Special Theme: India's Reusable Launch Vehicle Technology Demonstrator: The Future of Space Transportation System

K. Sivan¹ · Naresh Ch. Murmu²

Published online: 18 November 2017
© The Institution of Engineers (India) 2017

Indian Space Research Organisation (ISRO) has successfully demonstrated on certain critical technologies of Reusable Launch Vehicle in May 2018. During this mission, the demonstrator was heavily instrumented and excellent flight data were obtained on-board through suitable sensors and flight telemetry system which gave valuable and crucial details of hypersonic aero-thermodynamics, autonomous navigation, guidance, control, integrated flight management, etc. The flight measured data were analysed and found to be excellent match with ground simulation and predictions, which gives confidence to take up further developmental activities in this area. It is appropriate to consolidate the valuable data and publish the technical contents as a Special Issue in Journal of The Institute of Engineers (India): Series C. Towards this, 14 technical articles covering wide ranges viz. aeroacoustics, thermal protection system, aero thermal structure, guidance, control, material, sensor etc. are presented.

The paper, “Quality Assurance and T&E of Inertial Systems for RLV Mission” describes the Quality assurance and Test and Evaluation (T&E) activities carried out for the inertial systems flown successfully. As part of reliability analysis, Failure Mode effect and Criticality Analysis (FMECA) and derating analysis are carried out in the initial design phase. Test data analysis, health parameter plotting

and test report generation are automated. The automations significantly reduced the time required for these activities and helped to avoid manual errors. Further, T&E cycle is optimized without compromising on quality aspects. Meticulous planning and execution of T&E helped to achieve zero defect delivery of inertial systems.

The paper, “Inertial Navigation System for India's Reusable Launch Vehicle Technology Demonstrator (RLV TD—HEX) Mission” describes the configuration of Inertial Navigation System (INS) used in RLV TD Program. A new INS is designed, realised and qualified to meet the mission requirements of RLV TD. Additional redundancy in acceleration channel, in-built inclinometer based bias update scheme for acceleration channels and sign conventions as employed in aircrafts are introduced in new INS. For ascent phase control, data acquisition in micro cycle periodicity (10 ms) is incorporated which is required to provide rate and attitude information at higher sampling rate. Provision is incorporated for acquisition of rate and acceleration data with high resolution for aerodynamic characterisation and parameter estimation. GPS aided navigation scheme is incorporated to meet the stringent accuracy requirements of the Mission. The paper, “Mission Management Computer Software for RLV-TD” describes the functions and features of the components of the Mission Management Computer software. A hard real-time system is introduced for handling the mission requirements in an integrated manner and for meeting the stringent timing constraints. Redundancy management and fault-tolerance techniques are also built into the system. It is introduced to achieve a successful mission even in presence of component failure. The paper, “Mission Management Computer and Sequencing Hardware for RLV-TD-HEX-01 Mission” describes the details of mission critical avionics hardware mainly Mission Management Computer (MMC) and Sequencing hardware. The Navigation,

✉ K. Sivan
director@vssc.gov.in; k_sivan@vssc.gov.in

¹ Department of Space, Vikram Sarabhai Space Centre, Indian Space Research Organisation, Government of India, Thiruvananthapuram, India

² Surface Engineering and Tribology Division, CSIR- Central Mechanical Engineering Research Institute, Durgapur, India

Guidance and Control (NGC) chain for RLV-TD is dual redundant with cross strapped Remote Terminals (RTs) interfaced through MIL-STD-1553B bus. MMC is Bus Controller (BC) on the 1553 bus, which does the function of GPS aided navigation, guidance, digital autopilot and sequencing for the RLV-TD launch vehicle. MMC is built around Intel i960 processor and has inbuilt fault tolerance features like ECC for memories. Fault Detection and Isolation (FDI) schemes are implemented to isolate the failed MMC. Stage Processing System (SPS) is 'RT' on the 1553 bus which receives the sequencing and control related commands from MMCs and posts to downstream modules after proper error handling for final execution. SPS is designed as a high reliability system by incorporating various fault tolerance and fault detection features. The paper, "Development of RLV-TD Stage Separation System" presents details the evolution of the Split Collet based separation system used in the separation of the spent booster stage from the RLV. The separation mechanism is very compact, yet has a very high load bearing capacity. 6 Split Collet separation systems are introduced in RLV-TD. Each mechanism is designed for a load of 220 kN. All the six separation mechanisms separate within 15 ms. Structural, functional and environmental qualification tests are carried. Three levels of integrated tests are also carried out with the structure. The design details and the challenges faced during flight qualification of the system are also described. The paper, "Smart Sensors for Launch Vehicles" describes the construction, working and flight performance of the smart sensors. The smart sensor integrates signal conditioners, digitizers and communication systems to give digital output on a common digital data bus. An inbuilt microcontroller gives the sensor embedded intelligence to carry out corrective action for sensor inaccuracies. A smart pressure sensor is developed and introduced to increase the reliability as well as simplicity in integration so as to obtain improved data output. The paper, "Configuration and Design of Checkout System for Reusable Launch Vehicle" describes about the systems involved in the testing of this new concept launch vehicle. This paper describes about the system used for RLV avionic system integrated level testing and launch operations. The checkout system for RLV is designed to meet the requirements of the vehicle power control, the parameter measurement and monitoring, execution of tests, enabling the automatic launch processing and finally the ignition of the first stage booster rocket after confirming the health of the entire systems. The tests carried-out on RLV is classified into five categories, the power system test and measurement verification, the navigation sensor consistency tests, the guidance and control tests, the control command sequence verification tests, and the actuator control system tests. Test automation systems and test procedures are designed to

