A typical large clean room, one of almost 80 such rooms at ISRO. Photo courtesy ISRO.

HVAC for INDIA'S SPACE PROGRAM

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Space activity is a multi-disciplinary effort requiring inputs from different sources of which airconditioning & refrigeration is one important field. It is difficult to envisage progress in space sciences considering the reliability that is required for research and development, without the use of airconditioning & refrigeration.

The Indian space program made a very modest and humble beginning in a dilapidated church building in Veli, Thiruvananthapuram, Kerala, sometime in the year 1969. Since then the program has grown by leaps and bounds and presently it encompasses a wide spectrum of applications serving national interests.

The Department of Space, of which the Indian Space Research organization(ISRO) is the main constituent, is involved in carrying out R&D in satellite and launch vehicle technology with a goal to achieve self reliance. It provides national space infrastructure for the telecommunication and broadcasting needs of the country, in addition to satellite services for weather broadcasting and monitoring. Satellite imageries are also available for survey of natural resources and the security needs of the country, for developmental and societal applications involving tele-education, tele-medicine and village resources. All these actions are achieved by providing satellite transponders and facilities to meet communication and TV broadcasting.

About the Author

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Currently, two major operational space systems viz. INSAT (Indian National Satellite) and IRS (Indian Remote Sensing) satellites are available. Two operational launch vehicle systems viz. PSLV (Polar Satellite Launch Vehicle) and GSLV(Geostationary Satellite Launch Vehicle) are currently available to inject the satellite payloads into the required orbits.

The manufacture of the satellite and launch vehicles involves the setting up of hi-tech infrastructure at various locations depending on the sub-assemblies. All operational systems are essentially qualified after sufficient research and development takes place. The basic R&D involves the development of launch vehicle and associated technologies in such varied fields such as aeronautics; avionics; composites; computers and information technology; control, guidance and simulation; launch vehicle design; mechanical engineering; mechanisms, vehicle integration and testing; propellants, polymers, chemicals and materials; propulsion, propellants and space ordnance; and system reliability.

Air conditioning for the above applications essentially involves maintenance of controlled conditions of temperature, humidity, cleanliness and in certain cases, specific air flows. Typical environmental conditions are:

Temperature : 22±2°C
Humidity : 50±5% RH
Cleanliness : 20/ 5/ 0.5 micron (whichever applicable, depending on the application)
Velocity : as applicable.
Positive pressure: 15 pascal (for clean rooms)

The ensuing paragraphs describe in detail, the role of HVAC in various activities related to space programs.

Use of Clean Rooms

Many of the processes are carried out in clean rooms of required class. A number of clean rooms of non-unidirectional type involving class 100,000 to class 10,000 are available. For very specialized processes having critical electronics involving fabrication, assembly and testing of different types of gyroscopes, momentum wheels, solar array drives etc, unidirectional clean rooms of class 100/ 1000 with horizontal air flow are established. These clean rooms are around 24 m x 10 m x 3m in dimension. Similar clean rooms are established for assembly, packaging and testing of hybrid thick film circuits, screen printing, development of hydraulic control systems etc.

For integration of space hardware of large dimensions such as liquid motors and stages, large spaces with adequate material handling facilities are needed. Integration is carried out in controlled atmosphere involving class 100,000 clean rooms. Such facilities are generally large with footprints ranging from 200m^2 to 500m^2 and heights ranging from 8m to 18m.

The design, development and manufacture of payload and subsystems such as transponders, meteorological and remote sensing cameras calls for large clean rooms with typical environmental conditions indicated earlier.

The acquisition of data and processing of the same for remote sensing applications again calls for large clean rooms with typical environmental conditions. These involve equipment and dark rooms associated with film processing.

Manufacture of Composites

The manufacture of composites used in upper stage rocket motors calls for use of CMM (co-ordinate measuring machines) where controlled atmosphere and specified temperature gradients are to be maintained (0.5°C/hr, 0.5°C/m and 2°C over 8 hours) and in such cases, the air flow has to be regulated to ensure that typical indoor environmental conditions as stated above, are maintained. This is done by utilizing permeable fabric air ducts made out of washable polyester so that no drafts are created and preventing heat ingress by providing suitable insulation to the building envelope. Control of relative humidity is carried out through heater banks controlled by current valves (silicon control rectifiers—SCR) and actuated by means of a BMS system.

