Wind Tunnel Correlation Study of Aerodynamic Modeling for F/A-18 Wing-Store Tip-Missile Flutter

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Wind tunnel testing of the F/A 18 wing with underwing stores and tip missile discovered several cases of flutter for which acceptable correlation was not obtained by adjustment of stiffness and mass Studies were conducted to evaluate the effect of aeodynamic modeling on three of the uncorrelated cases using the doublet lattice theory Results are presented showing the effect of individual system components on flutter Acceptable correlation is shown for total models of the wing rack store missile configuration, although models with air acting on the missile but not on the underwing store are also satisfactory

Introduction

SEVERAL cases of flutter were observed in wind tunnel testing of the F/A 18 wing with underwing stores and tip missile, for which acceptable analytical correlation was not obtained The aerodynamic idealization in use at the time had been found suitable for close correlation for clean wing flutter and for other wing store tip missile configurations It was based on wing and missile modeled as a flat plate and ignored the aerodynamics on the underwing store Aerodynamic modeling of underwing stores and more complete modeling of wing tip missiles was not included in the original analyses because acceptable correlation between experiment and analyses is usually obtained for real world aircraft with the simpler modeling, at lower cost

The studies herein were undertaken to improve the correlation for the wind tunnel configurations by more com plete aerodynamic modeling A secondary objective was to establish in a general sense aerodynamic modeling techniques for wing store tip missile flutter

Several recent studies and tests have considered the effect of store aerodynamics on unsteady wing airloads (e g , Refs 1 3) with emphasis placed on wings with tip missile Current wing store flutter prediction techniques are discussed in Ref 4 and an extensive parametric study of the effect of store aerodynamics on wing store flutter is reported in Ref 5 This paper presents flutter results based on complete three dimensional modeling of the wing store missile system and describes the selective effect of the launcher on a classic "dome ' flutter mode It is also the first known effort which evaluates the effect on the flutter prediction of complete aerodynamic modeling for a wing with multiple stores and tip missile

Three separate antisymmetric flutter cases involving stores on an outboard pylon and wing tip missile were evaluated The cases were:

1) A light store with missile off
2) A heavy store with missile on
3) Two medium weight stores on a rack with missile on

The F/A 18 flutter model is shown in Fig 1 for the most complex case 3 configuration which illustrates all of the system components Cases 1 and 2 use the same pylon with no rack The model is wall mounted in the MCAIR Polysonic Wind Tunnel

Received May 31 1983; revision received Nov 8 1983

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The doublet lattice procedures of Ref 6 which have been incorporated into the Ref 7 computer program were used in the study Flutter was calculated by standard $V g$ techniques based on reduced frequency k The missile and store bodies were modeled both with slender body theory and equivalent panels Project NASTRAN data sets were used for the vibration modes Generalized aerodynamic forces were calculated for individual system components (e g missile fins) and selectively summed for the parametric evaluaton of the effects on flutter

Aerodynamic Modeling

The doublet lattice analytical model for the wing and launcher, considered a flat plate, is shown in Fig 2 It consists of 126 boxes on the wing with boundary lines corresponding to leading and trailing edge control surfaces Another 32 boxes model the launcher also a flat plate Symmetrical air loading was assumed because of the wall mount in the wind tunnel even though the model has freedom in roll which simulates antisymmetric motion

Tip missile modeling is shown in Fig 3 The missile was idealized for static airloads as a slender body and separately by eight panels of 17 chordwise boxes each which creates an octagonal cylinder open at both ends Flutter was evaluated with the slender body theory only For both models the missile fins were divided into two strips, where the inner fin strip was the same width as the body strip between the fin and launcher The launcher was also divided into two strips with the outer launcher strip also equal to the width of the body strip This strip width adjustment in the critical fin body launcher in

