Experimental Investigation on the Interaction of Supersonic Plume with Launch Pad Structure

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Abstract

With the advent of increased launch frequency, ISRO is planning to meet the demand by augmenting the existing launch pad at Sriharikota using an innovative scheme of launch vehicle integration and transfer sequence. Under this project, the integrated launch vehicle will be transferred on Mobile Launch Pedestal (MLP) from the integration facility to the First launch pad on a rail track. This rail track will cross the Jet Deflector Duct (JDD) with a rail track span of 7.5m. The rail track will be supported on the girder, which will be subjected to severe thermal environment generated due to the interaction of hot supersonic jet from C-D nozzle with a 9 ^{0}cant angle, through the launch pedestal cut-out during launch vehicle lift-off. In order to design the rail track girder beam, cold and launch pad measurements are initiated to study this thermal & flow related problem and map the extent of interaction of hot supersonic jet on the launch pad structure, simulating the rail beam structure. Pressure, temperature, heat flux and flow visualization results are presented and discussed in this paper. From the flow visualization results and launch pad measurements it is understood that there is no direct impingement of supersonic jet on the launch pad structure, resulting in a benign condition of flow parameters.

Keywords: *Supersonic jet interaction; cold flow, launch pad measurements, surface flow visualization, fluid & thermal environment, launch vehicle lift-of simulation.*

1. Introduction

Studies were initiated to characteristics the pressure and thermal loads on the proposed girder beam through scaled down cold & hot flow studies. Cold flow studies are carried out using GN2 as surrogate gas and hot flow studies with scaled solid rocket motor, simulating the actual strap-on vehicle both geometrically and thermo-physically. Actual launch pad lift-off environment is simulated during the experiments and lift-off trajectory is maintained by increasing the nozzle exit distance from the initial lift-off condition. Figure 1 shows the typical configuration of study. The MLP with girder column was realized and the supersonic plume interaction with newly proposed girder was studied using surface flow visualization technique for various lift-off heights during cold flow experiments.

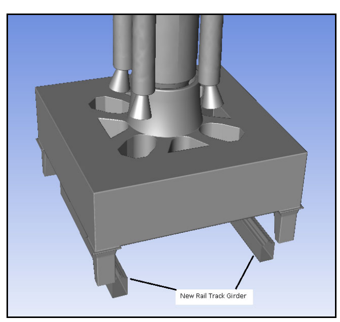

Figure 1: Proposed New Rail Track girder within the launch pedestal and its interaction with strap-on supersonic jet

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2. EXPERIMENTAL METHODOLOGY

As discussed earlier, the supersonic plume issuing out of strap-on jet of the launch vehicle might interact with the newly prosed rail track girder, which is within the span of the MLP compared to the old track bema which is far away from the hot plume. To investigate this problem cold and hot flow model tests are carried out and are reported in this paper.

2.1. COLD FLOW EXPERIMENTS

The cold flow experiments are carried out using one strap-on jet plume issuing out of C-D nozzle with GN2 as surrogate gas with 1:32 scale. The rail beam girder and the MLP top surface and the cut-out hole were uniformly coated with Titanium dioxide and olive oil in proper suitable mixture to find the shear layer interaction of the jet with the beam. The distance from the nozzle is varied from then initial stand-off distance by a nozzle exit diameter (De as non-dimensional parameter) to simulate the vehicle trajectory to a certain height. In cold flow experiments, the chamber pressure is set as 24.6 bar for compensating the change in the specific heat ratio (γ) between actual hot & cold flow cases as mentioned in Table.1. The flow visualization setup is shown in Figs.2 & 3 below.

Table 1: Simulation Parameters

Parameter	1:1 Strap-on Jet	Cold Flow (1:32)
Chamber Pressure (bar)	36.5	24.6
Nozzle exit pressure (bar)	0.66	0.66
Mach number	3.08	3.08
Mass Flow rate (kg/s)	252.16	0.49
Area ratio (Ae/At)	7.56	4.65
Nozzle Exit Dia. (mm)	982	30.83
Nozzle Throat Dia.	357	14.28
Specific heat ratio (γ =Cp/Cv)	1.2	1.4

