Computer-aided programming had its beginnings in the 1950s when point-to-point tape machinery made manual programming an enormously laborious task. A computer-aided programming system uses an English-like computer language to define a part's geometric configuration and describe the desired machining operations. The language acts as a translator. The programmer "talks" to the computer via the keyboard in the programming language. These language statements are stored in a file called the source code file. The language processor converts these language statements into the CL file. The CL file is, in turn, converted into the final tape image file by the postprocessor.

Languages

The use of NC computer languages is not very common today. CAD/CAM systems have largely supplanted their use. A number of languages have developed over the years. The more common ones are:

- **APT (Automatic Programmed Tools)**—This is the granddaddy of all NC languages. It can generate complex geometry in all five axes simultaneously. Developed to run on large mainframe computers in the early 1960s, versions are available that run on a PC.
- **AD-APT (Adaption of APT)—**A “stripped down” version of APT developed to run on small computers. Today’s PC computing power has rendered it obsolete.
- **COMPACT II—**Still in limited use today, Compact II can accomplish the same tasks as the APT language, but it is limited to three axes.
- **UNIAPT—**Similar to the APT language but designed to run on small, mini-computers. The advent of powerful PCs and CAD/CAM systems has rendered it obsolete.

The Role of APT Today

Despite the claims of CAD/CAM and solid modeling manufacturers, APT is the one system that can do all types of programming. If it is mathematically possible, the APT language can generate the tool path for it. For this reason, APT is still in use in some aerospace companies. The APT language should be of special interest to all NC programmers for another reason: APT forms the basis for most of the centerline data files generated by today’s CAD/CAM programs. The postprocessor engine used by many of today’s CAD/CAM and solid modeling systems is APT based. A basic understanding of APT can help a CAD/CAM programmer troubleshoot a CL file problem.

APT Programming

An APT program is comprised of the *geometry section* and the *motion section.* In the geometry section, the programmer defines the shape of the part using the APT language. In the motion section, the programmer describes the tool motion used to produce the part. Instructions to turn on the spindle, define spindle speed, turn on the coolant, and turn on cutter diameter compensation are also included in the motion section.

APT Geometry Statements

The following are examples of how geometry is defined in APT. Again, the purpose of this text is not to teach computer-aided programming. However, an overview of APT can be a valuable aide in an NC programmer's skill set when it comes to dealing with CAD/CAM CL files and troubleshooting post processor problems.

All APT geometry statements are constructed in the same logical manner:

<Geometry Name> = MAJOR WORD/<definition>

The <Geometry Name> is any name, up to 6 characters, that the programmer assigns to the definition. For example points can be named SAM, SUE, or MARY. Generally, the programmer assigns names with more meaning to the geometry: P1, P2, P3 for points; L1 or L2 for lines; C1 or C2 for circles; and so on. MAJOR WORD is the geometry type defined (POINT, LINE, CIRCLE, PLANE). The <definition> is the statement or statements that define the geometry.

Geometry Examples

P1 =POINT/6,6,6	(Point defined by its Cartesian coordinates.)
P2 =POINT/INTOF,L1,L2	(The intersection of lines L1 and L2.)
P3 =POINT/CENTER,C1	(The center of circle C1.)
L4 =LINE/P1,P2	(Line through points P1 and P2.)
L5 =LINE/P2,PARLEL,L1	(Line hrough point P2, parallel to line L1.)
L6 =LINE/P1,LEFT,TANTO,C1	(Line through point P1, tangent to circle C1 on the left.)
C1 =CIRCLE/CENTER,P1, RADIUS,1.0	(Circle with P1 as the center, with a radius of 1.0 inch.)
C2 =CIRCLE/CENTER,P5,L1	(Circle with P1 as the center, tangent to line L1.)
PL1 =PLANE/P1,P2,P3	(Plane containing points P1, P2, P3.)
PL2 =PLANE/XYPLAN,1.0	(Plane parallel to the XY plane at a distance of 1 inch.)

APT Motion Statements

All APT motion statements are constructed as follows:

MAJOR WORD/minor word,scalar

The MAJOR WORD is the command word, such as SPINDL, GOTO, CYCLE, and so on. The minor word is a descriptor word, such as IPM (inch per minute), IPR (inch per revolution), RPM (revolutions per minute), ON, OFF, and so on. The descriptor describes or "types" an associated scalar. A *scalar* is simply an APT term for a numeric value. Not all APT motion statements have minor words and/or scalars. Some are simply major word commands.

The following sequence is an example of APT motion statements.

```
FROM/0,0,0
LOADTL/1,ADJUST,1
CUTTER/1.0
SPINDL/RPM,2500,CLW
FEDRAT/20,IPM
RAPID
GO/PAST,L5,ON,PL1,PAST,L4
CUTCOM/LEFT,11
GO/TO,L1
TLLEFT,GOLEFT/L1,TANTO,C1
GOFWD/C1,TANTO,L2
GOFWD/L2,TANTO,C2
GOFWD/C2,TANTO,L3
GOFWD/L3,PAST,L4
GOLFT/L4,PAST,L1
RAPID
GODLTA/0,0,1
RAPID
GOTO/0,0,0
```

APT Program Example

Figure 15-2 shows a part to be programmed using the APT language. Only the inside contour of the part is to be milled, and the six $^{1}/_{4}$-inch holes are to be drilled. Generally, an NC programmer makes a sketch of the part geometry to be defined for reference purposes. This is illustrated in Figure 15-3. The APT source file is contained in Figure 15-4. The resulting CL file is contained in Figure 15-5 and the final tape image file in Figure 15-6.

CAD/CAM SYSTEMS

Each CAD/CAM system's user interface is different. The menu selections and methodology behind the design differ significantly from program to program. For this reason, it is well beyond the scope of this text to attempt to teach a CAD/CAM program. Each shop or school uses the system of its choosing. Students are encouraged to consult the system documentation that their shop and/or school uses to see how a part is programmed using that system.

Despite the different use interfaces, each CAD/CAM system provides the same capabilities to the programmer. The programmer can define tools to be used for a cut, indicate the speed and feed for the cut, select a series

