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SAFETY SYSTEMS FOR SATELLITE TRANSPORTATION

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SYNOPSIS

Programme critical, high cost and delicate space hardware like satellites built with pressurised tanks, sensitive optics, delicate electronics and hazardous chemicals need protection from various environmental hazards during transportation by road and air. These hazards are categorised into mechanical, climatic and electrical hazards. The mechanical hazards include shock, vibration and handling loads. The climatic hazards include temperature, humidity, rain, dust, different pressure, fire, etc. Electro static discharge and RF radiation are electrical hazards. These hazards lead to one or the other kind of damage like functional impairment, distortions, breakage, high stresses, condensation, corrosion, contamination and other forms of destruction. Specially designed transportation systems incorporating various safety devices to offer adequate protection during transportation are developed and successfully used for all satellites built by ISRO.

Key words: Satellite, Environmental hazards, Safety Devices, Transportation, ESD protection, Rapid Decompression.

INTRODUCTION

ISRO Satellite Centre has pioneered the art of developing sophisticated satellites for communication, remote sensing and weather forecasting. Increasing demand has imposed many complexities in the development of satellite in terms of overall mass, size, optimisation of power, mass budget, etc. Present day state of art satellite contains highly sophisticated, delicate and sensitive electronics, optics, pressurised tanks and hazardous chemicals. These satellites need to be transported to various test facilities and launch site by road and air. Thus, the systems used for transporting the satellite also need to be highly sophisticated to protect the satellite from all environmental hazards that may be encountered during packing, storage and transportation.

A simple packaging technique started with a wooden crate to carry Engineering Model of Aryabatta satellite, the forerunner of Indian Satellite Programme to Cosmodrome, Russia, during 1973 has now grown in multitude, comprising many sophisticated state of art protective systems. The present day Satellite Transportation System (STS) comprises following sub systems:

- Shock and Vibration Isolation System
- Pressure Equalisation and Rapid Decompression System
- Passive Thermal Control System
- Gaseous Nitrogen Purge System
- Passive Dehumidification System
- Handling Devices and
- Transit Data Acquisition System

These systems protect the satellite from environmental hazards and monitor the environmental parameters during shipment. The following paragraphs describe in brief the hazards encountered during shipment, protection offered by various sub-systems of STS, their features, and the various qualification tests performed.

ENVIRONMENTAL HAZARDS

The destructive environmental factors that are likely to affect, adversely, the satellite during handling, storage, packing and transportation are indicated in Fig. 1. These hazards depend on various factors like the size and weight of the STS, type of aircraft, condition of roads, speed of travel and climatic conditions during storage and transportation.

MECHANICAL HAZARDS

The usual mode of satellite transportation is by road and air. Table 1. Illustrates the various shock and vibration levels experienced during road and air transportation. The equivalent handling loads related to handling with over head crane, forklifts are expressed as 100 mm edge drop of STS.

CLIMATIC HAZARDS

The ambient temperature may vary from -50°C to +50°C and humidity may go up to saturation on a rainy day at seashore locations. The satellite and some of its sub systems like batteries etc., are to be maintained between -10°C to +25°C. Also, the relative humidity need to be maintained between 40 to 50% RH to avoid corrosion and static charge buildup.

Rain and dust are other hazards, which severely contaminate and deteriorate the optical systems of the satellite. It is essential to have a leak proof sealed container for this purpose and in some cases pressurised containers are proposed to prevent dust in-flow. Excessive pressure variation occurring during air transportation is a major catastrophe and positive relief system is a mandatory part of the STS.

