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An Industry Perspective on the Beginnings of CAD

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Abstract. This paper is a discussion of the early days of CAM-CAD at The Boeing Company, covering the period approximately 1956 to 1965. This period saw probably the first successful industrial application of ideas that were gaining ground during the very early days of the computing era. Although the primary goal of the CAD activity was to find better ways of building the 727 airplane, this activity led quickly to the more general area of computer graphics, leading eventually to today's picture-dominated use of computers. The paper started as an internal exchange of memories between some of the people primarily concerned, but is now offered as the possible start of a discussion involving other such initiatives during that period.

Categories and Subject Descriptors: J.2[Physical Science and Engineering]: Aerospace; J.6[Computer-Aided Engineering]: CAD, CAM; K.2[History of Computing]: Hardware, Systems

General Terms: Design, Measurement

Keywords: CAM, CAD, Boeing, Numerical control, Digital plotters

1. INTRODUCTION

Several independent early steps had taken place towards the idea of computer-aided design (CAD) during the early 1960s. CAD is the use of computer technology to aid in the design of a product [3]. That is, it is the mathematical definition of lines and surfaces for drawing lines and cutting parts with the computer.

Computer-aided manufacturing (CAM) comprises the use of computer-controlled manufacturing machinery to assist engineers and machinists in manufacturing or prototyping product components, either with or without the assistance of CAD. CAM certainly preceded CAD and played a pivotal role in bringing CAD to fruition by acting as a drafting machine in the very early stages. All early CAM parts were made from the engineering drawing. The origins of CAM were so widespread that it is difficult to know whether any one group was aware of another. However, the NC machinery suppliers, Kearney & Trecker etc., certainly knew their customers and would have catalyzed their knowing one another, while the Aero-Space industry traditionally collaborated at the technical level however hard they competed in the selling of airplanes.

Some early attempts at CAD and CAM systems occurred in the 1950s and early 1960s. We can trace the beginnings of CAD to the late 1950s when Dr. Patrick J. Hanratty developed Pronto, the first commercial numerical-control programming system. In 1960, Ivan Sutherland at MIT's Lincoln Laboratory created Sketchpad, which demonstrated the basic principles and feasibility of

computer-aided technical drawing [5]. A brief history of the subject appears at [2].

2. PERSONAL ENTRIES

This work shows how CAD developed at a time when confidentiality and corporate loyalty was prevalent in many industrial settings. This story is a highly personal rendition of what we believe to be an independent development of CAD. It includes a description of the earlier implementation of CAM, without which CAD could not have happened, given the computer technology of the time.

2.1 The Introduction of Computer-Aided Manufacturing (CAM) in the Boeing Aerospace Factory in Seattle, by Ken McKinley

When I joined Boeing in 1952, fresh out of college, our most advanced computers in support of Engineering were CPC's (Card Programmed Calculators). Early in 1953 an IBM 701 was installed, our first electronic computer. (IBM said they would install a total of 18 of them and that was all the world would ever need.)

Already in 1956 Boeing ordered a range of newfangled Numerically-Controlled machine tools (how quickly the world became complicated), and Dr. Jim Price and I, under the supervision of Ed Carlberg, were assigned the task of working with Manufacturing to provide a solution to the task of converting the drawing of a part to be milled to the languages of the machines.

I mention Jim Price (one of the smartest and nicest persons I have known) because he was picked to solve the mathematical problems. For example wing surfaces and body shapes were usually defined as cross sections drawn by splines and ducts, a carry-over from boat building. One of Jim's contributions was a program that simulated the spline with a formula (given sufficient points).

Ed Carlberg brought together a group of programmers and Manufacturing engineers under my lead, about 15 as I remember, from Seattle and Wichita to design and implement the needed system. We had to train many of them to program the IBM 704. (Some of the Wichita people were trained on COBOL which created some interesting conflicts.) We decided not to use FORTRAN because it was brand new and appeared to be more suited to formula programming (it had as yet no subroutine facility), whereas we were designing a system on the order of an assembler or compiler.

Concurrent with the training we were working with the Manufacturing personnel on the team about the design of the system. Based on my recent experience with the implementation of a "user friendly" assembler and compiler program on the Univac 1103A, (previously designed and implemented, prior to Fortran, by Mandy Grems on the IBM 704), I recommended that we develop a program to use the language of the Manufacturing Engineer to describe the part and the milling process to the computer. This would be the language used by those manufacturing personnel trained to be "Part Programmers". This approach was accepted by the manufacturing members and we then proceeded with the system design and its flow charting. We in Seattle then programmed the system on the IBM 704. The Wichita people went home and programmed the system for their IBM 705. The former became known simply as the Boeing System, while the latter was dubbed Waldo.