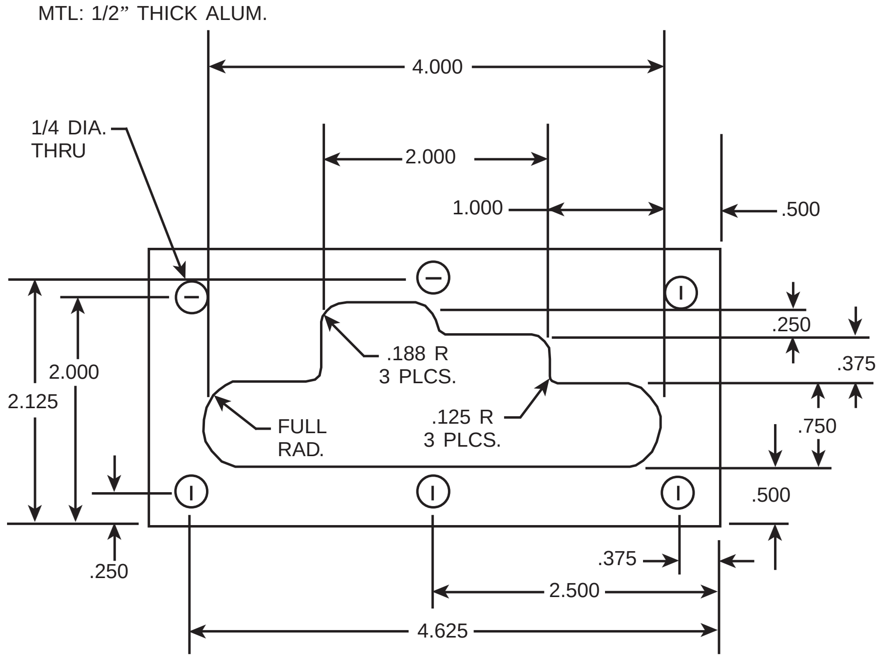

FIGURE 15-2
Part drawing

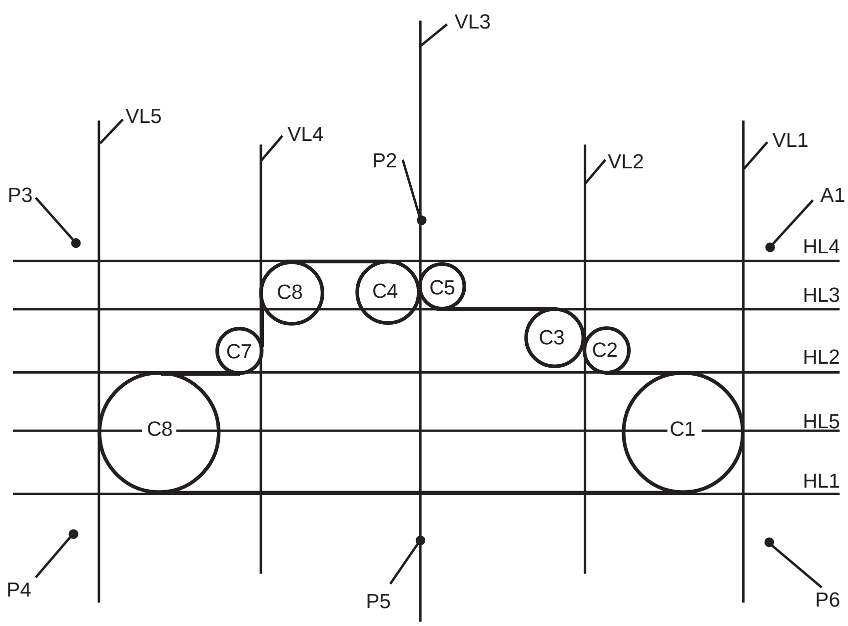

FIGURE 15-3
Part geometry

```
PARTNO APT MILL EXAMPLE
MACHIN/UNCX01,24
APTAC/ON

PPRINT ********************
PPRINT COORDINATE SYSTEM ORIGIN
PPRINT X0 = LOWER RIGHT CORNER OF PART
PPRINT Y0 = LOWER RIGHT CORNER OF PART
PPRINT Z0 = 2.000 INCHES ABOVE TOP OF PART
PPRINT ********************
PPRINT MACHINING SEQUENCE
PPRINT TOOL 1:  ROUGH MILL INSIDE CONTOUR OF PART
PPRINT TOOL 2: FINISH MILL INSIDE CONTOUR OF PART
PPRINT TOOL 3: CDRILL AND CSINK 1/4 HOLES TO .260 DIA.
PPRINT TOOL 4: DRILL 1/4 DIA. HOLES
PPRINT ********************

$$
$$PART GEOMETRY
$$
PL1 =PLANE/XYPLAN,-1               $$TOP OF PART
PL2 =PLANE/PARLEL,PL1,ZSMALL,.51   $$.01 BELOW BOTTOM OF PART
CLR =PLANE/PARLEL,PL1,ZLARGE,.05   $$.05 ABOVE TOP OF PART

VL1 =LINE/YAXIS,-.5
VL2 =LINE/PARLEL,VL1,XSMALL,1
VL3 =LINE/YAXIS,-2.5
VL4 =LINE/PARLEL,VL2,XSMALL,2
VL5 =LINE/PARLEL,VL1,XSMALL,4

HL1 =LINE/XAXIS,.5
HL2 =LINE/PARLEL,HL1,YLARGE,.75
HL3 =LINE/PARLEL,HL2,YLARGE,.375
HL4 =LINE/PARLEL,HL3,YLARGE,.25
HL5 =LINE/PARLEL,HL1,YLARGE,.375

C1  =CIRCLE/XSMALL,VL1,YLARGE,HL1,YSMALL,HL2
C2  =CIRCLE/XLARGE,VL2,YLARGE,HL2,RADIUS,.125
C3  =CIRCLE/XSMALL,VL2,YSMALL,HL3,RADIUS,.188
C4  =CIRCLE/XSMALL,VL3,YSMALL,HL4,RADIUS,.188
C5  =CIRCLE/YLARGE,HL3,XLARGE,OUT,C4,RADIUS,.125
C6  =CIRCLE/XLARGE,VL4,YSMALL,HL4,RADIUS,.188
C7  =CIRCLE/XSMALL,VL4,YLARGE,HL2,RADIUS,.125
C8  =CIRCLE/YLARGE,HL1,XLARGE,VL5,YSMALL,HL2

ZSURF/PL1
    P1   =POINT/-.375,.2
    P2   =POINT/-2.5,2.125
    P3   =POINT/-4.625,2
    P4   =POINT/-4.625,.25
    P5   =POINT/-2.5,.25
    P6   =POINT/-.375,.25
    PAT1 =PATERN/RANDOM,P1,P2,P3,P4,P5,P6
```

FIGURE 15-4
(Continues to page 336)

```
$$
$$MOTION STATEMENTS
$$
FROM/0,4,0
PPRINT ********************
PPRINT 3/8 END MILL - USES CRO REGISTER D11
PPRINT ROUGH MILL INSIDE CONTOUR - LEAVE .01 FINISH STOCK
LOADTL/1,ADJUST,1
CUTTER/.375
SPINDL/3800,CLW
COOLNT/ON
FEDRAT/.003,IPR

RAPID,GO/ON,VL2,CLR,ON,HL5
THICK/0,.01,.01
GO/ON,VL2,PL2
CUTCOM/LEFT,11

PPRINT *****
PPRINT MILL .750 WIDE SLOT
PPRINT *****
GO/HL2
    GOLFT/HL2,TANTO,C8
    GOFWD/C8,TANTO,HL1
    GOFWD/HL1,TANTO,C1
    GOFWD/C1,TANTO,HL2
    GOFWD/HL2,PAST,VL2

PPRINT *****
PPRINT MILL BALANCE OF SLOT
PPRINT *****
GO/HL3
    GOLFT/HL3,PAST,VL3
    GORGT/VL3,HL4
    GOLFT/HL4,VL4
    GOLFT/VL4,ON,HL5

PPRINT *****
PPRINT CANCEL CRO, RETURN TO TOOL CHANGE
PPRINT *****
CUTCOM/OFF
GOHOME/1
$$
PPRINT ********************
PPRINT 1/4 END MILL - USES CRO REGISTER D21
PPRINT FINISH MILL SLOT
PPRINT ********************
LOADTL/2,ADJUST,2
CUTTER/.250
SPINDL/4000,CLW
COOLNT/ON
FEDRAT/.002,IPR

THICK/0
RAPID,GO/ON,(LINE/PARLEL,VL1,XSMALL,.375),CLR,ON,HL5
NOPS,GO/PL2
AUTOPS
```

FIGURE 15-4
(Continues to page 336)

```
PPRINT *****
PPRINT FINISH MILL CONTOUR OF ID
PPRINT *****
CUTCOM/LEFT,21
GO/HL2
    GOLFT/HL2,TANTO,C2
    GOFWD/C2,TANTO,VL2
    GOFWD/VL2,TANTO,C3
    GOFWD/C3,TANTO,HL3
    GOFWD/HL3,TANTO,C5
    GOFWD/C5,TANTO,C4
    GOFWD/C4,TANTO,HL4
    GOFWD/HL4,TANTO,C6
    GOFWD/C6,TANTO,VL4
    GOFWD/VL4,TANTO,C7
    GOFWD/C7,TANTO,HL2
    GOFWD/HL2,TANTO,C8
    GOFWD/C8,TANTO,HL1
    GOFWD/HL1,TANTO,C1
    GOFWD/C1,TANTO,HL2
    GOFWD/HL2,PAST,VL2

PPRINT *****
PPRINT CANCEL CRO, RETURN TO TOOL CHANGE
PPRINT *****
CUTCOM/OFF
GOHOME/1
$$
PPRINT ********************
PPRINT NO. 4 CDRILL - CDRILL 6 PLCS. TO .260 DIA.
PPRINT ********************
LOADTL/3,ADJUST,3
SPINDL/3500,CLW
COOLNT/ON
CYCLE/DRILL,.183,.004,IPR,.1,PULBAC,99
    GOTO/PAT1
CYCLE/OFF
GOHOME/1
$$
PPRINT ********************
PPRINT 1/4 DRILL - PECK DRILL .250 THRU 6 PLCS.
PPRINT ********************
LOADTL/4,ADJUST,4
SPINDL/3000,CLW
CYCLE/DEEP,.6,.003,IPR,.1,INCR,.25,PULBAC,99
    GOTO/PAT1
CYCLE/OFF
GOHOME/5
FINI
```

