DYNAMIC ANALYSIS OF LAUNCH VEHICLE TO DIFFERENT GUST PENETRATION EFFECTS

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Abstract-*The computation of dynamic loads on a launch vehicle due to atmospheric gust is essential for the design of launch vehicle structural systems. The simplest gust representation is the immersion gust. Here, all the locations of the launch vehicle is assumed to experience the gust simultaneously without any time delay. However, a more accurate analysis includes gust penetration effects. In the former, the vehicle length is assumed to be very small compared to the gust wavelength (i.e., the vertical length of gust).In the latter, the top station point on the vehicle is faced by gusty wind at the initial stage whereas the remaining portion of the vehicle is affected by the wind prevailing at that altitude. The gust penetrated area increases as the vehicle moves on. A Multistage Launch Vehicle is analyzed to study the gust response at various mach number, frequency and time instants for fully immersed condition as well as penetration through gust condition. A software is developed to compute the time delay at different station points on the launch vehicle when it passes through the gust. A comparative study was carried out between both the effects and the acceleration response are computed in both cases.*

***Keywords*-Launch Vehicle, Gust, time lag, mach number, fully immersed, penetration through gust, gust response.**

I.INTRODUCTION

Launch vehicles while free standing prior to launch or during its ascent are exposed to several dynamic environmental conditions. Among these the more critical is atmospheric turbulence. Analyses performed to establish launch- and space-vehicle atmospheric turbulence loads are generally referred to as gust loads analyses. Gusts are short duration high speed winds. The gust is pictured as a horizontal layer in the sky that the vehicle ascends into. When a sudden gust acts on a launch vehicle, it can cause an increase in angle of attack. The computation of dynamic loads on a launch vehicle due to atmospheric gust is essential for the design of launch vehicle structural systems. The simplest gust representation is the immersion gust. However, a more accurate analysis includes gust penetration effects. In the present work, software was developed for generating gust models at various instances considering different gust penetration effects. A comparative study was carried out between both the effects and the acceleration response are computed in both cases.

2. LITERATURE SURVEY

During early 1963,Homer G Morgan et.al.[2] discussed about the response of a launch vehicle to a number of detailed wind profiles. The response of vehicle flying through these detailed profiles are compared with the same response of same vehicle flying through balloon-measured profiles. The available data on the derived gust velocities in thunderstorms for altitudes up to 34,000 feet was presented by H.B.Tolefron[3] from previously evaluated effective gust velocities. The results indicate that the intensity of derived gust velocities in thunderstorms is essentially constant for altitude up to 30,000 feet. Rick Newlands et.al.[5] discusses that the major disturbances affecting the trajectory are thrust misalignments and winds(especially upper atmosphere wind).Large forces normal to the centerline of the airframe can be created by gusts and can cause a small angle of attack α, which creates side loads within the fuselage. It was suggested that the easiest to develop and use for essentially vertical trajectories is synthetic wind profile. A new method for gust analysis is introduced by M.C Kim et.al[6]. Monte Carlo gust loads analysis approach which uses the turbulent components of measured wind profiles as forcing functions and determine loads of desired level. Most of the studies concentrates on Wind profile development, Statistical estimation of gust loads and Elastic response of launch vehicle to gust In the present work, elastic response of launch vehicle to sinusoidal gust with different penetration effects at various time instances is carried out and thereby computed the dynamic (design) loads on launch vehicle.In Ref [1],a software 'GUST_SIMULATION' was developed to generate automatically the gust input excitations for a standard FEM package. This software generates the gust excitation force for fully immersed condition where all the locations on the launch vehicle experiences gust loads simultaneously without any time delay. This software is modified to a new software 'GUST_TIMELAG' that can generate gust penetration effects also. Here each location on the launch vehicle experiences the same gust at a specific time delay depending on the velocity of the vehicle.

3.DYNAMIC ANALYSIS OF LAUNCH VEHICLE

Large forces normal to the centre line of the launch vehicle (lift forces) can be created by gusts. The sudden gust velocity vector, when added to the vehicle's airspeed vector, causes a small angle of attack α. This Aerodynamic Normal Force is expressed by the relation,

Normal force = $C_N \frac{1}{2}\rho V^2 S$ =

$$\alpha \frac{\partial C_N}{\partial \alpha} \frac{1}{2} \rho V^2 S = \alpha \frac{\partial C_N}{\partial \alpha} qS \qquad \text{(Eq. 1)}$$

Where '$S \frac{\partial C_N}{\partial \alpha}$' is the lateral aerodynamic force coefficient, 'q' is the dynamic pressure, '∝' is the angle of attack of Launch vehicle flight path.

