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F-16 Flutter Model Studies with External Wing Stores

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INTRODUCTION

The prediction and the prevention of flutter on fighter aircraft carrying stores is a subject which is currently receiving widespread attention (for example, see ref. 1). Because tactical airplanes such as the F-16, shown in figure 1, carry a variety of external stores, numerous potentially flutter critical store combinations must be evaluated during flutter clearance studies. The addition of external stores to the wing changes the structural dynamics of the airplane usually resulting in a reduction of flutter speed.

The flutter prevention and clearance task for the F-16 airplane is being accomplished in a combined analysis, wind-tunnel dynamic-model test, and flight flutter test program. The purpose of this paper is to present some results obtained from transonic flutter model studies of the F-16 airplane with external wing stores. The flutter model was constructed to support the flutter prevention and clearance program from preliminary design through flight flutter tests. The wind-tunnel results were used to demonstrate the required flutter speed margin and to verify analytical methods. Approximately 270 wing-store configurations have been identified for the F-16 airplane from the 21 take-off store loadings shown in figure 2. The vast majority were found by analysis to present no problem. A few loadings were found to be marginal from a flutter standpoint with respect to the required flutter margin of safety. The flutter model test configurations were chosen to include the marginal loadings along with a representative cross-section of store weights and shapes and those configurations to be flight flutter tested.

The model tests were conducted in the National Aeronautics and Space Administration's Langley transonic dynamics tunnel. This facility was specifically designed (refs. 2 and 3) for experimental studies on flutter and other aeroelastic phenomena. The quarter-scale, full-span, free-flying transonic flutter model was designed and constructed by the Fort Worth Division of General Dynamics Corporation. The model was dynamically and aeroelastically scaled to simulate the F-16 airplane during sea level flight at Mach number of 1.2. The quarter-scale F-16 model wind-tunnel test program was initiated in June 1975 and continued into March 1977. One hundred and forty-nine model configurations were tested during four tunnel entries made during this period, 86 days of testing. The first two entries were preliminary tests where the model design was based on calculated values of airplane mass, stiffness, and vibration modes. For entries three and four the model was updated to incorporate measured airplane mass and stiffness.