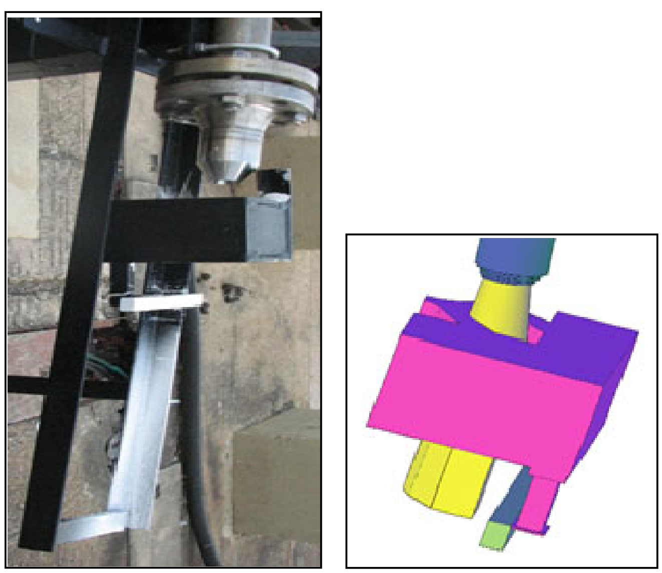

Figure 2: Cold Flow Experimental Set-up for Flow Visualization

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The cold flow visualization experiments are conducted at various L/De cases (L is the any lift off height and De is the nozzle exit diameter) and the results for specific cases are only presented due to brevity of space in Fig.3. From the cold flow tests, it is observed that no plume impingement is seen on the newly proposed girder at lower lift-off; however, as the L/De increases, the supersonic jet spills over the MLP top and a very weak interaction of plume with Girder is observed as shown in Fig.3. This preliminary study clearly shows that the strap-on supersonic plume is not impinging on the newly proposed rail girder beam. For further confirmation, hot flow tests are planned.

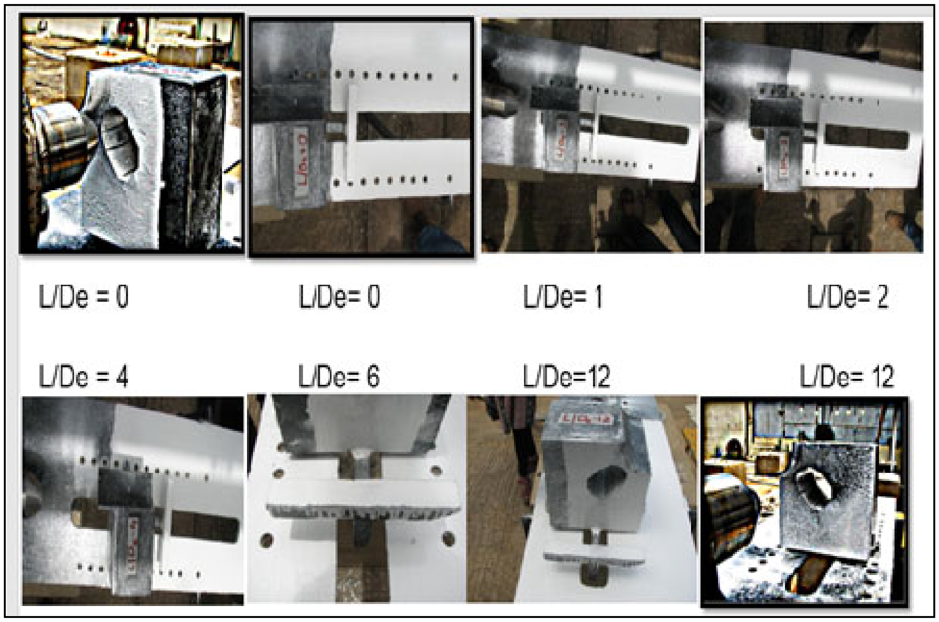

Figure 3: Cold Flow Visualization at various Lift-off Heights

These flow visualization results have given an insight on the probable sensors measurement range required for measuring the heat flux, temperature and pressure on the proposed girder.

2.2. LAUNCH PAD MEASUREMENTS

Launch pad measurements were carried out during the lift-off PSLV launch vehicle. Structure simulating the newly proposed Girder is erected and measurement provisions were made to measure pressure, heat flux and temperature along the length of the girder and depth of the girder. Location plan showing the sensors mounted on the launch pad is shown in Fig. 4 and Fig.5.

Expected depth of the girder is 750mm, hence a vertical member of 900mm is drawn from the launch pedestal simulating the depth of the girder. Level 0 corresponds to the ground level and level 900 corresponds to 900mm below ground level.

