A Refrigerated Altitude Chamber for Aircraft Testing

By L. P. SPALDING

THE urgent need for improvement in aircraft design and performance which wartime requirements imposed on industry promoted the acquisition of many new facilities for research and testing. Early in the war, North American Aviation built its own wind tunnel, and subsequently it has participated in the Southern California Cooperative Wind Tunnel program which was described in a previous issue of *Engineering and Science*.[1] During 1944, in furtherance of its policy of technical advancement, plans were started by North American for a refrigerated high-altitude testing chamber.

Many design problems have been created by the growing number and complexity of airplane accessories and systems such as cabin pressurization, defrosting, ventilation, heat exchange, and hydraulic equipment, and by the requirements for their satisfactory operation throughout extreme ranges of temperature, pressure, and humidity. There is available only limited experience from which to predict behavior in service. Checking of these items during flight tests of prototype or experimental airplanes is time-consuming and may cost from $500 to $1,500 per hour.[2] Also, when mistakes or malfunctioning are discovered, their correction on the completed airplane involves added expense, production delays, and interruption of essential flight testing. The desirability of proving components and designs at an early stage of development, using laboratory facilities which duplicate the operational environment of the airplane at a cost of $50 per hour, was a major factor in the decision to install an altitude chamber. Consideration was also given to its potential use for physiological work such as pilot indoctrination and checkout for high-altitude flying.

[1] *Engineering and Science*—July, 1945.

[2] See "Flight Test" by Frank Davis—*Engineering and Science*—May, 1946.

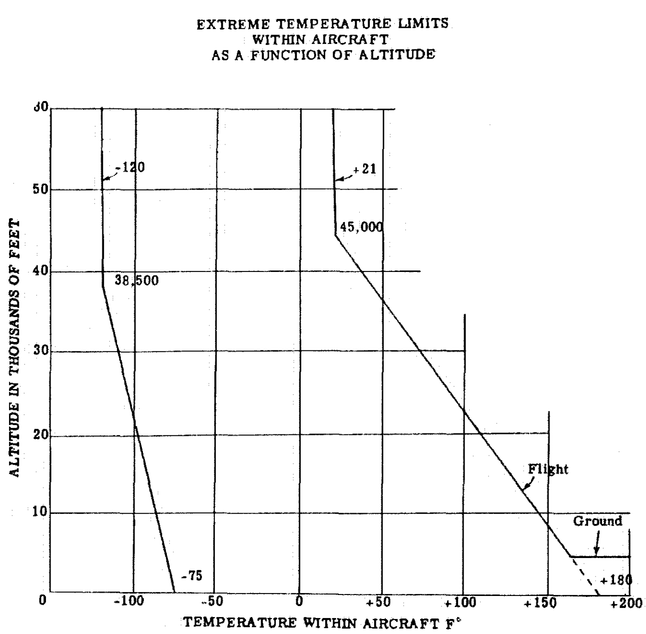


FIG. 1

DESIGN STUDIES AND REQUIREMENTS

Preliminary design plans incorporated reinforced concrete for the main chamber because of existing shortages in steel plate, and indicated savings of $5,000 to $10,000 in cost. However, doubts as to the reliability of concrete for vacuum service with rapid and severe temperature changes, the great difficulty of moving or altering the chamber if this were required at any future time, and a gradual easing of the steel procurement situation, resulted in a final decision to use steel plate construction.

Dimensions of the chamber were dictated by a somewhat arbitrary requirement that it should accommodate the entire fuselage of typical fighter airplanes, or large pressurized sections of bomber or transport types. It was felt that functional test data obtained on an entire system, including observations on the behavior of related systems or accessories, and with all items located and interconnected as in the finished airplane, would be more reliable and significant than tests of individual components. These requirements led to a working section having the form of a horizontal cylinder, 42 feet long and 15½ feet inside diameter (less space for floor and ceiling ducts). Convenient access to the chamber was considered a prime requisite of the design. This necessitated a ground-level interior floor and a quick-opening door of full cross-section size, incorporating a large airlock.

Required rates of climb and dive were evaluated in their fundamental relation to pressure changes, with attention also being given to accompanying temperature changes which might be representative of flight conditions. (See Fig. 1.) A rate of climb of at least 7,500 feet per minute at sea level was established as a compromise between current and predictable airplane performance and the size of evacuating equipment necessary. A second objective was the attainment of an altitude of 50,000 feet in ten minutes. The rate of descent could be set at almost any figure, depending only on the arrangement for admitting outside air to the chamber. An analysis of typical tests to be performed suggested, however, that extremely rapid dives under precise control and with simulation of attendant changes such as temperature rise would not be too important. Accordingly it was decided to design for a 7,500 feet per minute maximum controlled diving rate, with supplementary provisions for rates of the order of 20,000 feet per minute which could be used for special work or in emergencies involving personnel in the chamber.

The ceiling, or maximum attainable pressure altitude, was governed by vacuum pump characteristics and by unavoidable small leaks which occur at packing glands, door seals, and similar locations. In view of the diminishing returns in pressure changes corresponding to increasingly higher altitudes, a limit of 60,000 feet was chosen. This is equivalent to a working pressure of 1.05 pounds per inch or a vacuum of 27.8 inches. In the selection of a vacuum pump for this installation, both rotary and reciprocating types were considered. The former appeared to have some advantages in smoothness of operation, particularly in freedom from pulsation.

