February 6 1984

Mr David Chapman
Senior Vice-President of Manufacturing
Data General Corporation
4400 Computer Drive
Westboro
MA 01580

Dear Mr Chapman

Gwen Bell has told me that you have offered to help us try to obtain a large computer-designed aircraft part, such as a wing, from Boeing. I enclose copies of two letters I have written so far to people at Boeing and also the proposal for the exhibit The Computer and the Image.

Nothing brings an exhibit to life more than an exciting three-dimensional object, especially a large one. In a recent gallery I put together for the Science Museum, London on Seeing the Invisible we exhibited an entire helicopter engine fitted with a borescope to illustrate methods of seeing inside solid objects. The display works well and has a continuous stream of people waiting to look inside to see the turbine blades turning.

In the case of the present exhibit, an aircraft part is especially appropriate both because of the long history of computer-aided design of aircraft surfaces and because of CAD's central role in the process. The gallery is about 55 foot square; something about 25 feet long would suit us perfectly!

Please do not hesitate to contact me should you require any further information or have some comments. The address at our new site is: The Computer Museum, Museum Wharf, 300 Congress Street, Boston, MA 02210, telephone 426-7190. Thank you very much for your help.

Yours sincerely

Dr Oliver Strimpel
Curator

enclosures

Phoned up 10 August to give news of delivery of Boeing parts
Renewed request for big part.

April 3 1984

Mr David Chapman
Senior Vice-President of Manufacturing
Data General Corp
4400 Computer Drive
Westboro
MA 01580

Dear Mr Chapman

Thank you very much for pursuing the possibility of a large computer-designed exhibit with Boeing.

The first major exhibit the visitor sees when he enters the Museum is the SAGE computer and a mock-up of the 'blue room' typical of such installations. We feel, therefore, that the overall bias of the Museum would be too military if the dominant piece in the exhibit <u>The Computer and the Image</u> was a cruise missile.

Is there any chance of obtaining a substantial computer-designed piece from a civilian aircraft? It need not be a wing.

Thank you again for your help. I look forward to hearing from you.

Yours sincerely

Dr Oliver Strimpel
Curator

The
Computer
Museum

One Iron Way
Marlboro
Massachusetts
01752

NB: Founder: Henry Ramsay 'CAD Lab'
Head of Boeing Computer Services
206 251 2852

January 30 1984

Sent copy to Ramsay 1/Feb

Mr Christopher Klomp
Director of Engineering Computing Systems Development
Boeing Company MS 6E-30
PO Box 3707
Seattle
Washington 98124

Dear Mr Klomp

Further to my recent telephone conversation with Mr Rudi Gern, I am writing to ask whether you might participate in an exhibit at The Computer Museum entitled The Computer and the Image due to open in December 1984.

I enclose a recent quarterly report of the Museum which shows some pictures of our new site in downtown Boston and an article reprinted from Discover magazine on the old site. The move also coincides with a change of emphasis - state-of-the-art computing will be displayed as well as the history of computing.

The proposed 5000 square foot exhibit on the computer and the image is described in the enclosed outline. We would like to display a large, arresting object in the CAD/CAM section (see page 6 of the proposal) and use this both as a "bait" and as the example of the finished product of a CAD/CAM process. Ideally, a simplified CAD system would be running in the gallery for the visitors to interact with. Images of rendered aircraft surfaces can also be displayed statically or on film. We would also like to include some of Boeing's pioneering work in the subject using the IBM 2250 system and earlier.

We are seeking donations of hardware from computer manufacturers and have already had positive responses from DEC, HP, Apollo, Lexidata, Computervision, NYIT and others. If there is some specific system which might demonstrate your application in a museum setting we would be pleased to pursue the possibility of obtaining the necessary hardware.

I hope you will be able to participate in this exhibit and look forward to your reply. Our new address is: The Computer Museum, Museum Wharf, 300 Congress Street, Boston, MA 02210, telephone 617-426-7190. Please do not hesitate to contact me should you require any further information.

Yours sincerely

Dr Oliver Strimpel
Curator

February 1 1984

Mr Henry Ramsay
Boeing Computer Services Company
MS 6E-18
PO Box 24346
Seattle
Washington 98124

Dear Mr Ramsay

Further to our telephone conversation today I am enclosing a copy of the gallery proposal for The Computer and the Image. I also enclose a copy of my letter to Mr Klomp as it goes into somewhat more detail about what sort of exhibit we would like.

Perhaps you would like to know that we have been in touch with GE with regard to showing the use of CAD with the turbine blade and with IBM for CAD in creating layouts of VLSI components. In each case it should be possible to exhibit the resulting product. I appreciate, however, that your products are on a different scale, but know that this would make it all the more arresting and striking an exhibit. Perhaps you might know of a source of non-airworthy aircraft parts designed with the help of computers that we might exhibit.

Let me know if there is anything else you may wish to know about the exhibit or about the Museum. The new address is : The Computer Museum, Museum Wharf, 300 Congress Street, Boston, MA 02210. I look forward to hearing your suggestions. Should it look as though Boeing will participate, I could visit you during the second week of March when I plan to be on the West Coast.

Yours sincerely

Dr Oliver Strimpel
Curator

enclosures

Ascii 51 CRTRL EA : Advance Slide
52 C ER : Advance Projector .
until in home position

dimension
Painted ; grey ; + drawings

206 773 2816
Boeing Aerospace
in Kent
Seattle area,

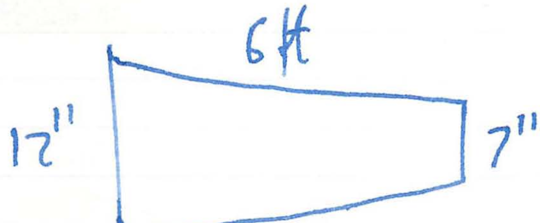
Bill Parker
Boeing

Bud Hebler
Pres, Boeing Aerospace

from 'airforce missile'
designed & manufactured
by computer & robotics
+ computer drawing
+ photos of robot, machine
+ general writing.

B52
B1
Wing from air-launched
cruise missile
Strategic weapon

6ft long ; wing tip 7"
across



thin

heavy : metal wing

aerodynamic curved
surface
25 - 30 lbs

5 axis computer machine that does cutting , sands surface , robot

BOEING COMMERCIAL AIRPLANE COMPANY

P.O. Box 3707 m/s 6E-20
Seattle, Washington 98124

A Division of The Boeing Company

Gerber

July 30, 1984

Were all plots made by computer?

Tabulated ← What is material?

Is it computer drawings? Maybe manually drawn.

What is ₵?

Are arrows on the drawing the path of cutting tool?

Is 5 made by computer? Scale?

Dr. Oliver Strimpel
Curator, The Computer Museum
Museum Wharf
300 Congress Street
Boston, Massachusetts 02210

Dear Dr. Strimpel,

As requested in your letter of January 30, 1984, we are sending you the enclosed items for your upcoming exhibit, "The Computer and the Image".

The theme which we selected is that of CAD/CAM as applied to Boeing's commercial airplane products. In particular the theme stresses the application of geometric modeling and graphics techniques to our production processes in design and numerical control parts fabrication.

The following is a brief description of enclosed items:

1. A 16mm film, made up of several small, self-explanatory segments showing CAD/CAM at Boeing.

2. The 35mm slides and associated text tell about our manufacturing/engineering interface, kinematics, parametric design, and interactive computer graphics.

3. The "SPLICE RIB - WING TIP" used on the 727. The computerized engineering model was directly assumed by manufacturing for N/C parts fabrication.

4. The "CARRIER WING FITTING ASSEMBLY - OFF WING ESCAPE SLIDE SYSTEM" used on the 757. The computerized engineering model was directly assumed by manufacturing for N/C parts fabrication.

5. The "HORIZONTAL TAIL - H5" is part of a wind tunnel model used for aerodynamic testing. The surface model for an entire airplane is stored in the computer, allowing manufacturing to access as fine a set of points off the surface as is necessary to machine the part using N/C machine tools. The computerized surface model is then used by quality control to check the part for dimensional accuracy.

Scale.

Cast for extrusion

Planar cuts through model.

Data transfer

BOEING

If you need any further information concerning the enclosed, please feel free to contact Mr. Rudi Gern at (206) 251-2316.

We hope that this contribution of the Boeing Company serves your purpose and we wish you a most successful exhibit.

fr. Klomp

C. W. Klomp
Director
Engineering Computing Systems

C E Bradner

C. E. Bradner
Director
Operations Computing Systems

SWS:pb
-392/A-6.4.1

BOEING

DR. STRIMPEL 10/03/84

PER OUR CONVERSATION OF 10/02/84 HERE ARE THE PHOTOGRAPHS SHOWING SOME OF THE MANUFACTURING ENVIRONMENT OF THE SPLICE RIB-WING TIP.

PHOTO #1 SHOWS THE PART BEING MACHINED ON A SUNDSTRAND OM-3 5-AXIS N/C MILLING MACHINE.

PHOTO #2 & 3 SHOWS THE N/C PART PROGRAMMER DISCUSSING VARIOUS ASPECTS OF THE PART WITH THE N/C MACHINE OPERATOR.

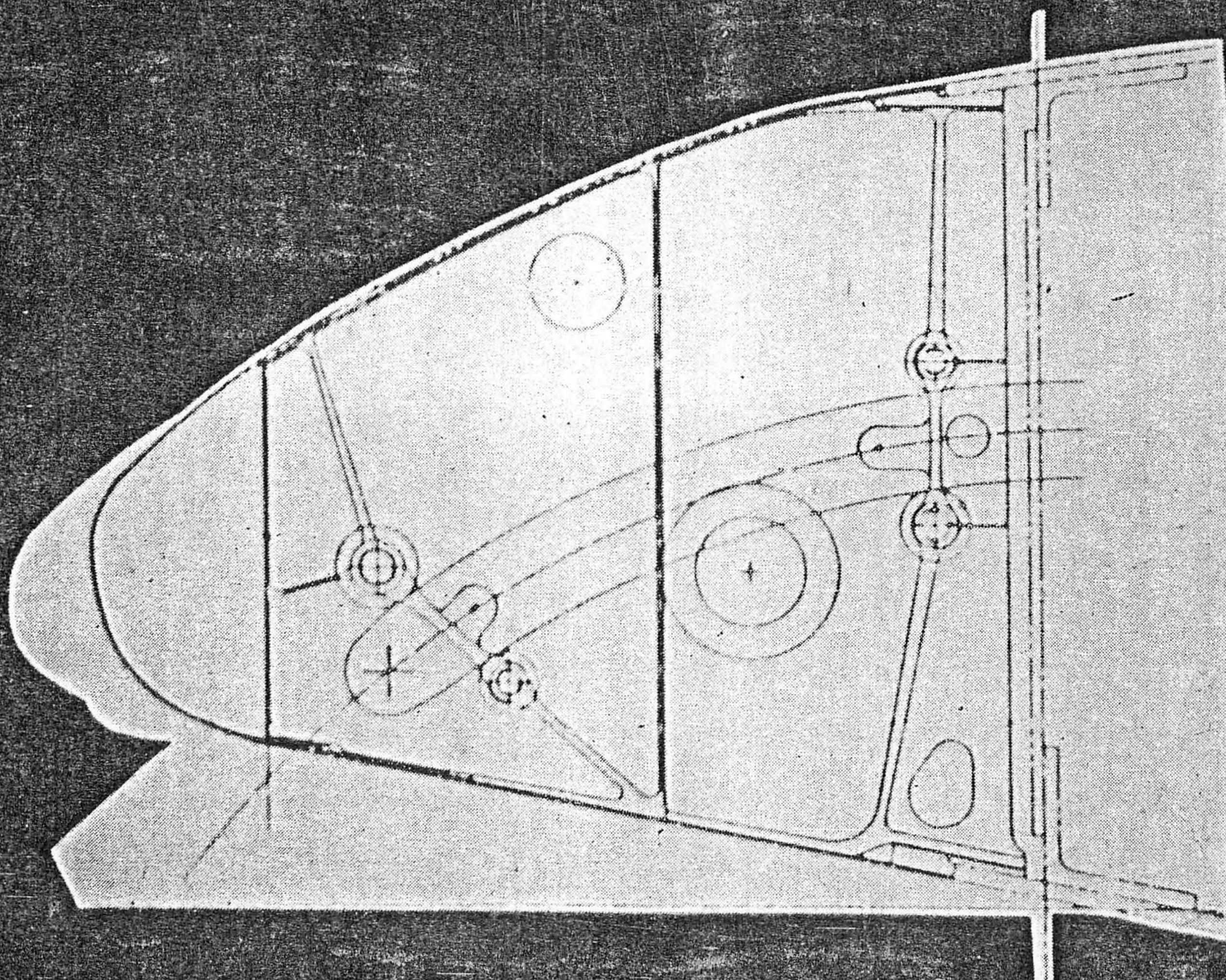
Scott W. Smith
SCOTT W. SMITH


RICHARD M.
FRESHLEY

LAYOUT PASSENGER ACCOMMODATIONS

Special Parametric Program

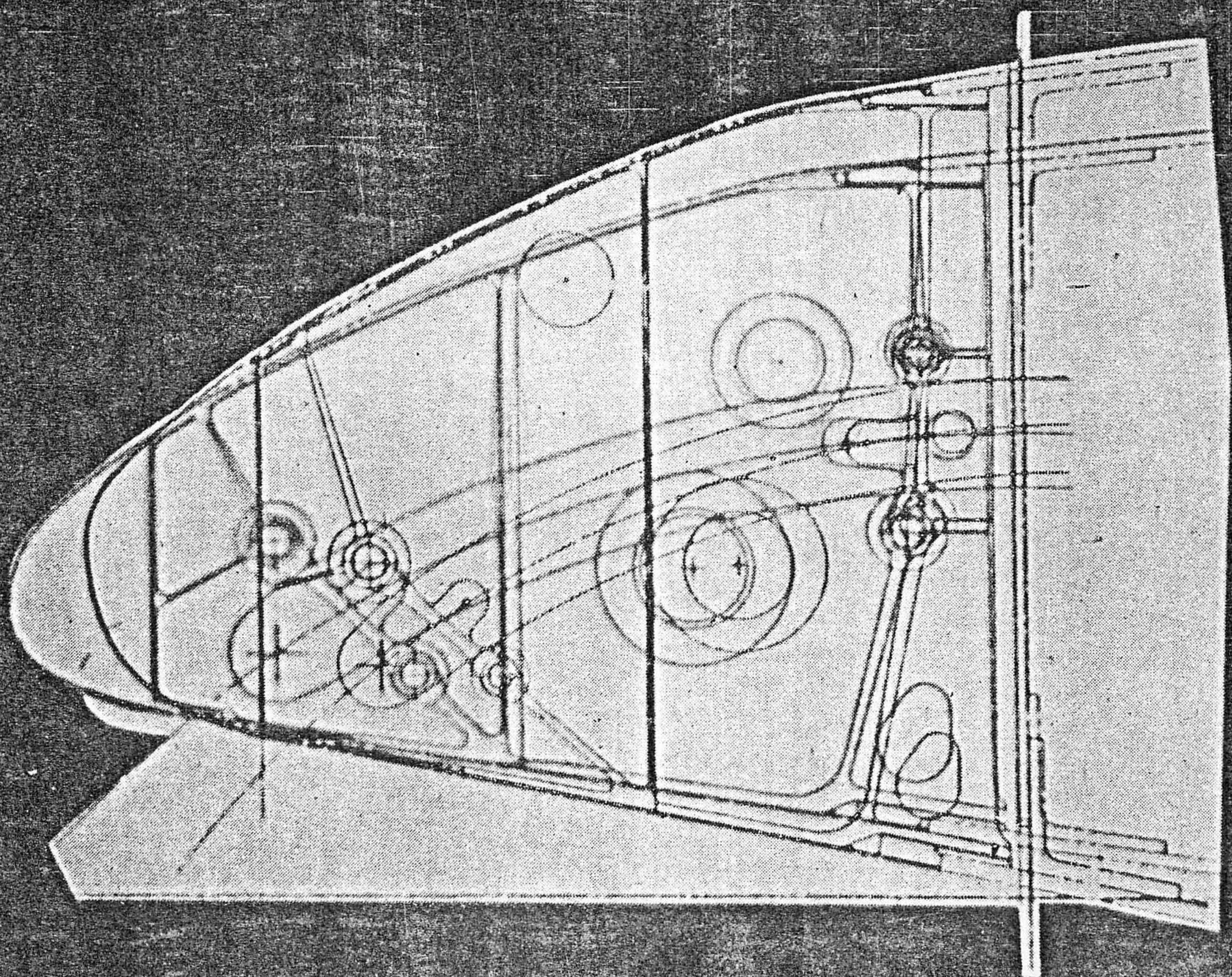
Family of Parts Definition



Leading Edge Ribs

Special Parametric Program

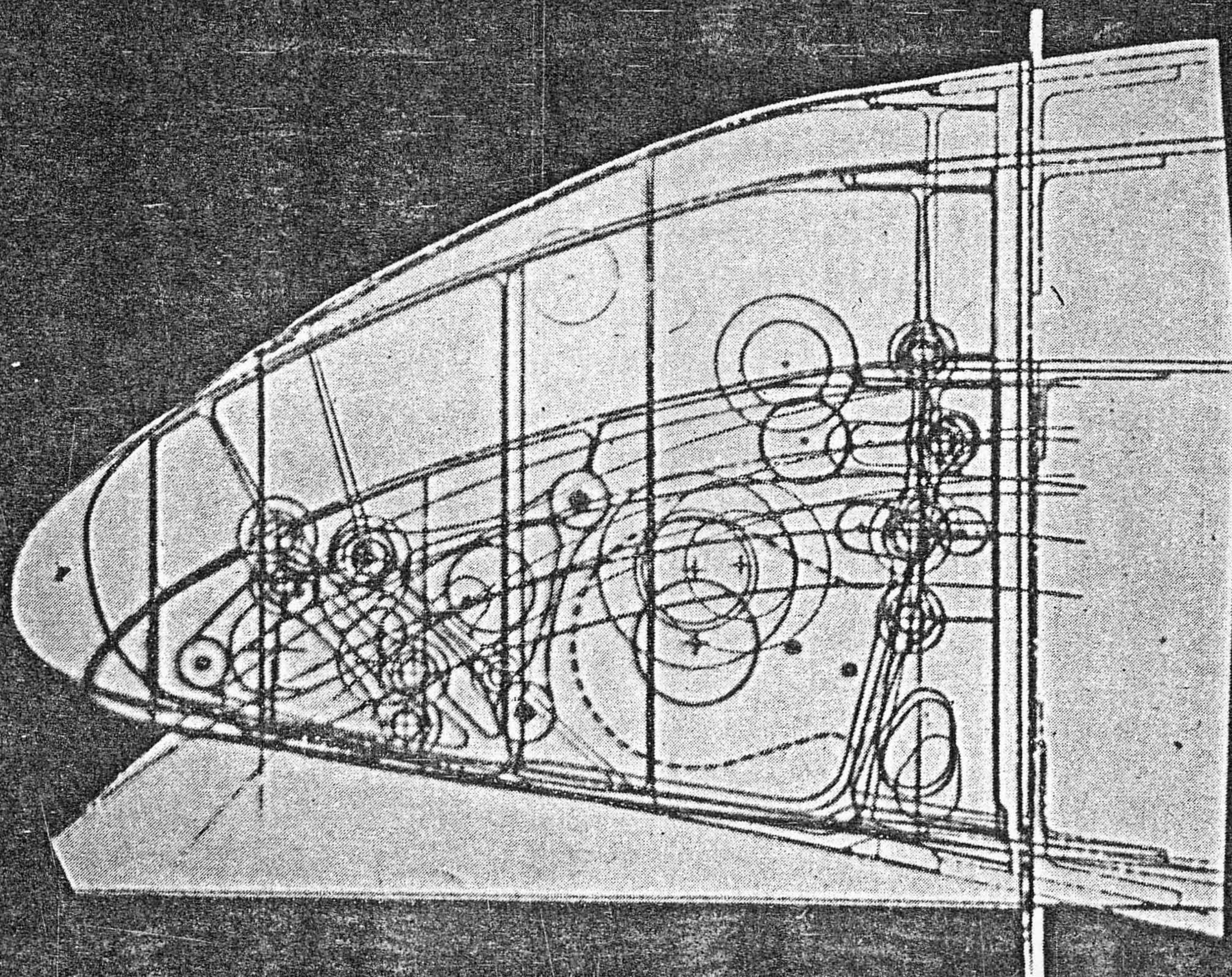
Family of Parts Definition



Leading Edge Ribs

Special Parametric Program

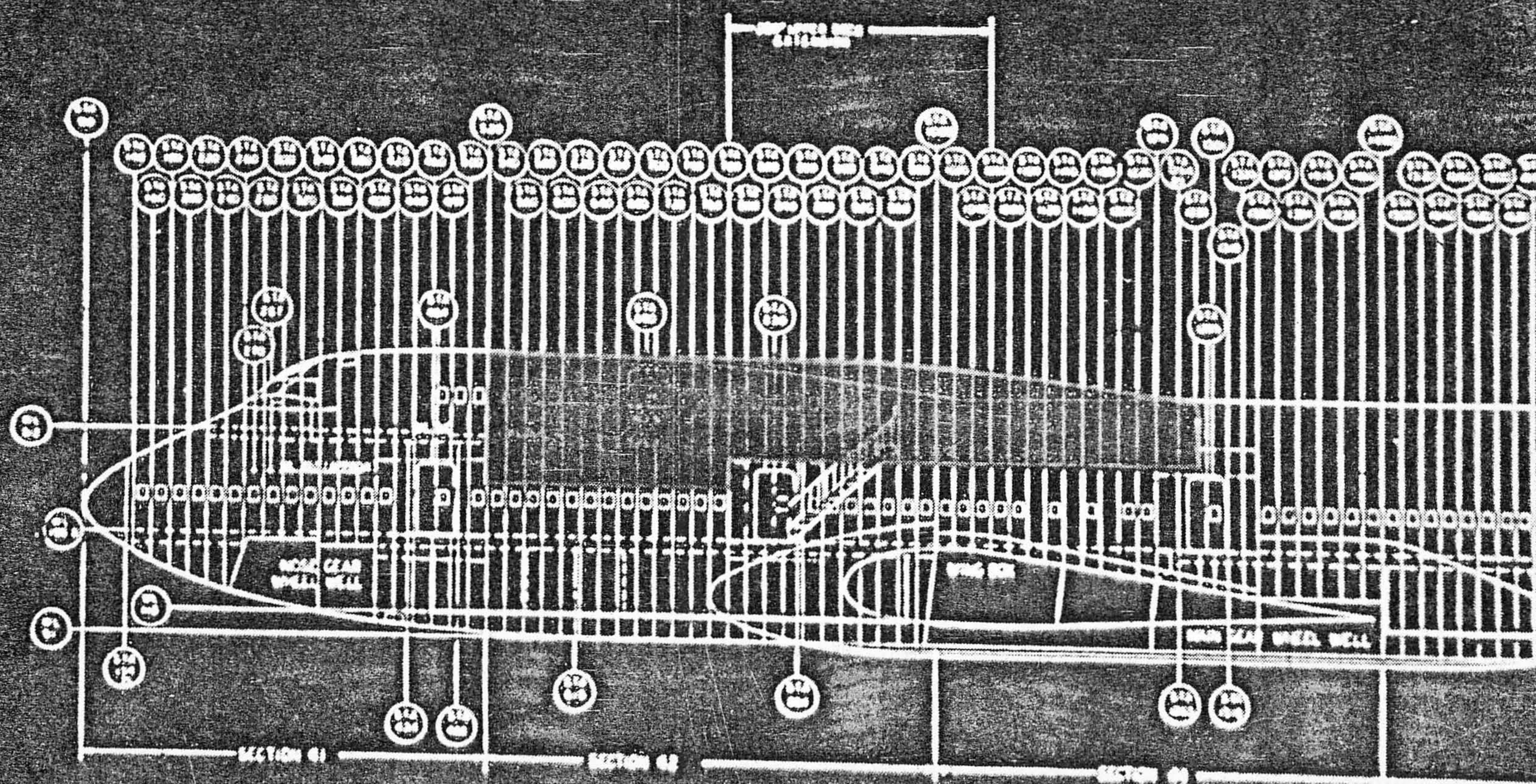
Family of Parts Definition

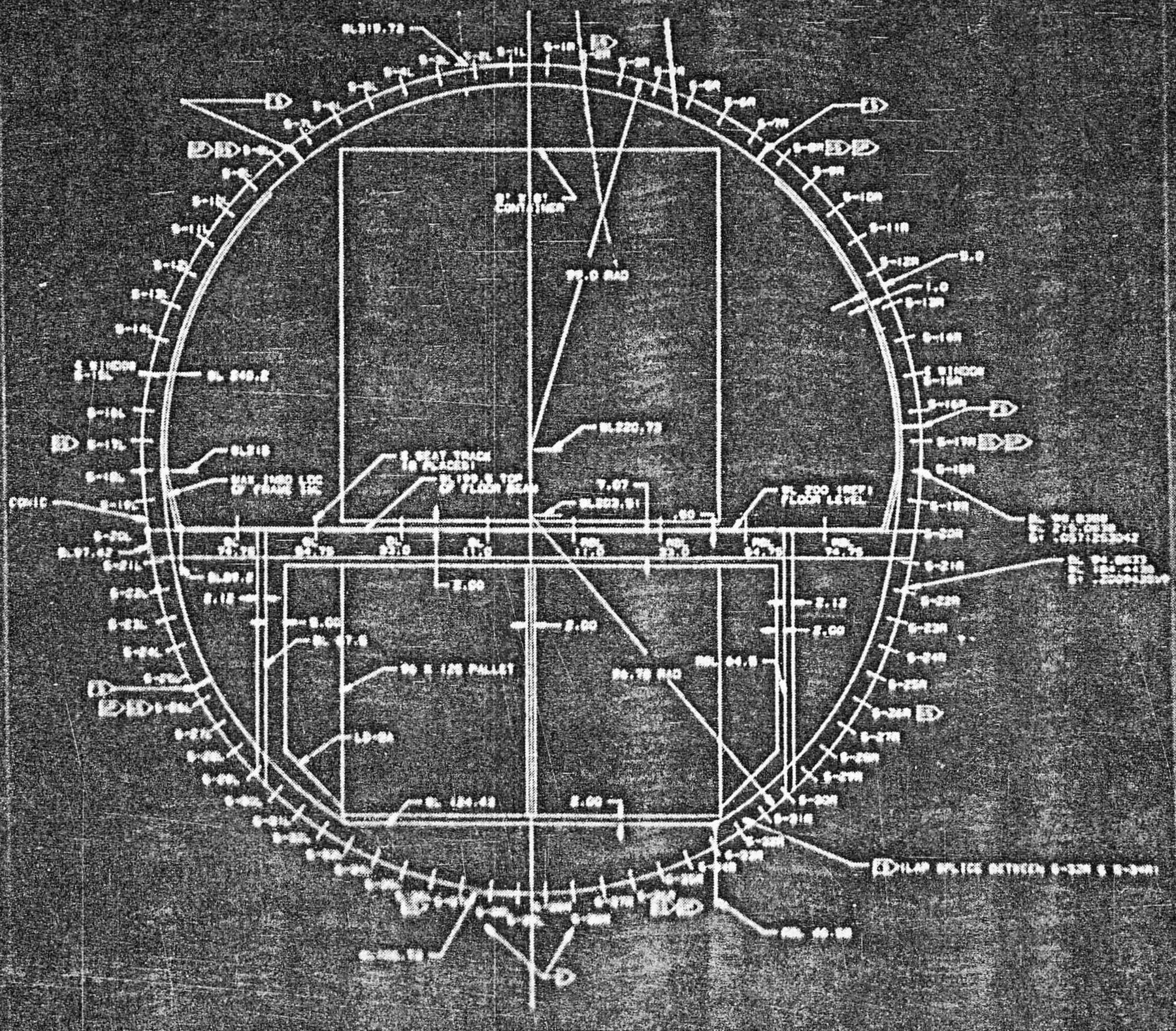


Leading Edge Ribs

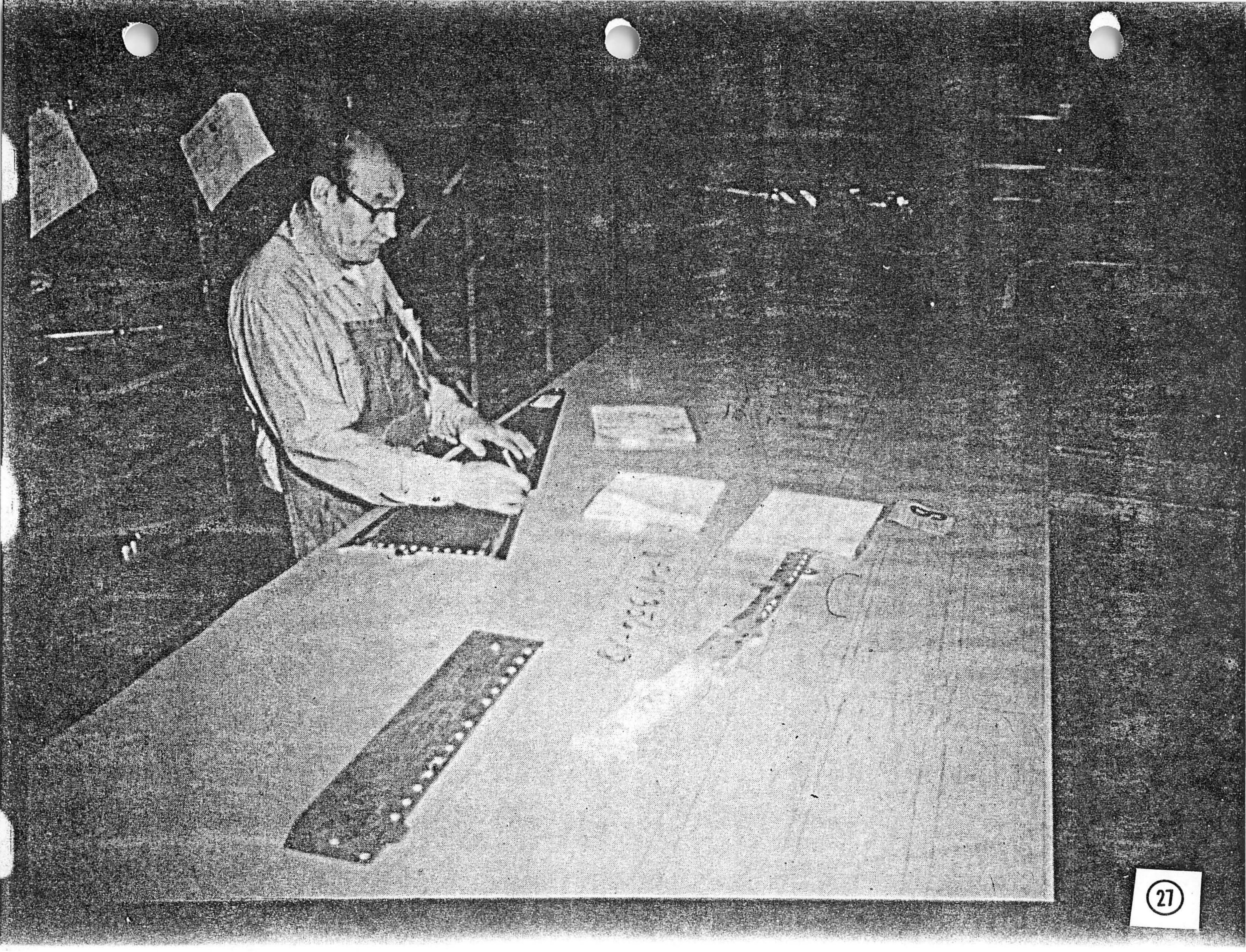
Fuselage Centerline Diagram

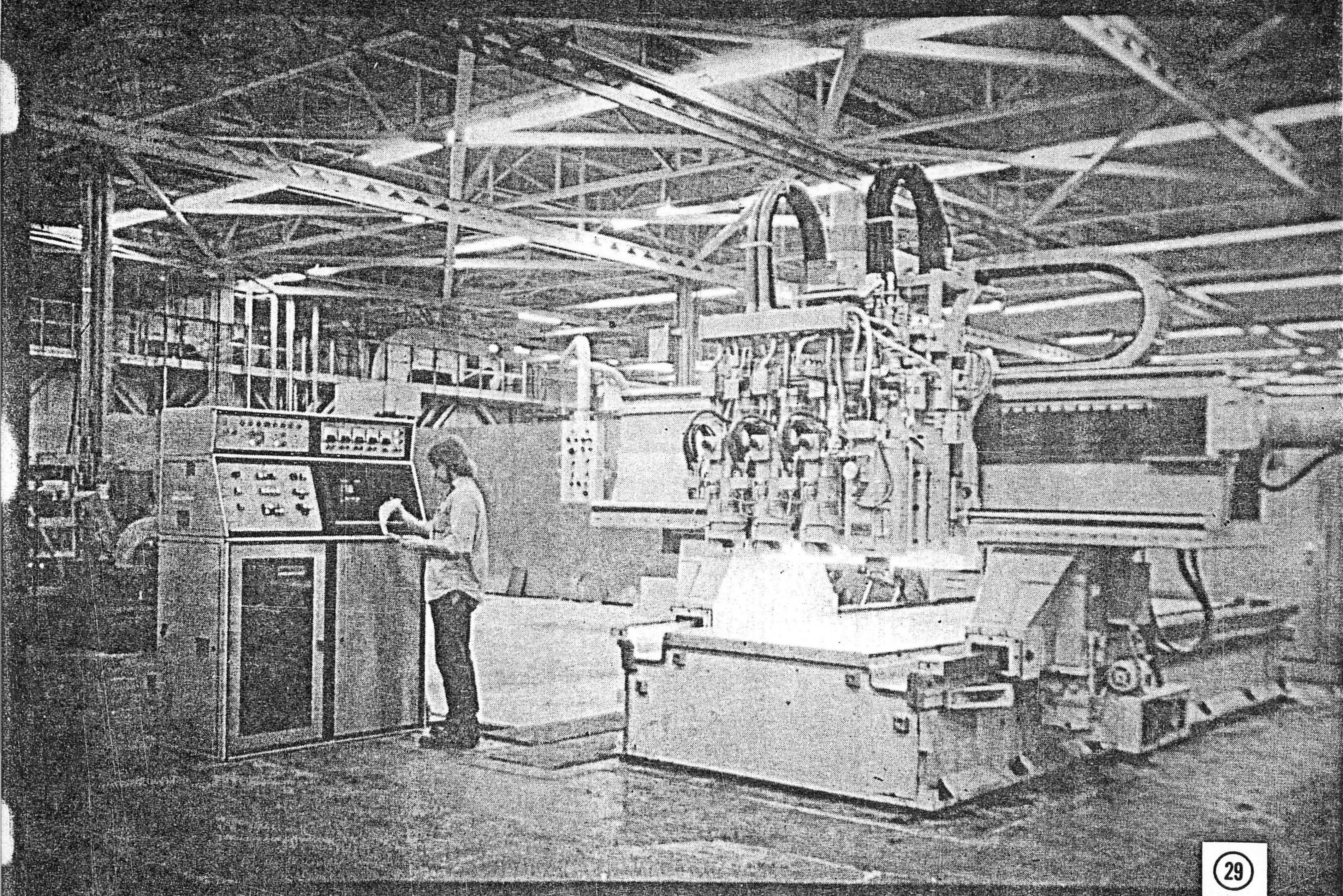
Basic 747 Stretched Upper Deck





REAR VIEW-CONSTANT SECTION (108 X 213)

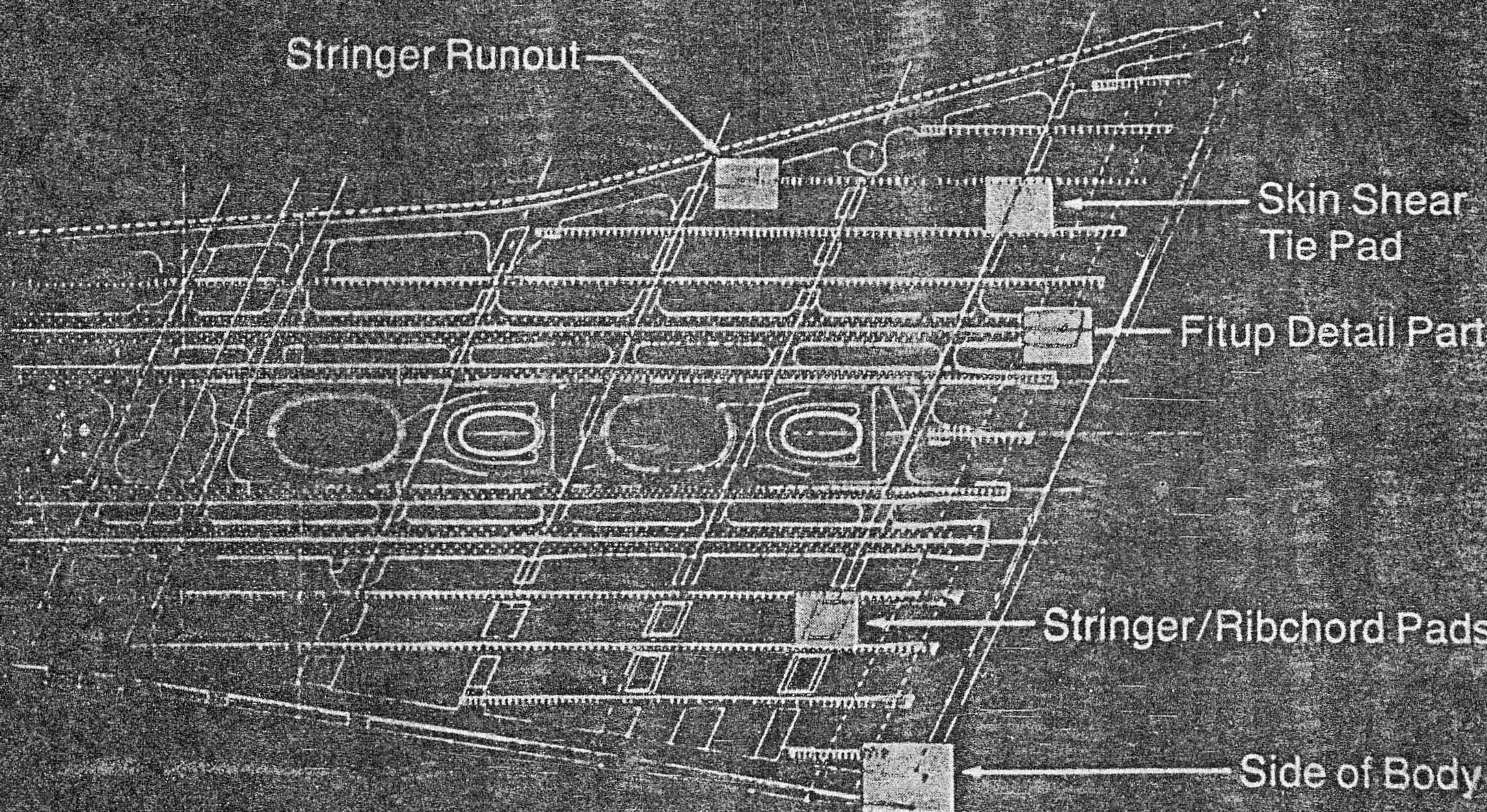


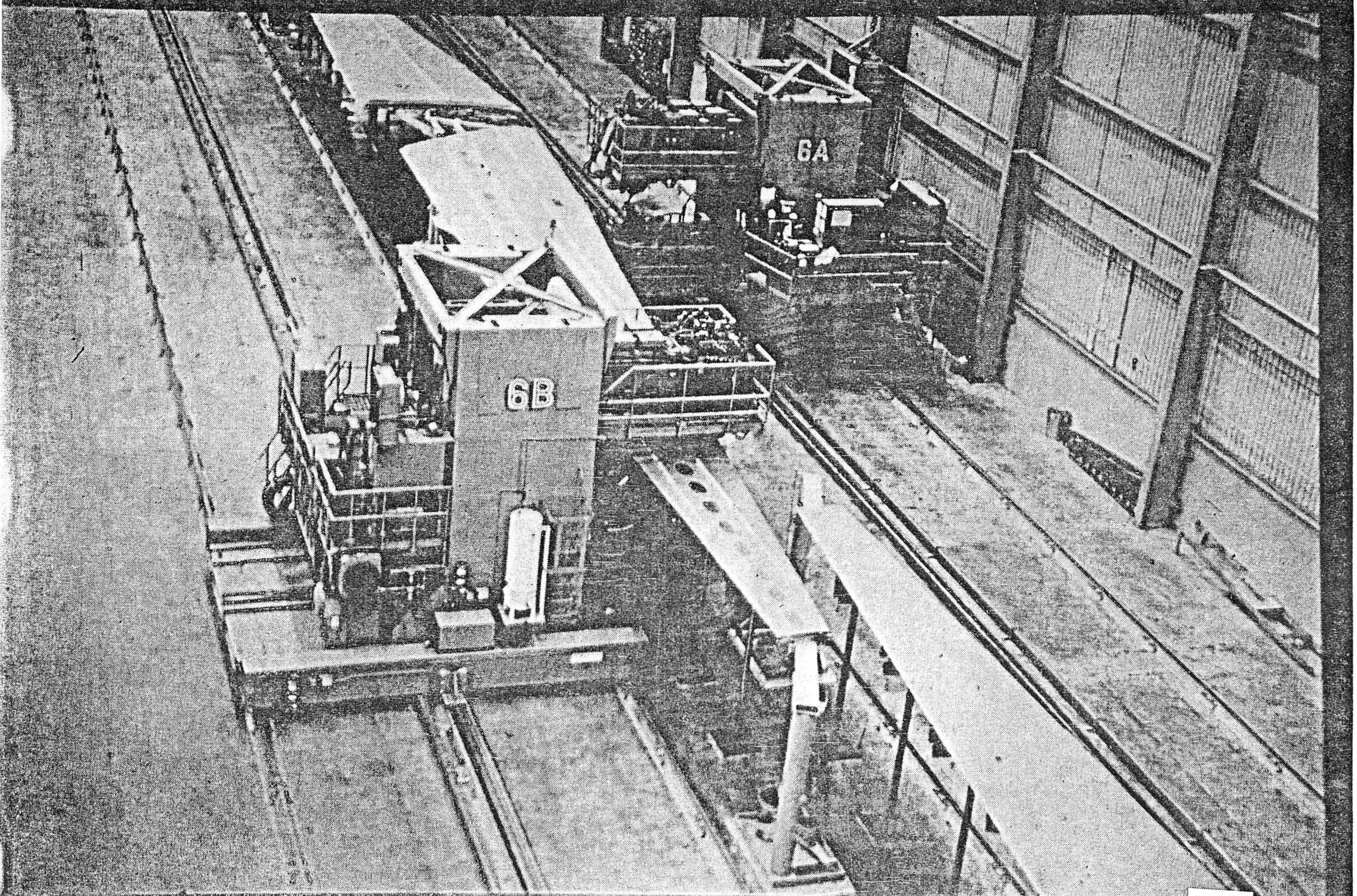


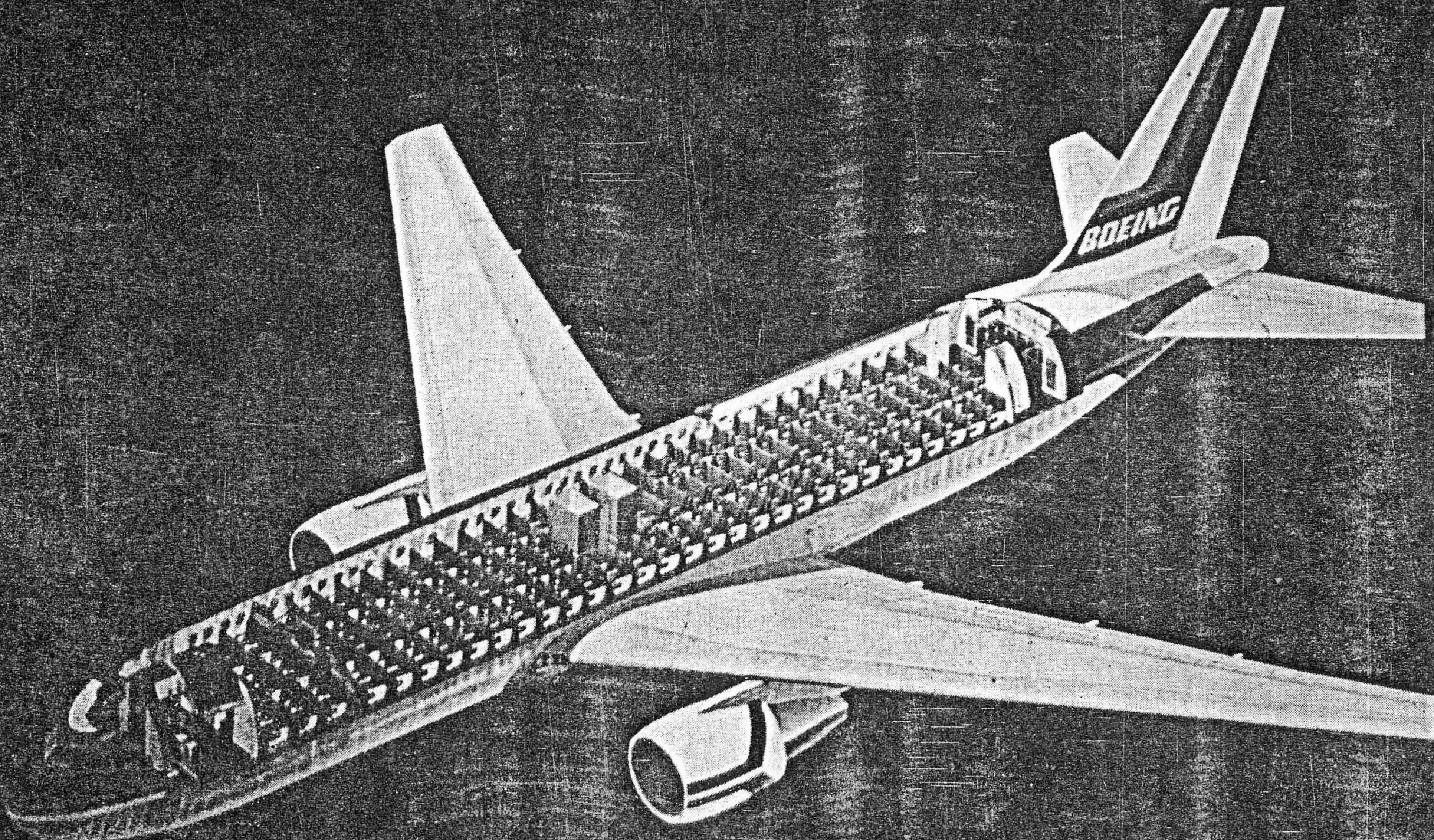
29

Parametric Program Computerized Assembly

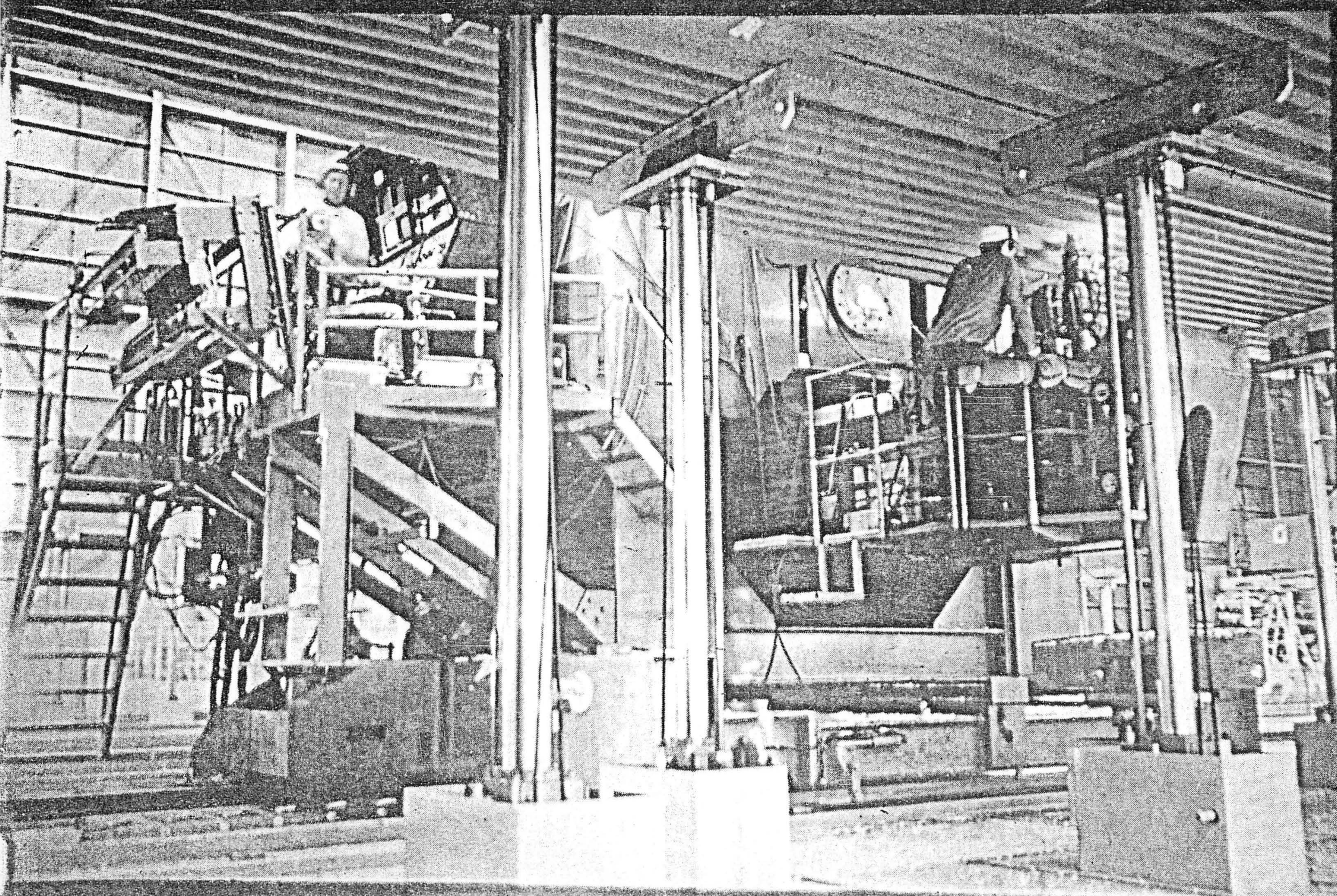
Contribution to Error Reduction



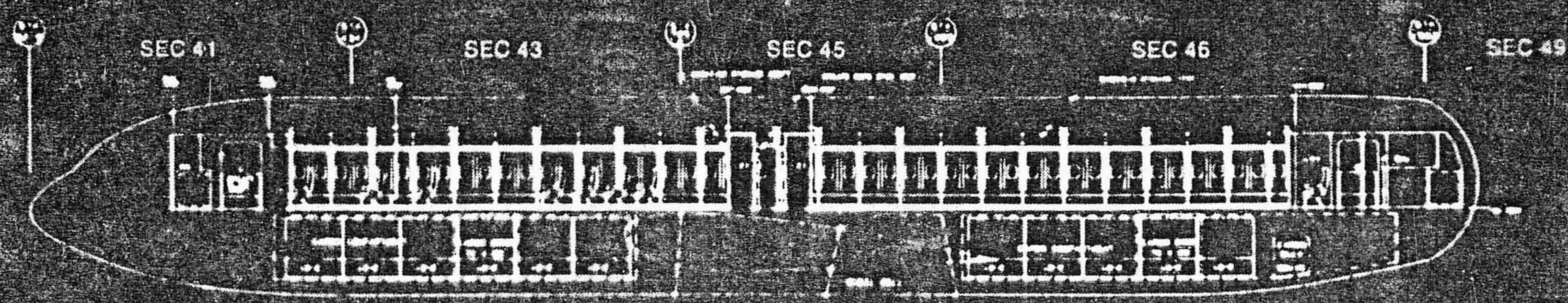

6A
6B


BOEING

11

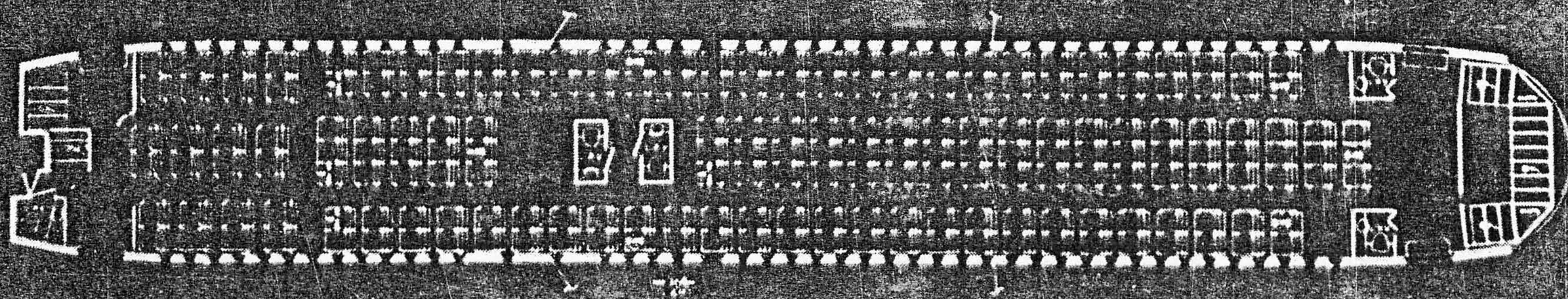


LOPA Design
Computerized Assembly



L. H. SIDE VIEW OF R. H. SIDE

Sidewall Panels



Seats, Galleys and Lavatories

FROM: BOEING AEROSPACE COMPANY
P.O. BOX 3999
SEATTLE, WASHINGTON 98124

SHIP TO / MARK FOR: DR. OLIVER STRIMPEL
CURATOR, THE COMPUTER MUSEUM
MUSEUM WHARF
300 CONGRESS STREET
BOSTON, MASSACHUSETTS 02210