Manufacture of Solid Propellants

The manufacture of solid propellants calls for airconditioned rooms where special vertical mixers are used. In the earlier days (early 70's) these called for low humidity areas and safety was a primary concern. Since RH values were less than 35%, vapor barrier treatment was required and to maintain these low RH values considering the hazardous nature of the process, special flameproof electric strip heaters were used. Also since no electric controls were allowed, pneumatic controls to regulate chilled brine flow were used to maintain temperatures.

However with the development of better propellant chemicals and with the advent of rotating bed solid desiccant chemical dehumidifiers, matters are considerably simplified and presently, normal airconditioned atmospheres with relatively higher RH values are permitted. However hazardous classifications for areas where solid propellants are manufactured, still exist.

Manufacture of Space Ordnance

The manufacture of space ordnance used in pyro-devices, igniters and separation devices calls for

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spaces with indoor temperature ambient conditions of 22°C±2°C and low humidity requirements of less than 35%. Since handling of explosives in group II A/ II B atmospheres is involved (as per Indian Standard IS–2148 & IS–2206), special care has to be taken in providing special earthing for all electrical equipment, use of flameproof motors, rotating bed solid desiccant chemical dehumidifiers and occasionally once- through airconditioning systems. Necessary care to prevent passage of explosive particles by using suitable filters is also required.

Manufacture of Propulsion Systems

Liquid and cryogenic propulsion systems call for design and system engineering of earth-storable liquid and cryogenic engines, and stages for launch vehicles. Design and development of bipropellant thrusters and electric propulsion thrusters for spacecraft, control components and control systems are also needed. These activities call for close environmental control and in some cases clean rooms of Class 10,000/ 100,000. Environmental conditions maintained are typical, as enumerated earlier, in facilities of large dimensions having material handling equipment. Facilities handling stage insulation processes have once-through air systems, since toxic chemicals are involved. Some of these facilities are also hazardous in nature and electric equipment is selected for Group IIA/ IIB atmosphere classification. Storage of rocket stages is done in large air conditioned rooms of around 1000m^2 area having a height of 15m, with emphasis on humidity control, and having material handling facilities.

Satellite Systems

The preceding paragraphs dealt with the launch vehicle hardware design, manufacture and storage facilities. The aim of launch vehicle systems is to deliver spacecraft/ satellites to their intended orbits. The subsequent paragraphs deal with the design, development, testing and storage of spacecraft / satellite systems.

Satellite systems are designed for specific scientific, technological and application missions. Generally these are divided into three categories:

- Communication and weather satellite systems
- Remote sensing satellite systems
- Scientific satellite systems

Satellite systems are a package of mechanical and electronic systems. The satellite consists of various subsystems which are assembled on a structural grid. These subsystems mainly consist of packages for:

- Telemetry, Tracking and Command(TTC)
- Power, consisting of solar array panels(for generating power from sunlight and charging the batteries)
- Batteries(generating power during eclipse periods)
- Control systems to ensure stabilization of satellite and orient the satellite in a particular direction
- Sensor systems consisting of Sun, Earth and Star sensors to provide reference directions
- Payloads such as transponders for communication satellites, cameras for remote sensing satellites and experiments for scientific satellites.

All the processes concerning the manufacture, integration and testing of these satellites call for controlled atmospheres mainly consisting of large clean rooms of Class 10000/ 100000. The manufacture of electro-optic sensors and subsystems calls for more stringent Class 100 unidirectional clean rooms which are of modular construction. Typical temperature, RH and clean room conditions are provided, with dark rooms in some specific cases. The testing of satellites, in various modes, is carried out in *Thermovac* chambers of varying diameters which simulate vacuum and thermal conditions of outer space.