An interconnecting member simulating the length of the girder is realized at an elevation of 750mm below ground level simulating the bottom portion of the girder. Temperature measured during the lift-off is shown in Fig.6. Table 2, shows the peak temperature measured at each measurement location.

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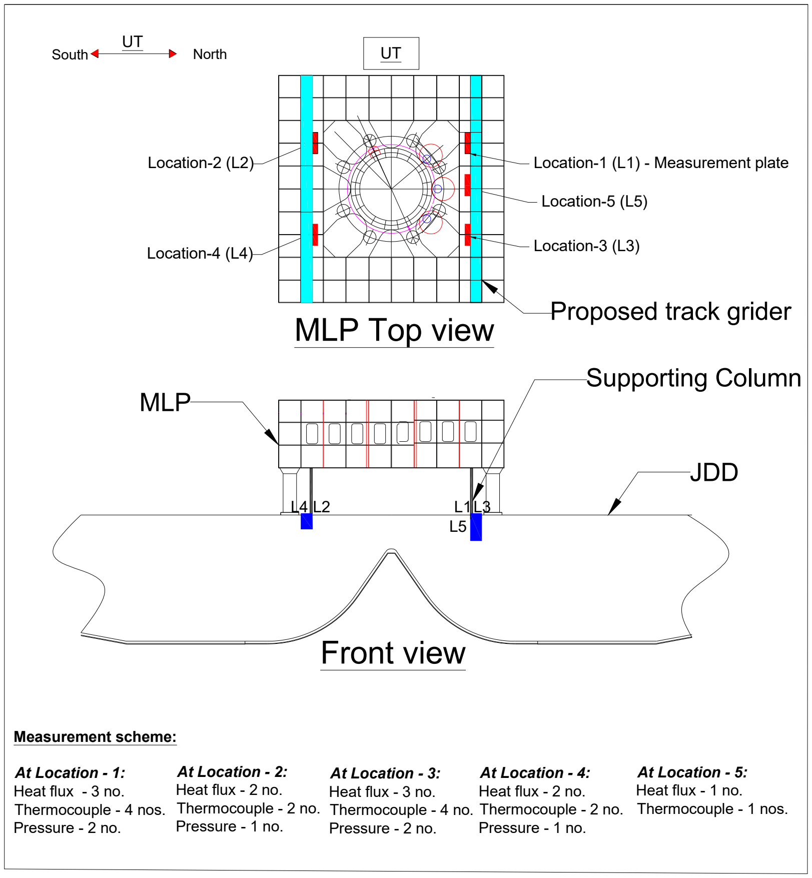

Figure 4: Sensor locations in the launch pad.