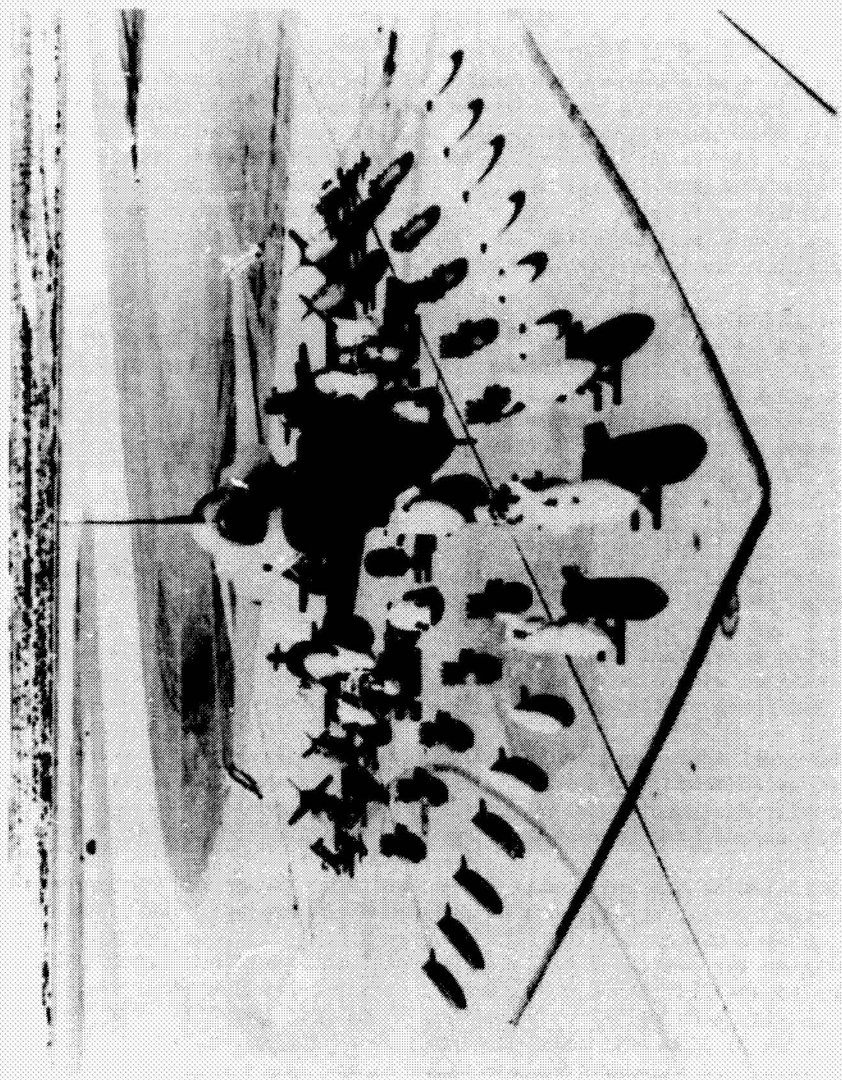

Figure 1.- F-16 Carries a Variety of External Stores.

LOADING	TIP	0.83	0.63	0.37	CENTERLINE	0.37	0.63	0.83	TIP
AIR-TO-AIR									
1	AIM-9J	-	-	370 TK	-	370 TK	-	-	AIM-9J
2	AIM-9J	AIM-9J	-	370 TK	ALQ-119-12	370 TK	-	AIM-9J	AIM-9J
3	AIM-9J	-	ALQ-119-14	370 TK	-	370 TK	ALQ-119-14		AIM-9J
23	AIM-9J	-	ALQ-119-14		300 TK				AIM-9J
AIR-TO-GROUND									
4	AIM-9J	-	ALQ-119-12	(6) MK-82	300 TK	(6) MK-82	-	-	AIM-9J
5	AIM-9J	-	(3) MK-82	370 TK	ALQ-119-12	370 TK	(3) MK-82	-	AIM-9J
6	AIM-9J	-	(3) MK-82R	370 TK	ALQ-119-12	370 TK	(3) MK-82R	-	AIM-9J
7	AIM-9J	-	(1) MK-82R	(4) MK-82R	300 TK	(4) MK-82R	(1) MK-82R	-	AIM-9J
8	AIM-9J	-	(1) MK-84	370 TK	ALQ-119-12	370 TK	(1) MK-84	-	AIM-9J
9					DELETED				
10	AIM-9J	-	(3) AGM-65	370 TK	ALQ-119-12	370 TK	(3) AGM-65	-	AIM-9J
11	AIM-9J	-	(1) GBU10A/B	370 TK	ALQ-119-12	370 TK	(1) GBU10A/B	-	AIM-9J
12	AIM-9J	-	(1) GBU8/B	370 TK	ALQ-119-12	370 TK	(1) GBU8/B	-	AIM-9J
13					DELETED				
14	AIM-9J	-	ALQ-119-12	(4) CBU-58/B	300 TK	(4) CBU-58/B	(2) CBU-58/B	-	AIM-9J
15	AIM-9J	-	(1) SUU-25C/A	370 TK	ALQ-119-12	370 TK	(1) SUU-25C/A	-	AIM-9J
16	AIM-9J	-	(3) MK-20 MOD 4	370 TK	ALQ-119-12	370 TK	(3) MK-20 MOD 4	-	AIM-9J
17	AIM-9J	-	ALQ-119-12	370 TK	B-43	370 TK	-	-	AIM-9J
18	AIM-9J	-	ALQ-119-12	370 TK	B-57	370 TK	-	-	AIM-9J
19	AIM-9J	-	ALQ-119-12	370 TK	B-61	370 TK	-	-	AIM-9J
20	LAUNCHER	-	(1) SUU-20B/A w/BDU-33B/B	370 TK	-	370 TK	(1) SUU-20B/A w/BDU-33B/B	-	LAUNCHER
21	LAUNCHER	-	(1) SUU-20B/A w/MK-106	370 TK	-	370 TK	(1) SUU-20B/A w/MK-106	-	LAUNCHER
22	LAUNCHER	-	-	370 TK	FERRY 300 TK	370 TK	-	-	LAUNCHER

Figure 2.- F-16 Full Scale Development Take-Off Store Loadings.

