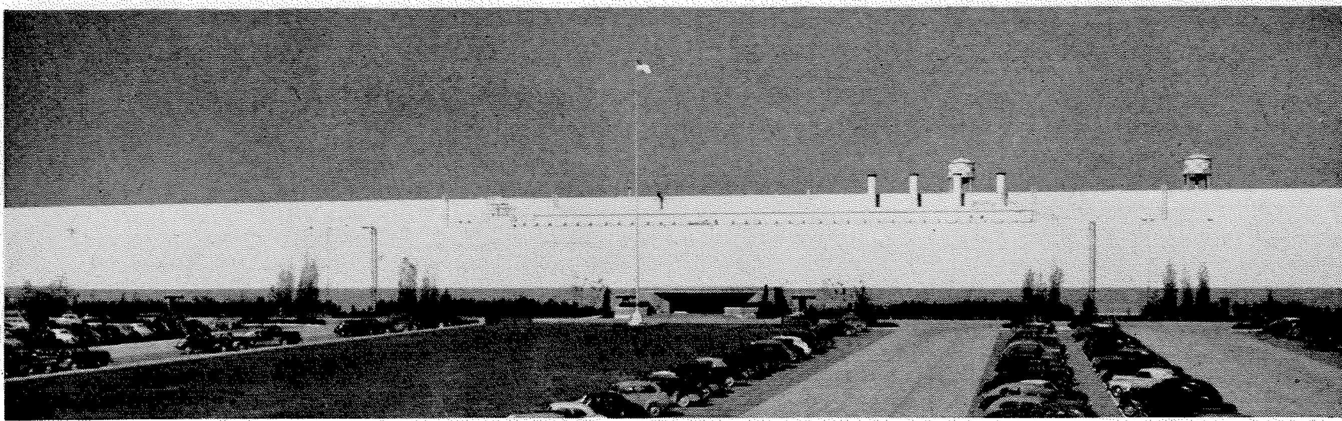
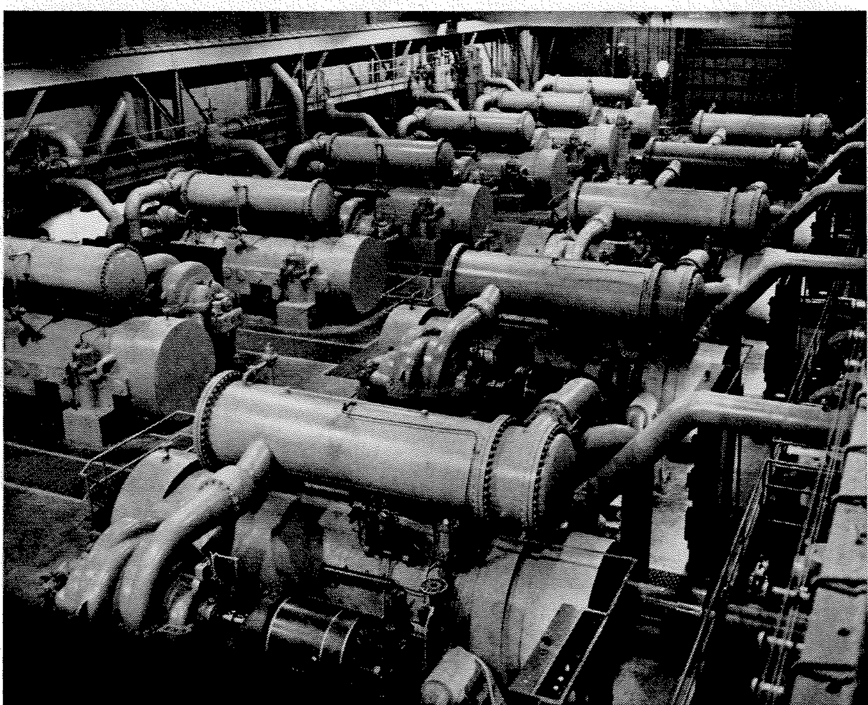


FIG. 1—Main entrance to administration building, showing stacks above boiler house and assembly building in background.

