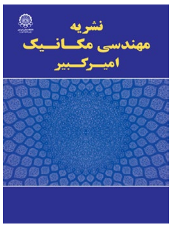

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(1) (2020) 27-30
DOI: 10.22060/mej.2018.13788.5717

Gust Response Analysis of Flexible Aircraft

J. Masrour, S. H. Sadati* , M. Shahravi

University Complex of Aerospace Engineering, Malek Ashtar University of Technology, Tehran, Iran.

ABSTRACT: Aircraft flexibility causes problems and difficulties which this problems even might endanger health and safety of the aircraft. This phenomena changes dynamic response of the aircraft to surface control and gust inputs with respect to the rigid models. Also, it has diverse effect on flight quality and handling characteristics. As a result, considering flexibility effects on dynamics response of aircraft is significant which requires that coupled dynamic and vibrational equations of aircraft. The present paper, introduce the dynamics of a large aircraft has been developed on base of a six degree of freedom model, which includes two rigid and four flexible degrees. Quasi steady aerodynamics has been used to describe interaction between solid and fluid dynamics. The essence of this model, enhance perdition of dynamic response to gust and other external disturbances, because of its effects of elastic modes. The characteristics of this external disturbances and elastic model, causes more flexible modes to be exited and strain energy ratio in general dynamics of the aircraft, increases. The effects of different parameters, like stiffness, gust length and profile, has been studied in numerical simulation.

Review History:

Received: 18 Dec 2017
Revised: 24 Dec. 2017
Accepted: 7 Sep. 2018
Available Online: 22 Dec. 2018

Keywords:

Flexible aircraft
Quasi steady aerodynamics
Stiffness
Gust response

1- Introduction

Flexible aircraft design is constrained by gust loads. Gust response has significant effect on aircraft characteristics, including stability, control, dynamic structural loads and etc. Incorporating these constraints in the early design process with an appropriate level of fidelity presents a significant challenge, due both to the need for more detailed aerodynamics and control modeling. The Federal Aviation Regulations (FAR) [1] require transport aircraft to be analyzed by discrete gust and continuous turbulence analyses. Nowadays, the focus on weight minimization for aircraft, leads toward more and more flexible vehicles. These structures may not exhibit the usual wide frequency separation among the rigid body degrees of freedom and the remaining elastic modes. So that the decoupling this two area can lead to mistakes/errors in analyses of flight performance, flying qualities, and control systems design. Non-linear static aeroelastic analysis of the high- aspect-ratio wing with geometric nonlinearity effect has been performed by Mian et al [2] .Haddadpour and Ashktorab [3] analyzed wing aeroelasticity effects on flight dynamics of a flexible aircraft. A relatively low-order linear dynamic model was developed by Schmidt [4] for the longitudinal flight-dynamics analysis of a flexible flying-wing research drone. In the present work a flexible aircraft has been simulated in step and ‘ 1-cosine’ gust. The expression for the flight dynamics and aeroelasticity equations has been coupled. It is assumed that aircraft wing is flexible and other parts are rigid. Wing has been modelled as a flexible beam with two bending and two torsion modes.

2- Methodology

Discrete gusts effect has been modeled in this paper. The gust velocity varies in a deterministic manner, usually in the form of a ‘1-cosine’ shape (i.e. there is an idealized discrete ‘event’ that the aircraft encounters), and it is modelled as [5]:

$$w_g = \frac{w_{g0}}{2}\left[1-\cos\left(\frac{2\pi}{T}\right)t\right] \tag{1}$$

In which “t’ is time in second, w_{g0} is gust velocity, and “T” is gust period which is equal to:

$$T = \frac{L}{U_0} \tag{2}$$

L is gust length and U is aircraft velocity. Gust is considered as an external force and causes lift force on aircraft:

$$f = \Delta L = .5\rho u^2 \frac{w_g}{u} \tag{3}$$

Dynamics of aircraft has been modeled with considering plunge and pitch of rigid mode and torsion and bending of flexible wing. Total kinetic energy is equal to sum of tail, body and wing

$$T = T_f + T_w + T_t \tag{4}$$

*Corresponding author’s email: hsadati@mut.ac.ir

Wing has been modeled as a beam with bending rigidity of E*I* and torsional rigidity of GJ, potential energy is equal to:

$$U=\frac{1}{2}\int_0^1\left[EI\left(\frac{\partial^2 h}{\partial y}\right)^2+GJ\left(\frac{\partial \alpha}{\partial y}\right)^2\right] \qquad (5)$$

By using Lagrange equation it is possible to obtain generalized coordinate forces Q_h and Q_α of the wing

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right)-\frac{\partial T}{\partial q_i}+\frac{\partial \bar{U}}{\partial q_i}=Q_i \qquad (6)$$

Besides Lagrange, equation has been applied for calculation of flight dynamics forces.