MODEL

The quarter-scale flutter model is shown installed in the Langley transonic dynamics tunnel in figure 3. The model is suspended in the wind-tunnel test section by a two-cable mount system. The use of the two-cable mount system (ref. 4) allows close simulation of the free-flight rigid-body modes of complete aircraft in the wind tunnel. The system consists of a pair of cables which pass through pulleys in the model; one cable extends upstream in a horizontal plane and the other extends downstream in a vertical plane. The cable mounted model was "flown" in the wind tunnel by means of remotely controlled horizontal tails which provided roll and pitch trim control.

MODEL FABRICATION

The wing, horizontal tail, and vertical tail were all constructed in a similar manner. Precured fiberglass skins were bonded to a contoured Nomex honeycomb core. A machined aluminum fitting was bonded to the root of each surface to provide a means of attachment to the fuselage. Proper mass distributions for each surface were obtained during assembly by use of ballast weights which were a mixture of tungsten chips and epoxy resin. The wing included leading-edge and trailing-edge devices. The leading-edge actuator stiffness was simulated by four tuned steel springs. The flaperon actuator restraint stiffness was simulated by a steel spring at the root. The wing assembly was bolted to steel support beams which are rigidly attached to the fuselage spar. The fuselage consists of a thin wall steel spar box with fiberglass shell sections attached. The nine shell sections are of sandwich construction with fiberglass skins bonded to Nomex core. A flow through inlet duct was installed on the model to insure correct flow around the fuselage. This inlet duct is a fiberglass shell with a cross-sectional area sized to establish the proper flow conditions at a simulated sea level altitude and a Mach number of 0.90.

WING PYLON STORE STATIONS

As shown in figure 4, external stores can be mounted at nine stations--one on the fuselage centerline, six under the wing, and two at the wing tips. Electronic countermeasure pods, bombs, and fuel tanks are examples of stores carried on the fuselage centerline. Three types of flexible pylons (fuel, weapons, adapter) attach to wing hardpoints. Flexible pylon locations are shown in figure 4 as a fraction of wing semi-span. The fuel tank store stations are located inboard (0.37) near the fuselage. The air-to-ground stores are carried at the weapons station located outboard of the wing mid-span (0.63) and at the inboard station. (0.37). Air-to-air missiles are carried on an adapter pylon (0.83) and on a launcher located at the wing tip.

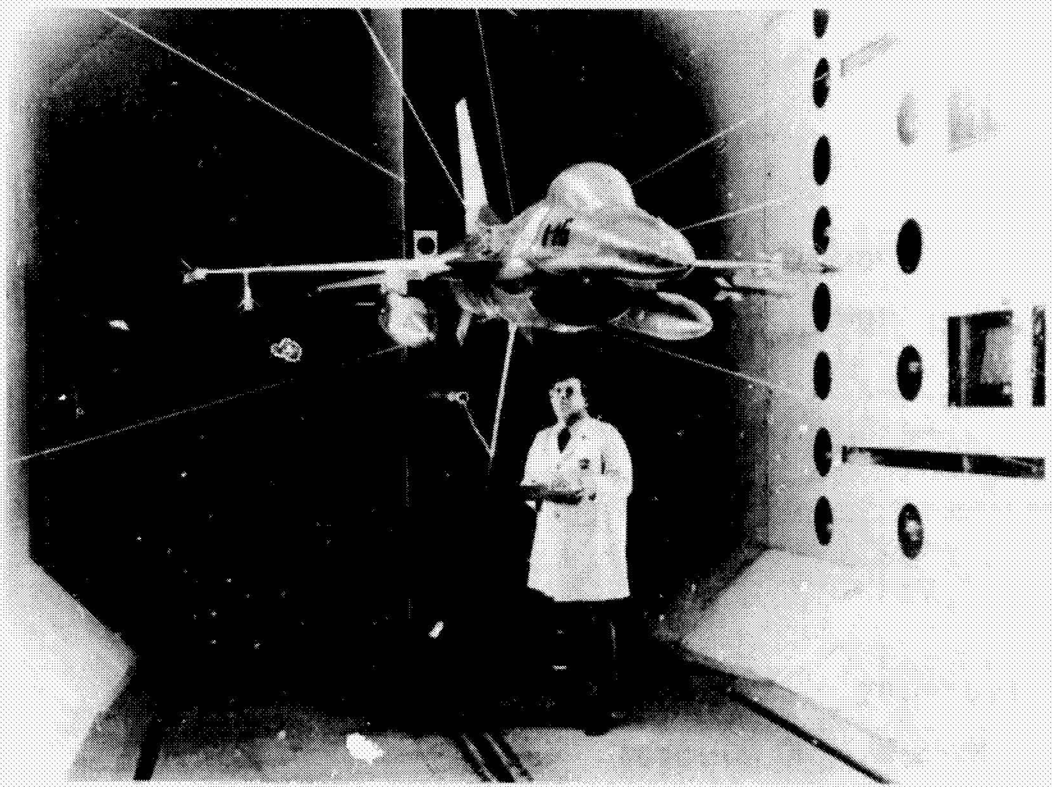

Figure 3.- Quarter-Scale Flutter Model Installation.