To the best of my knowledge the Seattle and the Wichita systems in terms of the part programming language were identical initially. Several years later Wichita went commercial with NC services and may have extended Waldo a bit over time, but I doubt that it could be identified as a totally different language.

A tough part of the programming effort was the "post processors". To make life interesting, each type of machine tool had a different physical input form; analog or digital magnetic tape, punched Mylar tape, or cards. They also had to accommodate differences in the format of each type of data. This required lots of discussion with the machine tool manufacturers - all very typical of a new industry before standards came about.

An interesting sidelight: we had one type of machine tool that required analog magnetic tape. To get to that medium we punched cards on the IBM 704 containing the post processor data. These went to downtown Seattle for conversion to Univac cards, then back to the 1103A for conversion to punched tape, which was sent to Wichita to

produce analog magnetic tape. The need to use the 1103A made it the world's largest, most expensive punched tape machine in the world.

Another sidelight: detecting and correcting part programming errors was a serious problem, both in time and material. The earliest solution was to do an initial cut on wood or plastic foam, or, on suitable machine tools, to replace the cutter with a pen or other type of scribe to "draw" the part. Thus the first ever use of an NC machine tool as a computer-controlled drafting machine.

Meanwhile the Air Force recognized that the cost and the diverse solutions of their many suppliers to the NC challenge was a serious problem. I assume that because of their association with MIT they were aware of the efforts of Processor Doug Ross to develop an NC computer language. Anyway I, as the Boeing representative, spent two weeks at the first APT (Automatic Programmed Tooling) meeting at MIT in late 1956, with representatives from many other aircraft related companies, agreeing on the basic concepts of a common system where each company would contribute a programmer to the effort for a year. We committed to support mainly the "post processor" area. Henry Pinter, one of our post processor experts, was sent to San Diego for a year, where the joint effort was based. As usually happened in those pioneering days it took more like 18 months to complete the project. After that we had to implement APT in our environment at Seattle.

Concurrent with the implementation we had to sell ourselves and the users on the new system. It was a tough sell believe me, as Norm Sanders was to discover later over at the Airplane Division. Our own system was working well after overcoming the many challenges of this new technology, which we called NC. The users of our system were not anxious to change to an unknown new language that was more complex. But upper management recognized the need to change, not least because of an important factor, the imminence of another emerging technology called *Master Dimensions*.

2.2 The Introduction of Computer-Aided Design (CAD) in the Boeing Airplane Division in Renton, by Norman Sanders

The year was 1959. I had just joined Boeing in Renton, Washington, at a time when professionals created all engineering design drawings by hand. Indeed, at that time all design drawings were made by hand; the definition of every motorcar, aircraft, ship and mousetrap consisted of lines drawn on paper, often accompanied by mathematical calculations where necessary and possible. What is more, all animated cartoons were drawn by hand. At that time, it would have been unbelievable that what was going on in the aircraft industry would have had any effect on The Walt Disney Company or anyone else in the cartoon industry. Nevertheless, it did. Hence, this is a strange fact of history that needs a bit of telling.

I was very fortunate to find myself working at Boeing during the years following the successful introduction of its 707 aircraft into the world's airlines. It exactly coincided with the explosive spread of large computers into the industrial world. A desperate need existed for computer power and a computer manufacturer with the capacity to satisfy that need. The first two computers actually to work started productive life in 1948 and 1949; these were at the universities of Manchester and Cambridge in England. The Boeing 707 started flying five years after that, and by 1958, it was in airline service. The stage was set for the global cheap travel revolution. This took everybody by surprise, not least Boeing. However, it was not long before the company needed a shorter-takeoff airplane, namely the 727, a replacement plane for the Douglas DC-3. In time, Boeing developed a smaller 737, and a large capacity airplane — the 747. All this meant vast amounts of computing and as the engineers got more accustomed to using the computer there was no end to their appetite.

