Experimental Study on gsLVM3 for Transonic Buffet Estimation

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ABSTRACT

In modern launch vehicles, the unsteady aerodynamic forces caused by flow separation during the transonic regime induce aeroelastic instabilities like buffeting, which may lead to structural failure. Quantifying the buffet loads in the critical transonic regime is important to ensure the safety of the vehicle structure. The complexity of the buffeting phenomena makes the computational effort difficult to predict the aerodynamic-elastic-inertial interactions. Hence the designer has to employ experimental approach to evaluate the necessary aeroelastic characteristics of launch vehicles. This paper presents a case study of experimental aeroelastic studies on gsLVM3 launch vehicle. For this an aerodynamically shaped and dynamically scaled model is designed, fabricated and wind tunnel tested. The responses of the mounted sensors on the model have been acquired during the tunnel testing and analyzed. The transonic buffet experienced by the model has been presented in the form of dynamic bending moment for different flight conditions. Finally, the critical buffet loads for the full scale vehicle are obtained using appropriate scale factor.

Keywords: *Launch Vehicle, Buffet, Aeroelastic Scale Factors, Wind Tunnel Testing.*

1. INTRODUCTION

The modern launch vehicles are generally slender flexible elastic bodies, which have bulbous nose to accommodate the satellites. The flexibility of the slender body and its vibrations may interact with a separated oscillatory flow, which leads to aeroelastic problems such as buffet, coupled oscillations, fuel sloshing etc., during the flight. Indeed aeroelastic problems may adversely affect the performance of the vehicle and some time even may cause structural failures. This paper is addressing the estimation of buffet loads through experimental method.[1] Basically buffet is an aeroelastic instability, which occurs during elastic structure's interaction with aerodynamic forces. Buffet can be defined as the unsteady response of the vehicle due to the oscillatory loads caused by flow separation and vibratory motion in the transonic *(Mach = 0.8 to 1.2)* flow regime. Buffet load is the extra bending load experienced by the vehicle. The occurrence of buffeting depends primarily on the shape of the vehicle. Even though launch vehicles are generally slender in nature they have local variations of cross sectional area that is relatively rapid. These area variations lead to adverse pressure gradients and separated flows. So, it is understood that the buffeting pressures are very configuration dependent. Both their intensity as well as the frequency content is very much functions of the geometry producing the separated flow.[2] Buffet can be of two kinds, one is low frequency gross bending response and the other high frequency shell breathing oscillations and structural panel vibrations. In the transonic regime the physics of the flow is so complex that the experimental methods are preferred over computational methods to qualify the vehicle from aeroelastic instabilities.

2. METHODOLOGY OF AEROELASTIC TESTING OF GSLVM3

To estimate the buffet loads on the gsLVM3, a 1: 42 scaled model was designed. The test procedure involves following steps:

(a) Derivation of aeroelastic scale factors
(b) Model design, analysis
(c) Model support system design
(d) Fabrication of the components and its assembly to build the model
(e) Instrumentation, ground testing of the model
(f) Wind tunnel testing, data analysis.

2.1 Aeroelastic Scale Factors

To derive the aeroelastic scale factors, the flight conditions (Mach number, dynamic pressure, altitude, velocity) of the full scale vehicle are considered along with the flow conditions that can be simulated in the wind tunnel, available at NAL. The different scale factors derived are geometric scale ratio, dynamic pressure ratio, flexural stiffness ratio, weight ratio and frequency ratio etc.

2.2 Model Design Analysis

An equivalent type construction, namely stiffeners, rings, skin arrangements was chosen to realize the model. The design of the model also takes care of the fabricability of the model and strength requirements from the tunnel safety point of view. To simulate the scaled mass and stiffness distributions to capture the required dynamics in the model, finite element based optimization procedures are employed.

2.3 Model Support System Design and Fabrication

In order to mount the model in tunnel, a sting-spring support system has been designed to suit the tunnel mounting pod. This support system simulates the free-free boundary condition of the model.

2.4 Model Fabrication and Non-Structural Mass Simulation

Light weight composites like glass/carbon fibre reinforced plastics and metallic materials like Aluminum and steel are used to fabricate the different components of the model. Further fabricated components are assembled to build the integrated model. The non-structural masses like propellant, electronics etc., are simulated using lead pieces.

2.5 Model Instrumentation

The model was instrumented using different types of sensors like strain gages and accelerometers based on the requirements. The gsLVM3 model has more than 20 strain gages bonded to inner surface of the skin along its length.

2.6 Ground Testing (GT)

In GT both static and dynamic tests are performed.[3] The static test is carried out by applying load on the model to measure the deflections and strains at different gage locations to compute the bending moment calibration factors. The calibration factors can be used to calculate the unknown bending moment which model experiences during simulated loading in wind tunnel. Also through the static test, the static strength of the model is checked. Further the dynamic test is conducted by exciting the model through electro-dynamic shaker as shown in Fig. 1 to establish the dynamic characteristics (frequencies and mode shapes) of the model. The burst random signals are used as input signals to excite the model. Fig. 2 shows the mode shape comparison of first two bending modes of the model. A good comparison in mode shapes shows how closely the designed model has been simulating the required dynamics.