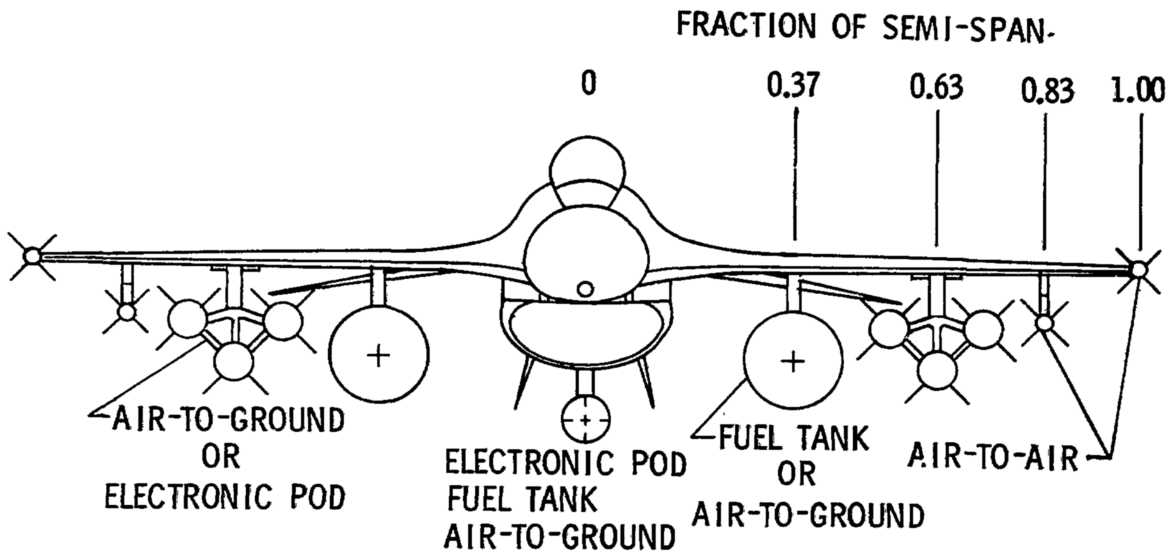

Figure 4.- Wing Pylon Store Locations.

ANALYSIS

In support of the wind-tunnel tests, flutter analyses were made at Mach numbers of 0.9 and 1.2 for each configuration to be tested. These calculations were made by Dave Shelton, Darlene Watts, and Paul Waner of the General Dynamics Corporation. The aerodynamic representation used in the wing-store analyses was based on the technique developed by Cunningham in reference 5.

It was found that the analysis gave a conservative prediction of the wind tunnel test results. Differences between the analyses and test results are attributed to the difficulties in accurately predicting the flutter speed of lowly damped roots. In cases where the analytical and model experimental results differ, the model results are considered to be more reliable in predicting full scale airplane flutter characteristics.

RESULTS AND DISCUSSIONS

Highlight results from the wind-tunnel model studies are presented in this section. The wind-tunnel model results are presented in the form of a reference equivalent airspeed ratio V/V_{REF} as a funtion of Mach number. The following topics are covered herein:

1. Asymmetrical Store Configurations Have Higher Flutter Speeds
2. Flutter Speed With Air-To-Air Missiles Increased by Use of Ballast
3. Low Damping Precedes Flutte[illegible] a GBU-8/B Heavy Bomb
4. External Fuel Tank Usage [illegible]

ASYMMETRICAL STORE CONFIGURATIONS HAVE HIGHER FLUTTER SPEEDS

Asymmetrical external store configurations are possible for an airplane such as the F-16; that is, the store loading on one wing differs from that on the other. The use of a complete flutter model flown on the two-cable mount system allows for experimental flutter clearance of asymmetrical external store configurations. A procedure often used (refs. 6 and 7) to reduce the size of the flutter prevention task is to analyze all configurations as being carried symmetrically. The assumption is that asymmetric configurations are inherently more stable than symmetric configurations. Experimental evidence to support this assumption for the F-16 is presented in figure 5. For the symmetrical fuel tank and underwing missile configuration shown at the top of figure 5, antisymmetric

