Advanced Materials Research Vols. 588-589 (2012) pp 1161-1167
Online available since 2012/Nov/12 at www.scientific.net
© (2012) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.588-589.1161

Environmental Data Acquisition System for Satellite Transportation

Shashank Srivastava*, Shreeniwas Sahu, A.Sekar, K.V.Govinda

ISRO Satellite Centre, Airport Road, Bangalore, INDIA
e-mail: shashank@isac.gov.in

Keywords: Environmental Data Acquisition System (EDAS), Shock Response Spectrum(SRS), Global Positioning System(GPS), Polar Satellite Launch Vehicle (PSLV),GeoSynchronous Launch Vehicle(GSLV), Power Spectral Density(PSD), Indian Standard Time(IST), Percentage Error(% Er) SatelliteTransportation System(STS), Recorder Control Parameters(RCP), Spacecraft/Satellite(S/C)

Abstract. Program critical, high cost and delicate space hardware like satellite built with pressurized tanks, sensitive optics, delicate electronics and hazardous chemicals need protection from various environmental hazards during transportation. These environmental hazards include shock, vibration and handling loads and climatic hazards such as temperature, humidity, rain, dust due to harsh ambient atmospheric conditions etc. The Satellite Transportation System (STS) is equipped with adequate protection and monitoring system. The environmental data acquisition system is used to monitor the environmental conditions of satellite during transportation. This paper describes the data acquisition system used for quantitative validation of shock and vibration attenuation system and temperature and humidity control system. The acquired data are processed and interpreted to express the environmental conditions during various phases of development such as road survey analysis, performance validation and refinement of design for the shock and vibration isolation system of trucks and STS. Further, these data are used for the post-transportation health assessment of satellite that are vital to minimize post transportation tests on satellite.

Introduction

ISRO Satellite Centre builds the state of art sophisticated satellites for communication, remote sensing, scientific experiments, weather forecasting and interplanetary missions. Increasing demand and challenges has imposed many complexities in the development of satellite in terms of overall mass, size, optimisation of power, etc. Present day state of art satellite contains highly sophisticated, delicate and sensitive electronics, optics, pressurised tanks and hazardous chemicals. Satellites are generally designed and optimized for the launcher loads encountered during various stages of launch. These loads include Quasi-static, Sine vibration, Random vibration, Acoustic and Shock loads. The typical launcher loads [1-3] for satellite design consideration as applicable to launch vehicles Ariane 5, GSLV and PSLV respectively are given below. The longitudinal direction refers to the vertical axis or the thrust axis of the launch vehicle.

a) ***Quasi-static loads:***

Acceleration [g]					
Ariane 5		GSLV		PSLV	
Longi.	Lateral	Longi.	Lateral	Longi.	Lateral
4.55[g]	0.25 [g]	4.1 [g]	0.2 [g]	7.0 [g]	1.5 [g]

b) ***Sine Vibration levels:***

Longitudinal: (Acceptance Level)					
Ariane 5		GSLV		PSLV	
Freq [Hz]	Ampl. [g]	Freq [Hz]	Ampl. [g]	Freq. [Hz]	Ampl. [g]
2-50	1.0	5-10	5 [mm DA]	5-12	4.5 [mm DA]
50-100	0.8	10-50	1.0g	12-38	1.2
-	-	50-100	0.5g	38-60	1.2-0.5
-	-	-	-	60-100	0.5

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of TTP, www.ttp.net. (ID: 218.248.39.241-12/12/12,11:47:51)

sweep rate: 4 [Oct./min.]					
Lateral: (Acceptance Level)					
2-25	0.8	5-10	2.5 [mm DA]	5-7	4.5 [mm DA]
25-100	0.6	10-50	0.5	7-30	0.45
-	-	50-100	0.25	30-100	0.30
sweep rate : 4 [Oct./min.]					
DA - Double Amplitude					

c) ***Shock Levels (All three Axes):***

Ariane 5		GSLV	PSLV	
Freq. [Hz]	SRS [g]	50[g], 10 [ms], half sine, one/axis/direction	Freq. [Hz]	SRS [g]
100	20		100	20
400	650		1000	1500
665	880		5000	1500
1000	2000		-	-
10000	2000		-	-
SRS- Shock Response Spectrum				

Satellite is required to be transported to various test facilities and launch sites by road and air during various phases of Assembly Integration and Testing (AIT) and launch preparations. The mechanical hazards encountered during transportation include shock, vibration and handling loads. The climatic hazards include temperature, humidity, rain, dust etc[5]. It is important that these environmental conditions experienced by the spacecraft should be significantly low and benign compared to launcher loads.