Controlled Conditions in the
WORLD'S LARGEST WINDOWLESS FACTORY

BY FRANK CLAYTON

WHEN it was announced early in 1941 that the United States would start on a program aimed at the construction of 500 heavy bombardment airplanes a month, the first reaction of members of the aircraft industry, particularly engineers engaged in plant design, was to translate this quantity into terms of new factories and to speculate on their size and locations. Based on the production then being realized, it appeared that six to eight new plants would be required, each as large as the Consolidated Aircraft San Diego plant or the Boeing plant at Seattle.



AT LEFT:

FIG. 2—Turbine deck showing eleven of the twelve refrigeration units. Refrigerant condensers are at the top, evaporators under them, and steam condensers and circulating pumps at lower level under the deck.

SELECTION OF SITES

In selecting sites for the new plants, primary consideration was given to the following factors:

1. Protection.
2. Weather.
3. Labor supply.
4. Terrain.
5. Utilities.

Consideration of the first factor precluded location of the new plants near the Pacific or Atlantic coasts, although the Douglas Long Beach plant was then under construction. In general, the new plants were all located in the Middle West or South.

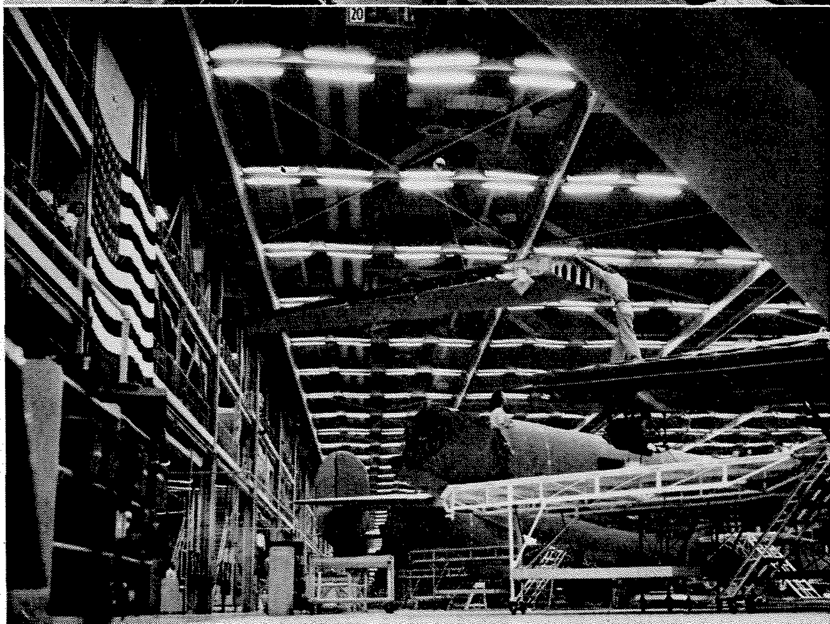
The second consideration, weather, while important for flying and testing, has become less and less a factor in manufacturing as air conditioning has come into wider use.

While the needs of war industries in general have caused large movements of labor all over the country, often doubling the population of communities, for example San Diego and Fort Worth, it is desirable and generally necessary to locate any new large factory near an adequate supply of labor. This assures at least manpower enough to get started, and a fairly large com-

AT RIGHT:

FIG. 3—General view of final assembly line showing high bay lighting installation.

FIG. 4—Assembly area showing monorail crane, lighting system and, above trusses, ventilating air distribution.



munity usually has more capacity than a small one to absorb additional population or at least accommodate it while new facilities are being acquired.

Consideration of terrain is very important, since every large aircraft plant must have an adjacent, suitable air field. Realizing the vast training program necessary to utilize the expanded production, and the limited approaches and available space at most air terminals, most of the new plant projects included new air fields. At Fort Worth the field is operated by and shared with the Air Training Command. It is important, especially for flight testing, to have not only runways of adequate length but an unobstructed surrounding terrain, preferably one where there is reasonable chance to set a plane down in an emergency without completely wrecking it or losing the crew.