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}}\right)=Q_\theta \qquad (7)$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial w}\right)-\dot{\theta}\frac{\partial T}{\partial u}=Q_z \qquad (8)$$

Generalized forces can be obtained by putting Q_i and arranging aerodynamic and structural forces. Then it is possible to write [4]:

$$\left(M_s+M_a\right)\ddot{q}+\left(C_s+C_a\right)\dot{q}+\left(K_s+K_a+Knl\right)q=F \qquad (9)$$

$$q_1=z,\quad q_2=\theta,\quad q_3=\eta_1,\quad q_4=\eta_2\ ,q_5=\phi_1,q_6=\phi_2$$

In above equation z and θ are rigid modes, η_1,η_2 are two bending modes of wing, and φ_1,φ_2 two torsional modes of wing. F is discrete gust effect.

3- Discussion and Results

Response of elastic aircraft to a '1-cosine' gust has been simulated. At first a comparison between rigid and elastic aircraft to gust has been shown in figure 1. In this case a 1-cosine gust with 5m/s vertical velocity and gust length of 250 has been applied to rigid aircraft [6] with 150m/s velocity. Results has been depicted in Figure 2. In rigid case, aircraft is seen to pitch nose up very slightly, pitch nose down as the tail plane enters the gust and the tail plane lift increases, and then pitch nose up again; the aircraft finishes with zero attitude and pitch rate, having climbed to a slightly higher altitude. The CoM (center of mass) acceleration first peaks at a negative value (i.e. upwards), as the aircraft initially encounters the gust, and then peaks at a positive value (i.e. downwards) as the nose down pitch takes effect. But flexible dynamics of aircraft strongly effects on convergence of pitch response and pitch oscillations continuous, until it is damped. In the next figure gust amplitude effect on flexible aircraft has been studied. The gust amplitude of 50,100 and 250 meters has been simulated in Figure 3. Though the maximum pitch happens in 250 length gust but maximum acceleration exerted to aircraft occurs in 50 m length gust and by increasing gust length maximum acceleration decreases.

Win stiffness effect has been studied in Figure 3. Normal stiffness of wing has been compared with 0.5 and 1.5 times stiffness and has been compared with rigid aircraft. By increasing stiffness behavior of pitch response becomes more similar to rigid aircraft and maximum acceleration of Com decreases. The coupling between torsional and bending flexibility of flexible mode and its effect on over all dynamics of aircraft has been shown in facing with ' 1-cosine'. According to results, interaction of flexible and rigid modes in flexible aerial vehicle is such that ignoring strain energy of structure in flight dynamics causes unpredictable behavior and difficulty in control of rigid dynamics of aircraft.

4- Conclusion

In this paper a six-degree of freedom model accounting torsional and bending vibration of the large substructures of the aircraft, has been used in order to obtain the interaction of rigid and flexible body motions. Response to step and "1-cosine" gust has been simulated. The effects of different parameters, like stiffness, gust length and profile, has been studied in numerical simulation It has been shown that coupling between rigid and flexible modes cannot be ignored and should be accounted.