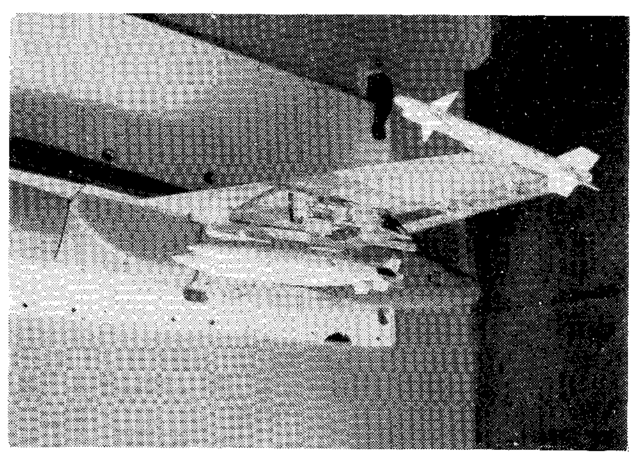
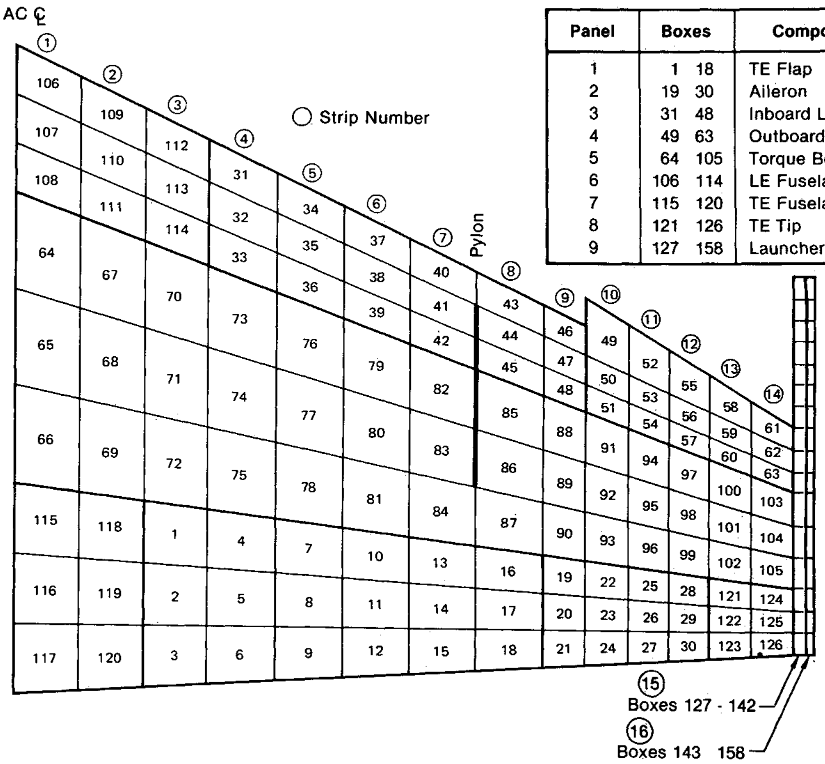


Fig 1 F/A 18 flutter model for multiple store configuration



Panel	Boxes	Component
1	1 18	TE Flap
2	19 30	Aileron
3	31 48	Inboard LE Flap
4	49 63	Outboard LE Flap
5	64 105	Torque Box
6	106 114	LE Fuselage
7	115 120	TE Fuselage
8	121 126	TE Tip
9	127 158	Launcher

Fig 2 Wing launcher aerodynamic model

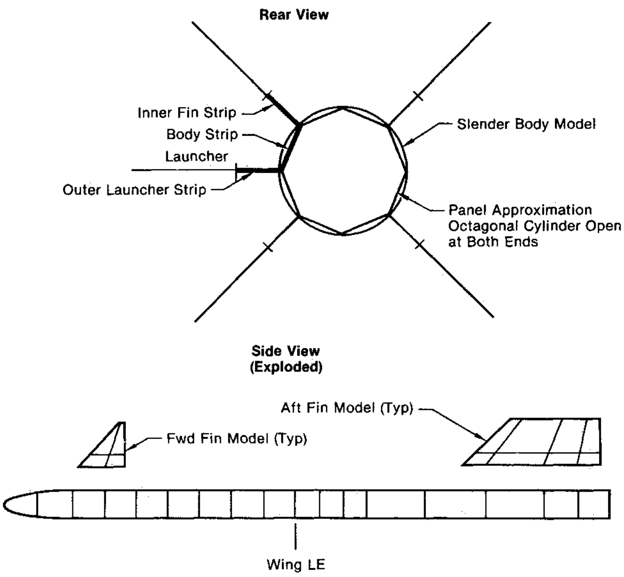


Fig 3 Missile aerodynamic model

tersection was necessary to ensure reasonable horseshoe vortex flow patterns in the doublet lattice code