And it should perhaps be added that computers in those days bore little superficial similarity to today's computers; there were certainly no screens or keyboards! Though the actual computing went at electronic speeds, the input-output was mechanical, using punched cards, magnetic tape and printed paper. In the 1950s, the computer processor was made of vacuum tubes, the memory of ferrite cores, while the large-scale data storage consisted of magnetic tape drives. We had a great day if the computer system didn't fail during a 24 hour run; the electrical and electronic components were very fragile. (See the pictures at the end.)

We would spend an entire day preparing for a night run on the computer. The run would take a few minutes and we would spend the next day wading through reams of paper printout in search of something, sometimes searching for clues to the mistakes we had made. We produced masses of paper. You would not dare *not* to print for fear of letting a vital number escape. An early solution to this was faster printers. About 1960 Boeing provided me with an ANalex printer. It could print one thousand lines a minute! We soon had a row of ANalex printers wall to wall as Boeing never bought one of anything. The timber needed to feed our computer printers was incalculable.

3. THE EMERGENCE OF COMPUTER PLOTS

With that amount of printing going on it occurred to me to ask the consumers of printout what they did with it all. One of the most frequent answers was that they plotted it. There were cases of engineers spending three months drawing curves resulting from a single night's computer run. A flash of almost heresy then struck my digital mind. Was it possible that we could program a digital computer to draw (continuous) lines? In the computing trenches at Boeing we were not aware of the experimentation occurring at research labs in other places. Luckily at Boeing we were very fortunate at that time to have a Swiss

engineer in our computer methods group who could both install hardware and write software for it; he knew hardware and software, both digital and analog. His name was Art Dietrich. I asked Art about it, which was to me the unaskable; to my surprise Art thought it was possible. So off he went in search of a piece of hardware that we could somehow connect to our computer that could draw lines on paper.

Art found two companies that made analog plotters that might be adaptable. One company was Electro Instruments in San Diego and the other was Electronic Associates in Long Branch, New Jersey. After yo-yoing back and forth, we chose the Electronic Associates machine. The machine drew lines on paper 30x30 inches, at about twenty inches per second. It was fast! Moreover, it was accurate—enough for most purposes. To my knowledge, this was the first time anyone had put a plotter in the computer room and produced output directly in the form of lines. It could have happened elsewhere, though I was certainly not aware of it at the time. There was no software, of course, so I had to write it myself. The first machine ran off punched cards, and I wrote a series of programs called Plot1, Plot2 etc. Encouraged by the possibility of selling another machine or two around the world, the supplier built a faster one running off magnetic tape, so I had to write a new series of programs called Tplot1, Tplot2, etc. (T for tape). In addition, the supplier bought the software from us, which was Boeing's first software sale!

While all this was going on we were pioneering something else. We called it *Master Dimensions*. Indeed, we pioneered many computing ideas during the 1960s. At that time Boeing was probably one of the leading users of computing worldwide and it seemed that almost every program we wrote was a brave new adventure. Although North American defined mathematically the major external surfaces of the wartime Mustang P-51 fighter, it could not make use of computers to do the mathematics or to construct it because there were no computers. An account of this truly epochal work appears in the book by Roy A. Liming [1].

By the time the 727 project was started in 1960, however, we were able to tie the computer to the manufacturing process and actually define the airplane using the computer. We computed the definition of the outer surface of the 727 and stored it inside the computer, making all recourse to the definition via a computer run as opposed to an engineer looking at drawings using a magnifying glass. This was truly an industrial revolution. The team who invented and implemented these ideas was led by Grant W. Erwin Jr. If ever there was an example of the right person being in the right place at the right time it was there. I do not believe we could have done what we did in the time allowed had we not had Grant Erwin. He was a superb leader and manager as well as numerical analyst. His group had to invent techniques to solve

problems the academicians had not yet attempted because they lived lives often so remote from the real world of engineering and manufacturing.

When the Master Dimensions group first wrote the programs, all we could do was print numbers and draw plots on 30x30 inch paper with our novel plotter. Mind-blowing as this might have been it did not do the whole job. It did not draw *full scale, highly accurate engineering lines*. Computers could now draw but they could not draw large pictures or accurate ones.

4. CAM TO THE RESCUE!

Now there seems to be a general belief that computer-aided design (CAD) preceded computer-aided manufacturing (CAM). All mention of the topic carries the label CAD-CAM rather than the reverse, as though CAD led CAM. However, this was not the case, as came out clearly in Ken McKinley's section above. Since both started in the 1956-1960 period, it seems a bit late in the day now to raise an old discussion. However, there may be a few people around still with the interest and the memory to try to get the story right. The following is the Boeing version, at least, as remembered by some long retired participants.