The Compact Antenna Test Facility

The ground testing of satellite antenna and communication systems calls for a compact antenna test facility (CATF) with stringent environmental conditions. The facility consists of a reflector of 66 tons mass and a sub reflector of 33 tons mass. These reflectors are of highly polished surfaces of large dimensions. The facility is fairly large with an area of approximately 600m^2 with special pyramidal shaped foam absorbers for the walls, ceiling and floor. Environmental requirements call for a typical clean room and temperature gradient of 1°C between the front and back of the reflectors, and 1.5°C between the top and bottom of the reflectors. In addition the gradient has to be maintained at 0.2°C/ hr during operational periods and 1°C/ hr during non-operational periods. To maintain these conditions/ gradients, vertical laminar flow conditions are established locally by suitably locating the supply and return air paths and to maintain a velocity not exceeding 0.2m/s.

Storage of Propellants

After all launch and satellite systems and subsystems are made available, they are assembled at the launch site. The launch of a vehicle needs large quantities of propellants, both solid and liquid. Solid propellants are manufactured in vertical mixers. The storage of liquid propellants calls for refrigeration for underground storage tanks which contain skin toxic liquid propellants. Chilled brine (mono ethylene glycol) at –1°C is piped to

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these underground tanks to keep the propellants within safe temperature limits.

The storage and handling of cryogenic propellants (liquid hydrogen-LH2 and liquid oxygen-LOX) calls for a high degree of safety. Liquid hydrogen, which has a wide flammability limit, is colorless and odorless and the flame is almost invisible. This calls for equipment and motors with Group IIC classification in airconditioned spaces. These spaces also have once-through air systems and air ducts have special fail-safe back-draft dampers operated by weights.

The Launch Site

The testing of satellite systems at the launch site is carried out in large size clean rooms of Class 100,000 with typical environmental conditions. The satellite is then moved to the launch site.

Earlier, up to the mid 90's, the integration of the launch vehicle and the satellite used to take place at the launch site inside the mobile service tower (MST). The MST would then be moved back just before the launch leaving only the vehicle at the umbilical tower (UT). The MST is a huge structure with a footprint of 700m^2, height of around 75m, weighing more than 3400 tons and mounted on 32 wheels each 1.2 m in diameter. The MST is fully airconditioned with a vertical laminar flow clean room for the satellite stage and the rest of the areas normally air conditioned. Because of the very nature of construction of the MST, leakage of conditioned air is inevitable and hence this has to be factored in while designing the airconditioning system. During the process of launch vehicle integration and the satellite mating, the total MST is kept in closely controlled environmental condition. Since fuel filling operations take place inside the MST, the whole area is treated as hazardous. The satellite which is mated to the launch vehicle is also to be kept under closely controlled environmental conditions (a class 10,000 clean room at a height of around 45m). The satellite at this point of time is in an active mode, with the payload power switched on, and surrounded by the fairing (heat shield). Consequently the satellite system has to be kept under closely controlled environmental conditions. This is done by means of a satellite cooling system which pumps in conditioned air at a rate of 1800 kg/ hr at 10°C, 55% RH, a high pressure of 625mm wg and Class 10,000 cleanliness level. All the low side airconditioning equipment is installed inside the MST at different levels, with the high side installed outside, some distance away from the launch pad. As the MST is mounted on wheels and has to be moved back before launch, flexible removable braided hose connectors for the chilled water piping between high and low side are installed.

Photo 1 : India's PSLV rocket stands inside the vehicle assembly building.

