Engineering Notes

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An Experiment on the Gust Response of a Transport Airplane by Free-Flight Model

Makoto Kobayakawa* and Hiroshi Maeda†
Kyoto University, Kyoto, Japan

Introduction

AMONG many published papers on the gust response of aircraft, there have been some papers on the response characteristics of aircraft by wind tunnel tests.[1,2] Although the present authors performed experiments by wind tunnel tests,[3] it was found that many problems, e.g. resonance of support of the wind tunnel model, occur and it was very difficult to acquire useful data. Here, the gust response of an aircraft is examined by free-flight experiment. The procedure of this experiment is that the dynamically similar model of a mid-sized jet transport encounters an impulsive gust during its free flight,[4] and the response of the model is acquired by telemetry.

Methods of Experiments

The dynamically similar model of the airplane is launched horizontally. When the model reaches a steady flight condition, an impulsive vertical gust is encountered. Then, the acceleration of the model is acquired by the on-board g-meter through telemetry. Since the flight speed of the airplane is constant (crusing condition), experimental parameters are the gust velocity and the width of the gust velocity profile.

A sketch of the apparatus is illustrated in Fig. 1. Each part is explained in the following:

A. Airplane Model and Telemetry

Dimensions of the model are shown in Table 1, and three-side views are illustrated in Fig. 2. The actual airplane is a mid-sized jet transport with STOL ability. It is clear from Table 1 that the similarity is satisfactory except for I_y. Moreover, the elastic similarity was not considered in making the model. This model carries a g-meter and transmitter as payloads. The signals are transmitted by FM modulation. The main transmitting frequency is 82 MHz.

Table 1 Dimensions of the airplane model

	Desired value	Measured value
Width, ft	2.008	2.008
Length, ft	1.903	1.903
Weight, lb	0.430	0.430
Inertial moment (I_y), lb/ft^2	4.581×10^{-2}	5.886×10^{-2}
Flight speed, ft/s	46.918	45.934
Lift coefficient (C_L)	0.318	0.328
Reduced scale $= l_m / l_\alpha = 1/50$		
Material of the model = balsa		

B. Launcher and Gust Generator

A truck which moves along a 3-ft monorail is used for launcher. The kinetic energy is obtained by a coil spring. The jet which is used for the gust is generated from a very narrow slit (1/5 in. wide and 3 ft long). The velocity profiles are illustrated in Fig. 3, where h is the altitude over the slit.

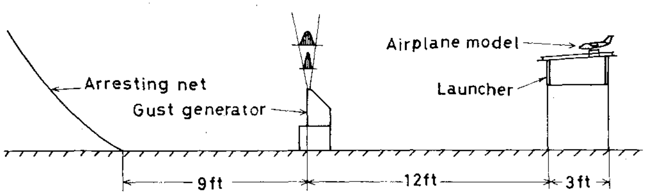

Fig. 1 Sketch of the apparatus of free-flight experiment.

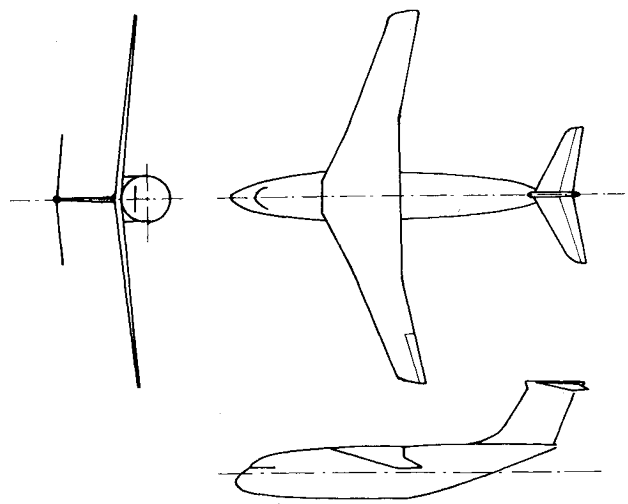

Fig. 2 Three-side views of the airplane model.

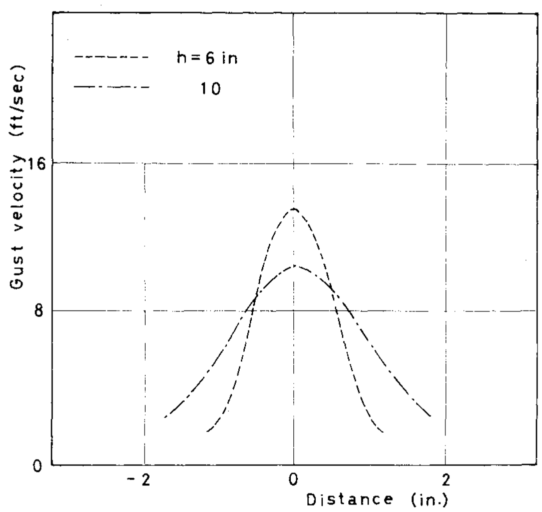

Fig. 3 Gust velocity profile.

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Index categories: Aerodynamics; Testing, Flight and Ground.

*Associate Professor, Aeronautical Engineering.
†Professor, Aeronautical Engineering.