4.1 Numerical Control Systems

The Boeing Aerospace division began to equip its factory about 1956 with NC machinery. There were several suppliers and control systems, among them Kearney & Trecker, Stromberg-Carlson and TRW. Boeing used them for the production of somewhat complicated parts in aluminum, the programming being carried out by specially trained programmers. I hasten to say that these were not *computer* programmers; they were highly experienced machinists known as *part programmers*. Their use of computers was simply to convert an engineering drawing into a series of simple steps required to make the part described.

The language they used was similar in principle to basic computer languages in that it required a problem to be analyzed down to a series of simple steps; however, the similarity stopped right there. An NC language needs commands such as *select tool, move tool to point (x,y), lower tool, turn on coolant*. The process required a deep knowledge of cutting metal; it did not need to know about memory allocation or floating point arithmetic.

An irony that would astonish computer historians today was that at Boeing, as described by Ken McKinley, we had two NC languages in the factory before FORTRAN became available in the computer room. It is important to recognize that individual initiative from below very much characterized the early history of computing—much more than top-down managerial decisions. Indeed, it took an unconscionable amount of time before the computing bill reached a level of managerial attention. It should not have been the cost, it should have been the *value* of computing that brought management to the punch. But it wasn't. I

think the reason for that was that we computer folk were not particularly adept at explaining to anyone beyond our own circles what it was that we were doing. We were a corporate ecological intrusion which took some years to adjust to.

4.2 Information Consolidation at Boeing

It happened that computing at Boeing started twice, once in engineering and once in finance. My guess is that neither group was particularly aware of the other at the start. It was not until 1965 or so, after a period of conflict, that Boeing amalgamated the two organizations, the catalyst being the advent of the IBM 360 system that enabled both types of computing to cohabit the same hardware. The irony here was that the manufacturing area derived the earliest company tangible benefits from computing, but did not have their own computing organization; they commissioned their programs to be written by the engineering or finance departments, depending more or less on personal corridor contacts.

As Ken McKinley described above, in the factory itself there were four different control media; punched Mylar tape, 80-column punched cards, analog magnetic tape and digital magnetic tape. It was rather like biological life after the Cambrian Explosion of 570 million years ago—on a slightly smaller scale. Notwithstanding, it worked! Much investment had gone into it. By 1960, NC was a part of life in the Boeing factory and many other American factories. Manufacturing management was quite happy with the way things were and they were certainly not looking for any more innovation. "Leave us alone and let's get the job done" was the attitude. Nevertheless, modernization was afoot.

The 1950s was a period of explosive computer experimentation and development. In just one decade, we went from a 1K to 32K memory, from no storage backup at all to multiple drives, each managing a 2,400-foot magnetic tape, and from binary programming to FORTRAN. At MIT, Professor Doug Ross, learning from the experience of the earlier NC languages, produced a definition for the *Automatically Programmed Tools* (APT) language, the intention being to find a modern replacement for the already archaic languages of the 1950s.

4.3 New Beginnings

Since MIT had not actually implemented APT, the somewhat loose airframe manufacturers' computer association got together to write an APT compiler for the IBM 7090 computers in 1961. Each company sent a single programmer to Convair in San Diego and it took only a year to do the job, including the user documentation. This was almost a miracle, and was largely due to Professor Ross's well-thought through specification.

When our representative returned from San Diego, I assumed the factory would jump at APT, but they didn't. At the Thursday morning interdepartmental meeting,

whenever I said, "APT is up and running folks, let's start using it", Don King from Manufacturing would say, "but APT don't cut no chips". (That's how we talked up there in the Pacific Northwest.) He was dead against these inter-company initiatives. Eventually, I heard him talking. The Aerospace Division (Ed Carlberg and Ken McKinley) was testing the APT compiler but only up to the point of a printout. No chips were being cut because Aerospace did not have a project at that time. So I asked them to make me a few small parts, which they kindly did. I secreted the parts in my bag and had my secretary (Delma Wilkinson) tape the chips to a piece of cardboard labeled "First ever chips cut by APT". At the end of the meeting someone brought up the question of APT. "APT don't cut no chips" came the cry, at which point I pulled out my bag from under the table and handed out the piece of cardboard and the parts for inspection. Not a word was spoken. That became "King's last stand". (That was how we used to make decisions in those days.)

