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FLUTTER CLEARANCE FLIGHT TESTS OF AN OV-10A AIRPLANE MODIFIED FOR WAKE VORTEX FLIGHT EXPERIMENTS

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SUMMARY

Envelope expansion, flight flutter tests of a modified OV-10A aircraft are described. For a wake vortex research program, the airplane was modified to incorporate three, forward-extending instrumentation booms, one extending forward from each wing tip and one from the right side of the fuselage. The booms are instrumented with sensors to measure the velocity and direction of local air flow. The flutter tests results show that the modified OV-10A aircraft is free from flutter at speeds up to 330 KEAS at 5000 feet altitude.

INTRODUCTION

As part of an ongoing research program to understand the effects of atmospheric characteristics such as turbulence and winds on wake vortex flows, NASA Langley has specially instrumented an OV-10A (NASA 524) airplane for use in flight research studies. Figure 1 is a photograph of this airplane.

The OV-10 will be flown in airport approach and departure corridors with onboard instrumentation used to measure atmospheric characteristics. These data will be used to extrapolate independent atmospheric and vortex intensity data measured on the ground adjacent to the flight corridors. Both sets of data will be used to validate computer models of wake vortex decay and transport. The validated computer models will then be used to develop an operational Aircraft Vortex Spacing System (AVOSS). The AVOSS will be used to increase airport capacity by safely reducing landing and departure separations in most weather conditions. For these tests the OV-10A will not purposely penetrate vortices produced by other aircraft. It is expected that additional tests will be conducted where the OV-10 is flown into the wake produced by other aircraft and the characteristics of the wake determined. The response of the OV-10A to these wakes will also be measured.

The modifications of the basic OV-10A included the addition of three instrumentation booms and an onboard instrumentation pallet. A large, graphite-epoxy boom extending approximately one chord length forward of the leading edge of the wing was installed on each wing tip. At the end of each of these booms is a pair of vanes as well as a pitot-static probe. One vane was oriented to measure angle of attack; the other vane was oriented to measure angle of sideslip. A third forward-extending boom was mounted to the right side of the fuselage near the nose. A 5-hole pressure probe was mounted on the forward end of this boom to measure flow angles and velocity. These three systems are necessary to measure the severe flow gradients found in vortex flows.

The addition of the booms to the aircraft raised some concerns as to whether the airplane flutter characteristics might be affected. Consequently, it was decided to conduct envelope expansion flutter clearance flights as part of the aircraft functional check flights, with flutter clearance taking priority over functional checks. To this end the aircraft was instrumented with accelerometers to measure in flight dynamic response so that the flutter characteristics could be assessed. This report contains the results from these flutter clearance flights.

AIRPLANE STRUCTURAL DYNAMIC CHARACTERISTICS

Natural Vibration Characteristics

Some ground vibration tests were conducted for the cantilevered booms, booms attached to the airplane, and for the airplane with and without the booms. (ref. 1) Ground vibration test data for other OV-10 configurations were also available. (refs. 2 and 3)

The natural frequencies of the booms are given in Tables I and II. Table I contains the data for the wind-tip boom; Table II contains the data for the nose boom. The natural frequencies of the wind-tip boom given in Table I were obtained for the boom cantilevered from a massive backstop and for the boom mounted on the airplane. The cantilevered fundamental frequency was 15.8 Hz in both the vertical and lateral directions. There were slight differences in frequency for the second bending mode in the two directions. The vertical frequency was 47.2 Hz and the lateral frequency was 49.6. When mounted on the airplane, the boom had a first bending mode frequency of 12.3 Hz. The frequencies of the mode that was primarily the second bending mode was 48.0 Hz in the vertical direction and 50.3 in the lateral direction.

The natural frequencies for the nose boom, given in Table II, were only obtained for the boom mounted on the airplane. The frequencies of the first bending mode were 16.9 Hz in the vertical direction and 17.2 Hz in the lateral direction.