FIGURE 15-4
Apt program manuscript

```
PARTNO APT MILL EXAMPLE
MACHIN/UNCX01,24
PPRINT ********************
PPRINT COORDINATE SYSTEM ORIGIN
PPRINT X0 = LOWER RIGHT CORNER OF PART
PPRINT Y0 = LOWER RIGHT CORNER OF PART
PPRINT Z0 = 2.000 INCHES ABOVE TOP OF PART
PPRINT ********************
PPRINT MACHINING SEQUENCE
PPRINT TOOL 1:  ROUGH MILL INSIDE CONTOUR OF PART
PPRINT TOOL 2: FINISH MILL INSIDE CONTOUR OF PART
PPRINT TOOL 3: CDRILL AND CSINK 1/4 HOLES TO .260 DIA.
PPRINT TOOL 4: DRILL 1/4 DIA. HOLES
PPRINT ********************
FROM   /0,4,0
PPRINT ********************
PPRINT 3/8 END MILL - USES CRO REGISTER D11
PPRINT ROUGH MILL INSIDE CONTOUR - LEAVE .01 FINISH STOCK
LOADTL /1,ADJUST,1
CUTTER /.375,0,0,0,0,0,5
SPINDL /3800,CLW
COOLNT /ON
FEDRAT /.003,IPR
RAPID
GOTO   /-1.5,.875,-.95
GOTO   /-1.5,.875,-1.51
CUTCOM /LEFT,11
PPRINT *****
PPRINT MILL .750 WIDE SLOT
PPRINT *****
GOTO   /-1.5,1.0525,-1.51
GOTO   /-4.125,1.0525,-1.51
ARCDAT /-4.125,.875,-1.51,0,0,1,.375
ARCMOV /CCLW,-4.125,.6975,-1.51,180.0000021
GOTO   /-.875,.6975,-1.51
ARCDAT /-.875,.875,-1.51,0,0,1,.375
ARCMOV /CCLW,-.875,1.0525,-1.51,180.0000021
GOTO   /-1.6975,1.0525,-1.51
PPRINT *****
PPRINT MILL BALANCE OF SLOT
PPRINT *****
GOTO  /-1.6975,1.4275,-1.51
GOTO  /-2.6975,1.4275,-1.51
GOTO  /-2.6975,1.6775,-1.51
GOTO  /-3.3025,1.6775,-1.51
GOTO  /-3.3025,.875,-1.51
PPRINT *****
PPRINT CANCEL CRO, RETURN TO TOOL CHANGE
PPRINT *****
CUTCOM /OFF
GOHOME /1
PPRINT ********************
PPRINT 1/4 END MILL - USES CRO REGISTER D21
PPRINT FINISH MILL SLOT
PPRINT ********************
LOADTL /2,ADJUST,2
CUTTER /.25,0,0,0,0,0,5
SPINDL /4000,CLW
COOLNT /ON
FEDRAT /.002,IPR
RAPID
```

FIGURE 15-5
(Continues to page 338)

```
GOTO    /-.875,.875,-.95
GOTO    /-.875,.875,-1.51
PPRINT  *****
PPRINT  FINISH MILL CONTOUR OF ID
PPRINT  *****
CUTCOM/LEFT,21
GOTO    /-.875,1.125,-1.51
GOTO    /-1.375,1.125,-1.51
ARCDAT  /-1.375,1.375,-1.51,0,0,1,.125
ARCMOV/CLW,-1.625,1.375,-1.51,90.17707064
GOTO    /-1.625,1.437,-1.51
ARCDAT  /-1.688,1.437,-1.51,0,0,1,.188
ARCMOV  /CCLW,-1.688,1.5,-1.51,90.00000105
GOTO    /-2.38140581,1.5,-1.51
ARCDAT  /-2.38140581,1.75,-1.51,0,0,1,.125
ARCMOV  /CLW,-2.62628935,1.69968051,-1.51,78.54181737
ARCDAT  /-2.688,1.687,-1.51,0,0,1,.188
ARCMOV  /CCLW,-2.688,1.75,-1.51,78.38830059
GOTO    /-3.312,1.75,-1.51
ARCDAT  /-3.312,1.687,-1.51,0,0,1,.188
ARCMOV  /CCLW,-3.375,1.687,-1.51,90.00000105
GOTO    /-3.375,1.375,-1.51
ARCDAT  /-3.625,1.375,-1.51,0,0,1,.125
ARCMOV/CLW,-3.625,1.125,-1.51,90.17707064
GOTO   /-4.125,1.125,-1.51
ARCDAT/-4.125,.875,-1.51,0,0,1,.375
ARCMOV/CCLW,-4.125,.625,-1.51,180.0000021
GOTO   /-.875,.625,-1.51
ARCDAT/-.875,.875,-1.51,0,0,1,.375
ARCMOV/CCLW,-.875,1.125,-1.51,180.0000021
GOTO   /-1.625,1.125,-1.51
PPRINT  *****
PPRINT  CANCEL CRO, RETURN TO TOOL CHANGE
PPRINT  *****
CUTCOM/OFF
GOHOME/1
PPRINT  ********************
PPRINT  NO. 4 CDRILL - CDRILL 6 PLCS. TO .260 DIA.
PPRINT  ********************
LOADTL/3,ADJUST,3
SPINDL/3500,CLW
COOLNT/ON
CYCLE/DRILL,.183,.004,IPR,.1,PULBAC,99
GOTO   /-.375,.2,-1
GOTO   /-2.5,2.125,-1
GOTO   /-4.625,2,-1
GOTO   /-4.625,.25,-1
GOTO   /-2.5,.25,-1
GOTO   /-.375,.25,-1
CYCLE/OFF
GOHOME/1
PPRINT  ********************
PPRINT  1/4 DRILL - PECK DRILL .250 THRU 6 PLCS.
PPRINT  ********************
LOADTL/4,ADJUST,4
SPINDL/3000,CLW
CYCLE/DEEP,.6,.003,IPR,.1,INCR,.25,PULBAC,99
GOTO   /-.375,.2,-1
GOTO   /-2.5,2.125,-1
GOTO   /-4.625,2,-1
GOTO   /-4.625,.25,-1
GOTO   /-2.5,.25,-1
GOTO   /-.375,.25,-1
CYCLE/OFF
GOHOME/5
FINI
```

FIGURE 15-5
Apt generated CL file

```
%
( APT MILL EXAMPLE)
(POSTED ON 05/02/00 15.10.52 THRU UNCX01,24)
N1G20G91
N2G28G0Z0.
N3G30G0G91X0.Y0.M1
N4G90
N5G40G80G90G17G98G8P0
N6T1M6
N7T2
N8M8
N9S3800M3
N10G0X-1.5Y.875
N11G43Z.05H0
N12G1Z-.51F11.4
N13G41Y1.0525D11
N14X-4.125
N15G3X-4.125Y.6975I0.J-.1775
N16G1X-.875
N17G3X-.875Y1.0525I0.J.1775
N18G1X-1.6975
N19Y1.4275
N20X-2.6975
N21Y1.6775
N22X-3.3025
N23Y.875
N24G40
N25M109
N26G91G0G28Z0.M5
N27G30X0.Y0.M19
N28M1
N29G40G80G90G17G98G8P0
N30T2M6
N31T3
N32M8
N33S4000M3
N34G0X-.875Y.875
N35G43Z1.05H0
N36G1Z.49F8.
N37G41Y1.125D21
N38X-1.375
N39G2X-1.625Y1.375I0.J.25
N40G1Y1.437
N41G3X-1.688Y1.5I-.063J0.
N42G1X-2.3814
N43G2X-2.6263Y1.6997I0.J.25
N44G3X-2.688Y1.75I-.0617J-.0127
N45G1X-3.312
N46G3X-3.375Y1.687I0.J-.063
N47G1Y1.375
N48G2X-3.625Y1.125I-.25J0.
N49G1X-4.125
N50G3X-4.125Y.625I0.J-.25
N51G1X-.875
N52G3X-.875Y1.125I0.J.25
N53G1X-1.625
N54G40
N55M109
N56G91G0G28Z0.M5
N57G30X0.Y0.M19
N58M1
```