On the other hand, some manufacturers of rotary pumps expressed concern over the possible behavior of their liquid seals (oil or water) at the high and low temperatures to be encountered, anticipating either vapor back-up or congealing. In general the available rotary pumps were inferior in performance to readily obtainable reciprocating types, while costs ranged from 50 to 200 per cent greater. For these reasons, a decision was made in favor of a reciprocating vacuum pump.

Although the Army Air Forces had established a temperature range of —65°F. to +160°F. as acceptable for the testing and approval of aircraft components, recorded ground and flight observations prompted an extension of these limits to —100°F. and +200°F. A minimum of about —120°F. would be in even better accord with known extremes; however, calculations showed that this could not be attained without added costs for refrigeration which were far out of proportion to any benefits which might be realized. Rates of cooling and heating, commensurate with the established rates of climb and dive, were calculated from data paralleling those used in the construction of Fig. 1.

Humidity control to simulate all degrees of saturation, from desert aridity to fog and rain, and means for the creation of icing conditions with sleet or snow were included in the design specifications for the chamber. This involved provisions for the introduction of water or saturated vapor into the circulating air system of the chamber and supplementary external equipment to provide air under controlled conditions for setups being tested. Aside from humidity control, the supplementary air source is an essential requirement for the testing of cabin air systems, particularly on jet-engined airplanes. In these installations, air for pressurization and heating of the cabin is taken from the engine compressor, possibly at a temperature of 400°F. and a pressure of 25 pounds per square inch. The air may be handled through intercoolers, turbine coolers, and sensitive flow and pressure regulating valves. In simulating operational conditions, compressed air from the factory system was considered unsuitable since it contains water, oil, and dirt, which are difficult to remove—aside from the problem of temperature and humidity control. The several requirements involved suggested an air supply system designed along the following lines. Atmospheric air is drawn through a filter and through refrigeration coils for dust and moisture removal, preheated, compressed by an oil-and-water-free compressor, and delivered to a receiver in which temperature and humidity may be adjusted. Air from the receiver may be supplied either to the chamber or to test equipment in the chamber.

A high rate of air circulation over the heat exchangers was required to effect the desired rapid temperature changes and also to maintain uniformity throughout the chamber when holding fixed conditions. Further specifications for a circulating fan were established by provisions for ducting down from the fan outlet to deliver around 10,000 cubic feet per minute at a reasonable static pressure for such studies as windshield icing and heat exchanger performance. Air velocities of 150 miles per hour over a small area were desired. No attempt was made to duplicate the 300 miles per hour and higher speeds of current airplanes, since this would have entailed major design and equipment changes and carried us into the field of refrigerated wind tunnels. The relative merits of axial flow and centrifugal fans were considered in designing the circulatory system. A centrifugal type was finally selected, since it appeared to be safer from the standpoint of ice accumulation which would lead to clearance difficulties or unbalance. Also, a more convenient and effective installation could be made with this type than with an axial flow fan.

