EXPERIMENTAL INVESTIGATION OF FLIGHT AND PHYSICAL PARAMETERS AFFECTING THE VIBRATION RESPONSE SEVERITY OF SUBSYSTEM CARRIED BY JET AIRCRAFT

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ABSTRACT

In this study, Experimental Modal Analysis (EMA) of a subsystem carried by a jet aircraft which is in real flight condition is performed. The main purpose of this study is to investigate relationship between vibration response of the subsystem and flight parameters like mach number, attitude, propulsion severity and number of the jet engine of the jet type aircraft, also physical parameters as mass, mass moment of inertia in three axes of the subsystem. Parameters are collected in real flight condition by data storage system. In signal processing, vibration response is expressed as power spectral density functions in frequency domain. Root mean square of values in terms of gravitational acceleration (GRMS) is also used to define vibration response severity in singular number. Time history data is checked, if the signal is stationary or not. Data are filtered to clean static effects like jet maneuver. It is seen that mach number and flight attitude of the jet has strong effect on subsystem vibration response magnitude. Also, results show that, change of the external geometry of the subsystem influence the vibration response. According to results, it can be said that, subsystem physical parameters have small impression on vibration response.

INTRODUCTION

Jet type aircrafts carry electronic warfare pods, missiles, bombs and external fuel tanks. These subsystems expose to high vibration environment. As a result of high vibration condition, mechanical parts in the object can loss its structural integrity, also electronic cards and circuits can be malfunctioned. Since the selection of subparts of the subsystem like seeker, measurement units, pumps like structures, electronic control units, it is important to know vibration level before flight in preliminary design phase of a research projects. In some military standards vibration levels for subsystem is generally high due to unknown parameters [DOD, 2008]. In these standards it is advised to avoid using these levels if there is any measurement data. Researchers examine the military standard levels and compared

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the vibration levels with their measurements. Measurements show that, levels that given with the military standard are exaggerated [Nevius, et. al. 1981].

Generally main vibratory loading sources of a subsystem that carried by a jet type aircraft is given Table 1 [Harry, et. al. 1968].

Table 1. Vibration sources of the subsytem carried by jet type aircraft

Vibration source	Effective frequency band(Hz)
Fluid flow effect	100-2000
Buffet	5-500
Flutter	2-30
Turbojet engine noise	10-20000

Typical subsystem aircraft interface is given in Figure 1. Generally two hooks of the subsystem are fixed to two lugs of the aircraft. Also, sway braces of the aircraft have positive contact with the subsystem in lateral direction.

Figure 1. Subsystem - Aircraft interface view

Literature Review

Researchers predict some responses by using flight parameters. Flutter behavior is predicted by means of flight parameters [Yildiz, 2007]. Aerodynamic constants are calculated by evaluating the physical and initial condition of bullets by system identification method [Mahmutyazicioglu, 2001]. Also, prediction of aerodynamic constants of one shot autonomous vehicle is validated by flight tests. This work is performed by using artificial neural networks [Kutluay, 2011].

Flow induced vibration is also studied numerically. Side mirror vibration of the automobile as a result of turbulent flow is studied numerically and validated by experiments. Transient analysis is performed in computational fluid dynamics. Time history data are processed and converted into frequency domain data. Frequency domain loads in terms of pressure are applied to system by finite element method. Validation is performed by impact hammer and wind tunnel tests [Ogawa, et. al. 2016].

Random Vibration Theory

Autocorrelation function can be defined in terms of expected values as shown below [Newland, 1993].

$$R_{xx}(m) = E[x(t)x(t+m)]$$

The power spectral density of a stationary random event x(r) is mathematically associated with the autocorrelation function by the discrete-time Fourier series expansion. In terms of frequency, this is given by,

$$P_{xx}(f) = \frac{1}{f_s} \sum_{m=-\infty}^{\infty} R_{xx}(m)\, e^{\frac{-j2\pi\, m\, f}{f_s}}$$

The mean power of a signal over a designated frequency band [f1,fω2], 0 ≤ f1 ≤ f2 , can be calculated by integrating the PSD over that frequency band as,

$$P_{[f_1,f_2\,]} = \int_{f_1}^{f_2} P_{xx}(f)df$$

It can be seen from the expression above $P_{xx}(f)$ is the power content of a signal in a certain frequency band.