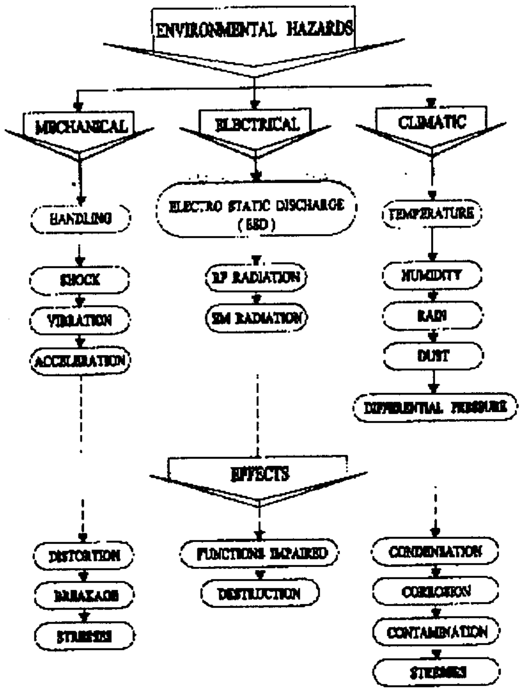
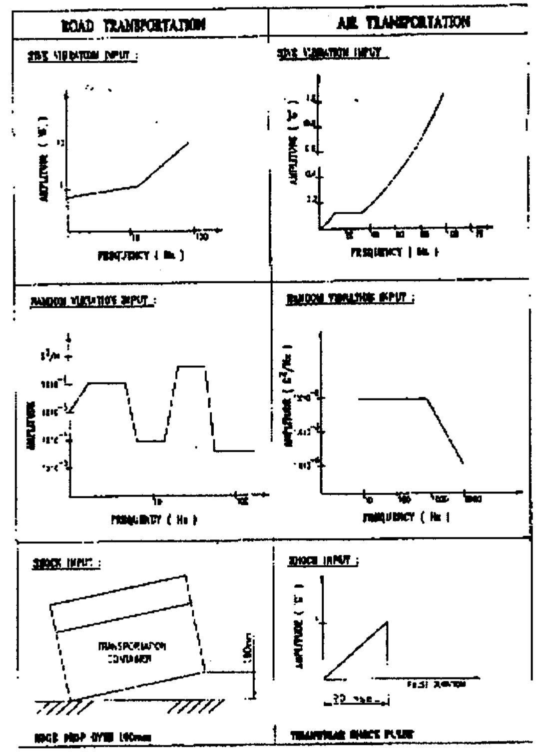


Fig.1 Environmental Hazards and their Effects

TABLE I. TYPICAL MECHANICAL ENVIRONMENTAL HAZARDS EXPERIENCED DURING TRANSPORTATION



ELECTRICAL HAZARDS

Electro Static Discharge and RF radiation are the two important sources of hazards that can cause destruction or impairment of electrical functions of the satellite and its various subsystems.

PROTECTION SYSTEMS:

Shock and Vibration Isolation System

The isolation system comprises helically wound isolaters. These isolaters are designed to offer a low natural frequency to isolate the relatively high frequency vibrations that lead to fatigue caused structural damage. They also exhibit a non-linear softening stiffness characteristic by under going large deflection to absorb energy during impact and shock loads. The interstrand displacement within the wires of the cable offer coulomb friction damping which reduces the transmissibility at resonance frequency greatly. By proper mathematical modeling during analysis and followed by tests, the stiffness and damping properties are tuned to meet the specific satellite dynamic response for the input conditions. Also, for road transportation, controlling the speed of travel wherever feasible brings down the shock/vibration level to a greater extent.

Pressure Equalisation and Rapid Decompression System:

During air transportation, the STS is placed in the cargo compartment of the aircraft. The cargo compartment of the aircraft undergoes pressure fluctuation, which is schematically shown in Fig. 2. Under Normal Flight Conditions, the cargo compartment pressure decreases from atmospheric pressure at sea level to a minimum of 737 mbar during climb at the rate of -89.63 mbar/min. During descent, the pressure increases back to standard sea level pressure at the rate of +53.78 mbar/min. Wherever, during emergency (rapid decompression) conditions, the cargo compartment pressure drops linearly from normal pressure of 737 mbar to the standard ambient pressure of 147.5 mbar corresponding to flight altitude of 13716 m, in one second. The STS is a large cubical shell structure measuring 5.8 m x 40 m x 4.0 m and designing the panels of the container for the above said pressure conditions would result in a heavier container which is difficult to handle and transport.