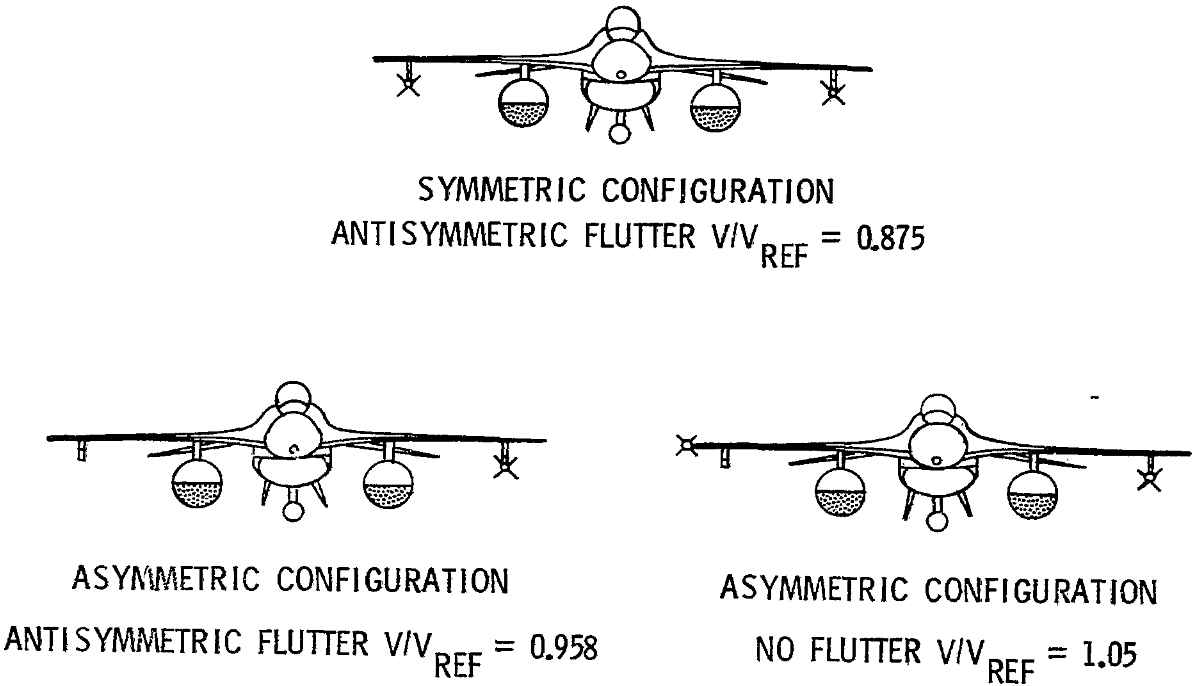

Figure 5.- Asymmetry Increases Flutter Speed.

flutter occurred at a reference equivalent airspeed ratio of 0.875. The asymmetric configuration shown at the bottom left of figure 5 was obtained by removing an under-wing missile. Flutter then occurred at a reference equivalent airspeed ratio of 0.958. For the asymmetric configuration of a wing-tip missile on one wing and under-wing missile on the other wing, as shown at the bottom right of figure 5, no flutter occurred out to an equivalent airspeed ratio of 1.05. The symmetrical configuration fluttered at a lower speed than either asymmetrical configuration shown in figure 5. The effect of asymmetrical store configurations in this case is to increase the flutter speed.

FLUTTER SPEED WITH AIR-TO-AIR MISSILES INCREASED BY USE OF BALLAST

A large portion of the flutter model tests was devoted to configurations with four air-to-air AIM-9J missiles. Preliminary model test results are given in figure 6a. For the basic four missile configuration symmetric flutter occurred at Mach numbers 1.12 and 1.09, near the required flutter margin of safety boundary. As seen in figure 6a, removal of the tip missiles resulted in antisymmetric flutter occurring at reduced airspeeds at Mach number of 1.0 and 1.07. This flutter mode was the result of coupling between two closely spaced antisymmetric modes, under-wing missile pitch at 9.55 Hz, and wing first bending at 9.62 Hz. In view of the above results, an analytical and model parametric study was undertaken to evaluate methods of increasing the flutter speed by increasing the frequency separation of these two modes. Methods examined included moving the under-wing missiles forward, stiffening the missile launchers, and adding ballast weight to the missile launchers.