The natural frequencies of the most prominent airplane modes are given in Tables III and IV. These data are for fully fueled conditions. The natural frequencies of the clean airplane are given in Table III. All of the available vibration data, refs. 1-3, was used to develop the annotated frequencies in this figure. The natural frequencies of the airplane with the booms attached are presented in Table IV. Again all of the available vibration data was used to develop the annotated frequencies presented in Table IV. The natural frequencies for configurations with less fuel were similar to those given in the table. The primary effect of reducing fuel loading was to increase the frequencies of the modes that contained a large amount of wing motion. For example, the frequency of the first wing bending mode for the clean airplane with one-half fuel was 8.75 Hz as compared to 8.5 HZ for the fully fueled condition.

A comparison of the frequencies given in the various tables clearly shows that the primary effects of adding the booms to the airplane was to add additional modes to the spectrum rather than causing significantly changes to the basic airplane modes.

Flutter Characteristics

Results from previous flutter analyses and tests are not available for the OV-10A. Flutter analysis results are available, however, for an OV-10D (NOS) airplane which is a night observation version of the OV-10A. To create the OV-10D, the basic OV-10A was modified by adding additional electronics in an elongated nose, a M-97A gun system on the fuselage centerline, and new electronics in the cargo bay. The engine and propeller system were also upgraded.

Calculated flutter results are presented in reference 4 for three OV-10D configurations. One of these configurations has the NOS equipment removed, which makes this configuration very similar to the OV-10A. The calculated flutter speed for this OV-10D was 432 KEAS at a frequency of about 16 Hz. The critical flutter mode was identified as horizontal stabilizer bending. Furthermore, there was a region of low, yet stable, damping predicted for a nominal 6 Hz fuselage mode in the 120-150 KEAS range. Because of the similarities of these two configurations, it is believed that the basic (unmodified) OV-10A under study here has flutter characteristics similar to those calculated for the OV-10D with the NOS equipment removed.

INSTRUMENTATION

Two accelerometers were installed on the left wing of the OV-10A to measure dynamic response of the airplane during the flight flutter tests. One accelerometer was mounted at the outboard end of the front spar, the other near the outboard end of the rear spar. Ground vibration tests results for this airplane (ref. 1), and previous ground vibration (refs. 2 and 3) and flutter results (ref. 4) for other OV-10 configurations indicated that accelerometers located at these two places would be sensitive to all modal vibrations important to flutter. This includes the previously mentioned horizontal tail bending mode which also contains a significant amount of wing bending motion.

Two additional accelerometers were installed near the forward end of two of the instrumentation booms, one on the right-wing-tip boom and one on the fuselage-mounted boom. The accelerometer on the wing-tip boom was oriented to be primarily sensitive to motion in the pitch plane. The accelerometer mounted on the fuselage boom was rolled 45° to the left so that it would be sensitive to motion in both the pitch and yaw planes. Although these accelerometers were not installed explicitly for the flutter tests, they were monitored during the tests.

DATA ACQUISITION AND DISPLAY

Analog signals from the four accelerometers were amplified, digitized, and recorded using equipment mounted on the instrumentation pallet in the airplane. The signals were also telemetered to a ground station where they were scaled to g units and converted to analog form for real-time display. The onboard tape recorder provided backup should the telemetry system fail. The tape was never needed in this investigation.

The accelerometer signals were routed to a recording strip chart whose scale had been adjusted so that the signals levels could be reckoned directly in g units. The signals were also routed to a switching system that provided a means for any pair of signals to be analyzed by using a two-channel transfer function analyzer. This analyzer was used to obtain linear peak-hold spectra which are often used in flutter studies (refs. 5 and 6) The strip chart also had channels that displayed airspeed, altitude, aileron position, and time code. Another strip chart had channels that displayed heading, left rudder position, elevator position, airspeed, right alpha (pitch) vane, right beta (yaw) vane, normal acceleration and time code.

