INSTANT MODULAR 3D MOCKUP FOR CONFIGURING

CONTROL AND DISPLAY EQUIPMENT

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INTRODUCTION

A reusable modular 3D type mockup for use in the layout of control and display equipment has long been required in human factors work. The design of operational hardware, in many cases, seldom reflects the use of design standards and guides which human engineering specialists have developed over a period of many years (1 through 11).

In the conception, design, acceptance, and fabrication of control and display equipment, a definite sequence of activities takes place from the conception of a system to the fabrication of the first working model. Figure 1 illustrates an abbreviated equipment development life cycle, depicting the "popular method"* and the "effective method."* The "popular method" is one of expedience and is the procedure customarily used in the design and development of display and control equipment. The military was instrumental in incorporating this mockup method as a prerequisite in the design and development of all military hardware from weapon systems to aircraft, and is still enforcing use of mockups by writing requirements into contracts and specifications.

In the "effective method," a versatile mockup is used to insure better compliance with human engineering design principles and increase the probability of an acceptable end product from the user's viewpoint. The author feels that this method has the greatest payoff potential in terms of economy and operator acceptance.

The important difference between the two methods is that the effective method uses the mockup in conjunction with operator acceptance before the start of the detailed equipment design, whereas, the popular method uses the mockup after the preliminary equipment design which later usually requires changes.

The three objectives of this paper are to:

(1) Describe the important facets of a 3D modular mockup developed at the NASA-Ames Research Center.

(2) Illustrate the utility of the 3D mockup for configuring control and display equipment, and

(3) Point out the specific advantages of using the 3D mockup concept properly in the control and display equipment development cycle.

Although the description, effectiveness, economics, and role of the 3D modular mockup will receive major emphasis in this paper, the specific advantages of using the 3D mockup type concept properly in the equipment life cycle will be detailed in the final portion of this paper.

*Names given by the author.

The Need for the Development of the Modular 3D Mockup.

In the development process of control and display equipment it has been known that the designers have little or no knowledge of, or disregard, or they concoct human engineering standards and guides. Recent studies have again brought this fact into focus (12,13). These studies show that the designers had divergent rank ordering of operational contingencies and acceptability in equipment design from that of the user-developer of an operational system with human engineering background. It was shown that the designers had little or no interest in human factors information or in the incorporation of human factors design criteria in the design and development of equipment. An enormous quantity of basic human factors data is generated yearly and the professional people involved in this field are generally knowledgeable about the data and specifically knowledgeable of data in their specialized nitch of endeavor. The problem exists mainly in the dissemination and communication of data to the designers of equipment and/or systems who are not aware of the existing data, not involved with the human factors field and thus do not use the existing useful data. This failure to use existing human factors information in the design of equipment involving a man machine interface is costly and, in extreme cases, can cause the loss of lives.

To generate useful basic data is not enough. One must be ingenious enough to go a step further and devise means of automatically forcing the use of existing data in the design or development task.

Characteristics of the Modular 3D Mockup.

Development of the 3D Mockup.

A modular 3D mockup technique was developed in 1966 as a method for forcing (automatically) some of the human engineering design constraints (e.g.: optimum reach, height, viewing and control limits, etc.) in the design of control and display equipment. A collection of existing human factors anthropomorphic data from available sources (1 through 11) was consolidated, and the results showing optimum ranges and dimensions for equipment operators in the shirtsleeve condition are provided in Figures 2 to 10.

Figure 2. Recommended Console Dimension and Viewing Angles

Figure 3. Recommended Console Dimensions and Panel Angles

Figure 4. Manual and Visual Parameters for Seated Console Operation - Top View

Figure 5. Optimum Visual and Control Areas in Relation to "See-Over" Console Dimension Requirements - Top View

Figure 6. Wrap-Around Console Dimensions for Seated Operation

Using the results in these figures as a design guide, the modular 3D mockup design was developed by the author and Mr. Donald Bean of Formetrics and the mockup was fabricated by Formetrics of Palo Alto, California.

Integral Parts of the Modular 3D Mockup.

The parts for the modular mockup (see Figure 11) consist of the following items:

(1) Console base cratings 25" high × 26-1/4" deep × 21" wide with 2" adjustable legs.

(2) Console overhang writing shelf, 4 types; single bay, three bays, five bays, and wrap around five bay.

(3) Side panels for base 21.87" × 28".

(4) Front and back panels for base 21.87" × 19-1/4".

(5) Side panels for top panel crating 10-1/2" × 20.87", 5-1/4" × 20.87", 26-3/4" × 20.87".

(6) Panel tops 19-1/4" × 20.87".

(7) Panel tops (end) 20-1/4" × 20.87".

(8) Panel tops (front) 5-1/4" × 19-1/4".

(9) Small 38^{o} 7.12" × 8-3/4" × 5-1/4" × 19-1/4" panel cratings.

(10) Large 67^{o} 17-3/4" × 7" × 16-1/4" × 19-1/4" panel cratings.

(11) Small 5-1/2" high × 19.87" deep × 19-1/4" wide panel cratings.

(12) Large 10-3/4" high × 19.87" deep × 19-1/4" wide panel cratings.

(13) Small 8-3/4" high × 19" long × 1/4" thick metal panels.

(14) Small 5-1/4" high × 19" long × 1/4" thick metal panels.

(15) Large 10-1/2" high × 19" long × 1/4" thick metal panels.

(16) Large 17-1/2" high × 19" long × 1/4" thick metal panels.

(17) Various magnet backed controls and displays.

(18) Snap on fixtures for the side panels.

(19) Wing nuts, screws, clamps, and bolts.

(20) Storage cabinets with castors.

Figures 12 through 15 illustrate some of the configurations which can be assembled. Figure 12 shows the 1 bay and 3 bay console with different panels, sloping at angles within the desired limits of human engineering design criteria. In Figure 15, the five bay wrap around configuration is shown with a set of side panels (blinder-partition) placed between the first and second bays, and the fourth and fifth bays. This design eliminates the odd shape panel area which would be required between these bays if the side panels were not present, and facilitates greatly in the designing of any wrap around control console.

The panel face and bay sizes were designed to available standard off-the-shelf chassis and enclosure equipment sizes. The panel and bay heights were also based upon standard off-the-shelf equipment dimensions in multiples of 3/4 inch.

The mockup control and displays are actual hardware or face replicas to scale (e.g.: Micro Switches, T.V. Monitors, Rototell Lites, G.E. Meters, Raytheon Knobs, etc.) with magnetic backing, which enables the control and display hardware to be attached easily to the metal panel facing.

Other items used with the 3D modular mockup are the instant lettering (press-on type), adhesive black tape 1/8", 1/16" (for bracketing), and a Polaroid camera for recording various configurations.

Mockup Functions.

The modular 3D mockup was developed to fulfill the following functions:

(1) To provide means for facilitating the layout of control and display equipment economically and expeditiously.

(2) To act as a catalyst in designing-developing equipment that is more compatible with the optimal operational capabilities of man.

(3) To provide means for 3D presentations of control and display equipment in the design stage, using a building block-Erector Set type operation.

(4) To incorporate human factors anthropomorphic data (design criteria) automatically into all equipment configured with the modular 3D mockup.

(5) To help determine the degree of complexity involved in an operator's tasks-operations, and locate weak operational links in the equipment design by performing simulated operations with the mockup.

(6) To help increase operational reliability by having the user suggest design inputs that are acceptable to his operational capabilities and requirements.

(7) To aid in the systemization of operational contingencies of the equipment being designed.

(8) To encourage the use of standard dimensions, parts, fabrication design, etc., and keep within the original design limits.

(9) To function as a reusable design tool that is flexible in application, with interchangeable parts, easy to assemble, and without need for assembly tools.

Use of Mockup in the Design of Control and Display Equipment.

The Process of Designing Control and Display Equipment Using the 3D Modular Mockup Method.

Control and display equipment design using the modular mockup method requires that the individual designing the equipment be familiar with the operating procedure sequence, or is an operator for the equipment to be designed (e.g.: pilot, navigator, radio operator, sub controller, computer operator, etc.). A cooperative effort of both the designer and operator can also be made.

The general overall length, width, and height of the equipment are determined from the number of control and display functions the equipment must support and other constraints (e.g.: how many display and control items must be placed on the equipment?, what are the internal chassis and external panel sizes of these controls and displays?, how many operators will monitor the equipment?, how large or small a facility area will the equipment be placed in?, etc.). Once the overall physical size of the equipment is determined, panel crating modules are aligned one on top of another to the desired height, and other modules are placed side by side until the desired length is reached. Then, panel facings are fastened onto the crating vertically or with a sloping panel. (The built-in panel angles are within human engineering design criteria purposely to prevent the designer from deviating from optimal anthropomorphic limits.)

The time required for mocking up control and display equipment from the modular 3D mockup and parts is minimal compared to other mockup methods, because detailing of parts and dimensions are not required in this set up process. They are all built into the parts. For example, the time required to set up the console shell configuration shown in Figure 13 was 8 minutes.

From this general point in the equipment development cycle, the design strategy must become specific and involves the operational sequence, functional analysis, and operator contingencies. Once the operational sequence has been established the magnetized control and display pieces are placed on the equipment in locations based on link analysis, flow of operational procedures, and/or ease of operation. When the control and display pieces are placed suitably on the equipment panel, bracketing and lettering may be added. (The most time consuming and costly process involved with the modular 3D mockup method is the lettering of the panels, controls, and display hardware replicas with pressure sensitive letters.) A Polaroid camera is then used to take pictures of the mockup configuration which will be used later by the detail designer to draw specific dimensions, and to determine electrical wiring requirements, component weight distribution, power requirements, etc.

After the set of pictures is taken, the magnetic control and display hardware or the mockup can be rearranged to alternative design configurations for the same operation, and pictures taken of each new configuration. A comparative analysis of the different configurations can then be made by the designer and operator to determine the optimal design.

When the configuration selection has been completed, the 3D mockup kit parts can be stored in the 3 storage cabinets (see Figure 16) and rolled away to another area requiring the use of the mockup kit.

Mockup Application on a Centrifuge Control Console Design.

In configuring the centrifuge control console for the 50g centrifuge at Ames, the aforementioned process described in using the mockup kit (e.g.: link-analysis, operational flow, etc.) was used by both the author and the centrifuge operator. A set of centrifuge control console layouts were configured independently by the author and the operator. Then each participant selected a single configuration which he considered optimal from his set of layouts. The two configuration pictures were then compared and analyzed as to the design philosophy and adequacy of fulfilling the operational requirements. Since the individual console layouts were almost identical, it facilitated the development of a combined final configuration with minor modifications (see Figure 17).