meet the requirements and facilitate efficient execution. The paper, "Performance Evaluation of Nose Cap to Silica Tile Joint of RLV-TD under the Simulated Flight Environment using Plasma Wind Tunnel Facility" describes development and testing of thermal protection system used in the nose region of RLV-TD. The nose cap region is thermally protected by Carbon–Carbon (C–C) followed by silica tiles with a gap in between them for thermal expansion. The gap is filled with silica fibre. Base material on which the C–C placed is made of molybdenum. Silica tile with strain isolation pad is bonded to aluminium structure. These interfaces with a variety of materials are characterised with different coefficients of thermal expansion (CTE) joined together. In order to evaluate and qualify this joint, tests are carried out on specimen of thermal protection system in Plasma Wind Tunnel (PWT) Facility under the simultaneous simulation of heat flux and shear levels as expected in flight. The paper, "RLV-TD Flight Measured Aeroacoustic Levels and Comparison with Predictions" presents details of aeroacoustic levels and the comparison with the predictions. There are five external microphones, mounted on the fuselage-forebody, wing, vertical tail, inter-stage and core base shroud to measure the acoustic levels from lift-off to splash down. In the ascent phase, core base shroud recorded the overall maximum at both lift-off and transonic conditions. In-flight noise levels measured on the wing is second highest, followed by fuselage and vertical tail. Predictions for flight trajectory compare well at all locations except for vertical tail (4.5 dB). In the descent phase, maximum measured OASPL occurs at transonic condition for the wing, followed by vertical tail and fuselage. Predictions for flight trajectory compare well at all locations except for wing (– 6.0 dB). Spectrum comparison is good in the ascent phase compared to descent phase. Roll RCS thruster firing signature is seen in the acoustic measurements on the wing and vertical tail during lift-off. The paper, "Design, Analysis and Qualification of Elevon for Reusable Launch Vehicle" describes details about the configuration, design, qualification and flight validation of elevon for Reusable Launch Vehicle. Single elevon is designed to accommodate the actuator inside the wing instead of split elevon. The design methodology used for box type structure is considered for designing the elevon similar to aircraft. The design of structure is stiffness based to limit the deflection of panel so that it does not change the aerodynamic shape. High temperature, panel deflection, buckling, mass, cost and manufacturability are considered while designing the elevon. The design of elevon with Titanium alloy (Ti–6Al–4V) is carried out for aerodynamic load initially and then design was arrived through analysis for aero thermal loads. The hardware was qualified for aerodynamic, thermal and acoustic environments through extensive testing. Digital

image correlation (DIC) technique is used to map the displacement fields on the elevon. The paper, “Inverse Flush Air Data System (FADS) for Real Time Simulations” describes the Flush Air Data Sensing System (FADS) which makes use of surface pressure measurements from the nose cap of the vehicle. The surface pressure is used for deriving the air data parameters of the vehicle such as angle of attack, angle of sideslip, Mach number, etc. These parameters find use in the flight control and guidance systems, and also assist in the overall mission management. An inverse software to FADS which estimates the pressure data at the pressure ports for a given flight condition is developed. These pressure data at the nine ports will go as input to the FADS package during ground simulation. The software is run to generate the pressure data for the descent phase trajectory of the technology demonstrator. This data is used again to generate the air data parameters from FADS algorithm. The computed results from FADS algorithm match well with the trajectory data. The paper, “Final Phase Flight Performance and Touchdown Time Assessment of TDV in RLV-TD HEX-01 Mission” describes instruments and tracking methodology used during touchdown. Three ground stations are used for the telemetry data reception (including one in sea). To have the mission critical data during final phase of the flight, Telemetry via INSAT scheme was introduced. Using the onboard inertial sensor acceleration and various other accelerometers it was shown that the touchdown has happened at $T + 773.6$ s. This time of touchdown is cross verified by the strain data also which shows similar abrupt rise of strain at various structural points of the vehicle. The paper, “Instrumentation and Baseband Telemetry for RLV-TD HEX Mission” describes the specific requirements and features of the baseband telemetry system used in RLV-TD HEX mission. The configuration of the overall system, subsystem components and their features are described.

The additional requirements from the telemetry system for large number of temperature and strain measurements are addressed. The Strain Data Acquisition Unit (S-DAU) and Multiplexed Data Acquisition Unit (M-DAU) are inducted specifically to cater to the strain gauge channels and temperature measurements using thermocouples respectively. The optimized subsystem configuration for this unit is described and its field performance during subassembly level and flight is analyzed. A novel method of data recovery for those measurements affected by datum shift due to chassis voltage is introduced. The paper, “Servo Design and Control Electronics for RLV-TD Control Actuation System” describes the servo design and control electronics architecture of control actuation system. Eight electro hydraulic actuators are introduced in Reusable Launch Vehicle for vectoring the control surfaces about their axes. A centralised hydraulic power generating unit (HPU) is used for powering the eight actuators located in two stages. High bandwidth requirement from autopilot is met by the servo design using the nonlinear mathematical model. Single Control Electronics which drive four electro-hydraulic actuators is developed for each stage. High power electronics with soft start scheme is realized for driving the BLDC motor which is the prime mover for hydraulic pump.

It is envisioned that the researchers in the field of Reusable Launch Vehicle Technology may have an access to these wealth of flight data. The researchers also may get the glimpse of design methodologies in the area of aeroacoustics, aero-thermal, guidance, control, material, structures etc. of Reusable Launch Vehicle Technology.

We are grateful to Prof. Gautam Biswas, Editor-in-Chief of Journal of Institute of Engineers (India): Series C and Springer for providing us the opportunity to Guest-edit this issue. We also thank to the authors and reviewers. We welcome the feedback about the special issue.