ANNOUNCER: The Massachusetts Institute of Technology presents *Science Reporter.* Tonight's subject, APT.

Now here is your host Mr. Robert Woodbury.

WOODBURY: The parts you see here were made by using a new technique in the application of electronic controls to machine tools. The most recent development in this technique is called APT, "apt"-- automatically programmed tools.

Tonight, we have two of the men who were the leaders in the inception and development of this system. J. Francis Reintjes-- associate professor of electrical engineering and director of the Servomechanisms Laboratory at MIT-- and Douglas T. Ross-- head of the computer applications group of the Servomechanisms Laboratory.

We are all aware that we live in an industrial society, and that this way of life has been made possible largely by technical advance. Our jobs, our cars, our TVs, our clothes, much of our food, and even our vacation travel are provided for us by modern industrial enterprise.

When we try to understand how this industrial society came to be and how it works today, we think at once of the steam engine and the electric generator as its sources of power. We think of steel, aluminum, and plastics as new materials used to make products for our own use. A few of us are even familiar with some of the thousands of kinds of complex machinery used to work our farms, to make our clothes, even to bring us entertainment. But too often, we do not realize the importance of a little known, but crucial, kind of technical machine-- the type without which the rest would not be possible-- the machine tool.

Today the machine tool industry, although economically not one of our largest, is fundamental for our entire industrial society either in war or in peace. During the last 150 years, these machine tools-- in order to meet the demands of industry-- have become larger and more powerful, capable of more and more precision, and more and more automatic. They have, in fact, become so versatile and complex that they are capable of operation beyond the speed and skill of even the most experienced machinist.

In order to produce many of the intricate parts required today rapidly and cheaply and to make it possible to use our limited pool of highly skilled labor for other purposes, and new breakthrough was required. About seven years ago, the Massachusetts Institute of Technology successfully completed for the United States Air Force the development of an electronic device to operate machine tools by means of a series of holes punched in a tape and using the principle called Numerical Control.

Controls of this type have since then been extensively applied to several kinds of machine tools in industry, but even this complicated device had its bottleneck. Just recently, another breakthrough has eliminated many of the difficulties of the numerically controlled machine tool. This new approach resulted in the APT, or the automatically programmed tool.

Professor Reintjes, what are numerically controlled machine tools, and how do they work?

REINTJES: Well, Professor Woodbury, Numerical Control signifies a special way of controlling the movements of machine tools automatically through the use of coded numbers. These coded numbers appear as perforations on a piece of paper tape and contain all the information needed to guide the motions of the machine tool or [INAUDIBLE] the work.

The coded numbers which you see here are fed into an electronic device, which we call an electronic director. Electronic director in turn generates electrical signals, which operates servomechanisms, which in turn controls the machine tool.

Now Numerical Control began about 10 years ago here at MIT, and it took about 2 and 1/2 years from the start of the project to demonstrate its feasibility. In 1952, the feasibility of Numerical Control was proved out. And shortly thereafter, industry-- particularly the aircraft industry-- became interested in Numerical Control. And about two years ago, these machines began to appear on the production floors of aircraft companies.

These machines have special features which make them very attractive for use in the aircraft industry. Here, we see one of these machines on the floor of a plant of the Boeing Aircraft Company in Seattle, Washington. This is a numerically controlled skin mill. It is used for milling the wing skins of modern aircraft. Here, you see the numerical instructions being fed to the machine tool.

This is a large machine-- probably the largest-- to which Numerical Control has ever been applied. It has a bed plate approximately 80 feet long and a width of about 14 feet. Note that there are actually two cutting heads-- the other one on the left side, which you can see in a moment-- is not being used.

Any shape contour can be cut with Numerical Control. There's another shot of the numerical commands. The tool now is being withdrawn on the side of the workpiece. Pretty soon the tool will be withdrawn.

WOODBURY: Well, as I understand it then, the operator doesn't have to control this machine. It is done entirely by the tape and the electronic device.

REINTJES: Well, that's right Bob. You'll notice that there was no human operator required in this entire process.

WOODBURY: Well, now if we have been using these numerically controlled machines successfully for two years now, what is the need for this APT, or "apt."

REINTJES: Well, let's take a look at this diagram over here.

