FLIGHT FLUTTER TESTING USING PULSE TECHNIQUES

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Abstract

A case of flutter developed at a speed lower than had been flown previously. This incident precipitated the routine procedure of pulsing control surfaces as well as the firing of explosive charges during speed build-ups. In the interest of rapid evaluation of results, simple methods of data reduction were used. A case history is presented where in the pulse technique predicted flutter by extrapolating decay rates obtained at subcritical speeds; in addition, a case is presented where no valid extrapolation could be made.

INTRODUCTION

The need for systematically evaluating the structural stability of aircraft by flight testing has arisen out of the need for confirming the results of the flutter analysis as well as for searching out modes unforeseen by the analysis. It is the purpose of this paper to describe how the pulse technique has been used to fulfill this need during the flight testing of airplanes designed by the El Segundo Division of the Douglas Aircraft Company.

Methods used for the generation of pulses are described and the results of their application shown. The pulse technique has been used at Douglas because of its simplicity as compared to other methods such as the frequency response technique. Also, a minimum of auxiliary equipment is required, and data can be obtained without prolonged speed stabilization which is an advantage when exploring the speed envelope beyond the airplanes level flight capabilities.

GATHERING AND DATA INTERPRETATION

In conducting pulse tests the structural response has been measured primarily with accelerometers and occasionally with strain gages. Outputs have been recorded by oscillographs installed in the test airplane. With accelerometers, low pass filters usually have been used for suppressing the high frequency disturbances excited by buffeting, turbulence, and noise.

This filtering has been necessary in view of the method by which data has been reduced. Data reduction has consisted simply of measuring the decay envelope directly from the oscillograph record, computing the percent of critical damping, and plotting this damping as a function of speed. In this way, the damping is plotted for each frequency appearing on the record in a form sufficiently undistorted to establish the decay envelope. Ideally the damping speed plot thus obtained will form a smooth curve enabling an extrapolation to the flutter speed.

GENERATION OF PULSES

In view of the means of data reduction the primary requirement of pulsing is that the airplane structure be excited in the proper mode or modes at an amplitude substantially above the noise level. In an attempt to fulfill this requirement, pulses have been generated primarily by two methods: (1) manual control pulses, and (2) the firing of explosive charges.

For piloted aircraft, the advantages of manual control surface pulses are obvious in that no special equipment is required and the number of pulses per flight is practically unrestricted. However the shape and magnitude of the force-time curve are important. Thus limitations are imposed upon the manual pulse by the response characteristics of the control system, together with the rapidity by which the pilot can move the control. Based upon experience, it has been found that pilot technique is an important part of obtaining a satisfactory pulse. Usually, sharply applied control inputs of low amplitude have resulted in better excitation than those of large amplitude. Large amplitude inputs have invariably resulted in pulses of prolonged duration which fail to disturb the structural modes.

For single engine type airplanes with fairly rigid control systems, manual control surface pulses have been effective in exciting antisymmetric modes with frequencies as high as 20 cps. Symmetric modes have presented a greater problem. Attempts to excite symmetrical wing modes with elevator control pulses have been ineffective; however, there has been some success in exciting the first bending symmetrical stabilizer mode with the elevator.

The second pulse method which has been extensively employed is that of firing explosive charges. With this method, control over the force-time curve is possible, allowing a broader frequency spectrum to be examined as compared to the manual pulse method. Also, the pulse shapes formed by explosive charges are likely to be more consistent. Of course, a means for containing and firing the charge is required and, for this purpose, a breech-nozzle assembly has been developed by the Douglas Armament Group. This device has been called an "impulse generator", with a length of 3-3/4 inches and a cross section of 1-1/2 x 1-1/2 inches. The breech of the impulse generator has been designed to accept a standard Mark 1 bomb ejector cartridge. These units have been installed on wing tips, stabilizer tips, and fin tips.

A wing tip installation is shown by Figure 1 consisting of four units. Here the nozzles can be seen firing upwards. Thermostatically controlled heating blankets are wrapped around each unit to insure that the ignition delay time and burning rate remain unchanged with ambient temperature. Uniformity of ignition delay and burning rates are always desirable, but are especially important when synchronization between two pulses is required, e.g., when exciting symmetrical modes.

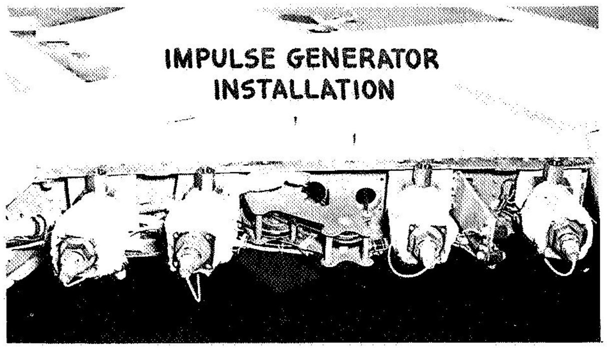

Figure 1. Impulse Generator Installation

Figure 2 shows an oscillograph record illustrating the satisfactory excitation of the first symmetrical wing mode during low-speed flight with an external store configuration. It can be seen that the wing tips are in phase following the firing, with a well-defined decay envelope. At high-speed, although the "hash" level was considerably higher than for the low speed case, it was still possible to sketch a reasonable decay envelope for computing the damping. Antisymmetric modes were excited by aileron and rudder pulses.