In addition airspeed data were determined from onboard sensors and displayed in several forms at the ground test center. Airspeed was also available through pilot callouts of the speed as read from his onboard instruments. Over the range of speeds and altitudes covered in this study, the pilot's indicated airspeed gage read approximate two knots below equivalent airspeed (KEAS). Consequently, the pilot's reading are interpreted herein as equivalent air speed values. As discussed in ref. 7, equivalent airspeed is the speed important to flutter. In the absence of significant compressibility and mass ratio effects the flutter speed expressed in KEAS is independent of altitude. This would be the expected case for the OV-10A.

TEST PROCEDURE

Prior to all taxi and flight tests the instruments where checked to see that they were working properly. For example, the tips of the booms were "plucked" to produce response in the first bending mode and the resulting accelerometer signal monitored.

Prior to the initiation of flight testing, several taxi tests were conducted, ranging in speed from very slow to almost takeoff speed. The accelerometer signals were monitored on the strip chart and analyzed using the transfer function analyzer.

Flight tests were conducted in two phases. The first phase was conducted in level flight. The aircraft speed was increased in increments until maximum level-flight speed was obtained. For the second phase, a sequence of dives was used to obtain higher speeds. For both phases the desired speed was reached at 5000 feet altitude. The accelerometer signals were continuously monitored during the flight tests.

Atmospheric turbulence and pilot initiated aileron "raps" were used to excite the aircraft. The pilot executed the aileron raps either on command from the ground or at agreed upon points in the preplanned flight trajectory.

RESULTS AND DISCUSSION

Taxi Tests

Prior to the first flight test a series of taxi tests were conducted to examine wing and wing-boom response. The maximum taxi speed was slightly below takeoff speed. The maximum response was obtained as the airplane taxied across a cable that had been laid across the runway for other purposes. Both the wind-tip and fuselage booms responded primarily in their first bending modes, 12.5 and 17.5 Hz, respectively. The wing tip boom responded more than the nose boom, maximum of ±6.8 g's versus ±2.5 g's. The forward-mounted wing-tip accelerometer responded more than the aft mounted accelerometer, maximum of ±5.8 g's versus ±4.6 g's. All structural responses were well damped. All frequencies of response were consistent with the ground vibration data. That is, dynamic structural responses only occurred at frequencies corresponding to identified natural frequencies of the airplane.

Level Flight Tests

For the first flight test, after the taxi tests were completed, the integrity of the telemetry signals and the levels of the accelerometer signals were monitored as the airplane took off and circled the Langley Air Force Base runway while maintaining 100 KEAS with the landing gear down. Because no unusual structural response was observed and the telemetry system appeared to be working properly, the aircraft was cleared to proceed to the flight test area slightly to the west north west of Langley. Indeed, the structural response in the air was considerably less than that observed during taxi. The pilot retracted the landing gear and proceeded at a nominal 100 KEAS to the test area.

Once on station, the pilot was instructed to gradually increase his airspeed to 120 KEAS. The response at this speed was very low level, not noticeably different from the response at 100 KEAS. The response was at such a low level that it raised concerns as to whether or not the accelerometers were functioning properly. Consequently, the pilot was instructed to return to the airfield for a touch-and-go landing to ensure that the instrumentation was working properly. The pilot returned and made the required landing. Because the acceleration response at touch down and during the ensuing ground run appeared to be normal, the pilot was instructed to affect a takeoff and return to the test area flying a speed no greater than 120 KEAS, which he did.

The low level of response was due to the fact that there was very little atmospheric turbulence to excite the airplane structure. For the remainder of the tests, aileron raps were used in addition to turbulence to excite the structure. The pilot gradually increased the airspeed from 120 to 150 KEAS while performing a number of aileron raps. The data displayed on the strip charts were continuously monitored. Spectral data were obtained periodically using the transfer function analyzer. The structural responses produced by the aileron raps were well damped. All responses appeared to be well damped. There was no extraordinary increase in level or response as airspeed was increased. The frequencies of the various structural modes that participated in the response did not change.

