TRANSIENT FLIGHT FLUTTER TEST OF A WING WITH TIP TANKS

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Abstract

Wing flutter was encountered during flight testing of the F2H-2 airplane with full wing tip tanks. As a result, more refined theoretical analysis as well as flight flutter tests were initated to establish corrective measures and to experimentally verify the stability of the improved system. The results from the flight flutter tests, utilizing the transient response technique, are presented. The method of excitation consisted of abrupt deflections of the ailerons resulting from "stick bangs" and data were measured by wing tip accelerometers.

A comparison of the results with theoretical predictions is presented and indicates that reasonably good correlation was obtained. The influence on wing flutter of tip tank fuel transfer cycle, which was incorporated to control the center of gravity range of the tank during defueling, is indicated by the measured results and compared with the theory. The final configuration utilized a transfer cycle which was proven stable as a result of flight flutter testing. It is concluded that transient response measurements resulting from stick bangs provide a reasonably reliable and safe technique of flight flutter testing for wings with external tanks or heavy stores.

INTRODUCTION

The Model F2H-2 Airplane is a single place, carrier-based, two-engine jet fighter. Its gross weight is approximately 20,000 pounds and it was designed to fly in the high subsonic region. All controls are manual except for the power-boosted ailerons. It differs from its predecessor, the F2H-1, in that it carries 200-gallon fuel tanks on each wing tip.

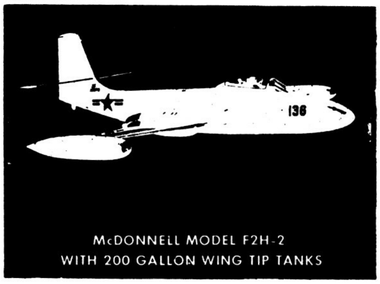

Figure 1. McDonnell Model F2H-2 with 200 Gallon Wing Tip Tanks

For flight testing the aeroelastic properties of the wing, two accelerometers were installed in each wing tip, one located forward and one aft as shown in Figure 2. The outputs from these accelerometers were recorded on an oscillograph. By comparison of the magnitude and phase of the various records, wing motion could be identified as symmetrical or asymmetrical, and some idea of the magnitude of bending and torsion at the wing tip could be determined.

The means of excitation – of inducing oscillations of the wing – was provided by the pilot. An asymmetrical pulse was induced by a sharp lateral blow on the control column by the pilot's fist. A symmetrical pulse was induced in the same manner by the pilot striking the control column forward or aft. The pilot excited the system by these "stick bangs" at each small increment in speed for a constant fuel loading condition, or at each small incremental change in fuel loading for a constant speed condition.

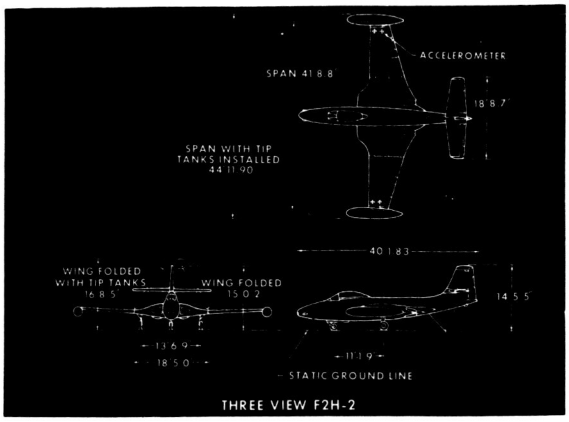

Figure 2. Three View F2H-2

Since the rate of transition from a stable to an unstable condition with increase in speed was quite low, as predicted by the initial theoretical analysis, this was considered to be a reasonably safe technique.

The oscillograph records obtained in this fashion were analyzed to establish the rate of decay, frequency, and mode of the wing oscillatory motion, as a means of defining the wing aeroelastic stability. Most of the flight testing was performed at approximately 10,000 feet altitude in order to test to the highest q possible for this Mach number limited airplane.

