Table 3 .... Atmospheric Pressure and Altitude

Absolute Pressure mm Hg	Equivalent Altitude in 1000 ft	Absolute Pressure mm Hg	Equivalent Altitude in 1000 ft
760.0	Sea Level	7.6×10^{-4}	300
522.7	10	2.4	320
349.5	20	9.0×10^{-5}	340
226.1	30	3.8	360
141.2	40	2.1	380
87.5	50	1.4	400
54.2	60	9.0×10^{-6}	424
33.6	70	6.3	450
20.9	80	4.8	474
13.0	90	3.7	500
8.3	100	2.6	550
5.4	110	1.8	600
3.5	120	1.3	650
2.4	130	9.3×10^{-7}	700
1.6	140	6.9	750
1.1	150	5.2	800
7.6×10^{-1}	160	3.9	850
5.3	170	3.0	900
3.7	180	2.3	950
2.5	190	1.8	1000
1.7	200	6.9×10^{-8}	1200
1.1	210	3.0	1400
7.1×10^{-2}	220	1.4	1600
4.4	230	6.8×10^{-9}	1800
2.7	240	3.6	2000
1.6	250	2.0	2200
8.8×10^{-3}	260		
4.8	270		
2.6	280		
1.4	290		

Based on 1959 ARDC Standards (Press. to nearest 0.1 mm Hg)

tomarily been designed to simulate altitudes for aircraft up to altitudes of 80,000 ft. Mechanical vacuum pumps are used to produce the vacuum condition. Table 3 gives best current equivalent data on pressure versus altitude. Recently, high altitude chambers have been appearing which are still of the same variety simulating 150,000 to 200,000 ft.

In very recent years, the need for space simulation chambers has become apparent. These chambers use various types of pumps in addition to mechanical vacuum pumps to produce absolute pressure in ranges of 10^{-4} to 10^{-8} mm Hg and above. Ideally, it would be advantageous to have chambers which would produce 10^{-13} mm Hg absolute pressure range, *but practical equipment for testing space packages at these* pressures is not available at this time.

Altitude Simulation

For the purpose of this discussion, the term altitude simulation is limited to the 250,000 ft level (1.6×10^{-2} mm Hg). This type of chamber usually is exhausted by mechanical vaccum pumps or, in special cases, steam ejectors. Various types of pumps are described herein but space does not permit including the rather complex and lengthy calculations required to determine equipment sizes.[3,4] Vacuum chamber size, pump-down rate, gas load from the test, type of gases to be pumped, the ultimate vacuum or altitude to be obtained, the probable outgassing of the structure and gaskets, and the temperature of the chamber all enter into the selection of the vacuum pumping system components.

Mechanical Vacuum Pumps

Rotary piston type pumps and vane type vacuum pumps are most commonly used to produce vacuum conditions within environmental chambers. Single-stage units blank off at approximately 1×10^{-2} mm Hg (10 microns) and two-stage units at 1×10^{-4} mm Hg. It is not practicable to design a system using these pumps to operate near this blank off point as capacity is practically zero. A careful evaluation of the pump performance and an estimate of the gas loads from the test parts and the system must be made to determine system performance.

Systems with gas loads in the micron range often employ positive displacement type blowers as boosters. These blowers, when backed by rotary or vane pumps, give a vacuum usable throughout from 10 to 1×10^{-3} mm Hg.[3]

Mechanical vacuum pumps are displacement machines using a special oil as the sealant. They tend to collect any condensable gases in the crankcase thereby limiting the ultimate pressure to the vapor pressure of the contaminants. Gas ballast is frequently used to help discharge moisture from rotary piston pumps. Crankcase heaters may also be useful. When heavy concentrations of condensables are to be pumped, cold traps (condensers) are often used.

Steam Jet Ejectors

Steam powered ejectors have been used for altitude simulation. These ejectors are mechanically simple and when arranged in five or six stages can produce vacuums in the 10^{-2} and 10^{-3} mm Hg range. Their use is particularly advantageous when corrosive gases or large quantities of condensables are to be pumped. Contaminants do not reduce performance. Initial cost is low if the steam source is not included. Control is difficult and personnel should never be allowed to enter a steam jet evacuated chamber because of the possibility of flash back of the steam. System sizing[4] and component design is based on well-established principles.

Space Simulation

A space chamber is basically a device that produces a near perfect vacuum for simulation of conditions beyond the earth's atmosphere. The requirements may involve high vacuum only or may include the thermal heat transfer problems and other factors encountered in space.

A glass vacuum bell jar may make an adequate small space chamber for limited applications. Large space simulators are necessarily constructed of stainless steel. Oil diffusion pumps, backed by mechanical vacuum pumps and frequently employing low temperature cold traps to aid in pumping are the most commonly used systems. Other types of pumps for small systems include ion, gettering, and cryogenic pumps.

Design considerations for producing the desired vacuum conditions in a space chamber are influenced by the general arrangement of the chamber and its auxiliary equipment.[5,6] It is impracticable, for instance, to locate high vacuum pumping equipment such as diffusion pumps any distance from a chamber because of conductance losses. It is also advisable to distribute the pump suction connections symmetrically around the test space to produce the best results. The investigation of certain types of equipment within the chamber may materially influence the design of the vacuum pumping system. For instance, when optical systems or very sensitive open type electronic systems are to be tested in the chamber, it is necessary to do everything that is practicable to eliminate back-streamed vapors from the pumping system components.