Like most manufacturing plants, aircraft factories require adequate utilities. A reliable source of satisfactory fuel is essential for heating, heat treating, process work, generating process steam, etc. Electric power is essential for lighting, ventilation, process purposes, and for operating productive machinery. Adequate quantities of pure water are needed for a variety of purposes ranging from drinking and sanitation to chemical baths, air conditioning and watering the lawn. Not of least importance in a factory employing thousands of workers is an adequate sewage disposal system.

Based on the above considerations, a survey had been made the previous year for a suitable site for a new Consolidated Aircraft plant, with Fort Worth as the favored location, but other considerations dictated its location in San Diego, where it is now known as Plant Two. The groundwork having been thus laid, Fort Worth was soon chosen as the site for a new heavy bomber plant to be owned by the U. S. Army and operated by Consolidated Aircraft Corporation. Since the merger with Vultee, this is known as Consolidated Vultee Aircraft Corporation, Fort Worth Division, and the plant itself as Government-owned Aircraft Plant No. 4.

PRODUCTION PLAN

The original production plan involved three plants to be operated by three different companies. At the same time Fort Worth was selected for a plant to be operated by Consolidated, Tulsa, Oklahoma, was chosen for a duplicate plant to be operated by Douglas. Both plants were to assemble B-24 airplanes from parts and components to be manufactured in a new plant to be operated by Ford Motor Company and located at Willow Run near Detroit.

As the plants were constructed, it became apparent that the Fort Worth plant would be ready for production long before any parts could be obtained from Willow Run, so early in 1942 it was decided to add a parts manufacturing plant at Fort Worth. This, combined with the original assembly plant and subsequent expansions, some still in progress, constitutes the largest factory of its kind in the world.

Starting out by assembling planes from parts shipped from San Diego, the first completed B-24 was turned out in April, 1942, 100 days ahead of schedule. In the meantime, parts manufacturing was started in the original assembly building, and considerable production was accomplished before the first set of components was received from Willow Run. Later, these came in on schedule, and the originally designed capacity of the assembly plant has been exceeded while at the same time an even greater quantity of completely Fort Worth built planes has been turned out.

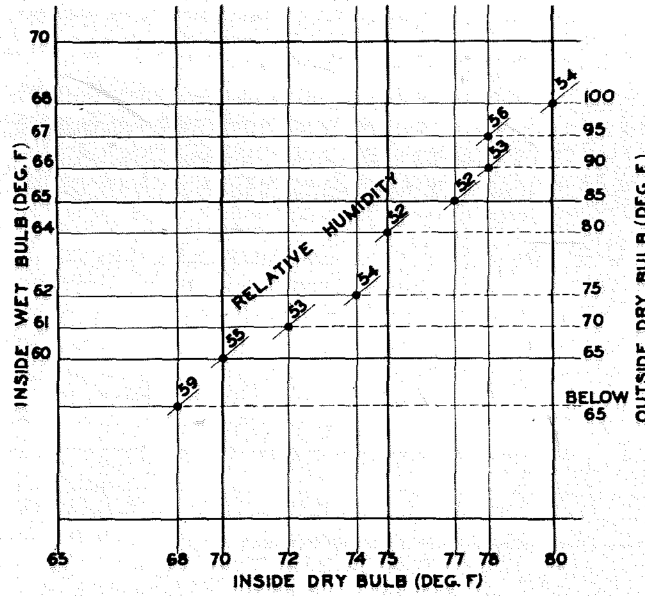


FIG. 5—Chart showing actual inside conditions held in factory areas at various outside temperatures. High relative humidity is possible without condensation due to wall insulation and construction.

ENGINEERING

In order to divide the burden as well as obtain the benefits of the experience of all three organizations, engineering of the various phases of the program was divided between them. Thus, Ford and Douglas worked on tooling and production, Ford actually building final assembly fixtures for all three plants, while Consolidated took over the plant engineering and machine tool procurement programs for both the Fort Worth and Tulsa plants.

These plants, owned by the U. S. Army, were designed and built by the Austin Company under contracts with the U. S. Engineers. Consolidated Aircraft Corporation was given a contract for consulting services and acted as consulting engineers on the design and construction of these plants.