Hence, STS is equipped with Pressure Equalisation System (PES) which allows controlled breathing of air in and out at the set sealing pressures and prevent excessive pressure/vacuum build up inside the container. Standard Low Pressure Two-way Breather Valves, (Sealing Pressure = 35 mbar) having volumetric flow rate estimated in relation with the volume of the container and rate of change of pressure, are chosen to protect the satellite from the pressure fluctuations experienced during Normal Flight Conditions.

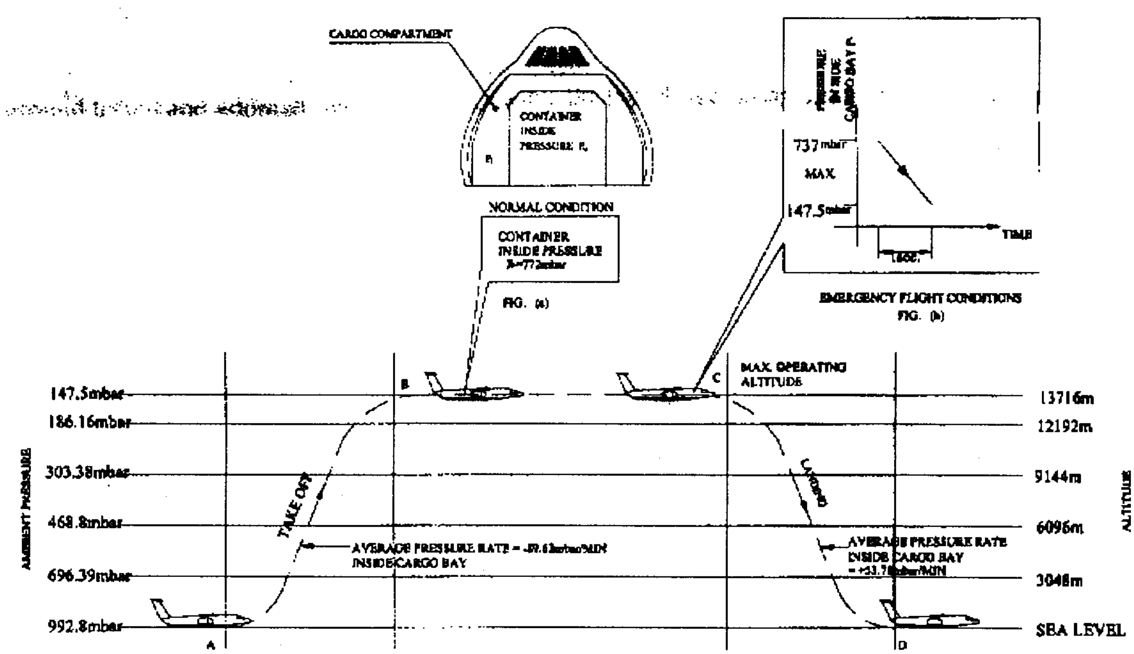


FIG.1. PRESSURE VARIATIONS INSIDE CARGO COMPARTMENT

However, the rate of pressure drop during emergency is very large and this condition needs a large opening in the container to equalize the pressure within a short time, which are not met by standard breather valves. An opening as large as 225 cm^2 per cubic metre volume of the container is required to meet this condition. The STS is totally sealed and made airtight to meet the cleanliness requirements and so having such openings, permanently, is not permissible.