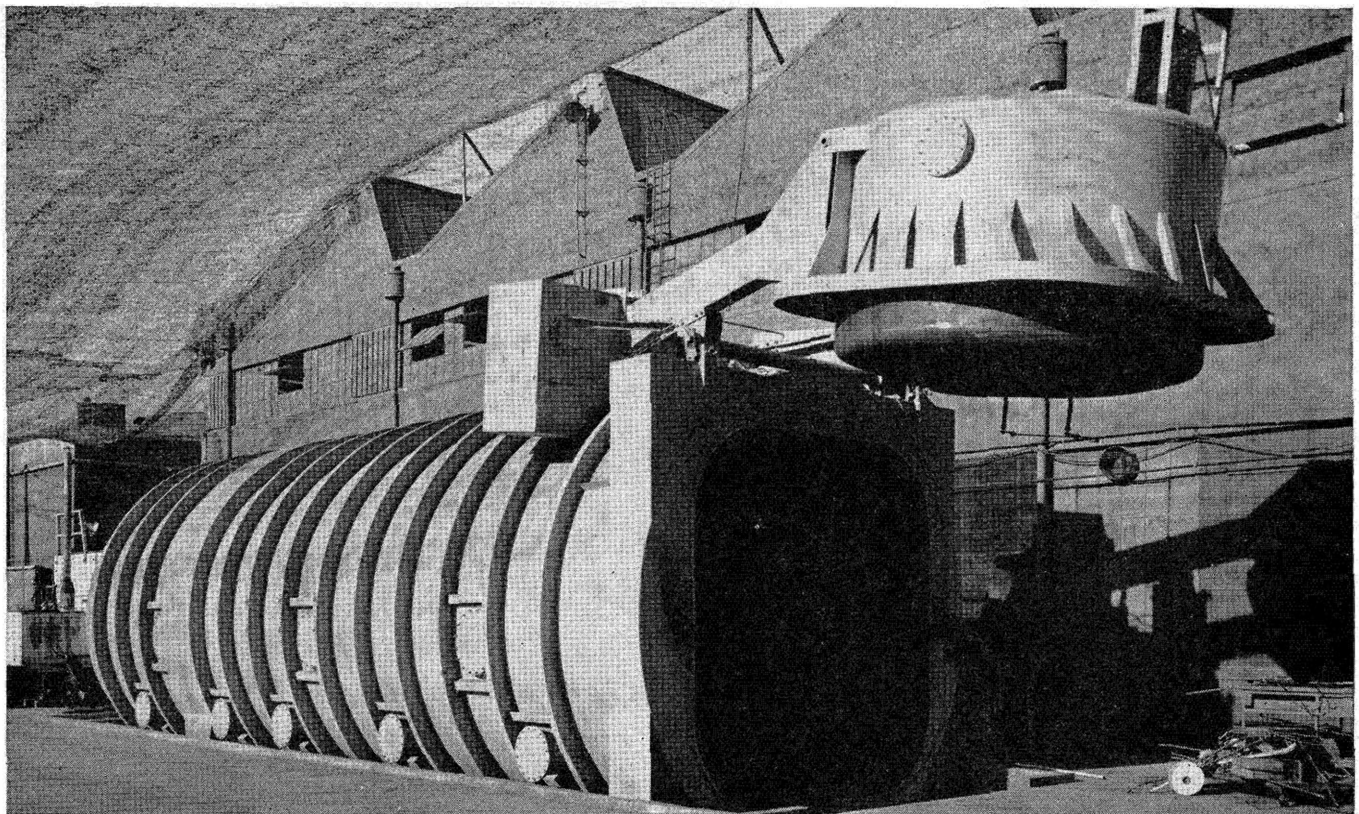
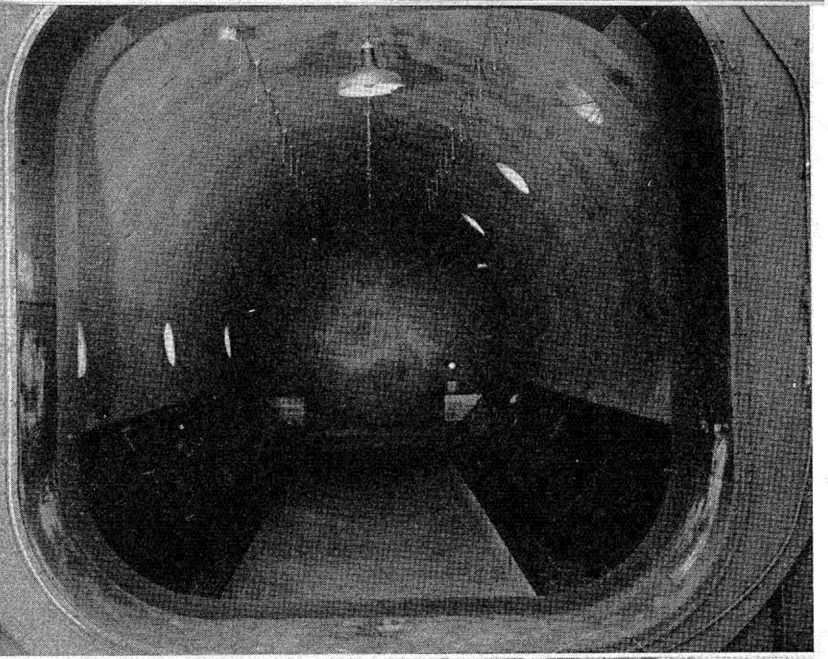
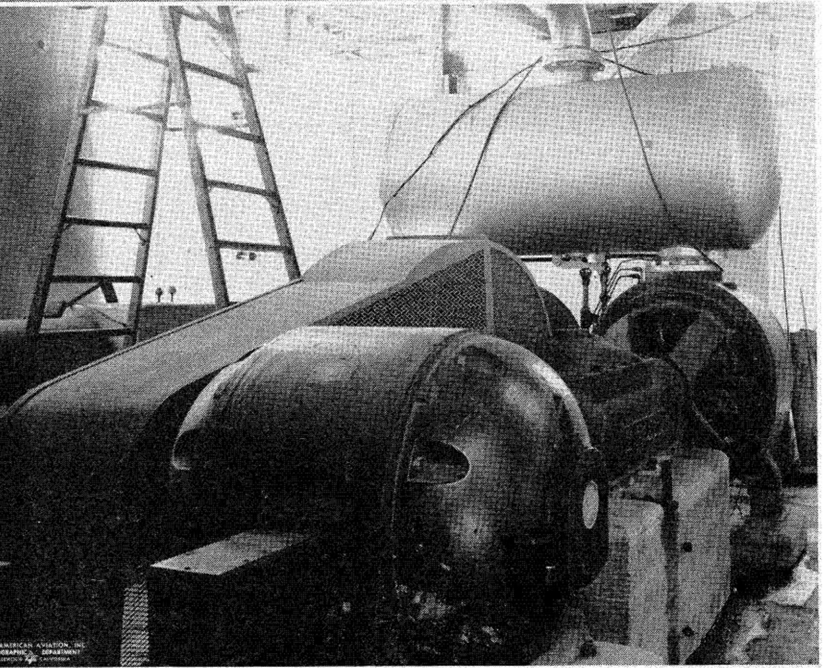


FIG. 2—General view of the chamber shell and door.