Satellite Transportation System (STS)

The satellite is transported by specially designed Satellite Transportation System (STS) that are equipped with sophisticated state of the art protective systems [5] viz.

- Shock and Vibration Isolation System
- Pressure Equalisation and Rapid Decompression System
- Passive Thermal Control System
- Gaseous Nitrogen Purge System
- Passive Dehumidification System
- Temperature and Humidity Control System
- Handling Devices and
- Environmental Data Acquisition System (EDAS)

Environmental Data Acquisition System (EDAS) referred here is used for monitoring, acquiring, logging, processing, analyzing and interpreting the environmental conditions experienced during the transportation. EDAS forms the validation system for the protective systems of STS that are designed to control and attenuate environmental hazards to S/c to benign levels.

Objectives

Environmental Data for Satellite Transportation.

EDAS is to perform the functions of multi channel monitoring and logging of relevant data during satellite transportation. These processes are required to be performed unattended, automated in a programmed way with built-in intelligence to log only the relevant data using predefined Recorder Control Parameters (RCPs). The program logics enable selective acquisition of significant and relevant data and thus avoid large size data collection that happens during continuous data acquisition. The condition for selecting data are fed during initial set-up through RCPs. Subsequential, these logged data are processed, analyzed and interpreted to generate useful database and corrective feedback for the improvements in the design of various protective systems. Further, since the satellites are transported within and outside the country, EDAS is required to be operative throughout the shipment duration, which varies from few hours to days and rugged to withstand the environmental conditions during the transportation.

Post-Transportation Health Assessment of S/C .

EDAS shall be capable of processing, analyzing and interpreting the acquired data for review of the relevant parameters which are significant to the satellite. By review of recorded data at the base and at the critical locations on the satellite, inferences are derived to assess the health of the satellite and its critical subsystems. Few of the post transportation verification tests may be called off by ascertaining the benign condition of the environmental influences on health of Spacecraft.

Validation of Suspension Systems.

Shock and vibration input levels to the satellite is a function of road conditions, vehicle speed, suspension system of vehicle, sprung and un-sprung masses of vehicle, suspension system of STS & S/C physical properties. The validation tests of these systems are done separately. EDAS is useful for the validation of suspension systems for various loads and road conditions.

The test results obtained from EDAS are used for tuning the isolator stiffness of the STS. The suspension system supporting satellite consists of number of links and moving elements, which enables tilting of satellite for horizontal transportation. During transportation all the moving links/elements are being locked. So, it is essential to establish the system integrity and performance of system under dynamic load conditions. This is carried out by monitoring acceleration levels along with associated frequency data at various locations on the suspension system and links.

Road Survey Analysis.

Road test is performed to characterize the integrated Satellite Transportation System carrying satellite simulation mass. The response at various locations on the simulator is monitored and analyzed in EDAS. The test is performed at various speed and various road conditions to predict dynamic load during flight model satellite transportation.

Environmental Data Acquisition System (EDAS)

EDAS is a multi-channel digital waveform recording system for shock, vibration, temperature and humidity measurements. Fig.1 shows block diagram of EDAS. EDAS is modular system and acquire the vibration data from three channels to maximum twenty-seven channels and one channel to maximum nine channels for temperature and humidity data. EDAS is designed to operate in continuous or in trigger mode operational. The continuous mode of operation is used for short duration and trigger mode operation is used where test duration is long and data size exceeds the available storage device. The trigger mode is based on setting acceleration value and useful for satellite transportation to cutdown insignificant vibration data.

EDAS uses peizo-resistive accelerometers, which offers superior low frequency response to record transportation vibration. The in-built temperature compensation feature of sensors measures data accurately in practically over a wide range of ambient temperature. The integrated temperature sensor measures both temperature and humidity data at different locations. Each sensor in EDAS is tagged with channel no. and unit no. Few salient features of EDAS are:

- Simultaneous digital acceleration waveform recording for all the channels.
- Auto DC offset correction before data acquisition.
- Automatic Date & Time tagging on records.
- User selectable channel triggering
- Fill & Stop/ Overwrite memory modes.
- Event based data partitioning of memory.
- Onboard memory for data storage.
- Upto twenty days unattended recording operation.
- Compact and self-contained mounts in any orientation.
- Remote download via internet connection.