The parts of the design which were not identical were the location of the emergency stop switch and the placement order of the roll, pitch, yaw, horizontal and vertical controls, and displays. The emergency stop switch located in the "operate start-stop" switching area of the operator's configuration was relocated to the bottom right hand corner of the console with a small hinged plastic cover on top of the switch to prevent possible activation of the emergency stop during normal operations.

The placement order of the roll, pitch, yaw, horizontal and vertical controls and displays were changed on the author's design (even though it reflected the operational procedure that was given to the author) because the design did not take into account a preoperational checkout-maintenance task. Finally, the design of the console shown in Figure 17 was shown to others involved in equipment selection for the centrifuge and found to be acceptable as a design to be considered for fabrication.

DISCUSSION

Historically, the mockup of a prototype enters into the equipment development during the design phase, after acceptable design drawings have been generated by the manufacterer. (See Figure 1.) The mockup in the "popular method" is used for design evaluation, critique, analysis, modification, etc., undoubtedly ending in a requirement by the user-operator, customer, etc., to have the manufacturer generate a better design which would be a "little more acceptable." This design change creates a voluminous amount of work in the modification of detail design, specification, reliability, administrative and manpower areas. Once an acceptable design mockup is fabricated, the equipment design proceeds to the production model. At this time, the mockups are usually discarded or reused as a promotional display, if salvageable.

In the "effective method" the 3D modular mockup is used as a tool early in the development cycle (after an operational concept has been established) for facilitating decisions on acceptable control and display equipment design. Acceptance problems are always present with any item whether it be food, equipment, ideas, or procedures. But of main concern here is the acceptance of a design early in the equipment development cycle so that costly modifications in design will not be requested after parts have been cut, equipment dimensions configured, drawings finalized, operational hardware ordered, etc. If such a design change occurs, the time and money lost to compensate for the required design change would more than pay for the cost of a 3D modular type mockup kit. In order to minimize such "happenings" the modular mockup kit should be used as a device for letting the equipment user, or buyer, suggest possible design features they would like to see incorporated into the equipment design. By permitting the user-buyer to rearrange the magnetized control and display hardware pieces and the panel modules into a "little more acceptable" design, it greatly increases the final equipment acceptance probability. At the same time this procedure facilitates design, reduces production time, and minimizes modifications. It is generally accepted that one is more apt to accept an item with which he is familiar or which has incorporated his inputs, than with those items which have not had the benefit of his inputs or with which he has had no personal association (14).

In the fabrication of the 3D mockup module kit, consideration was also given to panel facing light reflectance angles from different light sources of the working environment (i.e.: ceiling, walls, above working position, etc.). (See Figure 18.) However, the reflectance problem with glass display surfaces no longer appears to be a problem with present day technology. Surface reflectance has been decreased to less than 2% and transmittance, through glass, to better than 96%. (The effectiveness of coatings on glass is somewhat affected, though, by light from different angles of incidence.)

The importance of having the operational control and display equipment in a properly illuminated operational environment was also realized, therefore, a working environment illumination requirements guide was compiled (see Table I) (1,2,3,8,9,10,15) to minimize any possible washout effects of displays, and to help provide proper surround illumination for maintaining acceptable contrast ratios of the displays, etc.

There is a final point that can not be left unsaid. That is this - when austerity occurs in any design or developmental contract or during contract negotiations, one of the first efforts usually to be considered for omission from the proposed total effort is the human factors mockup effort which is erroneously regarded as something like the deluxe trim package for cars. One could live without it and should be considered only when extra monies are available. This stigma on the usefulness of mockups is very much in error in certain industrial practices. Persons requesting the deletion of a mockup effort are not truly cognizant of the value of mockup design analysis. The value of the mockup effort involved in the design analysis is expensive initially but money saving in the long run. The immediate impact of the usefulness of the mockup design analysis are not plainly visible, and the long lasting or economical effect can not be fully appreciated until it has been evaluated in use. Shortcomings in design, equipment size, possible operational sequencing problems, etc., which may not be readily visible on paper and pencil analysis, may standout in mockup methods, saving the customer the time and design modification costs, etc., that can easily cost more than the mockup effort.

A general summary on the usefulness, costs, advantages, disadvantages, etc., of different mockup methods are compared in Table II.

SUMMARY

The modular 3D mockup technique has been demonstrated to be the middleground between the user and the designer of the equipment. The mockup method helps the designer to see easily, without operational knowledge, what the operator is trying to convey.

The modular 3D mockup method is:

(1) An effective and a necessary communication link between the user and designer in developmental design of equipment.

(2) Versatile in application.

(3) Flexible in configuration and design.

(4) Economical in cost, and

(5) A time saver in design development compared to other mockup methods. A new technique, such as the latest vacuum formed mockup method (16), is too involved for each mockup process, limited in specific use, costly in operation, etc.

There is no limit to how this mockup method could be used (e.g.: aircraft instrumentation panels, computer control consoles, home appliance control panel, car-boat-sub-tank control areas, radio-radar equipment, etc., see Figure 19) saving time and money in the design and development process.

There also exists a great potential with this 3D mockup kit. That is, the kit itself can be made an economical source (library) of the state-of-the-art magnetized controls and displays, which can greatly facilitate the updating or the future planning of control and display systems-equipment.

This modular 3D method should become one of the permanent tools for the designers, operators, and human factors engineers involved in the design and development of control and display equipment.

REFERENCES

1. Woodson, W. E., Conover, D. W.: Human Engineering Guide, U. C. Press, Berkeley, Los Angeles, 1964.

2. Morgan, C. T., Chapanis, A., et al.: Human Engineering Guide to Equipment Design, McGraw-Hill Book Co., Inc., New York, 1963.

3. Tufts College, Handbook of Human Engineering Data, 1 November 1952.

4. NASA SP-3006, Bioastronautics Data Book, U. S. Printing Office, Washington, D. C., 1964.

5. Damon, A., Stoudt, H. W., McFarland, R. A.: The Human Body in Equipment Design, Howard University Press, Cambridge, Mass., 1966.

6. McCormick, E. J.: Human Engineering, McGraw-Hill Book Co., Inc., New York, 1963.

7. Dreyfuss, H.: The Measure of Man Human Factors in Design, Whitney Library of Design, 1960.

8. Military Standard 803A-3 (USAF), Human Engineering Design Criteria for Aerospace Vehicles and Aerospace Vehicle Equipment, 25 January 1966.

9. AFSCM 80-3 (USAF), Handbook of Instructions for Aerospace Personnel Subsystem Design (HIAPSD), 15 July 1966.

10. Marshall Space Flight Center, MSFC Standard 267A (NASA), Human Engineering Design Criteria, 23 September 1966.

11. Anatometer, Anatometric Associates, Rochester, New York, 1958.

12. Meister, D., Farr, D. E.: The Utilization of Human Factors Information by Designers. Paper presented at 10th Annual Meeting, Human Factors Society, Anaheim, California, November 1966.

13. Meister, D., Farr, D. E.: The Methodology of Control Panel Design. Final Report AF33(615)-1350, Bunker-Ramo Corp., Canoga Park, California, 1965.

14. Price, H. E., Kubokawa, C. C.: Pilot Acceptance Factors in the Development of All-Weather Landing and SST Navigation Systems. Paper presented at IFALPA Symposium, Rotterdam, The Netherlands, October 1965.

15. Westinghouse, Lighting Handbook, Bloomfield, New Jersey, June 1961.

16. Deats, C. V., Nielsen, G.: Construction of Vacuum-Formed Control and Display Mockup Panels, AMRL-TR-66-175, November 1966.

TASK-AREA	ILLUMINATION LEVEL	LIGHTING EQUIPMENT
DIM OUT, READING CRT DISPLAYS	2 FOOT-CANDLES MAXIMUM	RHEOSTAT CONTROLLED LIGHTING WITH 2 FOOT-CANDLE LEVEL MARKED
VIEWING ROOMS	5 FOOT-CANDLES MINIMUM	RHEOSTAT CONTROLLED LIGHTING WITH 5 FOOT-CANDLE LEVEL MARKED
HALLWAYS, STAIRWAYS, STOCK ROOMS, WASH ROOMS, STORAGE AREAS, POWER PLANTS, SERVICE-SUPPORT AREAS	10 FOOT-CANDLES MINIMUM	GENERAL LIGHTING, INITIALLY ADJUSTED
READY ROOMS, LAUNCH CONTROL FACILITIES PROLONGED MONITORING, GENERAL OFFICE, CONFERENCE ROOMS, NORMAL DETAIL WORK.	20-50 FOOT-CANDLES	GENERAL OVERHEAD LIGHTING, INITIALLY ADJUSTED TO LEVELS BETWEEN RECOMMENDED ILLUMINATION LEVELS
FINE DETAIL, CRITICAL DESK WORK, DRAFTING ROOMS, TELETYPE ROOMS, CLASSROOMS, TELEMETRY READOUT AREAS, CRYPTO AREA, FAIR CONTRAST, SPEED NOT ESSENTIAL, CONTROL AREA NOT REQUIRING LOW INTENSITY LIGHTING	50-100 FOOT-CANDLES	GENERAL LIGHTING PLUS SUPPLEMENTARY LIGHTING IF NECESSARY, HOMOGENOUS DIFFUSE LIGHTING WITH RHEOSTAT CONTROL (LUMINOUS CEILING)
DATA AND COMPUTER AREAS, TELEVISING OF EQUIPMENT AND MESSAGES, SMALL DETAIL, VERY DIFFICULT AND PROLONGED VISUAL TASKS WITH OBJECTS OF LOW BRIGHTNESS CONTRAST, HIGH SPEED AND ACCURACY ESSENTIAL	100 FOOT-CANDLES OR MORE	GENERAL LIGHTING (HOMOGENOUS DIFFUSE LIGHTING WITH RHEOSTAT CONTROL) PLUS SUPPLEMENTARY LIGHTING AND SPECIAL LIGHTING FIXTURES AS REQUIRED

Table I. Working Environment Illumination Requirements.

TABLE II

Item Compared / Type of Mockup	Paper Pencil	Cardboard	Wooden	Modular Wooden Magnetic	Functional Working	Breadboard Prototype	Vacuum Formed Plastic
Costs	Very low	Low	Medium	Initial cost high but cheap in the long run because of reuse capability.	Very high for single use. May be used for operational validation.	Higher than production model because of design time required.	Initial cost very high. Cost of mockup panel making operation remains high because of special machining work required for each new design.
Reuse Capability	No, mockup made for specific use.	Possibility but more likely disgarded because of low cost.	Possibility if use is made after design review (e.g.: sales-promotion, exhibit, etc.)	Can be used in design mockup of many systems using same and/or different type controls and display.	No, too specific in use.	No, too specific in use.	Possible if system is duplicated for other operations, otherwise NO! Very specific.
Time	Highly time consuming because of detail drawing and redrawing with every modification or iteration.	Highly time consuming if detail design is included.	Highly time consuming if detail design is included.	Least time required. Fastest of all mockup method because parts have been made prior to need.	Highly time consuming, more than wooden, cardboard type because detail design and functional-operational analysis is required.	Greatest time required of all mockup, more than production models.	Time consuming because molds must be constructed each time.