FIGURE 15-6
(Continues to page 340)

```
N59G40G80G90G17G98G8P0
N60T3M6
N61T4
N62M8
N63S3500M3
N64G1G43X-.375Y.2Z2.F7.H0
N65X-2.5Y2.125
N66X-4.625Y2.
N67Y.25
N68X-2.5
N69X-.375
N70M109
N71G91G0G28Z0.M5
N72G30X0.Y0.M19
N73M1
N74G40G80G90G17G98G8P0
N75T4M6
N76S3000M3
N77G1G43X-.375Y.2Z3.F6.H0M8
N78X-2.5Y2.125
N79X-4.625Y2.
N80Y.25
N81X-2.5
N82X-.375
N83M109
N84G91G0G28Z0.M5
N85G30X0.Y0.M19
%
```

FIGURE 15-6
Apt generated tape image file

of drawing features (called *elements*), and specifiy the direction of the cut. The computer will then generate a toolpath according to these instructions. The CAD/CAM program also includes some built in routines to simplify the programming of common toolpath operations such as:

- Multiple-pass roughing operations
- Pocket milling
- Hole operation cycles (such as drilling, reaming, and boring)

How CAD/CAM Organizes a Program

Generally, CAD/CAM systems organize their internal storing and tracking of NC programming commands in a tool-by-tool. This grouping of NC programs is called a *tool sequence.* Each time the programmer tells the computer to use a different tool, the computer begins a new tool sequence. The instructions that the programmer gives to the computer are generally stored in one or more files associated with the tool. One of these files will contain the tool centerline coordinates of the tool path. When the programmer instructs the program to generate the complete part program, these files will be used by the system to generate a centerline data file (CL file). The CL file is then postprocessed into a file containing the actual NC code for the machine. This file is called a *tape image file.* It is also referred to as the *punch file.*

The tool sequences generated by a CAD/CAM program contain tool path data based on the part drawing file at the time that the programmer defined the tool path. They are not programmatically related to the drawing file. Therefore, CAD/CAM systems share a weakness with language-based systems: If the part drawing changes, the tool path does not. When blueprint changes occur, the programmer must modify or re-define the affected tool paths, then re-generate the NC part program.

A CAD/CAM Example

Figure 15-7 depicts a part programmed using the AutoPro CAM system. Notice that the part is depicted as a “wire-frame” image. Figure 15-8 shows the CL file that was produced by the program. Notice the APT type of

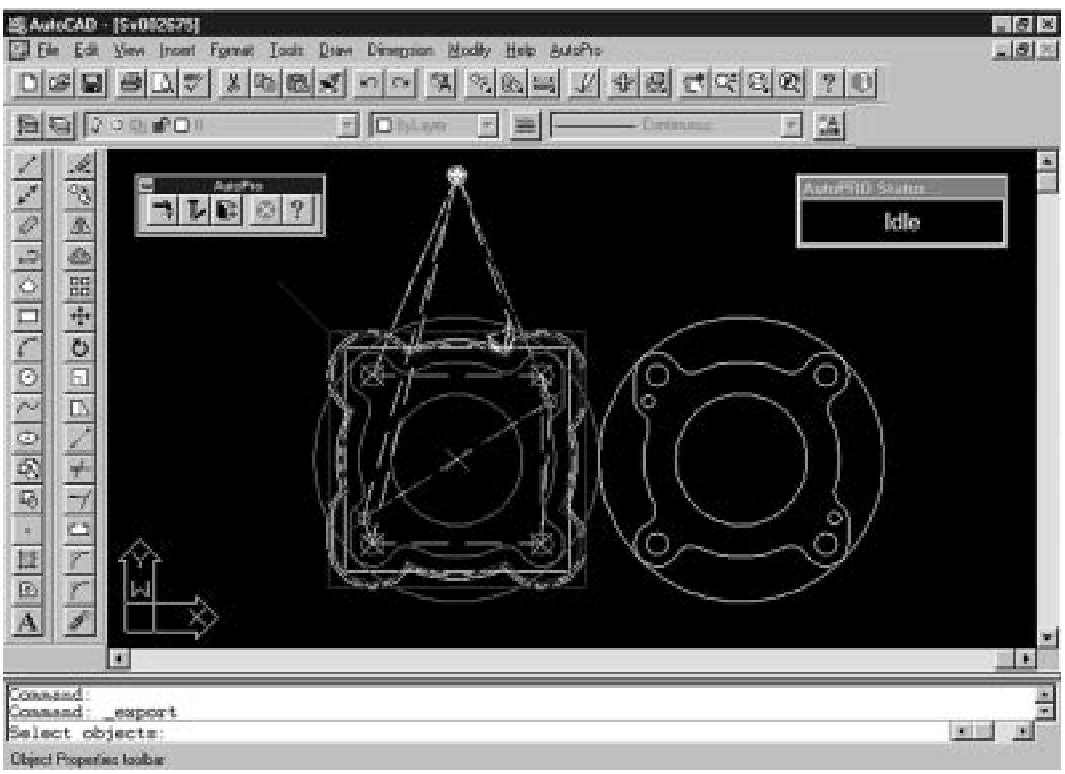

FIGURE 15-7
Part programmed in AutoPro CAD/CAM system

```
PARTNO   SV002675
PPRINT  (UCS)  TLP  FILE=INCLUD/SV002675.T01
UNITS/INCHES
CAMERA/CENTER,0,0,0
CAMERA/XAXIS,1,0,0
CAMERA/YAXIS,0,1,0
DISPLY/ON
PPRINT  ————————————————
PPRINTP/N  2783455-101  OP  060  SV002675  REV  D
PPRINT  ————————————————
PPRINTTL/1  7/16"  CARBIDE  END  MILL
PPRINTROUGH  &  FINISH  PROFILE
PPRINTUSE  CRO  #1
INSERT  G90G10L2P5X-23.2500Y-15.0010Z-23.5300
FROM   /-2.5,2.5,15
CUTTER /.4375,0,0,0,0,0,3.9
REMARK  <APRO-CMD/TULNAM=C:\CAMSYS\EM_FLAT.DWG>
REMARK  <APRO-CMD/SCALE=0.50000000>
REMARK  <APRO-CMD/TULDES=>
LOADTL/1,ADJUST,1,LENGTH,3.9
PREFUN/58,NOW
INSERTG08P1
SPINDL/8000,RPM,CLW,RANGE,1
FEDRAT/100,IPM
CUTCOM/LEFT,1
COOLNT/ON
RAPID
GOTO   /-2.5,2.5,-.03
FEDRAT /100,IPM
FEDRAT /100,IPM
GOTO   /-1.79875,1.79875,-.03
GOTO   /1.79875,1.79875,-.03
GOTO   /1.79875,-1.79875,-.03
GOTO   /-1.79875,-1.79875,-.03
GOTO   /-1.79875,1.79875,-.03
FEDRAT/70,IPM
FEDRAT/70,IPM
GOTO   /-1.188,1.74875,-.03
ARCDAT /-1.188,1.188,-.03,0,0,1,.56075
ARCMOV /CLW,-.70097517,1.46593412,-.03,60.28756965
ARCDAT /-.6998895,1.4665537,-.03,0,0,1,.00125006
ARCMOV /CCLW,-.69935107,1.46542554,-.03,85.8011983
ARCDAT /0,0,-.03,0,0,1,1.62375003
ARCMOV /CLW,.6993511,1.4654256,-.03,51.02413834
ARCDAT /.6998895,1.4665537,-.03,0,0,1,.00124999
ARCMOV /CCLW,.70097514,1.46593413,-.03,85.80016612
ARCDAT /1.188,1.188,-.03,0,0,1,.56074996
ARCMOV /CLW,1.74874996,1.188,-.03,150.28757094
GOTO   /1.74875,.82,-.03
ARCDAT /1.31,.82,-.03,0,0,1,.43875
ARCMOV /CLW,1.55858027,.45846244,-.03,55.48898136
ARCDAT /1.5592885,.4574324,-.03,0,0,1,.00124998
ARCMOV /CCLW,1.55808907,.45708052,-.03,71.8380835
ARCDAT /0,0,-.03,0,0,1,1.62374995
ARCMOV /CLW,1.46542552,-.6993511,-.03,41.86163233
ARCDAT /1.4665537,-.6998895,-.03,0,0,1,.00124999
ARCMOV /CCLW,1.46593413,-.70097514,-.03,85.79728667
ARCDAT /1.188,-1.188,-.03,0,0,1,.56074996
ARCMOV /CLW,.70097519,-1.46593409,-.03,210.57514236
ARCDAT /.6998895,-1.4665537,-.03,0,0,1,.00125006
ARCMOV /CCLW,.69935107,-1.46542554,-.03,85.79987778
```