These things happened in parallel with Grant Erwin's development of the 727-CAD system. In addition, the facility to have APT accept interpolated data points from CAD made it possible to tie the one system in with the other in what must have been the first ever CAM-CAD system. When I look back on this feature alone nearly fifty years later I find it nothing short of miraculous, thanks to Doug Ross's deep understanding of what the manufacturing world was in process of needing. Each recourse to the surface definition was made in response to a request form from Engineering, and each numerical cut was given a running "Master Dimensions Identifier" (MDI) number. This was not today's CAM-CAD system in action; again, no screen, no light pen, no electronic drawing. Far from it; but it worked! In the early 1960s the system was a step beyond anything that anyone else seemed to be doing - you have to start somewhere in this life.

5. DEVELOPING ACCURATE LINES

An irony of history was that the first mechanical movements carried out by computers were not a simple matter of drawing lines; they were complicated endeavors of cutting metal. The computer-controlled equipment was vast multi-ton machines spraying aluminum chips in all directions. The breakthrough was to tame the machines down from three dimensions to two, which happened in the following extraordinary way. It is perhaps one of the strangest events in the history of computing and computing graphics, though I don't suppose anyone has ever published this story. Most engineers know about CAD; however, I do not suppose anyone outside Boeing knows how it came about.

5.1 So, from CAM to CAD

Back to square one for a moment. As soon as we got the plotter up and running, Art Dietrich showed some sample

plots to the Boeing drafting department management. Was the plotting accuracy good enough for drafting purposes? The answer - a resounding No! The decision was that Boeing would continue to draft by hand until the day someone could show something that was superior to what we were able to produce. That was the challenge. However, how could we meet that challenge? Boeing would not commit money to acquiring a drafting machine (which did not exist anyway) without first subjecting its output to intense scrutiny. Additionally, no machine tool company would invest in such an expensive piece of new equipment without an order or at least a modicum of serious interest. How do you cut this Gordian knot?

In short, at that time computers could master-mind the cutting of metal with great accuracy using three-dimensional milling machines. Ironically, however, it could not draw lines on paper accurately enough for design purposes; it could do the tough job but not the easy one.

However, one day there came a blinding light from heaven. If you can cut in three dimensions, *you can certainly scratch in two*. Don't do it on paper; do it on aluminum. It had the simplicity of the paper clip! Why hadn't we thought of that before? We simply replaced the cutter head of the milling machine with a tiny diamond scribe (a sort of diamond pen) and drew lines on sheets of aluminum. Hey presto! The computer had drawn the world's first accurate lines by machine. This was done in 1961.

The next step was to prove to the 727 aircraft project manager that the definition that we had of the airplane was accurate, and that our programs worked. To prove it they gave us the definition of the 707 and told us to make nineteen random drawings (canted cuts) of the wing using this new idea. This we did. We trucked the inscribed sheets of aluminum from the factory to the engineering building and for a month or so engineers on their hands and knees examined the lines with microscopes. We computer folk held our breath. To our knowledge, this had never happened before. Ever! Anywhere! We ourselves could not be certain that the lines the diamond had scribed would match accurately enough the lines drawn years earlier by hand for the 707. At the end of the exercise, however, industrial history emerged at a come-to-God meeting. The chief engineer stood on his feet and said simply that the design lines that we had developed had been under the microscope for several weeks and were the most accurate lines ever drawn - by anybody, anywhere, at any time. We were obviously joyous and the decision was made to build the 727 with the computer. That is the closest I believe anyone ever came to the birth of *Computer-Aided Design*. We called it *Design Automation*. Later, someone changed the name. I do not know who this was, but it would be fascinating to meet that person.

5.2 An Unanticipated Extra Benefit

One of the immediate, though unanticipated, benefits of CAD was transferring detailed design to subcontractors. Because of our limited manufacturing capacity, we subcontracted the engine nacelles (the covers) to the Rohr Aircraft Company of Chula Vista in California. When their team came up to Seattle to acquire the drawings, we instead handed them boxes of data in punched card form. We also showed them ways to write the programs and ways to read and interpret them. Their team leader, Nils Olestein, could not believe it. He had dreamed of the idea but he never thought he would ever see it in his lifetime: *accuracy in a cardboard box!* Remember that in those days we did not have email or the ability to send data in the form of electronic files.