AFH:
CONTRACT:
W.O.:
AFH:
CONTRACT:
W.O.:

SHEET NO.	NO. OF SHEETS	ROUTING	MODE OF SHIPMENT	PPD	COLL	VOUCHER NUMBER
1	1			X		MA-22694

BILL OF LADING OR AIR MOVEMENT DESIGNATOR:
PRIORITY OR D/D: 8-7-84
DATE SHIPPED:

ORIGINATOR
NAME SCOTT SMITH
ORG. B-7150
M/S 6E-30 PHONE 251-2386

AUTHORIZATION
W.O. 8-B3003-7100-MUSEUM

ACCOUNTING DATA
TRANS. W.O. 8-B3401-7100-000000

APPROVED BY
NAME
ORG.
M/S PHONE

ITEM NO.	STOCK AND / OR PART NUMBER AND DESCRIPTION OF PROPERTY	UNIT OF ISSUE	QUANTITY RELEASED	QUANTITY SHIPPED	TYPE CONTAINER	CONTAINER NO.	UNIT PRICE	TOTAL PRICE
	LEVEL C/C DOMESTIC PRESERVATION NOT REQUIRED							
1	VERTICAL STABLIZER	EA.	1	1				
2	FILM REEL (16 MM)	EA.	1	1				
3	SLIDES (35 MM)	LT.	1	1				
4	MACHINED PARTS (ALUM.)	EA.	2	2				
5	DATA AND DRAWINGS	LT	1	1				
	SHIP FASTEST SURFACE							
	DATA PACKAGE NOT REQUIRED							

PARTS CHECK: 8-7-84
READY TO COVER: 8-7-4
DISPATCH: 8-7-4
PACKED BY: 4741

NO.	CONTAINER	W	H	L	TARE	NET	GROSS	CUBE
1	CT	12	20	12			21	
2								
3								
4								
5								
6								
7								

I certify that the items listed herein have been inspected by me or under my supervision, and they conform to drawing or specifications, except as noted.

BOEING QUALITY CONTROL
STAMP NAME [illegible] DATE 8-7-4

GOVERNMENT SOURCE REPRESENTATIVE
STAMP NAME DATE

I CERTIFY THAT I HAVE RECEIVED THE PROPERTY SHOWN HEREIN EXCEPT AS NOTED.

NAME DATE

REC. VOUCHER NO.

THE BOEING COMPANY

TRANSFER AND SHIPPING AUTHORIZATION

D3 4300 0750 ORIG 12/76

TO ASSURE LEGIBILITY, ALL ENTRIES SHOULD BE TYPEWRITTEN.

K75-013

Accompanied by a box of slides rec'd 10 Aug 84

(1) my introduction

December 7, 1982

(2) At the Boeing Commercial Airplane Company, we are divided into product divisions. The 747 and 767 airplanes are built at Everett. Gary supports that site.

The 727, 737 and 757 are produced at Renton. That is the site I support. As you might suppose, there is a little friendly competition between sites, especially as it relates to our two new commercial entries. So I wear my 757 hat to assure my identity. Also, if you or any of your friends are in the market for one of these airplanes, please contact us after this presentation. We can use a few sales right now.

Computing at Boeing is a multi-million dollar activity. We could spend a week just telling you about our development programs which are in progress in support of our next product venture. However, in view of your technical backgrounds, we were asked to confine our discussion to some of the applications we are using for detail design and for manufacturing. We will not spend time developing the return on investment of these applications although some savings will be mentioned in passing.

(3) Our agenda, then, will consist of me telling you a little about our manufacturing/engineering interface in BCAC and giving you some information on kinematics. Gary will cover parametric design and interactive computer graphics applications. Before I get into these applications, however, I should take some time to familiarize you

(4) with the tools we use and their overall integration.

Our batch processing confines itself primarily to geometry definition as opposed to analysis. We use APT, which stands for Automated Programmed Tooling. This is the language used in Manufacturing to drive the NC chip-cutting tools. In Design, we drive a pen, instead of a cutter, and thereby draw part geometry on paper or mylar to create engineering layouts and drawings. This tool is particularly effective for family of parts definition early in the product definition phase. Gary will go into the use of APT batch programs in more detail for you.

Our other batch process is TX95 which is the designation of our surface geometry system. It is a mathematical modeling program which uses second order equations for contour definition. All of the wetted areas of the airplane and much of the interior sidewall and ceiling panel surfaces are defined and controlled using TX95.

Jumping down to the bottom bullets, our interactive design machines are the Gerber IDS and Computervision, or CV's. We also have a small number of Applicons but they are not yet fully integrated into the CAD/CAM network.

As a matter of interest, the IDS systems and the CV's are not co-mingles on the same site. The history behind that is the 767 was the first program to endure (and I use the work advisedly) to endure a concentrated effort to use computing in the design process. The Company's background at the time, limited as it was, happened to be with a Gerber system. We had been doing a lot of development on the system and it was a key node in our integrated network plan. That drove the equipment selection. At peak engineering manpower, there were 25 systems with 5 local data base management systems, and 98 design scopes.

when the 757 Program was started, CV was considered the front runner in capability and we decided to purchase them. We were also driven by a strategy that we would not put all our ICG eggs in one basket. That later proved to be a wise decision.

5 Going back to the middle bullet, the whole bag of tools is tied together with the data base management system by the CAD/CAM Integrated Information Network, affectionately known as CIIN. The tools are all tied together through their own network information processors, or NIPs, and are thus able to communicate with each other. It is possible, for instance, to set at an IDS or CV terminal, access the TX95 loft and take a cut of the airplane wing. You can bring that cut back onto the scope and proceed with the normal detail design or analysis related to that contour.

The standard format of the geometric data base, shown in the central circle, is the lowest common denominator of entity exchange.

6 The geographic distribution of this system ranges across the nation via cable, telephone lines, and satellites, as well as trucking a few tapes around on occasion.

7 Our computer applications, as related to the design process, started in earnest back in 1960 on the 727 airplane. We used the TX95 system to completely define the exterior surface of the airplane. You can see the growth over the next 20 years. We have turned up the wick substantially in the last four years and have since added the 737-300 to the list. We are making some significant inroads into the design and manufacture of parts made from composites on that airplane. Again, we could spend an hour easily on the subject.

8 I want to turn your attention now to the manufacturing-engineering interface. To do this, I am going to use a very simple computer application.

9 A floor panel is essentially a two-dimensional assembly made up of a honeycomb panel with variations of cutouts, peripheral contours, fasterner patterns, and edge preparations. These panels fit together like a jigsaw puzzle to form the passenger floor of the airplane.

10 They are installed on the floor beams which are structural members of the basic monocoque configuration of the airplane. When we put both the floor panels and the floor beams in the computer, we can then use a technique we call computerized assembly to fit them all
11 together.

Now we can check for fit and for interference, tolerence, and general arrangement. We can also overlay footprints of galleys, stowage lockers and closets, and general seating arrangements, to check for compatibility. In addition, we can assure that fastener pattern locations agree between the panels and beams. It is easy to see the importance of this step and envision the impact of spotting errors at this point in design as opposed to discovering it out in the factory some 9-months later.

12 The panel itself is designed and stored in the computer as a leveled collection of data. The general arrangement and leveling of data is primarily the result of negotiations with Manufacturing to satisfy their fabrication, assembly and installation requirements. As you can see, the total panel is essentially point data with minimal annotation. The annotation is kept on one level, since normally, only the manufacturing engineer has any interest in it.

13 The flow of the computer data is from the engineer to the geometric
data base at the CAD/CAM data center. The manufacturing engineer
assesses the engineering data and processes it for NC usage. The
data is sent back to the GDB and on to the NC machine via the DNC
for machining of the floor panel. At the same time, the fastener
data is extracted from the GDB for use in the automatic floor drilling
14 equipment or AFDE system. Here you see a typical numerical controlled
machine, set up to route and drill floor panels using the engineering
released data set.

15 Geographically, the whole operation is supported by electronic movement
of data and automation of fabrication with the exception of trucking
the panels from our Auburn facility to the airplane.

16 When this process really pays off is in the installations. The slow,
manual drilling of fastener holes using templates, with the attendant
opportunity for errors and poor quality holes, is replaced by a
17 robotic process that is virtually error free with a quantum reduction
in time.

18
This all looks pretty spiffy and highly productive and it is. However,
we do have one small problem, the dual data source for configuration
19 control of the part and its installation. That is to say we have
a drawing, and its' electronic representation, the data set, both
in play.

20 These two come together at the end of manufacturing process when QC
buys the part. The implications are obvious. By way of example,
21 here is a case where the drawing shows one location for the fastener
and the data set lists another. Generally, this

happens when the designer changes the drawing manually and forgets to change the data set. Such errors are normally brought on by pressure of tight release schedules.

22 Another, typical discrepancy is disagreement between levels of data, in this case, the point data and the annotation map.

23 We find cases where a macro is developed to define a standard detail, but the designer modifies the configuration without suppressing the macro data.

24 And finally, a classic is discontinuity of the geometry definition. When the NC programmer in manufacturing converted the drawing to an NC tape, he or she would make checks for continuity so that cutter motion was assured. They knew the importance of that step because they had all been to their first tape tryout and received a first hand lesson early in their career. Now, the designer is responsible and some education is going to be required.

The solution to many of these problems is to delete one of the sources
25 of data, and to me the obvious one is the drawing. We are currently making significant moves in this direction at Boeing, but it is a slow and difficult task. We have spent over 50 years building and refining a paper work system that currently provides configuration control of one of the highest quality transportation products in the world, the Boeing Airplane. It will take time and patience to modify that system to accept such a radically different source of part definition. If we develop the necessary checking tools on the computer so that essentially error free engineering can be produced, we can make a significant step forward in the productivity benefits available in using computerized geometry data.

26 Next, I want to spend some time on one of the high leverage areas of computing use in engineering design. Kinematics is the branch of mechanisms dealing with problems of motion and, as you might imagine, on an airplane we have plenty of motion problems. Wing leading and trailing edges, nose and main landing gears, rudder and elevator and a myriad of system controls are all studies in kinematics. I'm going to show you three typical applications of how we solve some of these problems with computers.

27 Again, let's look at the tools first. We use APT, graphics systems and main frame programs. We may use these tools independently or in combination with each other. Generally, it is in combination because right now, one system does not have all the capabilities we need to define, analyze, and visualize any one particular problem. We wished they did but they don't. That's one of our challenges to the computing industry.

28 A typical data flow process might involve starting the design process on an ICG system like Computervision. Once the design is configured to the engineers satisfaction, the model is submitted to the Integrated Mechanism Program which resides on a large Cyber machine. The IMP processor has the ability to predict motion, forces and dynamics of mechanisms and display that data as a listing. In order to visualize the motion, however, we must either plot it on a quick-plot system or a flatbed plotter or bring it up on a scope. As you might suppose, intricate design problems can be very messy to display as a plot when small increments of motion are involved. Also, one desires a quick look at the analyzed data to determine where the critical areas of the problem lie. Therefore, we normally pass the IMP model data

to an interactive graphics system where motion can be simulated and special relationships can be quickly visualized and inspected. At BCAC, PDP-11 computers with Vector General Terminals are generally used for this purpose.

Having made the interactions necessary for a satisfactory design solution, the data ultimately ends up back at a CV where detail drawings and data sets can be produced. The analysis data may be used as part of a document to certify the design to the particular regulatory agency.

29 Let's look now at some applications of these computer tools. The first example I want to show you is an analysis of the passenger entry doors. There are anywhere from 4 to 10 of these doors on an airplane depending on the model.

30 These are plug type doors which have extremely complex motion. They
actually plug into the door frame and as the pressure differential
inside the airplane builds with altitude, the door is driven tighter
into the door frame. To open the door, it is first rotated open
31 inside the passenger cabin, then swung through the door frame, then
swung out to clear the door for passenger entry and egress. You
might wonder why these doors are so complicated. First, the design
puts the loads in the right place, on the door and not the mechanism
and second, it perserves valuable space inside the cabin which can
be used for revenue paying seats.

In this case study, we were looking to confirm motion, verify the mechanism and predict the loads of a design which had already been developed on the drafting board. The door and its' mating contours, along with links and cams were modeled from the engineering layouts.

32 With the model, we were able to move the door through incremental angles of motion. The center of gravity is identified as a circle, the load on a handle to open and close the door is represented as a rectangle and the instantaneous center of the door rotation is symbolized as a star. The cam surface which controls the door motion is the "S" shaped curve next to the star.

33 You see two incremental positions of the door with opening loads on
34 & 35 the handle and next two positions of the door with closing loads on the handle. Note that a person standing in the airplane trying to start the door moving closed is in fact, almost standing at the instant center of the door. Therefore, the force to close, loads the door mechanisms with very little resultant motion. Imagine a 100 pound stewardess, 15 feet in the air leaning out of the airplane trying to get this door closed.

36 As a result of modeling the mechanism in the computer, we were able to quickly investigate several alternate cam shapes.

37 The resultant plots showed we could keep the loads to start the door
38 closing very low. In fact, we brought the high motion loads into
39 a region where the attendant in the airplane would be better able to handle them. These loads were confirmed ultimately in the mock-up shop well ahead of production assembly and installation.

A spinoff of having modeled the door mechanism was that later we were able to run studies on effects of misrigging the door, door handle loads against opening the door under air loads, and door motion envelops for ground handling equipment.

40 The next case study involves a trouble shooting incident in the production line. The landing light housing, mounted on the nose landing gear interfered with the landing gear doors. The condition was discovered at functional test when the airplane is put on jacks in the factory and the gear is cycled.

41 We quickly modeled the light box and duplicated the nose gear mechanism and associated structure in the computer. We immediately embarrassed ourselves by determining that the problem belonged to engineering and not manufacturing who is normally responsible . . . right?

Our first approach was to re-rig the gear door linkages in the computer to allow delaying the door motion and thus providing clearance. Although we could prove the validity of this solution, it turned out to result in a drag penalty to the airplane and was not acceptable.

The box was then redesigned within an envelope determined by critical
42 gear and door positions. We put the new box in the model and
analyzed the configuration for minimum clearance. The results were
favorable and the design was completed.

We saved the shop and engineering a great deal of time and money which in the past would have been spent doing an in-line mockup and cycling the gear to determine proper rigging and adequate clearances. That gear operates off a 3,000 psi hydraulic system and is very difficult to control for small incremental motion studies.

43 The last example I want to show you involves a situation where we initialized the design and analysis on the computer. This, obviously, is the best use of a computer. The design problem was the exhaust gate on the 737-300 trailing edge flap. It was necessary to have a

section of the flap, which we call the exhaust gate, remain up out of the engine exhaust plume when the trailing edge flap is extended.

Here again, the kinematics of the system is very complex; almost
44 impossible to do on a drawing board with a high degree of certainty.
The exhaust gate rides on the mid flap which moves relative to the
wing chord plane. Our desire was to develop the mechanism, keep
loads low and use common parts on both right and left wings.

The mechanism is shown in the side and plan views. The high loads come in the "J" shaped cam.

45 As you can see, the monkey motion is very complex. The side view is superimposed for purposes of analyses.

Again, a plot of motion is available from IMP which quickly shows the
46 results of conditions under investigation. This plot shows how the
gate stays with the mid flap until about 14^{0} flap angle, then the
gate maintains its' position relative to the wing chord plane.

47 On this particular design, we were able to take a young engineer with a little over one-year of experience and do the job. He was able to take the initial design and reduce the cam forces significantly. The new design caused an early rotation of the gate which caused Aero to consider the effect, a condition they had not previously defined. Although the lower load cam was not accepted because of aerodynamic concerns, the overall design was completed and fully analyzed before any detail parts were designed.

48 Here again, IMP provides a detail listing of forces as a function of angle or whatever other parameters you might need to analyze the design.

By using the model on CV, we were able to verify link motions and check clearances and tolerances. Using the Vector General Scope, we investigated the smoothness of the flap motion and the symmetry of motion across the gate.

49 I want to make, what I feel, is an important point here. It has to do with quality of design and cost avoidance. This graph demonstrates my point.

The smooth curve, defined by the three solid dots represents a traditional load-angle analysis done manually. Experience plus time constraints are married together to develop such curves. With a brief prayer, such data is adopted as requirements for design. Any variations, as shown by the computer analysis, which by the way was done in this case in one tenth the time, were never discovered until parts failed in functional test, or worse, in service. The computer allows us to make the necessary iterations to assure design integrity. This is an intangible benefit which is often difficult to explain to a cost conscience manager, as many of you know. But we have proved it in the trenches many times.

These three examples of computer applications on kinematic design should give you some insight of what we are doing at Boeing, the power of the tools, and why we are so excited about pushing the state-of-the-art of these systems.

Now I'll turn the program over to Gary.

1

PARAMETRIC DESIGN

PARAM DESIGN

1 INTRODUCTION

2

3 Parametric design began on the 747 SP

747 SP

* Body Frames
* Floor Panels

4 The concept was expanded on the YC-14

YC14

* L.E. Ribs
* Inspar Ribs
* Body Frames

5 On our most recent programs, 767, 757
6 parametric design has been used extensively.

767
757

7 "Parametric Design" is applying CAD geometric computing techniques to design and drafting tasks that are similar and repetitive. It allows engineers to rapidly create and iterate the engineering design.

PARAM. DESIGN
PARAM PROCESS OUTPU
ZL

Parametric design is the process of selecting frequently used design configurations and parameters and creating a computer program for sizing and computing the part geometry and related data, i.e., weight, volume

The slide illustrates the parametric design of stiffeners. The input parameters are location of the stiffener, thickness, type of stiffener - Z, T, or channel and fastener spacing.

The parametric computer program processes the input and the corresponding output is displayed along with other part definitions.

8 This process is particularly useful when
9 addressing similar or "family of parts" application. Many design parts can be
10 described with primative geometric shapes that can be fed different parameters for different sized parts.

FAMILY OF PARTS RELATIONSHIPS

11 Parametric design is used at Boeing for the design of look-alike parts such as wing ribs, body frames, and complex structure such as side of body chord, and spar chords.

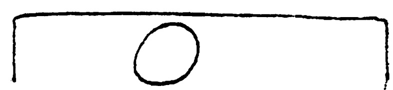
EX. OF PARAM. PROGRAMS

12 Body frames such as this one appear approximately every 20" in an airplane
13 as indicated here.

BODY FRAME

FUSELAGE CENTERLINE

14 Each frame is contour related and is sized to meet a specific frame station.



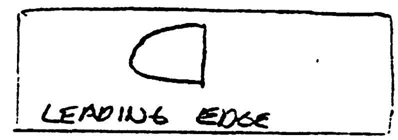
15 Design data is entered into the program which produces the families of inspar ribs, spars, skins and stringer detail.

TYPICAL PROGRAM STRUCTURE

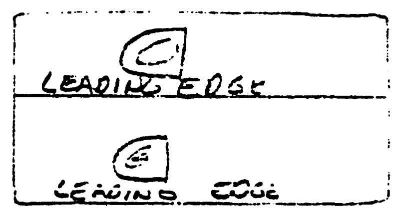
Looking at a parametric program module in a little more detail we see that input such as gage values, stiffener selection and rivet spacing parameters are typical type input. Note that intermediate data is stored for subsequent processing. I will mention a little later how the intermediate data can be used to produce lower level detail parts.

The process in the development of parametric PROGRAM is to design one part, and to determine the parameters necessary to design that part, and then modify the parameters enough to produce the remaining parts of the "family".

16 For example, this slide shows a leading edge
17 rib at one station along the wing.



18 The parametric program was written and in these subsequent slides 2 other leading edge ribs were produced with the same program. I have overlayed them with different colors to illustrate that the leading edge ribs look alike, but are unique in detail.



Parametric programs may be created on a mainframe computer or on some ICG systems that have computing programming capability.

For example, mainframe applications are for larger, more complex items such as the wing to body structure.

Interactive graphics applications are for smaller, lesser items such as floor panels and floor beams and sheet metal flat patterns.

Parametric programs are generally not used to complete drawings, but are used for layouts. These layouts are completed on ICG systems or by hand.

19 Mainframe programs are written in APT and some FORTRAN.

APT SYSTEM

This shows a breakout of the APT processor. The geometry definition is first created. Then motion instructions are used to generate plotting centerline data. Various post processors may be used to accomplish plotting or transfer datasets to ICG equipment.

Some of the reasons for using APT:

1. 3-D Geometry System
2. High level language, APT allows geometry definition with small numbers of statements.
3. APT has a good interface with lofting systems.
4. Commonality with Manufacturing N/C programming for possible data exchange.
5. Industry wide acceptance

OUTPUT

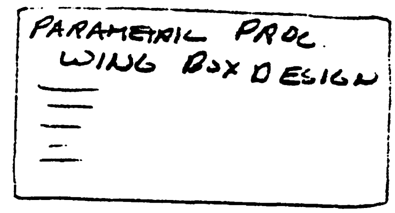
Output from parametric programs consist of:

- drawing layout plot without annotation
- geometry dataset and other associated data

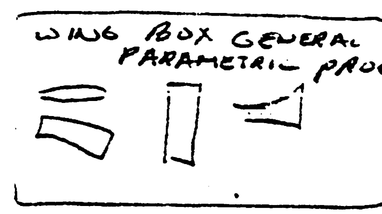
20 The 767 wing box was designed using a parametric program generally considered to be the most powerful and cost effective CAD program on the 767.

767 WING BOX

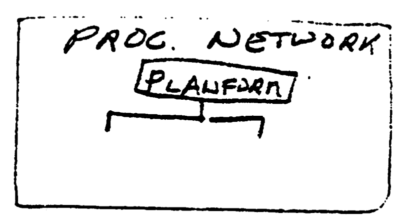
21 To design the wing box it was required that the program be able to handle all the design iterations of aerodynamic shapes, structural arrangements, structural thicknesses, structural concepts and sizes. In addition, the program had to be able to reflect changes to all components, programmed from a common origin, be compatible with interactive computer graphics, and satisfy all technical staff and Manufacturing data requirements.



22 The resulting wing box program allowed configuration and geometry concepts to be input, to produce the designs for panel, ribs, and spar layouts.



23 The program network looks like this. Its top down structure allows creation of airplane geometry which is then used to size detail components according to the outside envelope.

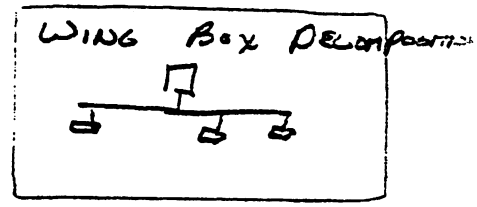


For example, planform geometry is combined with loft extractions to provide individual profiles for rib and spar programs. The spar program is then used to produce the spar layouts and rib layouts accordingly.

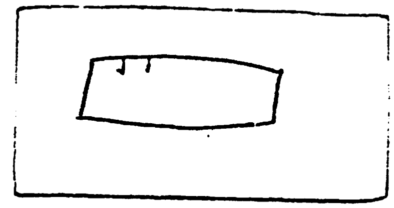
One key element here is that data used to size the spar in one layout is the same as the rib layout.

BECAUSE EACH MODULE SHARES COMMON INPUT. IF CHANGES ARE MADE TO THE THICKNESS OF A SPAR CORD, FOR EXAMPLE, ALL RIBS, CLIPS AND ITEMS RELATED TO IT ARE CHANGED WITHOUT REQUIRING A DESIGNER TO SPEND VALUABLE TIME INVESTIGATING AFFECTED

SLIDE This next chart shows a further decomposition of the wing box program. The parametric program can be designed to produce assemblies, and lower level parts.

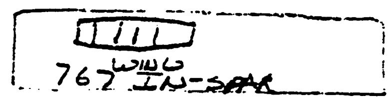


25 This is a layout from the rib program, which shows the wing profile cut commonly called the box section.

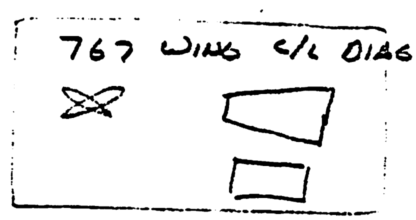


26 ...and with further detail the rib layout can be produced.

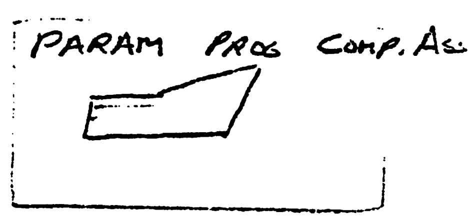
27 ...and finally, when the two previous slides are brought together in the graphics system, where annotation is added. The complete wing inspar rib is designed.



28 In the design you can see there are numerous wing inspar ribs. Each rib was produced from the same program with different input data. there were 35 on the 767 program. Similarly, wing panels use planform geometry in order to produce the panel layout.

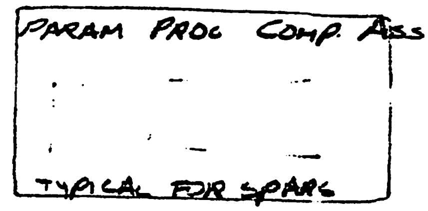


29 Computer modeling of wing components aid in reducing engineering errors. By modeling the stringers and panels in the computer we can assemble the panel and check for interferences in the design phase rather than in manufacturing. This slide shows typical areas of problems ... at the side of body, stringer rib chord pads and fitups of detail parts.



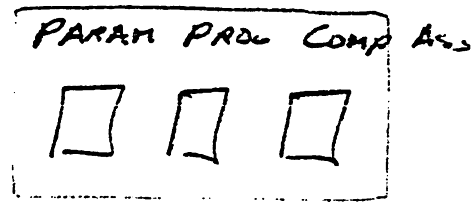
As you can imagine, minimizing engineering errors can result in a large down stream cost avoidance in Manufacturing.

30 Fastener patterns are also computed in the wing box program. Individual location of ribs are computed based on design criteria such as thickness and spacing. The fastener patterns are released in a dataset to use on the Gemcor riveter. I will show a picture of the Gemcor in a couple of slides.



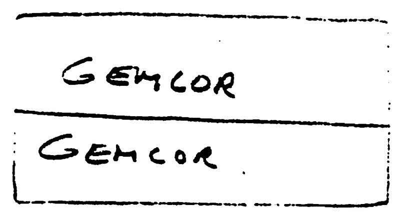
31 For the first time this allows engineering definition of all fastener locations. The printouts extracted from datasets allows:

- configuration control of tack fasteners
- generation of CAM tapes for pilots in stringers
- generation of tapes for Gemcor automatic riveting machines
- visibility of fastener locations

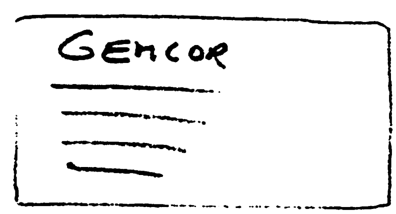


32 This is a photo of the Gemcor automatic riveting machine with the wing panel.

slide This next photo shows the underside of the wing panel on the Gemcor



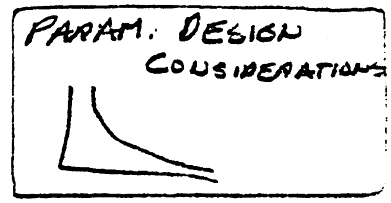
33 It is interesting to note that two new airplanes -- the 757 and 767 -- each had about 56,000 holes apiece on the wing panels and the panels were completed with no major engineering errors.



Also on the 767 program parametric design was used on the Class II mockup. Because of the quality of the computer plotted layout and their accuracy, the Class II mockup was utilized as a Class III mockup. This represented considerable savings.

A Class II mockup does not have the tolerance and accuracy requirements of a production airplane. It is for spatial layout and conceptual design. Class III must be sufficiently accurate to run tubing and electrical layouts.

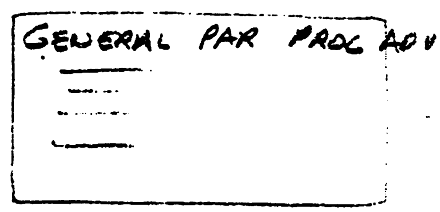
slide Anytime you make a parametric program you inherently inhibit to some degree the design flexibility. The more detail included in the program the less flexibility the designer has.



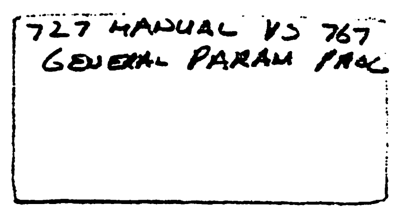
The blue and green areas on this slide are where parametric programs are used for more than one model. The brown and red areas are areas which are completed in graphics or by hand, or completed as specialized model unique programs.

34 This chart shows some typical advantages and design iteration flow times using parametric programs. As a comparison of doing similar jobs in the past, it took months to accomplish the design modification to a change to the 747

35 wing contour -- in a similar job that it took a week on the 767.



36 In addition to the general advantages, one major one is that parametric design programs provide capability to provide greater detail layouts earlier in the program. This means that Structures layouts can be completed earlier, which allows systems to begin their designs earlier.

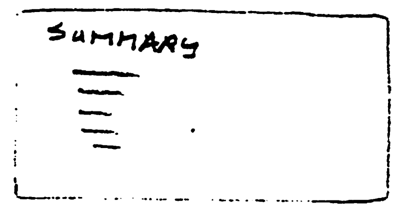


THE LAYOUT OF THE WING RIBS AND SPARS WAS ACCOMPLISHED APPROXIMATELY SEVEN MONTHS EARLIER THAN CONVENTIAL METHODS WOULD HAVE ALLOWED.

Parametric programs and CAD/CAM in general are allowing Boeing to re-assess the standard flow times necessary to design and build an airplane. The next aiplane will have a significantly shorter flow time from go-ahead to rollout than in the past.

slide

In summary parametric design allows:



- computerized assembly verification
- significan design changes can be accommodated in a much shorter time than before
- forces and requires design discipline because of the parametric design process
- before parametric design, drafters would draw each part separately, resulting in as many differences in parts as there were designers

(2)

1 INTRODUCTION

We use two main graphics systems at Boeing, Gerber IDS 3 and Computervision CADDS 3 systems. We also have a small number of Applicons.

ICG

Both graphic systems are stan-alone mini-computer systems with 4 or 5 storage tube graphic terminals on each CPU. The first slide shows a Computervision system with a printer on the left, DISK DRIVE, TAPE DRIVE ON THE TABLE, CPU UNDER THE TABLE. This is a similar SLIDE OF A Gerber system

CV SYSTEM

GERBER IDS SYSTEM

2 At Boeing we found it necessary that our systems be able to interface with other existing systems such as the TX95 master dimension systems, parametric design PROGRAMS or APT. We have also been able to take data from vendors developed on other computer systems and bring them into graphic systems. The output options are: datasets, which may be routed to the geometric data base for future use, for a plot or directly to Manufacturing for N/C programming.

ICG

INPUT OUPUT

3 These are some of the advantages of using ICG:

ADVANTAGES OF USING ICG

(2)

In addition to these items it must be realized that some tasks could not have been accomplished without use of ICG graphics. For instance there were not enough trained experienced people available for the new Boeing airplane programs. The ICG systems allowed the production of drawings that otherwise would not have been possible.

In some areas, like automatic diagram system, we are totally committed to doing the job with graphics and a backup method does not exist. No manual capability exists.

Next I would like to discuss some **successful applications** of ICG Graphics:

A. 3D - Application in cockpit area.

B. 2D - Building block application concept in Payloads

C. Use of levels to aid printed circuit board applications.

D. CAD/CAM - ICG is used to produce tooling templates.

E. TUBEND - 3D model of A/P hyd. systems

4 In the Flight Deck of an airplane it is necessary to shield electronics from moisture condensing in the airplane as it goes through the altitude and temperature changes. A fiberglass shield is built particularly around the structure, right into the nose for this purpose.

DRIPSHIELD

The problem is the challenges of 3-D, you have to be able to visualize and conceptualize to create geometry layouts within a graphics system. The product of the design process was a 3-D dataset, which was then transmitted to Manufacturing where the tooling and master modeling was accomplished directly off

5 of the dataset. The design was not taken from a 3-D model to a 2-D drawing and then have Manufacturing build a 3-D product, it went directly from a 3-D dataset to Manufacturing

767 PAPER MOCKUP

6 This is a photo of the model dripshield. The dripshield is installed in the airplane prior to electronical installation.

PHOTO OF DRIPSHIELD

slide ICG techniques were applied heavily in the interior design of the new airplanes.

LAYOUT PASS. ACC.

slide The exterior envelope of the body was fed into the graphics systems, where it was utilized to produce arrangements of furniture and seating arrangements for later customer approval.

9 In the layout of the passenger accommodations (called LOPA) there are a lot of repetitive features, which can be utilized in this design. The graphics system allow you to quickly move and replace, accomplish different arrangements in order to suit various customer needs.

LOPA COMP. ASS.

In developing a LOPA configuration for a customer it is not unusual to develop 8 to 10 variations before final customer approval.

11 This is a picture of the final product, the ~~interior of the 767 airplane.~~

INT. 767

The third example illustrates the application of leveling. Leveling on ICG systems performs the same function as the use of a multi-colored overlayed viewfoils. Levels of detail can be shown by adding or removing a given viewfoil, or with an ICG system by adding or removing the displaying of a level. Leveling can also be used to group information within a dataset. In this way all the information concerning a part or its manufacture can be maintained in a single dataset.

PC BOARD

13 The electrical area lends itself very well to the use of ICG equipment, particularly in the use of levels which is available on all our graphic systems. By using levels all of the information necessary to create a printed circuit board is contained in the single dataset.

~~PRINTED CIRCUIT BOARD~~

PHOTO LRU

14 Information concerning the location and thickness of connector pads and traces on the top side of a printed circuit board would be represented by one group of levels.

15 Silkscreen data would be represented by another.

16 And the underside of the board on still another.

A typical PC board dataset will contain ground plane, drill and trim, pad and trace information and silkscreen data. All of the information is transmitted from Engineering to Manufacturing in the form of a photo-plot tape from which the manufacturing process takes place.

slide This slide shows an example of an electrical schematic. Wiring diagrams and electrical schematics take advantage of the use of symbols and repetitive characteristics. The output is in the form of a dataset sent directly to 35mm film for the creation of technical publications. Computerizing these diagrams is very cost effective in providing customer unique data. For example the American Airlines maintenance manual will be unique. This application allows tailored manuals for each customer.

SCHEMATIC

20 The Graphics Automated Template System (GATS) is the primary template fabrication system used by BCAC and is an excellent example of how Manufacturing uses interactive computer graphics.

GATS

21 65% of the templates used are for sheet metal fabrication, and about 25% of them are flat.

TEMPLATES

22 GATS is software resident on CV. It allows production of templates, bluestreak, sheet metal parts, tooling components, and geometry for routing.

GATS DATA FLOW

In order to generate Numerical Control tape for template production, tool geometry must be input. This is done by one of two methods:

23 1) The engineering drawing can be digitized and the data processed goes directly in the CV system:

DIGITIZE

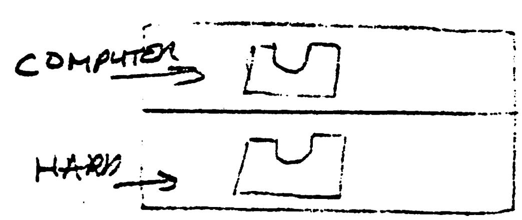
24 2) CAD datasets can be accessed through the geometric data base.

USE CV

25 After the geometric definition is entered, tool features are added, a cutter path is generated, and a punched tape is produced. Templates are then machined on NC milling machines.

BURGMASTER

26 This is an example of a template on the ICG screen. 8



26A ...and the output is punched tape, which drives NC milling, which produces the template as shown.

27 For some parts GATS provides information for a nesting and routing sequence. At one time nesting--which is laying out of the parts in such a way as to maximize use of the material--was done by a person who layed them out on brown paper and traced around.

NESTING

28 The computerized method is accomplished using ICG. Using the graphics CRT, the stored images of the parts are called up. The operator can move the images around on the screen and when satisfied with the nest, will
29 process the layout and automatically produce a floppy disk which is then run NC machine.

ICG

NC MACHINE

The advantage to using this method is speed, and automatic creation of the NC tape without additional steps in the process.

32 TUBEND

757 TUBEND

33 TUBEND is a computer system which integrates the entire hydraulic system design and manufacturing process, and is an example of engineering's use of interactive computer graphics.

The object of the system is to develop the airplane hydraulic system by direct interaction between the computer system and designer.

TUBEND supplies data for design judgment and decisions, supports rapid design iterations - both layout and analysis, and automates drafting standards and selection.

SLIDE WHAT IS IT

Before TUBEND...about 90% of the thousands of feet of hydraulic tubing for any new airplane had to be reworked and remade. ~~Tubing has a relatively high failure rate of service.~~

WHY? Because tubing for the first production airplane was copied from the tubing made to fit a mockup or model of the airplane. In mockup, tolerances are a problem because while structural details are built as close as possible, advanced layout drawings are used and no hard tooling is available.

THIS IS A SLIDE OF 757 MAIN WHEELWELL MOCKUP

Tubing is bent to fit such hard points as blocks, fittings, and clamps, and when copied for the first production airplane, most of the hard points are in different positions because of tolerance build up and last minute structural changes.

TUBEND builds a 3-D model of the airplane's hydraulic system as the designer loads the computer with installation positions and part performance data component by component.

TUBEND does not require the designer to be a programmer or mathematician. For example, if I want to install an actuator in the airplane, I tell the computer I want to install a component.

The computer asks, "What kind of component?"

I respond, "A flap actuator."

"Where is it located?" the computer asks. And I give it the waterline, buttock line, and station coordinates.

From there, with all components in the system, the designer can start to route the system on what is called a road map -- a diagram that shows how all the components are located.

35

TUBEND
~~SLIDE~~ OPLINE
THERMO

At this point several kinds of analysis can be done using programs interacting with TUBEND.

- o Analysis system to determine smallest, lightest tubes
- o System to determine high and low operating temperature range
- o Design parameters
- o Stress analysis

36

DATA FLOW

As a result of the installation of components and tube routing in the 3-D computer model, TUBEND can release information for drawings and to the mockup. This allows verification that conflicts have been resolved.

An additional "goodness" is no longer being dependent on master sample tubes. There are roughly 1200 master sample tubes for the 757, for example. This photo shows you how master tubes are stored.

MASTER SAMPLE

Master sample tubes are pieces of hydraulic tubes copied from tubes made to fit the mockup and reworked to fit the first production airplane. These tubes are then used as a pattern for subsequent tube fabrication.

Sample tubes are a problem because they go out of shape easily, and because there is no record as to what the tube geometry should be.

We also have numerically controlled tube bending equipment which works directly from geometric tube coordinates released from TUBEND.

SLIDE TUBE BENDING

The resulting tubes are also being checked against TUBEND - generated mylar checking templates.

SLIDE
CHECKING FIXTURE

40 In summary, TUBEND aids engineering and manufacturing.

~~SLIDE~~
USE OF TUBEND AIDS

Engineering can assume full responsibility for tube design, rather than relying on sample tubes.

Manufacturing can reduce tube development by the use of data sheets.

Production is aided because remaking of tubes is greatly reduced, and real tube tolerance is defined for installation.