Fig. 1: Model Undergoing GVT

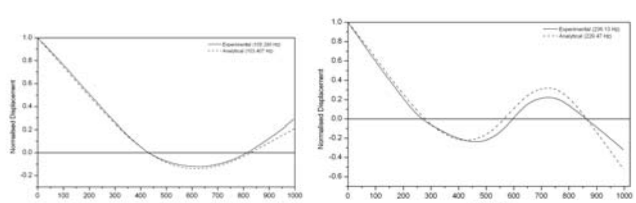

Fig. 2: Mode Shape Comparison of First and Second Bending Modes

2.7 Wind Tunnel Testing

The dynamically qualified model was then subjected to simulated aerodynamics at the appropriate Mach no's and dynamic pressures in the 1.2 m Trisonic NAL wind tunnel.[4] Fig. 3 shows the model mounted in the tunnel. After mounting the model in tunnel, all the sensors' wires were properly routed and connected to the data acquisition system using shielded cables to avoid the noise in the acquired data. The model was tested for different configurations, namely pitch plane, yaw plane, core vehicle alone and with nose cone variation for varying Mach number from 0.85 to 1.05. During each blow down the model was subjected to change in angle of attack from -4^{o} to $+4^{o}$ in a step of 2^{o}.

Fig. 3: Model in 1.2 m Trisonic Tunnel at NAL

Figure 4 shows the typical time plot of different strain gage outputs for varying angle of attack form -4^{o} to $+4^{o}$ in a step of 2^{o}. The time data obtained for each gage is processed using advanced algorithms in the CADA-X of LMS SCADAS III data acquisition and processing system to obtain the frequency domain PSD plot (refer to Fig. 5). Then the energy is calculated by integrating the PSD plot over a selected frequency band to calculate the strains experienced by each gage for a particular flow condition.

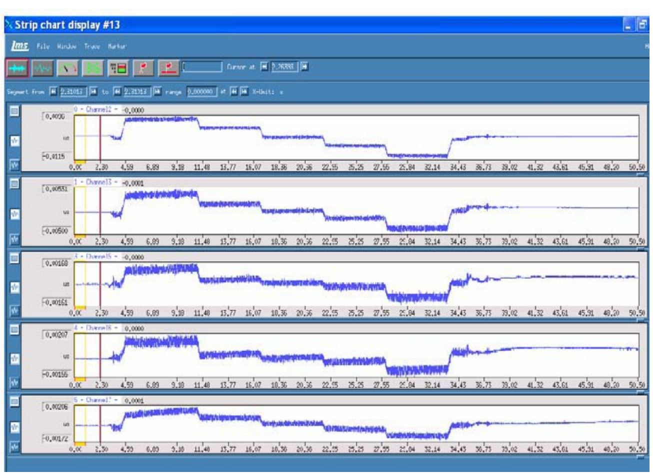

Fig. 4: Typical Time Plot of Strain Gages

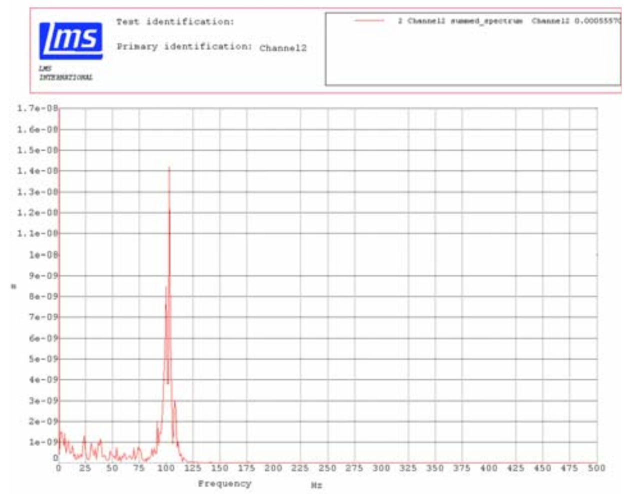

Fig. 5: Typical Bending Strain PSD Plot

3. RESULTS

The strains obtained from the PSD plots are used to estimate the dynamic bending moment at each gage location, considering the calibration factors. Figure 6 shows one typical bending moment distribution plot along the length of the vehicle for different angles of attack. The maximum bending moment obtained from this plot will be extrapolated using appropriate scale ratio to obtain the dynamic bending moment on the full scale vehicle.

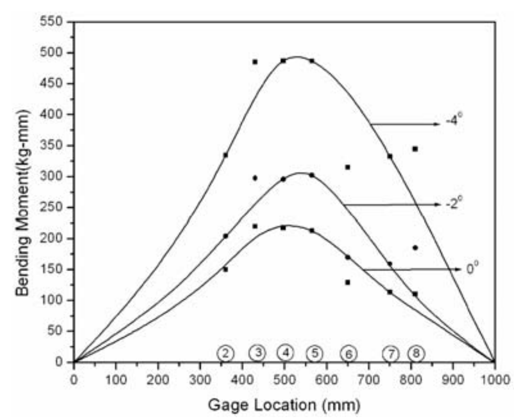

Fig. 6: Typical BM Distribution Plot

4. CONCLUSIONS

The aeroelastic Buffet of gsLVM3 vehicle has been experimentally computed through a wind tunnel study. Scaling laws and FE analysis tools for model simulation and signal processing tools for response calculation have been employed. The vehicle is qualified for a safe flight during a turbulent transonic regime.

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