DISCUSSION

Prior to the flight of the production model of the F2H-2, its prototype, the XF2H-1, modified to carry 200-gallon wing tip tanks having slightly smaller diameter and slighly greater length, had been thoroughly flight tested and had demonstrated adequate aeroelastic stability for all tank fuel contents from full to empty. Because of this, no problem areas were anticipated for the F2H-2 configuration, the two airplanes being considered fairly similar dynamically.

Each tip tank for the F2H-2, as well as for the XF2H-1, was divided into three compartments as shown in Figure 3, and by means of internal plumbing was defueled in a forward-aft-center (F-A-C) sequence by means of pressurized air. This defueling sequence was selected since it kept the tank center of gravity travel at a minimum, generally in a forward location with respect to the wing elastic axis which was considered stabilizing, and did not impose maneuvering load restrictions on the airplane.

Because the symmetric wing mode exhibited extremely good aeroelastic stability properties for all tip tank fuel conditions, the following discussion is confined to the asymmetric wing mode which became

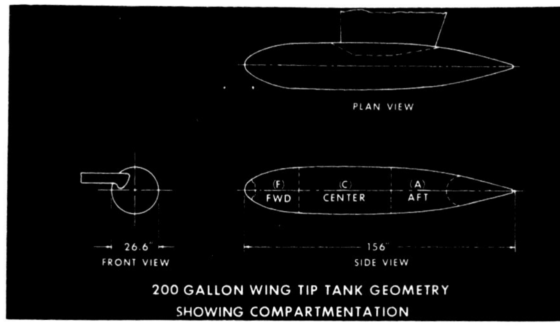

Figure 3. 200 Gallon Wing Tip Tank Geometry Showing Compartments

nearly neutrally stable for several tip tank fuel conditions during initial flight flutter testing.

The empty tank was the first configuration to be tested. Adequate stability was demonstrated and is seen in Figure 4 to be in fair agreement with the results of theoretical analysis which are also shown. All theoretical results are based on the use of incompressible flow three-dimensional strip theory and were conducted for the test altitude of 10,000 feet. The aerodynamic properties of the tip tank were represented by an equivalent rectangle which produced the same steady aerodynamic force and moment coefficients relative to the wing elastic axis as determined by wind tunnel tests. Fuel was considered as a solid mass.

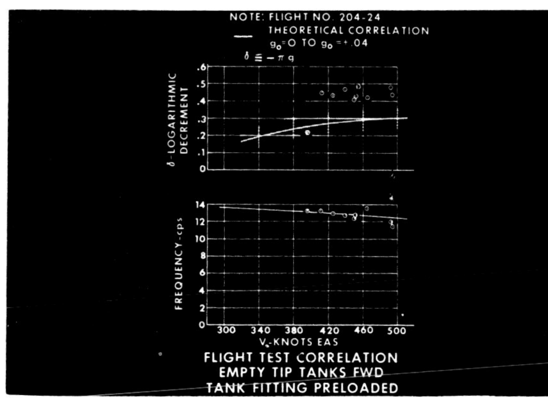

Figure 4. Flight Test Correlation Empty Tip Tanks Fwd Tank Fitting Preloaded

The next fuel configuration tested was the full tank. Near neutral stability was encountered at 450 knots equivalent airspeed in the asymmetric mode. It can be seen in Figure 5 that the test points show less stability than the theory at the higher speed end. This is probably due to the system being so nearly neutrally stable that any external disturbance would

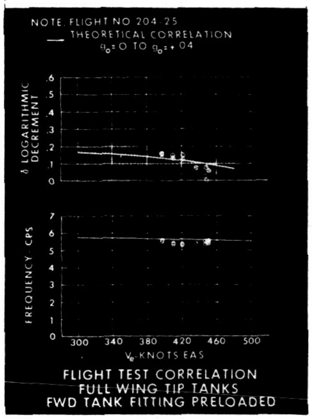

Figure 5. Flight Test Correlation Full Wing Tip Tanks Fwd Tank Fitting Preloaded

necessarily be amplified under this condition. The theory shown here is the result of an extensive program of ground testing and a prodigious amount of theoretical analysis which was initiated subsequent to this incident and which continued during and after the flight testing program had been concluded.