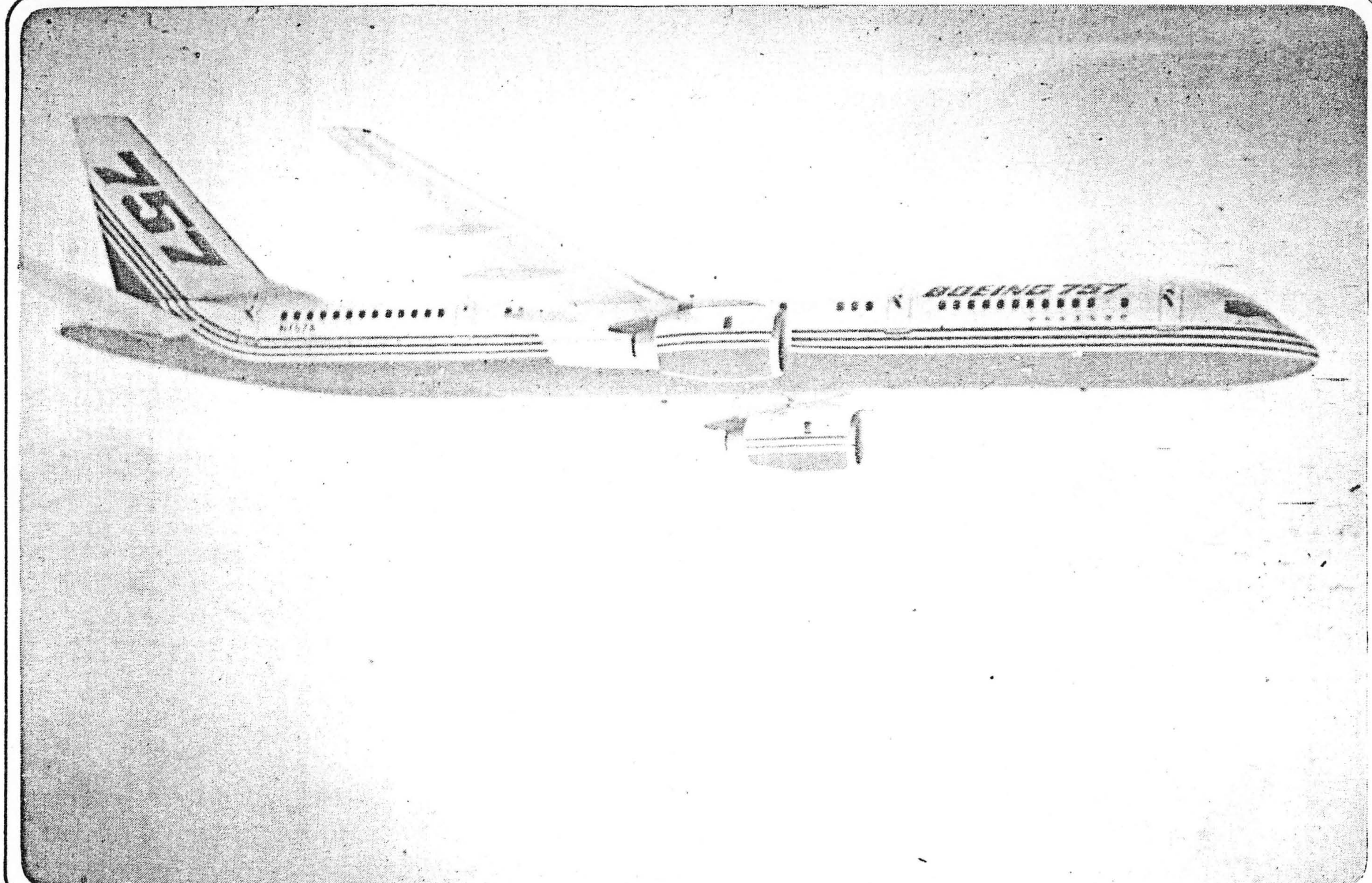
The service life of tubes is also increased because of stress reductions.

Delvin P. Tingwall

Chief Project Engineer

727/737/757 Engineering Computing

December 1982


757
BOEING 757

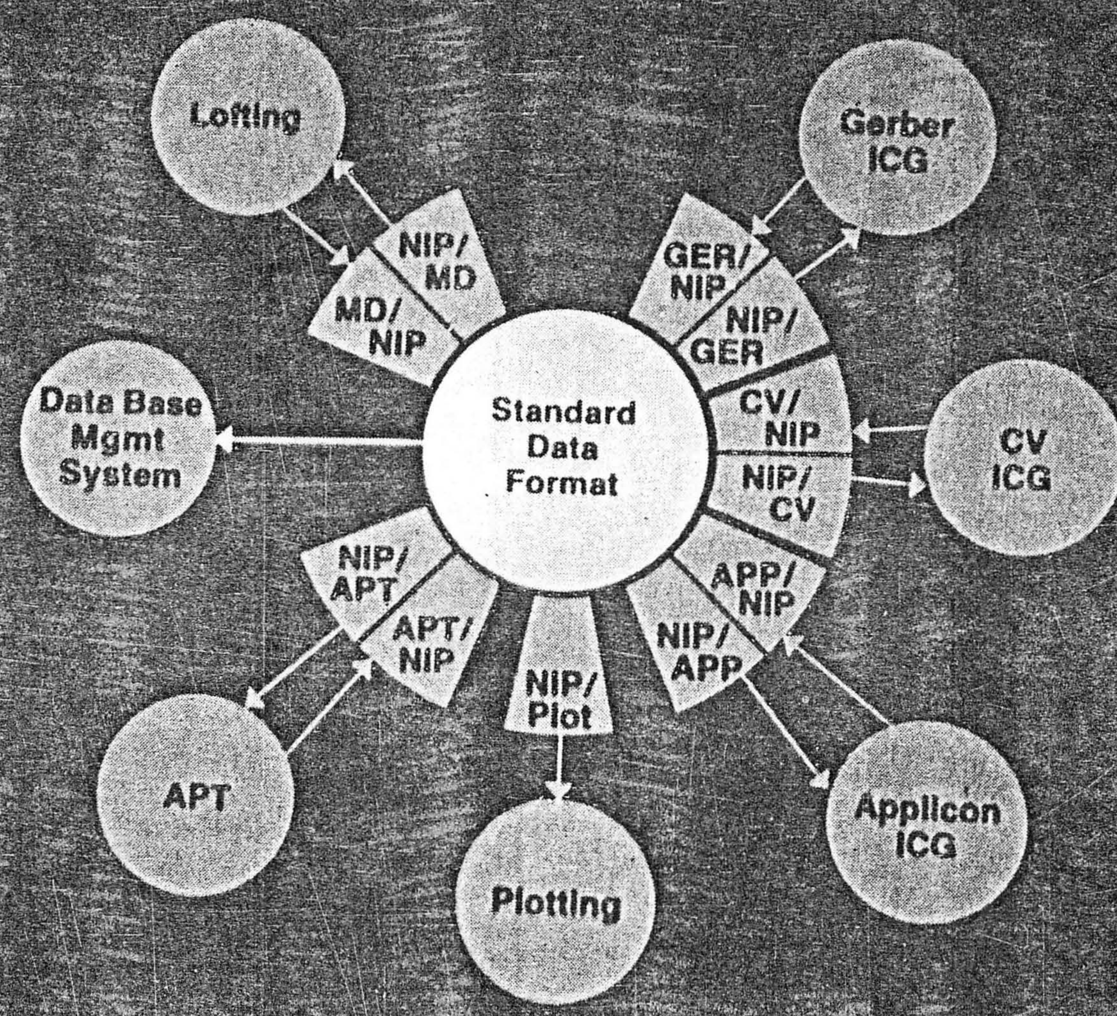
Agenda

- Introduction
- Manufacturing/Engineering Interface
- Kinematics
- Parametrics
- Interactive Computer Graphics

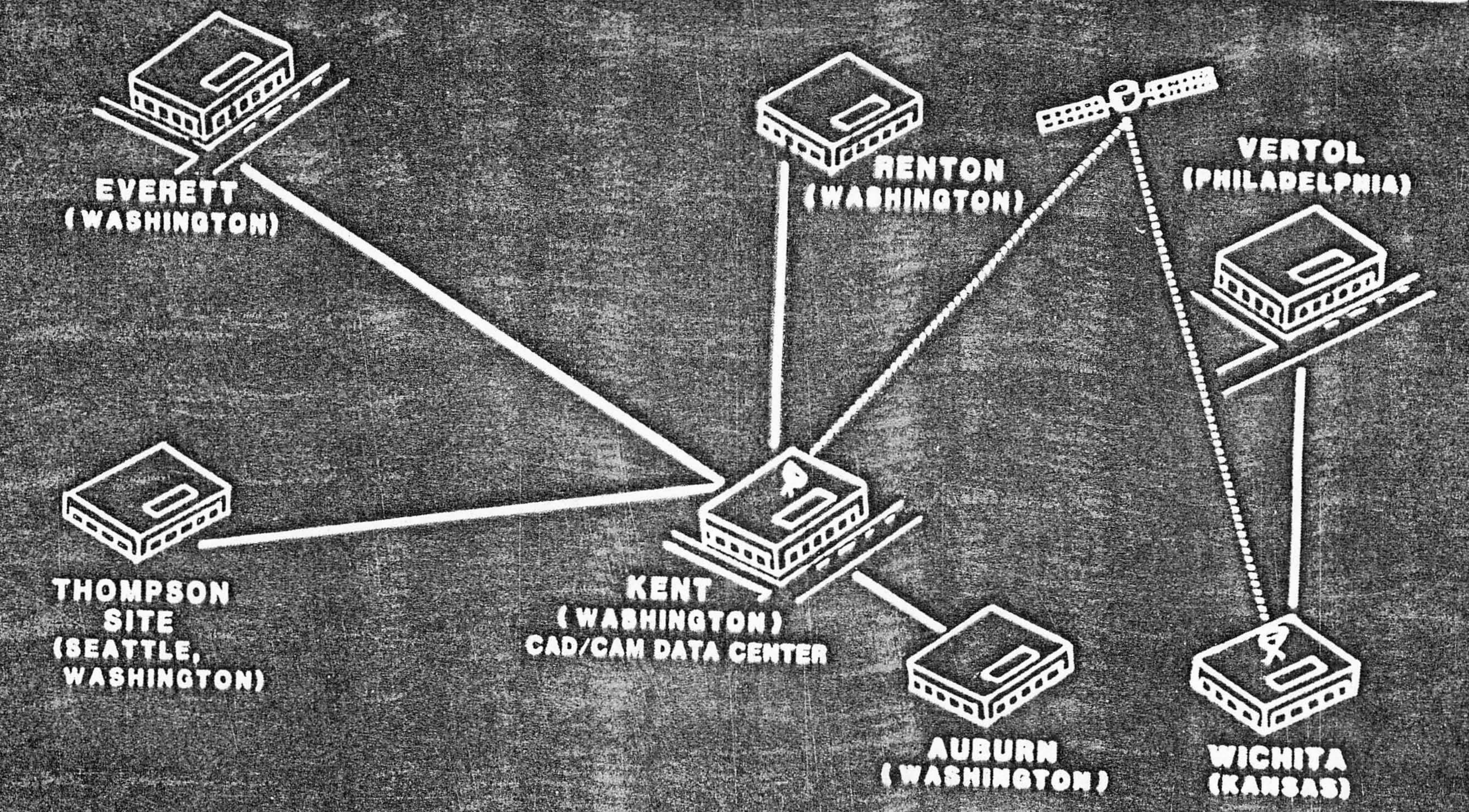
CAD Computing Systems

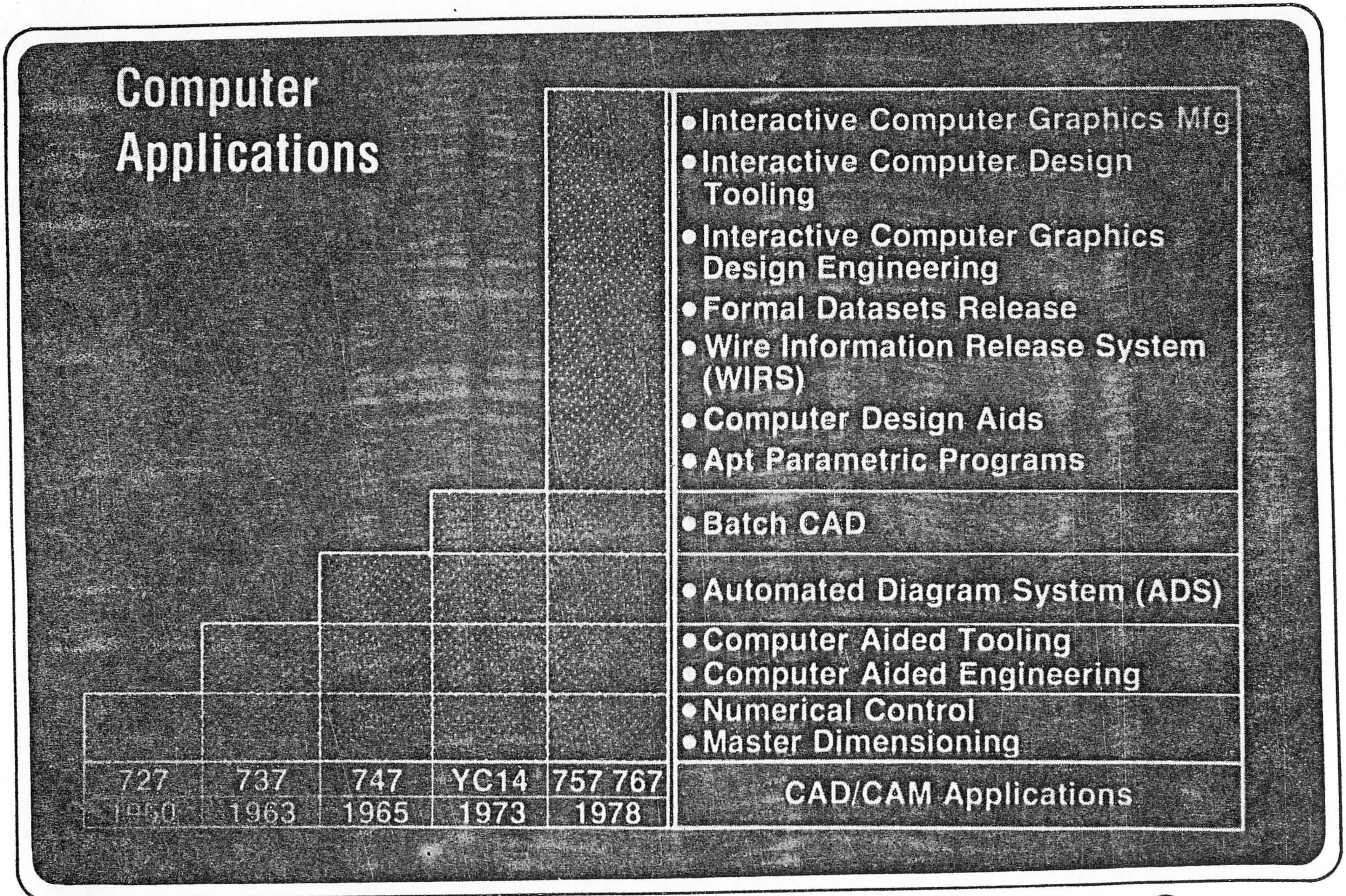
- Batch
    - APT
    - TX95
- Data Base Management System
    - CIIN
- Interactive Computer Graphics
    - IDS/DMS
    - CV

System Functional Schematic



GEOGRAPHIC DISTRIBUTIONS



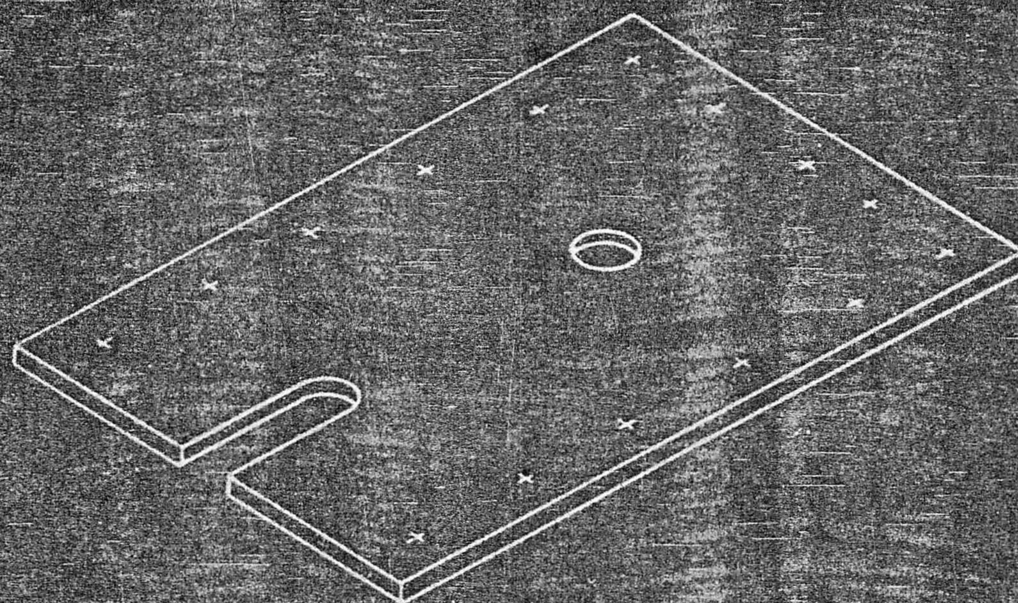


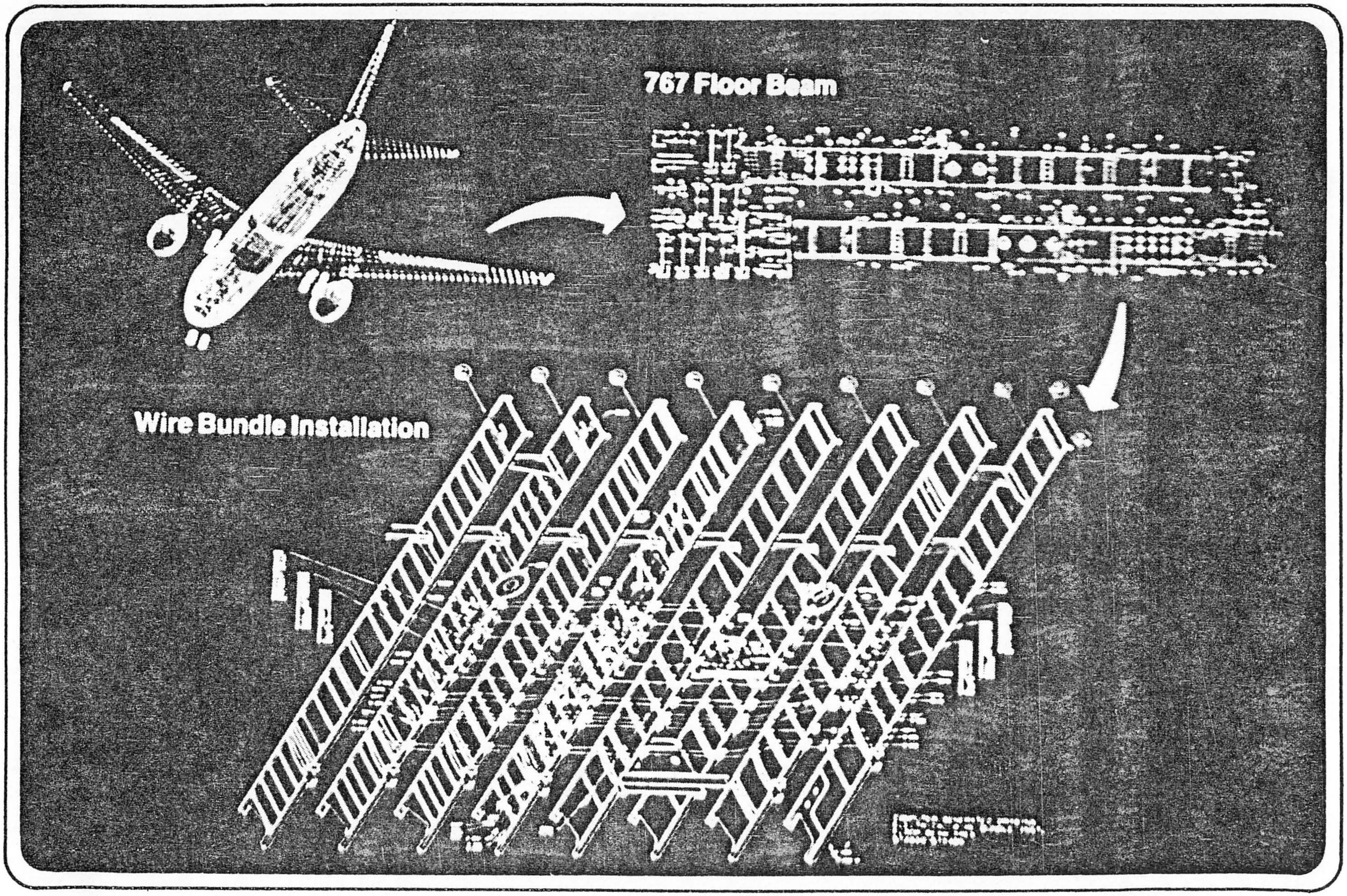
Computer Applications
• Interactive Computer Graphics Mfg
• Interactive Computer Design Tooling
• Interactive Computer Graphics Design Engineering
• Formal Datasets Release
• Wire Information Release System (WIRS)
• Computer Design Aids
• Apt Parametric Programs
• Batch CAD
• Automated Diagram System (ADS)
• Computer Aided Tooling
• Computer Aided Engineering
• Numerical Control
• Master Dimensioning
727
737
1963
747
1965
YC14
1973
757 767
1978
CAD/CAM Applications

CAD/CAM Interface

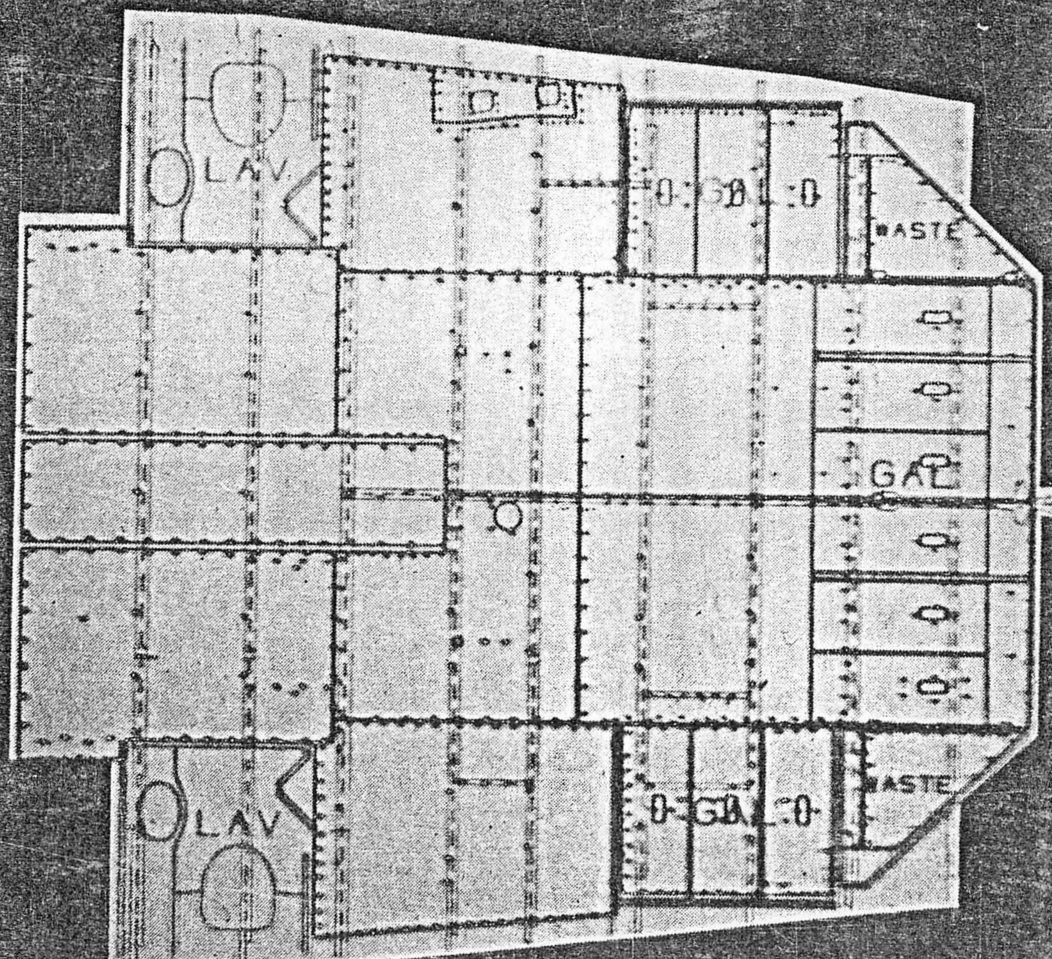
Floor Panels

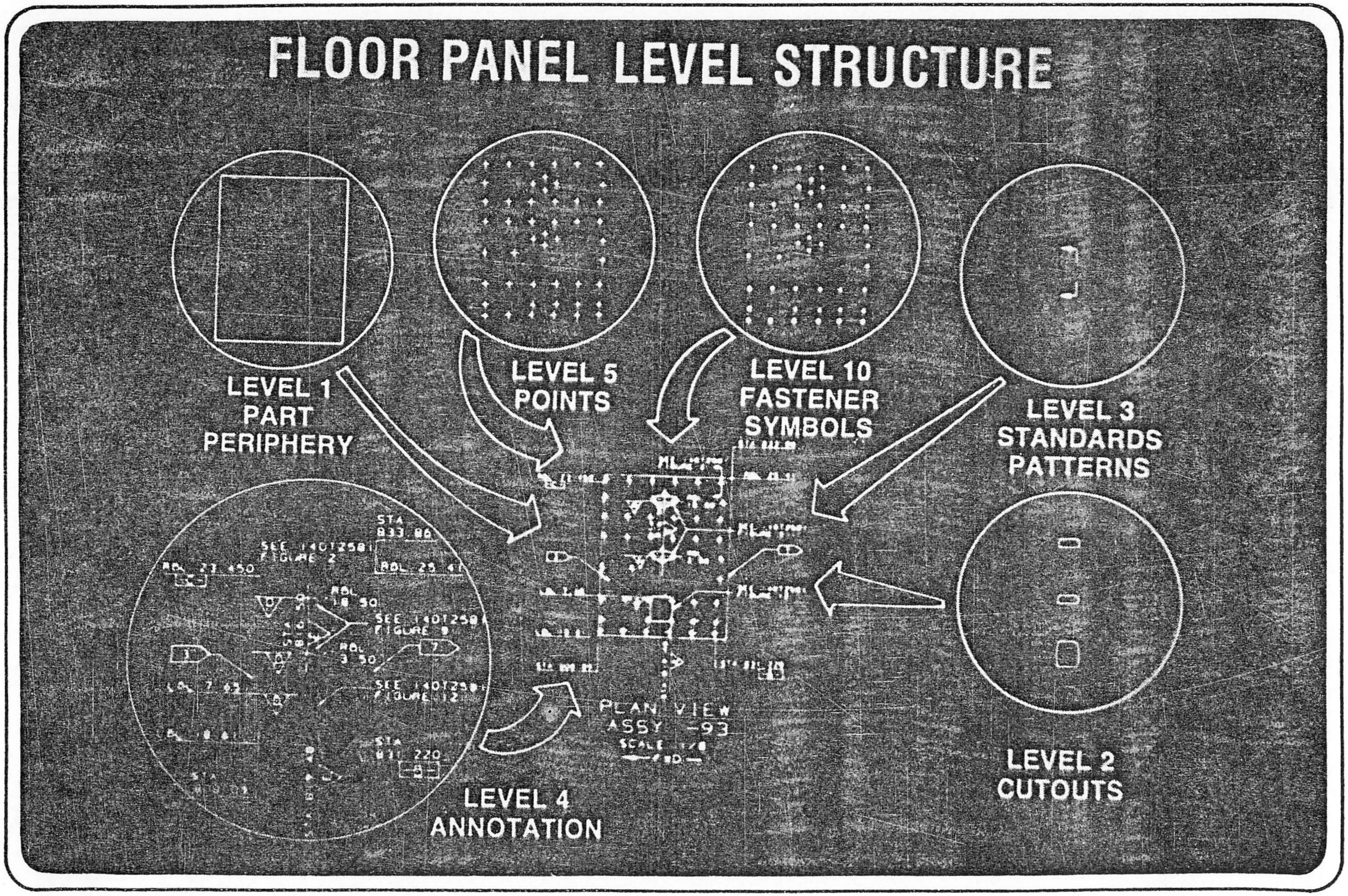
Typical Floor Panel

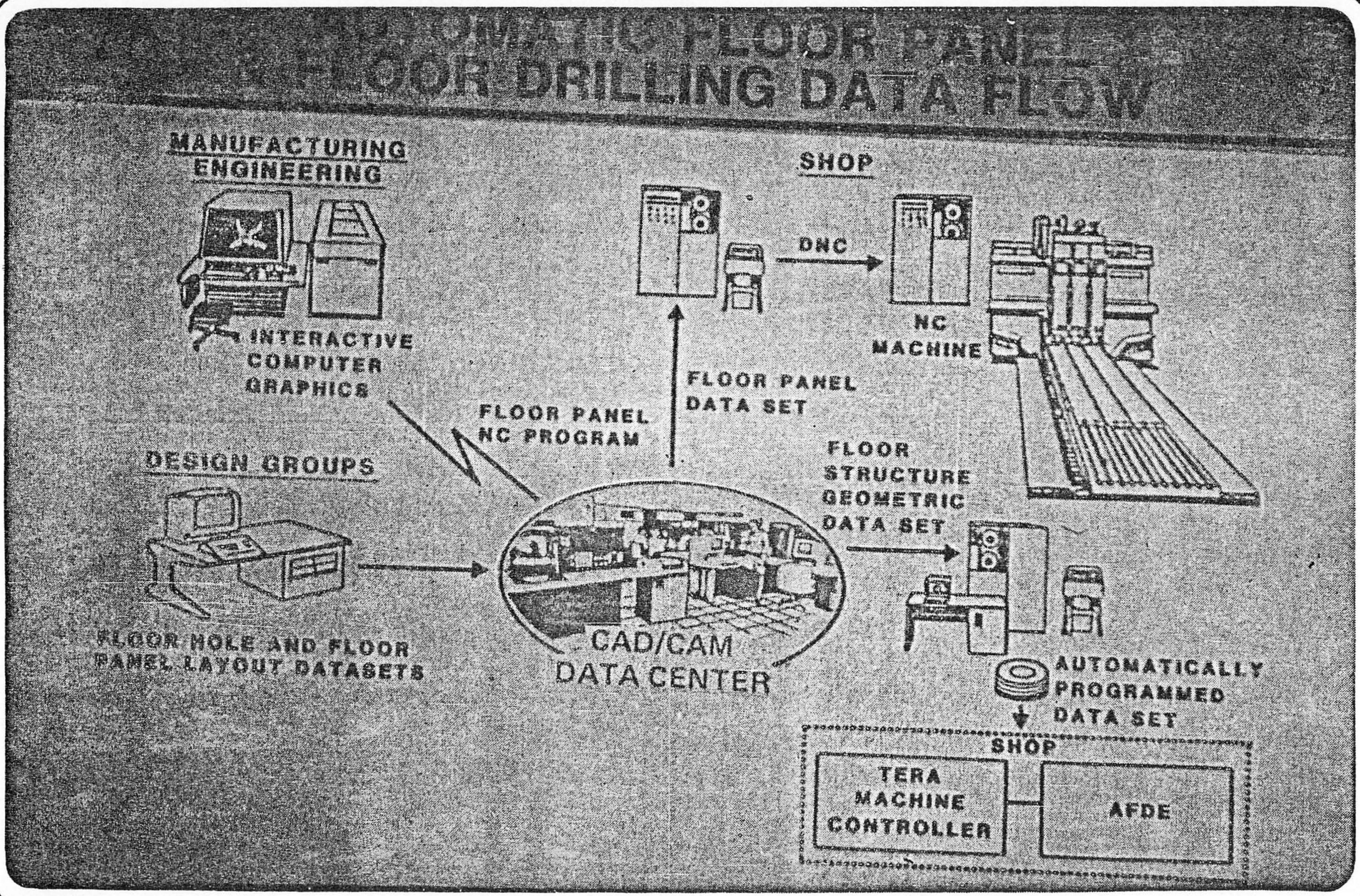


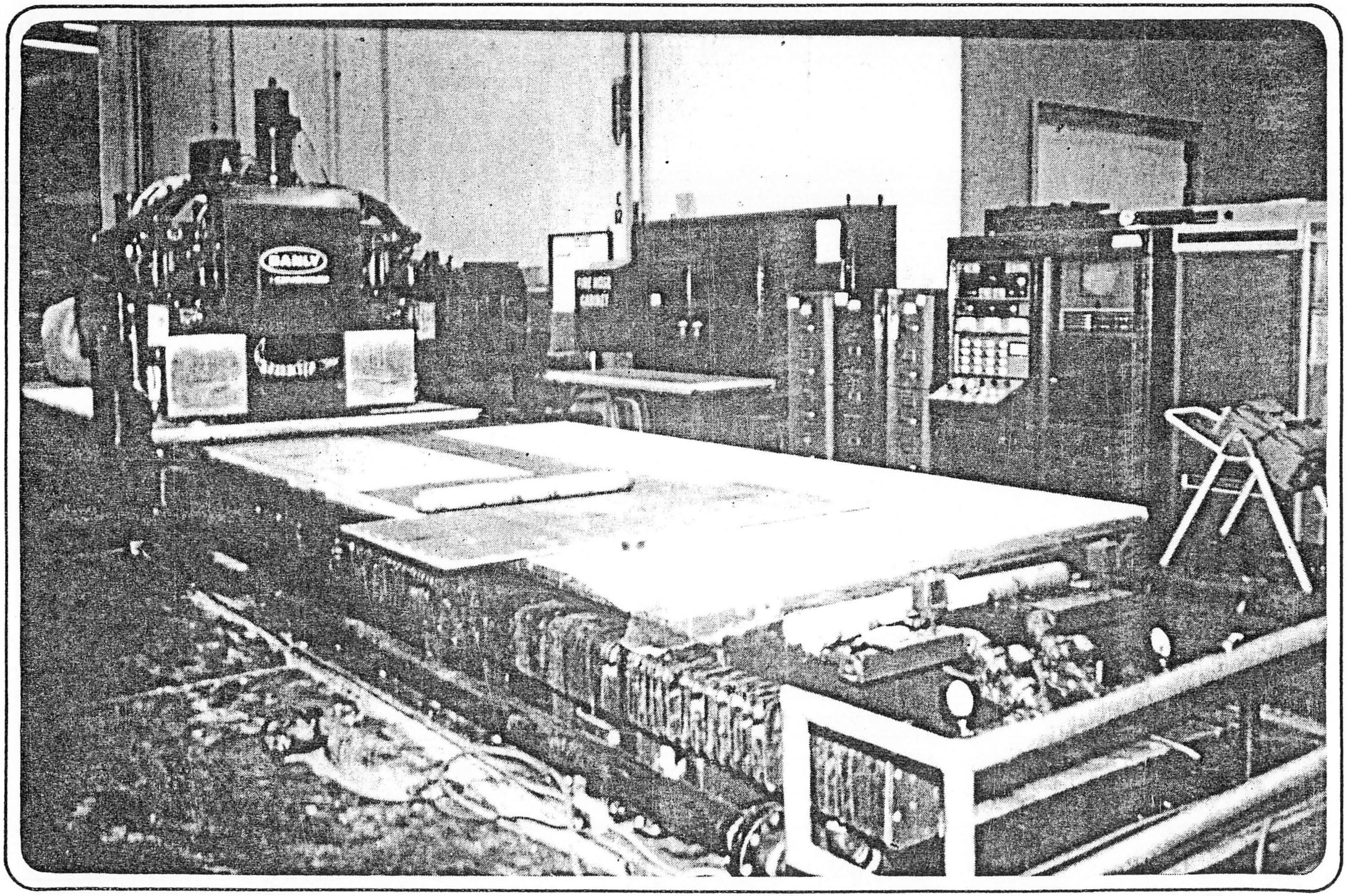

767 Floor Beam
Wire Bundle Installation

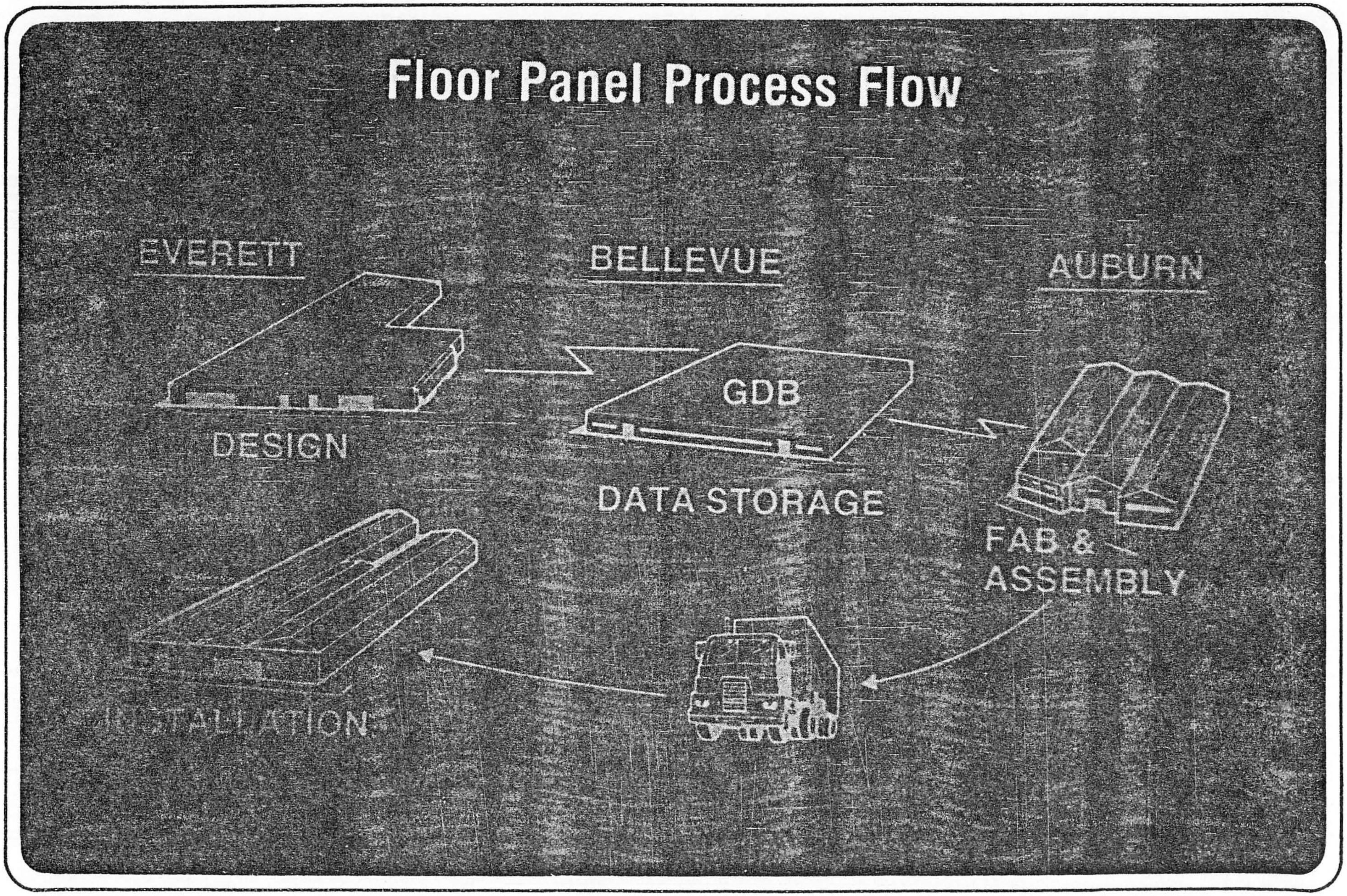
Payloads/Structures Common Data
Computerized Assembly

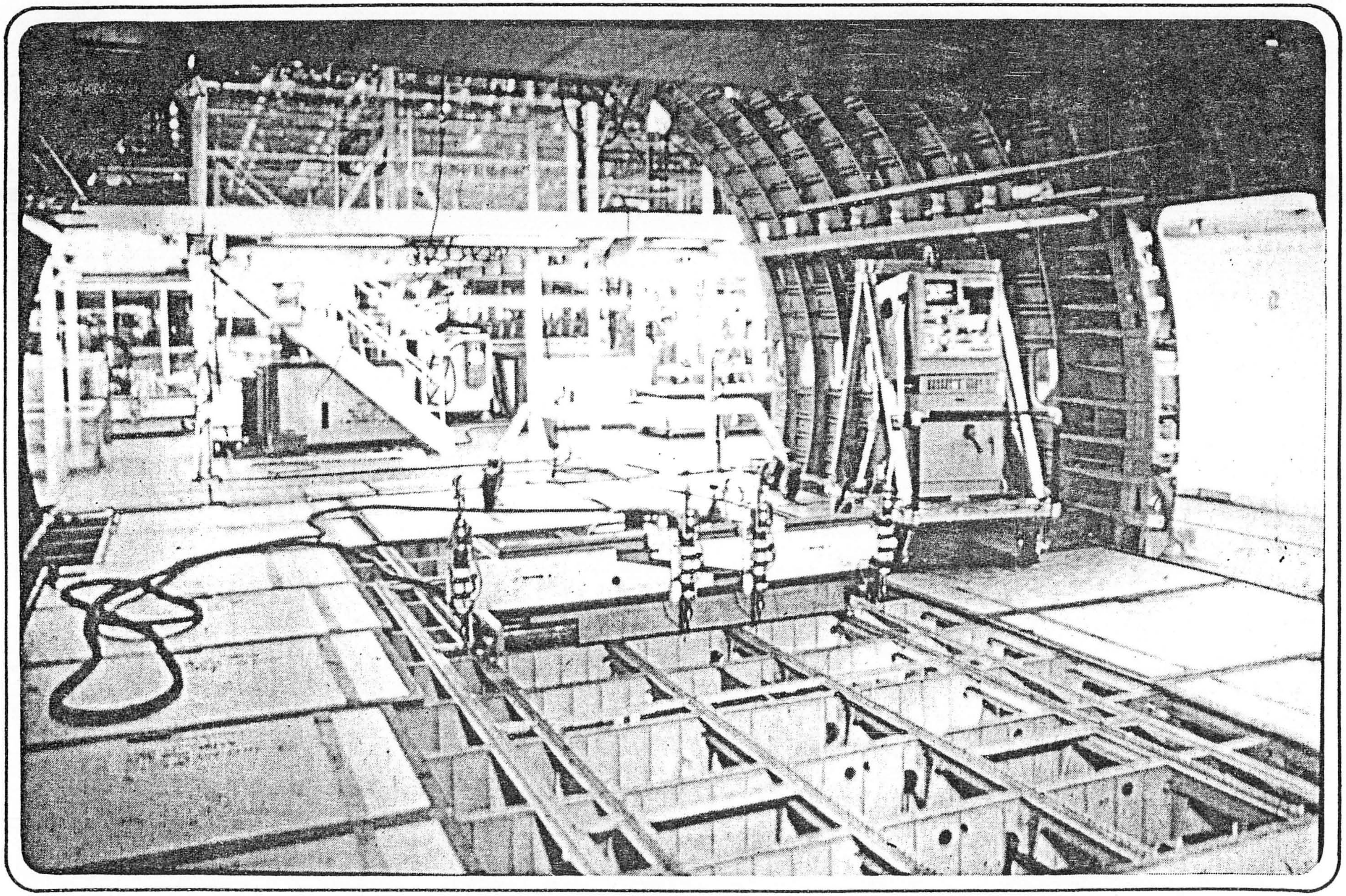


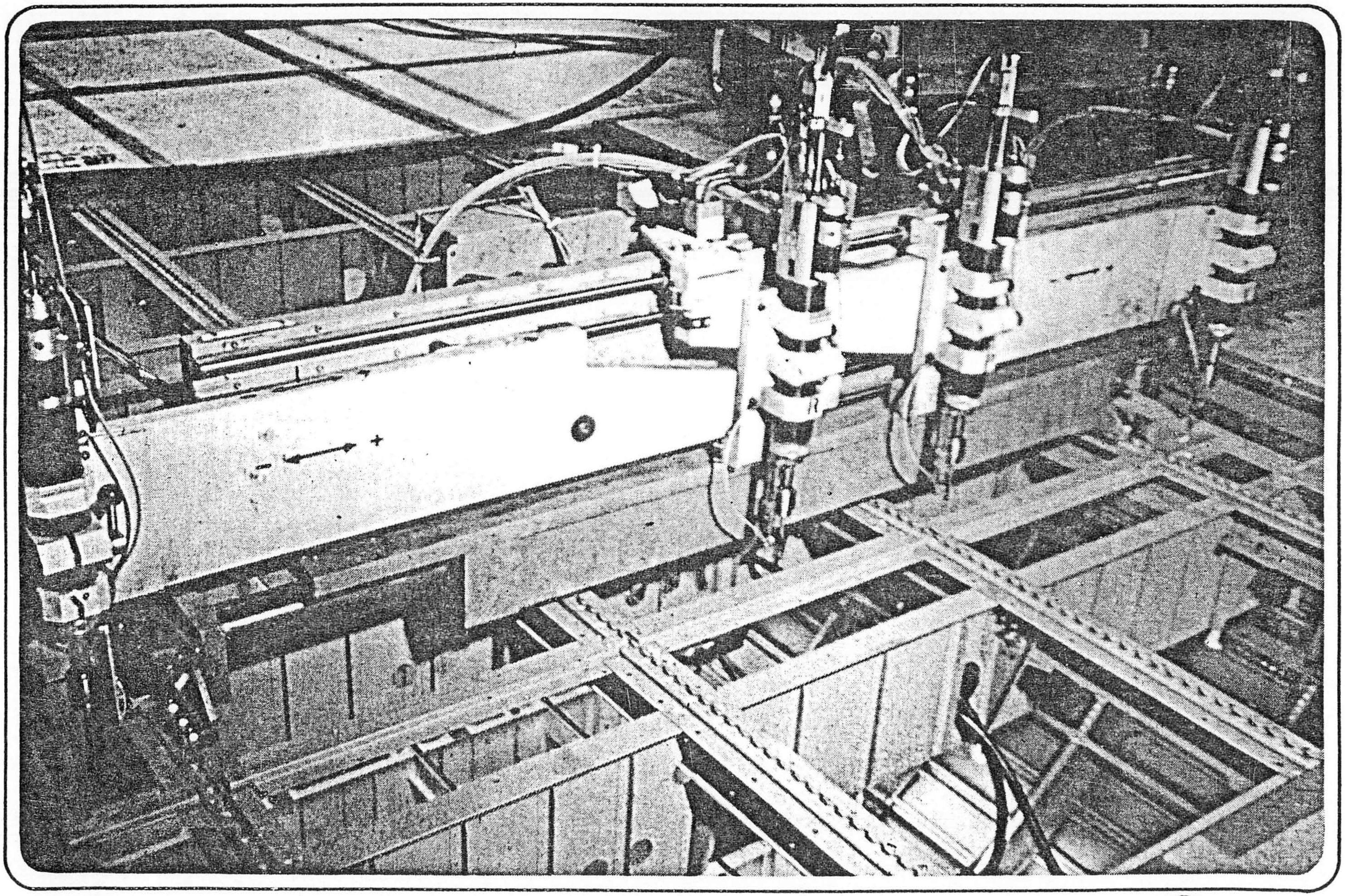

FLOOR PANEL LEVEL STRUCTURE
LEVEL 1
PART
PERIPHERY
LEVEL 5
POINTS
LEVEL 10
FASTENER
SYMBOLS
LEVEL 3
STANDARDS
PATTERNS
LEVEL 4
ANNOTATION
LEVEL 2
CUTOUTS
PLAN VIEW
ASSY -93


FLOOR PANEL
FLOOR DRILLING DATA FLOW
MANUFACTURING ENGINEERING
INTERACTIVE COMPUTER GRAPHICS
SHOP
DNC
NC MACHINE
FLOOR PANEL DATA SET
FLOOR PANEL NC PROGRAM
DESIGN GROUPS
FLOOR STRUCTURE GEOMETRIC DATA SET
FLOOR HOLE AND FLOOR PANEL LAYOUT DATASETS
CAD/CAM DATA CENTER
AUTOMATICALLY PROGRAMMED DATA SET
SHOP
TERA MACHINE CONTROLLER
AFDE