Modeling for the pylon and the light store of case 1 as a slender body is shown in Fig 4 The chordwise divisions are continuous from the wing intersection through the pylon and store Additional chordwise divisions were added to maintain reasonable aspect ratios for all of the boxes The other stores were modeled in a similar fashion and the rack was idealized as a horizontal flat plate Static airloads also were evaluated for the underwing stores with a cylindrical model using a diameter equal to that at the aft end of the store

Static Airloads

Static airloads were calculated to verify the adequacy of the modeling before proceeding to flutter An initial attempt to model the missile was patterned after Fig 10 of Ref 2 for the F 5 wing which involves an extension of the flat plate launcher to the center of the missile body combined with fins also extended to the body centerline This creates a cruciform model as shown in Table 1 The acute angle corners at the launcher fin intersection of this model cause the doublet lattice code to calculate erroneously large sectional lift coefficients over the entire wing The doublet lattice code of Ref 6 may be unique among doublet lattice codes but the more likely explanation for why doublet lattice worked for the F 5 cruciform model and not for the F/A 18 involves the location of the fins relative to the wing tip chord The large aft fins of the missile are located forward of the F/A 18 wing tip trailing edge maximizing the interaction with the wing while the fins are essentially aft of the F 5 wing tip trailing edge reducing the interaction

Several other abortive attempts were tried such as backing the fins off to the point of intersection with an imaginary missile body which was not modeled (see Table 1) The wing lift coefficients for that floating fin model were reasonable but the missile fin forces were erroneous

Plots of the static lift coefficient distribution are shown in Fig 5 for the wing with the missile modeled by both the flat plate and the equivalent octagonal cylinder The missile increases the loads over the entire wing with the greatest effect in the tip region The missile acts as an equivalent endplate The computed loads in the tip region with the slender body model are slightly lower than the octagonal cylinder loads as seen in Table 1 The center of pressure on the launcher moves aft about 28 in compared to the flat plate missile results. This aft movement of center of pressure is caused primarily by the large aft missile fins The effect of the wing snag also is apparent

Steady lift coefficients are shown in Fig 6 for the case 1 light store configuration compared to the wing with launcher only The wing was modeled without a snag for this and all of the following studies The wing has a small amount of aft sweep so that there is a lateral flow component in the outward direction The lift is thus increased inboard of the pylon and decreased outboard The net integrated result over the entire