In the formulation of gust response, the lateral aerodynamic force coefficient ($S \frac{\partial C_N}{\partial \alpha}$)given in Eq. 1 is converted into concentrated aerodynamic force coefficient (SC_N). Then, the resulting equation for gust response will become,

$$F_{Aero\ i} = SC_{N\ i} \times q \times \propto$$

where '$F_{Aero,i}$' is the aerodynamic force at ith station of vehicle and '$SC_{N,i}$' is the lateral aerodynamic force coefficient at i^{th} station

4.GUST RESPONSE

In the present work, a multistage launch vehicle was analyzed to study the gust response at various time instants and flight conditions considering gust penetration effects also. Finite Element model of the launch vehicle was generated in a standard FEM package. Aerodynamic force coefficient (SC_N) was applied on the vehicle and a sinusoidal gust profile tuned to the vehicles fundamental bending mode was applied. Two penetration cases were studied (i)fully immersed (ii)penetration through gust. In fully immersed gust, the analysis is accomplished by instantaneously enveloping the vehicle in a synthetic gust model. In penetration through gust, the top station point on the vehicle is faced by gusty wind at the initial phase whereas the remaining portion of the vehicle is affected by the wind prevailing at that altitude. The gust penetrated area increases as the vehicle moves on. Dynamic analysis was carried out using standard FEM package. For generating input load in FEM package format, software was developed using FORTRAN. This software can also generate the time delay that would occur at various time instants as the launch vehicle penetrates through the gust. The time delay that would occur at a particular point was calculated considering the distance travelled and the velocity of the vehicle.

5. RESULTS AND DISCUSSIONS

Transient response analysis was carried out to find the response at the satellite interface considering both penetration effects mentioned under section 4.Fig (1-2) gives the pictorial representation of the gust acting on the finite element model for the both cases. The analysis carried out at different Mach numbers with nominal and off nominal aerodynamic distributions. A sinusoidal gust profile tuned to the first three fundamental bending modes was considered for analysis. Simulation was performed for mach numbers values of 1.05, 1.1, 1.2 and the analysis was done considering vehicle frequencies up to 50Hz. However, the primary response is below 10Hz for most vehicle/payload system. The input excitation force in the standard FEM package format is generated automatically in the software 'GUST_TIMELAG'.

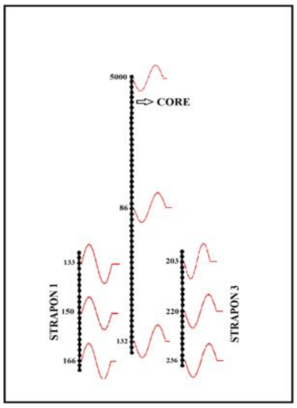


Fig-1 Fully immersed

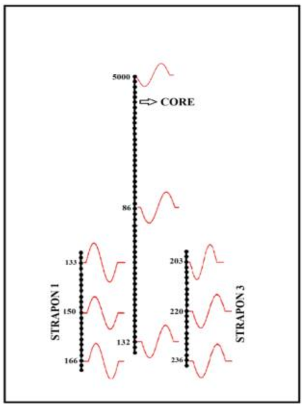


Fig-2 Penetration through gust

Table -1: Time delay at various station points at Mach 1.05

Distance from the top station point of LV(m)	Time(Sec)
0.00	0.000
30	0.1
40	0.14
50	0.168

Table-1 shows the time at which load are applied on different station points of the launch vehicle for the penetration through gust effect.

The acceleration response for various frequency modes, nominal and off-nominal aero load cases for immersion gust penetration were generated simultaneously using the software and is listed in Table 2. Maximum lateral acceleration of 5.84m/s^2 is obtained for gust tuned to second mode of the vehicle. Comparing the acceleration obtained for various aero loads, off nominal case1 gives maximum value of 7.12m/s^2

Table- 2: Lateral Acceleration response for immersion gust penetration

Frequency Modes	Lateral Acceleration (m/s^2)	Cases	Lateral Acceleration (m/s^2)
1	5.79	Nominal Case	5.79
2	5.84	Off nominal Case 1	7.12
3	5.29	Off nominal Case 2	6.85

Transient response analysis results at the satellite location were tabulated against both penetration effects and typical results are listed in Table 3. It was observed that the fully immersed gust had higher response for all conditions

Table -3: Acceleration response at critical point

Frequency Modes	Lateral Acceleration(m/s^2)	
	Immersion Gust Penetration	Penetration through Gust
1	5.79	5.71
2	7.12	5.87
3	6.85	5.71

Acceleration along the lateral direction for both penetrations is given in Fig-3 (a) and Fig-3 (b).