EDAS has dedicated analyzer to remotely communicate and upload/download data to and from recorder. Analyzer is used to upload Recorder Control Parameters (RCPs) to EDAS. RCP defines the editable control parameters like sampling rate, trigger level, no. of samples per window (event), pre-trigger & post trigger samples and memory modes. The data is processed in analyzer for interpration and analysis in various forms.

- Full waveforms of single or multiple events, tabular view of recorded data showing date, time, peak, rms etc.
- Compuation of velocity and displacement.
- Data Differentiation for jerk computation.
- FFT/DFT-based PSD analysis.
- Shock response spectrum (SRS) for transient data analysis.
- Inference about natural frequency and mode, observing the peak transmissibility.
- Transmissibility computation by transfer function between two channels.

Test & Evaluation of EDAS:

EDAS undergoes testing and evaluation in regular interval before satellite tranportation. The total system (end to end) is validated for amplitude and frequency. Several runs of test are carried out to validate EDAS. Table A & B shows typical test results of EDAS.

Table A: Amplitude Test

The test was intended to validate sensors output for acceleration amplitudes of 1g, 2g and 4g at frequencies 10Hz, 40Hz and 100 Hz. The results are given for frequency 40Hz. Similar results are seen at 10 & 100 Hz also.

Channel No.	Acceleration Amplitude [g]					
	1[g]	%Er	2[g]	%Er	4[g]	%Er
1A	1.018	1.8	2.003	0.15	3.987	0.32
2A	1.021	2.1	2.029	1.45	4.033	0.82
3A	1.023	2.3	2.018	0.90	3.995	0.12
1B	1.020	2.0	2.013	0.65	4.005	0.12
2B	1.018	1.8	2.036	1.80	4.029	0.72
3B	1.008	0.8	2.012	0.60	4.015	0.37
1C	0.997	0.3	1.985	0.75	3.948	1.30
2C	1.003	0.3	2.003	0.15	3.982	0.45
3C	1.001	0.1	1.998	0.10	3.969	0.78

Table B: Frequency Test

The test was intended to verify the sensors response in frequency domain for frequency range 10-100 Hz. Frequency range is choosen to encompass transportation frequencies.

Channel No.	Frequency [Hz]					
	10[Hz]	%Er	40[Hz]	%Er	100[Hz]	%Er
1A	9.94	0.60	40.16	0.40	99.25	0.75
2A	9.94	0.60	40.16	0.40	99.25	0.75
3A	9.94	0.60	40.16	0.40	99.25	0.75
1B	9.96	0.40	40.16	0.40	99.25	0.75
2B	9.96	0.40	40.16	0.40	99.25	0.75
3B	9.96	0.40	40.16	0.40	99.25	0.75
1C	9.94	0.60	39.98	0.05	99.75	0.25
2C	9.94	0.60	39.98	0.05	99.75	0.25
3C	9.94	0.60	39.98	0.05	99.75	0.25

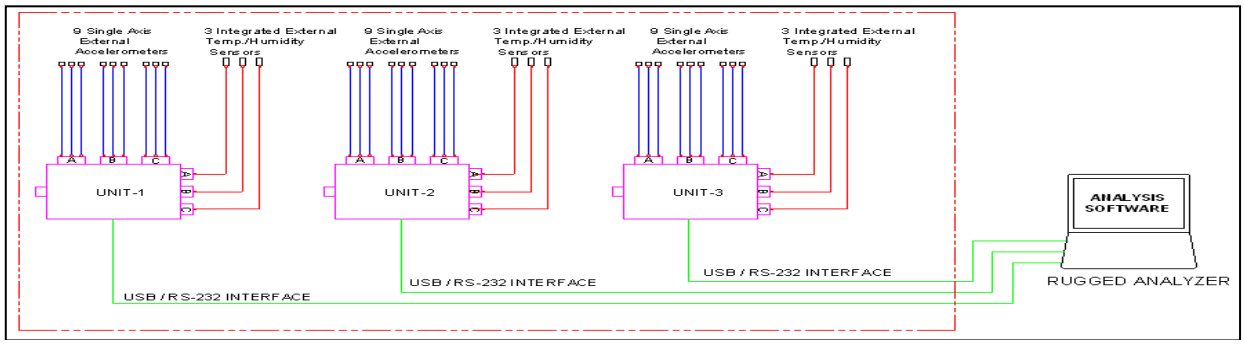


Fig.1 Block Diagram of EDAS

Satellite Transportation

EDAS is extensively used for satellite transportation within & outside India to test facilities and launch center. Fig.2 shows satellite transporation with EDAS. Different modes of transportation viz. Road, Air etc. are being adopted for satellite transportation. The duration of satellite transportation in each modes varies from few hours to days. During each mode of transportation, satellite encounters different environmental conditions.