When the first method (moving missile forward) was tested, the model and analysis showed different trends. However, by refining the analysis to include aerodynamic interaction between the wing and the missile, better correlation with the model results was obtained. The flutter model results showed that a 0.254 meter forward movement of the under-wing missile was beneficial for the loading with the two under-wing missiles, but decreased the flutter speed ten percent for the four missile loading.

The second method, stiffening the missile launchers, was successful in increasing the flutter speed, but required too large a weight penalty and was not considered an acceptable solution.

The third method, adding a small ballast weight to the missile launchers, was selected to improve the flutter characteristics of the four missile case. Ballasted-launcher test results are presented in figure 6b. The changes in the model from the initial test are slightly lengthened missile launchers (required to accommodate potential change over to AIM-9L missiles) which have a small ballast added in the nose. With launcher ballast, the four-missile loading (figure 6b) fluttered at a Mach number of 1.10, at an airspeed slightly higher than the initial case (figure 6a). The loading with the tip missile removed showed no flutter (figure

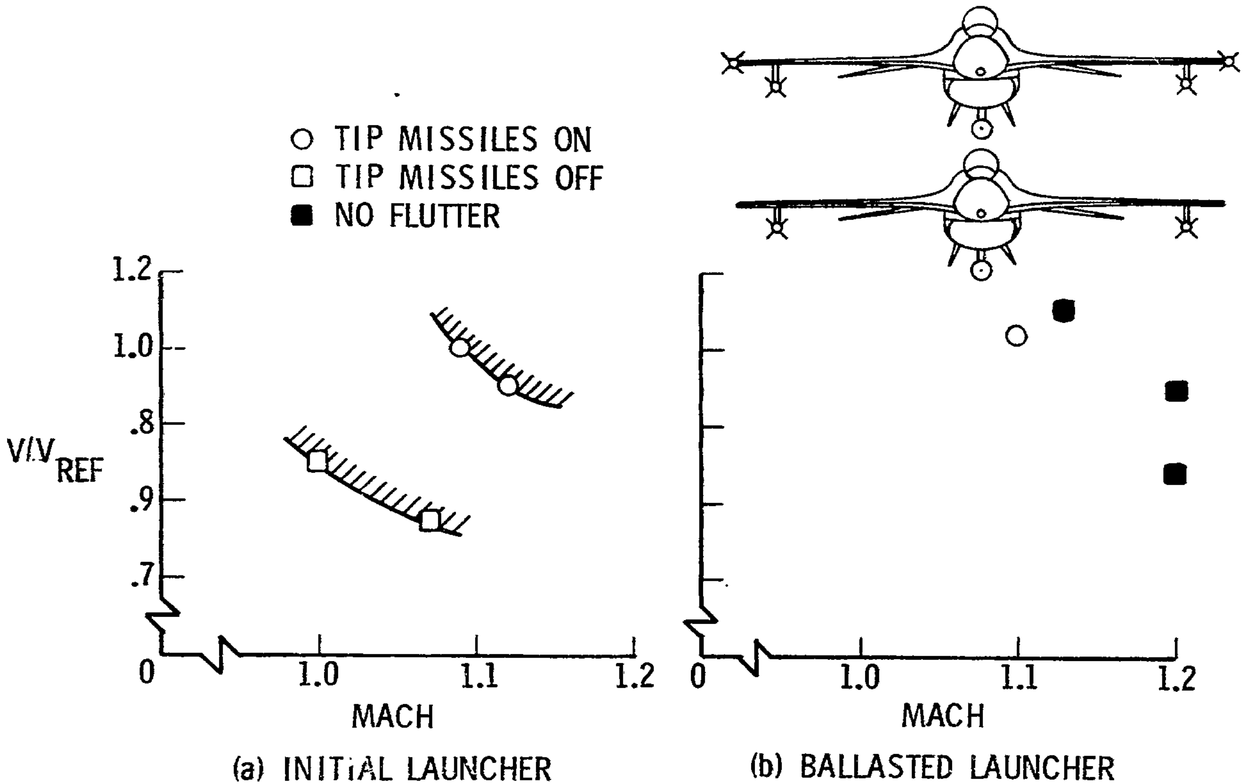

Figure 6.- Launcher Ballast Improves Missile Flutter Speed.