The aircraft, having been flutter cleared to 150 KEAS, the pilot performed some functional checks at lower speeds. These checks including engine shutdowns and propeller feathering, and cycling the landing gear. The structural response was monitored during these checks. No unusual response was observed. All responses were well damped.

Once these functional check were completed, the flutter clearance testing was resumed. After stabilizing at 150 KEAS at 5000 feet altitude, the pilot gradually increased the speed to 200 KEAS while performing aileron raps as required by the flutter test engineers. No unusual response was observed. All responses appeared to be well damped. There was no extraordinary increase in response with increasing airspeed. The frequencies of the various structural modes participating in the response remained unchanged. There was no indication whatsoever that a flutter condition was being approached. Thus it was concluded that the airplane was flutter free to 200 KEAS.

This flight was terminated because sunset was fast approaching. The aircraft returned to the airfield and landed without incident. Response data obtained during taxi after landing were consistent with before flight taxi data.

On the next working day, following preflight instrumentation checks and a short taxi test, the aircraft took off and returned to the flight test area to resume the flight flutter tests. The aircraft speed was gradually increased to 200 KEAS at 5000 feet altitude. During this increase in speed the accelerometer signals were monitored. The response obtained was similar to that obtained in the previous flight. The speed was gradually increased from 200 to 225 KEAS while the pilot did aileron raps and the accelerometer response was examined. No unusual response was observed. All responses appeared to be well damped. There was no extraordinary increase in response with increasing airspeed. The frequencies of the various structural modes participating in the response remained unchanged. There was no indication whatsoever that a flutter condition was being approached. The speed 225 KEAS was the maximum level flight speed of the airplane. Therefore, the airplane was flutter cleared to its maximum level flight speed.

Diving Flight Tests

To flutter check at speeds higher than 225 KEAS it was necessary for the pilot to dive the airplane. The procedure was to take the plane to an altitude higher than 5000 feet, then put the airplane in a dive using maximum power so that the desired speed was reached at 5000 feet. When the desired speed was reached, the pilot performed an aileron rap. The accelerometer output signals were continuously monitored during the climb, the dive, and the following pull out. Five dives were made. The first started at 8000 feet and reached 250 KEAS at 5000 feet. The four other maximum speed and starting altitude pairs were: 275 KEAS, 10,000 feet; 300 KEAS, 12,500 feet; 318 KEAS, 12,500 feet; and 330 KEAS, 12,500 feet. No unusual response was observed during these dives. Figure 2 is a reproduction of the strip chart recording of the response obtained for the 330 KEAS dive. Responses are given for the aft wing tip accelerometer, at the top in the figure, and the right wind-tip boom, at the bottom. The responses were relatively low level, of the order of 8 g's for both responses, and well damped. There was no extraordinary increase in response with increasing airspeed. The frequencies of the various structural modes participating in the response remained unchanged. There was no indication whatsoever that a flutter condition was being approached.

The 330 KEAS speed is the maximum dive this airplane was able to achieve. Therefore, the airplane modified with the instrumentation booms has been shown to be flutter free throughout its speed range at 5000 feet altitude.

CONCLUSIONS

Results from data obtained from envelope-expansion, flight flutter tests of the modified OV-10A show that the airplane is free from flutter at speeds up to 330 KEAS at 5000 feet altitude. Because flutter depends on equivalent airspeed, the airplane is flutter free at any altitude as long as 330 KEAS is not exceeded. (The previous statement assumes that there are no significant mass density and compressibility effects of the flutter speed, which would be the expected case here.) Flutter clearance to 330 KEAS is sufficient to ensure that the OV-10A will be free from flutter during the planned research flights.

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Table I. -Natural frequencies in Hertz of wind-tip boom.