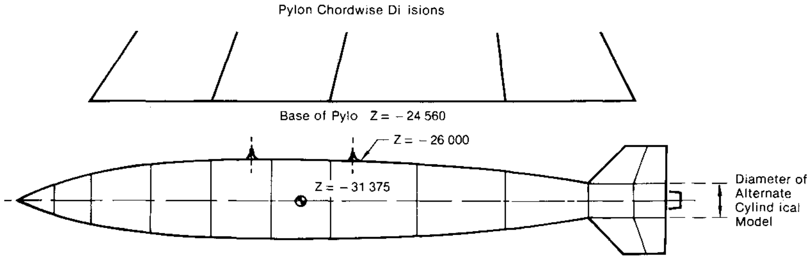


Fig 4 Light store aerodynamic model

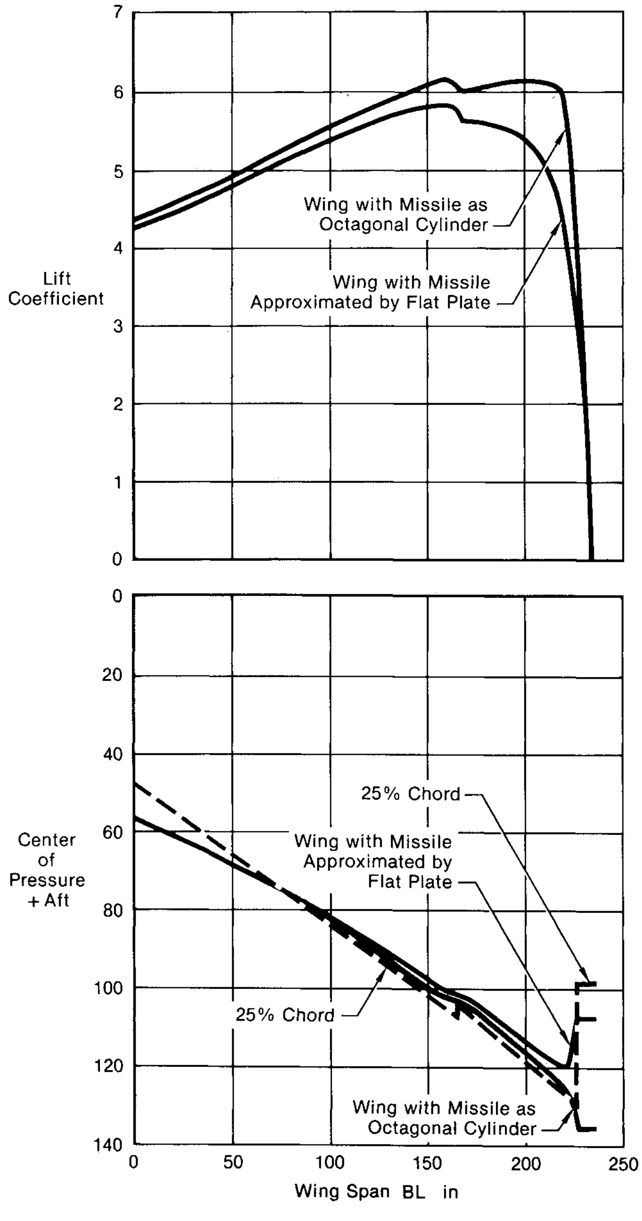
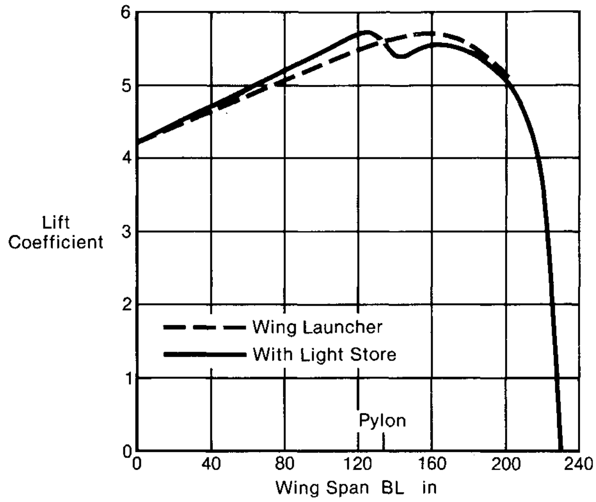


Fig 5 Wing with missile lift coefficient and center of pressure



Same results with
1) Slender body theory
2) Cylindrical body

Fig 6 Wing static lift coefficient case 1—light store missile off Mach 0 9

wing is nearly the same as for the wing and launcher alone Identical results were obtained for both store models

Figure 7 gives similar static data for the case 2 heavy store with tip missile configuration Results are shown for two store models both with and without tip missile The significant differences can be attributed to the tip missile The lift per turbations caused by the heavy store and pylon are similar to those for the light store and essentially cancel out

As mentioned before these static airload distributions were calculated to give credibility to the modeling technique before proceeding with flutter Slender body theory was used for all bodies in the flutter analyses Static data were not calculated for the case 3 configuration since the modeling techniques were essentially the same as used for cases 1 and 2

Flutter Results

Flutter was calculated for the three antisymmetric cases Calculations were not made for symmetrical motion because good correlation had been obtained with the simpler flat plate model of the missile and with no aerodynamics on the un derwing store