The key to Numerical Control is the instructions contained on this piece of paper tape. In order to get these instructions however, there is a large amount of data processing required because the basic information is contained on an engineering drawing like this.

From the engineering drawing here, we processed the data to get the numerical commands. Now, up to date, most of this data processing has been done manually by human operators with the aid of simple machine devices like desk calculators. In a few instances computers have been used.

Now, APT will materially reduce the time required to process this data. Through use of act, we can go very quickly therefore from this engineering drawing, through the data processing, and then get the Numerical Commands. And it will materially cut down the amount of time to machine a part like this, for example.

WOODBURY: Frank, this part here-- this actually made on an APT setter?

REINTJES: Yes, Bob. That's right. It was programmed through use of APT and machines over in our laboratory.

WOODBURY: Good. Well, this explains then the need for APT. Mr. Ross, could you tell us just what the APT system is and how it is used.

ROSS: Yes, I'd be glad to. We made up a chart here showing all of the important steps, and I think it gives about the clearest description of the overall procedure as well as the parts of the system itself.

The process begins, of course, with the designer conceiving of the part which he desires to have made. His first step is to go to the draftsman to make a detailed drawing of the part. Now, this drawing, at present, has a different form than existing drafting procedures-- slightly different-- in order to make the numerical information available. But also, we hope that with the further development of the APT system, the amount of detail can be greatly reduced and a lot of this information taken over by the APT language itself.

Now, once the drawing has been made, it is passed along to a new man in the picture. This is the part programmer, and he is the man who is trained in metal cutting and tooling and knows how to use this APT language and describe all of the information on the drawing in the manuscript form. So his job then is to take the information from the drawing and transcribe it in English-like statements. The spelling of the words is a little different, and we have rather peculiar punctuation at the present time. But essentially, this language is very close to English.

The complete instructions then describing both the geometry of the part and the tool motions required to make the part are written in this language on the manuscript. Then the manuscript is passed over to a keypunch operator, and this girl merely transcribes on an ordinary typewriter keyboard the language statements on the manuscript. And for every key that she touches on the keyboard, a unique pattern of holes is punched in the column on the card so that when she is done, she has transcribed all of the manuscript information into a form which can be read by a computer.

Now, the difficulty is that the APT language can be read only by an APT computer, and unfortunately nobody has such a device. Instead of going to the extra expense and engineering of designing a special computer with the proper characteristics, what we do is take a general purpose computer, which at this time it cannot read the cards and make sense out of them, but by reading in a master deck which we have written-- reading in this master deck of cards, allows the general purpose computer to masquerade as this APT computer which we would like to have. The APT computer can understand the statements punched on the cards in the APT language, and it can perform many intermediate operations of language translation, tool center corrections, and the last step is to translate the tool motions into the language of the machine tool director system.

Now, actually the last part of the APT system program now includes provisions for producing this information in many different punched tape languages. And in fact, the system also checks to make sure that the machine tool will be able to cut the part to the required tolerance. Some machines are larger than others, and the very large ones can't turn corners as quickly as the smaller ones so that in some cases, the APT system will automatically put in the proper slowdown so that no matter what machine tool system is being used, the part is produced to the required tolerance.

Then of course once the punched tape has been achieved, the next step is to put it into the electronic director. And from there on, the process is fully automatic, and the part is produced. And you can make as many or as few of these parts as you need.

WOODBURY: Doug, you've mentioned this APT language. Just how is this language actually used?

ROSS: Well, I think we can illustrate that best by making use of this same part that we had before.

We have here the part that was used previously, and notice that it is now machined to serve as an ashtray. But actually in the original design, it was intended to act as a rocker arm cam. Now, in other words, it has a circular top and a pivot point at the bottom, and in use, would have some running member working on the upper surface.

Now, let's look at the information that is on the blueprint for this particular part. Now, here is a drawing which doesn't have the same characteristics as a normal blueprint. In fact, it has less than is usual even for a Numerical Control so that we could illustrate the features of the language.

So here is the rocker arm cam, and the top surface is to be a circle of four-inch radius. And it is to be pivoted at a point which is 5 inches below the top most point of the circle.

Now, the corners are to be filled out with half-inch radius circles, and we want to have room for a bearing down here with another half inch circle. And the sides are completed by two straight lines tangent to these circles.