METHOD

Vibration data are collected with accelerometers. Sampling frequency is taken as 6000Hz since 20-2000 Hz is considered in aircraft vibration problems. Acceleration data are taken from the subsystem-aircraft interface location. Acceleration data is checked if they are stationary or not. Run test is performed with %2 sensivity.

Two type aircrafts are studied. Aircrafts have different external geometry. Their aerodynamic parameters are different, as well. Also they are different about turbojet engine quantity as given in Table 2.

Table 2. Aircrafts used in analysis

Aircraft	Exhaust Diameter(mm)	# of Propulsion system	Thrust(lb)
A/C-1	1015	2	15000
A/C-2	981	1	29500

Three types of subsystems are investigated. Subsystems are classified according to their masses, mass moment of inertia. They are given in Table 3 below.

Table 3. Subsystem used in analysis

Subsystem	Mass(kg)	Mass Moment of Inertia at CG in X direction(kgm^2)	Mass Moment of Inertia at CG in Y direction(kgm^2)	Mass Moment of Inertia at CG in Z direction(kgm^2)
S1	590	18	450	450
S2	340	8	60	60
S3	560	13	180	180

Data taken from aircraft like mach number, attitude, turbojet engine propulsion are classified to make equal condition for all subsystems and aircrafts. Flight conditions are given in Table 4 below. Fuel consumption of turbojet engine is taken as propulsion quantity.

Table 4. Flight Conditions

Condition	**Aerodynamic Parameters**		**Turbojet Engine Parameters**
	Mach Number	**Attitude (m)**	**Propulsion(lbs/s)**
A	0,84	1288	3,463
B	0,88	2605	3,521
C	0,92	40310	2,459
D	0,92	2525	9,971
E	0,7	23580	1,863
G	0,71	9003	1,404
H	0,76	4448	2,16

RESULTS

Flight Condition Effect

Vibration data in type of acceleration power spectral density(APSD) are like white noise, but a step to upward of amplitude can be seen in the mid-band(about 150 Hz) frequency for A/C-1. Data taken from the S1 for Condition A is given in Figure 2 and Figure 3. Rms level is 2.6 in terms of g.