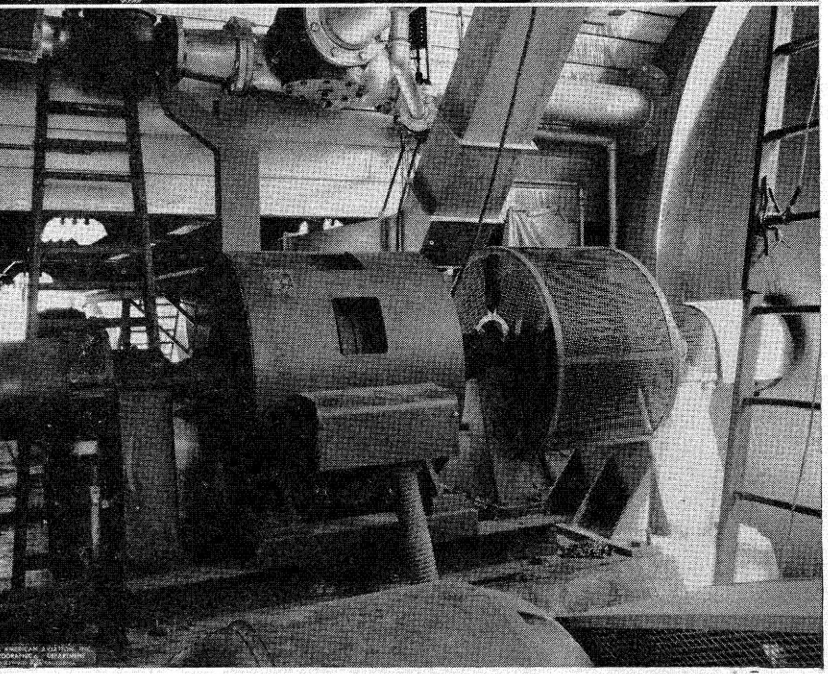


FIG. 3—Chamber interior showing cork lining and floor and fan supports. FIG. 4—Evacuation pump, model drive and receiver. FIG. 5—Fan drive and magnetic clutch.

REFRIGERATION

The relative merits of mechanical refrigeration versus dry ice as a means of cooling were carefully reviewed and several interesting points were brought out. Considerable previous experience had been obtained with equipment utilizing a methyl alcohol-dry ice system in which the chilled alcohol is circulated through conventional heat exchangers. Because of the fact that we had had a more limited experience with very low temperature mechanical refrigeration, a number of installations on smaller altitude chambers throughout the country were studied. The major points considered in analyzing the two methods were: over-all performance, simplicity and reliability of operation, initial cost, and operating cost. Conclusions regarding these items will be briefly summarized.

Systems involving dry ice and a liquid medium (usually methyl alcohol, acetone, or a mixture of the two) have a working low temperature limit of about —100°F., this being fixed by the fluid temperature, which is in the neighborhood of —115°F. A mechanical system can be devised to go as low as this, or even much lower, but it requires several stages, three being ordinarily specified for the temperatures involved in such an installation. Within the limits of the heat exchanger employed, dry ice cooling has the advantage of automatically accommodating itself to the heat load by changes in the rate of consuming dry ice, while the temperature is easily controlled by the fluid circulation pump. In contrast, the mechanical unit is limited in flexibility by the fixed characteristics of its compressors, although this difficulty is partially overcome in multi-stage equipment by the possibility of cutting in successive stages as needed. This lack of flexibility became apparent when calculations showed that a design based on a low limit of —100°F. and a reasonable capacity for heat extraction (say 100,000 B.t.u. per hour at —80°F.) would require several hours to reach —80°F. If the unit were designed to attain —80°F. in thirty minutes it would be greatly oversize and inefficient to operate while being held at some low temperature for a test of long duration. These design problems arise from the necessity of handling large and variable volumes of both liquids and gases through the closed system, which employs a condensable gas for cooling. Correspondingly, in the dry ice method there is some release of CO_2 from the alcohol during its passage through the heat exchanger. However, by the use of an open system the gas coming out of solution is allowed to expand in the return flow and escape from the fluid reservoir to the air. Some studies were made of a semi-closed system in which the CO_2 could be condensed and recovered, but this proved to be uneconomical.

The convenience and reliability of operation with dry ice were strong points in its favor. The only items involved are loading the reservoir with cakes of commercial dry ice, and a trivial amount of upkeep on the small circulating pump. Those familiar with large multi-stage refrigeration installations will appreciate the continuous maintenance involved and the added expense of a qualified stationary engineer to stand by at all times when the equipment is in use. A factor of great importance in the conduct of long tests, costly to re-run, is the chance of equipment failure—negligible in the case of dry ice refrigeration but a very definite possibility with mechanical units.

Cost figures for the two systems were quite surprising. Quotations from the few manufacturers willing to bid indicated an initial investment of about $125,000 for mechanical refrigeration and $10,000 for the dry ice type. Operating cost estimates, based on assumed efficiencies and energy conversions, were 58¢ and $20 per hour, respectively! This would indicate that the mechanical system should soon repay its higher initial cost. However, making reasonable allowances for depreciation, taxes, maintenance, and wages for the stationary engineer for the mechanical refrigeration, it was found that the dry ice system would be cheaper on an annual basis, unless operating time exceeded about 900 hours per year. Furthermore, the operating time would have to exceed about 1,400 hours per year for the mechanical system to pay itself off in its anticipated lifetime. Inasmuch as the estimated operating time was in the neighborhood of 600 hours per year, the economy of dry ice was apparent. This, coupled with the previously mentioned advantages, made dry ice the obvious choice.