For reasons of economy and speed, and due to their original duplicate designed functions, the Fort Worth and Tulsa plants were made identical as to size, shape, structural design and plant facilities. They differed only in orientation and utility services. Thus, it was possible to use the same structural, electrical and mechanical engineering and most of the plans for both plants. It was also possible to combine purchases of equipment for both. When the lighting fixtures and air-cooled distribution transformers were purchased in this manner, they constituted the largest orders, respectively, for either type of equipment in the history of the electrical business.

DESIGN CRITERIA

In line with the first factor in selection of a suitable site, one of the first criteria to be decided upon was that these plants were to be of "blackout" construction. This meant that they were to be operable day and night at full capacity without any possibility of light showing outside, especially from above. Actually, for convenience, safety and plant protection, both fence- and floodlights are liberally used but all are extinguishable from a single "blackout" switch located at the police supervisory desk.

The "blackout" feature obviously requires that all work be carried on under artificial light, and that mechanical ventilation and air conditioning be provided. Inasmuch as the course of the war has largely eliminated the need for "blackout" protection, it is a moot question today whether the original aim was really protection or the setting up of criteria requiring air conditioning. It is highly doubtful if, under conditions of critical material shortages, air conditioning would have been approved if the design of the plant had not made it a necessity.

Dimensional criteria were determined from the experience of Consolidated gained in the manufacture of B-24 airplanes as well as large flying boats at San Diego. Plans for moving assembly lines had already been conceived, and it was decided to incorporate this method in the new plants. Extensive studies were also made of other new plants such as the Vega plant at Burbank, Consolidated parts plant at San Diego, then under construction, and the Douglas Long Beach and North American Dallas plants, both air-conditioned and of "blackout" construction.

A comprehensive study of weather conditions in this vicinity covering a period of years was made, and on this basis the following criteria for air conditioning were determined:

Maximum summer conditions:
Outdoors—100° F. dry bulb.
78° F. wet bulb.
Indoors—80° F. dry bulb.
67° F. wet bulb.
Relative humidity in plant—52% to 56%.

Minimum winter conditions:
Outdoors— 0° F. dry bulb.
Indoors—65° F. dry bulb.
Relative humidity in plant—40% to 59%.
Control to be ± 1° F. within any zone, with 5° maximum variation throughout the plant.

Illumination design has been based on a maintained lighting intensity of 35 foot-candlepower at the working plane with maximum horizontal and upward components.

AIR CONDITIONING SYSTEM

From the assumed population of the plant, building dimensions and orientation, as well as lighting and productive machinery and equipment loads, it was determined that the capacity of the refrigeration system should be approximately 12,000 tons (7,000 tons in the original assembly plant design, and 5,000 tons for the added parts plant). With this capacity the thermal transmission of walls and roof was as follows:

Walls..................065 B.T.U. per hour per square foot
Roof....................07 B.T.U. per hour per square foot

These values have been realized through use of a unique construction of steel paneling combined with approximately four-inch thickness of fiber glass wool. By exposing the inner surface of the fiber glass, a very good acoustic condition in the plant has been achieved.

The volume of air circulated is equal to approximately 1.4 changes per hour based on total cubic content of the buildings, with 25 per cent to 100 per cent fresh air depending on outside conditions. This appears to be a slow rate of circulation, until it is realized that most occupancy is in the first 12 feet above the floor, whereas the average height of the roof is 55 feet. Actual circulating fan capacity in the assembly and parts manufacturing buildings alone is in excess of 2,600,000 cubic feet per minute.

The problem of air distribution was complicated by the requirement that all air-supply outlets as well as returns be located 40 feet above the floor so as to clear the monorail crane system secured to the lower chord of the roof trusses and covering the entire building area.

To accomplish this, and as a result of competitive designs tested under simulated conditions, double-purpose outlets were chosen which automatically change from diffusing characteristics when handling cool air on the "summer cycle" to concentrated downward distribution when handling warm air on the "winter cycle."

Temperatures in various zones are controlled by double range thermostats of pneumatic type, remote-controlled from the boiler room. Indoor and outdoor temperatures may be read and adjustments made, when and if necessary, anywhere in the plant from the master control panel.