FIGURE 15-8
(Continues to page 345)

```
ARCDAT /0,0,-.03,0,0,1,1.62375003
ARCMOV /CLW,-.69935111,-1.4654256,-.03,51.02413867
ARCDAT /-.6998895,-1.4665537,-.03,0,0,1,.00124999
ARCMOV /CCLW,-.70097514,-1.46593413,-.03,85.79983002
ARCDAT /-1.188,-1.188,-.03,0,0,1,.56074996
ARCMOV /CLW,-1.74874996,-1.188,-.03,150.28757094
GOTO   /-1.74875,-.82,-.03
ARCDAT /-1.31,-.82,-.03,0,0,1,.43875
ARCMOV /CLW,-1.55858027,-.45846244,-.03,55.48898136
ARCDAT /-1.5592885,-.4574324,-.03,0,0,1,.00124998
ARCMOV /CCLW,-1.55808907,-.45708052,-.03,71.8380835
ARCDAT /0,0,-.03,0,0,1,1.62374995
ARCMOV /CLW,-1.46542553,.69935107,-.03,41.86163122
ARCDAT /-1.4665537,.6998895,-.03,0,0,1,.00124999
ARCMOV /CCLW,-1.46593413,.70097514,-.03,85.79865485
ARCDAT /-1.188,1.188,-.03,0,0,1,.56074996
ARCMOV /CLW,-1.188,1.74874996,-.03,150.28757094
FEDRAT /35,IPM
GOTO   /-.54066964,1.58519256,-.03
FEDRAT /10,IPM
ARCDAT /-.79575688,1.74308651,-.03,0,0,1,.3
ARCMOV /CLW,-.72703091,1.4510647,-.03,45.00001288
FEDRAT /35,IPM
FEDRAT /35,IPM
GOTO   /-.7270309,1.4510647,-.03
ARCDAT /-1.188,1.188,-.03,0,0,1,.53074999
ARCMOV /CCLW,-1.4510647,.7270309,-.03,210.57514051
ARCDAT /-1.4665537,.6998895,-.03,0,0,1,.03125004
ARCMOV /CLW,-1.4383507,.6864301,-.03,85.79956108
ARCDAT /0,0,-.03,0,0,1,1.59374999
ARCMOV /CCLW,-1.52930217,-.44863559,-.03,41.86163281
ARCDAT /-1.5592885,-.4574324,-.03,0,0,1,.03124999
ARCMOV /CLW,-1.54158335,-.48318293,-.03,71.83856649
ARCDAT /-1.31,-.82,-.03,0,0,1,.40874994
ARCMOV /CCLW,-1.71874994,-.81999999,-.03,55.4889788
GOTO   /-1.71875,-1.188,-.03
ARCDAT /-1.188,-1.188,-.03,0,0,1,.53075
ARCMOV /CCLW,-.72703089,-1.45106471,-.03,150.28757038
ARCDAT /-.6998895,-1.4665537,-.03,0,0,1,.03125004
ARCMOV /CLW,-.6864301,-1.4383507,-.03,85.79957408
ARCDAT /0,0,-.03,0,0,1,1.59374999
ARCMOV /CCLW,.68643009,-1.4383507,-.03,51.0241423
ARCDAT /.6998895,-1.4665537,-.03,0,0,1,.03125003
ARCMOV /CLW,.7270309,-1.4510647,-.03,85.79957652
ARCDAT /1.188,-1.188,-.03,0,0,1,.53074999
ARCMOV /CCLW,1.4510647,-.7270309,-.03,210.57514051
ARCDAT /1.4665537,-.6998895,-.03,0,0,1,.03125004
ARCMOV /CLW,1.4383507,-.6864301,-.03,85.79956108
ARCDAT /0,0,-.03,0,0,1,1.59374999
ARCMOV /CCLW,1.52930217,.44863559,-.03,41.86163281
ARCDAT /1.5592885,.4574324,-.03,0,0,1,.03124999
ARCMOV /CLW,1.54158335,.48318293,-.03,71.83856649
ARCDAT /1.31,.82,-.03,0,0,1,.40874994
ARCMOV /CCLW,1.71874994,.81999999,-.03,55.4889788
GOTO   /1.71875,1.188,-.03
ARCDAT /1.188,1.188,-.03,0,0,1,.53075
ARCMOV /CCLW,.72703089,1.45106472,-.03,150.28756945
ARCDAT /.6998895,1.4665537,-.03,0,0,1,.03125004
ARCMOV /CLW,.6864301,1.4383507,-.03,85.79959224
ARCDAT /0,0,-.03,0,0,1,1.59374999
ARCMOV /CCLW,-.68643009,1.4383507,-.03,51.0241423
```

FIGURE 15-8
(Continues to page 345)

```
ARCDAT /-.6998895,1.4665537,-.03,0,0,1,.03125003
ARCMOV /CLW,-.7270309,1.4510647,-.03,85.79957652
GOTO   /-.7270309,1.5510647,-.03
INSERTG08P0
GOHOME /1
PPRINT (UCS) TLP FILE=INCLUD/SV002675.T05
UNITS/INCHES
CAMERA /CENTER,0,0,0
CAMERA /XAXIS,1,0,0
CAMERA /YAXIS,0,1,0
DISPLY /ON
PPRINT ─────────────────
PPRINTTL/ 2 1/2  X 100 DEG. SPOT DRILL
FROM   /0,4,15
CUTTER /.5,0,0,0,0,0,6
REMARK <APRO-CMD/TULNAM=.DWG>
REMARK <APRO-CMD/SCALE=1.00000000>
REMARK <APRO-CMD/TULDES=>
LOADTL /2,LENGTH,6,ADJUST,2
PREFUN /58,NOW
DISPLY /ON
SPINDL /5000,RPM,CLW,RANGE,2
FEDRAT /20,IPM
COOLNT /ON
RAPID
GOTO   /-1.188,1.188,2
PPWORD /DEEPCL, 208
CYCLE  /DRILL,.121,20,IPM,.1,.2,PULBAC,98
GOTO   /-1.188,1.188,.1
GOTO   /1.188,1.188,.1
GOTO   /1.31,.82,.1
GOTO   /1.188,-1.188,.1
GOTO   /-1.188,-1.188,.1
GOTO   /-1.31,-.82,.1
CYCLE/OFF
GOHOME/1
PPRINT (UCS) TLP FILE=INCLUD/SV002675.T03
UNITS/INCHES
CAMERA /CENTER,0,0,0
CAMERA /XAXIS,1,0,0
CAMERA /YAXIS,0,1,0
DISPLY /ON
PPRINT ─────────────────
PPRINTTOOL / 3 - .2992 DIA. HSS DRILL
DISPLY /ON
FROM   /0,4,15
CUTTER /.25,0,0,0,0,0,6
REMARK <APRO-CMD/TULNAM=.DWG>
REMARK <APRO-CMD/SCALE=1.00000000>
REMARK <APRO-CMD/TULDES=>
LOADTL /3,ADJUST,3,LENGTH,5.8
PREFUN /58,NOW
SPINDL /3920,CLW
FEDRAT /23.52,IPM
COOLNT /ON
RAPID
GOTO   /-1.188,1.188,2
CYCLE  /DRILL,.2108287,23.52,IPM,.1,.2,PULBAC,98
GOTO   /-1.188,1.188,.1
GOTO   /1.188,1.188,.1
GOTO   /1.188,-1.188,.1
```