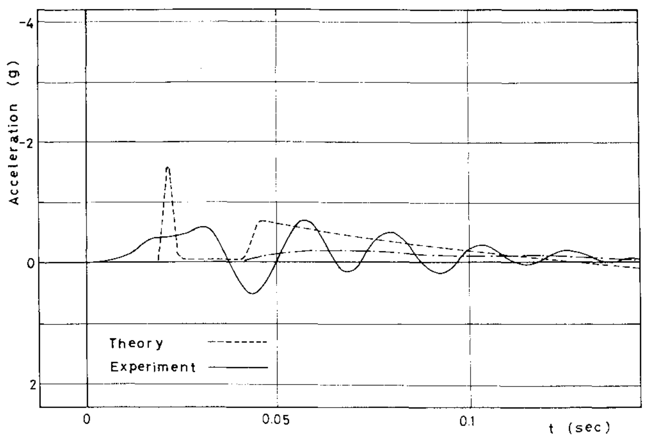

Fig. 4 Vertical acceleration of c.g. $h=6$ in.

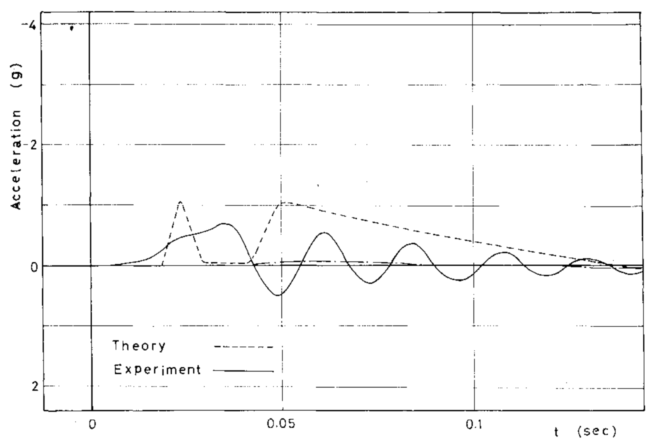

Fig. 5 Vertical acceleration of c.g. $h=10$ in.

Experimental Results and Comparison with Theoretical Values

The variation of the normal acceleration at the c.g. can be calculated theoretically when the airplane encounters a gust.[5] It is assumed that the airplane is rigid and that the wavelength of the gust is sufficiently long compared with the full length of the airplane. The gust velocity profile is approximated as a triangular form. Therefore, the induced angle of attack α_g can be expressed by supperposition of three ramp inputs. Laplace transformed form is given by

$$\bar{\alpha}_g = \frac{\alpha(1-2e^{-T_l s}+e^{-2T_l s})}{s^2} \tag{1}$$

where a is the inclination of the gust velocity profile and T_l is the nondimensional time duration for the airplane to pass through the halfwidth of the gust. The external forces are, therefore, given by the following equations:

$$\Delta\bar{F}_t = C_{z\alpha}\bar{\alpha}_g \tag{2}$$

$$\Delta\bar{F}_m = C_{z\alpha}(S_t/Sw)\hat{l}_t e^{-Ts}\bar{\alpha}_g \tag{3}$$

Equation (2) expresses the aerodynamical force on the wing, and Eq. (3) expresses the pitching moment due to the force on the tail. Here, only the short-period mode is considered. Substituting the above equations into the longitudinal equations, the acceleration of the airplane c.g. can be calculated by inverse Laplace transformation.

Experimental results and theoretical values are compared in Figs. 4 and 5. These figures show that the experimental results differ considerably from the theoretical values. First, an oscillation of very short period (0.02 s) appears in the experimental results. This oscillation is caused by the elastic oscillation of the wing. Next, although the impulsive response and the short-period mode appear separately in the theory, both phenomena overlap with each other in the experimental results. This may be considered as the effect of the wide fuselage and the sweptback wing of the airplane. The dashed line in these figures shows the theoretical short-period mode of the model, which agrees favorably with the experiment. However, the level of acceleration in the experiment is lower than that calculated. This tendency becomes stronger in Fig. 5. Similar results were obtained for the pitching angular velocity.

Conclusion

In order to examine the gust response of a mid-sized jet transport, free-flight experiments are performed using a dynamically similar model. The vertical acceleration is acquired through telemetry. The results do not agree with theoretical values and the effect of the elastic distortion of the wing on the response exceeded our expectation. These results should be compared with theoretical values by the panel method which takes the elasticity into consideration.

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Some Nonlinear Effects in Stability and Control of Wing-in-Ground Effect Vehicles

Rolf Staufenbiel*
Technische Hochschule Aachen, Aachen, Germany

Nomenclature†

h = height of mean quarter-chord point above ground
i_y = radius of gyration of the aircraft in pitch
s = Laplace transform variable
s_n = unit of length $= v_n\ t_n$
t_n = unit of time $= v_n/g$
$\hat{v}$ = nondimensional speed $= V/v_n$
v_n = unit of speed $= \sqrt{\dfrac{W/S}{\rho/2}}$

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Index categories: Handling Qualities, Stability and Control; Ground Effect Machines.

*Professor of Aerospace Engineering.

†The notation is based, where not specially explained, on the symbols of B. Etkin, *Dynamics of Flight,* John Wiley, New York, 1959.