TABLE II - Continued.

Item Compared / Type of Mockup	Paper Pencil	Cardboard	Wooden	Modular Wooden Magnetic	Functional Working	Breadboard Prototype	Vacuum Formed Plastic
Flexibility	No, good only for specific original application.	Possible, but more than likely not because of cheap construction.	Possible, but more than likely not because not worth the effort and cost required to reclaim usable wooden parts.	Unlimited when applied to control and display work. Mockup can be used totally or in parts for various configurations.	Parts can be recovered for other design use, but unless following designs have only minor modifications of the original design, total mockup is unusable.	Parts can be used for other design use, but unless following designs require only minor modifications of the original design, total prototype breadboard is unusable.	Very little to none, operational controls and displays may be incorporated.
Applicability	Only to original design application.	Only to original design application.	To original mockup design application and other designs if wooden parts are salvaged. Sales display.	For desired use in any associated mockup work in control-display applications Astronautics Aeronautics Commercial products.	Limited to original design use, but working parts may be reusable for other design work. Sales display.	Limited to original designs but working parts may be reusable for other related design work.	Limited to original design promotional displays, instructional panels.

TABLE II - Continued.

Item Compared / Type of Mockup	Paper Pencil	Cardboard	Wooden	Modular Wooden Magnetic	Functional Working	Breadboard Prototype	Vacuum Formed Plastic
Special Tools Required	Paper, pencil, scale, lead, eraser, eraser, eraser, etc. required for each design.	Knife, tape, glue, tape measure, paint, etc. required for each mockup operation.	Hammer, saw, paint, tape measure, nails, etc. required for each mockup operation.	No hand tools required once modular parts built. Tape and press-on lettering, if desired.	Mockup dynamics, fabrication tools, control fidelity, working environment, operational equivalence.	Working dynamics, fabrication tools output-input fidelity, realistic operational requirements.	Mold, vacuum form machine, milling machine, saw, plastic, lettering, drill, heater, trimming machine.
Human Engineering Design Criteria To Follow	H.E. design criteria must be incorporated each time a design is drawn.	H.E. design criteria must be incorporated each time a design is mocked up.	H.E. design criteria must be incorporated each time a design is configured.	Not required for general equipment configuration. H.E. design criteria built in. Control and display placement determined by operational sequence, etc.	H.E. design criteria must be incorporated for each functional working mockup constructed.	H.E. criteria must be considered for each breadboard prototype design. Otherwise operational equipment may have design drawbacks and problems.	Must be incorporated for each design configured.

TABLE II - Continued.

Item Compared / Type of Mockup	Paper Pencil	Cardboard	Wooden	Modular Wooden Magnetic	Functional Working	Breadboard Prototype	Vacuum Formed Plastic
Advantages	Cheap, does not take up space.	Cheap, physical dimension represented to scale.	No real advantage other than physical dimension is to scale in 3 dimension. Sturdy construction.	No cost after initial cost, fast efficient mockup method, no dimension analysis required, single man use mockup kit. Changes in design at no additional cost. Accurate 3D presentation. Highly effective.	Working dynamics included within realistic operational mockup.	Working dynamics and physical dimension requirements become obvious.	Good, fast way for reproducing numbers of realistic panels that are identical.
Disadvantages	Time consuming design mockup dimensions must always be calculated and 2 dimensional view does not present possible design hangups.	Extremely limited in application, one shot operation. No salvageable parts unless next mockup is similar in design. Detailing time consuming.	Extremely limited in application, time consuming. Any design change could be major effort in construction.	Time consuming to add on rub-on lettering.	Extremely high in cost, time consuming, limited in application, contingent upon availability of operational parts, malfunctions.	High in cost, time consuming, limited in application, bulky in size, reliability of operational parts, etc.	Very limited in use, time consuming, unsalvable panel, involved in too many intermediate machining processes, restricted to small panel sizes.

TABLE II - Concluded.

Type of Mockup / Item Compared	Paper Pencil	Cardboard	Wooden	Modular Wooden Magnetic	Functional Working	Breadboard Prototype	Vacuum Formed Plastic
Aesthetics	Limited unless perspectives are drawn.	Not too much.	Present, if properly finished off.	Can be representative of final design-operational model.	Impressive, may be like final operational equipment.	Not impressive, not involved with aesthetics.	Impressive, can be representative of working model.

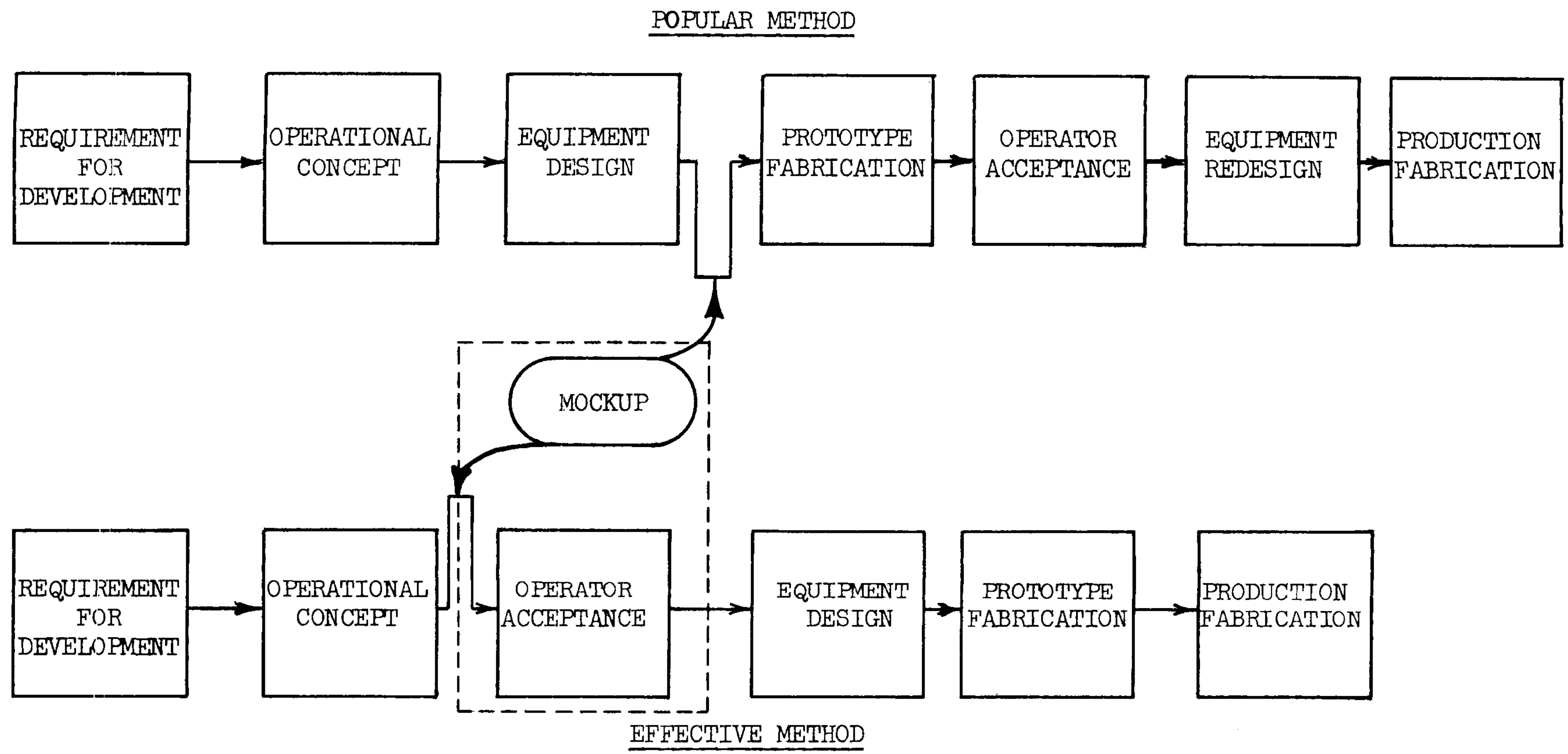

Figure 1. Abbreviated equipment development life cycle.

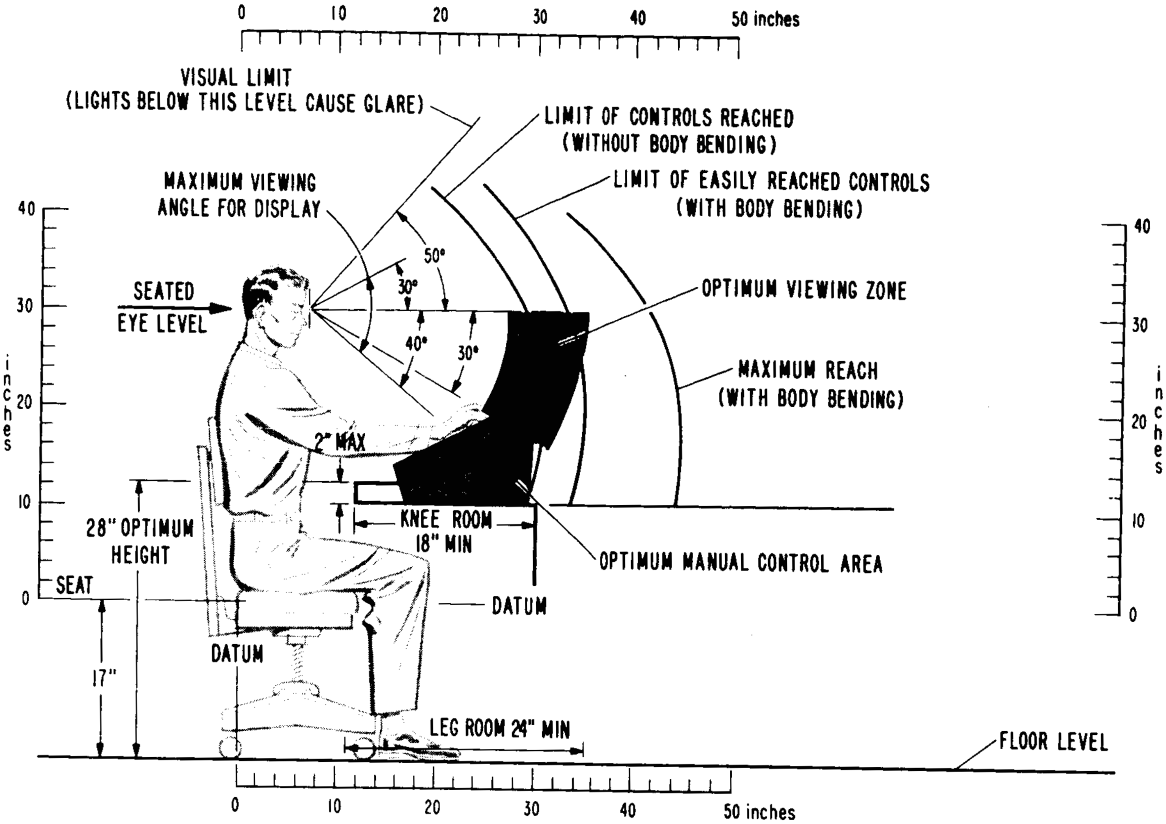

Figure 2. Recommended console dimensions and viewing angles.