Glass or stainless steel are best for space chambers because they have the least tendency to produce outgassing from their own surfaces. An ideal space chamber is a completely welded system but practical considerations of operations and maintenance prevent this. Gaskets made from elastomers produce certain basic outgassing loads and tend to limit the performance of the practical test chamber. Double seals are currently being provided on high vacuum chambers so that any deterioration of gaskets will not impair the performance and so that gaskets can be chilled to reduce their vapor pressure. Sheared metal and crushed metal seals are sometimes used to overcome some of the deficiencies of synthetic materials. Considerable improvement in performance of very high altitude simulators can be produced within a vacuum chamber by baking the chamber and its pumping system out at high temperature to remove entrained gases.

Space chamber test programs may require weeks, months, or even years to produce the desired data. It is therefore important to consider the economic feasibility of providing multiple pumping systems that can be removed one at a time for maintenance purposes without losing vacuum within the test space.

Diffusion Pumps

These are a form of booster pump using a special oil and jet assembly. In recent years considerable effort has been put into the development of higher capacity diffusion pumps of the oil fractionating and non-fractionating type. Manufacturers have increased performance many fold for the same size pump. Development work to reduce the quantity of back-streamed oil from the typical diffusion pump is producing results in new pumps and cold traps. The sizing of system components[7] is not an established technique but is based on empirical data.

Ion Pumps

Ionization and spattering of certain rare metals within an electrostatic field, will trap random gas molecules. Considerable work has been done to develop this system of pumping vacuum chambers on small systems but less field experience has been obtained on large systems.

Cryogenic Pumping

A cryogenic pump is a condenser operated at a low enough temperature to condense the gases that are present in the system. Thus, if an absolute zero surface could be obtained in an absolutely tight container, all the gas present would eventually condense and the ultimate in vacuum would be obtained. Liquid helium temperatures are near absolute zero and when used to refrigerate large surface areas can pump down systems of large capacity. For further information on the subject of cryogenics, see Chapter 65 of this volume.

Radiant Conditions of Space

A chamber to truly simulate space should be provided with a system of radiant heat transfer which will simulate the absolute zero sump of the sky and a heat source simulating the flux from a sun and the reradiation from planets. Surfaces for low temperature and those having high emissivity within a space chamber may be provided by stainless steel or aluminum *cold plates* filled with liquid nitrogen or other cryogenic fluid. It is necessary to treat the surfaces with a material that will give an emissivity close to 1.0 and yet not outgas or deteriorate under low temperature and vacuum conditions.

The simulation of the sun's heat flux is undergoing considerable developmental study. The sun's spectral distribution has a definite pattern which can be simulated with reasonable accuracy by a high temperature carbon arc or with mercury or Xenon lamps of special design. These systems have practical limitations. The lamps cannot be placed within the vacuum chamber and therefore a complicated system of windows is required. Other systems are used which compromise the spectrum of the sun when simulating the heat flux stresses encountered by an orbiting satellite. Sheathed resistance heaters, quartz tube lamps and similar devices have been used for this purpose.

SYSTEM CONTROL AND INSTRUMENTATION

Control Tolerances

The most distinguishing thing about environmental equipment control is the requirement for close control tolerance over a wide range as compared to that for heat treating, air conditioning, food storage, and similar equipment. Control of temperatures within a test space with a tolerance of ± 5 F deg is considered rough control, with high performance chambers requiring as close as ±0.5 or even ±0.1 F deg dry-bulb temperature control. Relative humidity is usually controlled to ±5 percent rh and sometimes as close as ±1 percent rh. To meet these close tolerances, the instrumentation system selected must have precision of measurement and control better than the specified tolerance for the test space inside the chamber.

Capacity and Load Matching

An environmental chamber usually has ample capacity to provide rapid changes in test space conditions. Consequently, the capacity is not matched to the load at any one control point. This causes additional problems in design of the controlling mechanism which must prevent large swings in controlled conditions. Modulation of the cooling, heating, humidification, or dehumidification capacity is usually necessary in an environmental chamber.

System Types

Dry-bulb control systems are of the type discussed in Chapter 13, Automatic Control, of the 1961 GUIDE AND DATA BOOK. Humidity control is usually obtained by controlling dry-bulb and wet-bulb temperatures using similar instruments and having the temperature sensing element for wet-bulb temperature equipped with a wet-bulb wick. A variation of the standard independent wet- and dry-bulb system is the use of two resistance bulbs, one wet and one dry, differentially connected to a single potentiometer which then reads wet-bulb depression. Greater control accuracy is possible with such a system as the instrument scale is extended. Wet bulbs must be designed for adequate wetting and for air velocity of about 1000 fpm which is optimum.

Direct reading and control of relative humidity are used only for special cases because most humidity tests are required at temperatures beyond the range of commonly available humidity transducers. Dew-point control of relative humidity suffers from the same disadvantages, though the recent introduction of the electrolytic hygrometers offers a system for dew points between 5 and −100 F. When controlling very low relative humidities, it may be necessary to exhaust a small amount of the air from the chamber across a wet-bulb