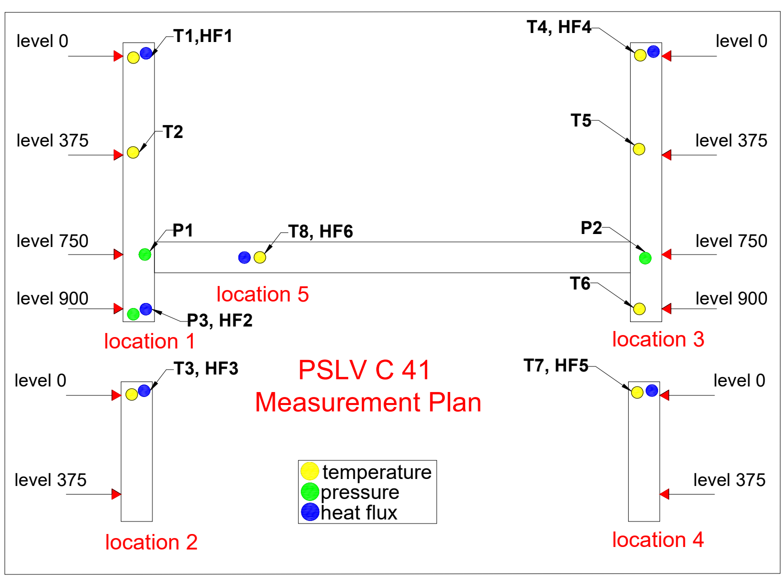

Figure 5: Sensor notations at each location of measurement

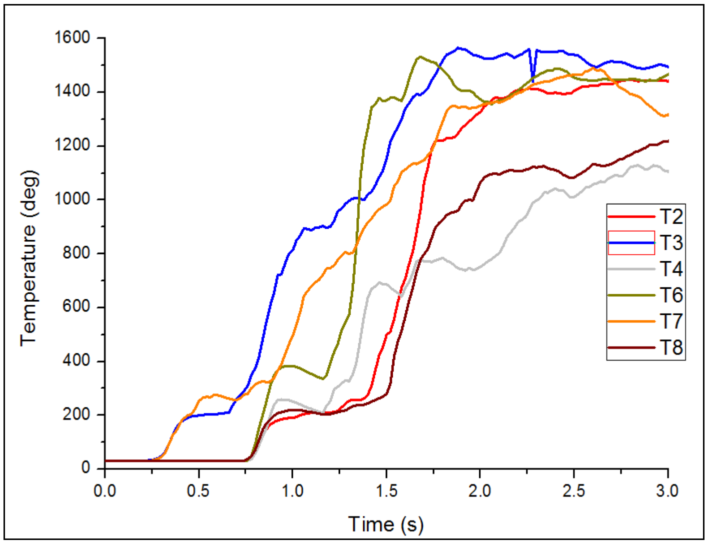

Figure 6: Temperature measured at each location

Table 2: Peak temperatures at each location

Peak temperatures values in T1 to T8 during PSLV lift-off		
Sl.no	**Location**	**Temperature – C^0**
T1	L1(level 0)	1097
T2	L1(level 375)	1447
T3	L2(level 0)	1560
T4	L3(level 0)	1229
T5	L3(level 375)	1052
T6	L3(level 900)	1530
T7	L4(level 0)	1489
T8	L5(level 750)	1222

Sensors at location T1 and T5 got saturated with in T+2seconds and are not shown in Fig.6. Similarly, peak heat flux and peak pressures measured are shown in Table 3 and Table 4.

Table 3: Peak temperatures at each location

Peak Heat Flux values in HF1 to HF8 during PSLV lift-off		
Sl.no	**Location**	**HF (W/cm^2)**
HF1	L1(level 0)	64
HF2	L1(level 900)	132
HF3	L2(level 0)	92
HF4	L3(level 0)	77
HF5	L4(level 0)	68
HF6	L5(level 750)	126

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Table 4: Peak Pressures measured at various location

Peak pressure values in P1 to P3 during PSLV C41 lift-off		
Sl.no	**Location**	**Pressure**
P1	L1(level 750)	27.9 mbar
P2	L3(level 750)	35.11 mbar
P3	L1(level 900)	19.56 mbar

5. RESULTS AND DISCUSSIONS

From the cold flow experimental results, it was evident that the supersonic jet from the nozzle is not impinging on the proposed girder. From the flow visualization results, launch pad instrumentation was carried out by choosing appropriate sensors. Range of sensors was determined from the experience gained in cold flow results. Since the cold flow tests have shown that there is no direct impingement of jet on the girder, Mild Steel structure with adequate thermal protection has been designed to erect in the launch pad experiencing the thermal and jet loads during launch vehicle lift-off.

From the launch pad data, it was further evident that there is no jet impingement and the peak temperature is in the order of 1560degC. Peak heat flux is 132 W/cm2 which was measured at the lowest elevation indicating that jet interaction increases as we go deeper in to the jet deflector duct. Peak pressure measured on the girder was 35.11mbar which is again implying that there is no direct jet impingement.

6. CONCLUSIONS

Cold flow scale model experiments simulating the launch vehicle lift-off scenario and launch pad measurements were carried out in order to investigate the possible interaction of supersonic jet issued from the strap-on booster with the newly proposed rail girder beam of launch pad structure. 1:32 scale cold flow surface flow visualization technique using Titanium Dioxide powder mixed with Olive oil is used to capture the flow interaction and from the results, it is observed that no jet impingement is seen on the girder structure during lift-off; however, a slight interaction is seen at higher L/De. Further investigation using launch pad measurements helped in arriving the thermal environment on the proposed girder during PSLV lift-off. Results indicate the that the peak temperature is about 1560degC, heat flux is about 132W/cm2 and the pressure is 35.11mbar. These results conclude that proposed girder can be realized and used since hot supersonic jet from the PS0-XL jet is not impinging on the girder and creating a huge thermal load. However, adequate thermal protection scheme shall be designed to minimize the potential damage created to the girder enabling to use it for multiple launches with minimum re-work.

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