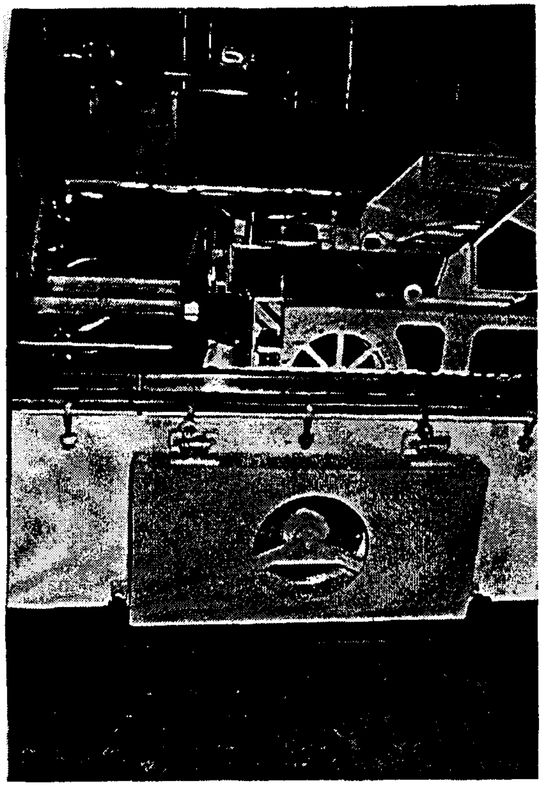


Illustration 1: RDS assembled on Transportation System for INSAT 2E Satellite.

The occurrence of the emergency condition, though less probable, is catastrophic to the STS and hence to the precious hardware packed into it. Considering the above emergency situation, during air transportation, a novel Rapid Decompression System (RDS) has been developed, ground tested and adopted.

The RDS supersedes in performance compared to the conventional Dead Weight Snap Panels and Burst Diaphragms. Unlike the Dead Weight Snap Panels, RDS does not involve pressure balancing dead weights and thus it is one order less in weight. Also, the performance of RDS is not affected by the acceleration/deceleration and angular orientation of sTS during airlifts. The Burst Diaphragms are not generally adopted for the application in STS as they cannot be reset for subsequent airlifts after occurrence of rapid decompression and they need to be replaced with new assemblies for protecting the STS in such instances.

Illustration 1. Shows the RDS assembled on Transportation System for INSAT 2E Satellite.

The mechanism incorporated in the RDS is a self-contained sensor cum actuator which seals the container up to a predetermined sealing pressure, actuates a hold down latch at a calibrate cracking pressure and initiates the opening of a panel door of large area for instantaneous pressure equalisation.

Passive Thermal Control System:

The extreme temperature limits may be encountered during transportation to various tests and launch centres may be +50°C. But some of the critical components of the satellite like Ni-H_2 batteries need to be maintained between -10°C to +25°C even during storage conditions. This problem needs to be overcome by adopting suitable temperature control system in the STS.

Thermal coupling between the satellite and the ambient is through:

- Natural convection between satellite and the inner wall of the STS,
- Conduction through the walls of the STS and
- Natural convection from the outer walls of STS to the ambient during storage and forced convection during movement.

Considering the ambient temperature, temperature to be maintained inside the STS, speed of travel and duration of travel a thermal mathematical model was developed, analysed and verified by a scaled model. Based on the above studies and the results obtained a two walled insulated container is incorporated for the STS. The insulator is specially developed polyurethane foam having density of $32 Kg/m^3$ and thermal conductivity of 0.015 K cal/mhoC as its characteristics. It may be noted that during INSAT-2E satellite transportation, the STS was equipped with an environmental data recorder, which confirmed that the temperature remained within the permissible limits.

Gaseous Nitrogen Purge System:

Some of the critical components of the satellite like power transfer rotary slip ring assembly need to be protected from humidity to avoid corrosion and contamination. Selective nitrogen purge system is conceived and adopted locally to protect all such sensitive components of the satellite. The highly purified dry nitrogen gas used in this purge system offers an inert atmosphere around the sensitive components apart from providing spark suppression characteristics. A typical flow rate of such a system is about 0.1 ft^3/min.

It is also possible to purge the entire satellite with gaseous nitrogen, on specific requirements, to totally prevent the inflow of external air during air shipment. However it is generally restricted due to the need of bulk volume of nitrogen to be carried along with the STS during shipment.

A typical nitrogen purge system comprises flow control valves, pressure regulators, check valves, pressure relief valves and filters to offer unattended purging throughout the transit.

Passive Dehumidification System:

The amount of moisture intrusion into the STS depends on the amount of air gulped during the storage and transportation. As discussed earlier, the STS is provided with Two-day breather valves, in order to prevent excessive pressure/vacuum build-up. The sealing pressure set at the valves is an important factor, which defines the amount of air breathed-in. During ground storage, due to fluctuations in the ambient temperature, in a day, the differential pressure across the wall of the container also varies proportionately.