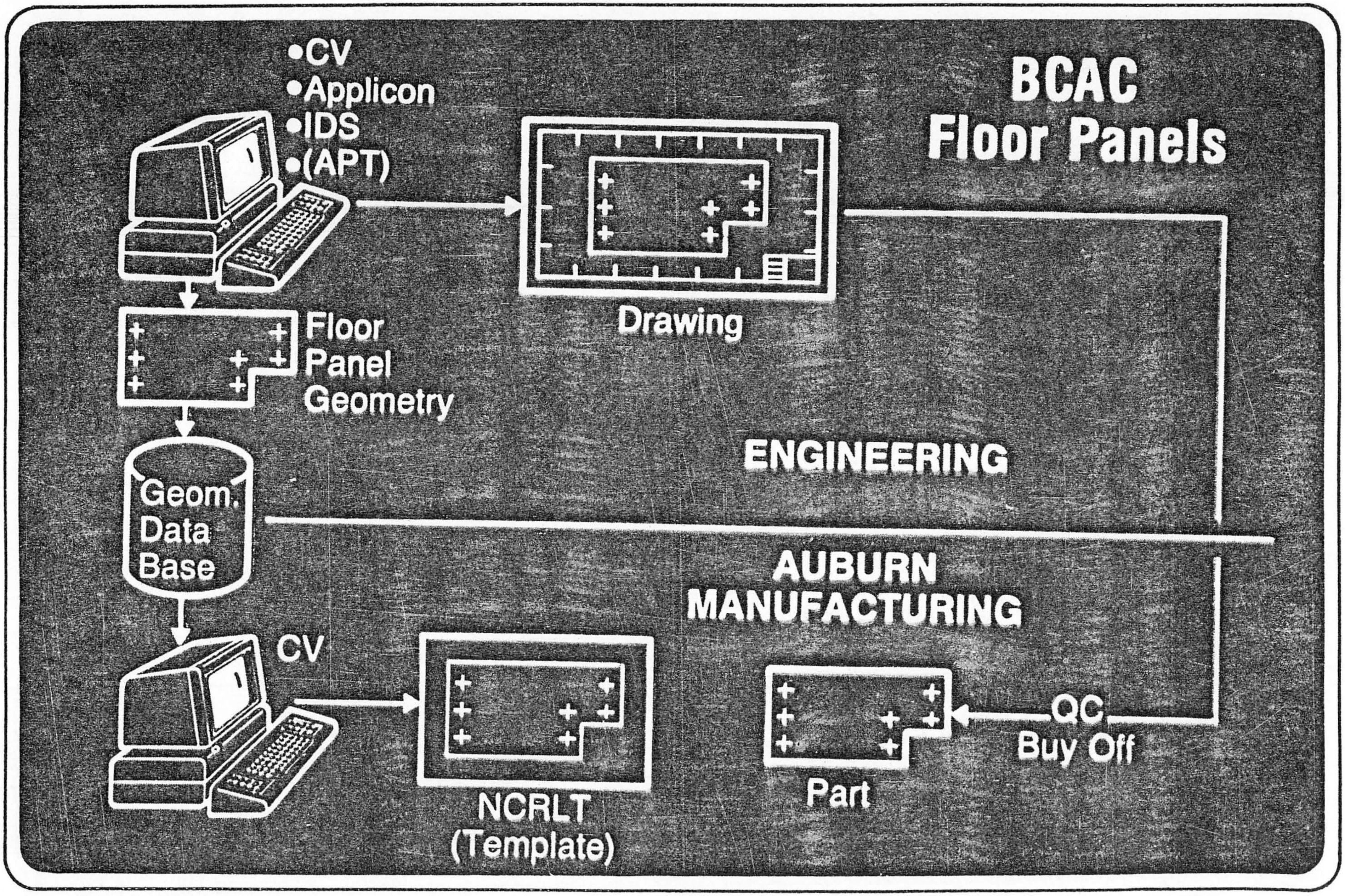

Floor Panel Process Flow
EVERETT
BELLEVUE
AUBURN
GDB
DESIGN
DATA STORAGE
FAB &
ASSEMBLY



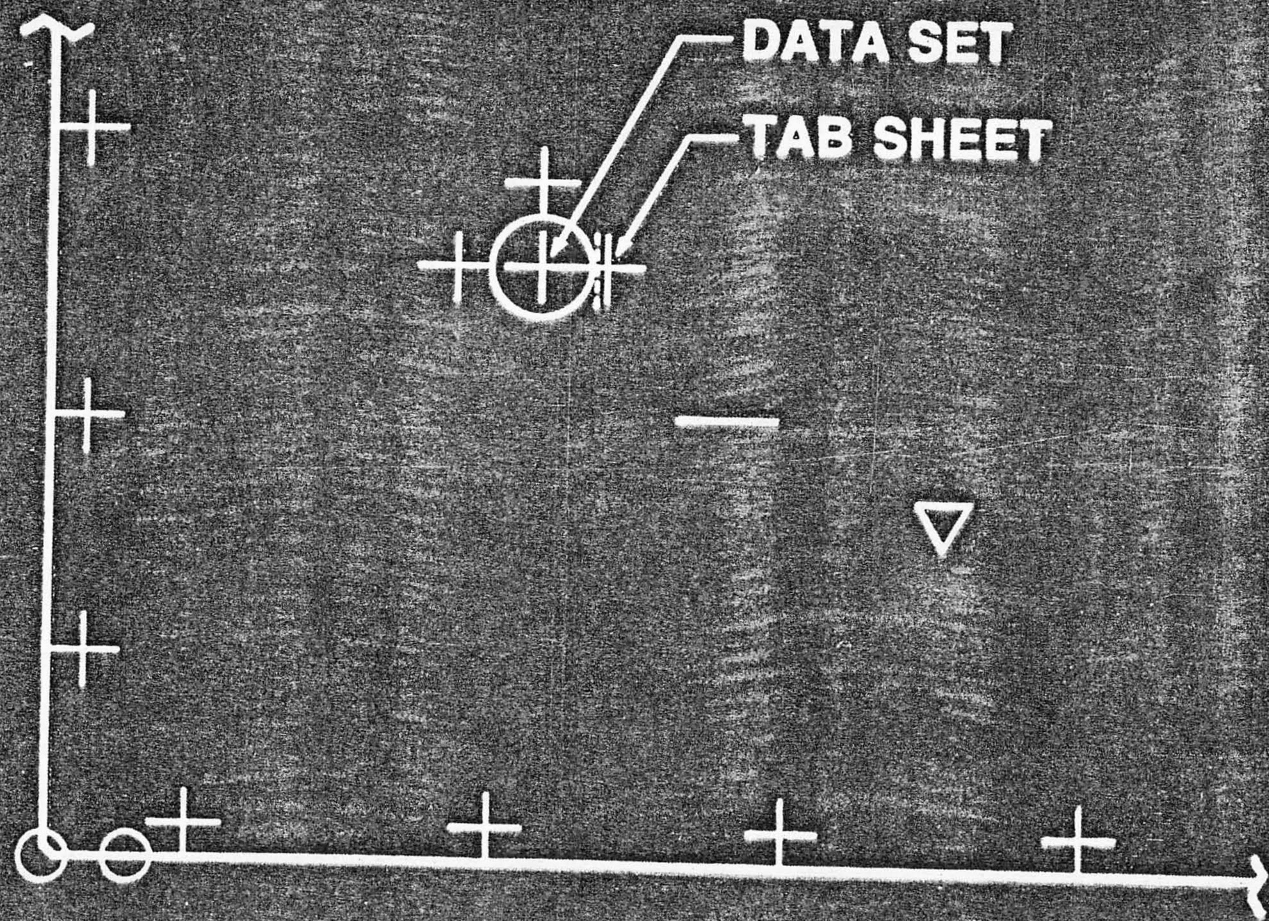


The Problem

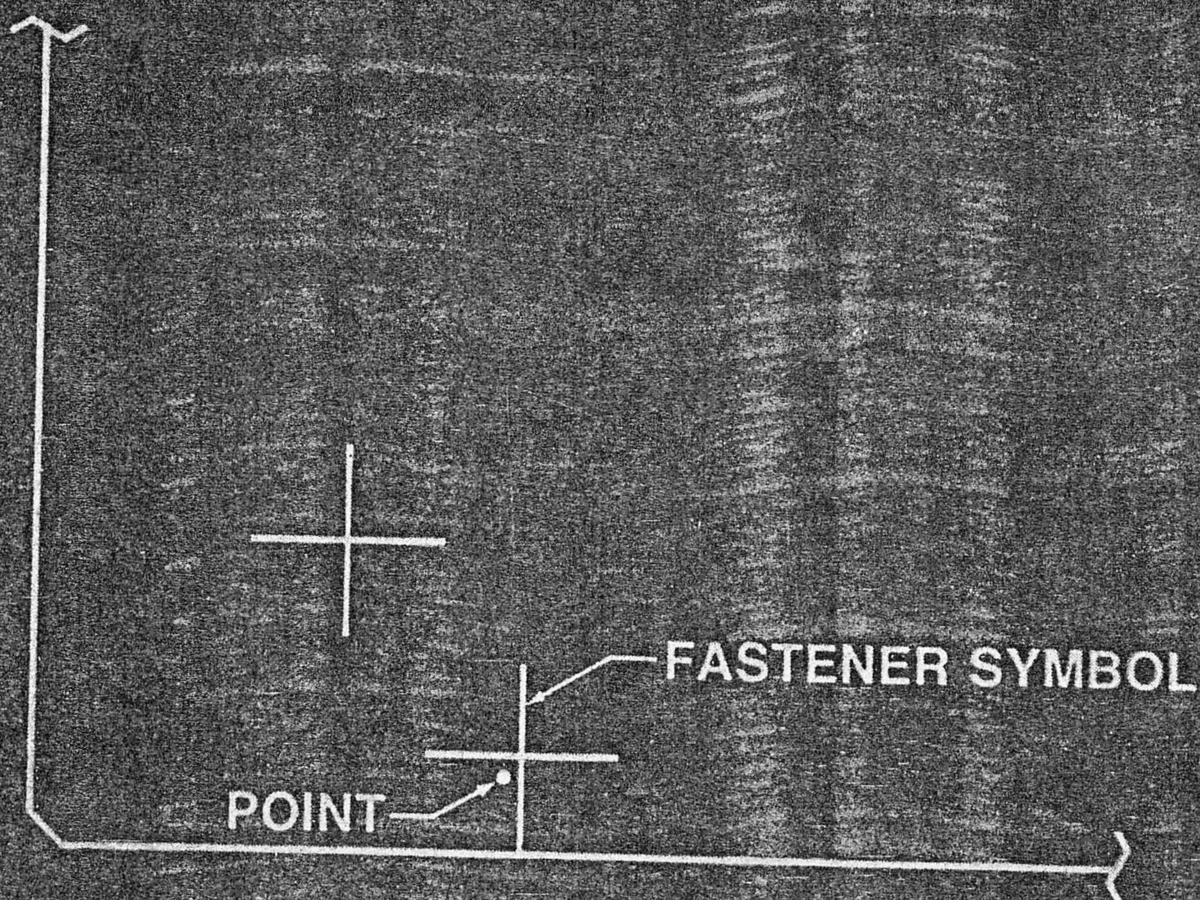
Dual data source for configuration control


BCAC
Floor Panels
•CV
•Applicon
•IDS
•(APT)
Drawing
Floor
Panel
Geometry
ENGINEERING
Geom.
Data
Base
AUBURN
MANUFACTURING
CV
NCRLT
(Template)
Part
QC
Buy Off

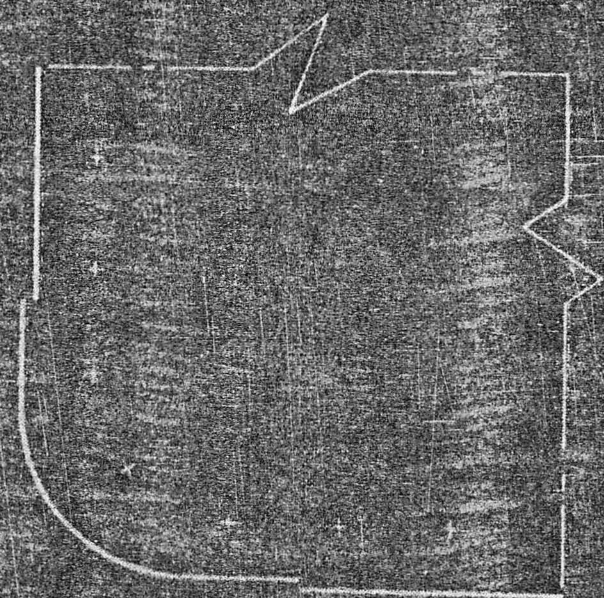
Fastener Location Showing Mismatch



Fastener Symbol/Point Location Disagree



Discontinuity



The Solution

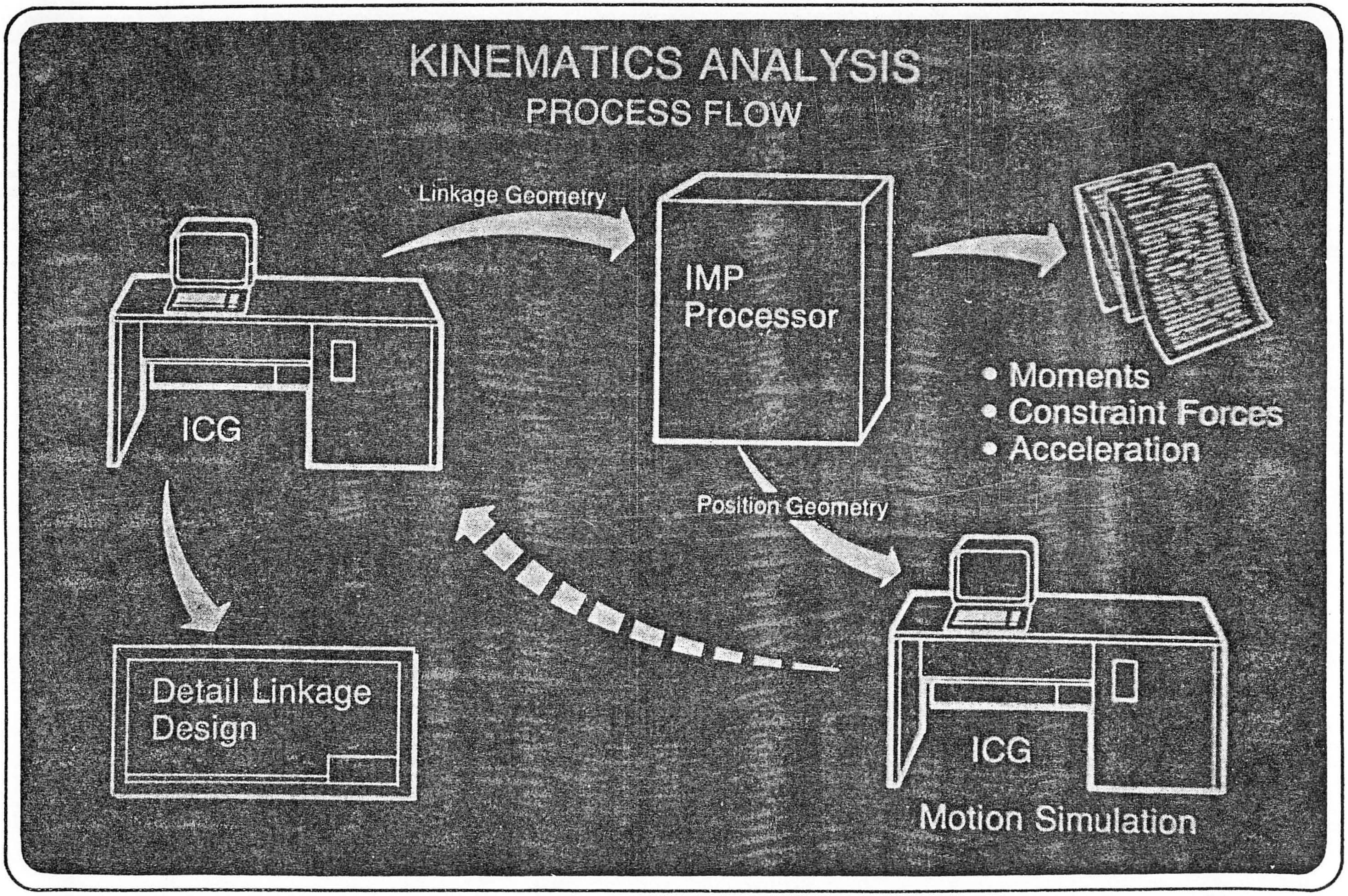
Single source for configuration control

THE DATASET

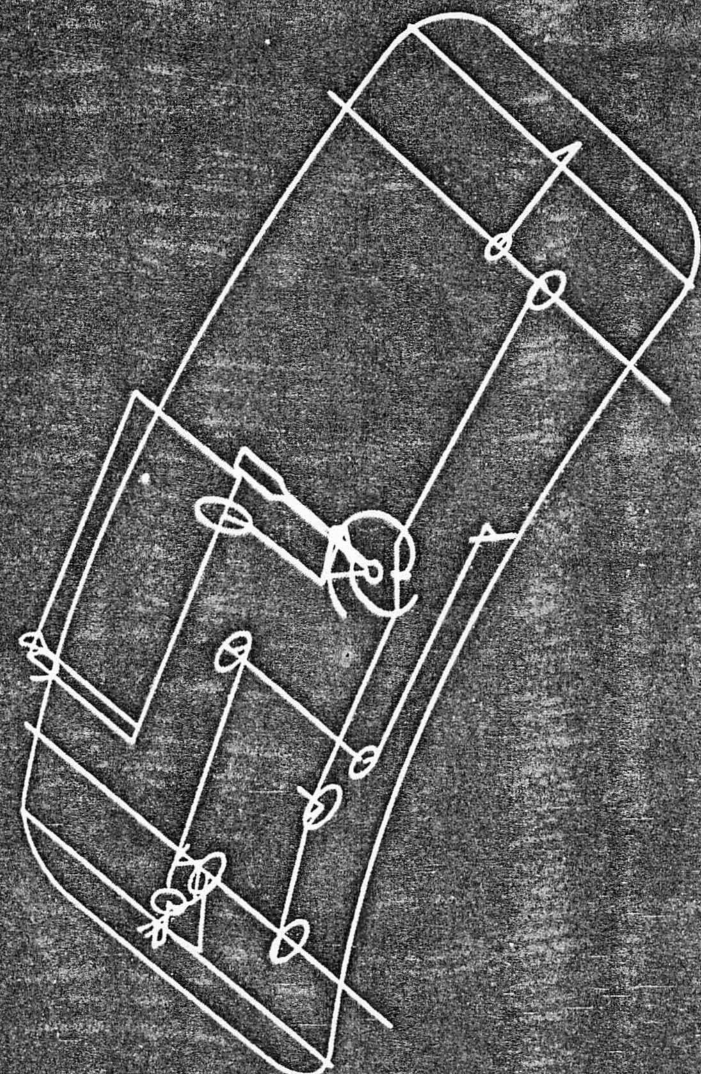
KINEMATIC MECHANISMS ANALYSIS

Kinematics

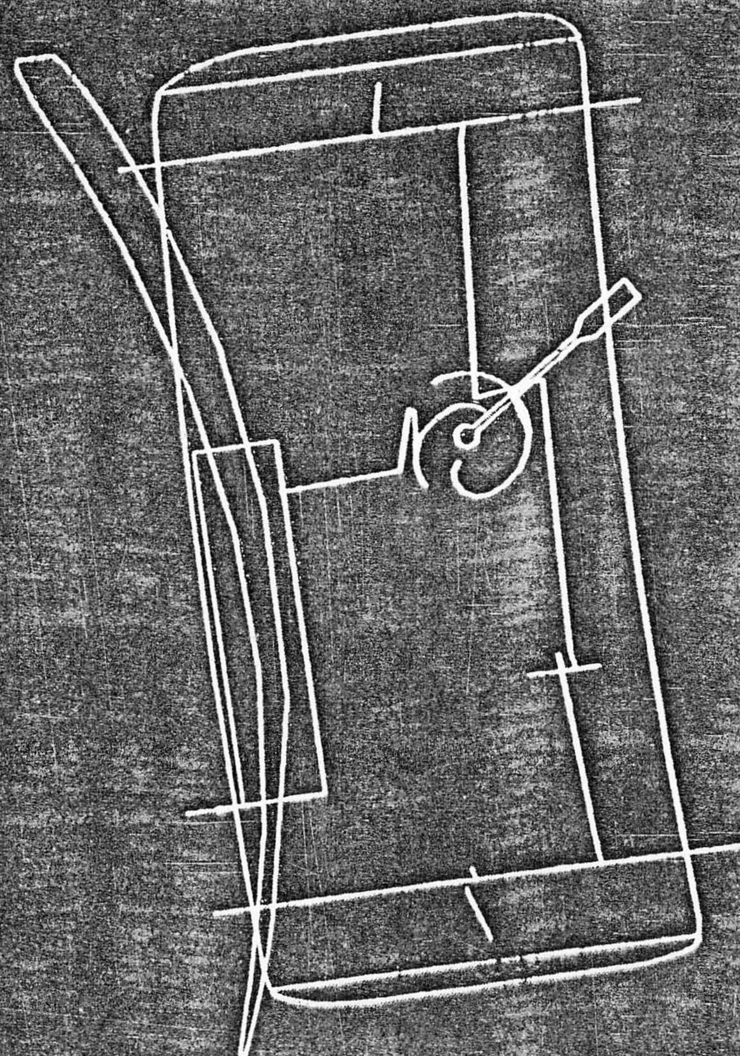
- Tools
  - APT
  - Graphic Systems
  - Main Frame Programs


KINEMATICS ANALYSIS
PROCESS FLOW
Linkage Geometry
IMP Processor
ICG
• Moments
• Constraint Forces
• Acceleration
Position Geometry
Detail Linkage Design
ICG
Motion Simulation

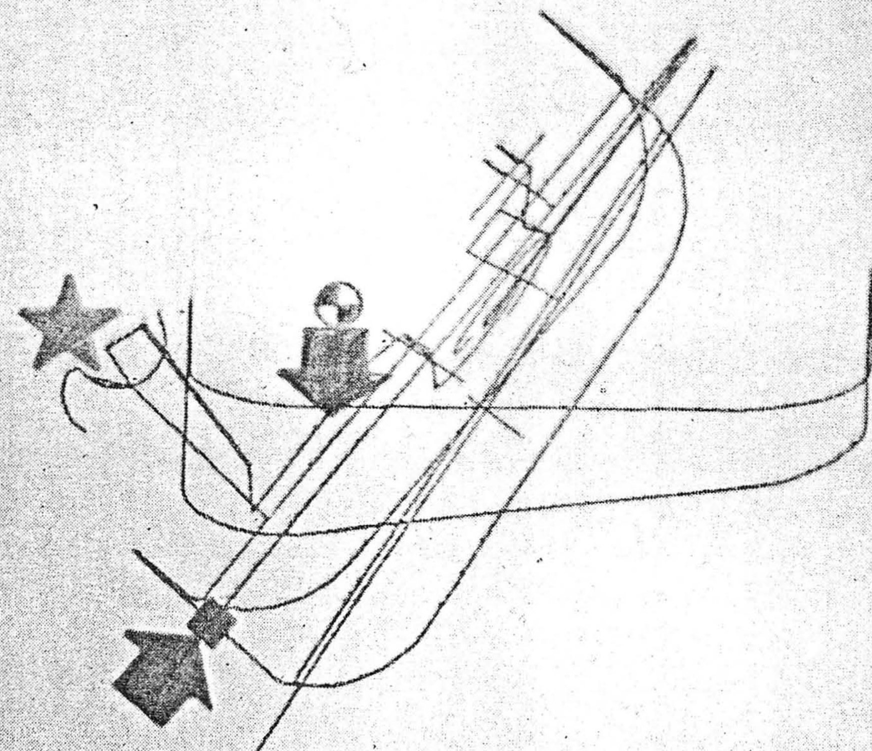
757 Passenger Door



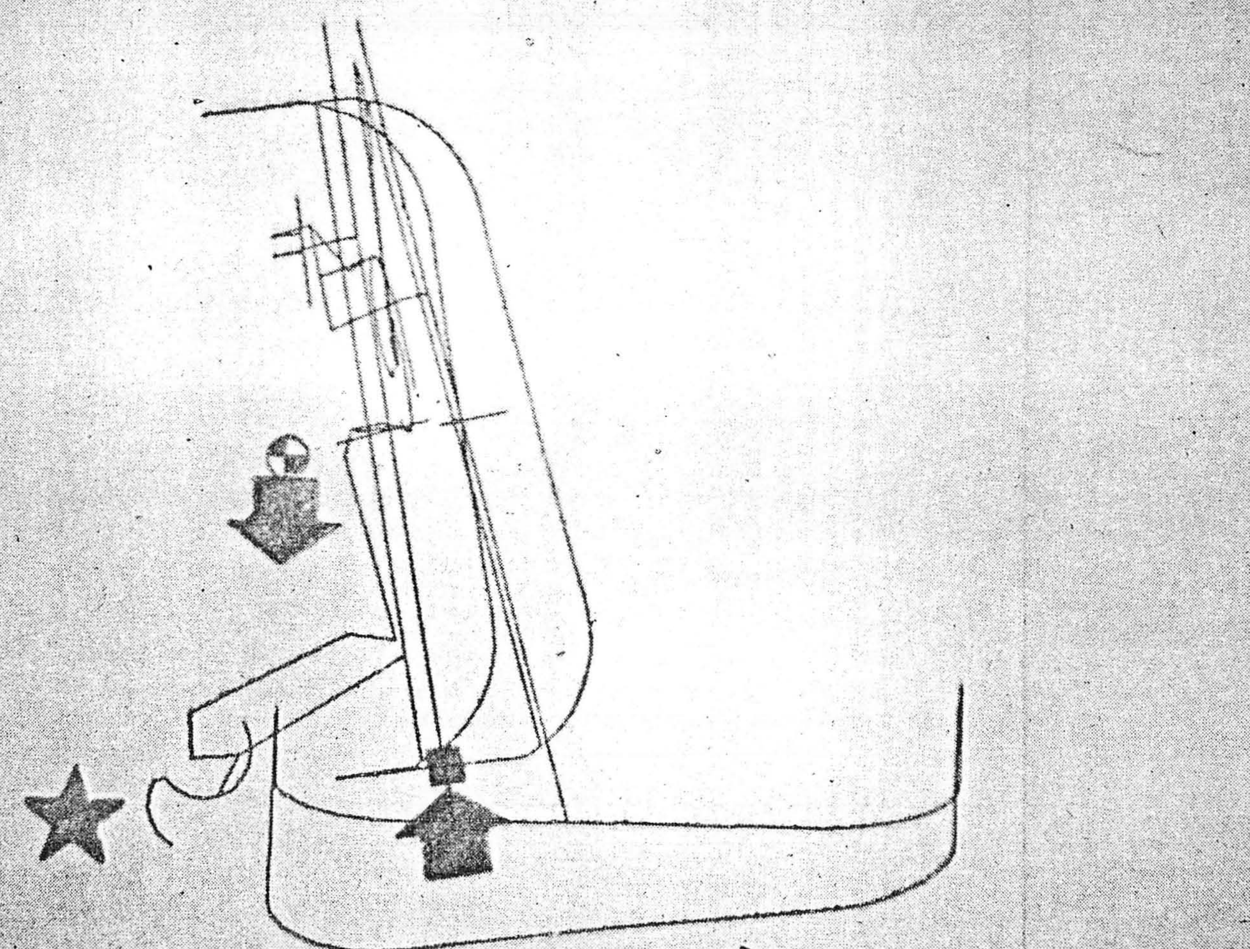
757 Passenger Door



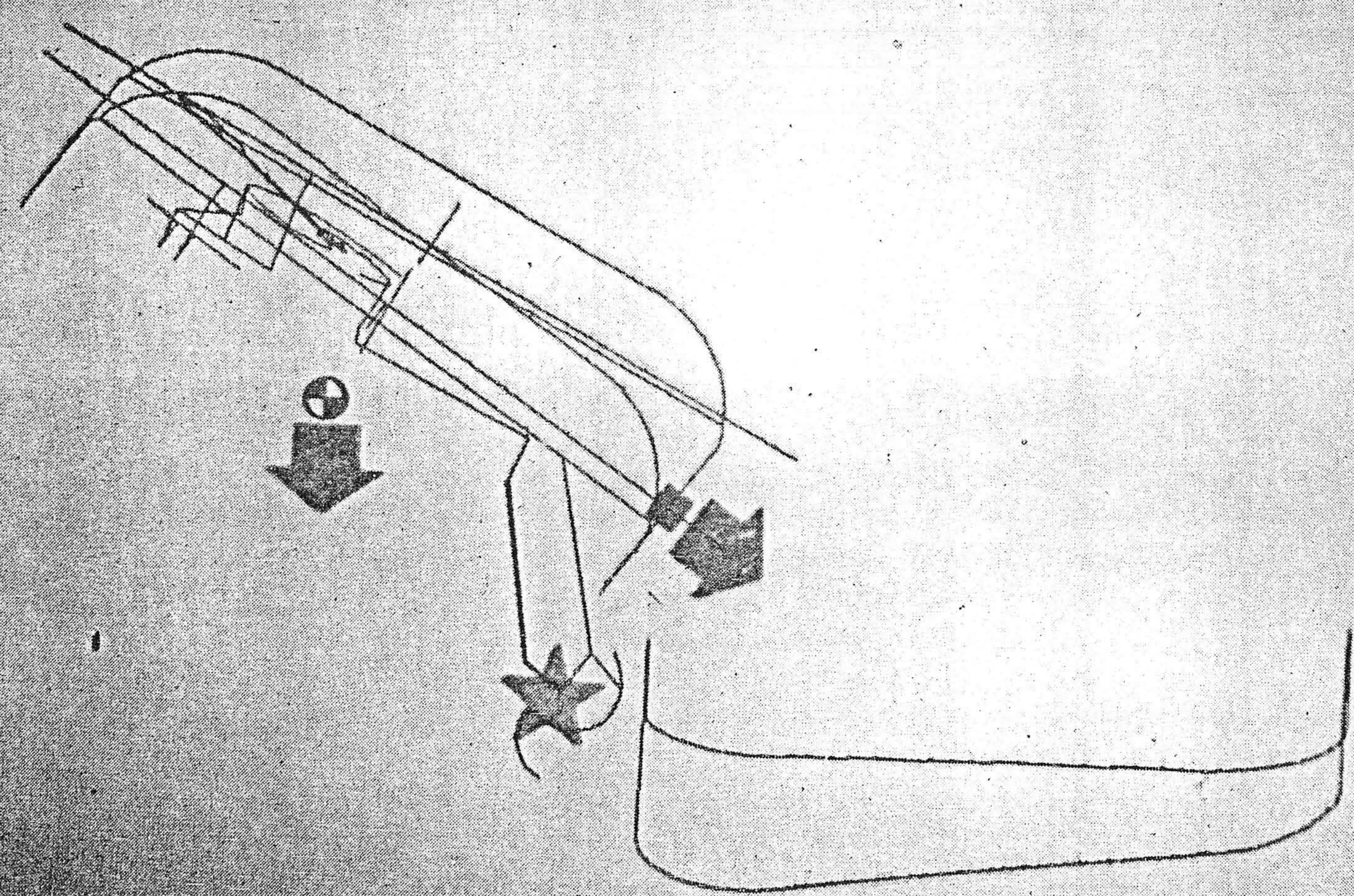
Passenger Door Loads

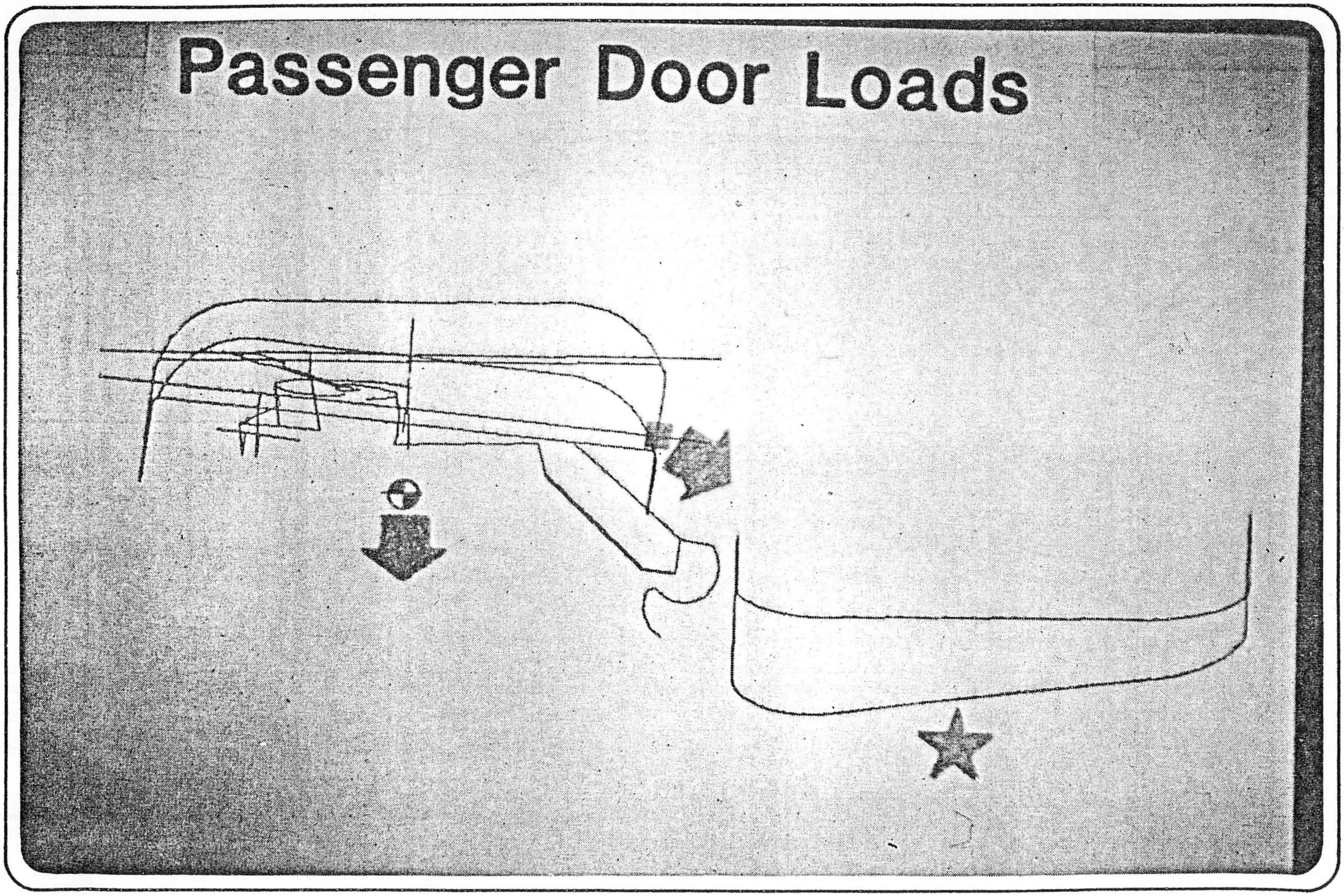


Passenger Door Loads

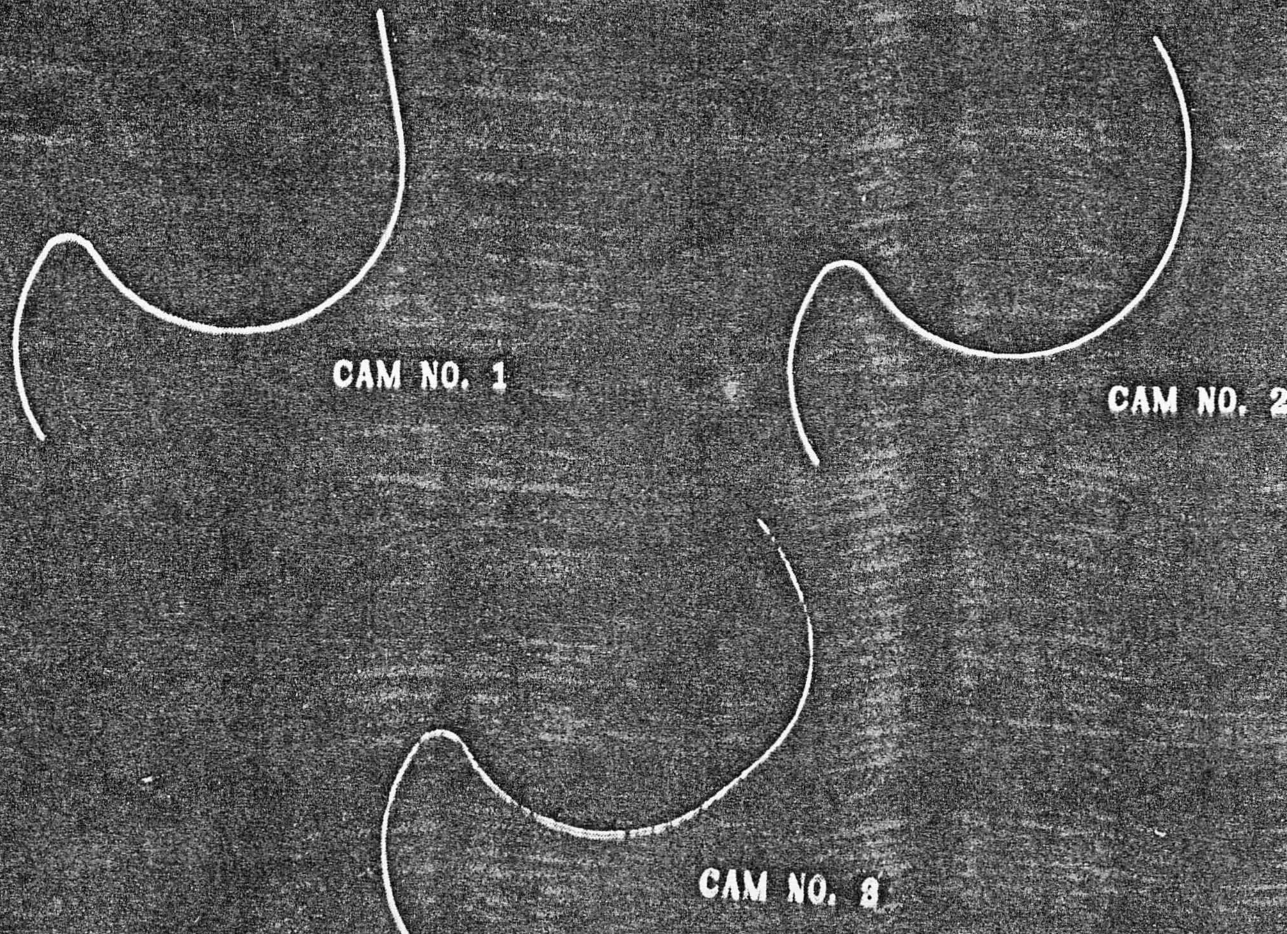


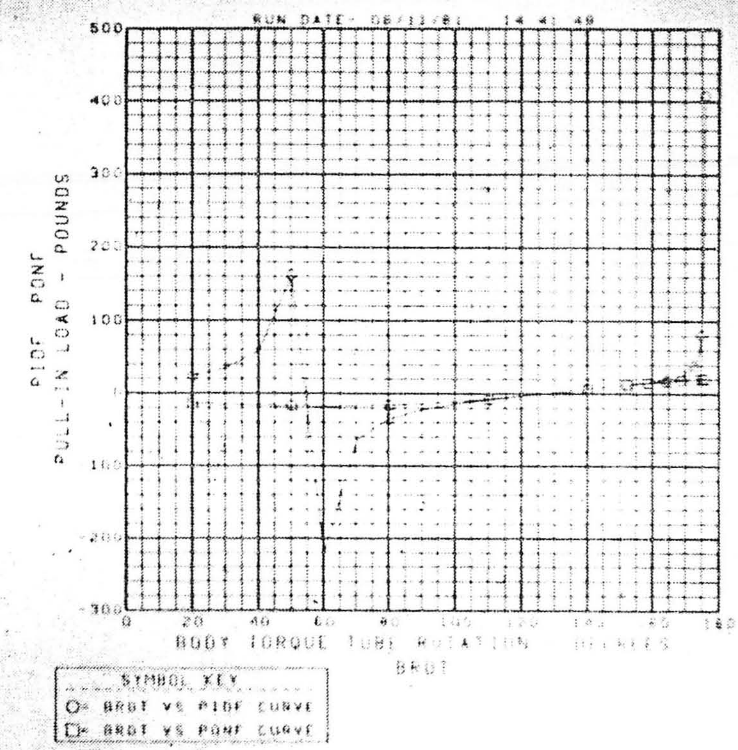
Passenger Door Loads




Passenger Door Loads

757 Door Hinge Cam Designs



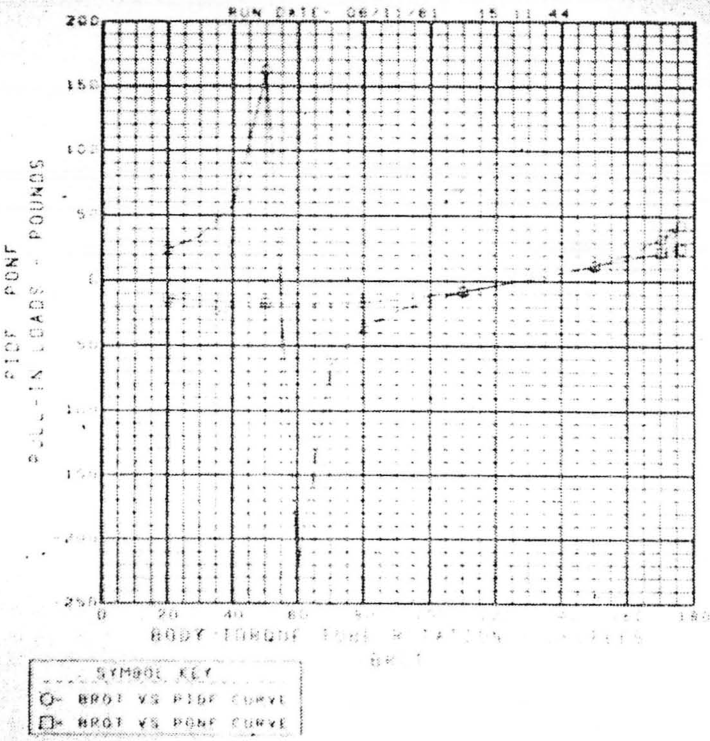


NOTE

1. PULL-IN LOADS ARE ASSUMED TO BE AT THE ASSIST HANDLE
2. PIDF IS THE LOAD REQUIRED TO PULL THE DOOR IN IF 30 DEGREES INBOARD IS ASSUMED TO BE THE DIRECTION OF THE PULL
3. PONF IS THE LOAD REQUIRED TO PULL THE DOOR IN IF THE MOST EFFICIENT DIRECTION IS ASSUMED TO BE THE DIRECTION OF THE PULL

757 PASSENGER DOOR NO. 2
PULL-IN LOAD 180-POUND DOOR
CAM NO. 1

THE BOEING COMPANY

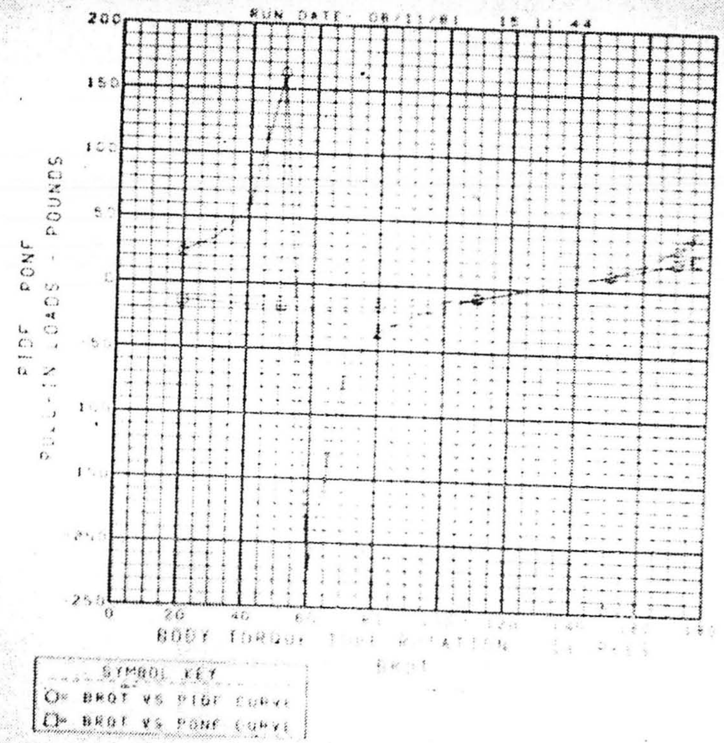


NOTE

1 THE PULL-IN LOADS ARE ASSUMED TO BE APPLIED TO THE ASSIST HANDLE
2 PONF IS THE PULL-IN LOAD IF THE DIRECTION OF PULL-IN IS ASSUMED TO BE THE MOST EFFICIENT
3 PIDF IS THE PULL-IN LOAD IF THE DIRECTION OF PULL-IN IS ASSUMED TO BE 30 DEGREES INBOARD
4 NO FRICTION WAS ASSUMED

757 PASSENGER DOOR NO 2
PULL-IN LOAD IND-POUND DOOR
CAM NO 2

THE BOEING COMPANY

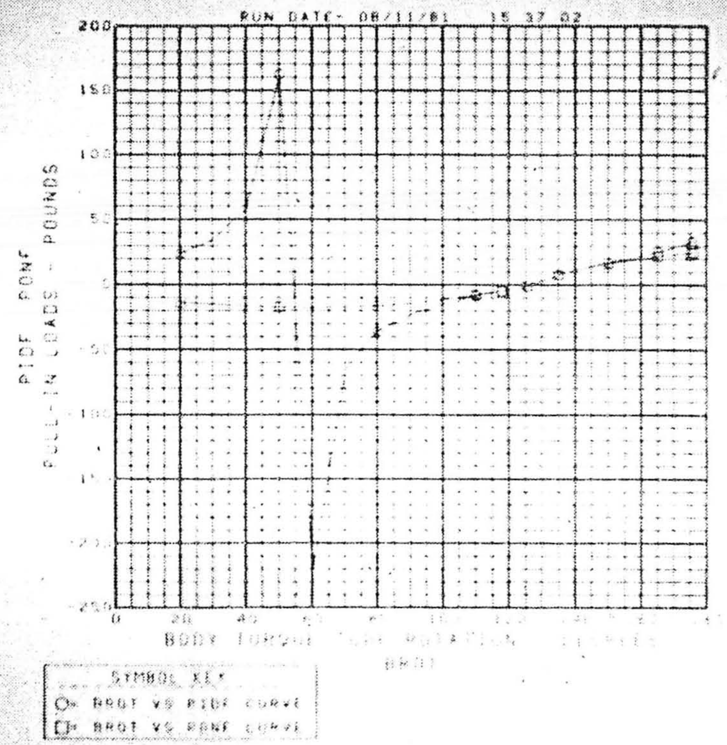


NOTE

1. THE PULL-IN LOADS ARE ASSUMED TO BE APPLIED TO THE ASSIST HANDLE
2. PONF IS THE PULL-IN LOAD IF THE DIRECTION OF PULL-IN IS ASSUMED TO BE THE MOST EFFICIENT
3. PIDF IS THE PULL-IN LOAD IF THE DIRECTION OF PULL-IN IS ASSUMED TO BE 30 DEGREES INBOARD
4. NO FRICTION WAS ASSUMED