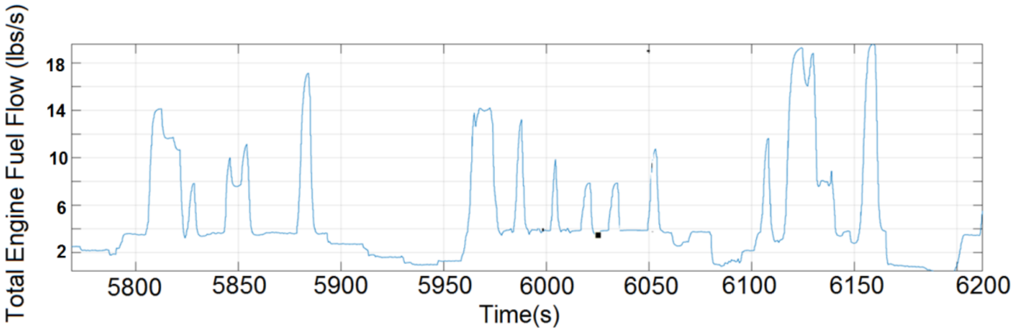

Figure 2. Time history propulsion data for S1, Condition A

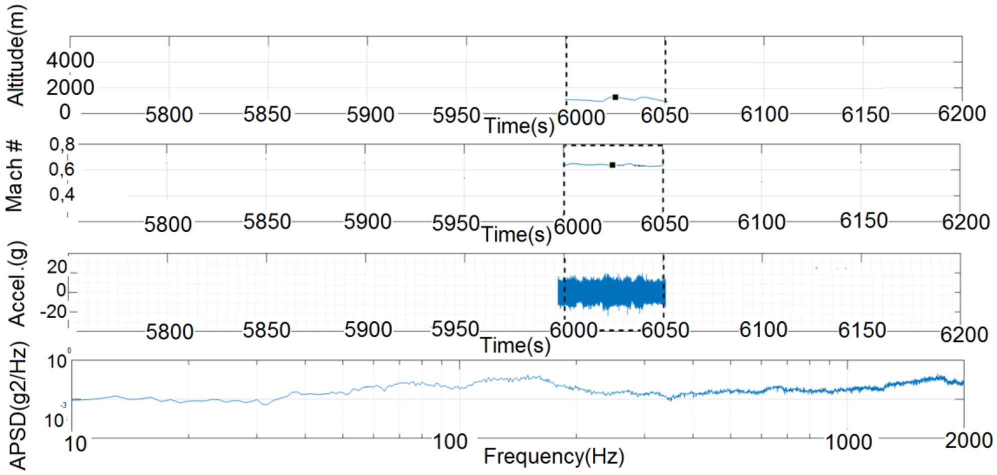

Figure 3. Time history mach number, altitude, acceleration data and frequency domain APSD data for S1, Condition A

Data taken from the S2 for Condition B is given in Figure 2 and Figure 3. Rms level is 1,8 in terms of g.

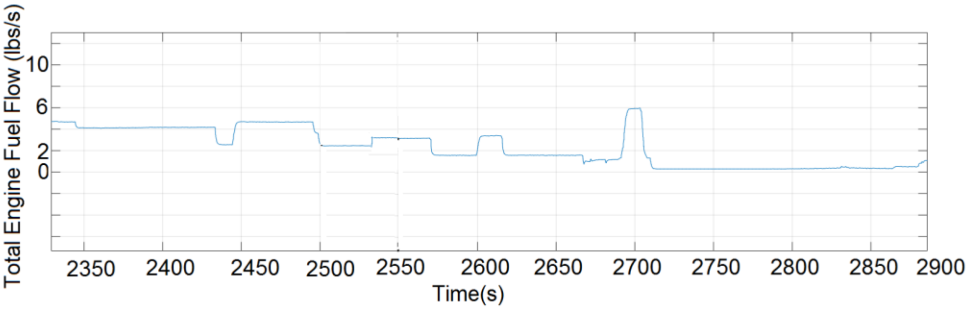

Figure 4. Time history propulsion data for S2, Condition B

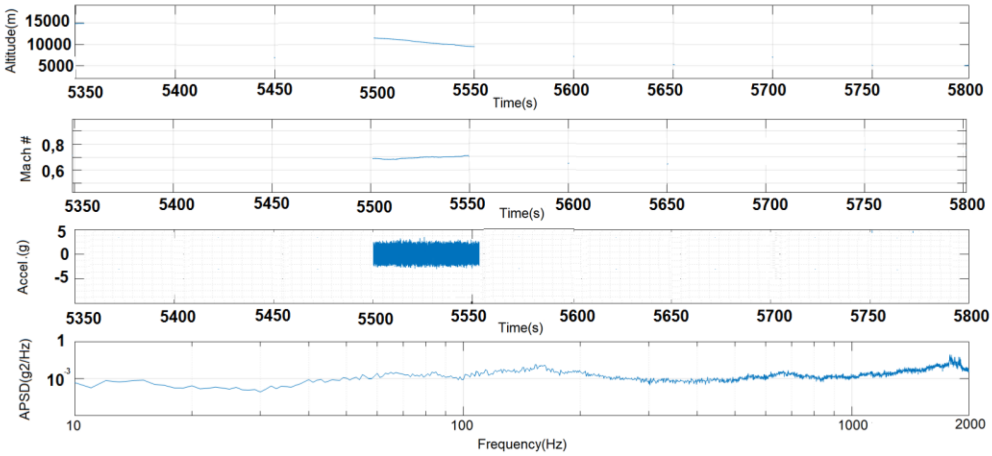

Figure 5. Time history mach number, altitude, acceleration data and frequency domain APSD data for S2, Condition B

Dynamic pressure is a function of Mach number and ambient atmospheric pressure is given below. ρ is density of the ambient air which is function of attitude, V is velocity, A is the cross section area perpendicular to velocity vector, C_d is drag coefficient.

$$P = \frac{1}{2} \times \rho \times V^2 \times A(\propto) \times C_d$$

Vibration level severity in terms of singular number defined as gravitational root mean square of the signal is strongly related to ambient dynamic pressure as it is given Figure 6 below.