6b) out to a Mach number of 1.13. The model test was terminated at this point (near maximum tunnel dynamic pressure) due to the development of a lateral instability of the model on the cables. With the addition of ballast to each airplane launcher, substantial improvement in flutter characteristics for the loading with the tip missile removed is seen. This result impacted the airplane design in that the airplane missile launchers have been modified for flutter speed improvement.

LOW DAMPING PRECEDES FLUTTER OF A GBU-8/B (HEAVY BOMB)

Flutter model test results for a GBU-8/B heavy air-to-ground weapon (1027 Kg, 2265 LBM) are presented in figure 7. This particular bomb is the only one out of the list of air-to-ground weapons which may be marginal from a flutter standpoint. All other weapons carried at the 63 percent span have more than the required flutter margin of safety based on model test results.

Mild symmetric flutter was observed just beyond the required carriage envelope (0.9 Mach). This flutter was preceded by a wide band of lowly damped oscillations as shown on the right of figure 7. Similar results were obtained with a half full 1400 liter (370 gallon) tank added to the wing at the inboard station as shown on the left of figure 7. The flutter occurred at approximately the same airspeed, but at a lower Mach number. Again the flutter points were outside the flight boundary. Variations in weapon pylon stiffness did not significantly change the test results.

The tunnel results indicate the possibility of encountering some lowly damped oscillations in flight although limited past experience (ref. 6) has shown this phenomena to be more prevalent in the wind tunnel than in flight. Possible alternate carriage configurations for this heavy weapon were investigated in the wind tunnel. Configurations without the AIM-9J missiles or with the wing tip missile moved inboard to the under-wing missile station were shown to substantially increase the flutter speed.

EXTERNAL TANK FUEL USAGE SEQUENCE CHANGE INCREASES FLUTTER SPEED

External tank fuel usage sequence was found to be important for a downloading of the four missile air-to-air configuration with a partially full 1400 liter (370 gallon) fuel tank at the inboard station. The effect of tank fuel usage sequence on flutter speed with the tanks half full is presented in figure 8. The configuration shown at the top of figure 8 consists of the fuel tanks and under-wing AIM-9J missiles. The half full tank shown in the lower tank sketch simulates the initial fuel usage sequence: forward bay first, then aft bay, then center bay. Antisym-metric flutter occurred for this configuration.

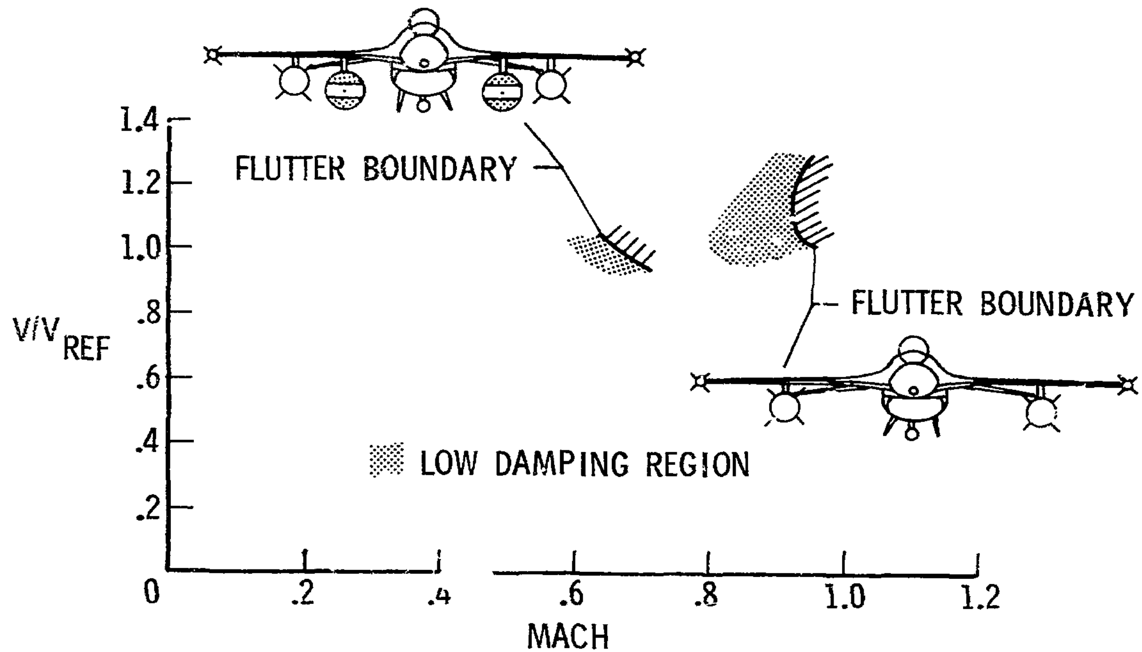

Figure 7.- Low Damping Precedes GBU-8/B Flutter.