Humidity control, while not as complete as in the conventional washed-air-reheat cycle system, is reasonably satisfactory and the operating cost is considerably lower. The range of relative humidity specified under "design criteria" is based on what the system is capable of and falls within a very desirable portion of the comfort zone as shown on standard psychometric charts, modified for the degree of air movement existing.

All fans in the main factory buildings are located on decks above the lower chord of the roof trusses and are connected by catwalks. Each deck has two fans averaging 40,000 cubic feet per minute each, driven by 30 and 40 horsepower motors. Cooling is by finned coil units through which is circulated chilled water from the central refrigeration system. Spray pumps and per cent of fresh air admitted, controllable from the boiler room, afford control of humidity, and self-cleaning oil type filters clean both the fresh and recirculated air. Air control is effected by means of pneumatically operated fresh air, recirculated air, face and bypass dampers. Minimum fresh air settings are determined largely by the need to supply exhaust air for spray booths, heat treat vent hoods, etc., amounting to over 300,000 cubic feet per minute. Excess exhaust air is discharged through automatically-controlled relief dampers which form a natural restriction, with the result that the buildings are carried at a positive static pressure of approximately one-quarter inch. This tends to exclude outside air when doors are opened.

Except for pedestrians, entrance and exit are via electrically-operated vertical lift doors varying in size from 20 feet wide and 15 feet high to 200 feet wide and 40 feet high. These admit the largest trucks, railroad cars, etc., and provide for removal of completed planes. To decrease exchange of air when large doors are opened, a series of high-velocity nozzles is provided above each, automatically controlled to emit a curtain of warm or cool air, as the case may be, across the door opening whenever it is operated. At the same time all relief dampers automatically close, tending to cause an outward flow of air.

Heating in the original assembly building is by warm water circulated through the same piping system used for cooling, and steam boosters for use when temporary heating is needed, as on a cool morning during weather when the general system is on the summer or cooling cycle. In the parts manufacturing building steam heat is utilized. Because of the distance from the central heating plant and the limitation of heat-exchanger capacity, it was found most economical to use high-pressure steam. This is advantageous also because of the demand for process steam throughout the parts manufacturing area.

The central heating and refrigerating plant consists of four steam generators each rated 100,000 pounds per hour at 225 pounds per square inch and no superheat. These are gas fired with automatic-combustion control and with fuel-oil standby. Steam is distributed to the assembly building and other buildings in the plant at 50 pounds per square inch for booster coils and process purposes, and at 125 pounds per square inch to the parts manufacturing building for both heating and process. Balanced type pressure reducing valves are used in both cases. All boiler auxiliaries, such as feed water pumps and forced and induced draft fans, are turbine driven.

Boiler feed water treatment consists of a lime soda ash filtering and treating unit operating on 10 pounds per square inch back pressure. Provision is made for feeding either filtered city water or raw lake water to the unit.

Warm water for assembly building heating is obtained by surface condenser-type heat exchangers, circulating water at approximately 90 degrees Fahrenheit.

Chilled water, varying from 47 degrees Fahrenheit to 59 degrees Fahrenheit as required, is cooled by means of 12 turbine driven centrifugal type compressors, utilizing freon F-11 as refrigerant. Eleven of these machines are rated 1,090 tons and one 550 tons, giving 12,540 tons total capacity of the plant. In practice, one machine is normally held in reserve at any one time, even in hottest weather. Steam consumption is approximately 15,000 pounds per hour at full capacity on each of the large machines. Refrigerant and steam condensers both use condenser water circulated from and to the nearby lake through a closed system. Approximately two gallons per minute per ton of condenser water is required which, together with other raw water needs, is circulated by means of five synchronous motor-driven pumps with a combined capacity of approximately 30,000 gallons per minute located in a pump house at the lake about three-quarters mile from the plant. This pump house also contains electric- and diesel-engine-driven fire pumps for the plant fire-protection system. Summer water temperature of the lake is approximately 85 degrees Fahrenheit.

Chilled water is circulated to all fan locations through a closed system by means of seven 300 horsepower induction motor driven centrifugal pumps, three of which are also used to circulate heating water in the assembly building.