757 PASSENGER DOOR NO 2
PULL-IN LOAD 180-POUND DOOR
CAM NO 2

THE BOEING COMPANY

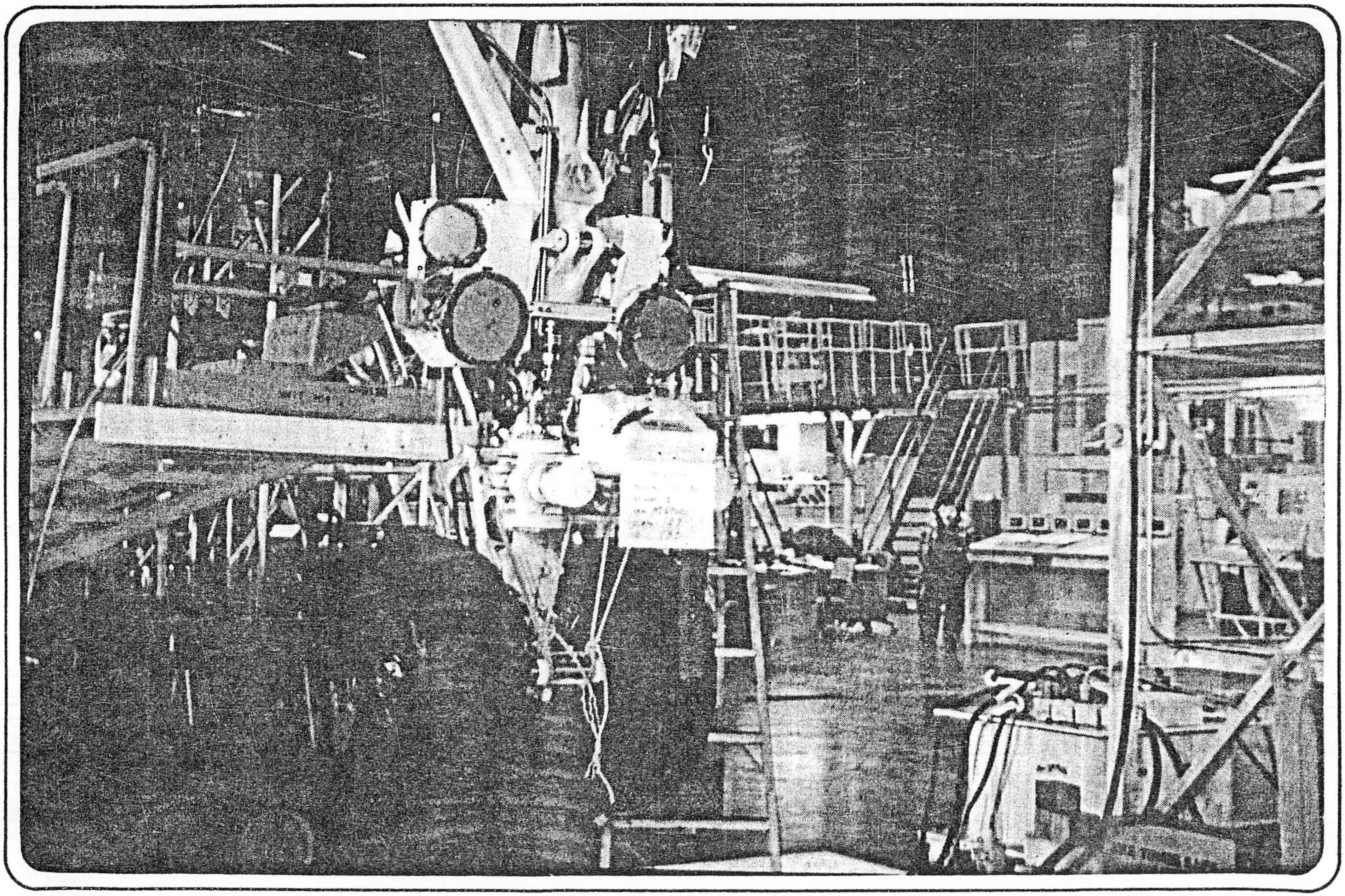


NOTE

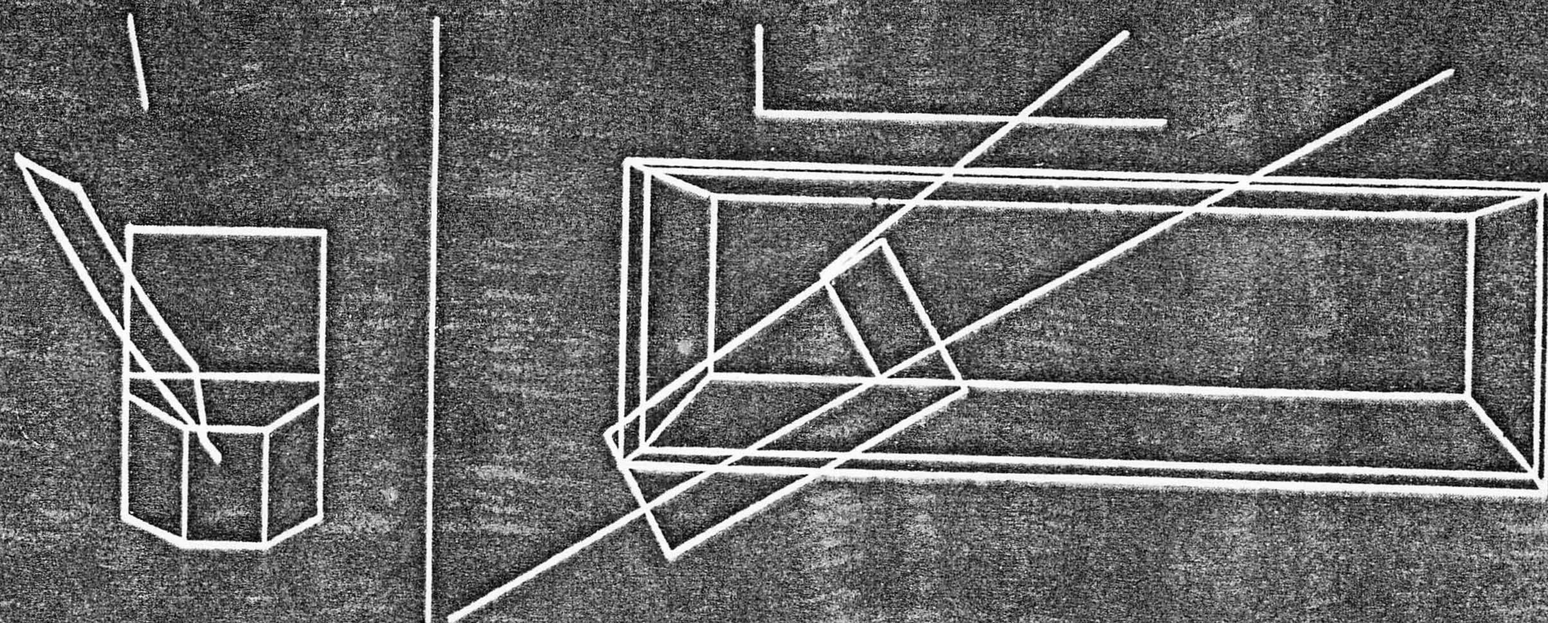
1 PONF IS THE PULL-IN LOAD FOR AN ASSUMED PULL-IN DIRECTION THAT IS THE MOST EFFICIENT FOR EACH POSITION
2 PIDF IS THE PULL-IN LOAD FOR AN ASSUMED PULL-IN DIRECTION OF 30 DEGREES INBOARD
3 THE LOADS WERE CALCULATED BY SUMMING MOMENTS ABOUT THE INSTANTANEOUS CENTER OF THE DOOR
4 NO FRICTION IS ASSUMED

757 PASSENGER DOOR NO 2
PULL-IN LOAD 100-POUND DOOR
CAM NO. 3

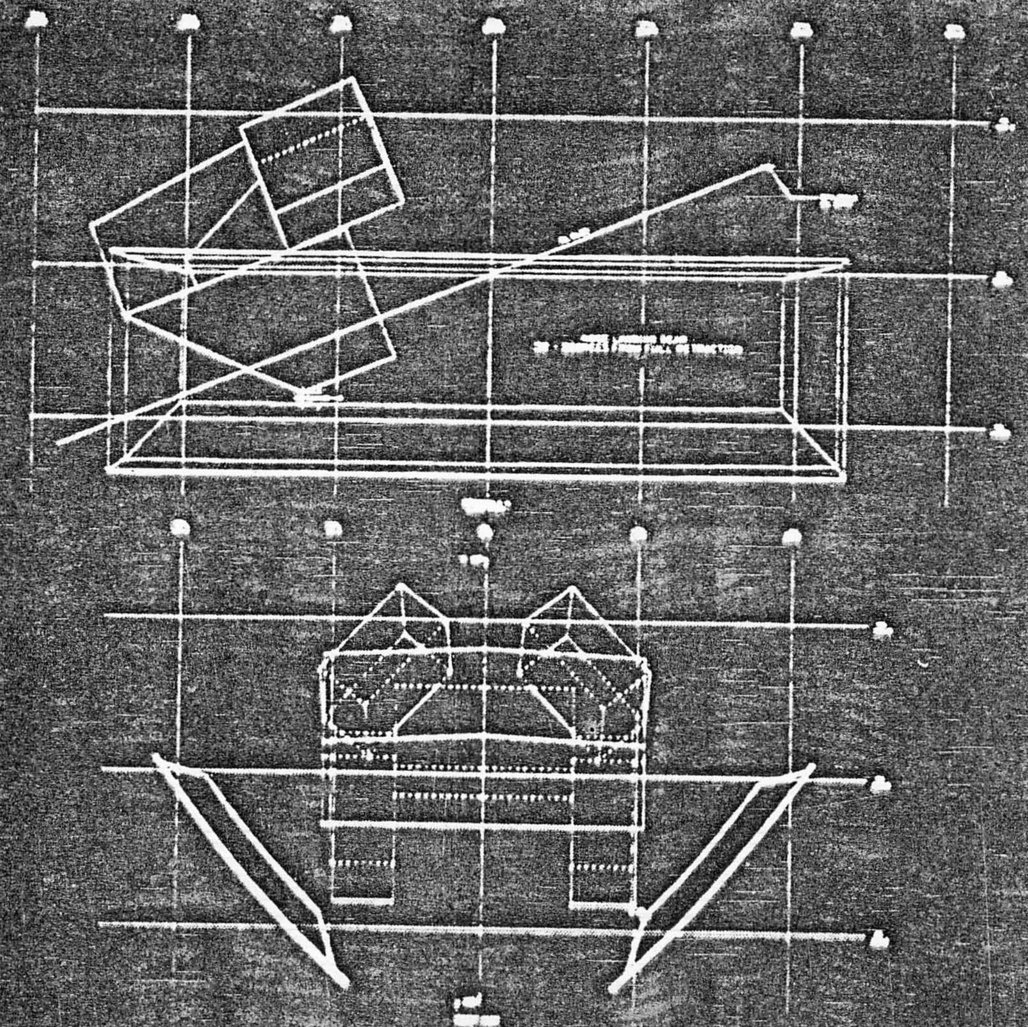
THE BOEING COMPANY



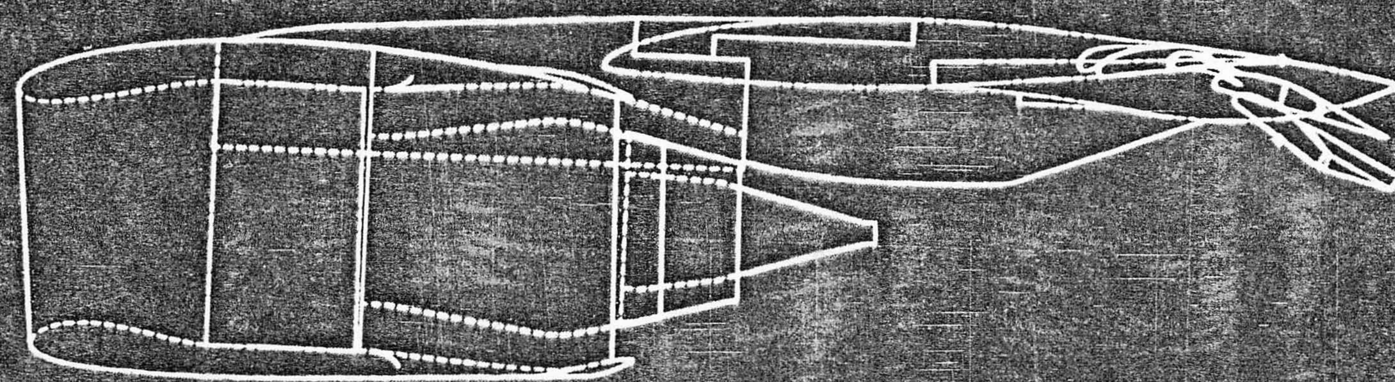
Nose Landing Gear – Light Box – Initial Design



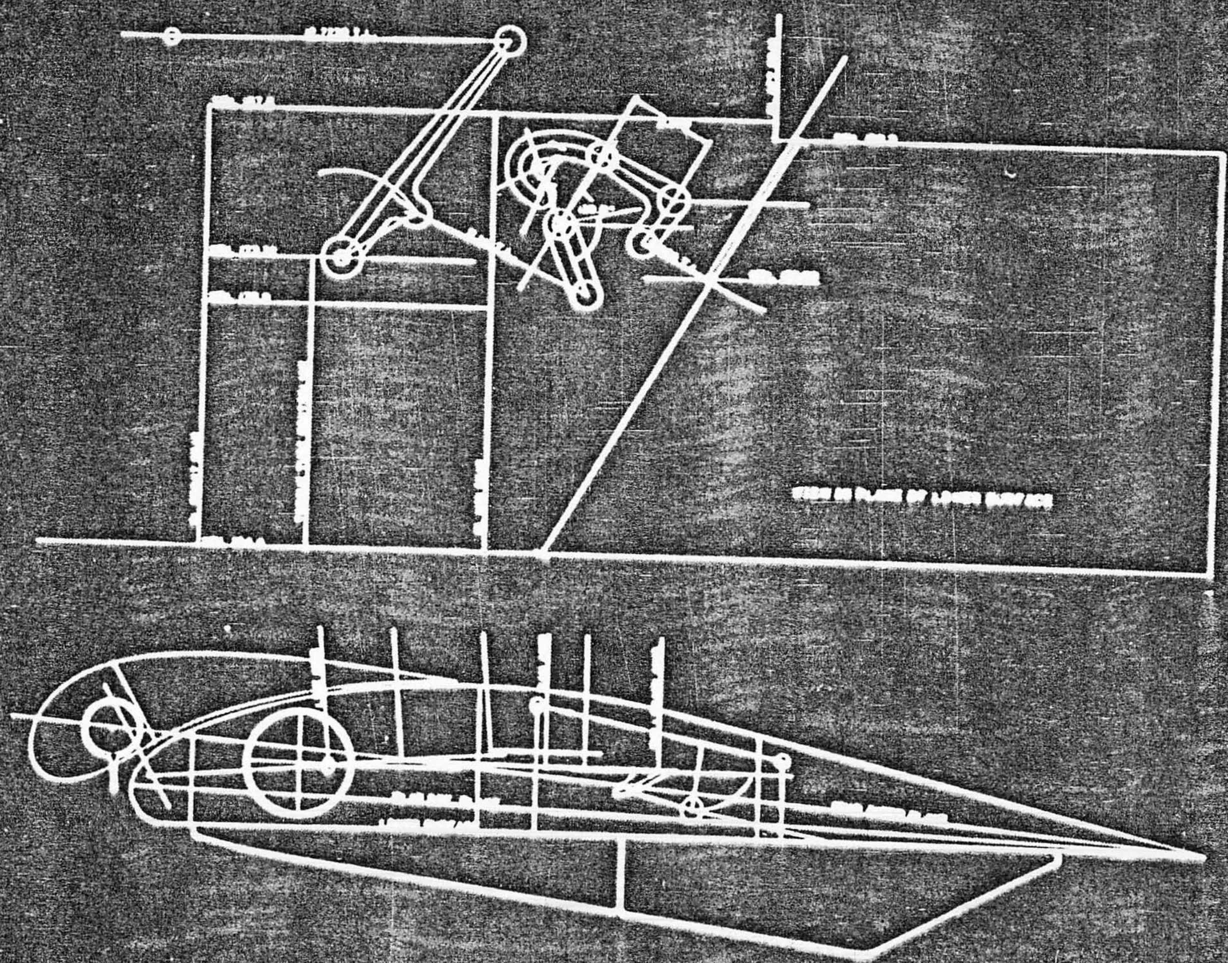
Nose Landing Gear – Light Box – Redesign



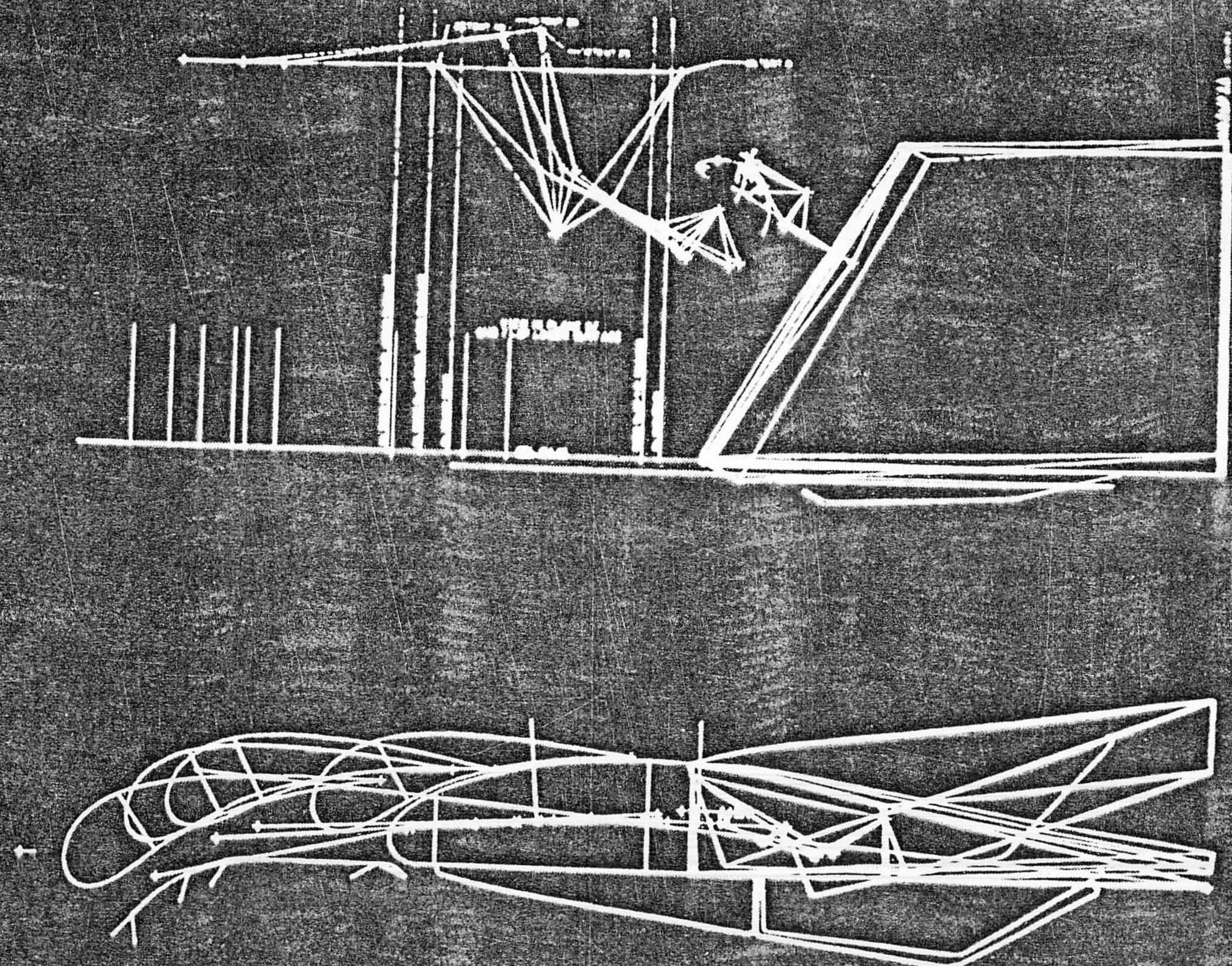
737-300 Exhaust Gates

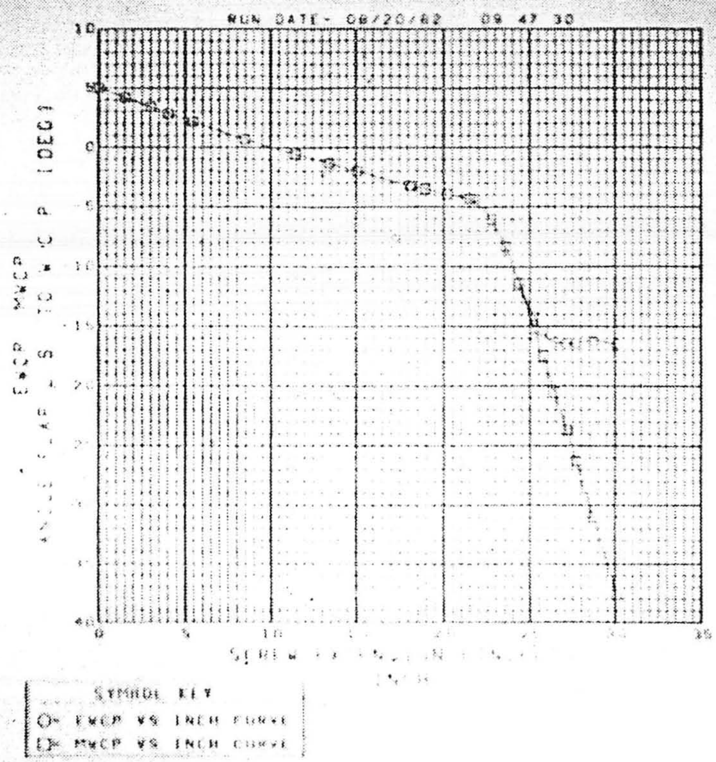


737-300 Exhaust Gate



737-300 Exhaust Gate Multiple Positions





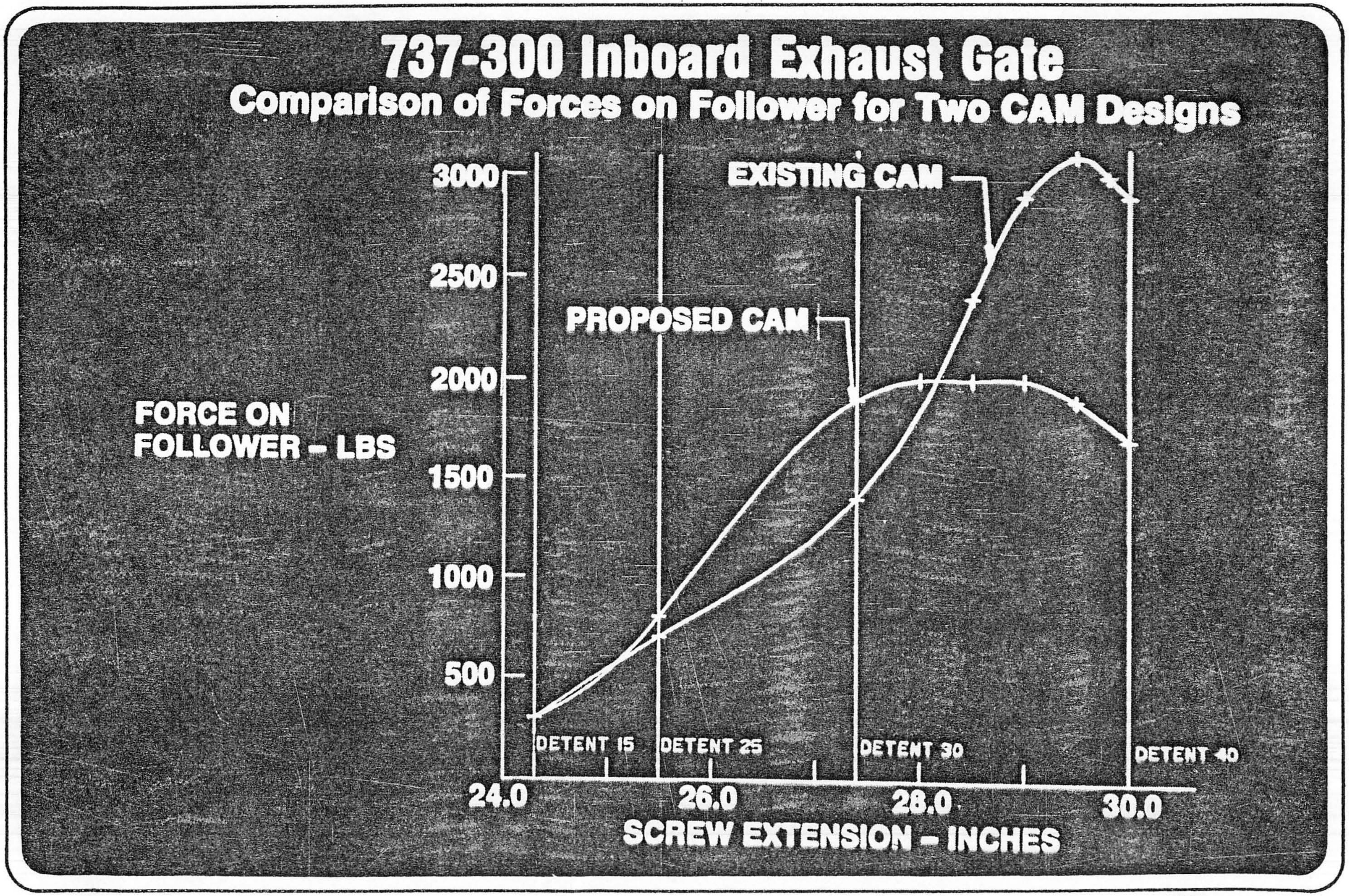
NOTE

PLOT OF EXHAUST GATE AND MID FLAP ANGLE MEASURED FROM LOWER SURFACE TO WING CHORD PLANE

DATA GENERATED FROM IMP INPUT FILE IEGIN

737-300 INBOARD EXHAUST GATE
IMP KINEMATIC STUDY
CAM DESIGN NO. 1

THE BOEING COMPANY

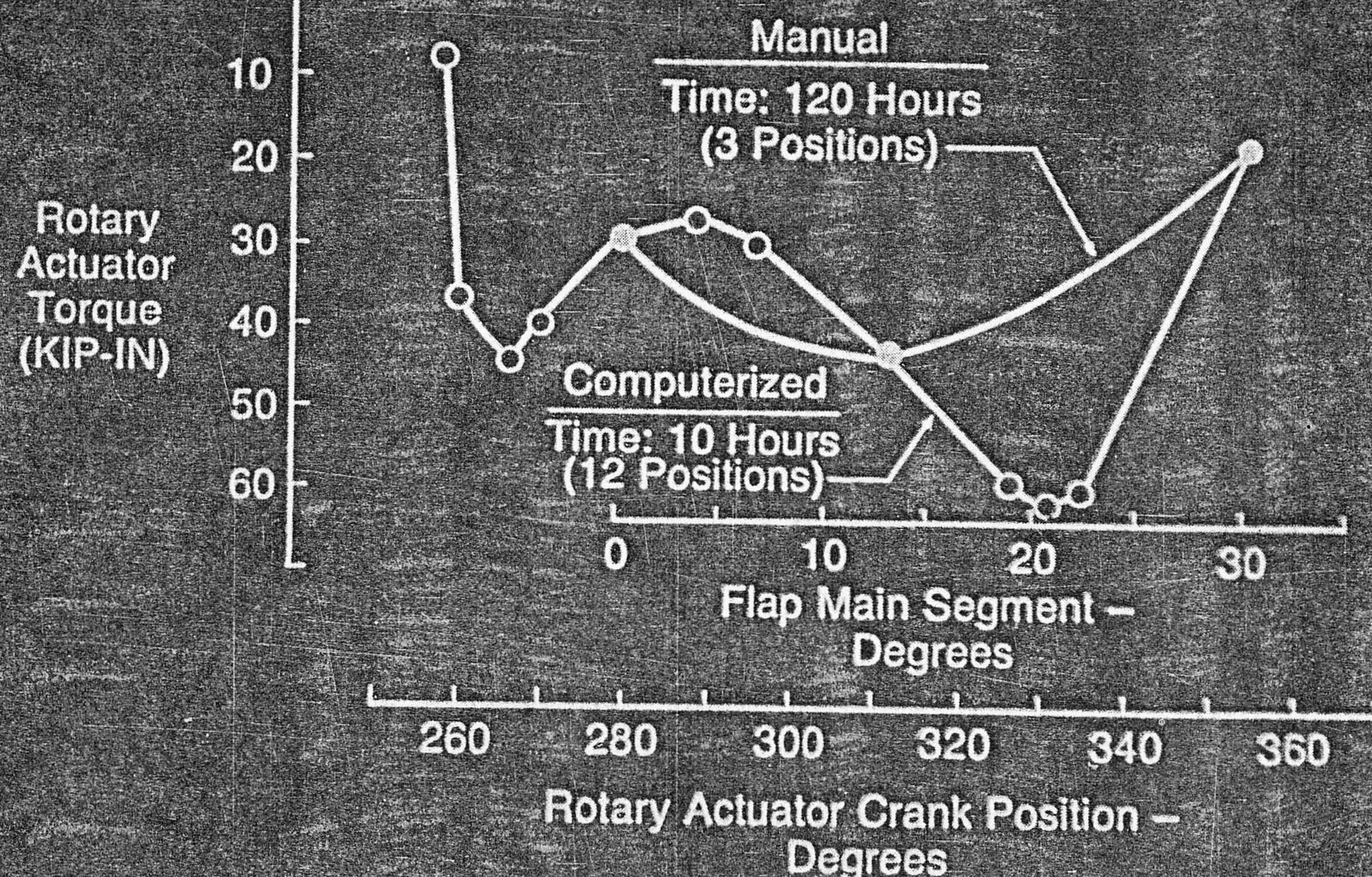

737-300 Inboard Exhaust Gate
Comparison of Forces on Follower for Two CAM Designs
EXISTING CAM
PROPOSED CAM
FORCE ON FOLLOWER – LBS
3000
2500
2000
1500
1000
500
DETENT 15
DETENT 25
DETENT 30
DETENT 40
24.0
26.0
28.0
30.0
SCREW EXTENSION – INCHES

DATA GENERATED BY IMP, TABULATED ON [illegible] TIME [illegible] BY STEVE [illegible]

737-300 OUTBOARD THRUST GATE
IMP KINEMATIC AND FORCE ANALYSIS
LINK PICK UP [illegible], INFINCON ROD [illegible]
CAM ARM ROTATED [illegible], BELLCRANK ARM [illegible]
COORDINATE SYSTEM : +X = AFT, +Y = UP, +Z = OUTBD.(LEFT WING)
ORIGIN : [illegible] STOWED AT [illegible]
[illegible] BELLCRANK
SYSTEM = 737-300 OUTBOARD EXHAUST GATE + FORCE ANALYSIS

IMP. TIME		0.0	22.[illegible]	30.[illegible]	31.[illegible]	36.[illegible]	38.[illegible]	41.[illegible]	[illegible]	[illegible]	MAXIMUM	AT
DETENT		STOWED	5	15	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ABS VAL.	TIME
**** VALUE ****												
VAL. INCH	X	[illegible]	13.39	26.43	17.81	[illegible]	19.1[illegible]	19.77	[illegible]	[illegible]	[illegible]	[illegible]
VAL. THRU	X	734.[illegible]	735.[illegible]	735.39	1359.8[illegible]	3034.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
**** POSITION ****												
JNT. FLS1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JNT. FLP1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JNT. BKR1	1	76.94	76.94	76.94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JNT. BPS1	1	-161.34	-161.34	-161.34	-161.34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	3	-176.38	-176.38	-176.38	-176.38	-176.38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MAG.	259.42	259.42	259.42	259.43	259.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
**** FORCE ****												
JNT. FLS1	X	174.69	174.69	174.69	[illegible]	718.18	1023.38	1442.86	1833.[illegible]	[illegible]	[illegible]	[illegible]
	Y	19.11	19.11	19.11	[illegible]	[illegible]	94.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Z	33.66	33.66	33.69	[illegible]	133.33	-273.23	-1268.81	[illegible]	[illegible]	[illegible]	[illegible]
	MAG.	[illegible]	[illegible]	[illegible]	313.31	727.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JNT. FLP1	X	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-467.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Y	[illegible]	[illegible]	178.51	313.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Z	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MAG.	[illegible]	[illegible]	178.51	313.31	727.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JNT. BKR1	X	[illegible]	[illegible]	[illegible]	[illegible]	1799.76	2419.39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1132.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Z	[illegible]	[illegible]	[illegible]	-131.83	-237.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2684.94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JNT. BPS1	X	0.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Z	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1645.97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1645.97	2154.36	[illegible]	2495.16	2495.16	[illegible]

Kinematics



Manual
Time: 120 Hours
(3 Positions)
Rotary
Actuator
Torque
(KIP-IN)
10
20
30
40
50
60
Computerized
Time: 10 Hours
(12 Positions)
0
10
20
30
Flap Main Segment –
Degrees
260
280
300
320
340
360
Rotary Actuator Crank Position –
Degrees

Gary E. Spies

Chief Project Engineer

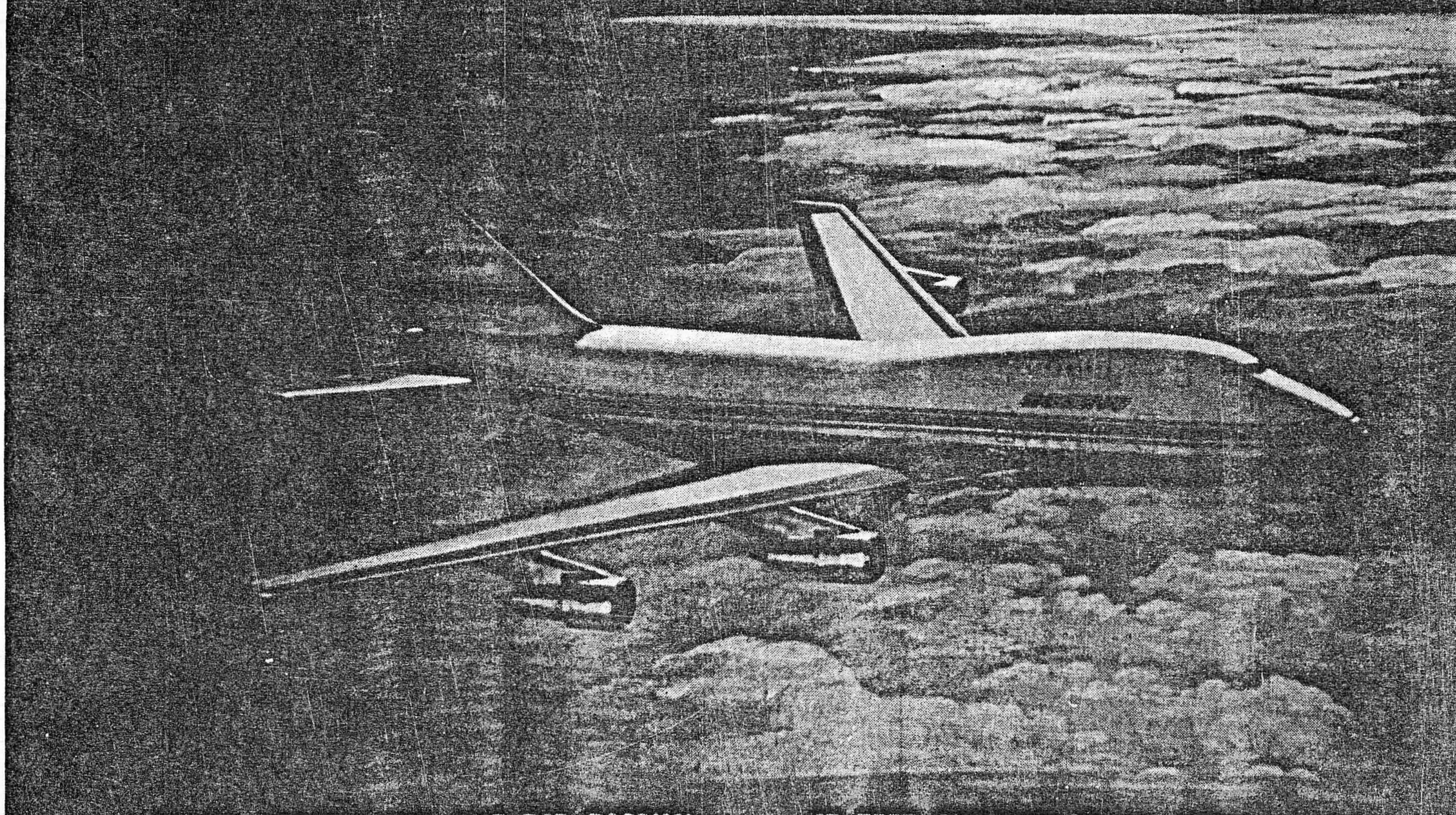
747/767 Engineering Computing

December 1982

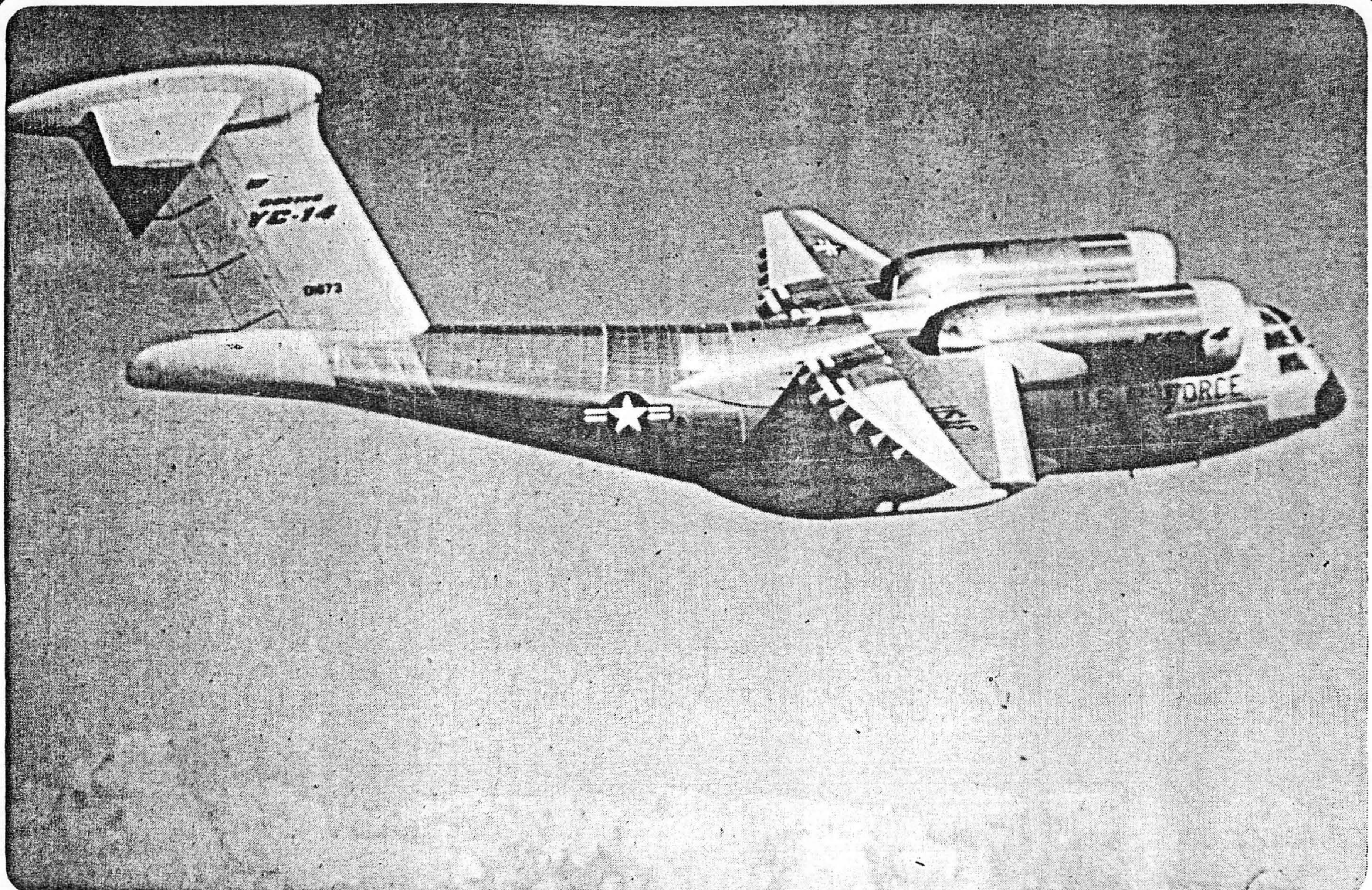

767
BOEING 767

PARAMETRIC DESIGN

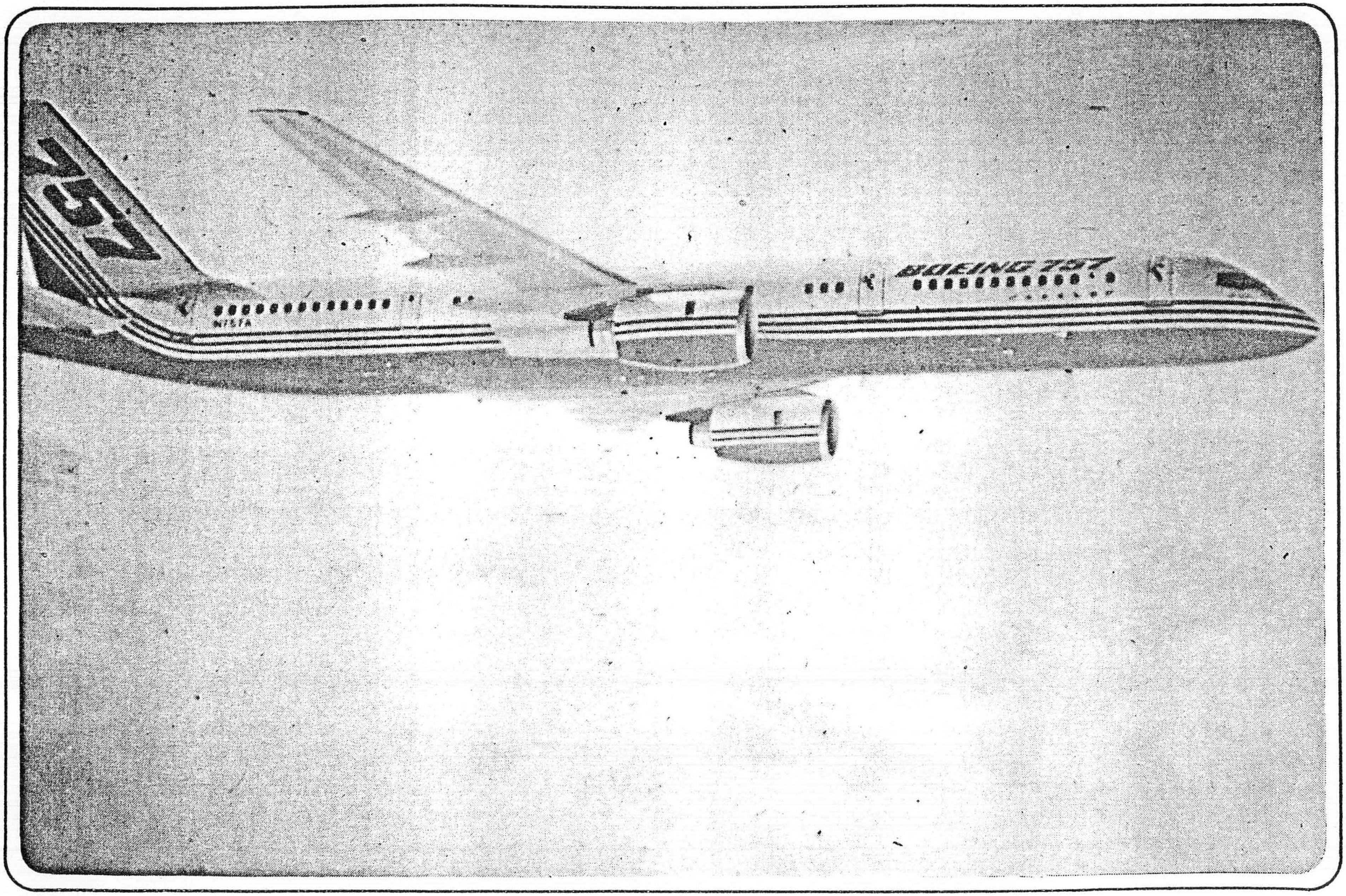
747SP (SPECIAL PERFORMANCE)



NEWEST ADDITION TO THE 747 FAMILY . . . . 47 FEET SHORTER THAN REGULAR 747


YC-14
FORCE

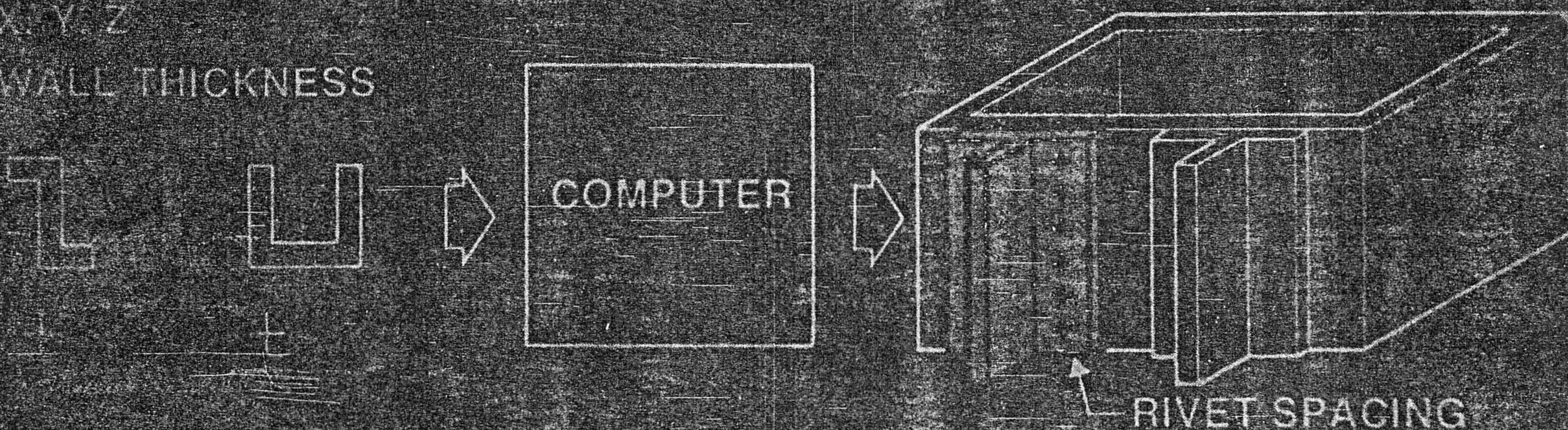

767
BOEING 767


757
BOEING 757

Parametric Design

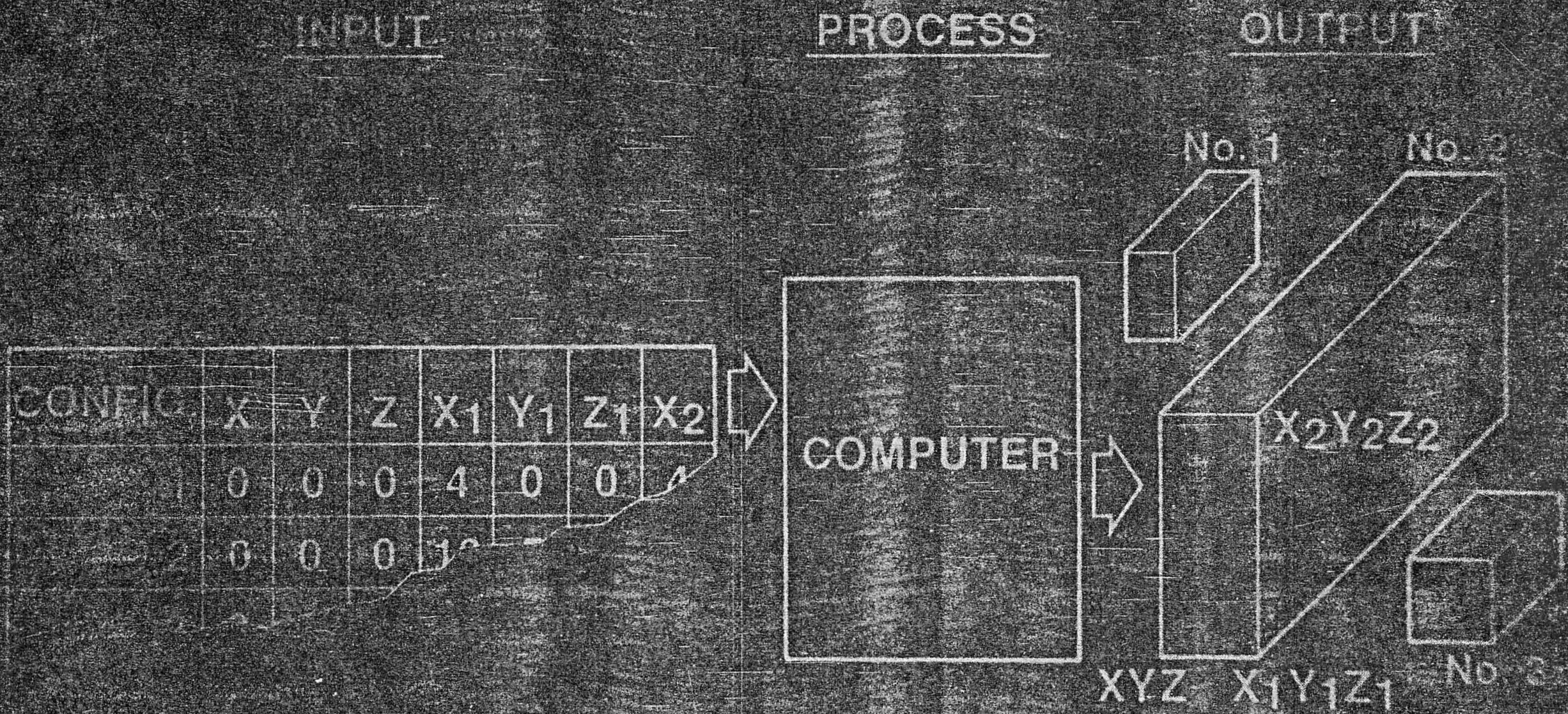
PARAMETERS	PROCESS	OUTPUT

- X, Y, Z
- WALL THICKNESS



PART DEFINITION
- DETAIL DESIGN
  - VOLUME
  - WEIGHT
  - STIFFNESS
  - ETC.