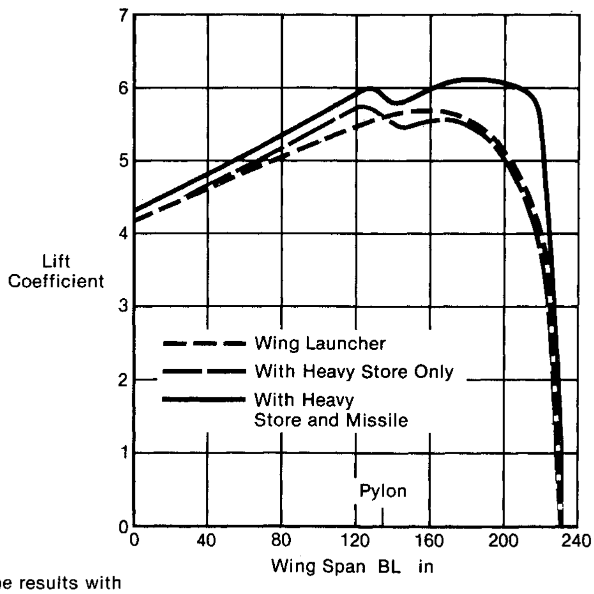
Case 1

Flutter boundaries for case 1—light store missile off—are shown in Fig 8 in terms of flutter velocity normalized at Mach 0 95 vs Mach number The analytical boundary for the wing only is unconservative and differs from the wind tunnel data on the order of 37% at Mach 0 95 When the launcher aerodynamics is added to the model the correlation is greatly improved

A V g flutter solution is shown in Fig 9a for the wing only Thirty vibration modes were used in the analysis to properly account for the leading edge control surface modes although only five modes are shown in the figure for clarity Mode 4 is the mode of interest It is a so called dome mode which is barely unstable Figure 9b shows the solution when the missile launcher is included The dome mode goes unstable at the correct velocity and has a maximum required damping of about $g = 0$ 05 The effect of the launcher on the other flutter modes is negligible This selective effect of the launcher was unexpected and is a phenomenon which is not described in the recent literature

Table 1 Wing static lift distribution—various missile idealizations, Mach 0 9

Wing strip	Flat plate missile	Cruciform model	Floating fin model	Octagonal cylinder	Slender body
1	4 32	6 68	4 45	4 42	4 40
2	4 58	7 14	4 72	4 69	4 67
3	4 78	7 57	4 93	4 90	4 88
4	4 97	8 03	5 14	5 10	5 08
5	5 20	8 70	5 39	5 34	5 32
6	5 42	9 55	5 64	5 59	5 56
7	5 62	10 64	5 90	5 83	5 80
8	5 81	12 14	6 15	6 07	6 02
9	5 89	13 82	6 31	6 21	6 16
10	5 66	15 03	6 16	6 04	5 98
11	5 64	17 67	6 28	6 13	6 04
12	5 53	21 69	6 38	6 18	6 07
13	5 26	28 30	6 45	6 19	6 02
14	4 72	41 20	6 55	6 22	5 93
Launcher 15 and 16	2 08	40 34	3 78	3 90	3 56



Same results with
1) Slender body theory
2) Cylindrical body

Fig 7 Wing static lift coefficient case 2—heavy store missile on Mach 0 9

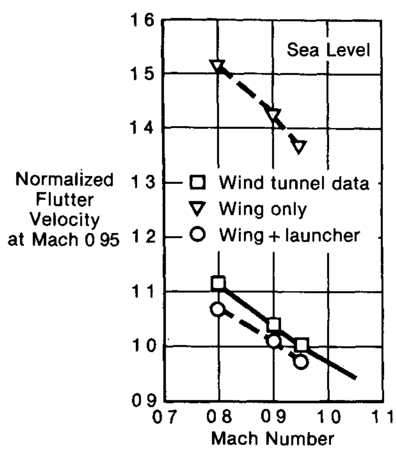


Fig 8 Flutter boundaries case 1—light store missile off

Case 2

Flutter boundaries for case 2—heavy store missile on—are shown in Fig 10 The flutter results for the flat plate model are conservative and have a flatter slope with Mach number The complete model results agree well with the experiment at both Mach 0 9 and 0 95 but are very costly because of the large number of boxes