DEVELOPING PULSE SHAPES

Some work has been done at Douglas, El Segundo in shaping the pulse of the explosive charges in order to emphasize the response of a given structural vibration mode. The impulse generator, when used with a standard ejector cartridge, generates a force curve similar to that shown at the top of Figure 3. The pulse rises sharply, reaching a peak value of about 1000 pounds in 7 milliseconds. With this pulse, one would expect the higher frequencies to be excited at the expense of the lower. The lower curve of Figure 3 shows an approximate half-sine pulse as generated by a specially developed reload. This half-sine reaches a peak value of about 500 to 700 pounds in approximately 17.5 milliseconds; longer rise times, it was found, could not be developed by reloading the

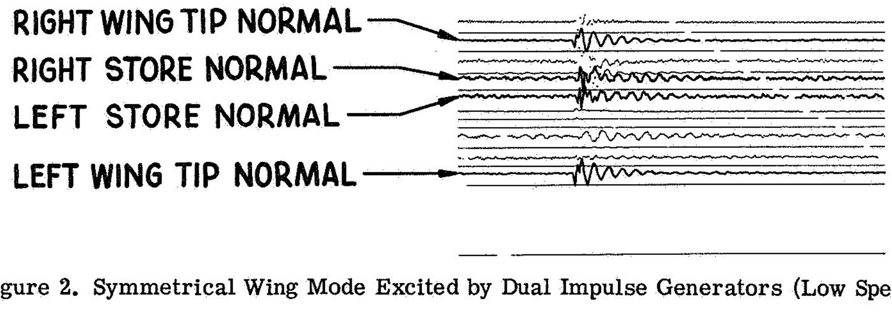

Figure 2. Symmetrical Wing Mode Excited by Dual Impulse Generators (Low Speed)

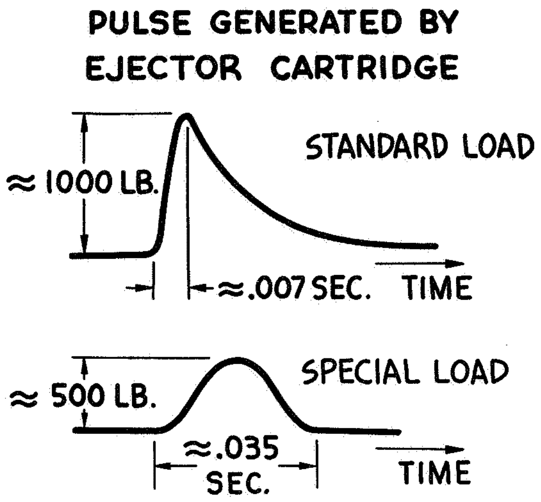

Figure 3. Pulse Generated by Ejector Cartridge

ejector cartridge without an unacceptable reduction in peak force and a deterioration of reliability.

An analog computer study was made to determine the response of a cantilever wing to the pulse shapes shown by Figure 3. Mass and elastic properties of the wing were included together with normal computer damping. Aerodynamic forces were not simulated. The computer study showed that best results, as measured in terms of maximum displacement response of the first bending mode per peak force input, could be expected when the rise time of a half-sine pulse equaled about 1/3 the period of the first bending frequency. For pulse shapes generated by a standard cartridge load, a rise time of 1/4 the period gave the maximum amplitude response per peak force input.

The analog results indicated that standard ejector cartridge loads were satisfactory for frequencies of about 40 cps. However, our critical flutter modes have been from 5 to 30 cps and, therefore, special reloads have been used. These special loads have operated effectively down to 12 cps. For lower frequencies, reliance has been placed upon control surface pulses.

APPLYING THE PULSE METHODS

The success, as well as lack of success, in using the pulse methods described can best be shown by citing three cases wherein the pulse method was used.

Case 1:

A small attack airplane experienced a fin-rudder flutter at a speed lower than the airplane had been flown previously. This flutter had not been predicted by analysis. No systematic pulsing in conjunction with the speed build-up program had been done prior to the flutter incident. This incident led to a flight program with an unstable configuration using manual rudder pulses and pulses by impulse generators while cautiously approaching the flutter speed. It was believed necessary to obtain a damping plot of the known unstable configuration in order to demonstrate the value of the pulse technique in predicting the approach to instability, thereby establishing a method whereby a "fix" could be demonstrated. Therefore, a speed build-up program was conducted wherein the decay rates, measured from the fin response, were plotted vs speed, as shown by Figure 4.