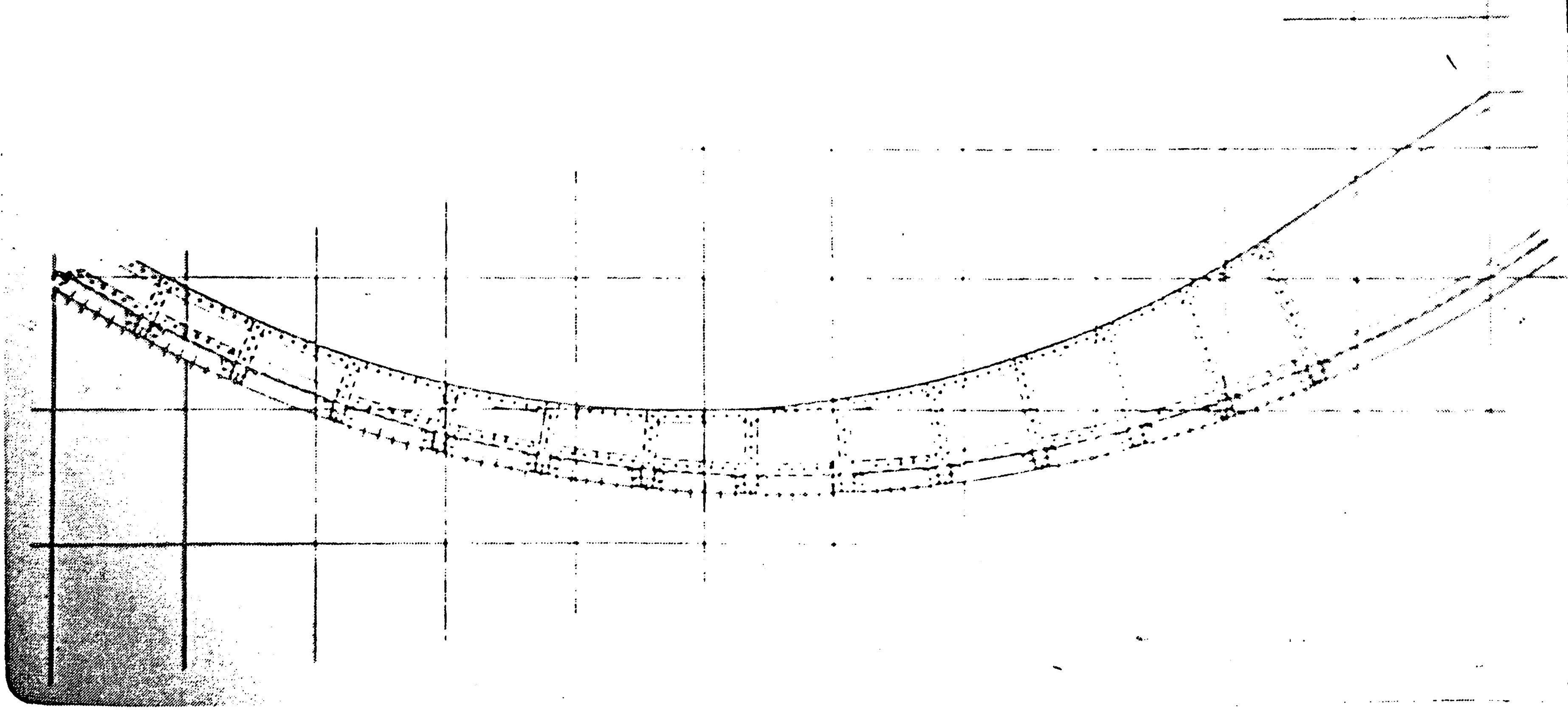
Family of Parts Relationships



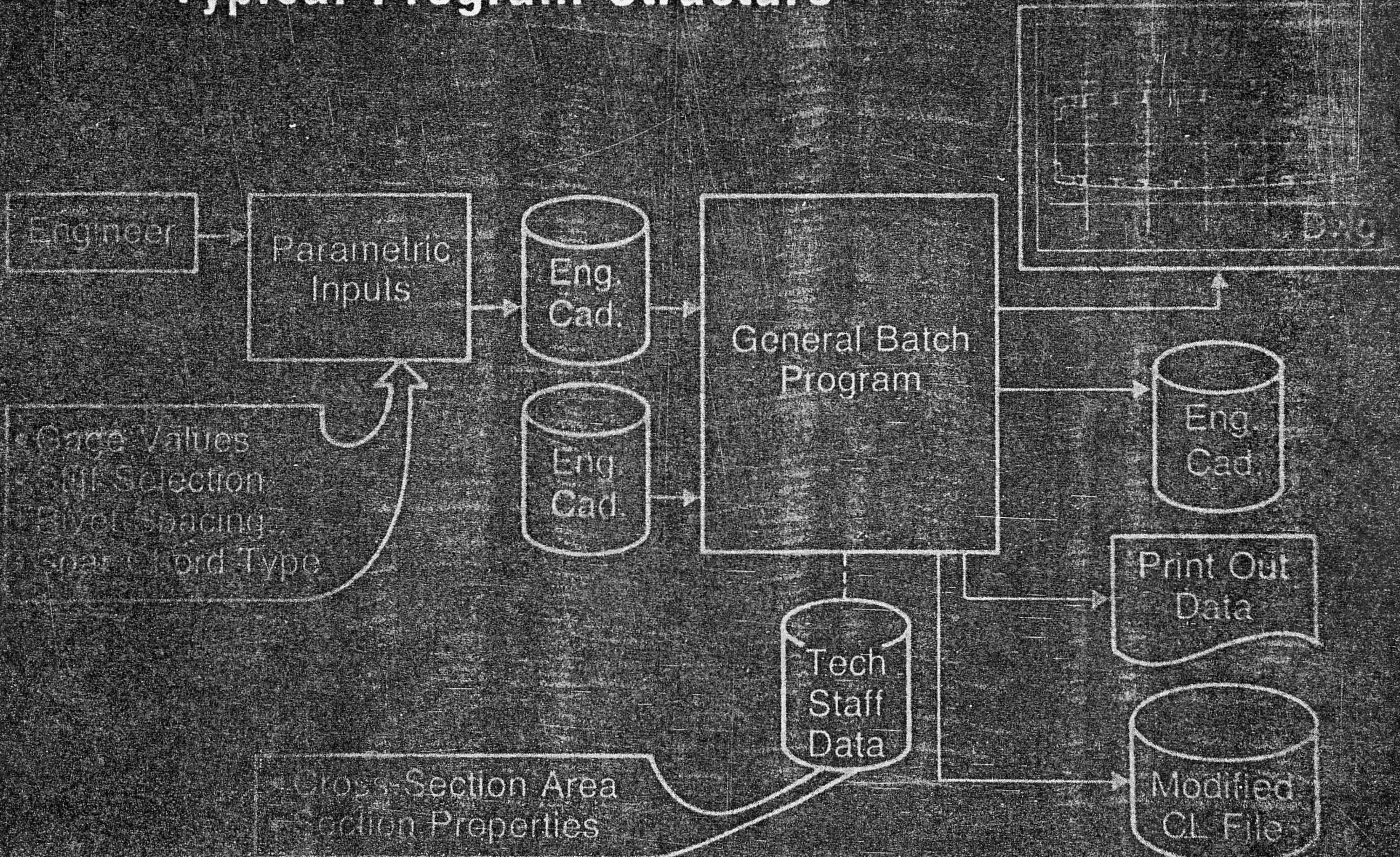
Examples of Parametric Programs

- Wing Box
  - Inspar Ribs
  - Wing Spars
  - Wing Stringers
  - Wing Panels
  - Wing Center Sections
- Body Structures
  - Floor Panels
  - Body Frames

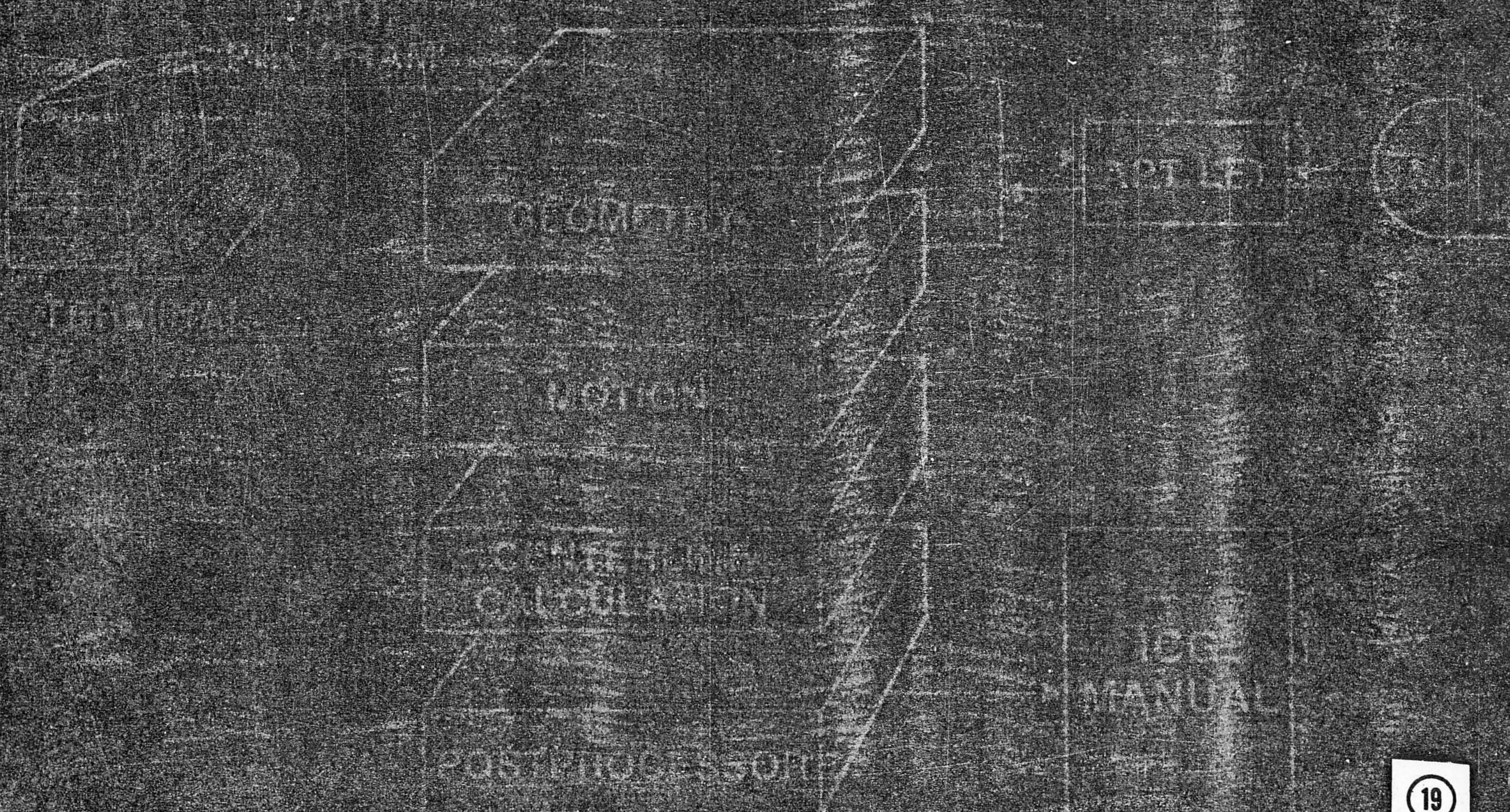
BATCH RUN—BODY FRAME



Typical Program Structure



APT System



767
Wing Box

Parametric Program Wing Box Design

Programming Requirements

Must be programmed to handle all the design process iterations of:

- Aerodynamic shapes
- Structural arrangement
- Structural thickness
- Structural concept and sizes

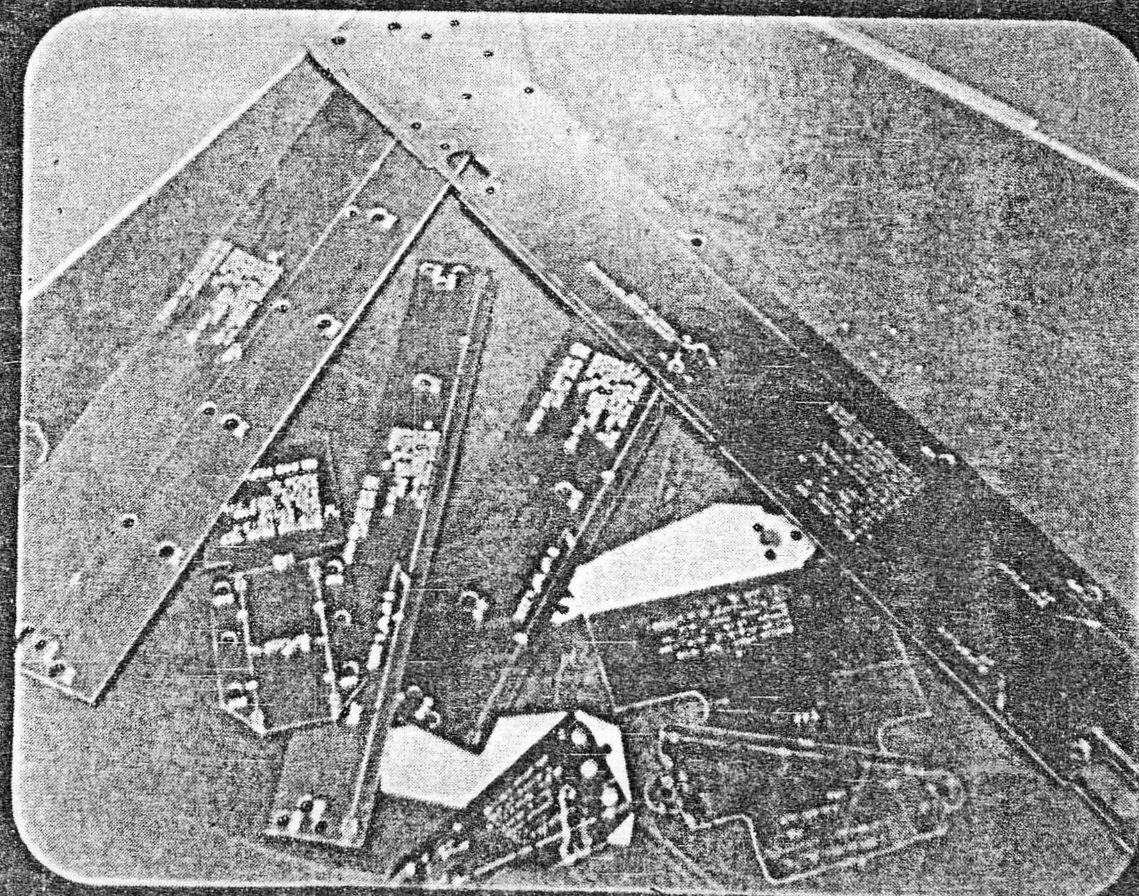
In addition must:

- Reflect changes in all affected components
- Be programmed from a common origin
- Be compatible with interactive computer graphics (ICG)
- Satisfy technical staff and manufacturing data requirements

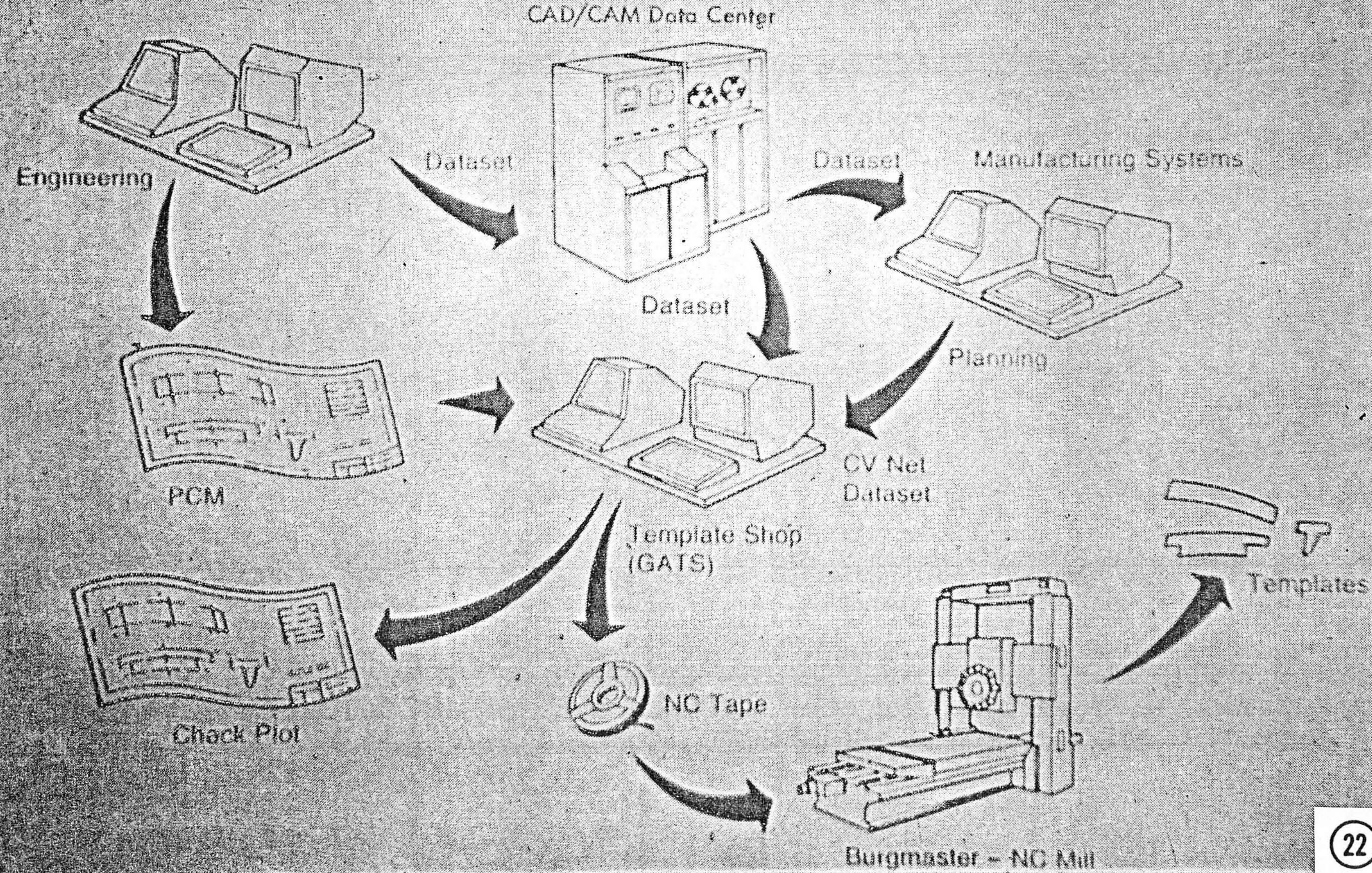
GRAPHICS AUTOMATED TEMPLATES (GATS)

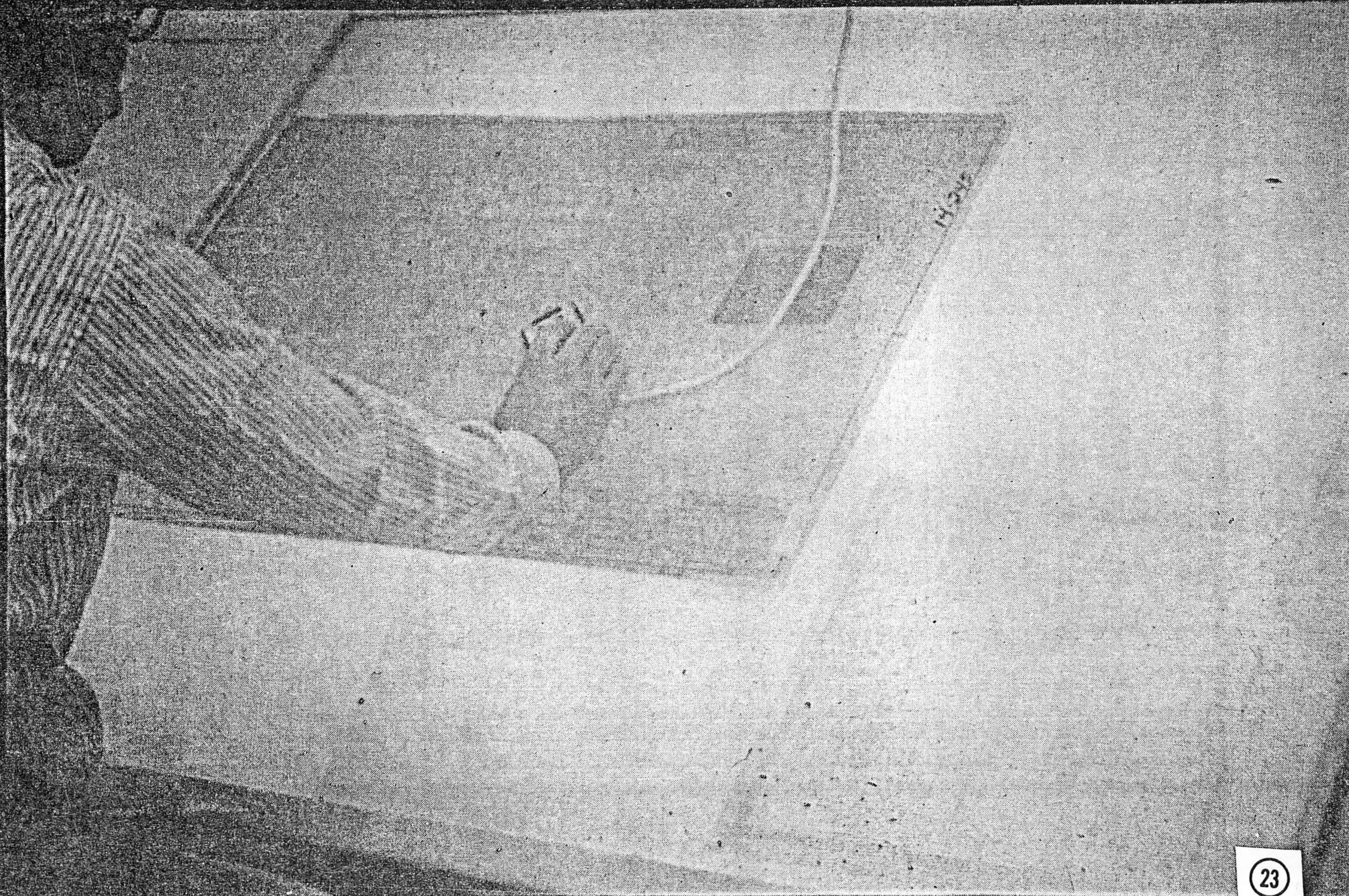
Templates

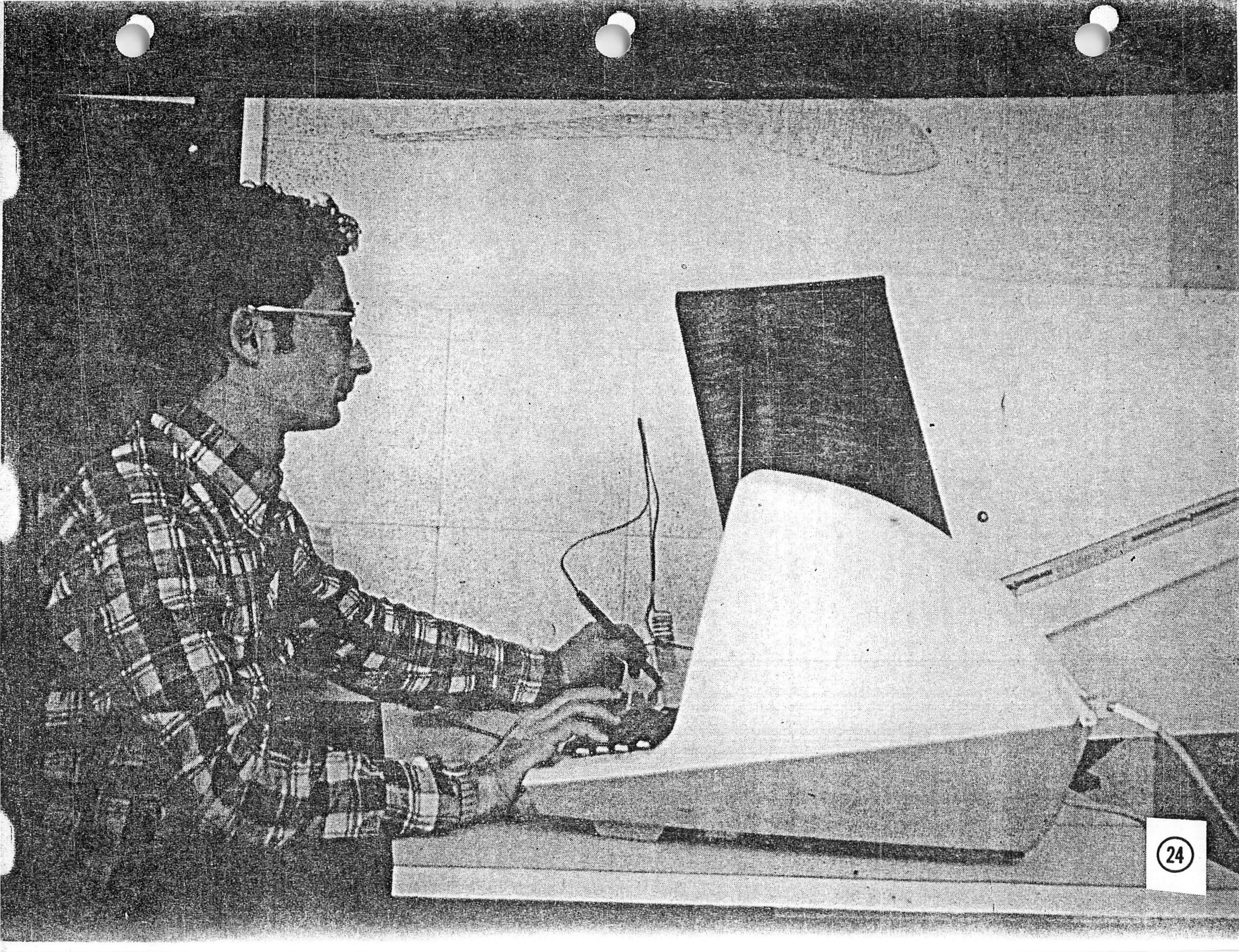
20-25%
are Flat



GRAPHICS AUTOMATED TEMPLATE SYSTEM DATA FLOW







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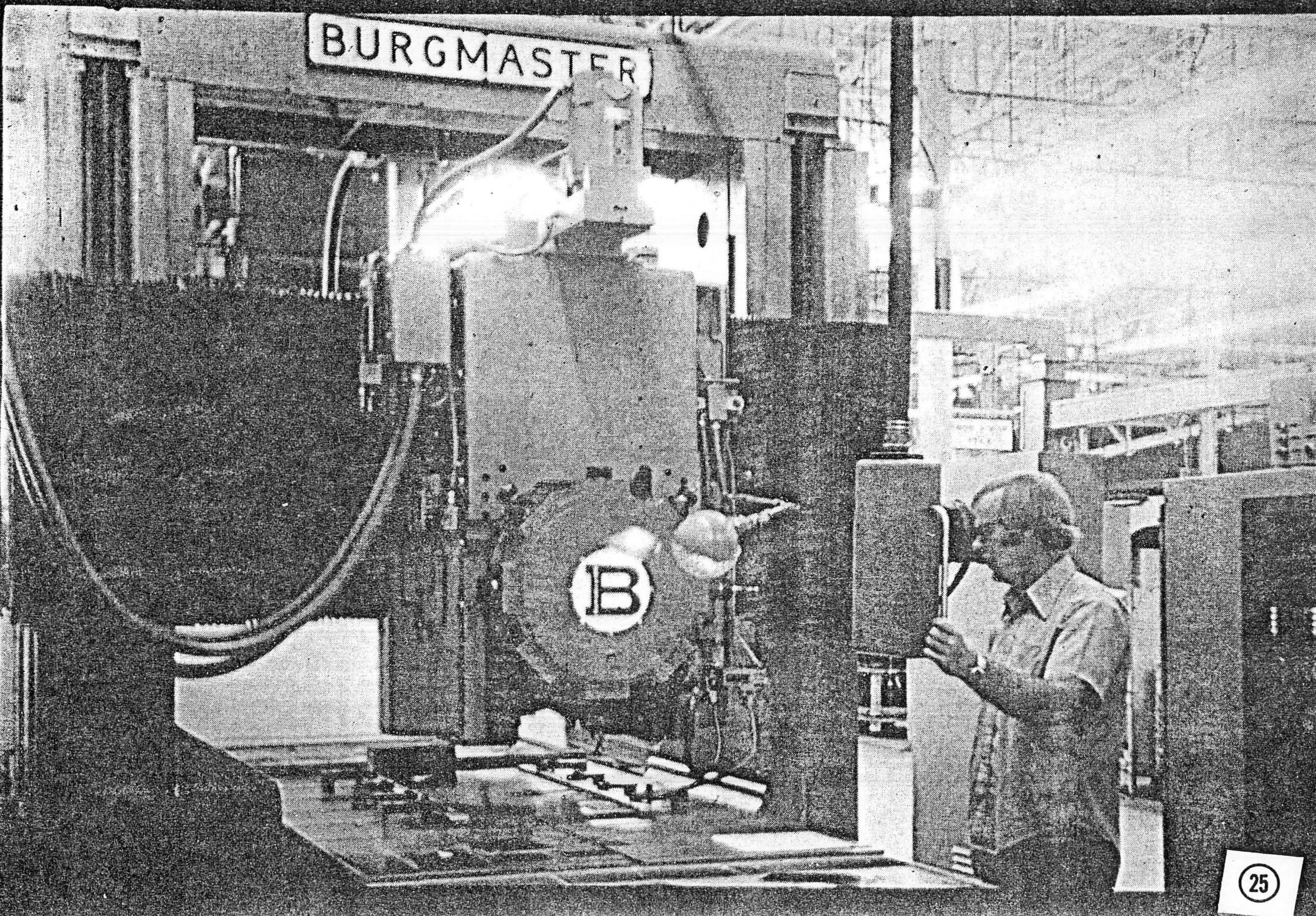

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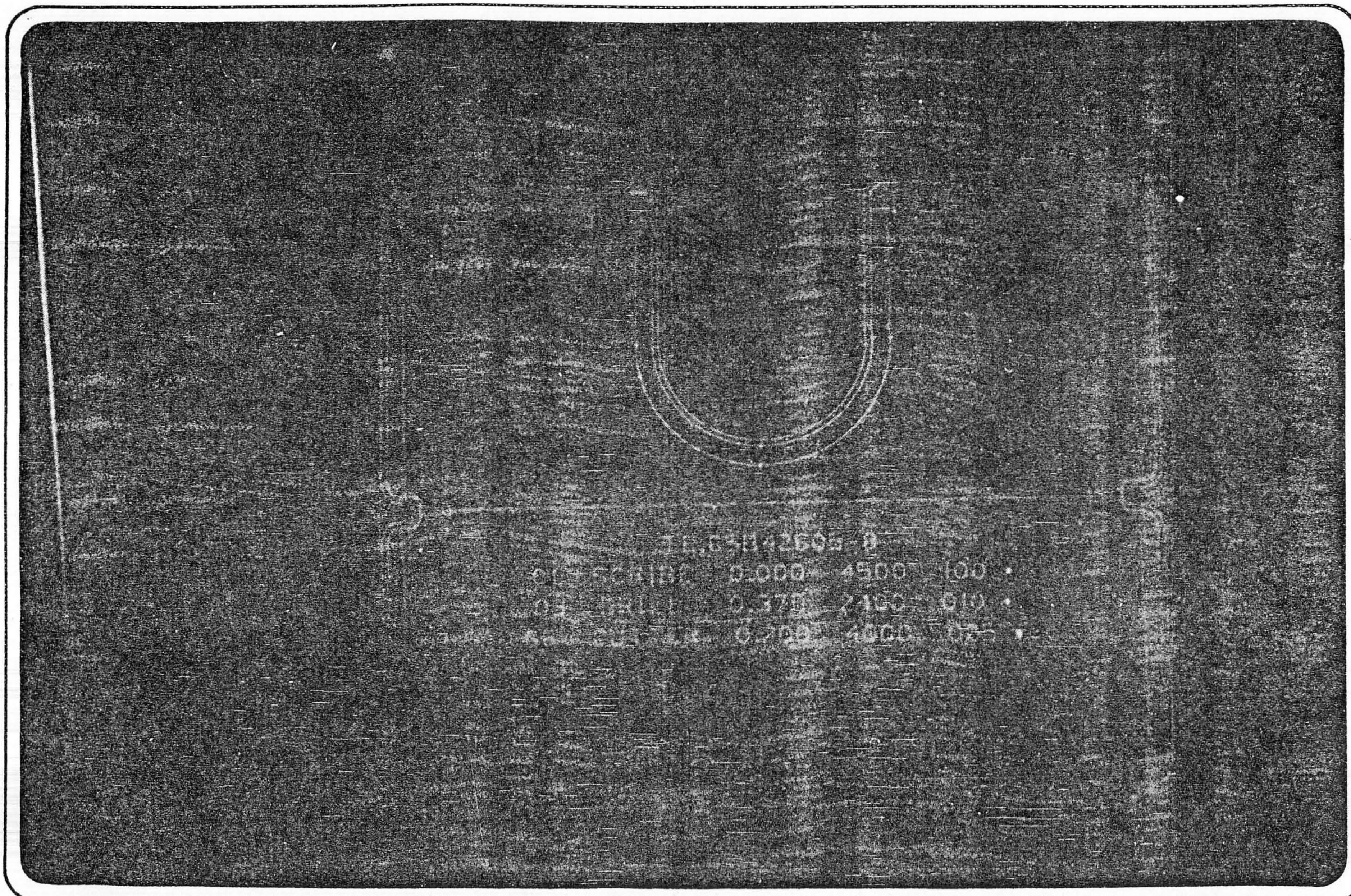
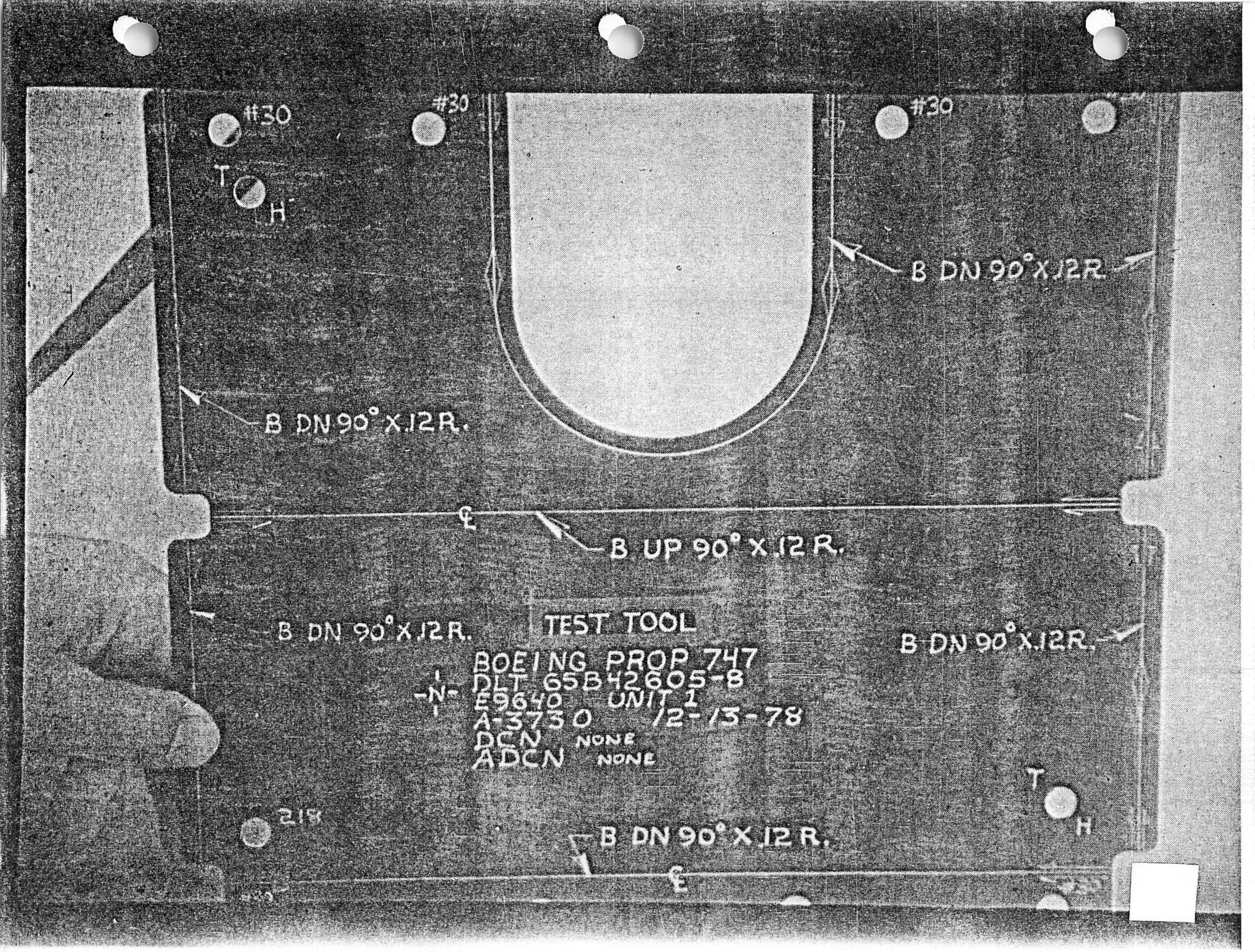
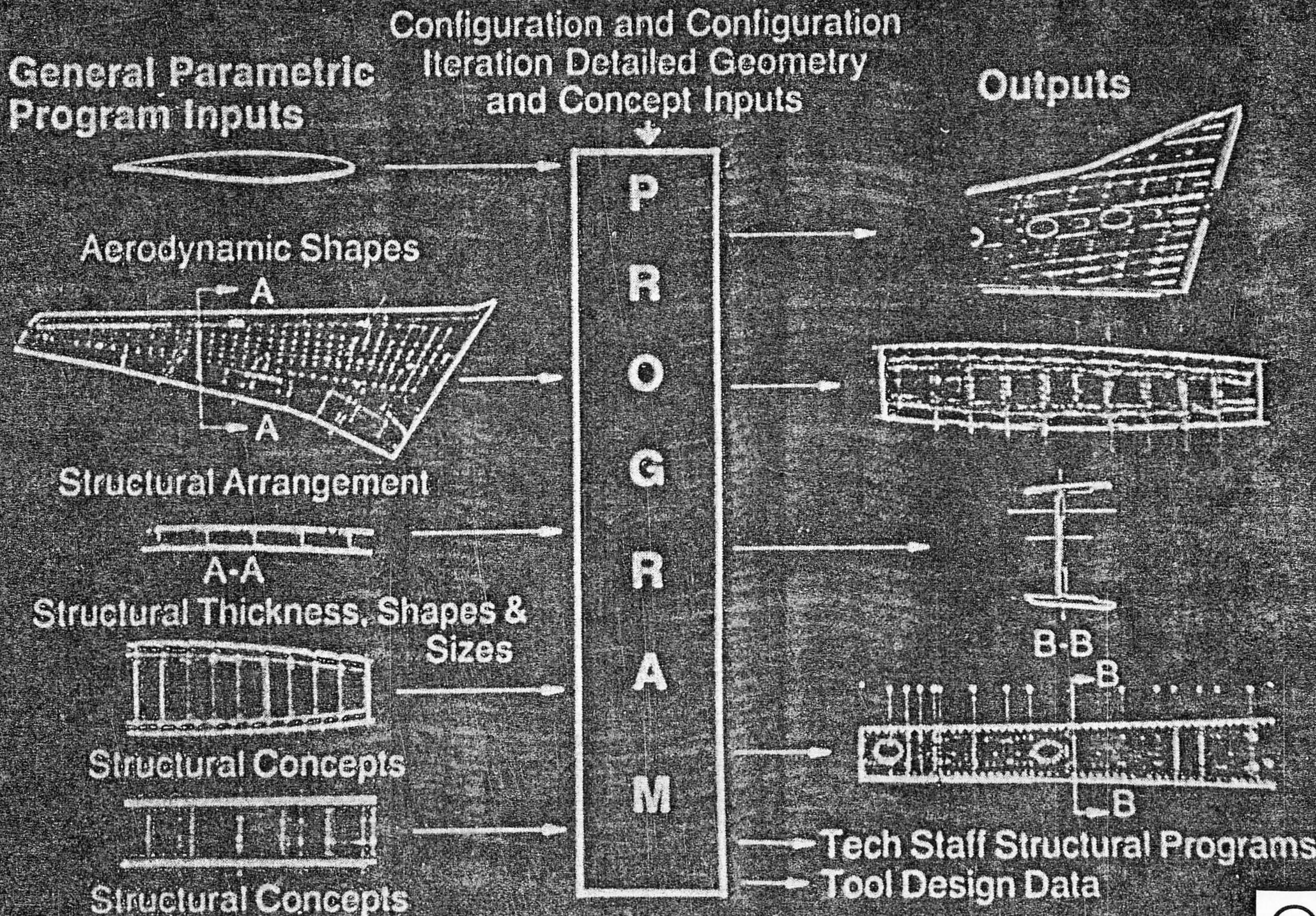


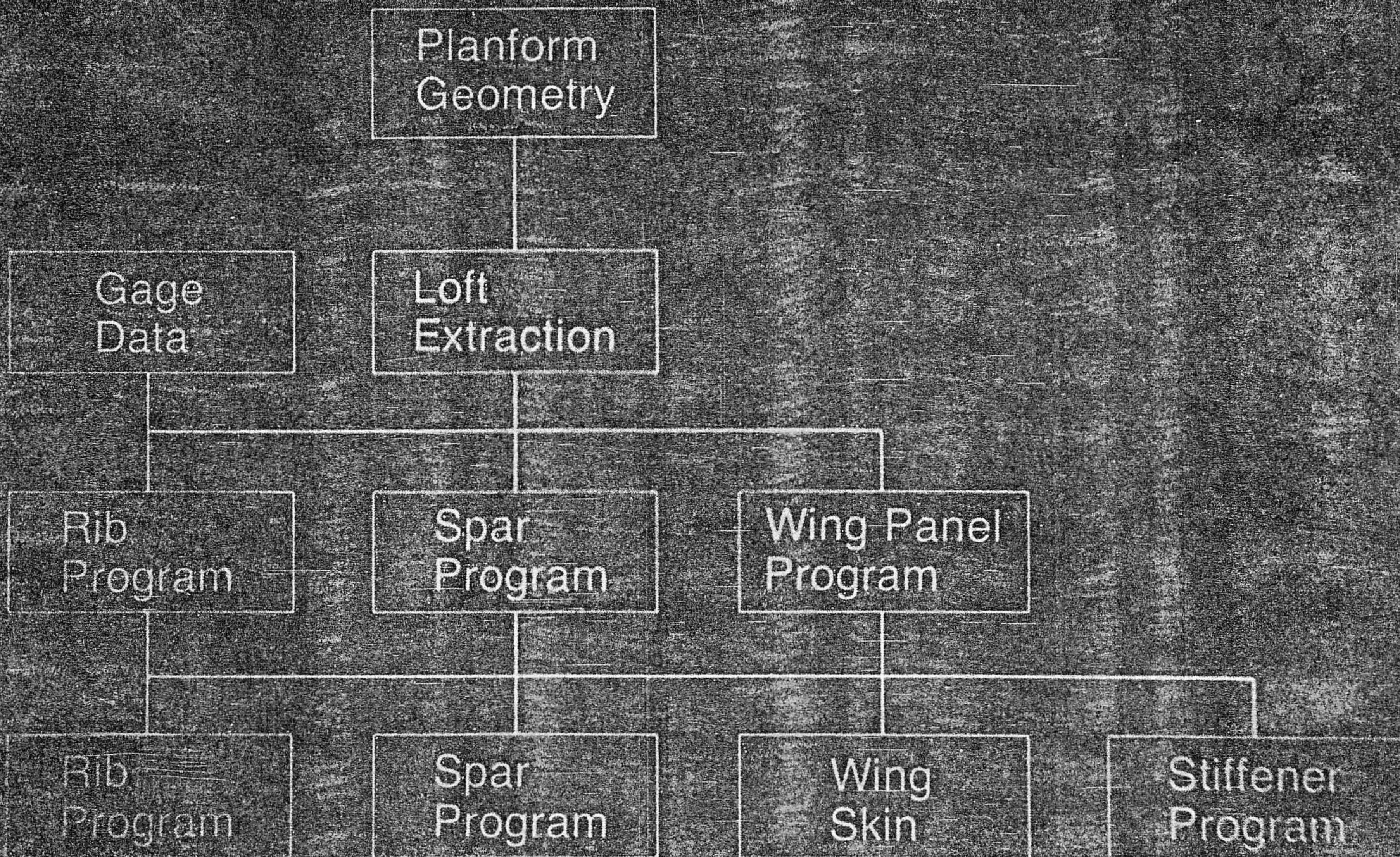

#30
#30
#30
T
H
B DN 90° X.12R.
B DN 90° X.12R.
B UP 90° X.12 R.
B DN 90° X.12R.
TEST TOOL
BOEING PROP 747
DLT 65B42605-8
E9640 UNIT 1
A-3730 12-13-78
DCN NONE
ADCN NONE
B DN 90° X.12R.
T
H
218
B DN 90° X.12 R.