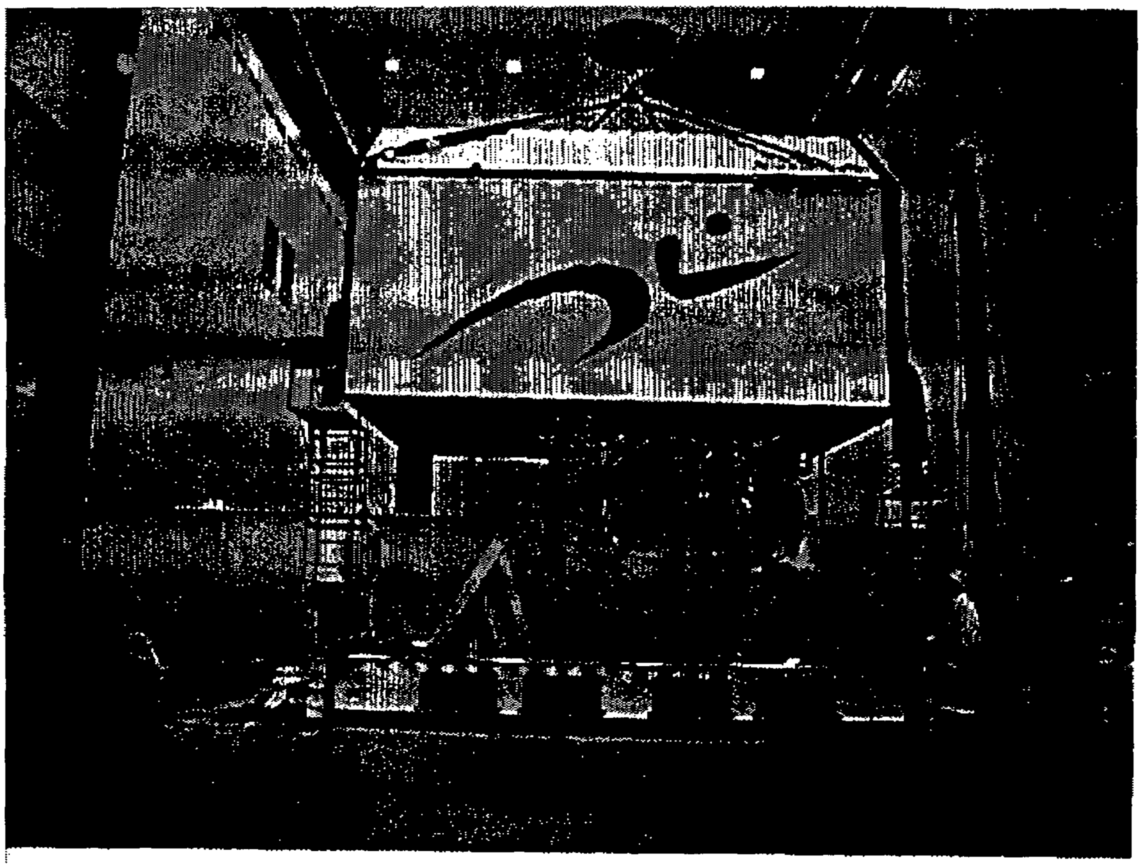


Illustration 2. Transportation System for INSAT 2E Satellite

Long term test results indicate that valves with sealing pressure at 17 mbar will open almost everyday while valves set to seal at 35 mbar open only 5 to 6 times a year and valves set for 70 mbar never open during storage. There are few locations in the world where greater temperature variation occurs. Hence it is suggested that valves set at 35 mbar will not open more than 30 times a year, considering worldwide transportation. Since the satellite shipment does not exceed a week's time, it is very unlikely for a valve set at 35 mbar to open during storage.

The total moisture intrusion also greatly depends on the number of airlifts. It is evident from Fig. 2, that during each decent, the cargo compartment pressure (737 mbar) builds back to normal sea level pressure. Thus, a valve set at 35 mbar allows ambient air to flow inside the container during every descent of aircraft. The quantum of desiccant required is estimated taking into account of the entire transportation profile like transit duration, number of airlifts, volume of the container, the relative humidity and temperature of ambient air maintained in the cargo bay.