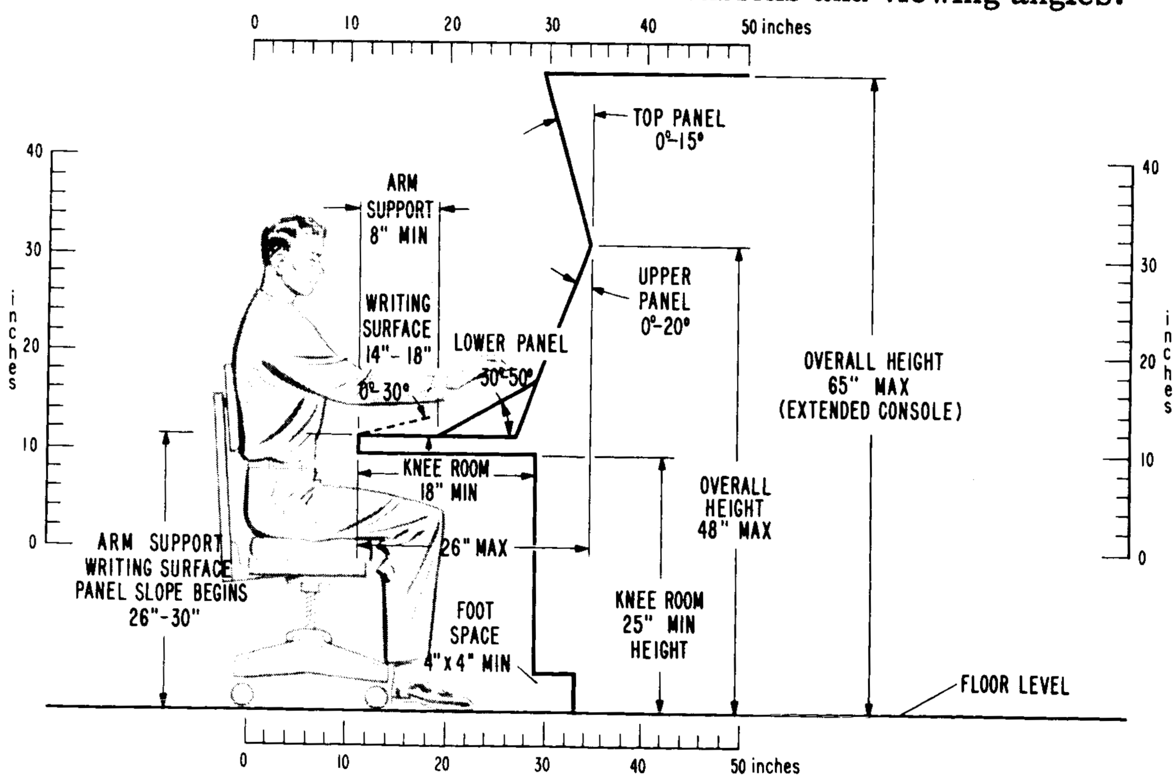

Figure 3. Recommended console dimensions and panel angles.

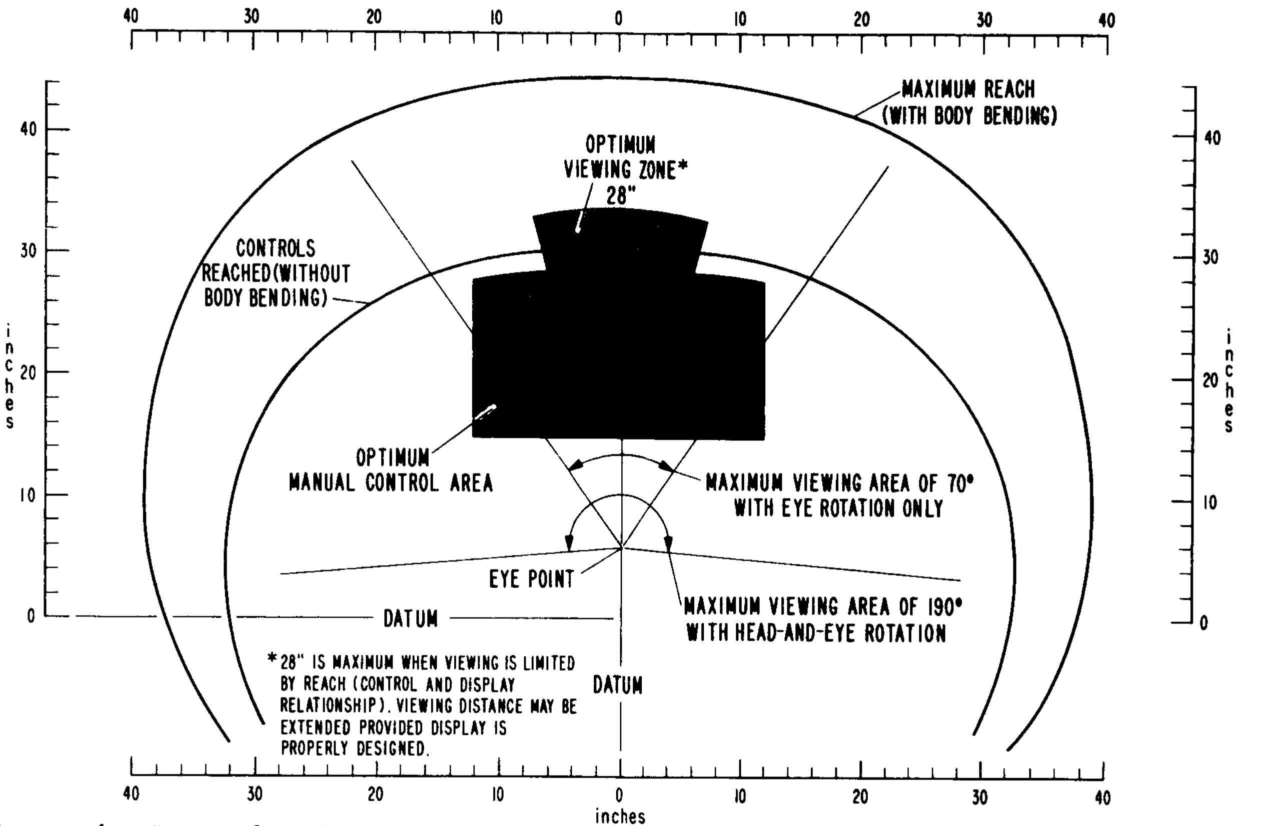

Figure 4. Manual and visual parameters for seated console operation - top view.

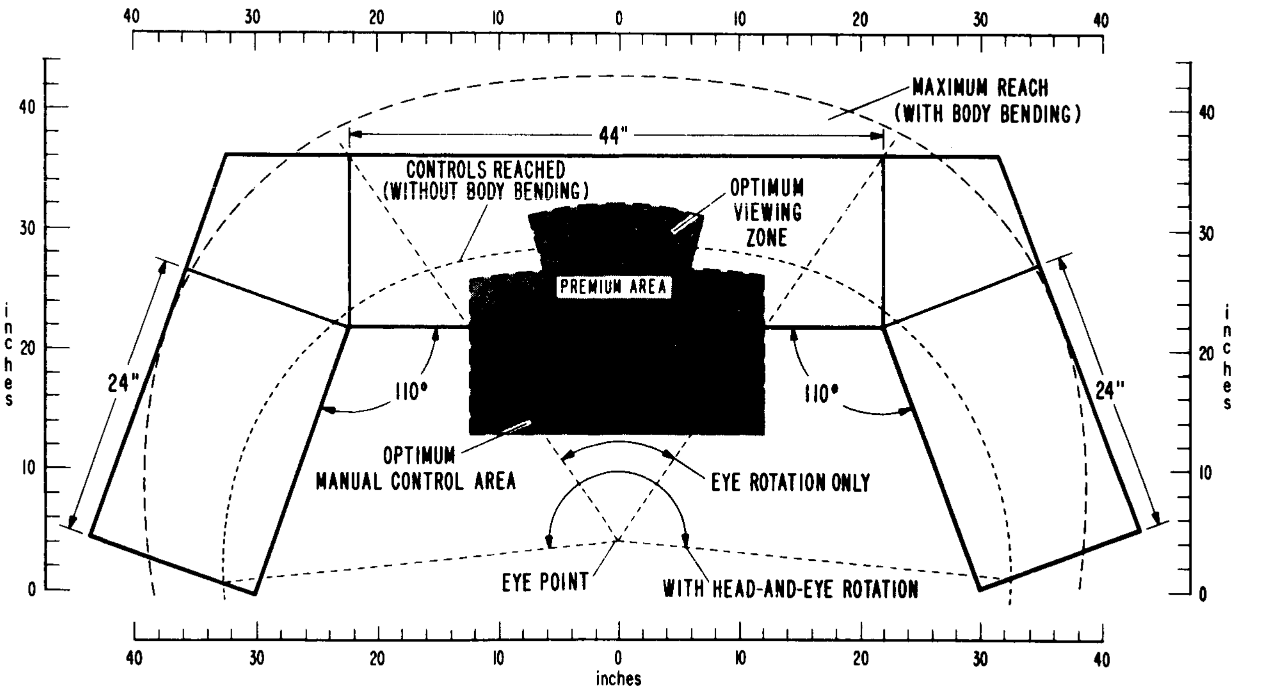

Figure 5. Optimum visual and control areas in relation to "see-over" console dimension requirements - top view.