(a) Cantilevered from rigid support

Mode	Frequency	Comment
1	15.7	First bending
2	47.2	Second vertical bending
3	49.6	Second lateral bending

(b) On airplane

Mode	Frequency	Comment
1	12.3	First bending
2	48.0	Second vertical bending
3	50.3	Second lateral bending

Table II. -Natural frequencies in Hertz of fuselage boom mounted on airplane.

Mode	Frequency	Comment
1	16.9	First vertical bending
2	17.2	First lateral bending

Table III. - Natural frequencies in Hertz of clean airplane, no booms.

Mode	Frequency	Comment
1	5.5	Coupled fuselage and tail booms
2	8.5	First symmetric wing bending
4	14.0	Wing-fuselage-empennage
3	18.1	First antisymmetric wing bending
4	21.5	Elevator bending
5	27.5	Asymmetric empennage
6	33.5	Coupled
7	37.5	Wing torsion

Table IV. - Natural frequencies in Hertz of airplane with booms.

Mode	Frequency	Comment
1	5.5	Coupled fuselage and tail booms
2	8.3	First symmetric wing bending
3	12.3	Wing-tip boom
4	14.0	Wing-fuselage-empennage
4	16.9	Fuselage boom
5	17.3	First antisymmetric wind bending
6	21.5	Elevator bending
7	27.5	Asymetric empennage
8	33.5	Coupled
9	37.5	Wing torsion

Figure 1. - Photograph of OV-10 airplane with booms.

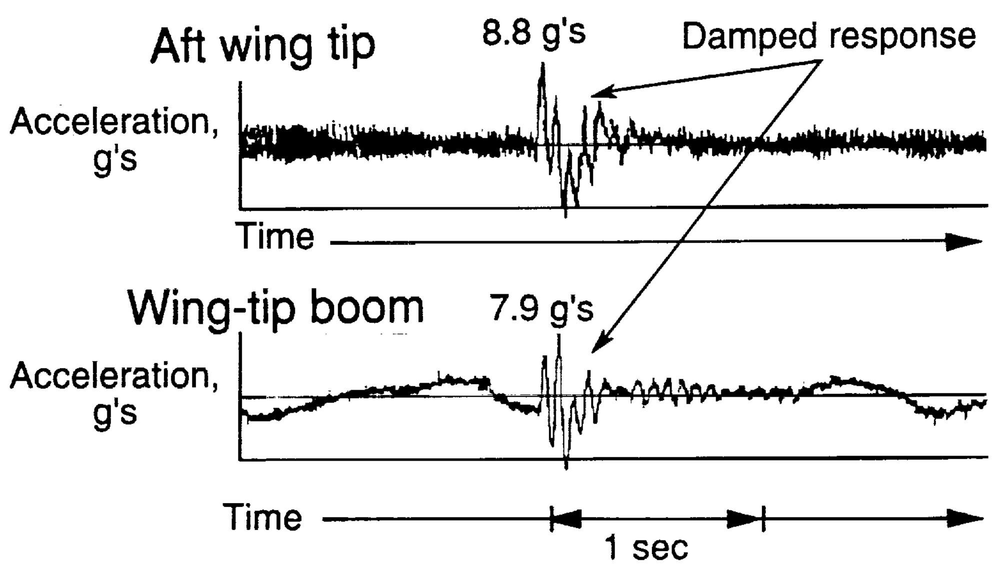

Figure 2. - Responses recorded on strip charts from aileron rap at 5000 ft altitude and 330 KEAS.

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Envelope expansion, flight flutter tests of a modified OV-10A aircraft are described. For a wake vortex research program, the airplane was modified to incorporate three forward-extending instrumentation booms, one extending forward from each wing tip and one from the right side of the fuselage. The booms were instrumented with sensors to measure the velocity and direction of local air flow. The flutter test results show that the modified OV-10A aircraft is free from flutter at speeds up to 330 KEAS at 5000 feet altitude.

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