FIGURE 15-8
(Continues to page 345)

```
GOTO   /-1.188,-1.188,.1
CYCLE/OFF
GOHOME/1
PPRINT  (UCS)  TLP  FILE=INCLUD/SV002675.T04
UNITS/INCHES
CAMERA/CENTER,0,0,0
CAMERA/XAXIS,1,0,0
CAMERA/YAXIS,0,1,0
DISPLY/ON
PPRINT  ─────────────────
PPRINTTOOL  /4  -  .1695  HSS  DRILL
DISPLY/ON
FROM   /0,4,15
CUTTER /.125,0,0,0,0,0,5
REMARK  <APRO-CMD/TULNAM=.DWG>
REMARK  <APRO-CMD/SCALE=1.00000000>
REMARK  <APRO-CMD/TULDES=>
LOADTL /4,ADJUST,4,LENGTH,4.8
PREFUN /58,NOW
SPINDL /9000,CLW
FEDRAT /30,IPM
COOLNT /ON
RAPID
GOTO   /1.31,.82,2
CYCLE/DRILL,.1719229,30,IPM,.1,2,PULBAC,98
GOTO   /1.31,.82,.1
GOTO   /-1.31,-.82,.1
CYCLE/OFF
GOHOME/1
REWIND
FINI
```

FIGURE 15-8
AutoPro generated CL file

construction of the CL file. While most CAD/CAM systems produce some APT-looking form of CL, AutoPro outputs standard APT CL data. Figure 15-9 is the resulting tape image file.

SOLID MODELING SYSTEMS

Solid modeling systems are the next evolution in CAD/CAM. There are two main features that distinguish a solid modeling system from today's CAD/CAM. The part is rendered as a solid model and second, the NC program is associated with this model. These terms are explained in the sections that follow. Two of the more common solid modeling systems in use today are Pro/Engineer, manufactured by Parametrics Technology Corporation, and CATIA, manufactured by IBM.

The Model

The part image used in a solid modeling system is represented as a solid object rather than as a "wire-frame" object. The part is rendered with

```
%
(   SV002675)
(AUTOPRO - POSTED ON 06/09/99 09.09.33 THRU UNCX01,25)
N1G20G91
N2G28G0Z0.
N3G30G0G91X0.Y0.M1
N4G90
(——————————————————)
(P/N 2783455-101 OP 060 SV002675 REV D)
(——————————————————)
(TL/1 7/16" CARBIDE END MILL)
(ROUGH & FINISH PROFILE)
(USE CRO #1)
N5G90G10L2P5X-23.2500Y-15.0010Z-23.5300
N6G40G80G90G17G98G8P0
N7T1M6
N8T2
N9G58
N10G08P1
N11S8000M3
N12M8
N13G0G41X-2.5Y2.5D1
N14G43Z3.87H1
N15G1X-1.7988Y1.7988F100.
N16X1.7988
N17Y-1.7988
N18X-1.7988
N19Y1.7988
N20X-1.188Y1.7488F70.
N21G2X-.701Y1.4659I0.J-.5608
N22G3X-.6994Y1.4654I.0011J.0007
N23G2X.6994Y1.4654I.6994J-1.4654
N24G3X.701Y1.4659I.0005J.0012
N25G2X1.7487Y1.188I.487J-.2779
N26G1Y.82
N27G2X1.5586Y.4585I-.4387J0.
N28G3X1.5581Y.4571I.0007J-.0011
N29G2X1.4654Y-.6994I-1.5581J-.4571
N30G3X1.4659Y-.701I.0012J-.0005
N31G2X.701Y-1.4659I-.2779J-.487
N32G3X.6994Y-1.4654I-.0011J-.0007
N33G2X-.6994Y-1.4654I-.6994J1.4654
N34G3X-.701Y-1.4659I-.0005J-.0012
N35G2X-1.7487Y-1.188I-.487J.2779
N36G1Y-.82
N37G2X-1.5586Y-.4585I.4387J0.
N38G3X-1.5581Y-.4571I-.0007J.0011
N39G2X-1.4654Y.6994I1.5581J.4571
N40G3X-1.4659Y.701I-.0012J.0005
N41G2X-1.188Y1.7487I.2779J.487
N42G1X-.5407Y1.5852F35.
N43G2X-.727Y1.4511I-.2551J.1579F10.
N44G3X-1.4511Y.727I-.461J-.2631F35.
N45G2X-1.4384Y.6864I-.0155J-.0271
N46G3X-1.5293Y-.4486I1.4384J-.6864
N47G2X-1.5416Y-.4832I-.03J-.0088
N48G3X-1.7187Y-.82I.2316J-.3368
N49G1Y-1.188
N50G3X-.727Y-1.4511I.5307J0.
N51G2X-.6864Y-1.4384I.0271J-.0155
N52G3X.6864Y-1.4384I.6864J1.4384
N53G2X.727Y-1.4511I.0135J-.0282
N54G3X1.4511Y-.727I.461J.2631
N55G2X1.4384Y-.6864I.0155J.0271
N56G3X1.5293Y.4486I-1.4384J.6864
N57G2X1.5416Y.4832I.03J.0088
N58G3X1.7187Y.82I-.2316J.3368
N59G1Y1.188
N60G3X.727Y1.4511I-.5307J0.
N61G2X.6864Y1.4384I-.0271J.0155
N62G3X-.6864Y1.4384I-.6864J-1.4384
```

FIGURE 15-9
(Continues on next page)

```
N63G2X-.727Y1.4511I-.0135J.0282
N64G1Y1.5511
N65G08P0
N66M109
N67G91G0G28Z0.M5
N68G30X0.Y0.M19
N69M1
(——————————————————)
(TL/ 2 1/2  X 100 DEG. SPOT DRILL)
N70G40G80G90G17G98G8P0
N71T2M6
N72T3
N73G58
N74S5000M3
N75M8
N76G0X-1.188Y1.188
N77G43Z8.H2
N78G81G98X-1.188Y1.188Z5.979R6.2F20.
N79X1.188
N80X1.31Y.82
N81X1.188Y-1.188
N82X-1.188
N83X-1.31Y-.82
N84G80
N85M109
N86G91G0G28Z0.M5
N87G30X0.Y0.M19
N88M1
(——————————————————)
(TOOL / 3 - .2992 DIA. HSS DRILL)
N89G40G80G90G17G98G8P0
N90T3M6
N91T4
N92G58
N93S3920M3
N94M8
N95G0X-1.188Y1.188
N96G43Z7.8H3
N97G81G98X-1.188Y1.188Z5.6892R6.F23.52
N98X1.188
N99Y-1.188
N100X-1.188
N101G80
N102M109
N103G91G0G28Z0.M5
N104G30X0.Y0.M19
N105M1
(——————————————————)
(TOOL /4 - .1695 HSS DRILL)
N106G40G80G90G17G98G8P0
N107T4M6
N108G58
N109S9000M3
N110M8
N111G0X1.31Y.82
N112G43Z6.8H4
N113G81G98X1.31Y.82Z4.7281R5.F30.
N114X-1.31Y-.82
N115G80
N116M109
N117G91G0G28Z0.M5
N118G30X0.Y0.M19
N119M1
N120M30
%
```

FIGURE 15-9
AutoPro generated tape image file

such detail that even its shadows are represented in the display. The solid part drawing is a complete graphical representation of the finished part or part assembly and it looks like a 3-d photograph. For this reason, the part or assembly drawings are called *models.*

Associativity

The tool paths defined to a solid modeling system are programmatically related to the part model. If the model changes, the program tool paths are automatically changed. All the program needs to do is "regenerate" the tape image file. This linking of the part program to the model is called *associativity.*

How Solid Modeling Organize Work

Solid modeling systems organize their part and NC program data in databases; the model is sometimes referred to as the part database. The underlying database structure or the system allows the associating of program data to part data.

From the NC programmer's perspective, solid modeling systems organize their data, like CAD/CAM systems, by tool sequences. Rather than storing the data in a series of tool related files, the tool sequence data is stored in a tool path database that is related to the part geometry database.