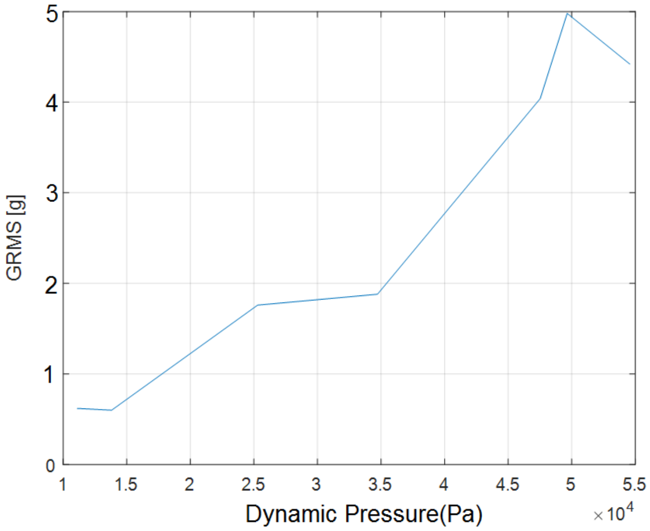

Figure 6. Vibration response severity in terms of gRMS relation with dynamic pressure graph

Subsystems Physical Parameters Effect

Vibration response severity of subsystems S1, S2 and S3 are compared in this section. A/C-1 is used in this comparison. Flight conditions C, D, G and H are investigated.

The Effect of mass difference on vibration response as RMS in terms of gravitational acceleration are given in Figure 7. It can be seen that vibration response is not so much sensitive to mass difference.

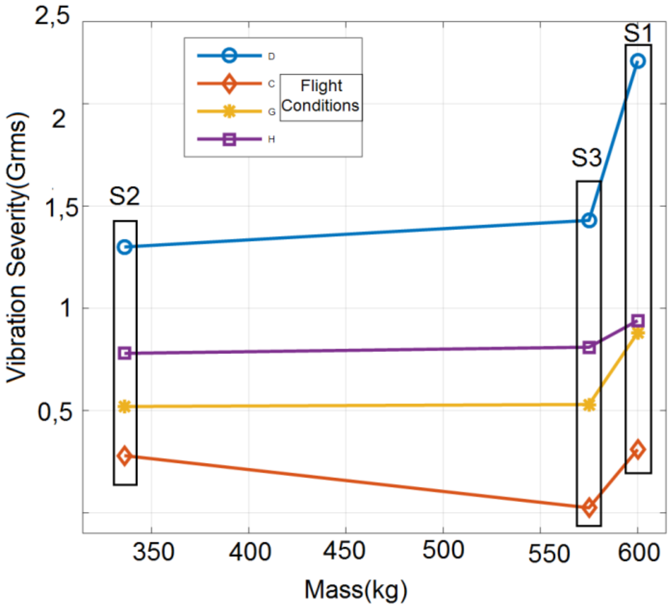

Figure 7. Vibration response severity of the subsystems according to mass difference

Mass moment of inertia is also checked, if it affects the vibration response severity. As it can be seen from the Figure 8, it has small effect on results.