5.3 Dynamic Changes

The cultural change to Boeing due to the new CAD systems was profound. Later on we acquired a number of drafting machines from the Gerber Company, and the traditional acres of drafting tables began slowly to disappear. Hand drafting had been a profession since time immemorial. Suddenly its existence was threatened, and after a number of years, it no longer existed. That also goes for architecture and almost any activity involving drawing.

Shortly afterwards, as the idea caught on, people started writing CAD systems which they marketed widely throughout the manufacturing industry as well as in architecture. Eventually our early programs vanished from the scene after being used on the 737 and 747, to be replaced by standard CAD systems marketed by specialist companies. I suppose, though, that even today's Boeing engineers are unaware of what we did in the early 1960s; generally, corporations are not noted for their memory.

Once the possibility of drawing with the computer became known, the idea took hold all over the place. One of the most fascinating areas was to make movie frames. We already had flight simulation; Boeing "flew" the Douglas DC-8 before Douglas had finished building it. We could actually experience the airplane from within. We did this with analog computers rather than digital. Now, with digital computers, we could look at an airplane from the outside. From drawing aircraft, one could very easily draw other things such as motorcars and animated cartoons. At Boeing we established a Computer Graphics Department around 1962 and by 1965 they were making movies by computer. (I have a video tape made from Boeing's first ever 16-mm movie if anyone's interested.) Although slow and simple by today's standards, it had become an established activity. The rest is part of the explosive story of computing, leading up to today's marvels such as computer games, Windows interfaces, computer processing of film and all the other wonders of modern life that people take for granted.

6. THE COSMIC DICE

Part of the excitement of this computer revolution that we have brought about in these sixty years was the unexpected benefits. To be honest, a lot of what we did, especially in the early days, was pure serendipity; it looked like a good idea at the time but there was no way we could properly justify it. I think had we had to undertake a solid financial analysis most of the projects would never have got off the ground and the computer industry would not have got anywhere near today's levels of technical sophistication or profitability. Some of the real payoffs have been a result of the cosmic dice throwing us a seven. This happened already twice with the first 727.

The 727 rolled out in November, 1962, on time and within budget, and flew in April, 1963. This would not have happened had we not used CAD. During the early period, before building the first full-scale mockup, as the computer programs were being integrated, we had a problem fitting the wing to the wing-shaped hole in the body; the wing-body join. The programmer responsible for that part of the body program was yet another Swiss by name Raoul Etter. He had what appeared to be a deep bug in his program and spent a month trying to find it. As all good programmers do, he assumed that it was his program that was at fault. But in a moment of utter despair, as life was beginning to disappear down a deep black hole, he went cap in hand to the wing project to own up. "I just can't get the wing data to match the body data, and time is no longer on my side." "Show us your wing data. Hey where did you get this stuff?" "From the body project." "But they've given you old data; you've been trying to fit an old wing onto a new body." An hour later life was restored and the 727 became a single numerical entity. But how would this have been caught had we not gone numerical? I asked the project. At full-scale mockup stage, they said. In addition to the serious delay what would the remake have cost? In the region of a million dollars. Stick that in your project analysis!

The second occasion was just days prior to roll-out. The 727 has leading-edge flaps, but at installation they were found not to fit. New ones had to be produced over night, again with the right data. And thanks to the NC machinery they were. Don't hang out the flags before the final chip has been swept up.

7. A FASCINATING IRONY

This discussion is about using the computer to make better pictures of *other things*. At no time did any of us have the idea of using pictures to improve the way we ran computers. This had to wait for Xerox Park, a decade or so later, to throw away our punched cards and rub our noses into a colossal missed opportunity. I suppose our only defense is that we were being paid to build airplanes not computers.

8. CONCLUSION

In summary, CAM came into existence during the late 1950s, catalyzing the advent of CAD on the early 1960s. This mathematical definition of line drawing by computers then radiated out in three principal directions with (a) highly accurate engineering lines and surfaces, (b) faster and more accurate scientific plotting, and (c) very high-speed animation. Indeed, the world of today's computer user consists largely of pictures; the interface is a screen of pictures; a large part of technology lessons at school uses computer graphics. And we must remember that the

computers at that time were miniscule compared to the size of today's PC in terms of memory and processing speed. We've come a long way from that 727 wing design.

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THE 707 CENTRE-ENGINE INLET, THE FIRST
COMPONENT EVER MADE BY COMPUTER
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