The Environmental Data Acquisition System is being used successfully for number of satellites within and outside INDIA.The data acquired using EDAS from these transportation were crucial in declaring the benign environment of transportation load and safe transportation of satellites.The data were also useful for road survey analysis, fine tuning of isolation system for subsequent satellite transportation.

It is also observed from the satellite transportation data that contrary to the beliefs of long duration shock and vibration environment the effective duration of shock & vibration above 0.4g is only for few seconds of travel duration of several days.Further on frequency analysis , peak levels are observed most of the (1-20 Hz) low frequencies that considered to be quasi-static acceleration to S/C. At few occasions the peak levels to S/C are found to be high frequencies, which is mainly shock loading due to condition like application of brakes or landing shocks during air transportation.

Refer plot for temperature & humidity environment, the average temperature & humidity condition near the S/C is maintained around clean room condition(21±2ºC and 50±5 %RH). The deviations from the cleanroom condition is due to extreme ambient environmental condition as shown in Fig:4&5.

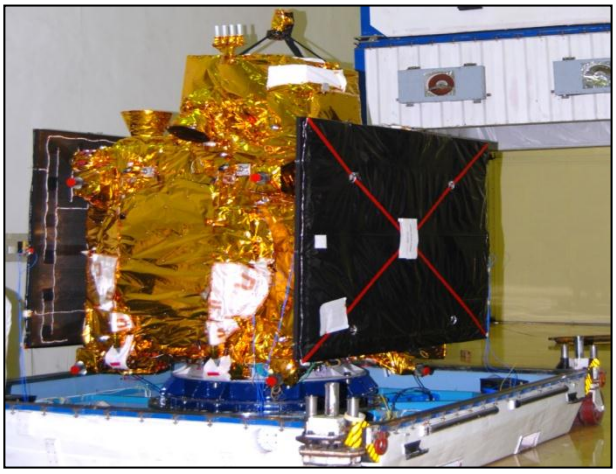


Fig.2 Satellite Transportation System with EDAS

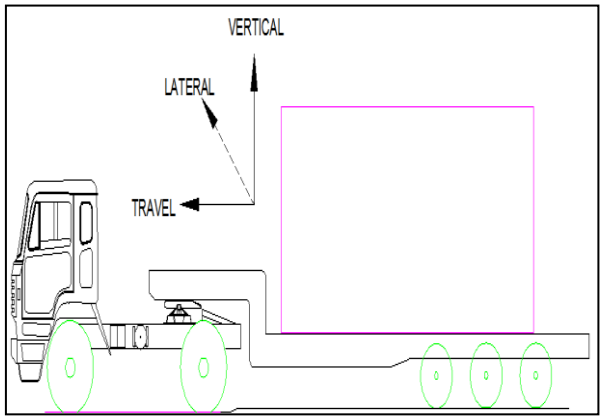
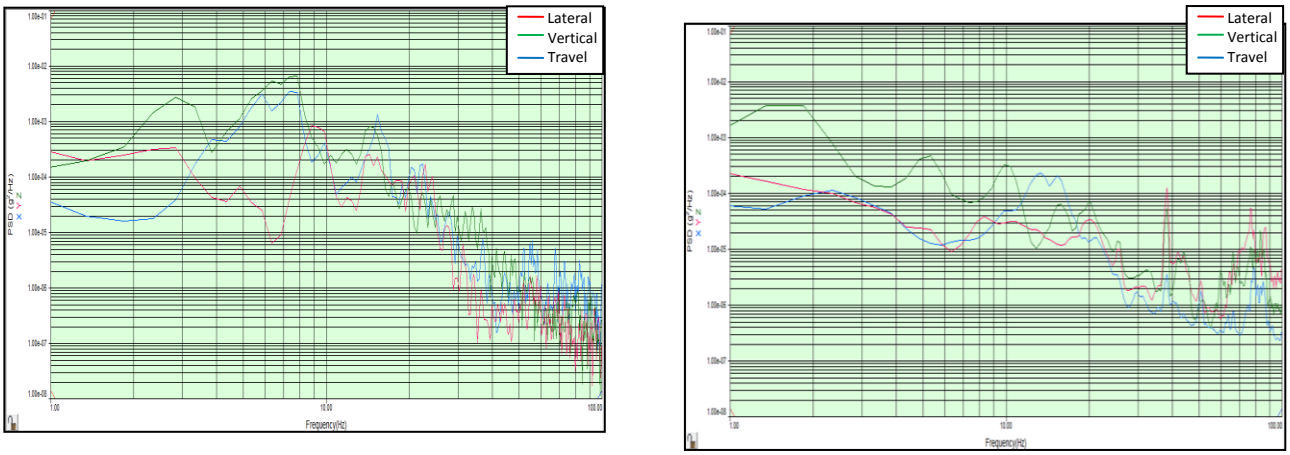