FEBRUARY

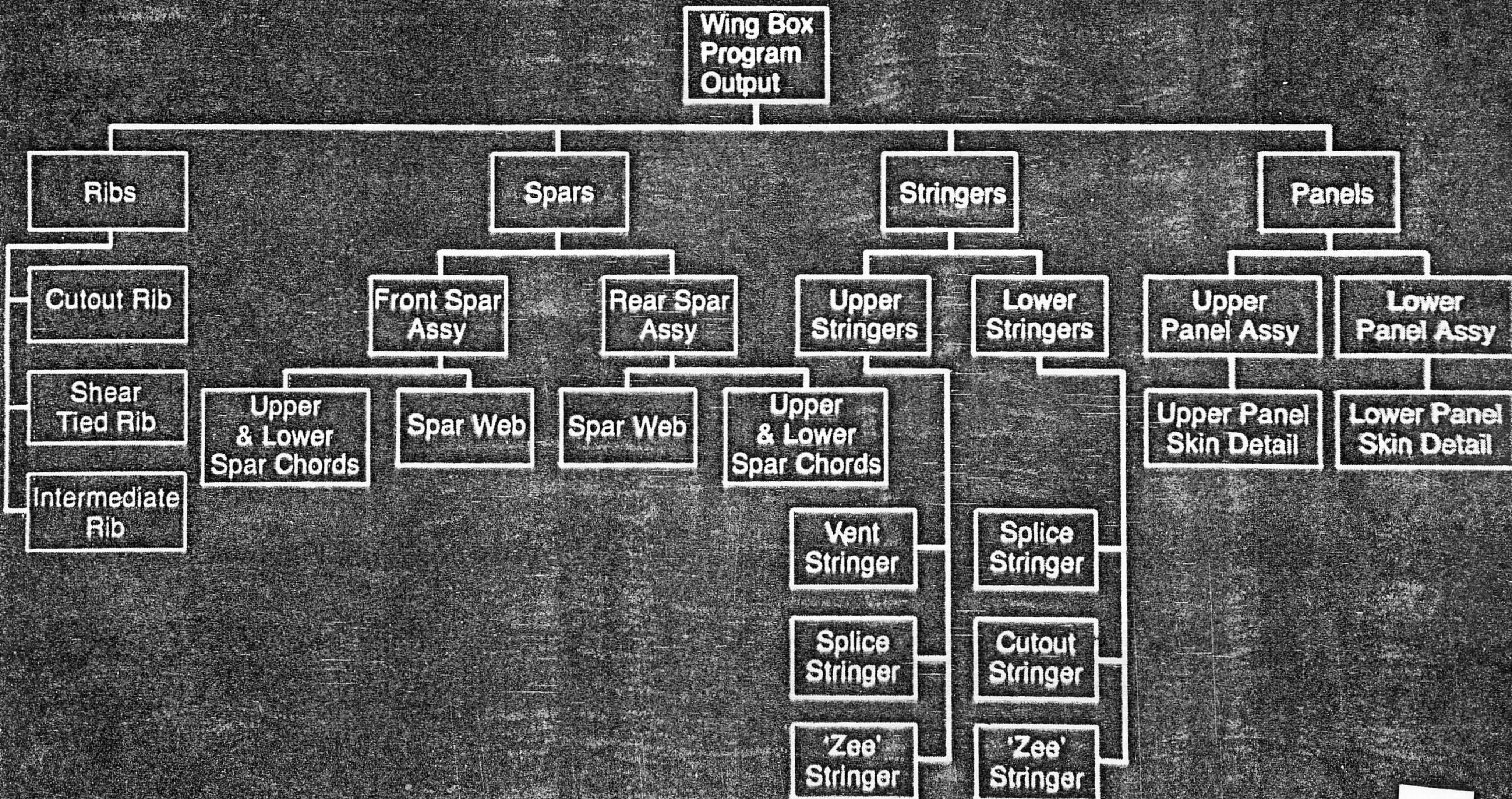
Wing Box General Parametric Program

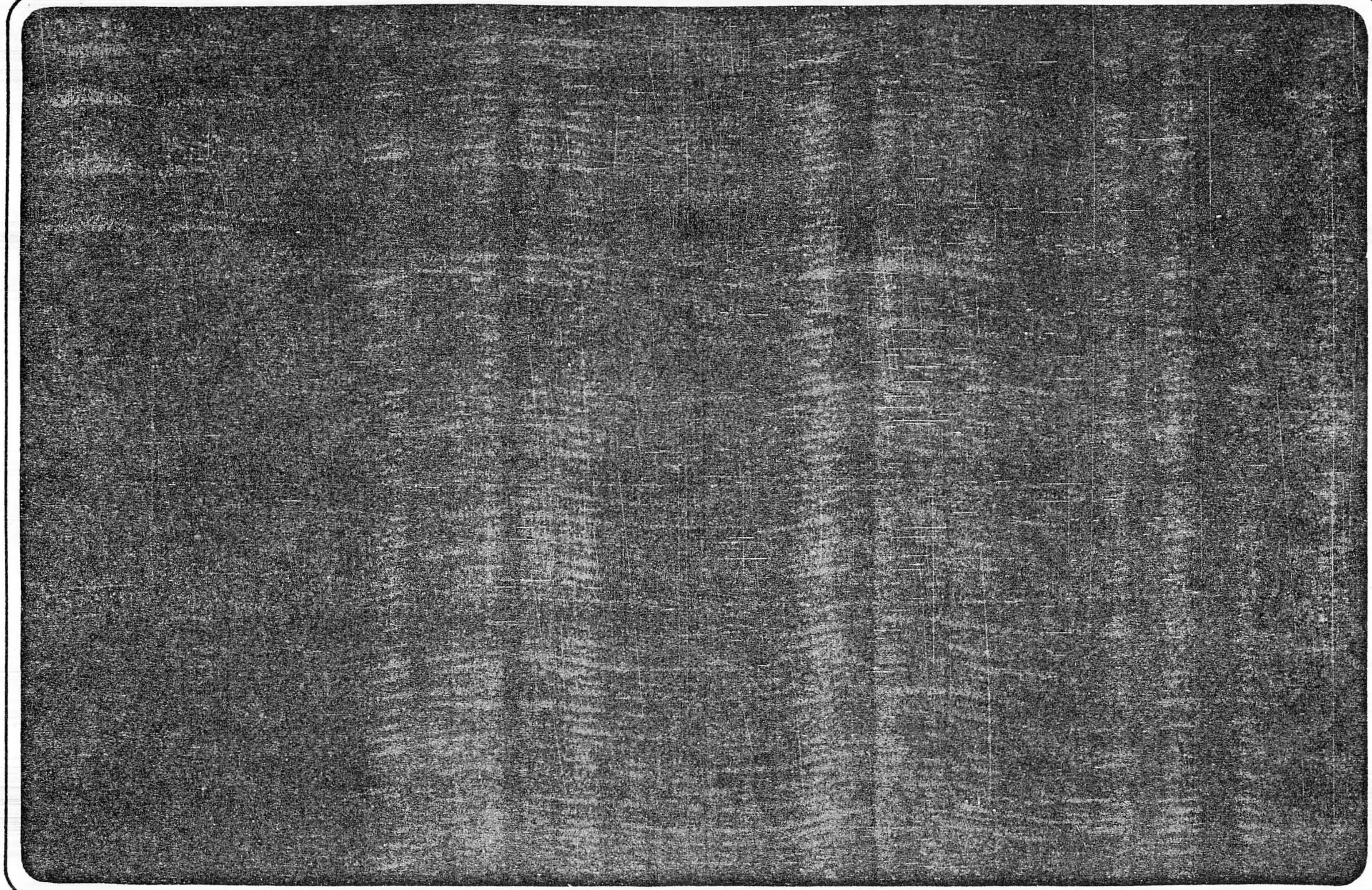


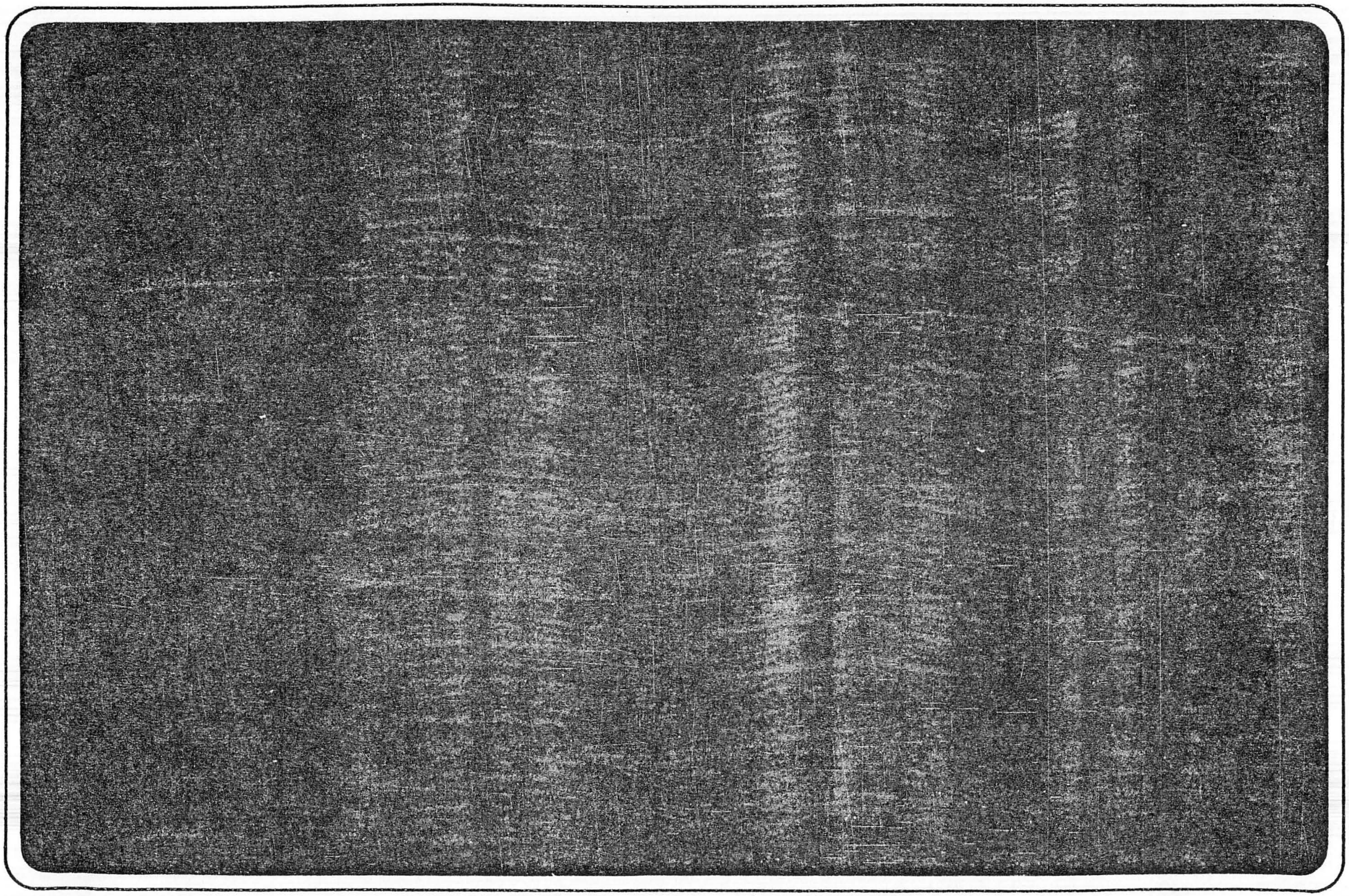
Program Network

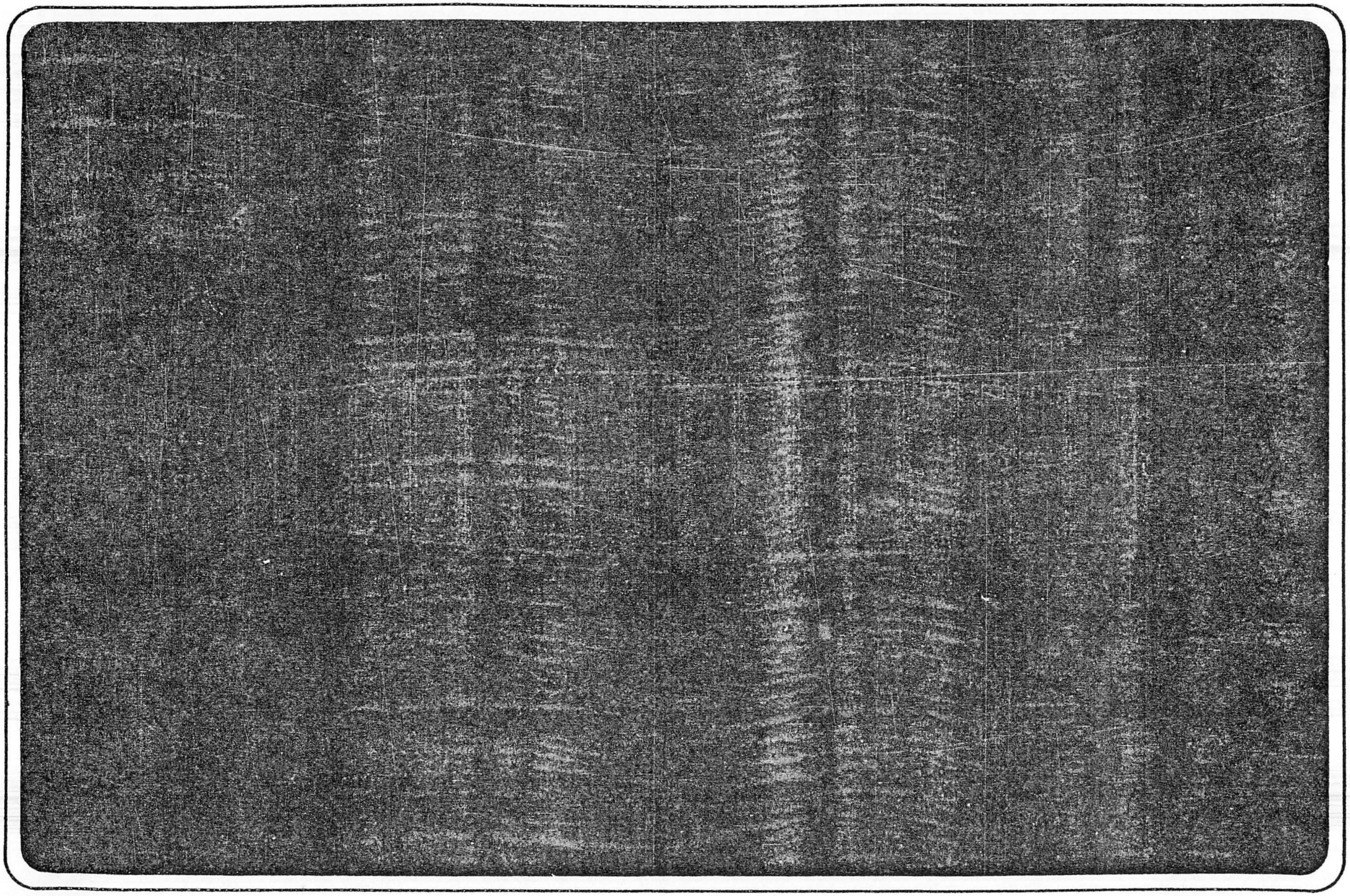


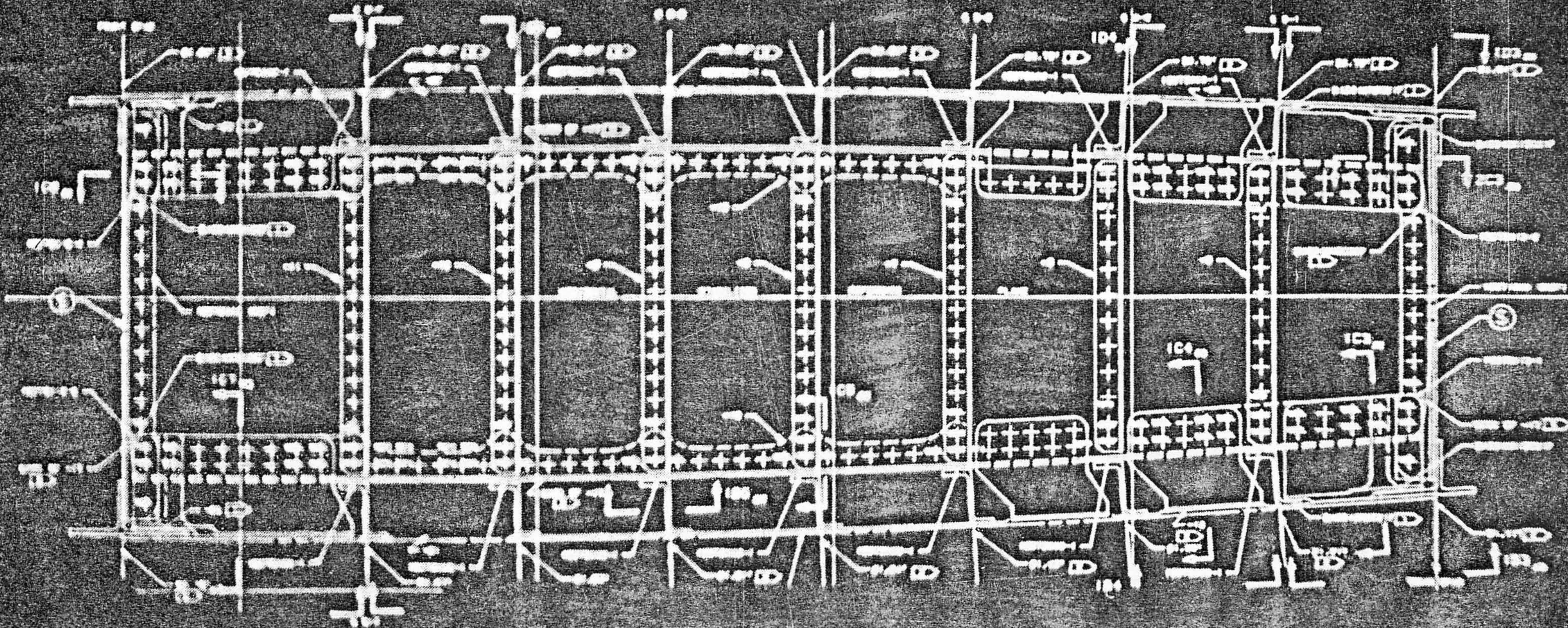
Wing Box Decomposition
(General Parametric Design)



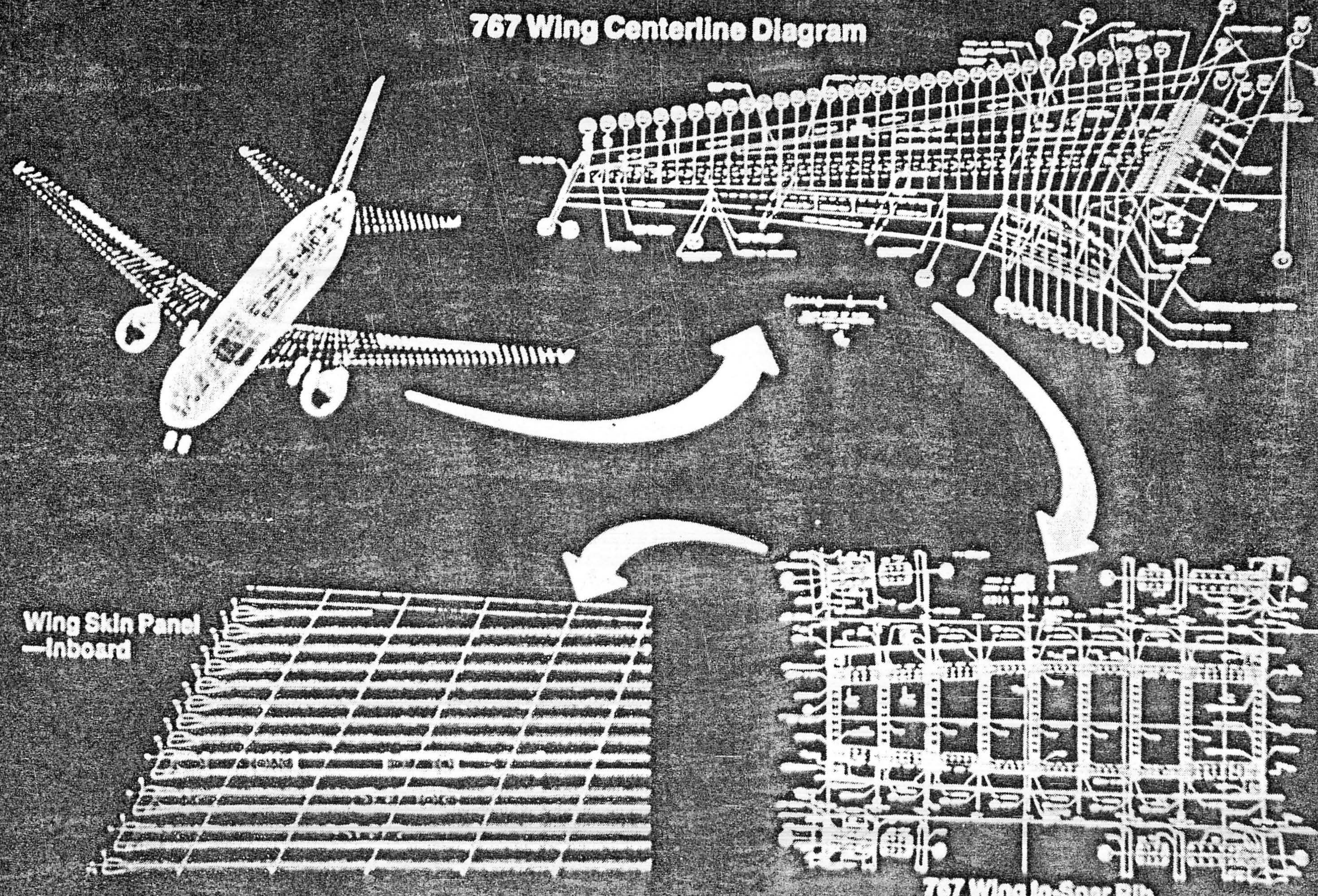




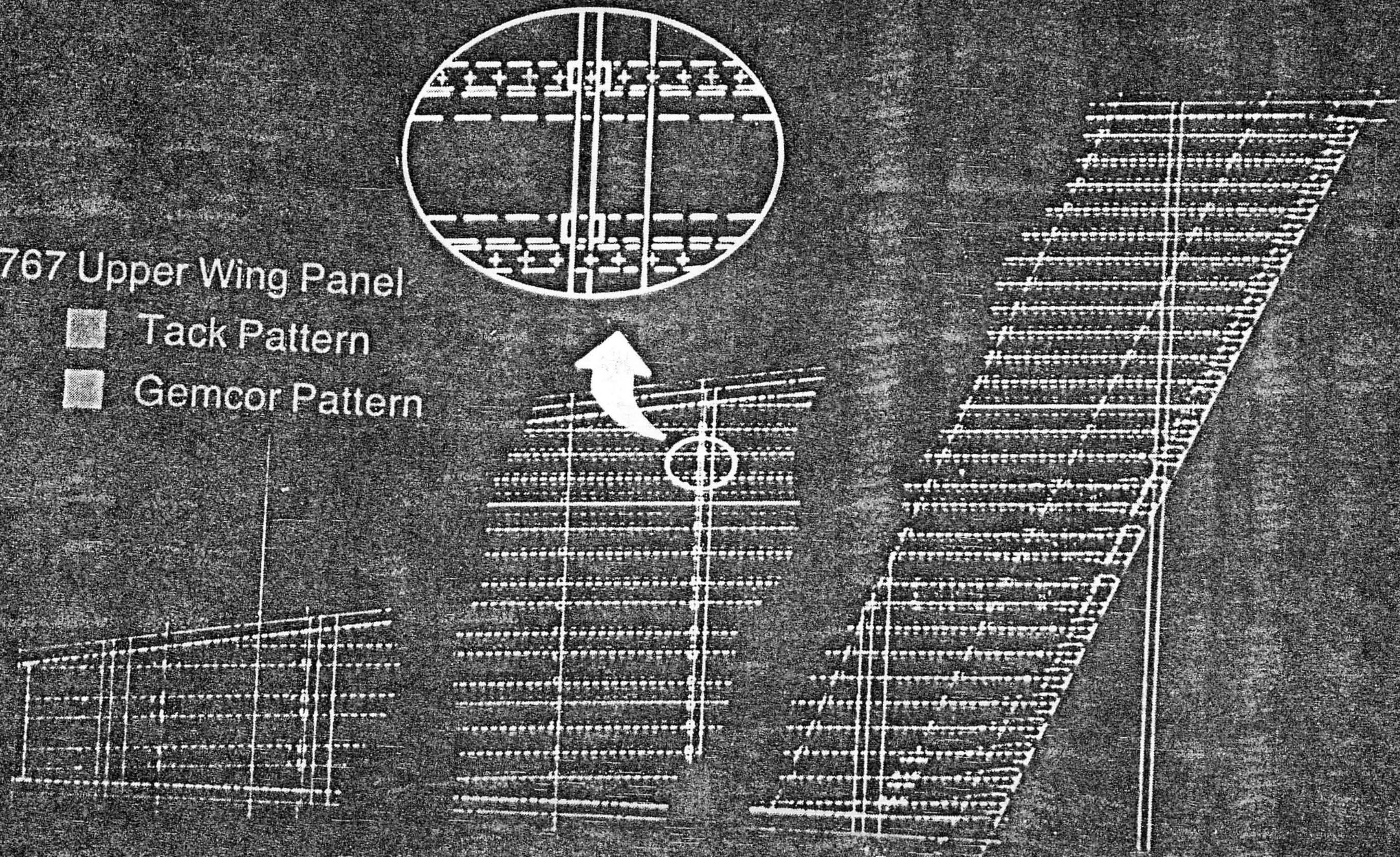




767 Wing in-spar rib

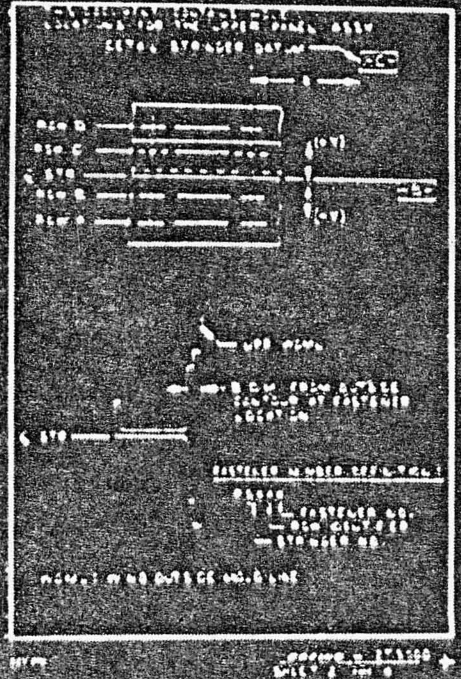

767 Wing Centerline Diagram
Wing Skin Panel
—Inboard
767 Wing In-Spar Rib

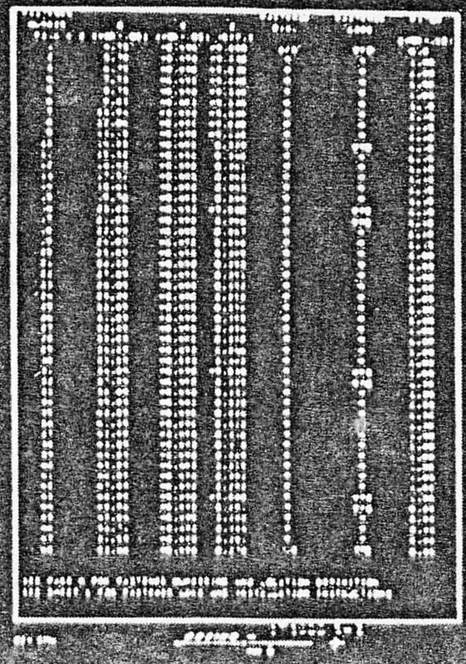
Parametric Program Computerized Assembly

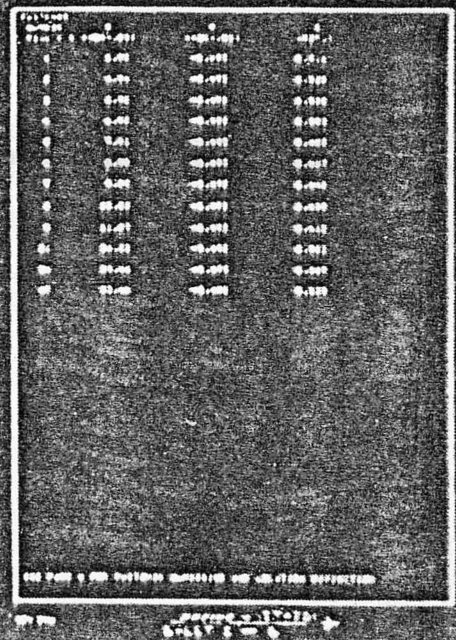


Typical for Spars and Ribs

Parametric Program Computerized Assembly







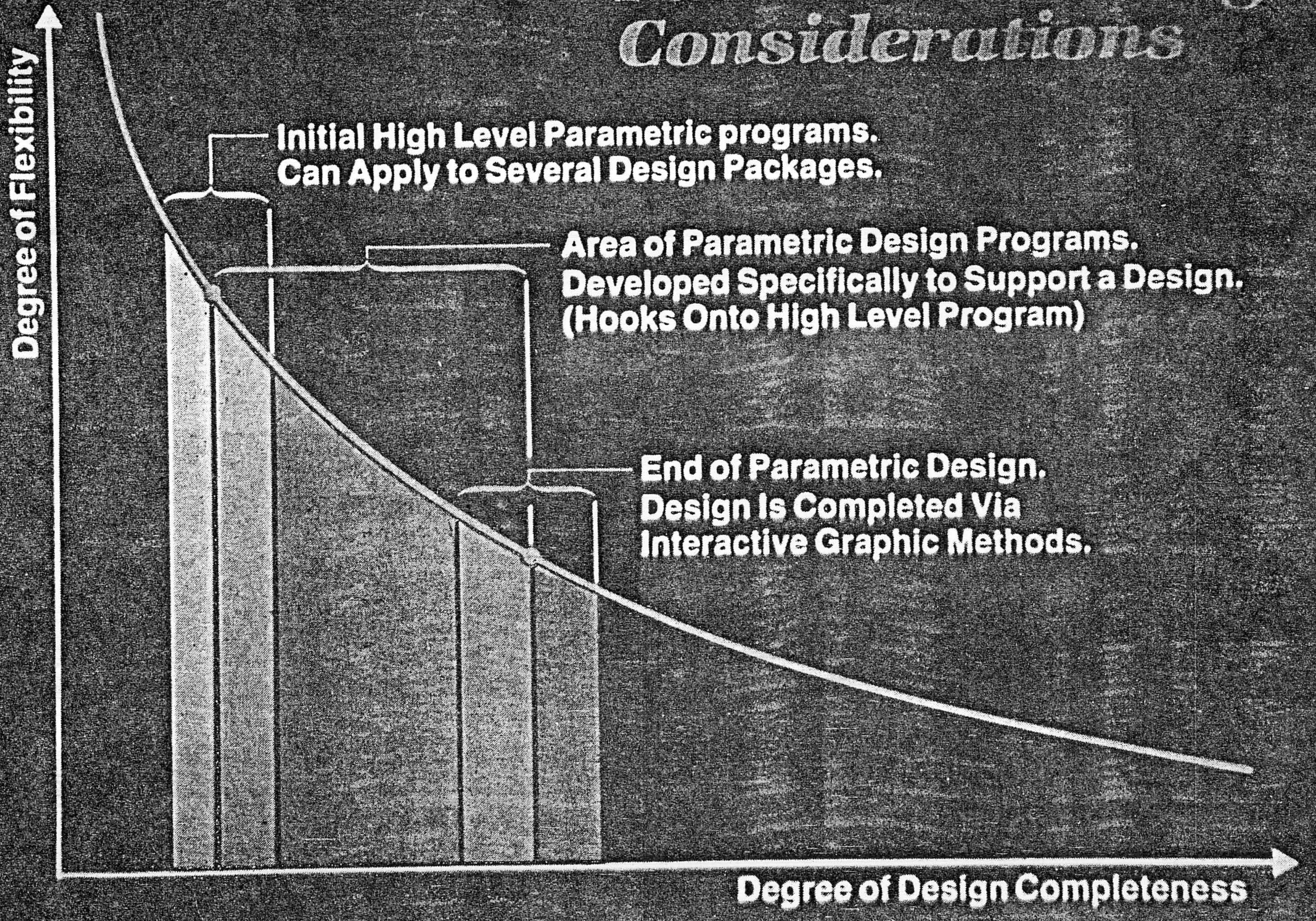
Allows Complete Definition of Fastener Locations

- Provides configuration control of tack fasteners
- Generates CAM tapes for pilots in stringers
- Generates tapes for Gemcor automatic riveting machines
- Provides visibility of fastener locations

Gemcor

- Each of the two airplane programs – 767, 757, had about 56,000 wing panel fastener holes
- Programs done at different times with different personnel
- Both had zero engineering errors with holes and fasteners
- This is a repeated process

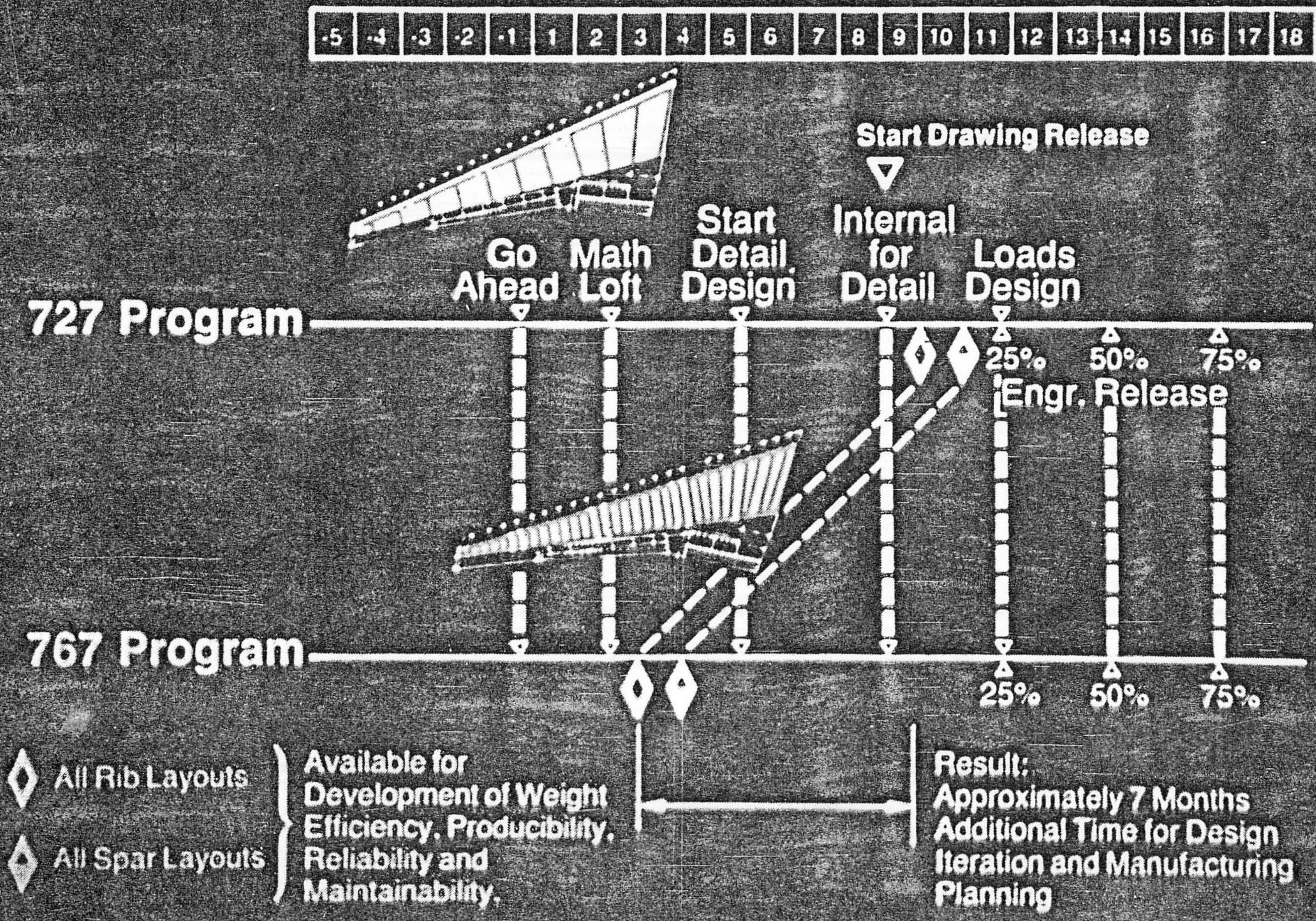
Parametric Design Considerations



General Parametric Program Advantages

- One week turnaround for respaced ribs and spars
- Overnight turnaround for rib or spar layouts to reflect skin panel changes
- Each module shares common inputs, design coordination is greatly minimized
- Components of the wing box can be plotted as computerized assemblies
- 767 Vertical stabilizer auxiliary spar final drawing completely revised in 3 days to save 20 lb

727 Manual vs 767 General Parametric Program Flow Time

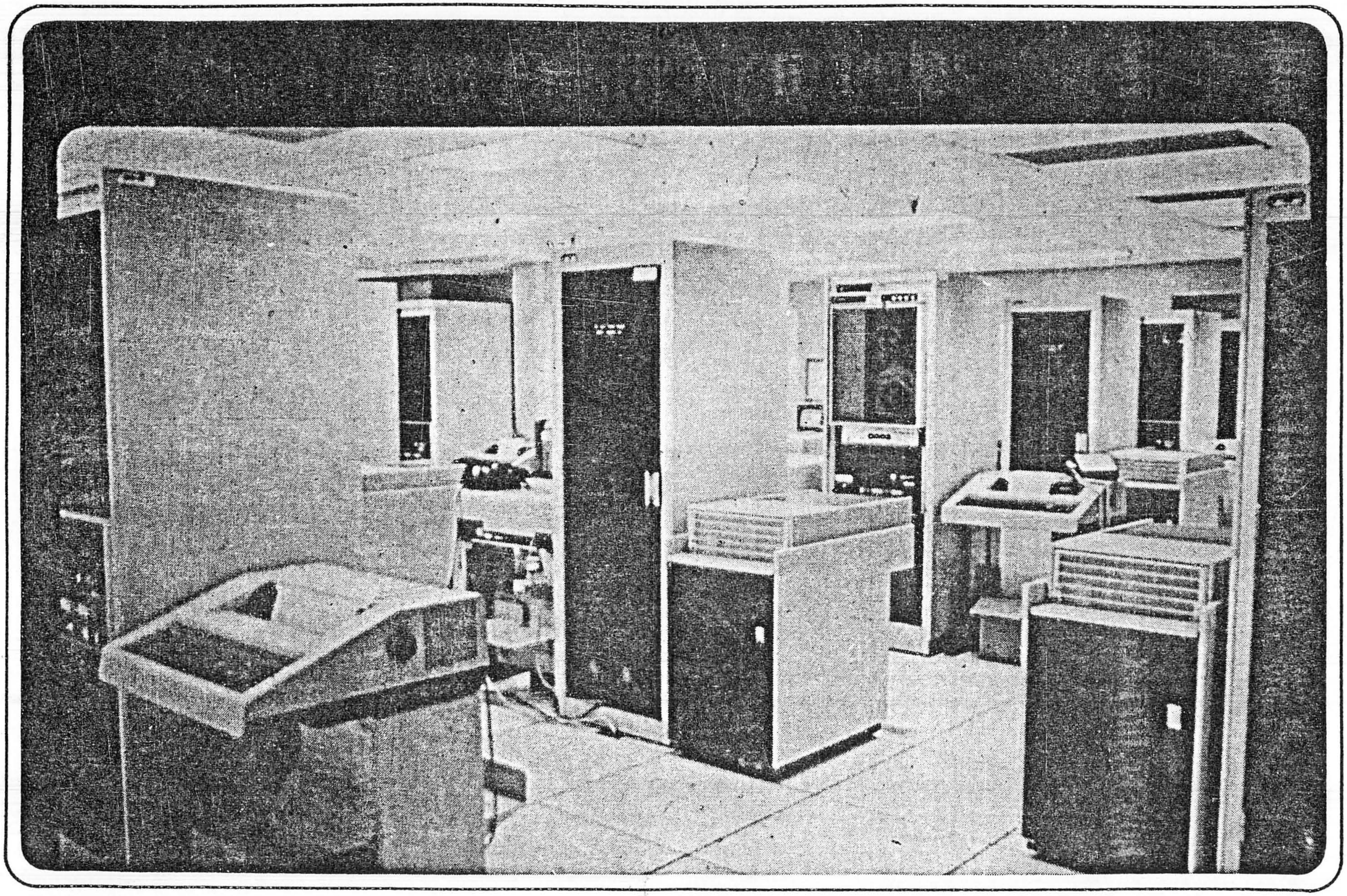


Summary

- Parametric design has proven to be very powerful.
- Design decisions are fast reinforced throughout the design package.
- Design discipline is much easier to obtain.
- Too much detail in the model can lead to inflexibility and to iteration problems.
- Rely on graphics (or on manual methods) to complete the design.
- Configurational control of parameters is very important.