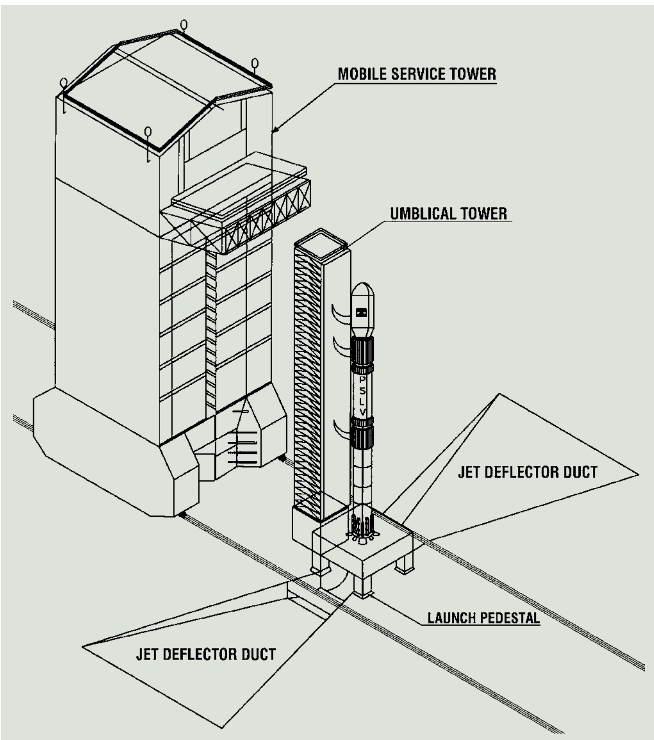

Figure 1 : Mobile service tower used for integration of the launch vehicle and the satellite upto the mid 90's

Subsequently, with improvements in integration processes and for easier workability, the integration and assembly of the satellite with the launch vehicle now takes place inside a vertical assembly building (VAB) see *Photo 1* having a footprint of 768 sqm and a height of 82m, The VAB is a fully airconditioned facility with a Class 10,000 clean room for the satellite stage and normal airconditioning for other areas. Since fuel filling operations take place inside the VAB, the whole area is treated as hazardous. The different stages of a launch vehicle including the strap-on motors are assembled in a vertical mode inside the VAB on a wheeled assembly vehicle similar to the MST. The satellite is the last piece

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of hardware to be mated to the launch vehicle before the launch. A satellite cooling system pumping in 4000kg/hr of air at environmental conditions as stated in the preceding paragraph is also provided. After integration the wheeled vehicle is moved to the launch pad which is 200 m away from the VAB and parked next to the UT for the launch.

Tracking of Orbiting Satellites

Once launch takes place and the satellite follows its intended orbit, it has to be tracked and subsequently controlled. This is done through telemetry and tracking facilities located at various places around the country and abroad. Telemetry and tracking functions for communications and remote sensing satellites are carried out from different facilities since communication satellites are in geo-stationary orbits (around 35,700 km above the earth) and remote sensing satellites are in low earth orbits (around 600/900 km above the earth) and having different orbital paths. All such tracking facilities are essentially airconditioned with typical environmental conditions.

HVAC Equipment in ISRO

ISRO has close to 80 clean rooms with a total area in excess of 8000m^2 located all over the country, to guarantee the reliability that goes into the manufacture of space components, in addition to large centrally airconditioned areas. Around 25,000TR of central airconditioning systems are available to condition these clean rooms and other laboratories. Airconditioning equipment ranges from small DX systems utilizing open/semi-hermetic reciprocating and scroll compressors to very large systems using open/ hermetic centrifugal and screw compressors. System capacities range from 10 TR in single installations to 2000 TR using multiple package chillers. Refrigerants used are predominantly R-22 with a few systems using R-134a. Secondary refrigerants are mostly water for normal applications and mono-ethylene glycol for low RH and process applications. Large water/ brine chilling units installed in the late 90's are equipped with microprocessor controls for efficient use of power. Building management systems (BMS) using DDC are also provided in many specific cases for remote operation and control of chillers and airhandling systems. All airconditioning plants and air handling units in the launch pad area are remote operated from the launch control center situated 6 km away from the launch site.

Precision ACs

For applications using computer and server systems, precision control package units have been installed in various capacities at various centers. Apart from these, many conventional package unit systems for airconditioning laboratory facilities have been installed in addition to countless unitary window and split airconditioners, including cassette type splits. Of late VRF systems have also been considered for specific applications.

Conclusion

The Indian space program has to its credit 25 launches with 49 spacecraft put into orbit including 8 spacecraft for foreign countries. Currently 11 communication satellites with 210 transponders and 7 remote sensing satellites are orbiting the earth.

Challenges in the future will be to implement the scientific mission to the moon, *Chandrayaan-1*, the Manned Space Program and missions to distant planets. The manned space program will especially pose many new challenges and developments required in life support systems, improved reliability and safety, crew escape system etc. While a few of these facilities are available in the country and could be used with augmentation, others have to be established afresh. Airconditioning and refrigeration will play no small part in this national endeavour. ❖