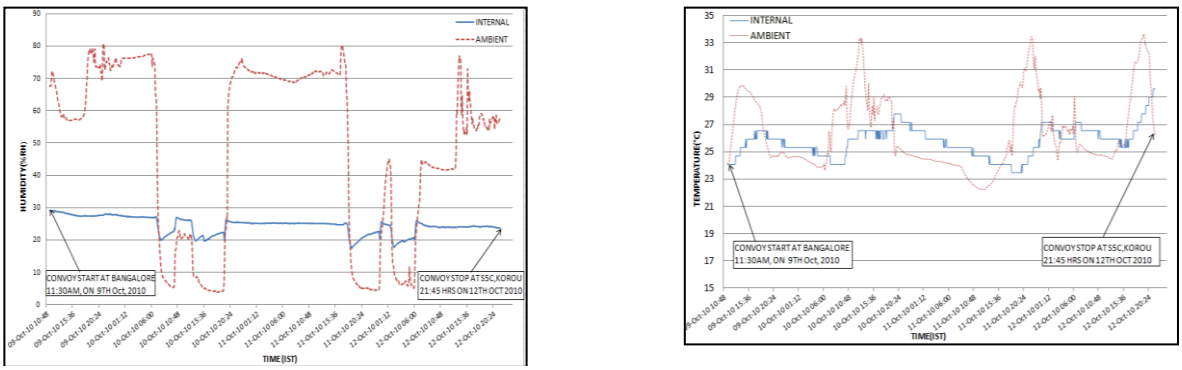
Fig.3 AxisDefinitionforSatelliteVehicle

Table: C

Spacecraft Projects	G_{RMS} (up to 100[Hz])			No. of events ≥0.4[g]	Max. Acceleration (0-peak)						Temperature [°C]		Humidity [% RH]	
					Lateral Axis		Vertical axis		Travel Axis		Min.	Max.	Min.	Max.
	Lateral	Vertical	Travel		Amp. [g]	Freq. [Hz]	Amp. [g]	Freq. [Hz]	Amp. [g]	Freq. [Hz]				
a) S/c Transportation (with in India) Mode: Road														
Spacecraft-1	0.090	0.060	0.040	4	0.48	14.6	0.41	1.5	0.28	11.2	20.7	24.2	36.4	63.3
Spacecraft-2	0.080	0.060	0.030	10	0.48	15.1	0.59	5.1	0.48	37.5	20.1	23.3	38.3	61.0
Spacecraft-3	0.062	0.076	0.030	9	0.50	12.0	0.41	9.5	0.48	12.0	19.5	25.7	32.5	68.8
Spacecraft-4	0.070	0.090	0.040	6	0.24	2.9	0.62	3.2	0.65	5.0	20.7	24.0	32.7	66.8
Spacecraft-5	0.050	0.090	0.060	7	0.33	14.7	0.60	11.7	0.35	22.5	18.9	24.9	36.8	73.1
Spacecraft-6	0.090	0.100	0.070	1	0.10	12.4	0.12	11.2	0.54	1.3	19.8	23.9	35.7	70.0
Spacecraft-7	0.055	0.100	0.058	8	0.17	16.8	0.45	1.5	0.43	25.0	18.9	23.0	36.3	73.5
Spacecraft-8	0.076	0.130	0.070	15	0.45	13.5	0.55	1.5	0.50	1.6	16.6	22.9	30.0	68.0
Spacecraft-9	0.089	0.092	0.065	3	0.14	2.0	0.57	80.0	0.64	24.0	14.9	24.1	33.0	78.0
b) S/c Transportation (outside India) Mode: Road – AIR – Road														
Spacecraft-10	0.082	0.144	0.145	21	0.57	15.2	0.64	5.9	0.77	4.4	21.3	28.9	37.6	56.9
Spacecraft-11	0.040	0.080	0.110	23	0.30	8.8	0.58	6.4	0.66	6.8	22.5	27.5	26.7	56.8
Spacecraft-12	0.033	0.079	0.069	7	0.23	8.5	0.50	6.0	0.37	11.5	22.5	30.7	31.0	55.9
Spacecraft-13	0.102	0.152	0.164	14	0.60	4.3	0.63	7.3	0.68	3.9	22.5	33.0	19.0	32.1
Spacecraft-14	0.062	0.152	0.113	2	0.20	8.3	0.51	7.3	0.40	5.4	23.5	29.0	19.0	29.0