The doublet lattice program of Ref 6 requires that the structural deflections be related to the aerodynamic boxes by polynomial curve fits in chord and span The best curve fit for the wing, from the aircraft centerline to the inboard side of the launcher was determined in a parametric study to be fifth order (y^5) in span and second order (x^2) in chord Fits with second order in chord also were used for the launcher and missile body All other components (e g missile and store fins and store body) were fit with first order in chord

Generalized aerodynamic forces which include the effects of the structural deformations were calculated separately for each of the components Flutter then was calculated for various combinations of generalized forces as shown in Table 2 For this case a model with generalized forces for the tip missile but not for the store is sufficient The deletion of the large store and its fins lowers the flutter speed only about 2% If the missile is not included however the calculated speed is very unconservative The missile forward fins lower the speed and are the primary contributors to the convergence to the desired speed The missile aft fins are relatively unimportant for this configuration

It is important to point out that the various idealizations of Table 2 are achieved with no modification to the aerodynamic model The doublet lattice aerodynamic influence coefficients (AICs) were calculated for the complete model and were not recalculated for the various idealizations Thus for example the aerodynamic flow on the large store is always present even though its generalized forces are deleted Because of this separate AICs were calculated with the large store aerodynamically deleted to verify the conclusion that the store aerodynamics are not required for convergence to the desired flutter speed

Case 3

Flutter boundaries for case 3—two medium weight stores on a rack missile on—are shown in Fig 11 For this case the complete model with all components included agrees well with the flutter model results at Mach 0 95 The polynomial curve fits for case 3 were the same as used for case 2 A parametric study was again performed to verify the best curve fits