Because of their capability, solid modeling systems require more powerful computers to run than their CAD/CAM counterparts. Until recently, these systems could only run on high-powered workstations and minicomputers. The advent of the Intel Pentium processors, high-end graphics cards, and the Windows NT operating system have allowed solid modeling systems to run on the PC platform.

A Solid Modeling Example

Figure 15-10 illustrates a part programmed using Pro/Engineer. Notice the solid representation of the part. A model of the fixture was linked to the part model to allow the programmer to see how the part and fixture were mounted together on the machine tool. Figure 15-11 is the CL file resulting from processing the program. Again, notice the APT-like syntax of this CL data. Figure 15-12 is the finished tape image file. Solid modeling systems tend to generate large program files. For the sake of brevity, only a section of the CL and tape image files are shown in these figures.

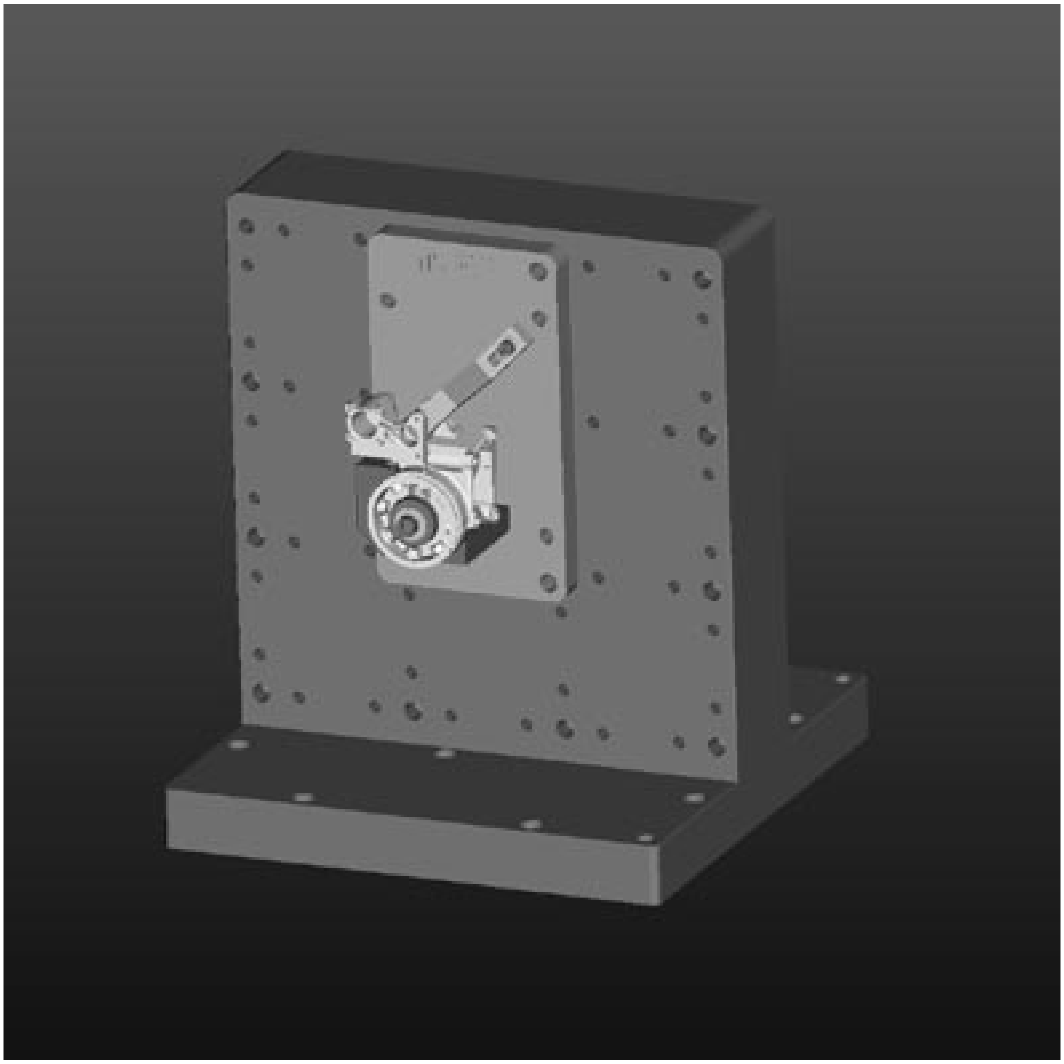

FIGURE 15-10
Part programmed using PRO/ENGINEER

```
$$*    Pro/CLfile   Version 2000i - 1999390
$$-> MFGNO / 5993235_101
PARTNO / 5993235_WORK
$$-> FEATNO / 47
MACHIN / SV500, 01
UNITS / INCHES
$$-> BLOCK_START /
PALLET / 1
$$-> BLOCK_END /
PPRINT / PART NAME : 5993235_WORK
PPRINT / DATE TIME : 14-FEB-00 15:50:47
PPRINT / OPERATION NAME : OP010
PPRINT /      TOOL TABLE SUMMARY
PPRINT / TOOL NUMBER TOOL ID OFFSET NO   TOOL COMMENT
PPRINT /      116    TOOL116 116    .750 DIA RELIEVED ENDMILL
PPRINT /      117    TOOL117 117    3.0 DIA FACE MILL
$$-> BLOCK_START /
INSERT G90 G10 L2 P1 X-12.403 Y-15.132 Z-31.4955
INSERT G90 G10 L2 P2 X-12.403 Y-16.2810 Z-31.4955
INSERT G90 G10 L2 P3 X-12.6862 Y-11.2092 Z-31.4655
INSERT G90 G10 L2 P4 X-12.615 Y-11.2092 Z-31.400
$$-> BLOCK_END /
PPRINT / NC SEQUENCE NAME : RGH_B0
PPRINT /      NC SEQUENCE COMMENTS
PPRINT / RGHS B0 OP10
LOADTL / 117,   OSETNO,   117 $$-> 3.0 DIA FACE MILL
$$-> CUTTER / 3.000000
SET / OFSETL,   54
$$-> CSYS / 1.0000000000, 0.0000000000, 0.0000000000, 0.0000000000,   $
            0.0000000000, 1.0000000000, 0.0000000000, 0.0000000000,   $
            0.0000000000, 0.0000000000, 1.0000000000, 0.0000000000
SPINDL / RPM, 12000.000000,   CLW
COOLNT / ON
RAPID
GOTO / 5.5000000000, 7.9705723359, 4.2500000000
FEDRAT / 150.000000,   IPM
GOTO / 5.5000000000, 7.9705723359, 4.0250000000
GOTO / 5.5000000000, 4.9705723359, 4.0250000000
GOTO / -5.5000000000, 4.9705723359, 4.0250000000
GOTO / -5.5000000000, 3.7229723359, 4.0250000000
GOTO / 5.5000000000, 3.7229723359, 4.0250000000
GOTO / 5.5000000000, 2.4753723359, 4.0250000000
GOTO / -5.5000000000, 2.4753723359, 4.0250000000
GOTO / -5.5000000000, 1.2277723359, 4.0250000000
GOTO / 5.5000000000, 1.2277723359, 4.0250000000
GOTO / 5.5000000000, -0.0198276641, 4.0250000000
GOTO / -5.5000000000, -0.0198276641, 4.0250000000
GOTO / -5.5000000000, -1.2674276641, 4.0250000000
GOTO / 5.5000000000, -1.2674276641, 4.0250000000
GOTO / 5.5000000000, 7.9705723359, 4.0250000000
GOTO / 5.5000000000, 7.9705723359, 3.9250000000
GOTO / 5.5000000000, 4.9705723359, 3.9250000000
GOTO / -5.5000000000, 4.9705723359, 3.9250000000
GOTO / -5.5000000000, 3.7229723359, 3.9250000000
GOTO / 5.5000000000, 3.7229723359, 3.9250000000
GOTO / 5.5000000000, 2.4753723359, 3.9250000000
GOTO / -5.5000000000, 2.4753723359, 3.9250000000
GOTO / -5.5000000000, 1.2277723359, 3.9250000000
GOTO / 5.5000000000, 1.2277723359, 3.9250000000
GOTO / 5.5000000000, -0.0198276641, 3.9250000000
GOTO / -5.5000000000, -0.0198276641, 3.9250000000
```