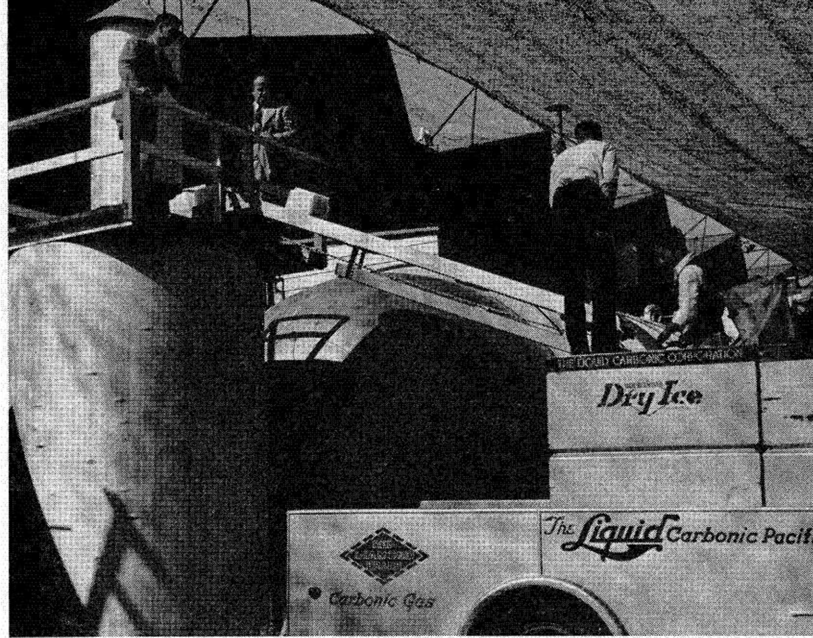
The final important design requirement for the chamber was that all operating equipment and variable conditions should be controlled by automatic recording instruments.

CONSTRUCTION AND BASIC EQUIPMENT

Detail design, construction, and installation of the chamber shell and door, were contracted to the Lacy Manufacturing Company. The shell, fabricated principally of 3/8 inch boiler plate, is 17 feet in diameter and 53 feet in over-all length, including a hemispherical blind end. External stiffening is provided in the form of T-section hoops on 3-foot centers. An additional support encircles the shell between two hoops two-thirds of the distance back from the front open end; this carries two shoulders which are fixed on reinforced concrete pedestal foundations. Similar supports are located at the front end, these being carried on rollers to allow for expansion and contraction of the shell. The entire chamber is set in a concrete lined pit which brings the interior floor to ground level (see Fig. 2).

The main door, approximately twelve feet square with rounded corners, has the form of a box measuring some eight feet from front to back. This section has two smaller doors, one at the front, the other leading into the main chamber, thus forming an airlock for ingress and egress during tests. The door pivots about a point above the front opening and is counterweighted with steel-encased concrete blocks totalling 15 tons. Opening and closing may be accomplished in one minute by means of a 2 horsepower gear-reduced motor. The door seats against rubber sealing strips on the face of the chamber, with no locking required because of a slight overbalance resulting from the pivot location. The outside airlock door seals only against external pressure, while the interconnecting door seals and locks against pressure in either direction. This permits use of the airlock as an independent small altitude chamber (without refrigeration) for physiological work.

An elevated observation catwalk extends along one side of the chamber and leads to the control room, located near the rear end at a slightly higher level. Six viewing ports, 24 inches in diameter, are located, three on one side at eye level above ground, the other three opposite at eye level above the catwalk. Six-pane windows 22 inches in diameter are installed with plastic-impregnated glass cloth retaining rings and impregnated cork gaskets. The pressure pane in each is 5/8 inch thick and the others 1/4 inch, all tempered glass with 1/4 inch spacing. The windows are hermetically sealed with internal desiccant to prevent fogging. Smaller windows are provided in the two doors of the airlock, and there is one in the center of each of the sides at eye level above the ground. Five 18-inch diameter access glands are located on each side of the chamber just above interior floor level. These may be used for mechanical drives,



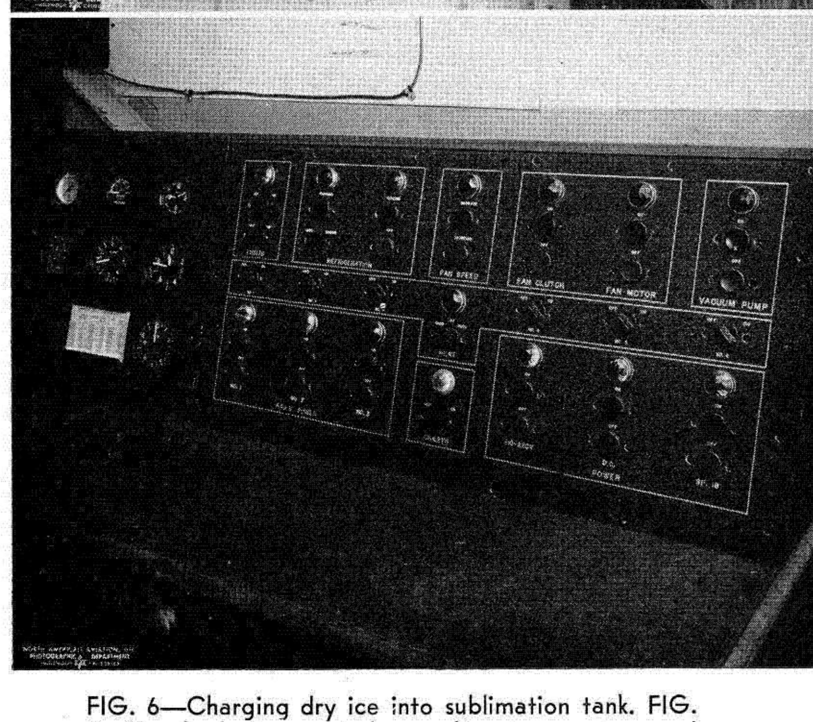


FIG. 6—Charging dry ice into sublimation tank. FIG. 7—Standard air-operated recording temperature and pressure instruments. FIG. 8—Control console.

fluid or power lines, and control or measuring circuits required in the performance of various tests.