Now, we will see later on that we run into a little bit of a problem because this point right down here-- the lower point, the center of that circle-- is defined only in terms of its relationship to the top circle, which in turn is defined only in relationship to these two side circles-- its tangent to both of those circles.

So you can see that this point down at the bottom here is not very well determined. It's specified all right, but we have quite a bit of intermediate steps that need to be done before we can actually locate that point.

Now, let's go on to the steps that the part programmer goes through.

The first thing that he does-- here's the part program, and we'll go through some of the actual instructions here to see how they work. Let's skip these first three lines. We'll come back to those later. They serve a very important function, but we'll save that.

The first thing that the part programmer does is to write down this first set of information. He says that the tool radius that he's going to use is to have a half-inch radius. The tolerance that he wants for approximating curves by the machine tools themselves can only cut little straight lines so that every curve must be approximated by a sequence of little straight lines. So the tolerance to which that approximation should be valid we want to be a hundredth of an inch.

The feed rate, or speed at which the tool is to move, is 7 and 1/2 inches per minute. I think you can see that these statements here, although condensed and spelled in a peculiar way, are actually quite close to normal English use.

Now, the next two statements here are ones that we won't spend any time with. They're needed for the present interim system, which is just a beginning system, but these will automatically be put in by later systems.

Now, having these things out of the way, the part programmer knows that the system will not ring alarm bells on him. He's got the necessary things stated. So now he can decide how the tool is to go.

Now, let's look over here at this drawing. Here's the tool path that he would like to use. He'd like the tool to start up in the air, move down to the bed of the tool, and then over in this direction, go past this extension of the line, and then start down. Now, reason for this is so that we get a nice smooth start on the part.

Then the tool proceeds around all of the curves and comes back to the beginning just far enough to complete the part, then retracts into the air, and moves back to the starting point. The machinist, the machine operator, can tell from dials on the machine control system that the machine has returned exactly to the point where it started so that this gives him a check as to the machine's operation.

Now, let's look at the language that carries this out. He wanted to start from this point up in the air. So he writes down from point so-and-so. And these numbers here give the x, y, and z-coordinates of the point in space. Then he wants to go to another point. And in the direction of a vector that points to the left, he wants to go past the line.

Now, notice over here that the line is defined as a tangent to this little circle in the corner and this circle at the bottom, and we haven't yet specified anything about those circles. So first, in order to find that line, we must do some constructions with the language which actually correspond to the operations that a draftsman normally would go through.

Now, let's take just a few of these lines and see how the language works. Circle 1 is the name that I want to give to the circle whose center is at x equals 0, y will 0, and radius 1/2 inch.

Over here on this diagram here, here is circle 1 at (0, 0) with radius 1/2 inch.

Now in order to find this lower point down here, we must do some constructions. And I won't go into the details of this, but what a draftsman would do is take his compass and swing these two large arcs determining the lower point, then construct a line passing through those points, and intersect with that line a circle around here of the proper radius so that where it intersected would locate this unknown point of the bottom circle.

Remember we said that that would give us a problem, but now our problem is solved. All we have to do is, using the language, to describe the construction of all these circles and intersections and so forth, and we come out with the desired point. Then we can define this circle. And using that with circle 1, we can then say that line 2 is tangent to it.

So let's refer back here. Here are the lines of the part program that carry out these operations. For instance here-- line one-- is the line through point A at an angle of 90 degrees with the x-axis. Very English-like where point A has been defined up here to be the y small intersection of circle 2 with circle 3.

So in this way then, the part programmer can construct things if he doesn't know them and get his part programming job done. Well, now at this point, he has line 2 defined. So all he has to say now is from the point where he was-- down here. Remember we were starting from here going in this direction. Now we want to go passed line 2. So that's what he writes.

And then with the tool on the right, go left a long line 2 and go forward along circle 5 where circle 5 is the name that we gave to the bottom circle and then introduce another definition of a circle because we haven't done it before. Then go forward on the line which is right tangent to circle 5 and right tangent to circle 6. This is to pick out the proper tangent line.

So in this way, we go through the entire procedure and come out with a complete part program.

WOODBURY: Doug, that shows us now how the part is originally made. How can we introduce any change in design which might be desired into this system.

ROSS: Well, that is why we left these top three lines until later. Notice that up here, we have given three symbolic names-- width, length, and rad. Now, these stand for essentially the width of the part, the length of the part, and the radius of this lower circle.