FIGURE 15-11

(Continiues on next page)

```
GOTO / -5.5000000000, -1.2674276641, 3.9250000000
GOTO / 5.5000000000, -1.2674276641, 3.9250000000
GOTO / 5.5000000000, 7.9705723359, 3.9250000000
GOTO / 5.5000000000, 7.9705723359, 3.8250000000
GOTO / 5.5000000000, 4.9705723359, 3.8250000000
GOTO / -5.5000000000, 4.9705723359, 3.8250000000
GOTO / -5.5000000000, 3.7229723359, 3.8250000000
GOTO / 5.5000000000, 3.7229723359, 3.8250000000
GOTO / 5.5000000000, 2.4753723359, 3.8250000000
GOTO / -5.5000000000, 2.4753723359, 3.8250000000
GOTO / -5.5000000000, 1.2277723359, 3.8250000000
GOTO / 5.5000000000, 1.2277723359, 3.8250000000
GOTO / 5.5000000000, -0.0198276641, 3.8250000000
GOTO / -5.5000000000, -0.0198276641, 3.8250000000
GOTO / -5.5000000000, -1.2674276641, 3.8250000000
GOTO / 5.5000000000, -1.2674276641, 3.8250000000
GOTO / 5.5000000000, 7.9705723359, 3.8250000000
GOTO / 5.5000000000, 7.9705723359, 3.7250000000
GOTO / 5.5000000000, 4.9705723359, 3.7250000000
GOTO / -5.5000000000, 4.9705723359, 3.7250000000
GOTO / -5.5000000000, 3.7229723359, 3.7250000000
GOTO / 5.5000000000, 3.7229723359, 3.7250000000
GOTO / 5.5000000000, 2.4753723359, 3.7250000000
GOTO / -5.5000000000, 2.4753723359, 3.7250000000
GOTO / -5.5000000000, 1.2277723359, 3.7250000000
GOTO / 5.5000000000, 1.2277723359, 3.7250000000
GOTO / 5.5000000000, -0.0198276641, 3.7250000000
GOTO / -5.5000000000, -0.0198276641, 3.7250000000
GOTO / -5.5000000000, -1.2674276641, 3.7250000000
GOTO / 5.5000000000, -1.2674276641, 3.7250000000
GOTO / 5.5000000000, 7.9705723359, 3.7250000000
GOTO / 5.5000000000, 7.9705723359, 3.6250000000
GOTO / 5.5000000000, 4.9705723359, 3.6250000000
GOTO / -5.5000000000, 4.9705723359, 3.6250000000
GOTO / -5.5000000000, 3.7229723359, 3.6250000000
GOTO / 5.5000000000, 3.7229723359, 3.6250000000
GOTO / 5.5000000000, 2.4753723359, 3.6250000000
GOTO / -5.5000000000, 2.4753723359, 3.6250000000
GOTO / -5.5000000000, 1.2277723359, 3.6250000000
GOTO / 5.5000000000, 1.2277723359, 3.6250000000
GOTO / 5.5000000000, -0.0198276641, 3.6250000000
GOTO / -5.5000000000, -0.0198276641, 3.6250000000
GOTO / -5.5000000000, -1.2674276641, 3.6250000000
GOTO / 5.5000000000, -1.2674276641, 3.6250000000
GOTO / 5.5000000000, 7.9705723359, 3.6250000000
GOTO / 5.5000000000, 7.9705723359, 3.5250000000
GOTO / 5.5000000000, 4.9705723359, 3.5250000000
GOTO / -5.5000000000, 4.9705723359, 3.5250000000
GOTO / -5.5000000000, 3.7229723359, 3.5250000000
GOTO / 5.5000000000, 3.7229723359, 3.5250000000
GOTO / 5.5000000000, 2.4753723359, 3.5250000000
GOTO / -5.5000000000, 2.4753723359, 3.5250000000
GOTO / -5.5000000000, 1.2277723359, 3.5250000000
```

FIGURE 15-11
PRO/ENGINEER generated CL file

```
%
( / 5993235_WORK)
(POSTED ON 02/14/00 15.51.50 THRU UNCL01,82)
N1 G20 G90
N2 M79
N3 G28 G91 B0.
N4 M92
N5 G61
N6 M77
N7 G64
N8 G30 G0 G91 X0. Y0. Z0. M1
N9 G90
(PART NAME : 5993235_WORK)
(DATE TIME : 14-FEB-00 15:50:47)
(OPERATION NAME : OP010)
(TOOL TABLE SUMMARY)
(TOOL NUMBER  TOOL ID OFFSET NO   TOOL COMMENT)
(116        TOOL116   116   .750 DIA RELIEVED ENDMILL)
(117        TOOL117   117   3.0 DIA FACE MILL)
N10G90G10L2P1X-12.403Y-15.132Z-31.4955
N11G90G10L2P2X-12.403Y-16.2810Z-31.4955
N12G90G10L2P3X-12.6862Y-11.2092Z-31.4655
N13G90G10L2P4X-12.615Y-11.2092Z-31.400
(NC SEQUENCE NAME : RGH_B0)
(NC SEQUENCE COMMENTS)
(RGHS B0 OP10)
N14 G98 G40 G80 G90 G17
N15 T117 M6
N16 T116
N17 G54
N18 S6300 M3
N19 G0 X5.5 Y7.9706
N20 G43 Z4.25 H117 M8
N21 G8 P1
N22 G1 Z4.025 F150.
N23 Y4.9706
N24 X-5.5
N25 Y3.723
N26 X5.5
N27 Y2.4754
N28 X-5.5
N29 Y1.2278
N30 X5.5
N31 Y-.0198
N32 X-5.5
N33 Y-1.2674
N34 X5.5
N35 Y7.9706
N36 Z3.925
N37 Y4.9706
N38 X-5.5
N39 Y3.723
N40 X5.5
N41 Y2.4754
N42 X-5.5
N43 Y1.2278
N44 X5.5
N45 Y-.0198
N46 X-5.5
N47 Y-1.2674
N48 X5.5
N49 Y7.9706
N50 Z3.825
N51 Y4.9706
N52 X-5.5
N53 Y3.723
N54 X5.5
N55 Y2.4754
N56 X-5.5
N57 Y1.2278
N58 X5.5
N59 Y-.0198
N60 X-5.5
N61 Y-1.2674
```

FIGURE 15-12
(Continiues on next page)

```
N62 X5.5
N63 Y7.9706
N64 Z3.725
N65 Y4.9706
N66 X-5.5
N67 Y3.723
N68 X5.5
N69 Y2.4754
N70 X-5.5
N71 Y1.2278
N72 X5.5
N73 Y-.0198
N74 X-5.5
N75 Y-1.2674
N76 X5.5
N77 Y7.9706
N78 Z3.625
N79 Y4.9706
N80 X-5.5
N81 Y3.723
N82 X5.5
N83 Y2.4754
N84 X-5.5
N85 Y1.2278
N86 X5.5
N87 Y-.0198
N88 X-5.5
N89 Y-1.2674
N90 X5.5
N91 Y7.9706
N92 Z3.525
N93 Y4.9706
N94 X-5.5
N95 Y3.723
N96 X5.5
N97 Y2.4754
N98 X-5.5
N99 Y1.2278
N100 X5.5
N101 Y-.0198
```

FIGURE 15-12
PRO/ENGINEER generated tape image file

VOCABULARY INTRODUCED IN THIS CHAPTER

Associativity
Automatic programmed tools (APT)
Centerline data file (CL file)
Computer-aided design (CAD)
Computer-aided manufacturing (CAM)
Computer-assisted programming
Offline programming
Solid Modeling
Postprocessing
Postprocessor

REVIEW QUESTIONS

1. What are the four ways computers are used in numerical control programming?
2. What is offline programming?
3. What does computer-aided programming allow the programmer to do?
4. What are the basic parts of a computer-aided programmig system?
5. Describe how an APT program generates an NC program.
6. Describe how a CAD/CAM system generates an NC program.
7. How does a solid modeling system different from a CAD/CAM system?