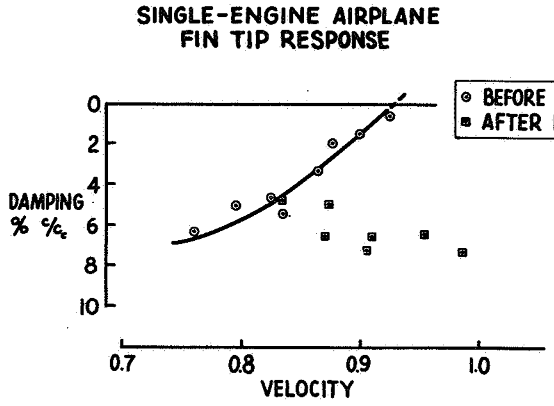

Figure 4. Single-Engine Airplane Fin Tip Response

This damping plot indicates a definite trend to neutral stability. Since tests were carried out at an altitude higher than where flutter had originally occurred, the speed where the actual flutter occurred is not plotted. Figure 4 also shows a plot of the damping data obtained after making the fix. All flights were made with a rudder damper installed and adjusted with one degree of free-play. This damper arrangement was used to limit the rudder amplitude, thereby preventing destructive oscillations in case the flutter speed was exceeded.

Case 2:

The next example concerns a flight test program wherein flights were conducted in the speed region where fin stability was predicted to be marginal. Manual rudder pulses failed to excite the instability or definitely indicate approaching instability. The technique was for speeds to be advanced with control surface pulses, followed by an impulse generator firing at a slightly lower speed. Flutter was excited by an impulse generator at a speed 5 knots lower than where a rudder pulse had been made. Figure 5 shows the oscillograph record of the oscillating surface with the amplitude limited by the free-play rudder damper.

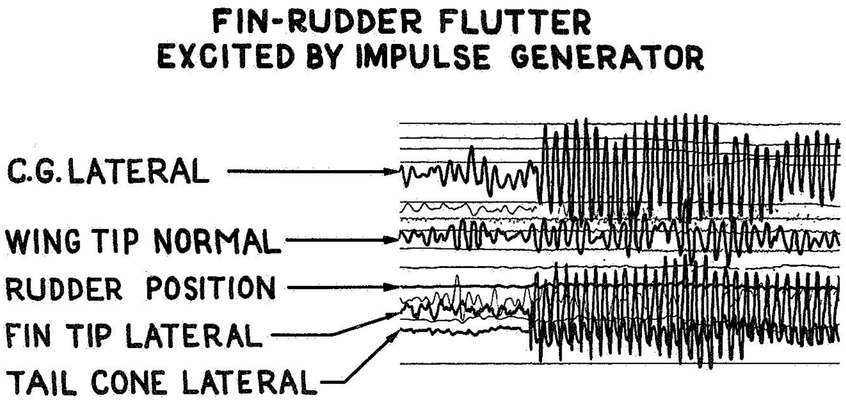

Figure 5. Fin-Rudder Flutter Excited by Impulse Generator

This case does not speak well for the pulse technique in that a flutter case was actually allowed to develop; however, it does illustrate the importance of proper excitation. We believe that the investigation of this case was complicated by static friction, as are most investigations of flutter involving control surfaces.

Case 3:

A twin-engine airplane had been given control surface pulses during the initial speed build-ups but, as attention had been directed to modes which were thought to be critical but in fact were not, a mode involving horizontal stabilizer yawing was not detected as becoming unstable. The flutter frequency was relatively low and did not involve sufficient response in the cockpit area for the pilot to be aware of its existence. After the flutter incident, speed build-ups were again made with proper attention given to the stabilizer yawing mode. The damping measured from the tests is presented by Figure 6 and shows the approach to instability. After stiffening the structure, pulse tests were again made. These results are also shown in Figure 6. Although the damping appears to be good, the data is scattered and a definite trend is not indicated; consequently, the flutter speed for the fix could not be predicted by extrapolating the damping plot.

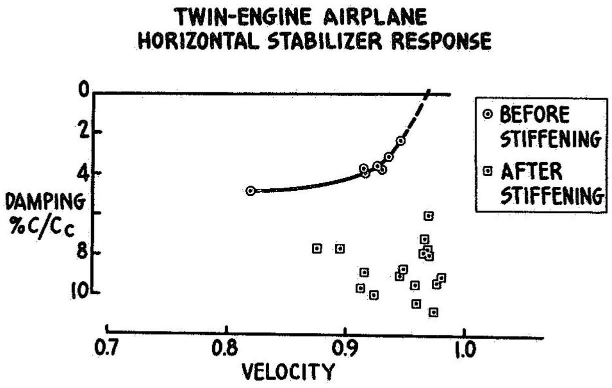

Figure 6. Twin-Engine Airplane Horizontal Stabilizer Response

CONCLUSIONS

Based on experience gained from flutter flight testing in general and from using the pulse techniques in particular, the following conclusions have been reached:

(1) It is possible to fly beyond the critical speed without exciting flutter.

(2) Systematic pulsing is necessary to minimize the possibility of flying into a dangerous speed range.

(3) Where flutter is known to exist, proper pulsing has yielded damping data which could be extrapolated to the flutter speed.

(4) A conscientious effort must be made to instrument and watch for unpredicted flutter modes; we must not be distracted by watching only those which have been predicted to be critical.

(5) Although it does not always establish the flutter speed, the pulse technique is useful in showing the margin of damping within the speed range of the airplane.