LIGHTING SYSTEM

The lighting requirements of a "controlled-conditions" plant are not essentially different from those of any plant operating more than one shift, except that the requirement of continuous operation means more frequent lamp replacements and greater maintenance. In selecting a lighting system, however, the total wattage is very important, not only from an energy cost standpoint but because of added load on the air conditioning system, which results in both investment and operating costs several times as great as any difference in cost of energy.

In order to obtain 35 foot-candlepower maintained minimum intensity at floor level from sources 40 feet high, the normal method had been to use relatively narrow distribution type reflectors with either incandescent, high-intensity mercury, or a combination of these two types of lamps. A few installations had been made of type *F* fluorescent lamps. The various systems analyzed for this plant, and their relative factors for comparison, are shown in Table No. I. (1—lowest to 5—highest cost).

TABLE I

Type of Lamp	*Installed First Cost*	*Operating Cost**	*Color Factor*	*Maintenance Cost*	*Light Distribution*
Incandescent	1	5	3	5	3
High-Intensity Mercury	3	1	5	3	5
Incand.-Mercury Comb.	2	4	4	4	4
Type F Fluorescent (40W lamp)	5	3	1	2	2
Type "RF" Fluorescent	4	2	2	1	1

*Including air conditioning.

The desire for high lighting intensity on the vertical plane indicated the use of wide angle distribution, even at 40-foot mounting height. This and other factors indicated in Table No. I led to the selection of type *RF*-industrial white 85-watt lamps, mostly in two-lamp wide-angle porcelain-enameled steel reflectors. These are installed in double rows bracketed from the main trusses which are on 25-foot centers. Individual fixtures in each row are on approximately eight-foot centers. Figuring 200 watts per fixture, including losses in the ballast, results in 1.92 watts per square foot of floor area. With the wide-angle distribution, over 700 fixtures contribute measurably to the light at any point. Also, and contrary to conventional illumination calculation, the intensity is very little different on a working plane at floor level or 15 feet above the floor as, for instance, on top of a wing or fuselage.

In order to increase the upward component in assembly areas, a white cement finish on the floor has been provided. This gives an upward intensity of approximately 12 foot-candlepower even under the wing of a plane, eliminating the need for auxiliary lighting on the final assembly line except inside the fuselage. The average life of type *RF* lamps has been found to be 4,000 hours, after which time all lamps in a given area are changed and reflectors cleaned. Later additions, as well as a large area under the parts manufacturing building mezzanine, utilize type *F* 100-watt lamps as the manufacture of type *RF* fixtures was stopped by W.P.B. during construction of the parts plant.

All factory lighting, except auxiliary and extension lights, is operated on 254 volts from the 254/440Y-volt, three-phase, four-wire distribution system. It is controlled by magnetically-operated latched-in contactors, usually of 100-ampere capacity, with individual circuit protection by means of cartridge fuses on the load sides. Push buttons are provided for operation from the floor without necessity of dropping circuit wiring for this purpose. This design has resulted in the use of no wire larger than No. 12 A.W.G. in any lighting circuits, and with maximum voltage drop of three per cent from transformers to fixtures.

EMERGENCY SYSTEM

Emergency lighting, absolutely necessary in a "black-out" plant, is provided by means of incandescent lights to give approximately one-eighth foot-candlepower intensity in general areas and one-fourth foot-candlepower on stairways, in passageways and at exits. A separate 2400-volt emergency feeder extends throughout the plant, normally energized from the main substation, and from a 500-kilowatt steam turbine-generator set which automatically starts upon failure of power. Individual areas are fed from small air-cooled transformers and magnetic throw-over switches which act upon failure of regular power supply in any individual area. In case of a power outage, the generator set will start, attain full speed and the first circuit close in approximately 11 seconds. There are three circuits, the other two closing a few seconds later. Emergency power from this system is also provided to operate enough outside flood- and fence-lights for safe evacuation and plant protection, as well as time clocks and the factory whistles.