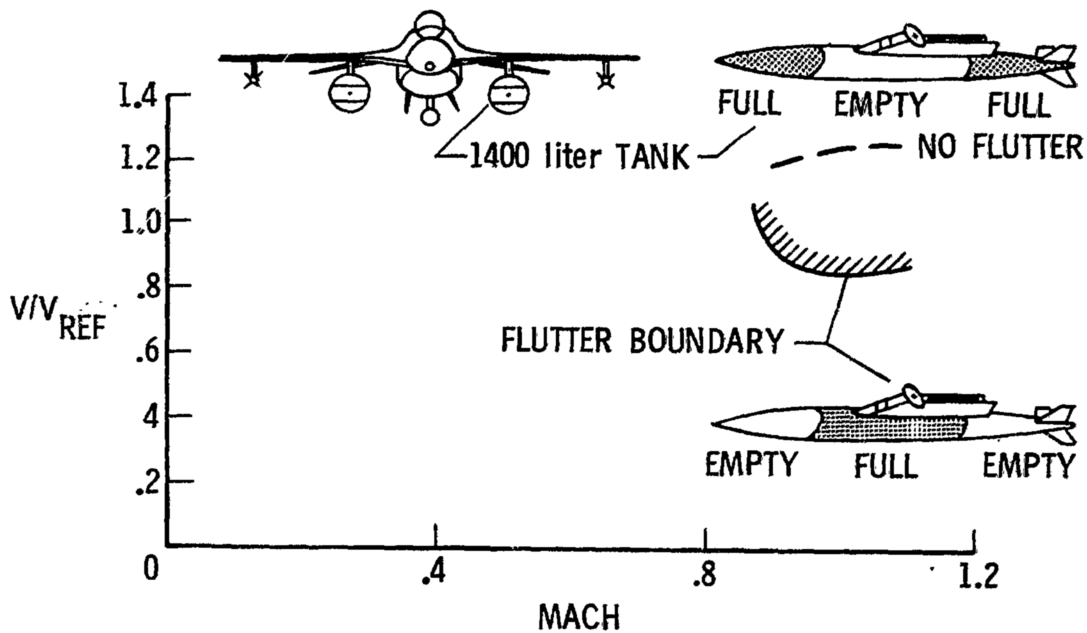

Figure 8.- External Tank Fuel Usage Sequence Change Increases Flutter Speed.

The flutter onset was preceded by a period of lowly damped response. Substantial improvement in flutter speed is shown for the half full tank (upper tank sketch) with the fuel usage sequenced so that fuel was used out of the center bay first. This modified fuel sequencing increases by a factor of four the pitch moment of inertia about the tank center-of-gravity for the half-full tank and eliminates flutter. This result impacted the airplane in that the external fuel tank usage sequence has been modified for flutter improvement.

CONCLUDING REMARKS

A large full span free flying model has proved to be an effective tool in defining flutter characteristics prior to flight tests of a high performance airplane with external wing stores. Satisfactory carriage has been demonstrated for a wide variety of external store loadings. The model test results were used to verify analytical methods and resulted in improved carriage capability of certain store loadings by changes to the missile launcher and external tank fuel usage sequence.

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16. Abstract

The flutter prevention and clearance task for the F-16 airplane is being accomplished in a combined analysis, wind tunnel dynamic model test, and flight flutter test program. This paper presents highlight results from transonic flutter model studies. The flutter model was constructed to support the flutter prevention and clearance program from preliminary design through flight flutter tests. The model tests were conducted in the National Aeronautics and Space Administration's Langley Transonic Dynamics Tunnel. The large full-span free-flying model is shown to be an effective tool in defining airplane flutter characteristics by demonstrating freedom from flutter for most configurations and by defining optimum solutions for a few troublesome configurations.

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