In examining the flight test results for the F2H-2 and the XF2H-1 Airplanes with full and empty tip tanks, it was noted that the frequency of the critical asymmetrical mode was ten to fifteen percent higher for the F2H-2 Airplane than for the XF2H-1 Airplane. A similar difference was noted during the ground vibration tests, but the full significance of this difference was not indicated by the relatively limited theoretical analysis for the XF2H-1 Airplane.

When more extensive analyses were conducted for the F2H-2 Airplane and the effect of a wide variation in wing torsional frequency was studied, the primary difficulty was uncovered. As shown in Figure 6, a region of relatively low flutter speed is encountered for certain values of wing torsional frequency. The minimum point is associated with a ratio of wing torsion frequency to wing asymmetrical bending frequency equal to one. A comparison of the operating conditions of the XF2H-1 and F2H-2 Airplanes in Figure 6 shows clearly why near-neutral stability was encountered at 450 knots equivalent airspeed for the F2H-2 while the XF2H-1 was adequately stable. One means of improving the F2H-2 stability is also indicated here. If the wing torsional frequency could be reduced in some way, it would approach the more stable XF2H-1 operating condition. This, as will be seen, is exactly what was done.

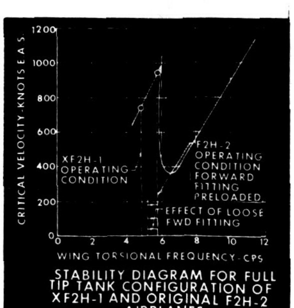

Figure 6. Stability Diagram for Full Tip Tank Configuration of XF2H-1 and Original F2H-2 Airplanes

Tests were conducted to compare the tank-to-wing attachment stiffnesses of the F2H-2 and XF2H-1 Airplanes and the forward attachment of the F2H-2 was found to be much stiffer than that of the XF2H-1. By rigging the forward tank-to-wing attachment, represented schematically in Figure 7, so as to permit some motion between the upper ball-socket arrangement which had previously been pre-loaded to an equivalent of 3 g's normal force on the tank, the stiffness contribution of the attachment was effectively reduced.

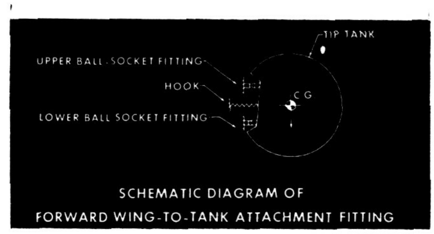

Figure 7. Schematic Diagram of Forward Wing-to-Tank Attachment Fitting

The system, so modified, was flight tested and with adequate looseness in the forward fitting as established by trial, proved to be a satisfactory configuration. A comparison of experimental and theoretical flutter stability for this configuration is shown in Figure 8. It was found that the frequency of the critical mode which had been theoretically shown to be proportional to the wing torsional frequency, had decreased by 12 to 15 percent as a result of loosening the forward fitting. This effect can be seen by a comparison of Figures 5 and 8.