Vibration Environment (PSD Vs Frequency)



Temperature Environment (Temp. Vs Time)

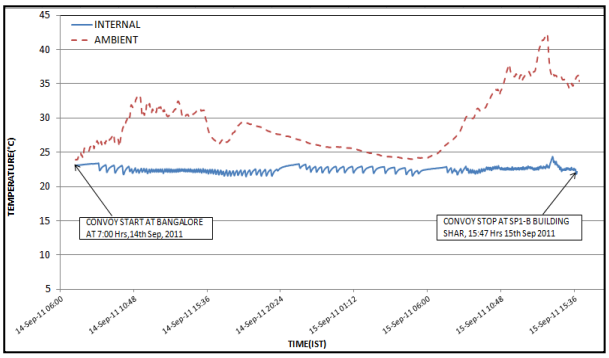
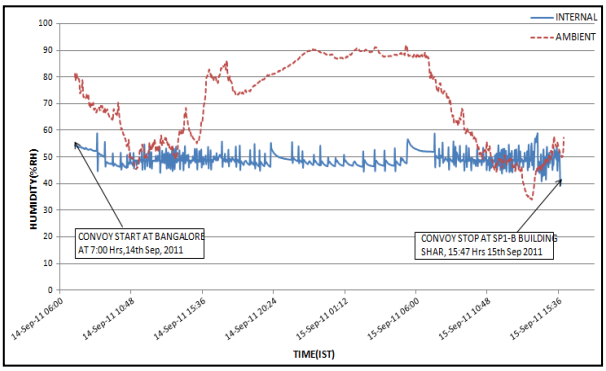


Fig.4 Satellite Transportation to Kourou, *French Guyana* (MODE: ROAD-AIR-ROAD)



Humidity Environment (Humidity Vs Time)

Fig.5 Satellite Transportation to SHAR, *India* (MODE: ROAD)

The axis shown in Table C represents the S/C orientation with respect to transporting vehicle axis as shown in Fig.3. Various plots in Fig.4 and Fig.5 shows typical acceleration, temperature and humidity conditions near S/C during full period of transportation within and outside India.
The plots confirm that these design parameters are achieved & controlled well within the launcher specification.

Summary

Environmental Data Acquisition System (EDAS) developed for satellite transportation is an essential subsystem of STS. Since its inception the system has been used successfully for a number of satellite transportation within and outside India. Data interpretation by EDAS helped in drawing conclusions and confirming the benign environmental condition during satellite transportation. With the help of this data, many critical, costly and time consuming tests on spacecraft can be avoided at launch site, which is essential to reduce the risks in carring out many tests at last moments and also to reduce the overall launch campaign cost. Referring to the summary of transportation data, considering the very low input levels and the capability to quantitatively express environmental conditions, it is worthwhile to utilize the present data to relook at the tests at launch base.

This exercise minimizes the spacecraft preparation duration and test activities at launch base and thus helps optimum utilization of spacecraft time and attendant.

References

[1] Ariane 5 User Manual

[2] GSLV User Manual

[3] PSLV User Manual

[4] “Shock & Vibration Hand Book” By Harris, Crede.

[5] “ Environmental Control and Safety System for Spacecraft Transportation” in 19th national convention of Aerospace engineers, Jaipur.

Advances in Mechanics Engineering
10.4028/www.scientific.net/AMR.588-589

Environmental Data Acquisition System for Satellite Transportation

10.4028/www.scientific.net/AMR.588-589.1161