ELECTRICAL DISTRIBUTION

The power capacity of the electric utility system in this territory, while ample to carry the plant, is relatively limited, especially as to summer demand due to very heavy air-conditioning loading. This was a large factor in deciding on steam-driven refrigeration. The plant service is from a switching station inserted in a 60-kilovolt network loop, and located approximately six miles from the main Fort Worth generating station which has a capacity of 50,500 kilowatts. In the opposite direction the loop is of limited capacity, but arrangement was made through the Federal Power Commission to have the two Possum Kingdom Dam generators, of 12,500 kilowatts each, carried on the line as a spinning reserve during those hours they would not normally operate.

The plant is served by two 10,000 kilovolt-ampere substations, 60—2.4/4.16-Y kilovolt, 60-cycle, three-phase. One of these serves the original assembly plant and the other, the parts plant. During the first year of operation over 50 outages occurred, mostly due to atmospheric disturbances on the west or weak loop of the network. A calculating board study of the system was made at Massachusetts Institute of Technology which indicated that with the west line open the entire plant load of approximately 16,000 kilowatts could be carried from the east, or Fort Worth side, with satisfactory voltage; but if the east line opened, the voltage drop would not only be excessive but the total load could not be carried at all. The study indicated that with the installation of 8500 kilovolt amperes of capacitors at the substations, the west line would carry approximately 12,000 kilowatts. In an emergency this is accomplished by cutting off the air-conditioning machinery with the exception of fans, enabling the factory to maintain full production.

As a result of the study, automatic circuit breakers were installed at the switching station, set to open either line separately in the event of a fault, and the capacitors were installed in the substations on the 4160-volt bus. It is now necessary to cut off half the capacitors during light load periods to prevent over voltage and corresponding short life of the incandescent lights in the plant.

Switching of 4160 volt power is done by means of remote controlled electrically operated metal clad outdoor switchgear. In general, each breaker controls a feeder handling two 600 kilovolt amperes, 4160—254/440-Y, three-phase, air-cooled transformers mounted on platforms in the building trusses approximately 45 feet above the floor. Primaries are protected by gang operated oil fuse cutouts. The 4160-volt distribution systems in both assembly and parts manufacturing buildings are radial type. A solidly grounded neutral is carried throughout the plant.

Power distribution is at 254/440-Y volts, grounded neutral, and is of two types. In the assembly building, because of both its great length and relatively light loading per unit of area, a straight radial system is used. Distribution is through a dead front switchboard at each transformer equipped with main air circuit breaker and fused circuit switches ranging from 30 to 400-ampere capacity. In the parts manufacturing building, where load density is greater and spacing closer, a secondary network is used, consisting of 1000-ampere plug-in bus arranged in two 550-ampere circuits each. Thus, at any cross section of the building, four 500-ampere circuits are available. Switchgear at each transformer consists of a main air circuit breaker, four network air circuit breakers and network protection relays. This has been of great convenience in that heavy machinery is frequently moved, and all loads are readily taken care of.

In addition to power distribution to individual loads, plug-in bus duct is widely used in machine tool areas. Also, 440-volt arctite receptacles are installed throughout the plant for plugging in arc welders, rectifiers, hydraulic test stands, etc.

Power for hand tools, extension lamps and other 120-

(Continued on Page 18)

education of the prospective magnesium user to overcome his fears of magnesium fires. Many years ago both gasoline and kerosene were thought to be so dangerous that neither would ever be commonly used. Today the inflammability of gasoline has been greatly increased and yet it plays a very important part throughout the entire daily lives of all of us. Dangerous? Yes, but only under certain conditions and certainly not when one knows how to handle it.

Most people do not realize that in every magnesium incendiary bomb is some thermite, a mixture of aluminum powder and iron rust. This mixture is first ignited and it is this that sets fire to the magnesium. Magnesium will burn but only if heated to 1,250 degrees Fahrenheit in the presence of air or an oxidizing material.

As to the fields where magnesium may be expected to make its first showing after the war, the following appear most worthwhile considering:

Lightweight household appliances, vacuum cleaners, sewing machines, refrigerators, furniture, folding tables, washing machines, ironers, dish washers and driers, clothes driers, ventilating and other fans, small motors, can all be made of greater usefulness with magnesium. Window shades, screens and frames for the windows themselves are possibilities.