Having improved the full tank stability sufficiently, testing was continued at gradually increasing speeds, with the tank fuel decreasing from full to empty at each speed. At 450 knots equivalent airspeed, a condition of low damping was found for a fuel content of from 150 to 120 gallons. This region is shown by theory in Figure 9. Figure 10 shows a "slice" taken through Figure 9 where the variation of damping with minutes of fuel transfer measured

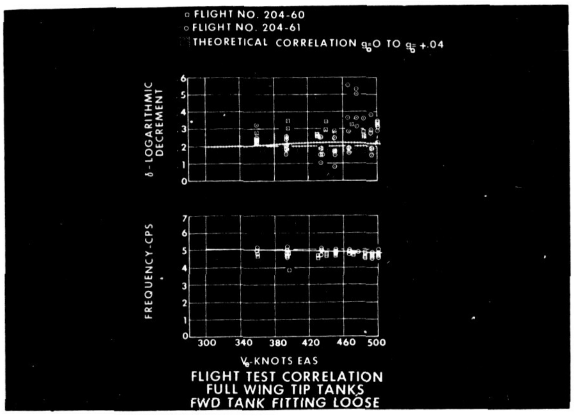

Figure 8. Flight Test Correlation Full Wing Tip Tanks Fwd Tank Fitting Loose

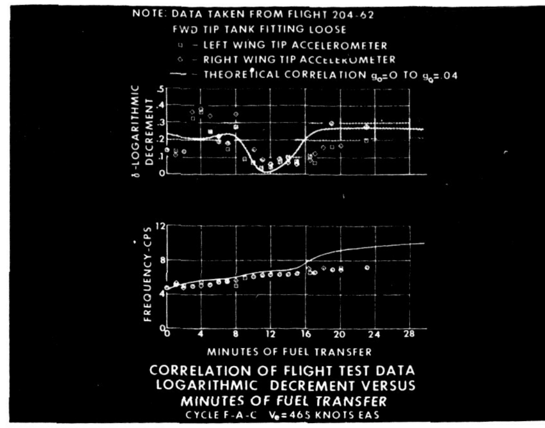

Figure 10. Correlation of Flight Test Data Logarithmic Decrement Versus Minutes of Fuel Transfer - Cycle F-A-C V_e = 464 Knots EAS

for a flight velocity of 465 knots is compared with theoretical results. Good correlation is seen to exist. (It might be mentioned here that it took about 27 or 28 minutes to transfer the 200 gallons of fuel from each tank.)

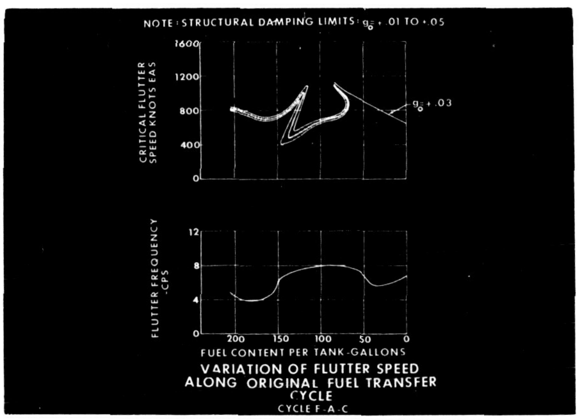

Figure 9. Variation of Flutter Speed Along Original Fuel Transfer Cycle - Cycle F-A-C

The region of relatively low speed instability was found, from a theoretical analysis, to be caused by the wing torsion to asymmetric bending frequency ratio being close to unity. Though the stability boundaries for various fuel loadings do not follow the same variation with change in the wing torsional frequency as shown for the full tank condition, Figure 6, the boundaries do have the common characteristic of a rapid transition in the oritical velocity of the system as the torsion to asymmetric bending frequency ratio of the wing approaches and passes through a value near unity. In the full tip tank configuration the torsion to asymmetric bending frequency ratio is somewhat less than unity (.85), while in the empty tank configuration the frequency ratio is somewhat greater than unity (1.44). It follows, then, that somewhere along the fuel transfer cycle, the operating frequency ratio must approach and pass through a value of unity, traversing the characteristic dip in the stability boundary. Whether or not this results in an unsatisfactory condition depends on the value of the minimum velocity of the dip.