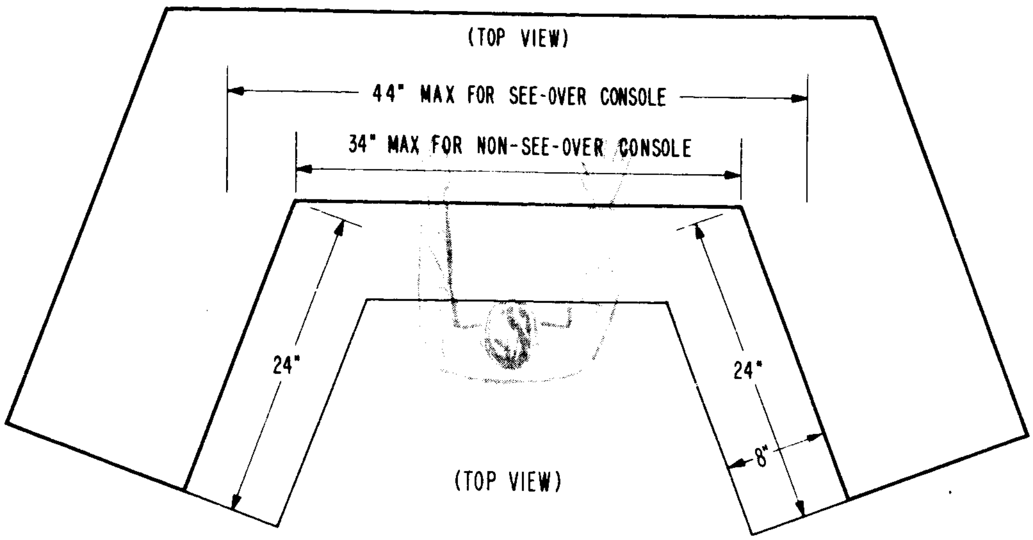

Figure 6. Wrap-around console dimensions for seated operation.

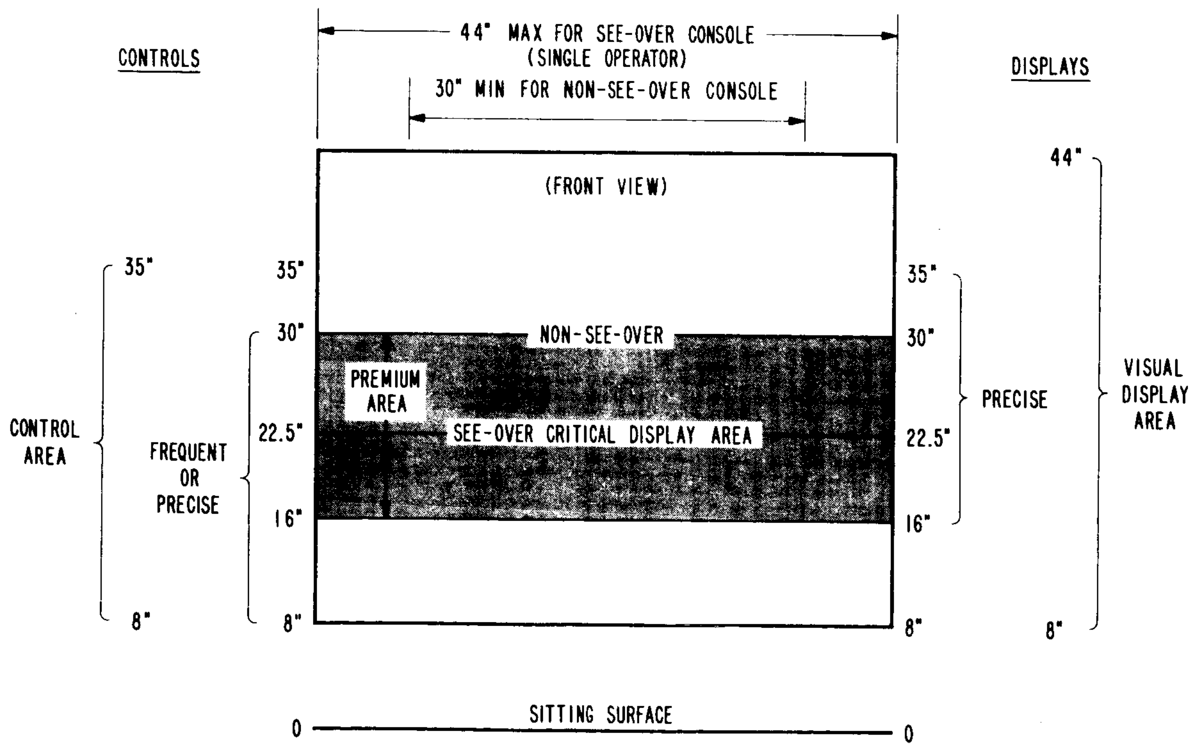

Figure 7. Vertical surface console dimensions for seated operation.

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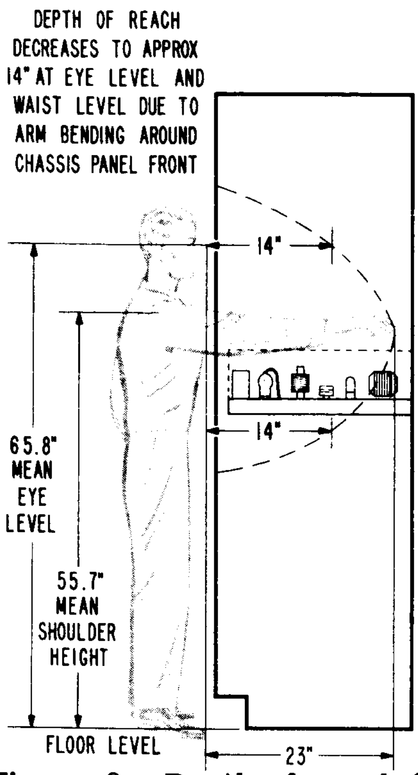

Figure 8. Depth of reach for 95% of population.

AAA494-2

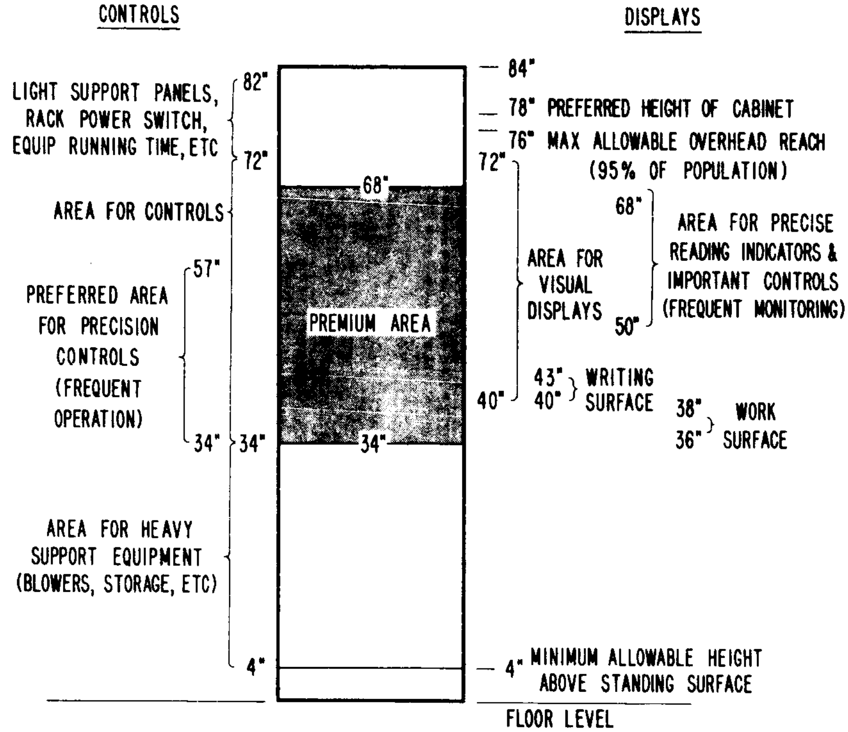

Figure 9. Instrumentation cabinet, panel area for standing operations.

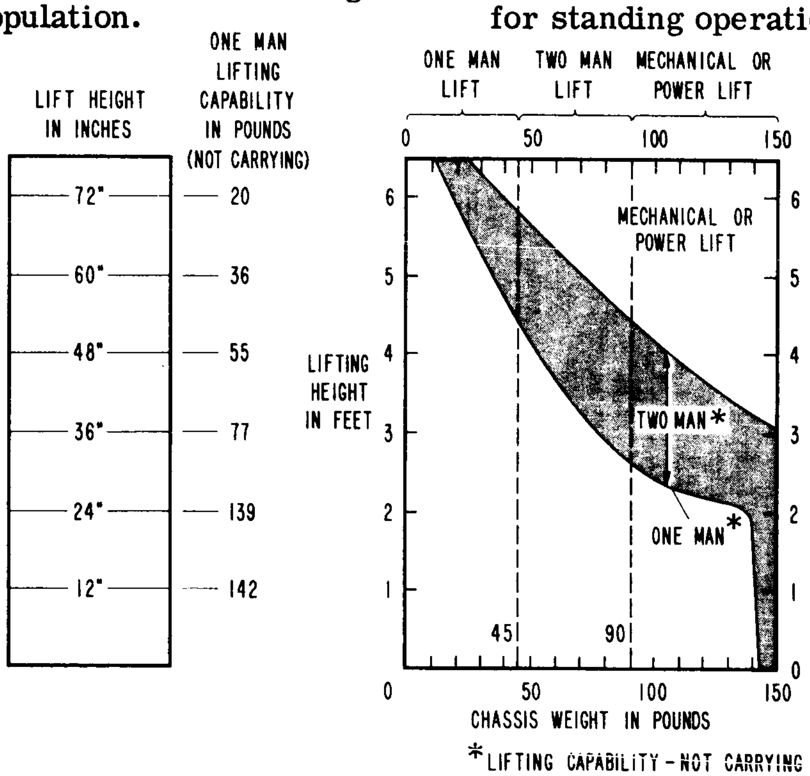

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Figure 10. Chassis weight distribution.