The chamber insulation (Fig. 3) consists of a complete 9-inch cork lining in three equal layers of overlapping slabs. The first layer was attached by means of clips and wires, automatic stud-welded to the shell; subsequent layers were wood skewered in place. Each slab was set with a mastic compound developed for sealing pressurized airplane cabins and possessing desirable adhesive qualities over the extreme temperature range to be encountered. The main door has a 9-inch lining on its inner face; the air lock is not insulated. Shoulders of high density cork extend along each side of the chamber for floor supports and the circulating fan is similarly carried on cork pedestals in the hemispherical section at the rear. Replaceable flooring is 2-inch by 12-inch tongue and groove redwood, heavily coated with phenolic varnish. Micarta rubbing strips are installed on mating cork surfaces of the doors and on the cork plugs used to fill those access glands which are not in use. Micarta sheets protect the cork side-walls for a distance of 3 feet up from the floor.

Evacuation equipment includes a duplex, double acting, reciprocating pump with 100 horsepower induction motor and V-belt drive at 277 revolutions per minute (see Fig. 4). The water jacketed cylinders have a 24-inch diameter and 10-inch stroke with 90° opposed cycles, giving a total of four pulsations per revolution and a positive displacement of 2.895 cubic feet per minute. This may be compared with the 8,600 cubic-foot volume of the chamber complete with all interior equipment, but excluding the volume of any test setups. The two vacuum inlets to the pump are manifolded through a small surge tank to an 8-inch line leading from the chamber. A separate 2-inch line connects with the airlock through a section of flexible hose. No difficulties have been experienced with pulsation effects in the chamber, although the original open exhaust was rather objectionable to the ear and caused some vibration in nearby laboratory equipment. Alleviation of this condition by the use of a silencer of the Maxim type was considered, but a simpler solution was reached by exhausting into an underground duct running alongside the pump.

The floor and a plywood "ceiling" form two longitudinal air ducts, each with a cross section of about 9 square feet, and each having an opening just inside the main door. These ducts lead back to a plenum chamber formed by a plywood partition slightly forward of the hemispherical rear section of the main chamber. The fan, located in this section, draws air through the ducts, over upper and lower heat exchangers, and exhausts horizontally through a 34-inch square opening slightly above the center of the partition. Transition ducts may be attached at this point to provide air at higher velocities over small areas, as previously described. The double inlet centrifugal fan is driven by a 150 horsepower induction motor directly coupled to a variable speed magnetic clutch with remote operating control for regulation over a range of 300 to 1,760 revolutions per minute (see Fig. 5). This unit couples to the fan through a floating shaft which enters the chamber wall through a seal of double bellows type. Fan bearings are of the bronze sleeve type, which permits limited axial motion resulting from temperature changes. A thrust bearing is also required to carry the inwardly directed atmospheric pressure loads transmitted by the shaft seal. All bearings, and the seal, run in a special low temperature lubricating oil. The fan is rated at 49,000 cubic feet per minute at 1,165 revolutions per minute and 3-inch static pressure, and 10,000 cubic feet per minute at 1,710 revolutions per minute and 24-inch static pressure; both at 70°F. and atmospheric pressure inlet conditions. Ratings were not available for high altitude or high and low temperature operation.

A sublimation tank, fluid pump, and heat exchangers comprise the refrigeration system. The tank, 5 feet in diameter and 12 feet high, is made of 1/4-inch boiler plate and insulated with 12 inches of cork. Its normal capacity is 700 gallons (alcohol or alcohol-acetone mixture), and 5 tons of dry ice. Fluid is drawn from the bottom by a 7½-horsepower, 450 gallons per minute positive displacement pump, and delivered through a 5-inch line to the two heat exchangers. A return line discharges the fluid in the upper part of the sublimation tank, whence it cascades over the dry ice. The pump and lines are lagged with 5 inches to 8 inches of cork. A motorized conveyor is employed to lift the dry ice blocks to the charging door located in the exhaust stack which surmounts the tank (see Fig. 6).

The heat exchangers, or cooling coils, are mounted above and below the fan. They are each 16 inches deep, 92 inches long, and 45 inches wide, giving a total face area of 47 square feet. Conventional construction is used, with copper tubes and headers, and aluminum fins spaced four per inch. Primary design calculations were based on a required capacity of 500,000 B.t.u. per hour, cooling 3,500 pounds of air per minute from —90°F. to —100°F., with the cooling medium entering the coils at —110°F. and leaving at —105°F. Obviously, much greater cooling rates are attained at higher chamber temperatures when the differential between refrigerant and air temperature is greater. Housed in each heat exchanger are 18 finned Calrod type electrical heating elements. These are connected in six groups, each with a capacity of 36 kilowatts, permitting a stepped heating rate up to 738,000 B.t.u. per hour for heating the chamber or defrosting the coils, when required. In a heating cycle, the refrigerant pump may be reversed to empty the coils of fluid in a few seconds.

CONTROLS AND ACCESSORIES

Operation of all basic equipment is centralized in the control room, which is located above and to one side of the rear of the chamber, and connects with an adjoining general research laboratory. The rearmost upper observation window of the chamber, supplemented by a 180°F. scanning lens, affords a view of test setups or personnel at any location in the chamber.

The Taylor Instrument Companies developed the basic control system, utilizing their standard air-operated recording temperature and pressure instruments, which are panel-mounted above the observation window (see Fig. 7). For the main chamber, provision is made for manual setting of temperature and pressure control points either separately or in conjunction. Provision is also made for automatically increasing or decreasing either or both set points at independently adjustable rates to simulate climbs and dives. A similar system controls pressure in the airlock and is provided with manual and automatic features.