It was found from theoretical analysis that the minimum velocities of the dip in the stability boundary were lower in the early stages of the fuel transfer cycle — when the tip tanks contained a large quantity of fuel — than in the latter stages of the fuel cycle. This indicated the desirability of making the transition through the critical frequency — which was unavoidable — late in the cycle when the tip tanks were nearly empty. The essential short-comings of the original fuel cycle (forward-aft-center) was that it did not accomplish this. The transition through the characteristic dip in the stability boundary occurred quite early in the cycle when the minimum velocity of the critical region was well within the operating speed range of the airplane.

By altering the internal plumbing of the tip tank the sequence in which the three fuel compartments of the tank were emptied could be changed. Without modifying the compartmentation of the tank there were just two alternate fuel transfer cycles which:

(1) did not yield a value of the wing torsion to asymmetric bending frequency ratio similar to that of the original cycle in the region of 120 to 150 gallons, and

(2) maintained a stabilizing tank center of gravity location well forward of the wing elastic axis.

As seen in Figure 11, the tank moment of inertia for both the intermediate cycle (A-C-F) and the final cycle (C-A-F) in the range of fuel content from 120 to 150 gallons is substantially greater than that for the original cycle (F-A-C) and consequently each produces a lower ratio of wing torsional frequency to wing asymmetric bending frequency, that is, in the direction of increased stability.

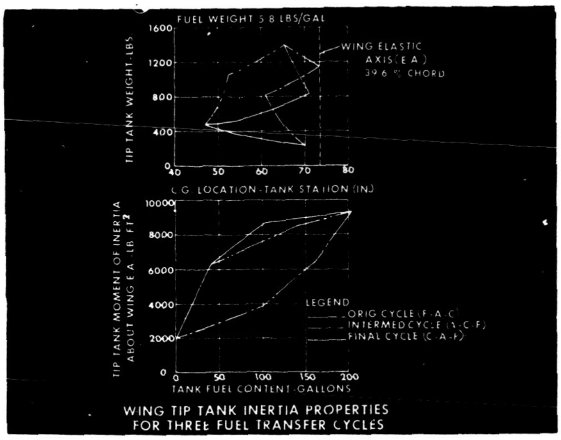

Figure 11. Wing Tip Tank Inertia Properties for Three Fuel Transfer Cycles

Both fuel cycles were flight tested. The theoretical variation of flutter speed with fuel usage is shown in Figure 12 for the intermediate fuel cycle. Adequate stability is seen to exist to about 500 knots equivalent airspeed. In Figure 13 flight test stability data in the form of logarithmic decrement versus minutes of fuel transfer obtained for the intermediate fuel cycle at a velocity of 470 knots equivalent airspeed is compared with theoretical results. Good agreement is seen to exist.

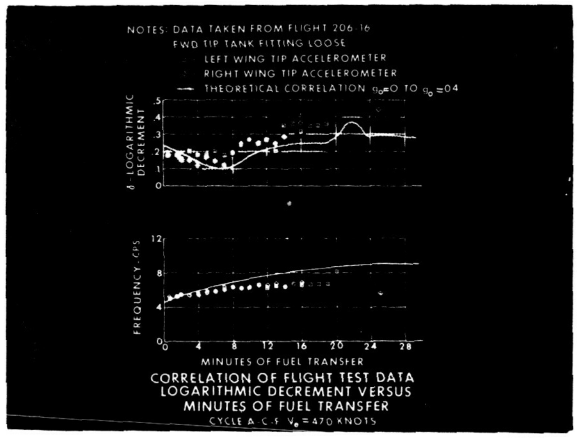

Figure 13. Correlation of Flight Test Data Logarithmic Decrement Versus Minutes of Fuel Transfer Cycle - Cycle A-C-F V_e = 470 Knots