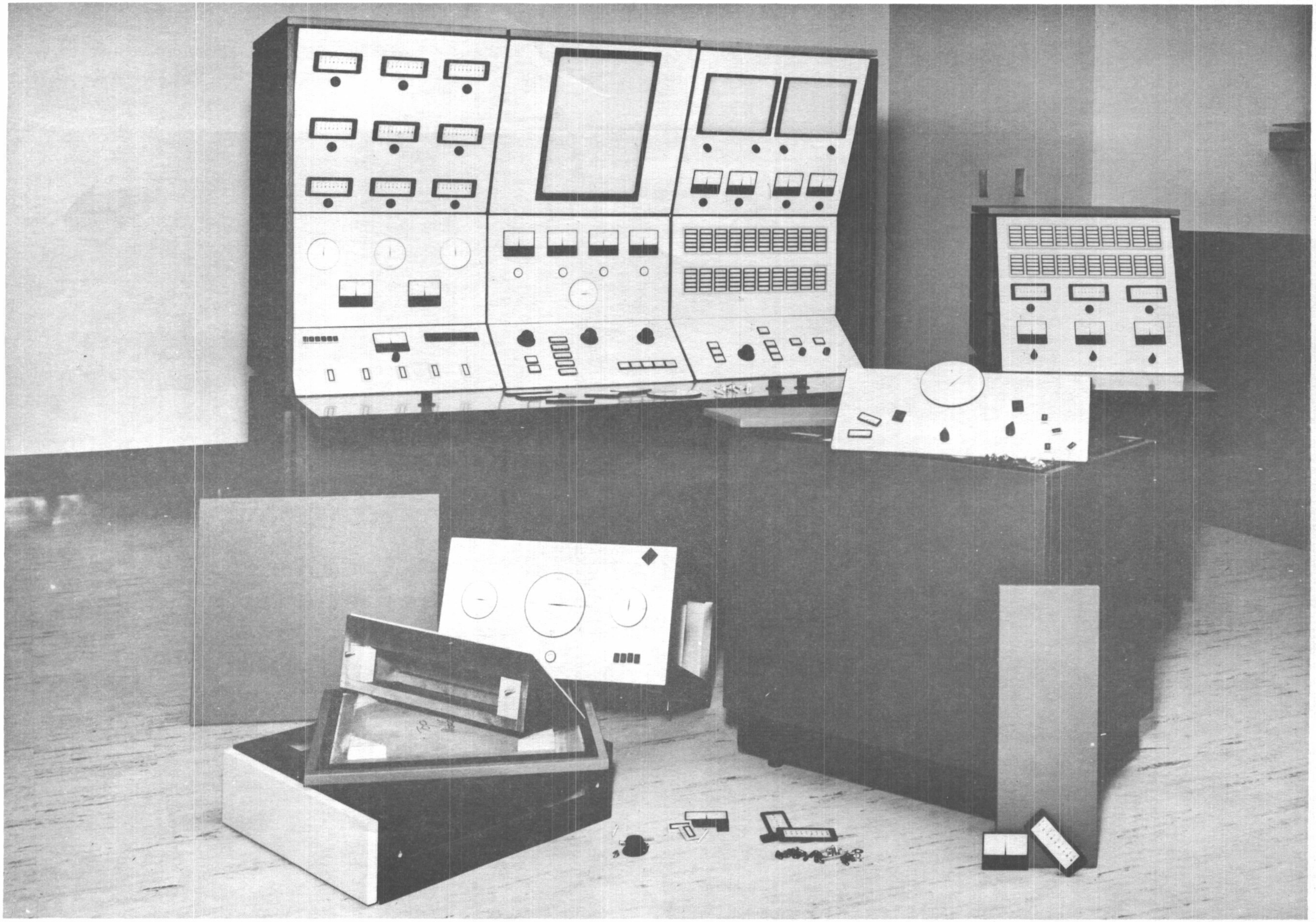

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Figure 11. Integral parts of mockup kit.

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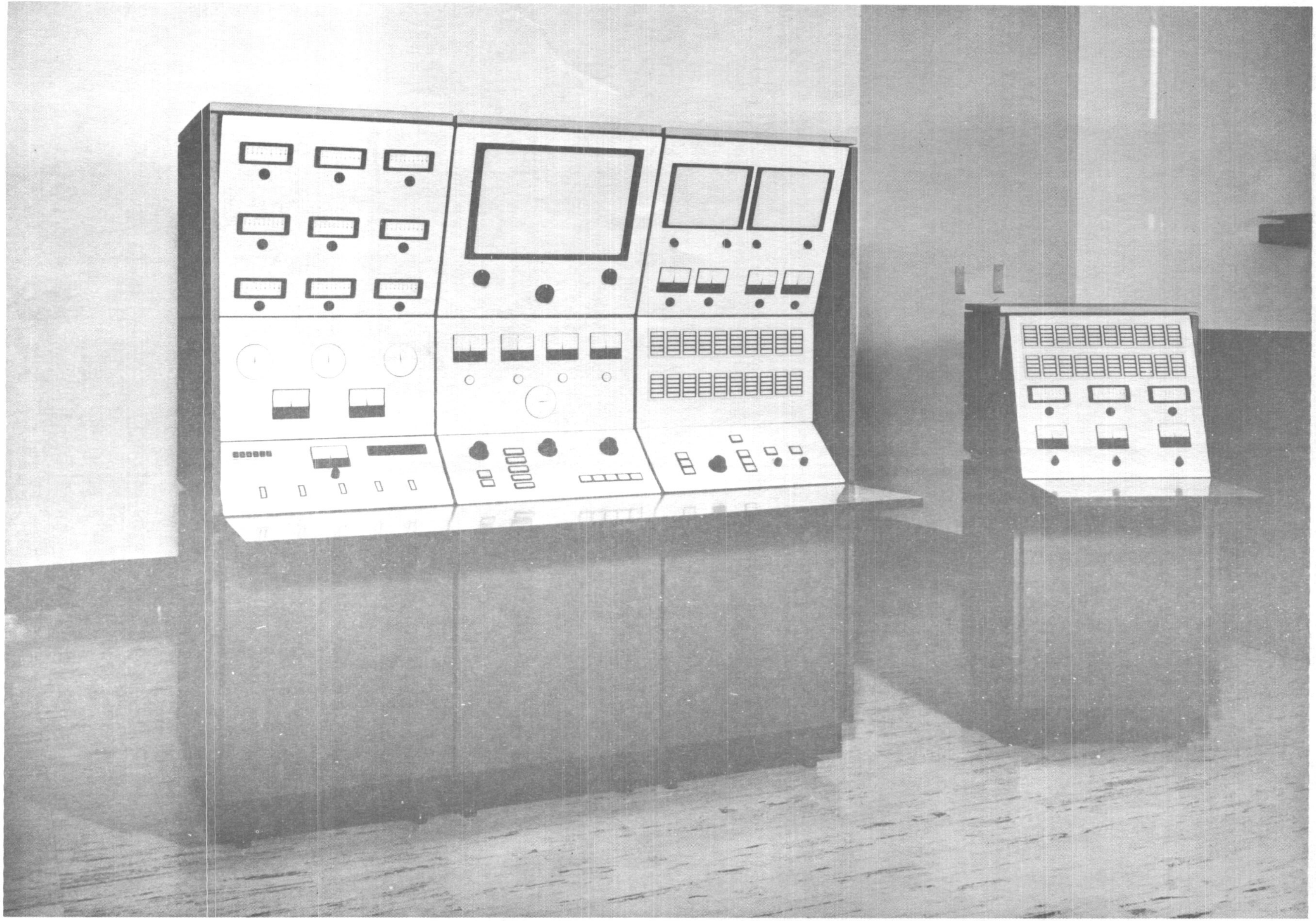

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Figure 12. One and three bay consoles.

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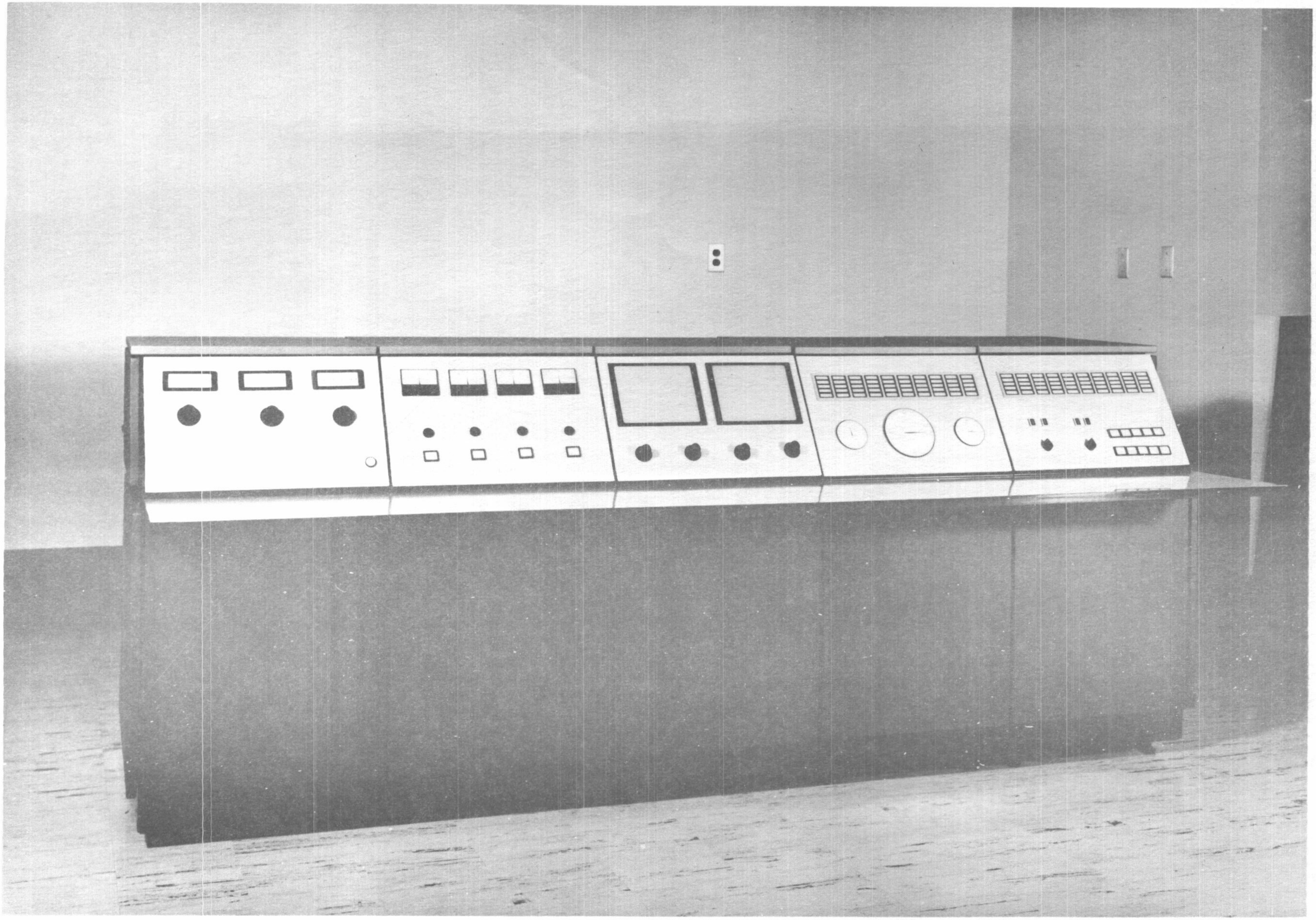

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Figure 13. Five bay "see-over" console.