The pressure control instruments operate diaphragm valves in the large and small lines leading from the vacuum pump to the chamber and airlock respectively. Regulation of rate of climb and holding at fixed altitudes are accomplished by this equipment, which also governs dive rates by the controlled admission of air through by-pass valves in the lines. Filtered inlet air may be taken from the atmosphere or from the supplemental conditioned air source described elsewhere. The temperature controller operates the refrigerant pump and heating elements through simple on-off circuits. With this arrangement there is some tendency toward over-riding and hunting. Studies are being made to overcome this defect by proportional input control; for example, by using a variable speed pump or a controlled by-pass in the refrigerant line.

Push-button controls and visual instruments for operating the equipment are grouped in a console (Fig. 8) at the right of the Taylor recording system, with the following items included:

Refrigerant pump—forward, reverse, manual and automatic
Heaters—manual and automatic, 1-6 banks
Fan—motor, clutch, speed control, and tachometer
Vacuum pump
Chamber lighting
Electric circuits to chamber—110, 220, 440 volts AC, 6-28 volts DC, and others
Thermocouples—20-point switch and temperature indicator
Sensitive altimeter
Rate-of-climb indicator
Clock
Oxygen supply and delivery pressures
Recording chart drive

A precision mercury manometer, calibrated in altitude, supplements the altimeter, which is subject to lag and other inaccuracies, and the recording instrument, whose readings cannot be estimated closer than 500 feet.

Additional instrumentation, primarily for the supplementary air source, is contained in another panel facing the control console. Provisions are made for indicating and recording air temperature from the preheater, air temperature and pressure in the receiver following the compressor, and air flow from the receiver to test set-ups in the chamber. Push-button controls for the compressor and heating and refrigerating devices are located in this panel, which also houses chamber humidity indicators and the central equipment for the communication system.

It may be noted that all of the controls described above are for operation of the chamber and accessories. In general, the operator will follow a prearranged schedule for any test run. Through observation of the chamber interior and by communication with other personnel he can satisfactorily carry out this assignment, devoting his attention to safety precautions and other necessary details. Separate facilities are provided for watching and recording the performance of items being tested. A station at ground level opposite the control room utilizes the center observation window of the chamber. The two important permanent installations at this point are a multiple manometer and a multiple point temperature recorder. The manometer has a flat bank of 30 tubes, each with 30-inch scale and usable with positive or negative pressures and various fluids to cover a wide range of measurement. Means are provided for introducing sensitized paper behind the tubes so that all manometer readings can be simultaneously recorded by a single exposure of the paper. The temperature recorder accommodates 140 thermocouples in seven banks of 20 each, with self-contained switching at the rate of one couple every 1.63 seconds, regardless of scale position. Different couple alloys and temperature ranges may be used with the different banks. At present five banks (100 couples) are wired for iron-constantan couples and a range of —150°F. to +800°F., and two banks (40 couples) use a chromel-alumel set for +700°F. to +1,850°F., giving adequate coverage for all contemplated work.

A communication system interconnects the control room and observation station with the chamber and airlock. Combination microphone-speakers are used in the control room and observation stations, with jacks also provided for individual earphones and microphones. Two junction boxes with phone jacks are in the airlock and four sets are spaced along each side of the main chamber, which also has a loud speaker.

The breathing oxygen system, for personnel in the chamber, comprises five aircraft oxygen bottles manifolded together, with lines to eight outlets in the main chamber and two in the airlock. Each outlet has a pressure regulator and instruments: one showing oxygen delivery pressure, the other a blinker signal indicating flow rate. As a matter of convenience in location and use, the oxygen outlets are housed together with the phone jacks in each of the ten junction boxes. Oxygen supply, and delivery pressure at the manifold, are checked by instruments on the main control console.

At the time of writing, details have not been worked out on the means of humidifying air in the chamber and simulating icing of test equipment. Water, saturated vapor, or steam, piped to nozzles at the fan outlet seem to offer the best possibilities, with steam being preferred on account of the lessened tendency to freeze in the inlet line.

To forestall any accidents which might arise during the conduct of tests at elevated temperatures (for example: the operation of combustion type cabin heaters) a fire extinguishing system has been provided. Ten 75-pound CO_2 bottles are manifolded to a distribution system with six outlets in the chamber, each having a conventional fusible plug for automatic release.

The supplementary air system previously referred to draws atmospheric air through a filter and two cooling stages. The first stage, employing a conventional Freon refrigeration unit of approximately two-ton capacity, operates at about +34°F. for removal of a large portion of the moisture. The second stage uses alcohol-dry ice cooling to complete the dehydration at about —65°F. This system was employed because of the greater ease of disposal of the congealed moisture in two increments; and mechanical refrigeration was preferred in the first stage because of simpler temperature control at the desired operating point. Air from the dehydrator is preheated to about 0°F. by an electrical resistance type heat exchanger, from which it is delivered to the compressor inlet. The compressor, with 12-inch bore and 11-inch stroke, has an intake capacity of 305 cubic feet per minute, operating at 300 revolutions per minute from a 60-horsepower, 1,200-revolutions-per-minute induction motor drive. Carbon packing is used in the compressor to eliminate the possibility of oil contamination. Outlet air is delivered to a receiver at 100 pounds per square inch and approximately 250°F., at a rate of 23 pounds per minute. This air may be supplied directly to the chamber or to test set-ups, or it may be further heated in the receiver, to a maximum of 400°F. Both flow and pressure of air from the receiver are controllable.