Now, by merely changing these three statements up here-- punching new IBM cards for these three statements here-- we can substitute into this program any numbers that we wish. And the system will then automatically substitute those numbers in the proper locations. For instance, width appears down here in the definition for a circle 3. The x-coordinate of the center is at width so that in this case, 3 would be substituted in here, and we would have the circle at the proper location.

Now, on our computer programs, we're using the IBM 704 computer at the computation center at MIT ourselves. And as part of the equipment of that computer, we have an output oscilloscope very much like a TV screen on which the computer can be programmed to draw pictures.

Now, here are some of the pictures that that program has made. Here is the ashtray, or the rocker arm cam, in a proper perspective. Now, in the next picture though-- believe it or not-- this is actually the same part only we've shrunk the top by means of these statements, and we've blown up by quite a great deal the lower circle. The design of the part is the same, but quite obviously, its dimensions have changed drastically. In actual use in aircraft plants such violent changes are unlikely, but we have a illustration here.

Here is the complete tool path for making the ashtray. You can see the tool center path in here, and these machine slots. And sort of the star of our show is from another network, but we did this program actually for my little girls. It's the most complicated part program that we have carried out. I think you can see it's Mickey Mouse, and we actually found some mistakes in our programs by means of this part.

WOODBURY: Thanks, Doug.

Frank, how long did it take to develop this APT? And was it done entirely at MIT?

REINTJES: Well, Bob, the original concept of APT was created at MIT by Doug and his group. And it required a relatively short period of time to prove out-- approximately 2 and 1/2 months. However, to work out all the details of programming to convert a general purpose computer into an APT computer took an appreciably longer period of time-- about 2 and 1/2 years in fact.

Fortunately, we had available to us the cooperation of 19 aircraft plants in this job of programming. Through the efforts of the aircraft Industry Association and these 19 aircraft plants, we were able to get an appreciable amount of programming time from them. And thus we were able to complete APT in a fairly reasonable time for the size of the job that had to be done.

WOODBURY: Doug, I notice that on this little part, we referred to the existing setup as APT 2, and I'm told that there is an APT 3 program underway. What is in the future of APT 2, and could you tell us a little something about what is to be done in APT 3?

ROSS: Certainly. As you can see, this part here was made with the APT 2 system, and the APT 2 stands for a system which is programmed in terms of curves in space. This is actually a saddle surface in here, and the curves go up and down. But each one of these passes required a separate statement.

Now, in APT 3, we had a research program of this sort for about two years now. And in APT 3, the entire region is machined at one time by means of one APT statement. In other words, you specify what surface you wish and what the outside pass is, and the system automatically puts on many hundreds of individual straight line cuts so that the entire part is machined to the required tolerance. This one is actually cut to a coarse tolerance for illustrative purposes.

WOODBURY: Frank, what are some of the influences which this APT is expected to have on industry other than just the convenience of doing this programming more rapidly and more simply?

REINTJES: Well, I do feel, Bob, of course, an important aspect of APT is the great saving in programming time which will result. One aircraft plant, for example, has reduced the programming time on a particular part from 200 man hours down to 5 man hours through use of APT. And this saving is appreciable.

Now, when you begin to realize that this technique is particularly useful in the manufacture of air vehicles, you can see savings of this kind are important, not only in terms of dollars, but also in terms of getting new vehicles more quickly.

WOODBURY: It has a very real military value as well for industry in general.

REINTJES: It certainly does. Of course it has use in other industries besides the aircraft industry. The automobile industry, for example, might find it useful in the manufacturing of its tools and dies.

WOODBURY: Good. Well, we're most grateful to you, Professor Reintjes and Mr. Ross, for telling us about this new technological development. I'm sure we have a better conception of the remarkable advances which are bringing about a revolution in machine tools and so contributing to the strength of the free world.

ANNOUNCER: *Science Reporter* has been presented by the Massachusetts Institute of Technology. Your host for this program on APT was Robert S. Woodbury, assistant professor of the history of technology at MIT.

His guests were J. Francis Reintjes-- associate professor of electrical engineering and director of the Servomechanisms Laboratory at MIT-- and Douglas Ross-- head of the computer applications group at the MIT Servomechanisms Laboratory.