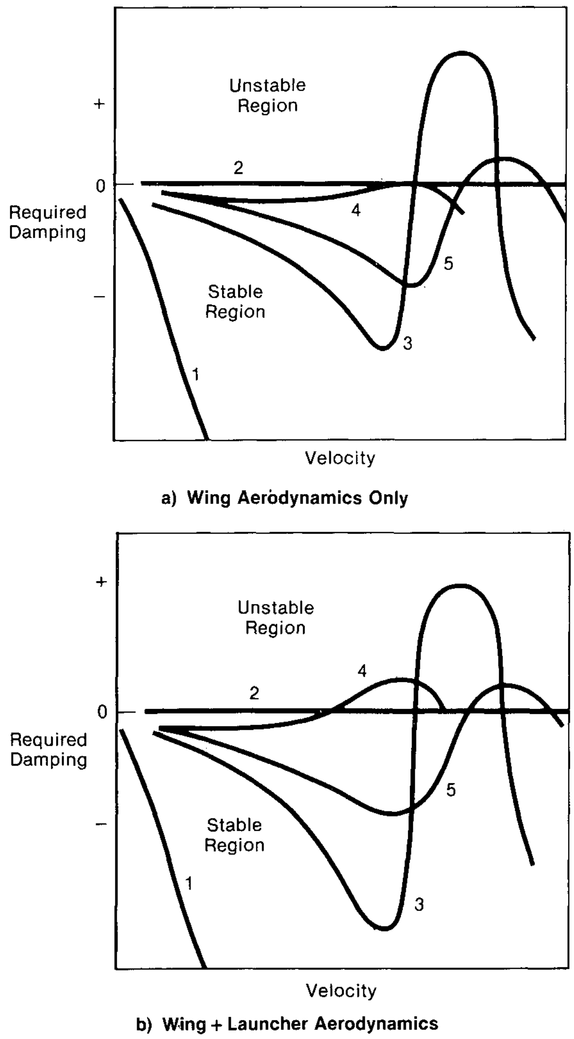


Fig 9 *V g* flutter solution case 1—light store missile off, Mach 0 9 sea level

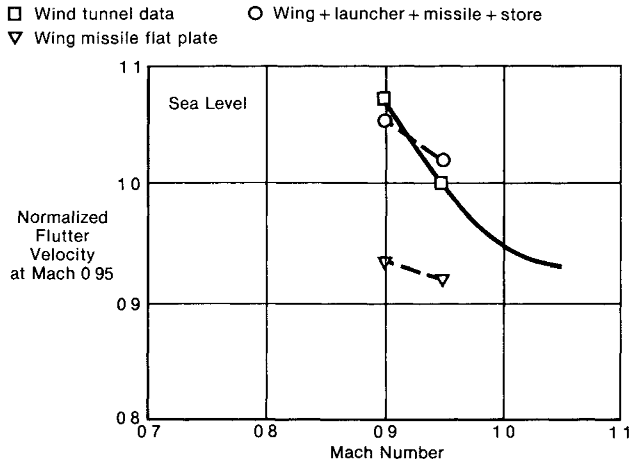


Fig 10 Flutter boundaries case 2—heavy store, missile on

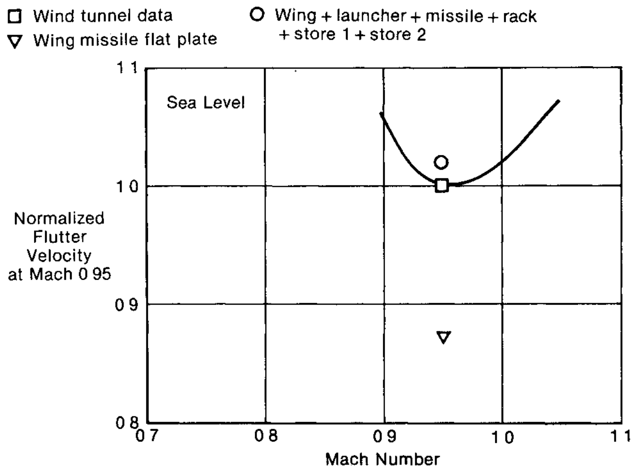


Fig 11 Flutter boundaries case 3—two medium weight stores on rack, missile on

Table 2 Flutter velocity ratios various idealizations case 2—heavy store missile on (flutter ratio with respect to wind tunnel at Mach 0 9, sea level)

Wing	Launcher	Missile body	Missile forward fins	Missile aft fins	Store body	Store fins	Flutter ratio
X[a]	X	X	X	X	X	X	0 981
X	X	X	X	X			0 962
X	X	X	X				0 961
X	X	X		X			1 033
X	X	X					1 038
X	X						1 049
X	X				X	X	1 056
X	X				X		1 055

[a] X = Generalized forces included

Table 3 Flutter velocity ratios various idealizations, case 3—two medium weight stores on rack, missiles on (flutter ratio with respect to wind tunnel at Mach 0 95, sea level)

Wing	Launcher	Missile body	Missile forward fins	Missile aft fins	Rack	Store body inboard	Store body outboard	Store fins inboard	Store fins outboard	Flutter ratio
X[a]	X	X	X	X	X	X	X	X	X	1 021
X	X	X	X	X	X	X	X			0 992
X	X	X	X	X	X					1 027
X	X	X	X	X						1 036
X	X				X					1 083
X	X	X								1 067
X	X									1 081

[a] X = Generalized forces included

Table 3 presents the flutter results for various idealizations. For this case, the complete model is within 2%. The flutter is still within 3% when the generalized forces on the stores are deleted but the rack is retained. Subsequent removal of the rack generalized forces creates a 4% difference. Again, the store aerodynamics are relatively unimportant. The tip missile, modeled with both forward and aft fins, however, is necessary for close correlation.

Conclusions

The principal conclusions, based on this particular wing, are:

1) Tip missile and launcher aerodynamics can have a significant effect on flutter, especially for antisymmetric motion with the missile aft fins forward of the wing trailing edge.

2) The missile fins are the primary contributors and require careful modeling; the forward fins tend to lower the flutter speed while the aft fins raise it.

3) A total aerodynamic model of the wing-store-missile configuration provides acceptable correlation with experimental data.

4) A model with no air acting on the underwing store gives satisfactory results.

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