GENERAL OBSERVATIONS

The inclusion in this article of test data from typical test runs with the chamber was desired; however, this information cannot be made available at present. It may be stated that in all important respects the actual performance of the equipment equals (and in many cases substantially exceeds) the original design requirements. For example, a sea level rate of climb of 10,000 feet per minute has been attained, in comparison with the specified minimum of 7,500 feet per minute. A ceiling of well above 60,000 feet has been reached; the actual figure is in doubt because of the limitations of measuring equipment available at the time. Runs of extended duration have been made at temperatures in the neigh-

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of Ships, and engaged in research and engineering work allied with the Navy's submarine program.

Fred returned to Edison as assistant manager of industrial sales after completion of his project at Columbia University in July of 1945. Recently he has been appointed district manager of the Edison Company's Compton district.

Howard B. Lewis, '23, entered C.I.T. in 1918, when the Institute was still the Throop College of Technology. Due to the loss of a term in his junior year with eye difficulties, he received his B.S. degree "in absentia" in 1923. He taught and studied at Cornell the following year and acquired an M.E. degree from Cornell in 1924.

After a year of teaching physics at Riverside High School, he spent six years with Howard Hughes as an experimental engineer, manager of the Hughes Development Company, and general manager and assistant to the president of Multicolor, Ltd., a production laboratory for the processing of colored and black and white motion picture film. These operations were drastically curtailed when the crash came and Howard Lewis found himself out in the cold world in the bottom of the depression. From this unhappy position he started a ten-year program of the development and proof of a philosophy and formula under which an engineer, or group of engineers, could maintain a reasonable degree of independence of action, and obtain and retain a fair proportion of the earnings resulting from the work done.

Work, worry, and luck brought sufficient success and security to justify expansion, and in 1940 Howard Lewis and Glen M. Larson formed the Lewis-Larson Company. They bought a building at 5959 South Hoover Street, Los Angeles, and remodeled and equipped it to serve as offices, laboratories, and experimental shops for twelve to fifteen men. There they gathered a group of men of varied talents able to do justice to almost any problem in the fields of mechanical, electrical, or chemical engineering not involving the expenditure of great blocks of manpower. The efforts of the Lewis-Larson Company have been devoted primarily to the service of the smaller business which needs high grade engineering services, but insufficient quantities of such service to justify maintenance of an adequate engineering staff of its own.

A REFRIGERATED ALTITUDE CHAMBER

(Continued from Page 9)

borhood of —100°F. and +200°F., with gratifying results as to uniformity throughout the chamber and constancy over the time periods involved.

Cost figures for this installation may be of interest to some readers. The basic chamber and operating equipment cost about $60,000, excluding engineering design time. The complete installation, including those accessories (such as the controlled air source) which are required for special tests, and also including design costs, represents an investment of about $75,000. A continuous and substantial backlog of items awaiting tests is convincing evidence of the usefulness of this equipment.

RECEIVES WILLARD GIBBS MEDAL

DR. LINUS C. Pauling, chairman of the California Institute of Technology chemistry division, and noted for his work on molecular structures, will receive the nation's highest award for progress in chemistry, the 35th annual Willard Gibbs Medal of the American Chemical Society, the society announced June 4.

C. I. T. NEWS

SUPERSONIC WIND TUNNEL

CALIFORNIA INSTITUTE OF TECHNOLOGY has just been granted priority approval by the Civilian Production Administration to erect a $150,000 addition to the aeronautics laboratory of the Guggenheim Graduate School. Housing a hypersonic wind tunnel which will be used for studies of projectiles at higher-than-sound speeds, the five-story structure will also contain classrooms for Army and Navy officers training in the special laboratory. Equipment valued at $90,000 will be installed in the building.

It will be recalled that the Cooperative Wind Tunnel has operating conditions to cover speeds up to the velocity of sound. A $2,500,000 project, financed and owned by four southern California aircraft companies—Consolidated Vultee Aircraft Corporation, Douglas Aircraft Company, Inc., Lockheed Aircraft Corporation, and North American Aviation, Inc.—the Cooperative Wind Tunnel is operated by the California Institute of Technology, and dedicated to the development of aeronautical science in war and peace, in the hope that America will always retain her leadership in the air.

ATHLETICS

By H. Z. MUSSELMAN

Director of Physical Education

ALL the spring sport teams, Track, Baseball, Tennis, and Swimming, experienced a very mediocre season, with victories few and far between. No contests in any of the four sports were won from Southern Conference opponents.

In contrast to the past three years, the 1946 teams were composed almost entirely of inexperienced material, most of which was about one year removed from varsity standards. On the whole, the Caltech teams were a little below pre-war standard, while our opponents, finding a greater response from former service men, were somewhat stronger than normal.

Coach Mason Anderson held a six-week spring football practice with thirty-five men reporting. At present, only one letterman from last year's team, Don Hibbard, end, is in school. However, about six lettermen who played on the 1944 and 1945 teams expect to be separated from the Service this summer, and are planning to enroll at the Institute this fall. Their return will greatly brighten the 1946 football outlook.

INVENTOR OF SYNCHOTRON

A NEW atom-smasher called the synchotron three times as powerful as the betatron, the next largest atom-smasher, is scheduled for completion at the University of California early next year, according to an announcement received from that institution.

The synchotron was invented by Dr. Edwin M. McMillan, one of the co-discoverers of neptunium, element 93, used in the manufacture of the atomic bomb. Dr. McMillan received his B. S. degree in 1928 and his M. S. in 1929 from the California Institute of Technology. As an undergraduate at C. I. T., Dr. McMillan took an active