Fig-3 (a)

FULLY IMMERSED GUST

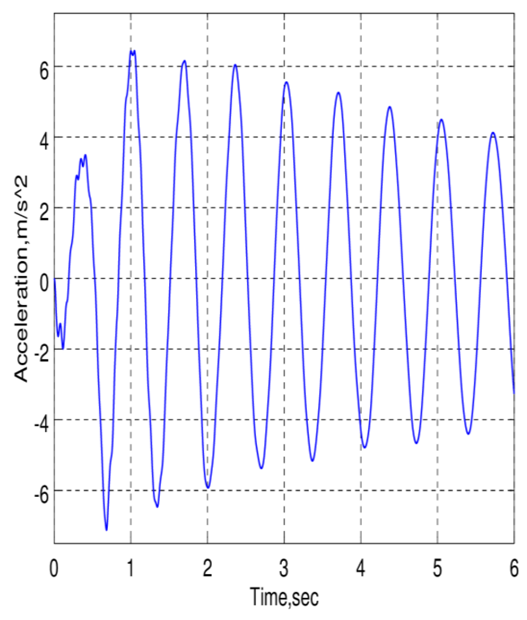
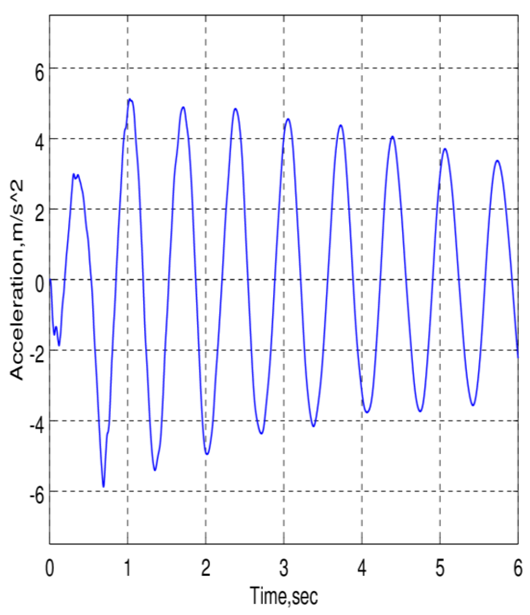


Fig -3 (b)

PENETRATION THROUGH GUST



6. CONCLUSIONS

The computation of gust loads on the structure of launch vehicle is a part of the engineering work during the development and certification phases of a new project. The software developed can be considered as a analytical tool capable of generating the gust load input for any type of launch vehicle with any type of gust penetration. A comparative study was carried out between both the penetration effects and the major response was determined. In the present study, it is observed that the fully immersed gust without any time delay had higher response for all mach numbers.

REFERENCES

[1]Aayillia K Jayasidhan,Jancy Rose K, R.Neetha," Dynamic Response of a Launch Vehicle to Wind Gust", 2015 IJEDR | Volume 3, Issue 3 | ISSN: 2321-9939.

[2] Homer G. Morgan and Dennis F. Collins, "Some Applications of Detailed Wind Profile Data to Launch Vehicle Response Problems", *NASA Langley Research Centre, Langley Air Force Base, Va.* Phoenix, Arizona, April 3-5, 1962

[3] H. B Tolefson., "Summary of Derived Gust Velocities obtained from measurements within Thunderstorms," *NACA Report 1285, Langley Aeronautical Laboratory, Langley Field, VA* July 27,1955

[4] Harold C. Lester and Harold B. Tolefson, "A Study of Launch Vehicle Response to Detailed Characteristics of the Wind Profile", NASA Langley Research Centre, Langley Station, Va., March 1964

[5] Rick Newlands, Martin Heywood and Andy Lee, "*Rocket Vehicle Loads and Airframe Design*", ASPIRE SPACE, Technical papers, 2012

[6] M. C. Kim, A. M. Kabe, S. S. Lee, "Atmospheric Flight Gust Loads Analysis," *Statistics & Satellite Replenishment Office, Structural Dynamics Department,* 1999

[7] S. I. Adelfang and O. E. Smith, "Gust Models for Launch Vehicle Ascent," *American Institute of Aeronautics and Astronautics, Inc,*1998

[8] Orvel E. Smith, Lambert D. Austin, Jr., "Sensitivity Analysis of the Space Shuttle to Ascent Wind Profiles", *National Aeronautics and Space Administration Technical Paper,* March 1982

[9] M. C. Kim, A. M. Kabe, J. B. Clark, "Statistical Analysis of Atmospheric Flight Gust Loads Analysis Data", *Statistics & Satellite Replenishment Office, Structural Dynamics Department,* 1999.