RF AND ESD PROTECTION

The design of STS ensures the electrical integrity of all the mechanical parts. The resistance between one end of the STS to the other end is kept less than 1W. The satellite inside the STS is also electrically connected to the STS through a braid, which ensures low resistance between the satellite and the STS. Under these circumstances the STA acts like a Faraday Cage. The double walled panel of the STS is also expected to give good shielding effect for both magnetic fields as well as electric fields. Thus the satellite is protected from the RF radiation.

The ESD can be classified into two categories, namely, the one caused by electric charge accumulated on the operating personnel and other caused by charging of the STS when it encounters with plasma environment. Man made ESD does not cause any problem because the container is always grounded and any amount of charge can not reach the satellite. Charging on the satellite due to space plasma does not take place since the STS does not encounter the space plasma. Thus the satellite is protected from both ESD and RF radiation.

STS SIZING AND ITS IMPACT

The overall sizing of the STS needs to be worked out with utmost care since the STS may have to overcome number of hurdles during transportation. They include limitations posed by high tension cables, bridges, trees, telephone and electric lines and narrow path ways encountered during road transportation. Also the door size of the aircraft cargo bay can be a hurdle during loading.

In order to optimize overall dimensions of STS a Rotary turntable has been designed and developed for the STS. This table, working on the four bar link mechanism principle, allows the loading of satellite into the STS in vertical mode and then turns the satellite to the horizontal mode thus enabling compact sizing of the STS. By adopting this technique the STS is totally protected from all the hazards that may be encountered during road and air transportation.

HANDLING AND OTHER APPENDAGES

The STS is provided with requisite handling and manoeuvering devices which include crane handling devices, fork lift handling devices, lashing interfaces, self-steering stowable castor wheels, tow bars, screw jacks etc. These devices adopt foolproof design and are built with adequate margin of safety to ensure the safe movement, lifting and transportation.

TRANSIT DATA ACQUISITION SYSTEM

The system makes the detailed record of environmental data like shock, vibrations, temperature and humidity encountered by the satellite during the complete transit duration. The system is a microprocessor based programmable device comprising built-in accelerometers, temperature and humidity sensors, signal conditioners and RAM for storing the data. This system facilitates reviewing of the transportation history and the environmental condition encountered by the satellite.

Illustration 2 shows STS built to meet the transportation requirements of INSAT 2E satellite.

TEST AND QUALIFICATION

A detailed test matrix is worked out and implemented during various stages of realisation of STS. They are identified in three major categories as shown in Table 2.

FURTHER DEVELOPMENTS:

- Air Suspension System for satellite transportation,
- Active Temperature and Humidity Control System and
- Flexible and inflatable encapsulation for satellite are the further developmental activities under way at the Mechanical Integration Div., AITG, ISRO Satellite Centre, Bangalore.

Table 2. Test Plan for Satellite Transportation System		
Static Tests	Dynamic Tests	Pressure & Leak Tests
Crane Handling Test	Vibration Isolator Characterisation	Water Tightness Test
Fork Lift Handling Test	Drop Test	Proof Pressure Test
Load Test and Stiffness test on Suspension Frame and Structural members	Road Transportation Test	Leak Rate Test
Load Test on Vibration Isolators		Cracking Pressure on Breather Valves and Rapid Decompression System.

CONCLUSION

A sophisticated transportation system incorporating Shock and Vibration isolation system, Pressure Equalisation System, Rapid Decompression System, Passive Thermal Control System, Gaseous Nitrogen Purge System and Passive Dehumidification System has been designed and developed for transporting satellites by road and air. Each and every sub-system has been designed and analysed for its characteristics followed by development and performance verification at the hardware level. The system has also been subjected to static, dynamic, pressure and leak rate tests at various levels before its acceptance for transportation of satellites. The multi-purpose INSAT 2E satellite was successfully transported using the STS from India to French Guyana during the first quarter of 1999.

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ABBREVIATION USED

STS – Satellite Transportation System

RDS – Rapid Decompression System

PES – Pressure Equalisation System

ESD – Electro Static Discharge

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