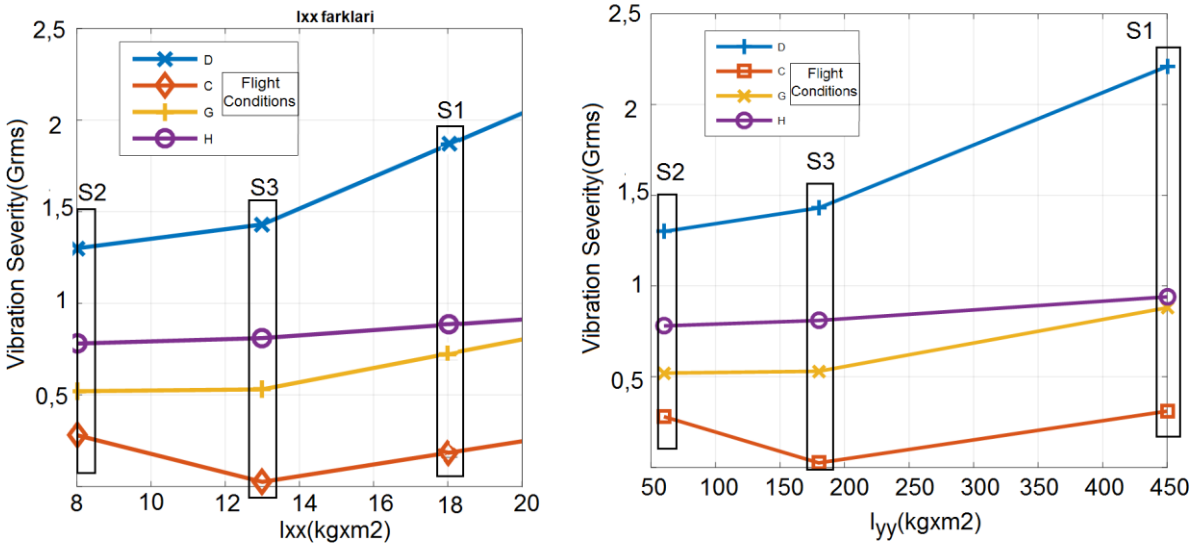

Figure 8. Vibration response severity of the subsystems according to mass moment of inertia difference

A/C Effect

Vibration response according to aircraft difference is also checked for one flight condition (Condition A) and one subsystem (S2). It can be seen from the Figure 9, A/C difference has strong effect on vibration response severity.

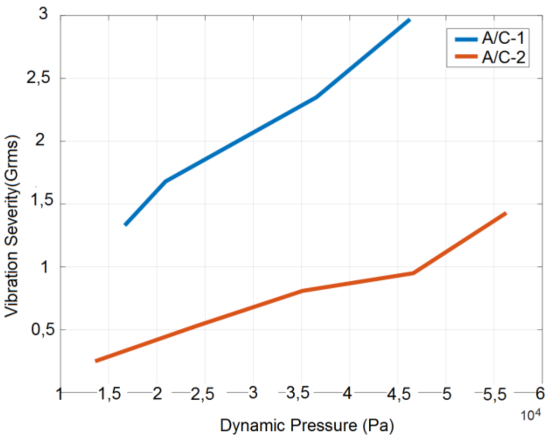

Figure 9. Vibration response severity of the subsystems according to mass moment of inertia difference

CONCLUSION

Prediction of the vibration response correctly in preliminary design phase save time and increase reliability of the products in aerospace industry. Vibration response of the subsystems carried by aircrafts is investigated and effective parameters are identified by experimental set-ups in this study.

It is seen that vibration response of the subsystem is strongly correlated with dynamic pressure which is a function of mach number of an A/C and ambient atmospheric air density. Nearly linear relationship between two parameters can be seen in Figure 6. Fuel flow rate of the turbojet engine which can be defined as engine noise has no remarkable effect on vibration response severity.

Moreover, subsystem physical parameters have small effect on vibration response. It can be seen in Figure 7 and Figure 8. Mass of the S1 and S3 is nearly same, but vibration response of those is so different. It can be due to aerodynamic constant or turbulent characteristics of the subsystem.

It can be seen from the graph A/C difference has powerful effect vibration level in same subsystem. It can be due to either of aerodynamic flow difference or acoustic induced vibration due to turbojet engine.

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