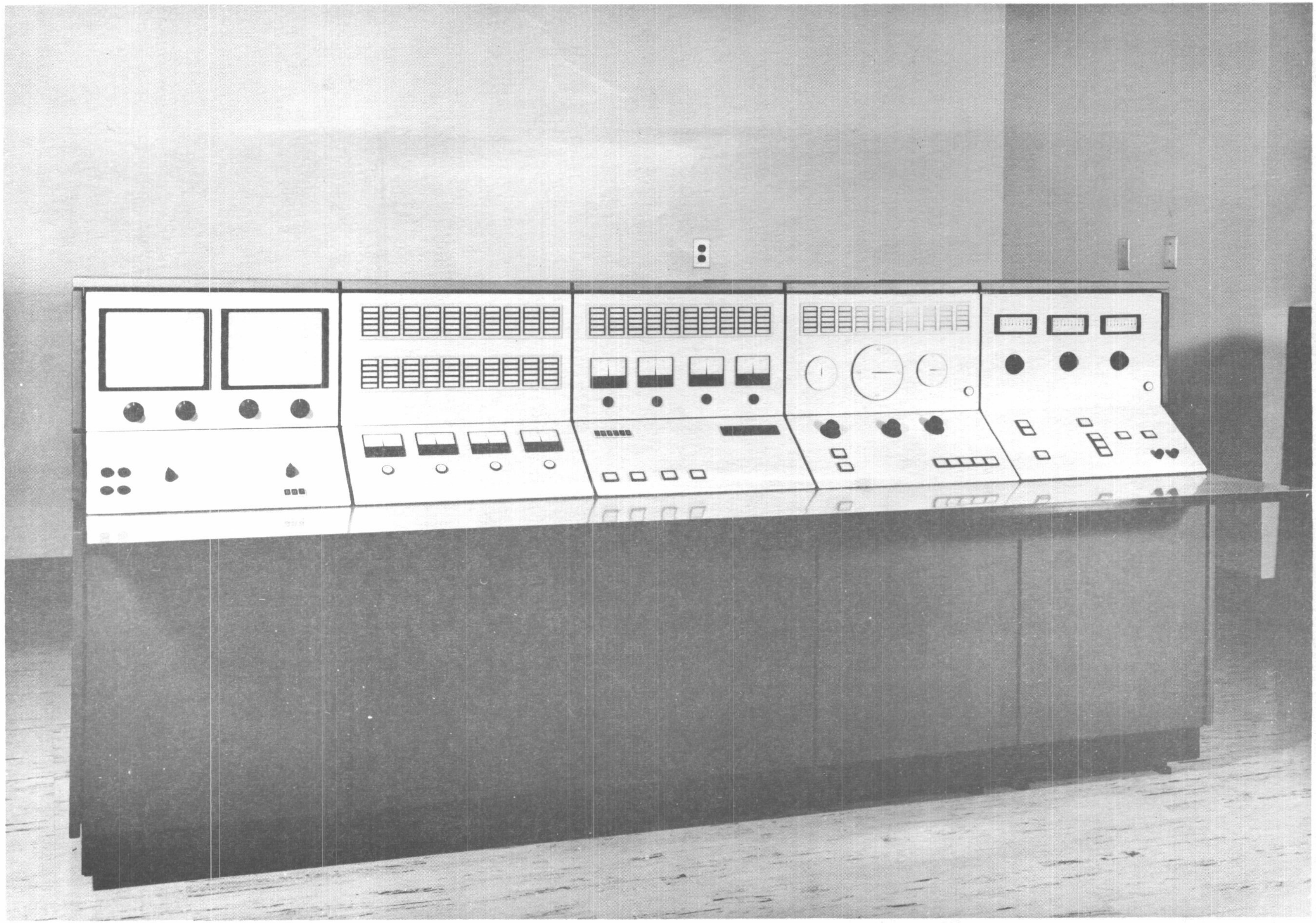

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Figure 14. Five bay console.

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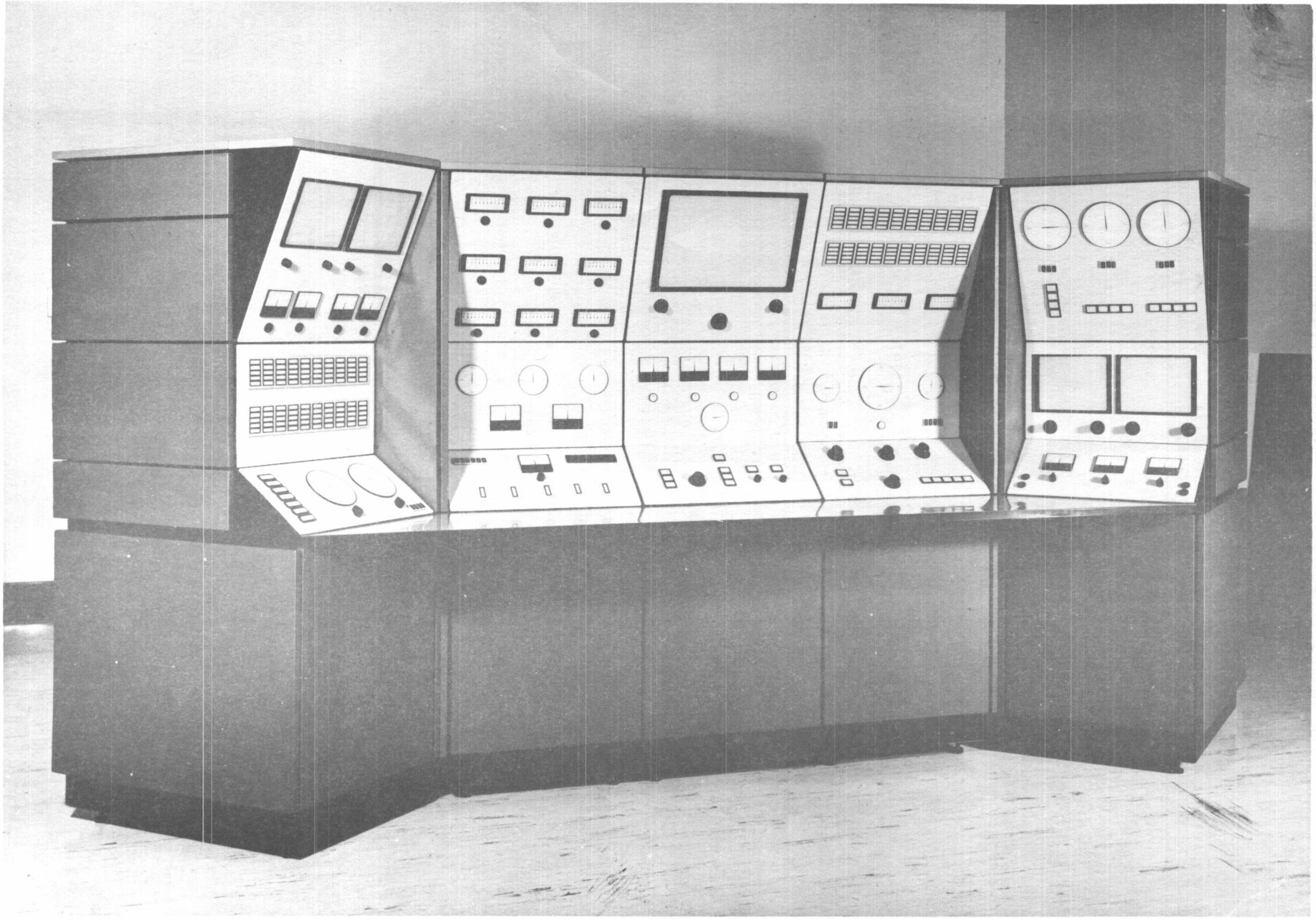

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Figure 15. Five bay wrap-around console.

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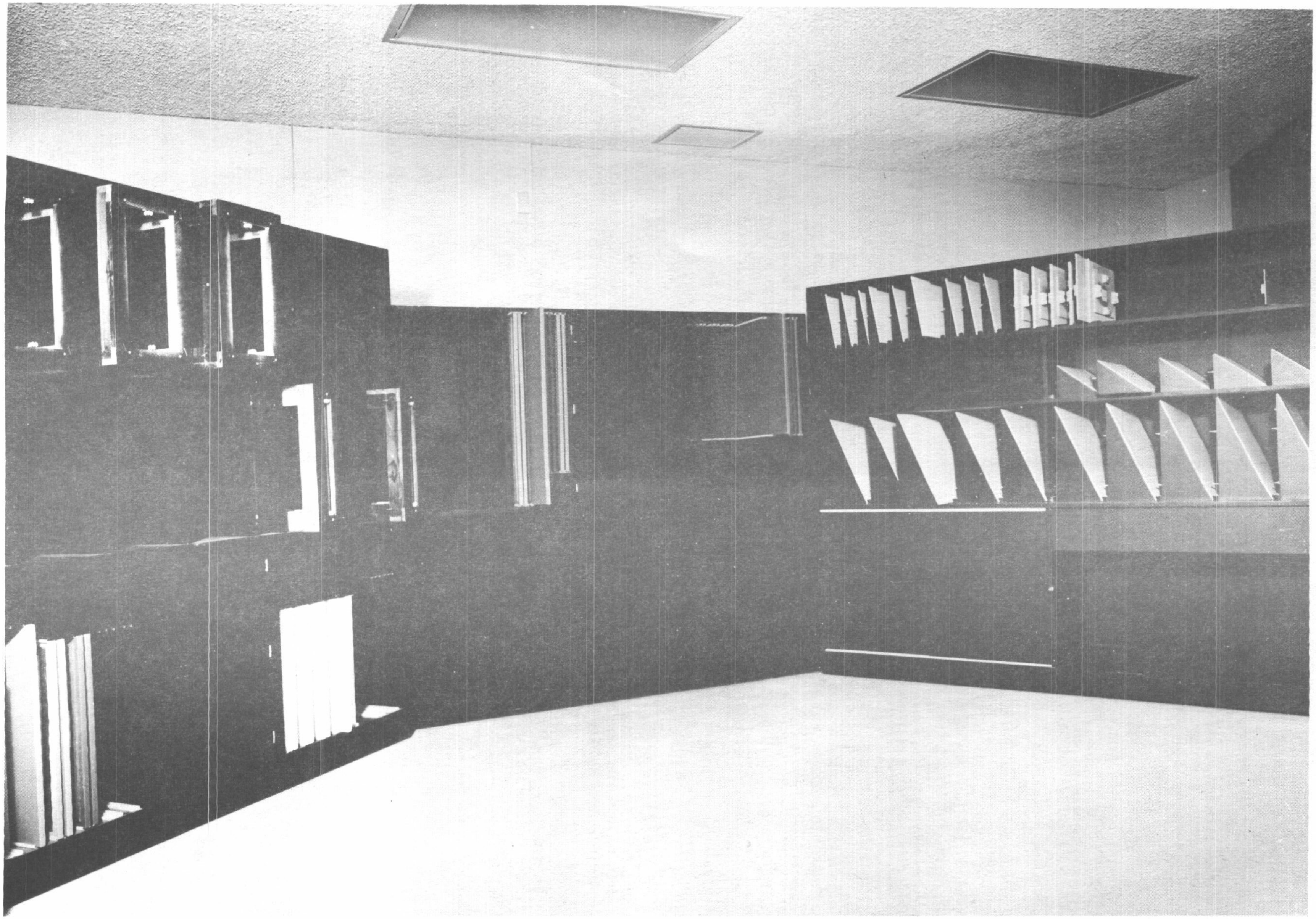

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Figure 16. Storage cabinet for mockup parts.