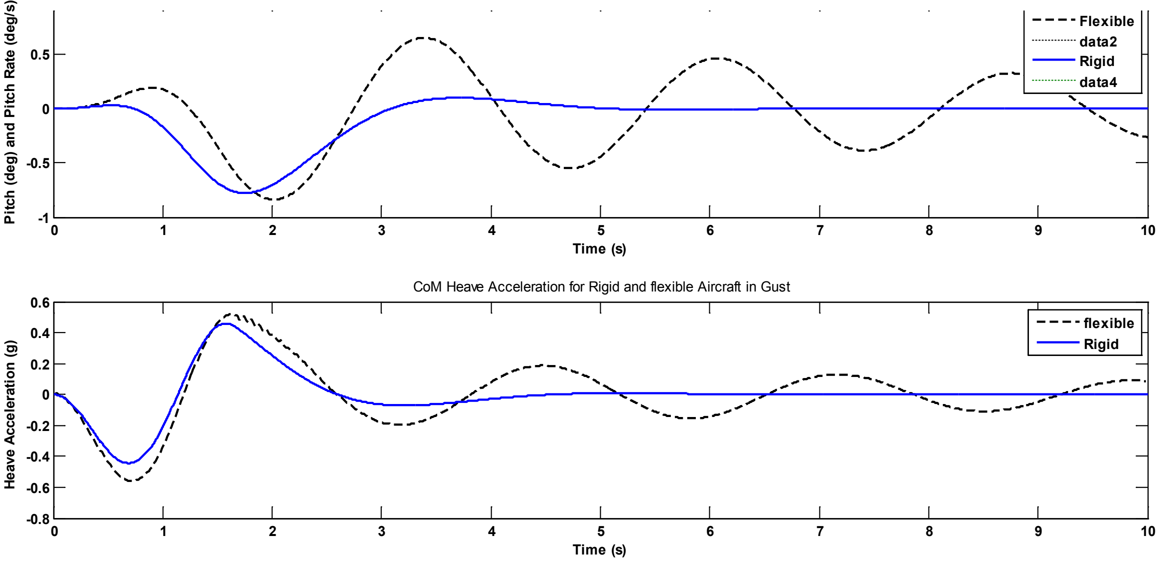

Fig. 1. Comparison between rigid [6] and flexible aircraft response to gust

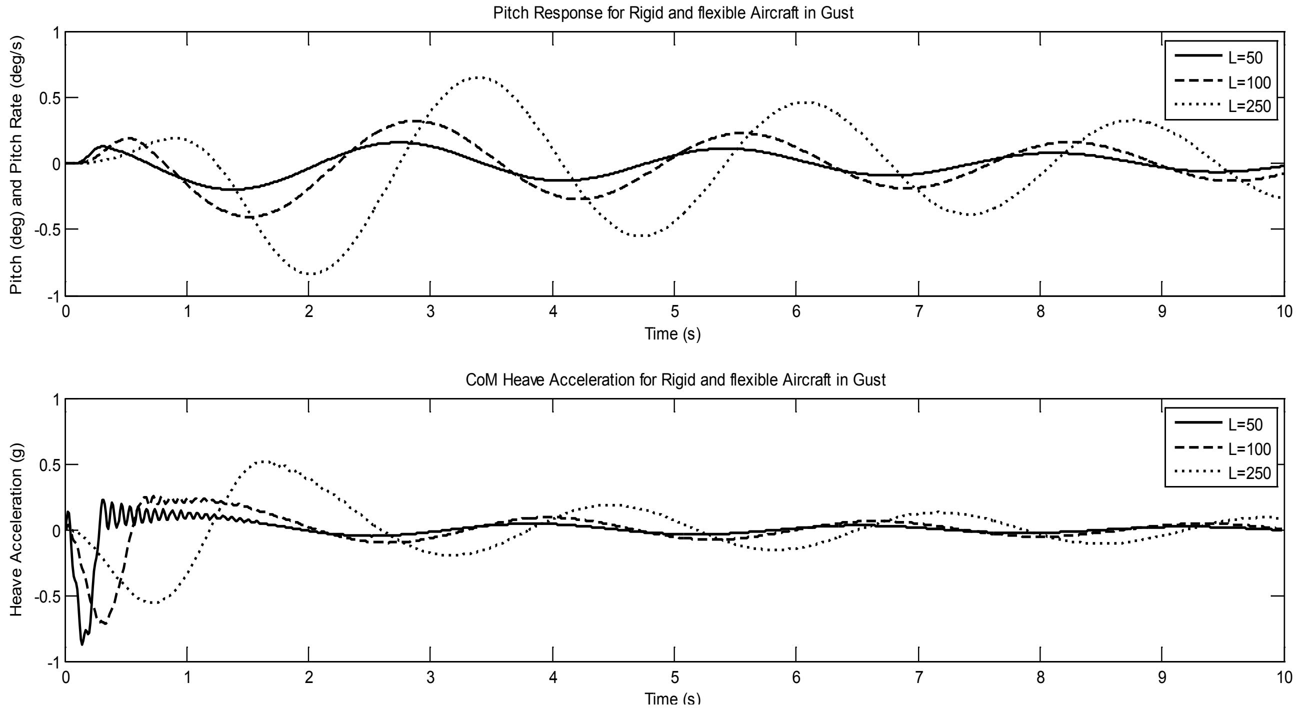

Fig. 2. Comparison between different gust lengths on aircraft dynamic response

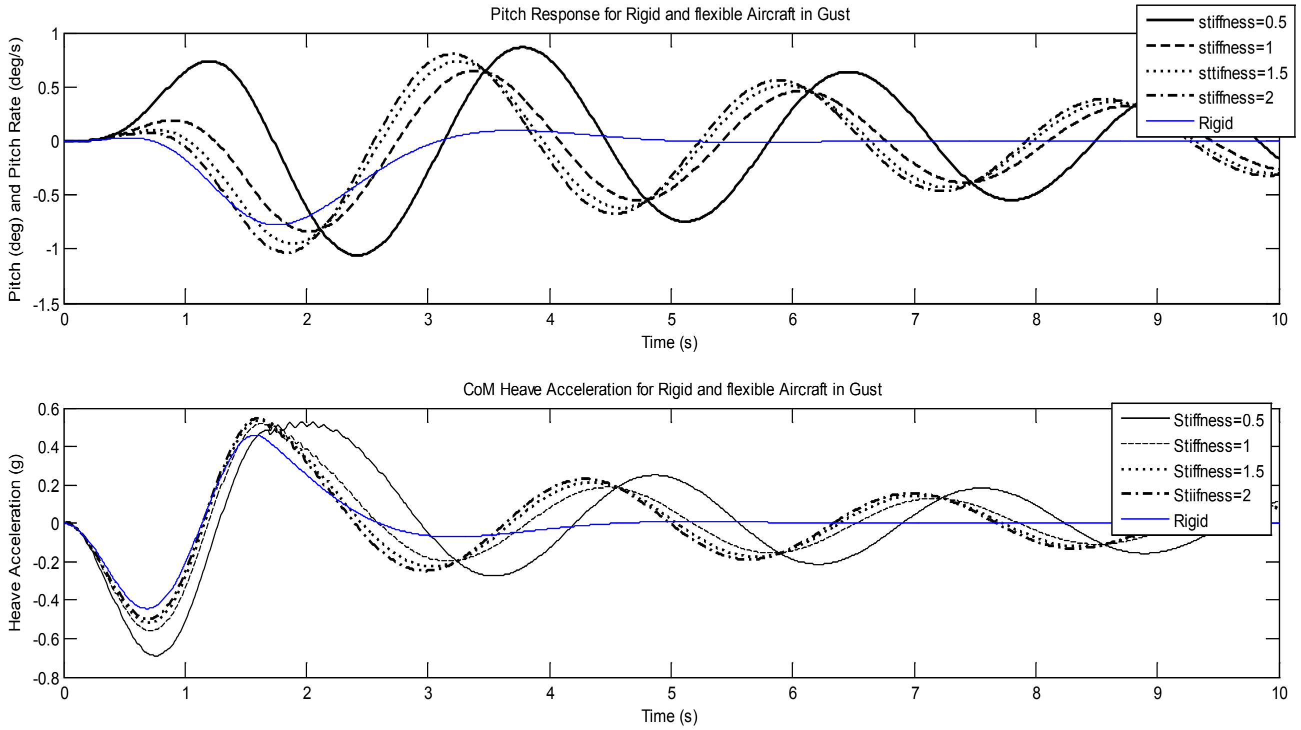

Fig. 3. Different wing stiffness effect on aircraft dynamic response

5- References

[1] Gust and Turbulence Loads. Code of Federal Regulations, Aeronautics and Space, Part 25.341, National Archives and Records Administration, Office of the Federal Register, Jan. 2003.

[2] R.D. Milne, Dynamics of the deformable aeroplane, HM Stationery Office, 1964.

[3] H. Hadadpour, Ashkorab, M., , Wing Aeroelasticity with Considering Aircraft Flight Dynamics, 14th aerospace conference of aerospace Socity, Tehran, Iran, 1393. (In Persian)

[4] D.K. Schmidt, MATLAB-based flight-dynamics and flutter modeling of a flexible flying-wing research drone, Journal of Aircraft, 53(4) (2015) 1045-1055.

[5] M.H. Sadraee, Stability and Flight Controll, Ayandeghan Publication, Tehran, Iran, 1379. (In Persian)

[6] J.R. Wright, J.E. Cooper, Introduction to aircraft aeroelasticity and loads, John Wiley & Sons, 2008.