In the field of transportation, by airplane, by automobile and by train, magnesium undoubtedly will fill a tremendous demand. Its use in airplane construction is increasing, and the per cent of the total weight of the plane that is magnesium continues to increase in present manufacturing practice. The advantages in airplane, rail and ship transportation obtained by use of light metals and alloys are quite obvious.

In the field of automobile manufacture, with continued high gasoline taxes it seems quite probable that the need for higher gasoline mileage to guarantee economical transportation will require lightweight cars.

In commenting on various possible uses for magnesium, Dr. Colin G. Fink suggests the use of magnesium for coins. Speaking of magnesium instead of copper pennies, Dr. Fink says, "There are approximately 1,000,000,000 copper pennies in circulation equivalent to 6,600,000 pounds of copper. The peacetime production cost of copper is six cents per pound as against about 14.5 cents for magnesium. For the same sized coin, the magnesium penny weighs but one-fifth the weight of the copper penny. In other words, 1,320,000 pounds of magnesium pennies at a base cost of $191,400 would replace 6,600,000 pounds of copper pennies at a base cost of $396,000. There is only enough copper in the world to last industry 40 years as against 10,000 years for magnesium."

In considering the possible future uses for magnesium and light metal alloys, it is difficult to find applications in which they cannot serve.

The Electron Microscope

(Continued from Page 13)

positive means of identifying the material. The microscope combined with the diffraction attachment becomes a research tool that is particularly advantageous for pigments, dusts, and various chemical preparations. Its usefulness in varied fields of research may lead in the future to an instrument in which individual particles only 50 atoms or so in diameter can be singled out of a sample of powder, photographed and then identified by "Submicroscopic chemical analysis," either by the diffraction method or by an analysis of the velocity of the electrons that emerge from the particle.

Windowless Factory

(Continued from Page 8)

volt equipment is supplied through 50 kilovolt-ampere, 440-120/208 volt, three-phase, air-cooled transformers installed at regular intervals throughout the plant. In general, each serves three multibreaker panel boards from which current is extended by conduit or through the underfloor duct system which is extended throughout most factory areas. Balance is maintained as closely as possible between phases.

CONCLUSION

To evaluate a "controlled conditions" plant properly in relation to traditional factory construction requires exhaustive analysis beyond the scope of this article. Certain advantages, however, are obvious. First, product quality and uniformity have a better chance of being maintained at a high level. Second, and especially in a severe climate, employee comfort and efficiency are greatly improved. Third, inaccuracies due to expansion and contraction can be held to a minimum. This is very important as assemblies of light metals get larger and larger, and for accurate machining of large light structures. Fourth, corrosion from both atmospheric conditions and handling is reduced.

The only serious disadvantage which has become apparent is that of increased investment and operating cost. This is a disadvantage only when full production is not maintained. In this respect it may be compared with a high-production special machine tool versus a less expensive but more common type.

For mass production, the special tool and the "controlled conditions" factory both have an outstanding place in the future of industrial development.

The Month in Focus

(Continued from Page 3)

that the public may be assured of safety. Another civil engineer may be concerned with the construction of channels, involving a knowledge of hydraulics as well as features of construction. Such differences may be cited in other branches of engineering. Thus it is apparent that the complete unification of engineers into a single professional group is difficult and that there are major barriers to the realization of this ideal. Some fields of engineering have been legally professionalized by several states in requiring licensing of those who wish to practice publicly. It is probable that more extensive developments will take place along these lines which will place the various fields of engineering on a professional basis in the eyes of the public.

Those who read "Mechanical Engineering" may have noted in the May issue the article by Hans Ernst on "High-Speed Milling with Negative Rake Angles." These developments originating on the Pacific Coast have led to greatly increased rates of production in milling operations. In this work, carbide-tipped cutters have been and are being operated at cutting speeds in excess of 500 feet per minute and with unusually high feeds. Some of the advantages obtained with these methods are higher production, improved finish, and less distortion of work due to heat. Naturally, these developments present many problems which require research to establish the soundest procedures. As a part of a program of studying milling operations under these new conditions, California Institute of Technology is conducting certain studies which will be interesting to watch. In his article in "Mechanical Engineering," Hans Ernst presents some interesting data in this connection.