The theoretical variation of flutter speed with fuel usage is shown in Figure 14 for the final fuel cycle. It exhibited the greatest stability of the three cycles becoming neutrally stable at about 600 knots equivalent airspeed, which was far in excess of the maximum velocity for this airplane. Here again in Figure 15 flight test stability data in the form of logarithmic decrement versus minutes of fuel transfer obtained for the final fuel cycle at a velocity of 470 knots equivalent airspeed is compared with theoretical results. It is to be noted that good agreement has been obtained here between the theoretical and test data for both the value of damping and frequency of the lowest damped mode. This fuel transfer cycle was incorporated as the final fuel sequence configuration because of its greater stability plus the fact that it did not impose flight load restrictions on the air-

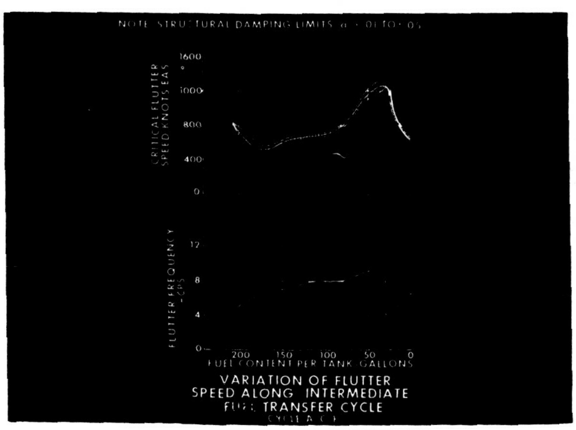

Figure 12. Variation of Flutter Speed Along Intermediate Fuel Transfer Cycle - Cycle A-C-F

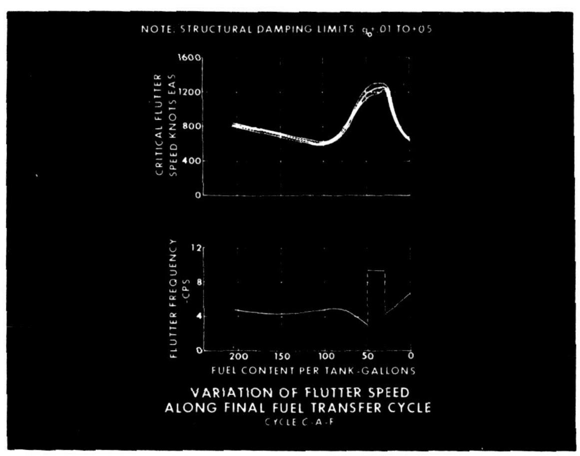

Figure 14. Variation of Flutter Speed Along Final Fuel Transfer Cycle - Cycle C-A-F

plane since the centers of gravity for conditions for large fuel contents were always relatively close to the wing elastic axis.

It has been shown how flight flutter testing by the transient response technique provided a reliable measure of the flutter stability of the wing tank configuration when employed in conjunction with theoretical analysis. It is concluded that transient response from "stick bangs" can provide a reasonably reliable and safe technique of flight flutter testing for wings with external tanks or heavy stores.

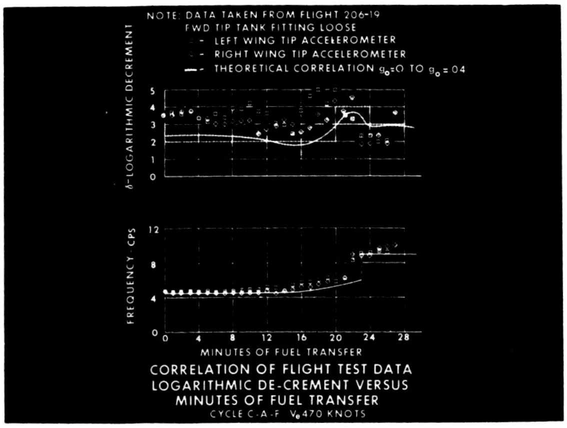

Figure 15. Correlation of Flight Test Data Logarithmic Decrement Versus Minutes of Fuel Transfer - Cycle C-A-F V_e = 470 Knots