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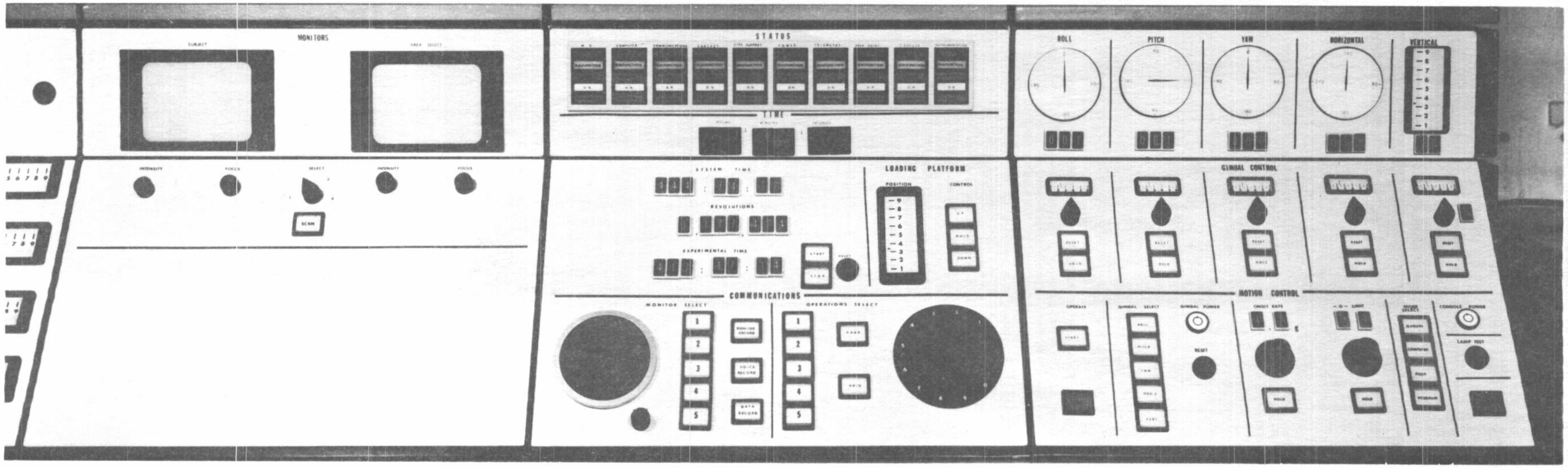

Figure 17. Centrifuge control console.

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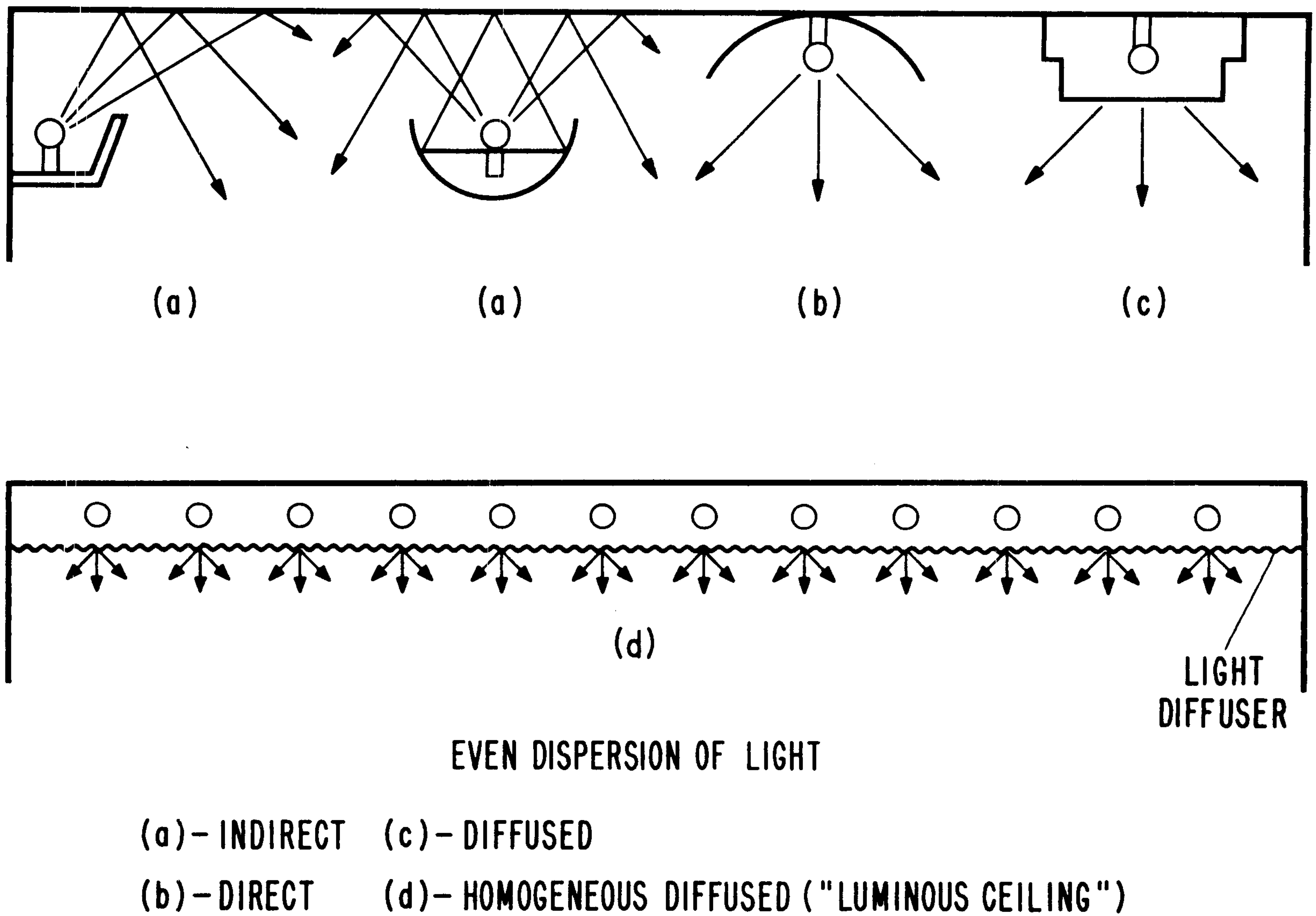

Figure 18. Light emitting methods.

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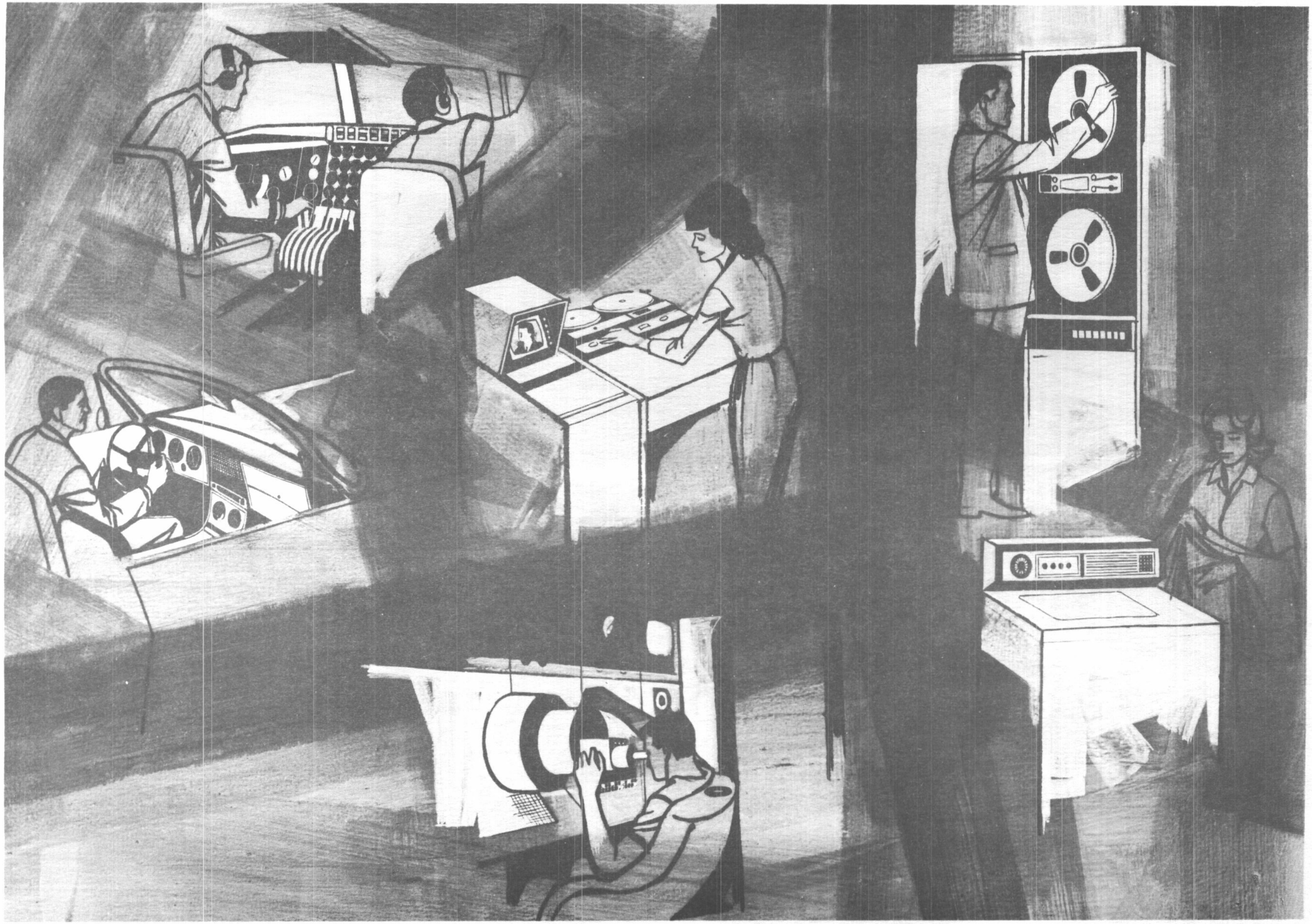

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Figure 19. Areas of application.

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