Interactive Computer Graphics

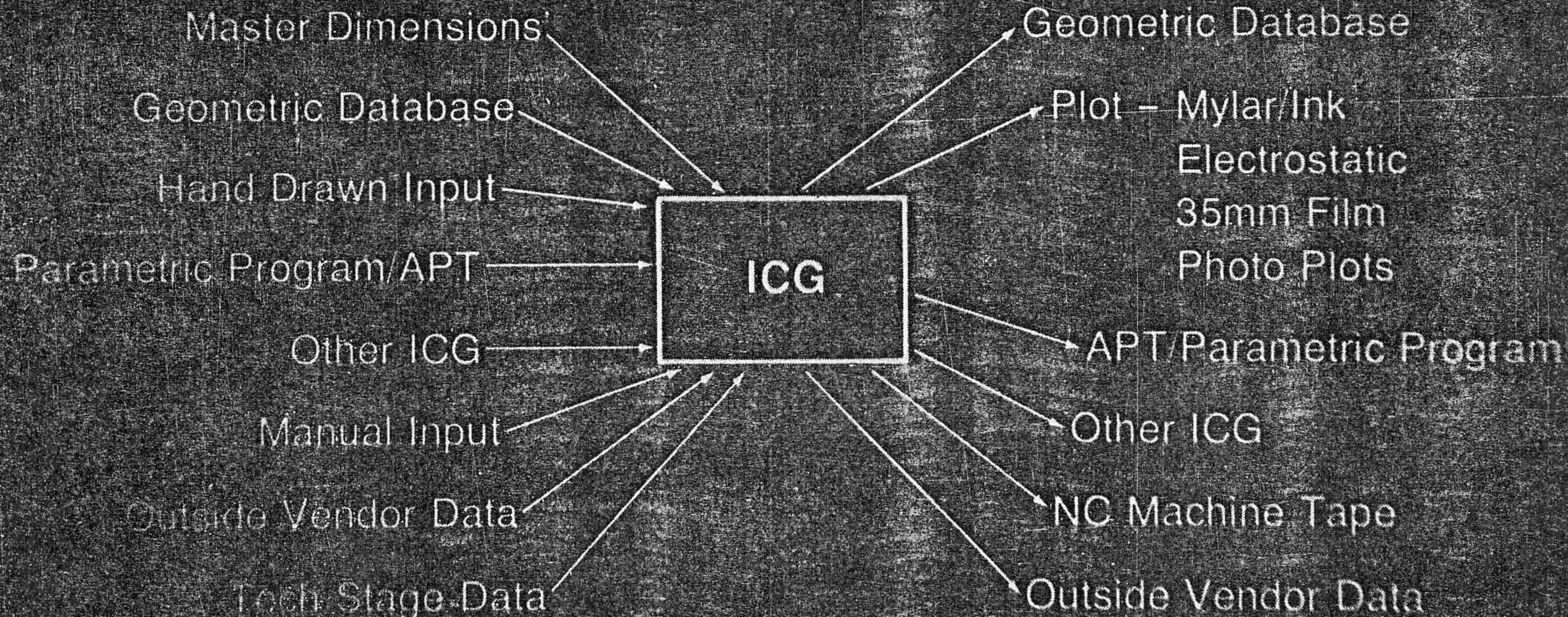
1A



ICG

ICG INPUT

ICG OUTPUT

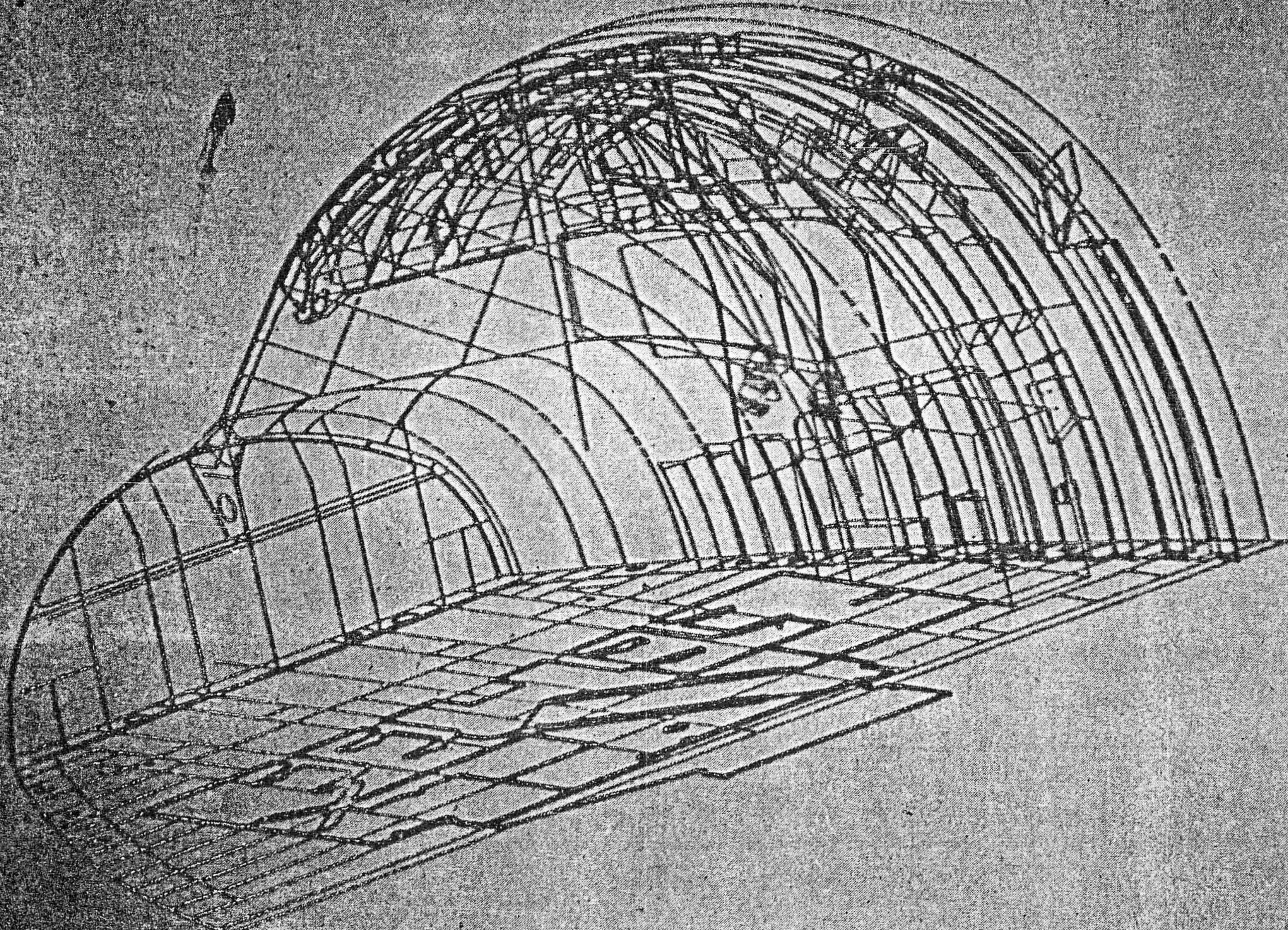


Advantages of Using ICG

- Can be operated by many skill levels
- Performs tasks that are repetitious
- Has versatility
- Flattens rising cost curves
- Improves accuracy
- Enhances storage and retrieval of data
- Provides common dataset structure

DRIPSHIELD

767 PAPER MOCKUP



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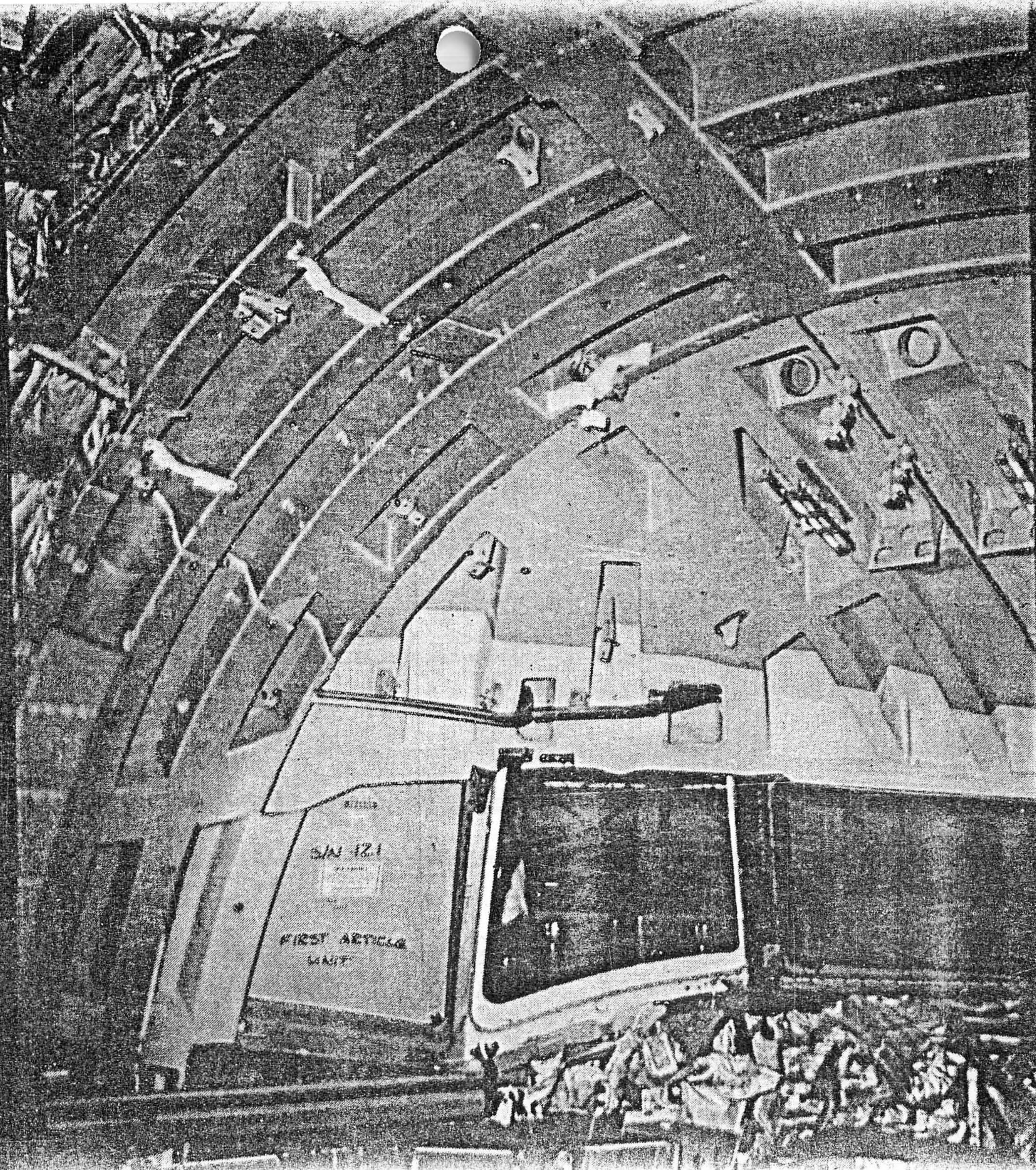
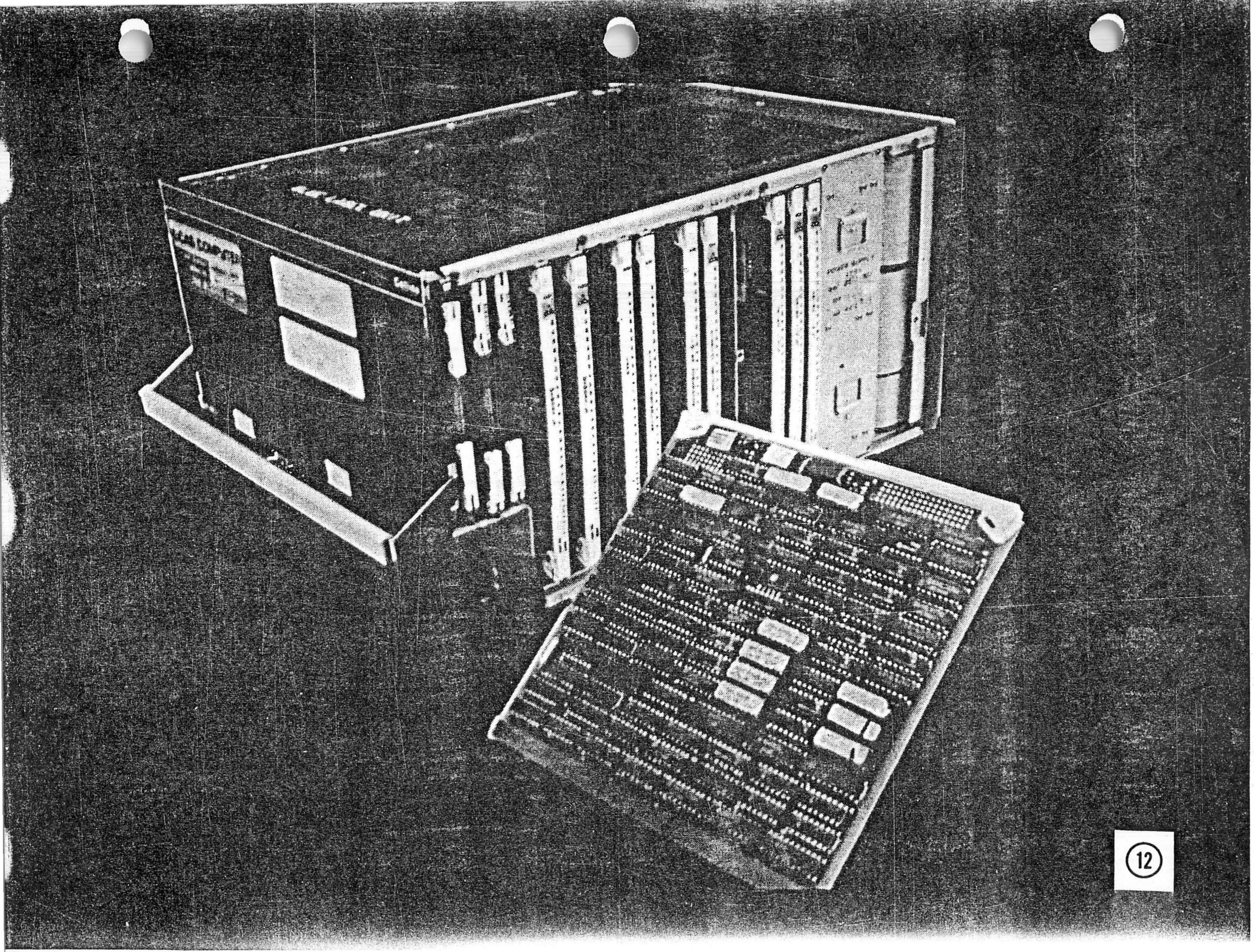

S/N 121
FIRST ARTICLE UNIT

PRINTED CIRCUIT BOARDS



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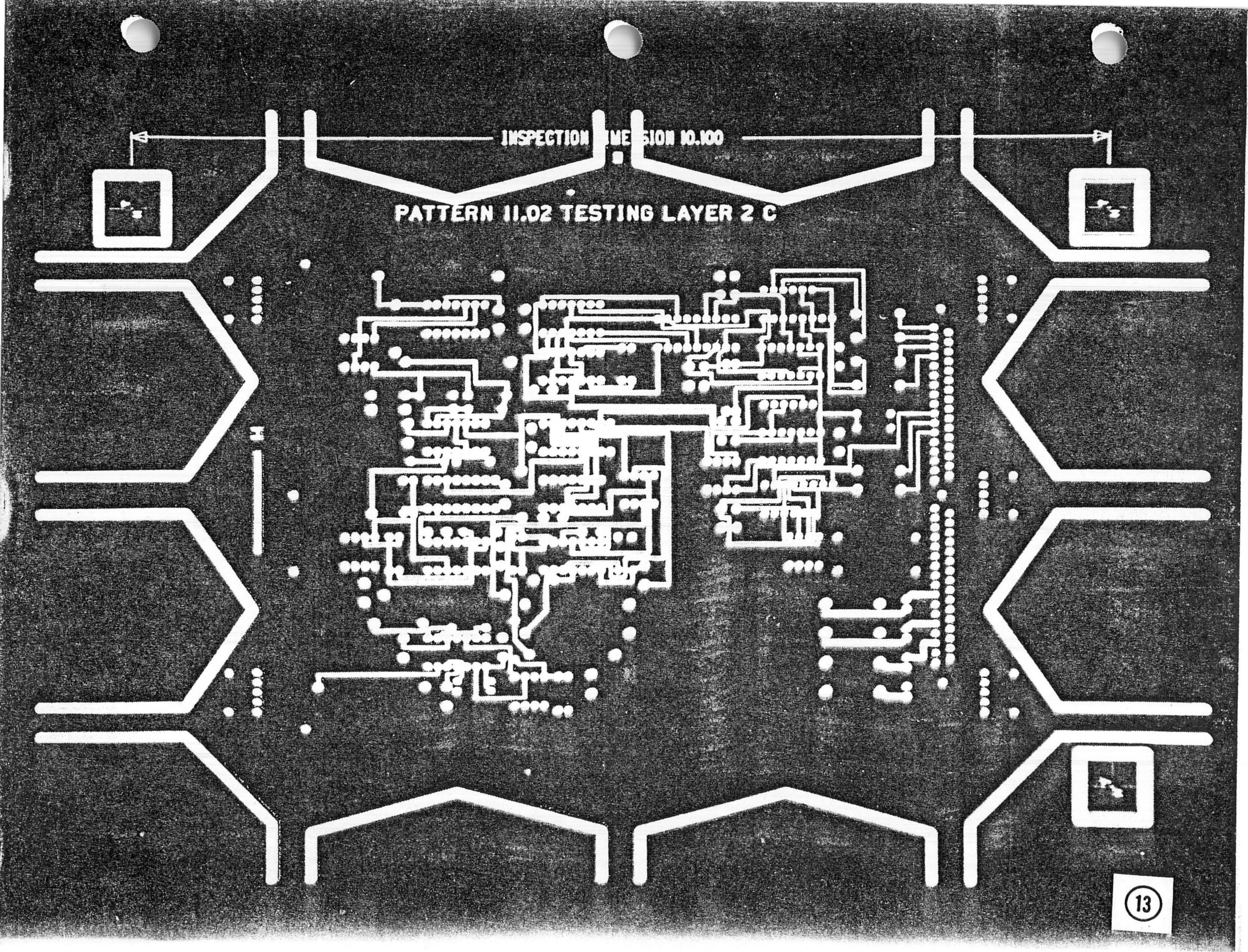
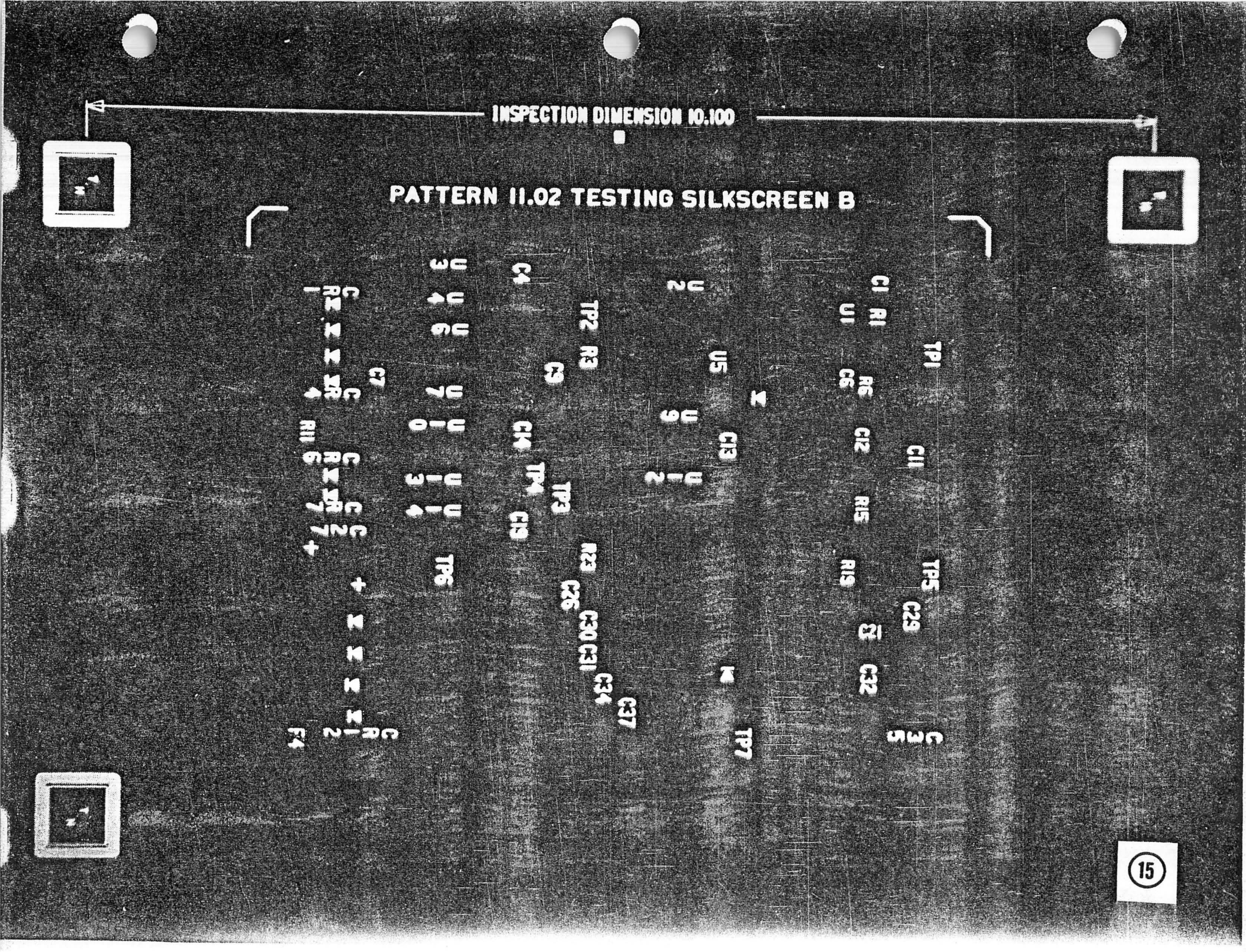
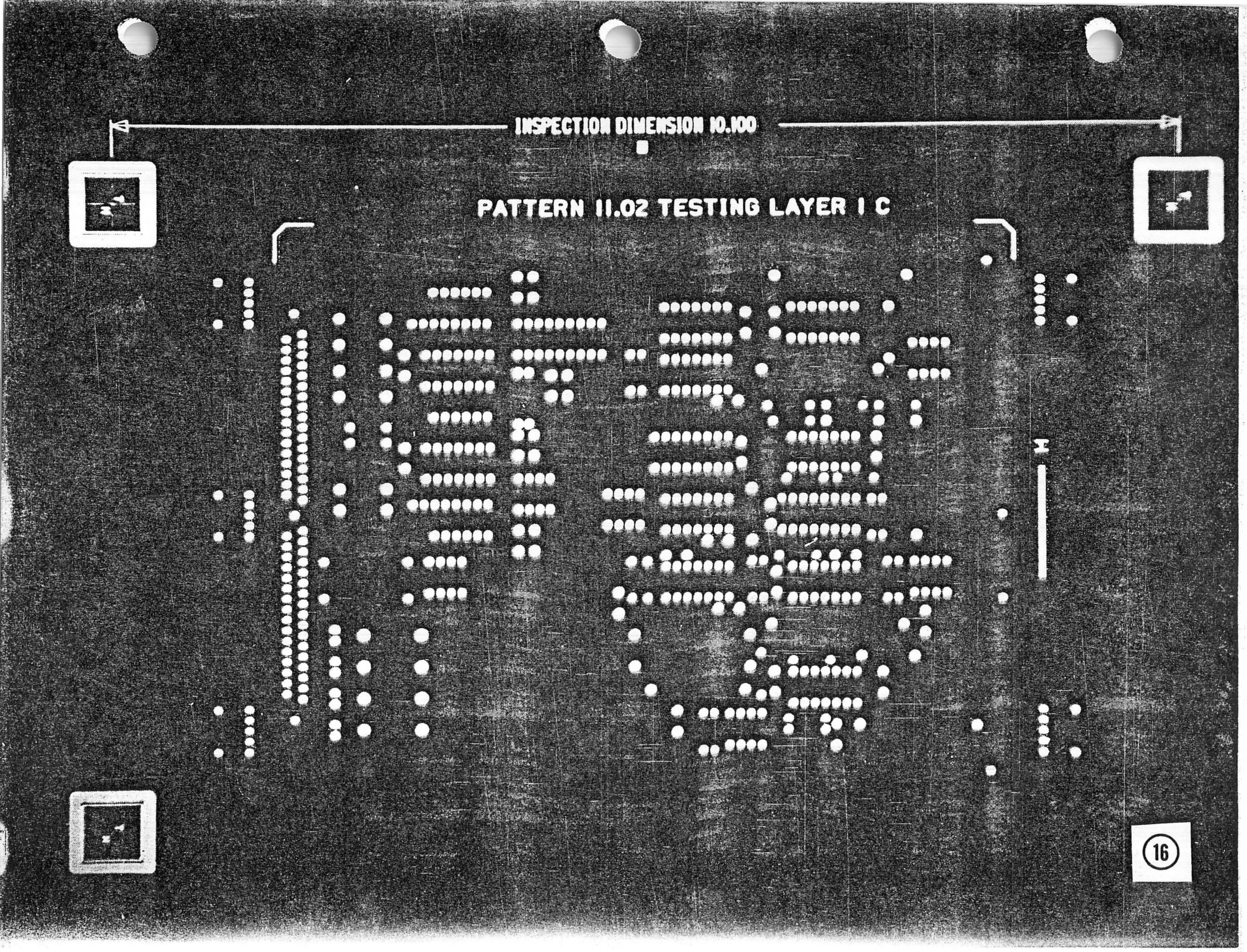

INSPECTION
PATTERN 11.02 TESTING LAYER 2 C
13


INSPECTION DIMENSION 10.100
PATTERN 11.02 TESTING SILKSCREEN B
15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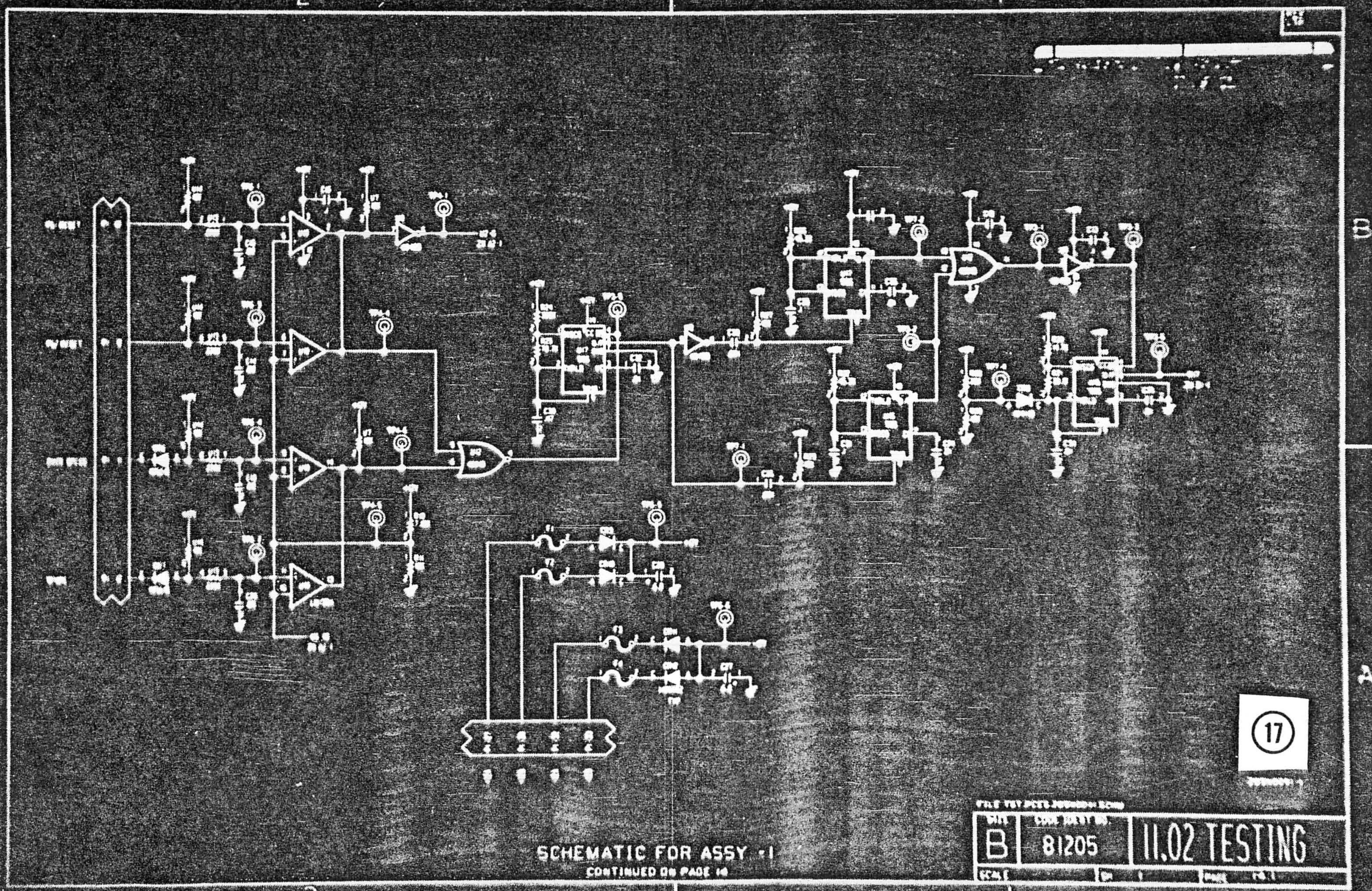


SCHEMATIC FOR ASSY -1

CONTINUED ON PAGE 16

757 Tubend

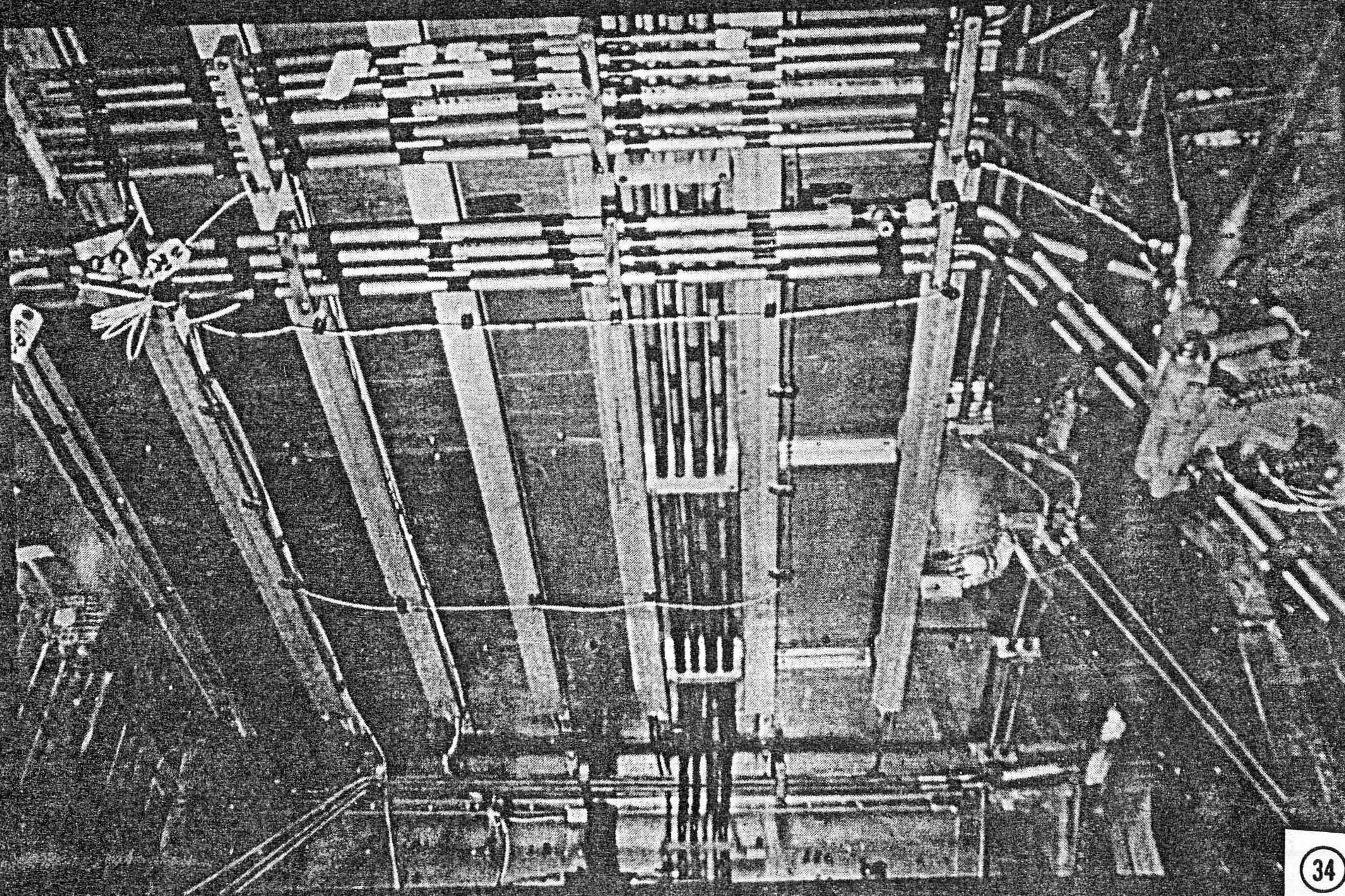
757 Tubend

WHAT IS IT?

TUBEND is a Computer Graphics Assisted System which INTEGRATES the Entire Process for HYDRAULIC SYSTEM DESIGN, Drafting and CAM Interface.

- Supplies Data for Design Judgment and Decisions
- Supports Rapid Design Iterations—Layout/Analysis
- Automates: Drafting
  Standards Selection
  CAD/CAM/APL/Interface

757 Main Wheelwell Mock



Tubend

OPLINE

An analysis system for determining the smallest, lightest tubing capable of maintaining satisfactory pressure and flow requirements to equipment under flight conditions.

THERMO

An analysis system for determining accurate high and low operating temperature ranges and aerodynamic heating effects.

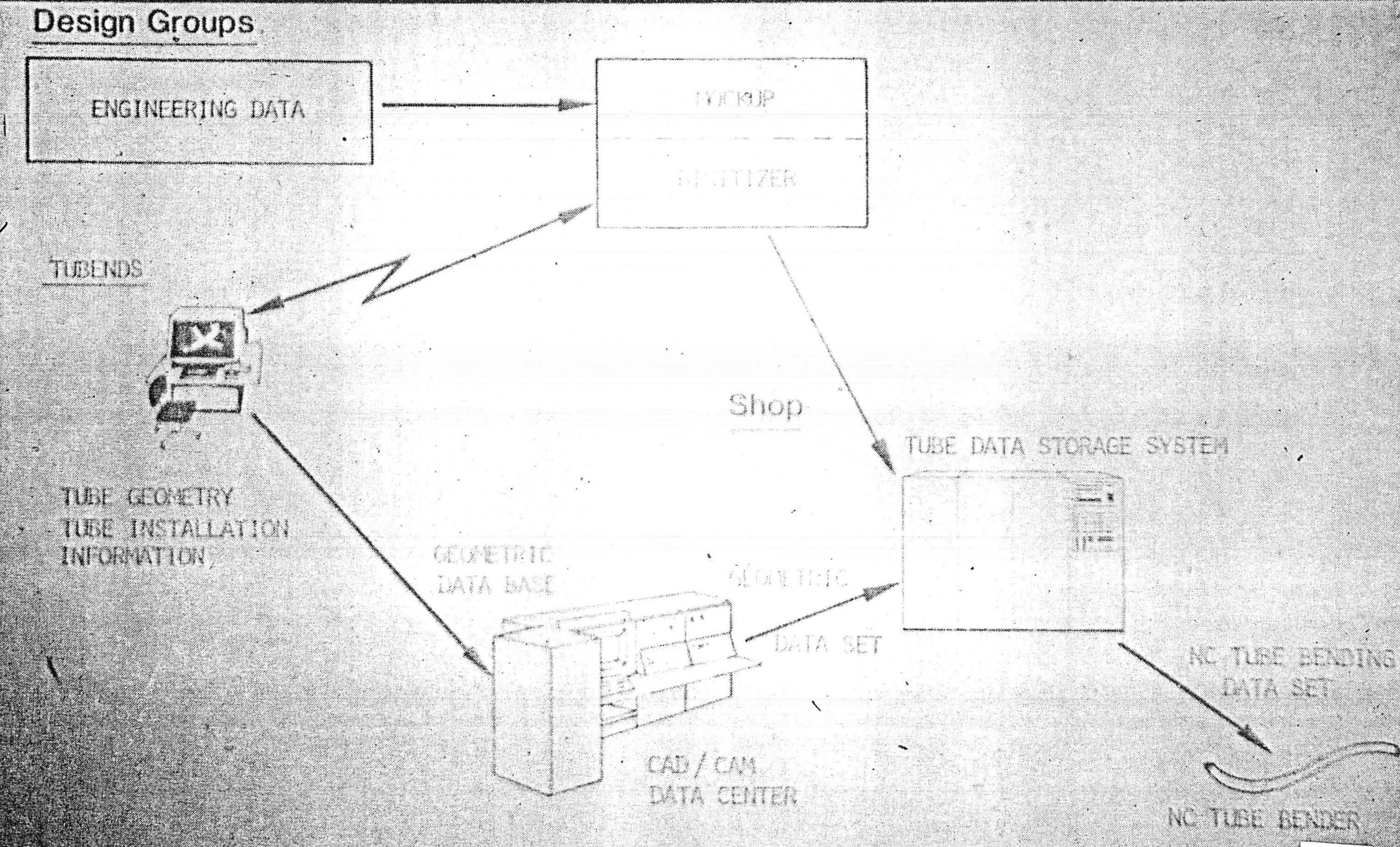
PRESSURE DROP

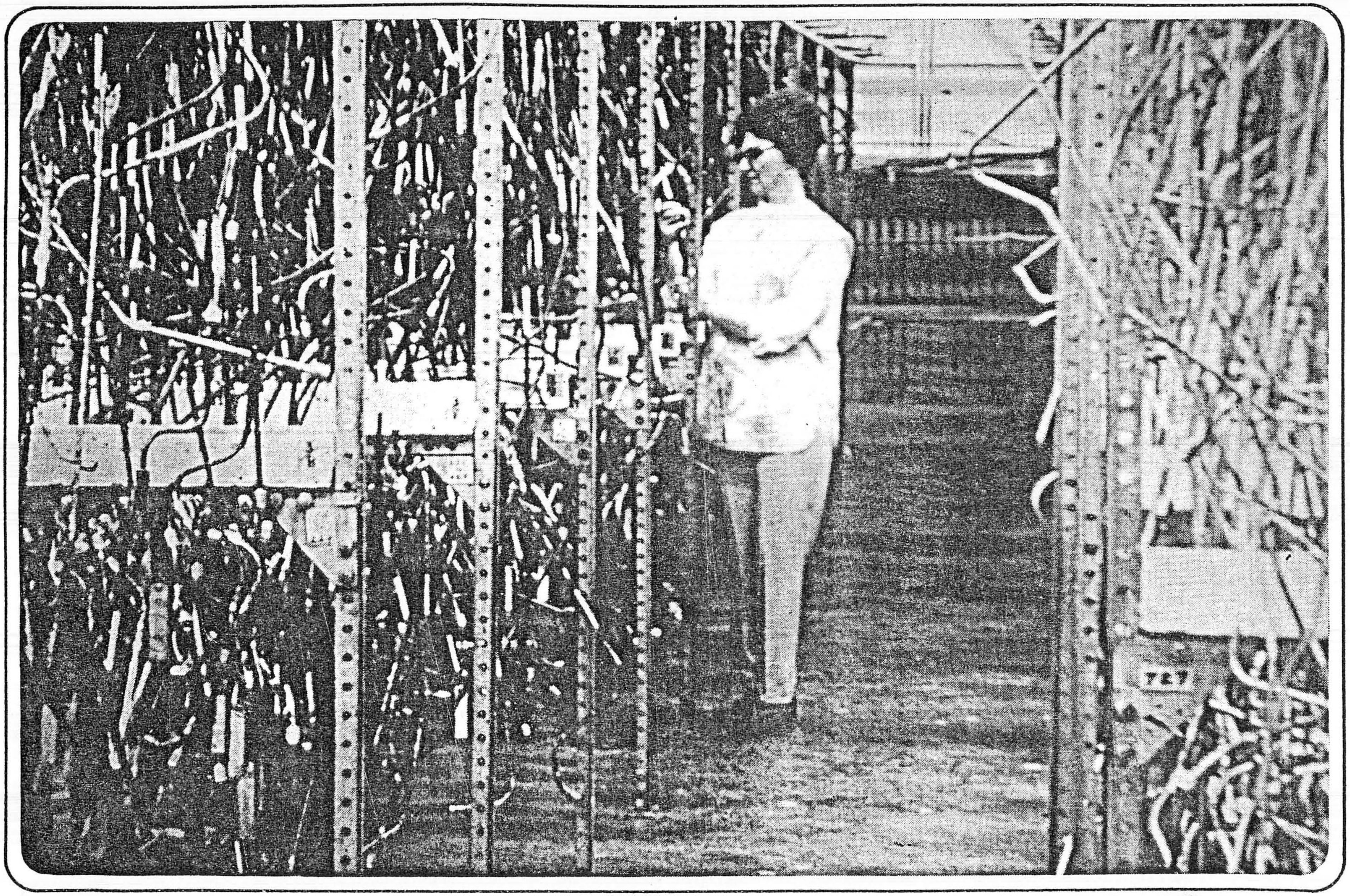
An analysis system which defines design parameters such as tube length, branch and/or sub-system in relation to operating conditions.

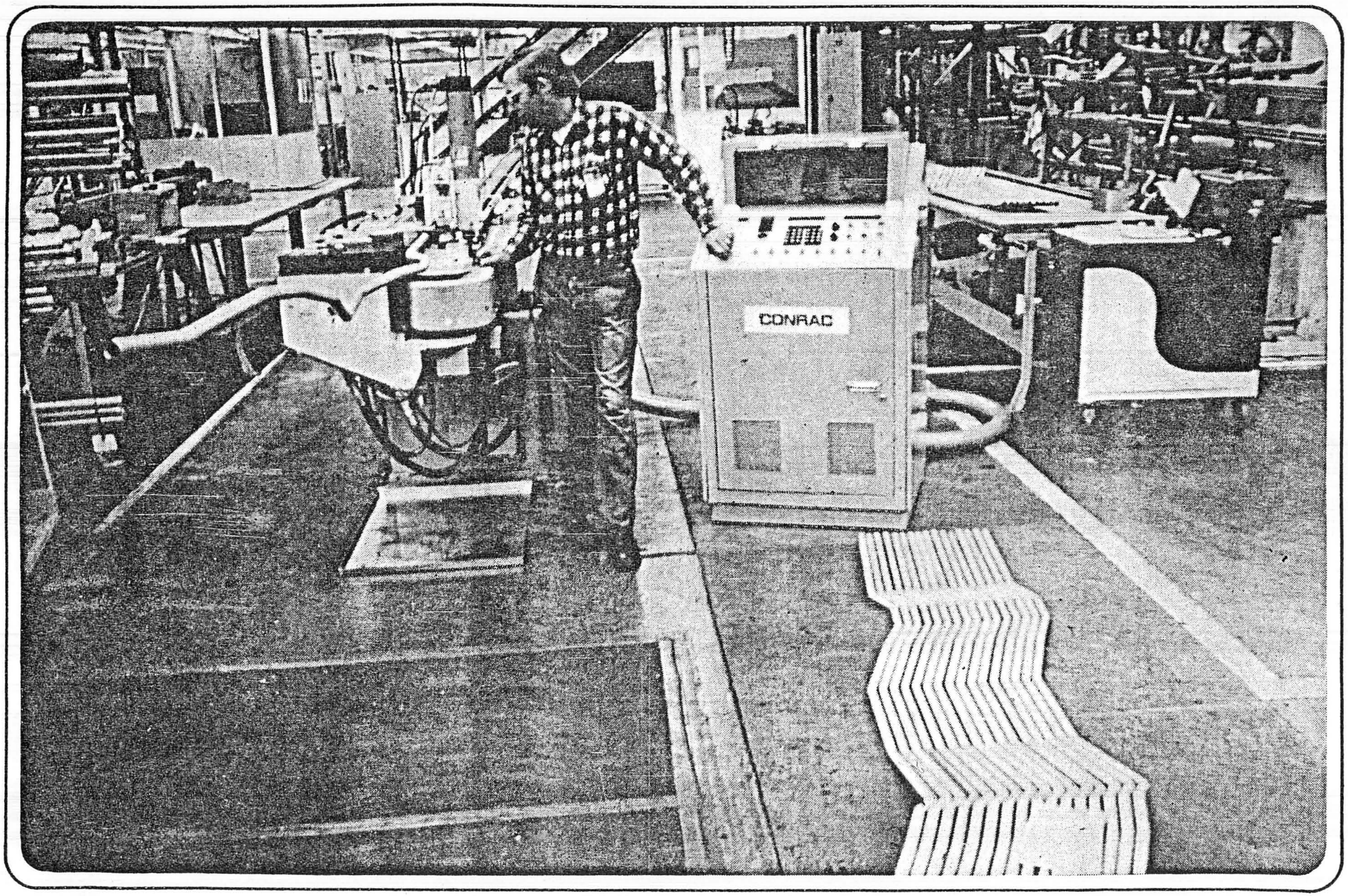
STRESS ANALYSIS

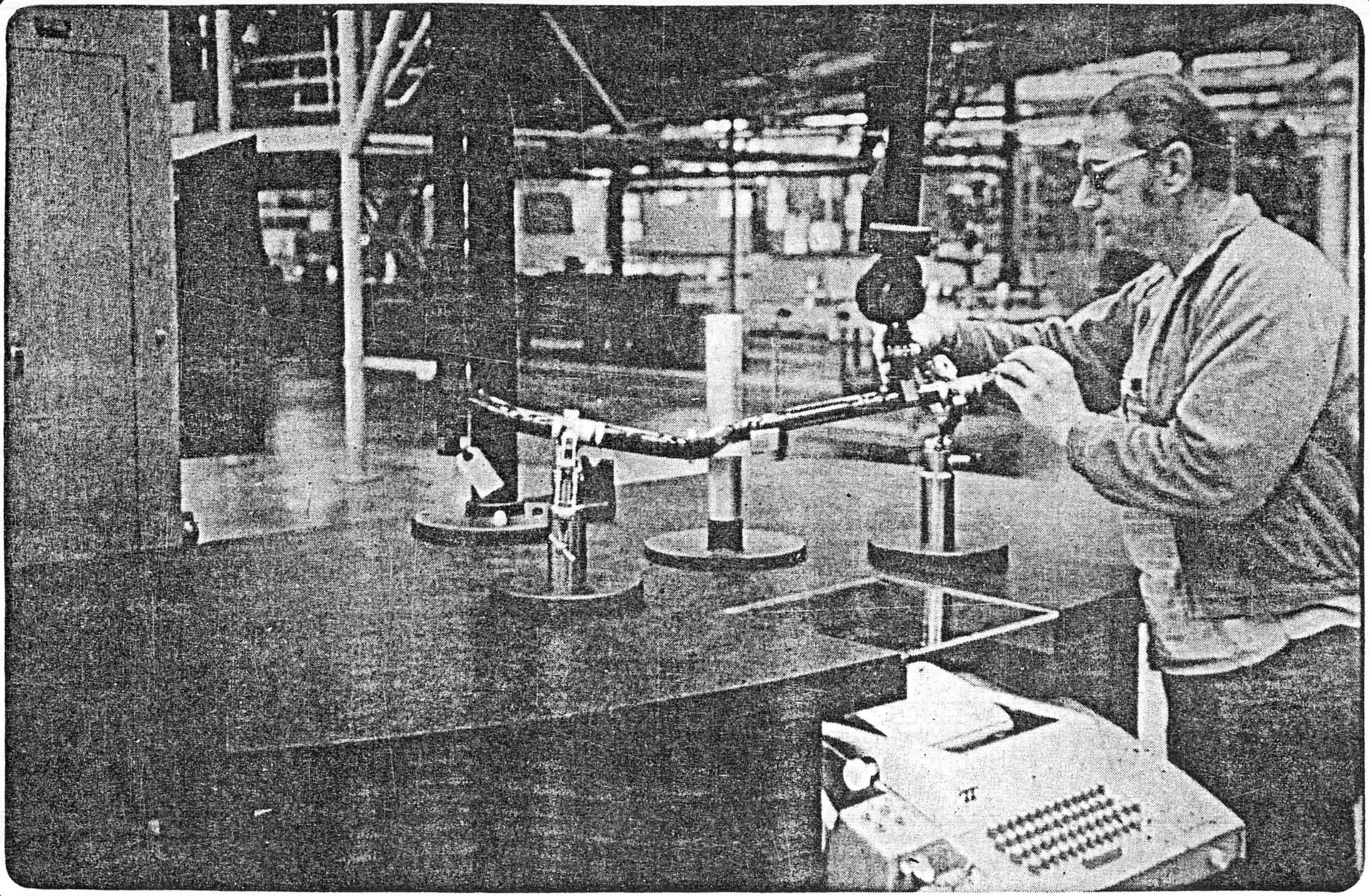
Finite elements of the stress analysis module will account for tube tolerance, deflection and vibration for fatigue evaluation.

TUBING FABRICATION DATA FLOW






CONRAC



Use of the Tubend System Aids...

ENGINEERING

Allow engineering to assume full responsibility for tube design and installation:

- Ultimately eliminate sample tubes
- Generate tubing APL without card, tape or manual input
- Simplify engineering drawing control for customer variables and derivatives

MANUFACTURING

Use class II tube development time to accomplish digitizing of tube coordinates:

- Reduce class III tube development time by use of data sheets

PRODUCTION

Significantly reduce remake of tubes during proof fit on the first production airplane

Define real tube tolerance for installation

SERVICE

Increase service of life of tubing installations through in-service stress reductions