DELTA WING FLUTTER BASED ON DOUBLET LATTICE METHOD IN NASTRAN*

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SUMMARY

The subsonic doublet-lattice method (DLM) aero-elastic analysis in NASTRAN as successfully applied to produce subsonic flutter boundary data in parameter pace for a large delta wing configuration. Computed flow velocity and flutter requency values as functions of air density ratio, flow Mach number, and educed frequency are tabulated. The relevance and the meaning of the calculated esults are discussed. Several input-deck problems encountered and overcome are ited with the hope that they may be helpful to NASTRAN Rigid Format 45 users.

PARAMETER SPACE

Flight velocity consideration and earth atmospheric properties suggest that ubsonic aerodynamic wing flutter may take place in lifting flight through dense ir (see Kuethe and Schetzer, reference 1). Based on atmospheric properties etween 15.24 km (50 000 feet) altitude and the ground, the dimensionless air ensity parameter can be specified as follows:

$$.12 \leq \text{air density ratio} \leq .967$$
referred to sea level

n subsonic flight, a Mach number range can also be specified:

$$.25 \leq \text{Mach number} \leq .95$$

nother dimensionless parameter, the reduced frequency, may be assigned a sual flutter-producing range:

$$.10003 \leq \text{reduced frequency} \leq .200$$

hese three-number intervals form a parameter-space volume within some part of hich the delta wing could flutter.

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THE NASTRAN AEROELASTIC METHOD

The organization of the aeroelastic analysis area in NASTRAN is described by figure 1, which shows the major program flow of a portion of Rigid Format 45.

A NASTRAN solution of the flutter equations goes through the 13-step sequence shown in figure 1. A short description of the thirteen (13) steps in terms of NASTRAN aeroelastic program modules follows.

(1) Step 1 sets up tables, structural matrices, and geometry data after real eigenvalue analysis.

(2) Module APD processes the aero data cards, and sets up aero tables. (SET1 referencing comes in here.)

(3) Modules PLOT and PLTSET form undeformed aero/structure plots. (PLOTEL cards come in here.)

(4) Module GI forms matrix G_{ka}^{T} for interpolation from structural to aerodynamic degrees of freedom. (CORE SIZE limit and matrix singularity may appear.)

(5) Module AMG obtains aero matrix A_{jj}, area matrix S_{kj}, downwash matrices D_{jk}^{1} and D_{jk}^{2}.

(6) Module AMP calculates the aero matrix list corresponding to the modal coordinates.

(7) Module FA1 computes mass matrix M_{hh}^{x}, stiffness matrix K_{hh}^{x}, and looping tabl (Doublet lattice computation enters at this point.)

(8) Module CEAD extracts complex eigenvalues and normalizes eigenvectors. (Hessenberg solution enters here.)

(9) Modules VDR and OFP prepare complex eigenvectors and place them on system output file for printing.

(10) Module FA2 appends eigenvalues, eigenvectors, case control, and V-g plot data to appropriate tables.

(11) Module XYTRAN prepares V-g plots under XYOUT requests, and module XYPLOT forms V-g plots for offline plot.

(12) Module DDR1 converts eigenvectors from modal to physical coordinates. Module SDR1 recovers dependent components of eigenvectors and also single-point forces of constraint. Module SDR2 computes element forces and stresses for output.

(13) Module PLOT obtains deformed plots of the structural and aero points.

DELTA WING MODEL DESCRIPTION

In this work the delta wing configuration is structurally modelled as in figure 2; aerodynamically, it is modelled as in figure 3. Figure 2, in fact, is a 3-dimensional figure, with only the top of the wing shown for sake of clarity. It should be noted that the modelled wing consists of a double delta, a flap, and an aileron. Furthermore, figure 3 shows respective trapezoidal boxes of the four panels used to represent delta 1 (boxes 101-108), delta 2 (109-144), flap (145-154), and aileron (155-166). The wing structure is represented by

18 quadrilateral membranes
1182 rods
657 shear elements
90 triangular membranes
508 grid points
191 plot elements
4 splines

together with their respective physical properties and geometric coordinates.

RUN-DECK PROBLEMS

The several deck-associated problems found and eliminated are identified in figure 1, next to the modules where they were found.

- FLUTTER card specified surface splining when linear splining was needed; S was changed to L in field 7.

- EIGC card in conflict with FLUTTER card; number of eigensolutions didn't agree with number of eigenvectors; a weakness in the Hessenberg method was strengthened by setting the number of eigenvectors equal to the minimum of the number of desired eigenvectors (on FLUTTER) and the number of eigenvectors found (on EIGC).

SET1 referencing, insufficient core for splining, and XYPLOT peculiarity are really extra-deck problems found; they are beyond the scope of this paper, but their solutions were accomplished by Howard Jew and Edward Hess, at Lockheed Electronics Company, Inc.

FLUTTER COMPUTATION

The doublet-lattice method in NASTRAN is adequately described in Doggett and Harder (reference 2). Computation modularly goes through the 13-module package shown in figure 1. Flutter results for the delta wing were obtained at the Johnson Space Center and Lockheed, Houston, using the UNIVAC-1110 computer, and running on NASTRAN Level 15.6.4S.

First a checkpointed cold start was made, taking about 30 minutes SUP time. Subsequent runs, going through various points within the parameter space volume domain cited above, were made as restarts from this single checkpointed run, each restart finishing in about 29 minutes SUP time.

Although numbers entered the computer run deck in English units, the results were converted to the International System of Units for presentation in this paper.

FLUTTER RESULTS

Table 1 summarizes the available flutter boundary data of the delta wing for points in a parameter space subvolume having air density ratio, flow Mach number, and reduced frequency coordinates. The corresponding dependent quantities are the critical flow velocity in meters/sec and the critical flutter frequency in Hz. For example, in row 7 of table 1, at air density ratio = .967, Mach number = .70, and reduced frequency = .200, the delta wing, if flown, would flutter at frequency of 2.89 Hz for flow speed of 194 m/sec.

Figure 4 illustrates a typical damping coefficient as function of flow velocity for various reduced frequencies (k). For the k = .200 curve, the two values of flow velocity at which the damping coefficient vanishes, are critical flow velocities 219 and 283 meters per second as shown in table 1. At (.967, .45, .200) the delta wing would flutter at a frequency of 3.25 Hz for a flow speed of 219 m/sec. However, at (.967, .45, .200), within the flow speed range of 219 to 283 m/sec, any small disturbance on the delta wing would be aerodynamically amplified and destroy the wing if unchecked. At (.967, .45, .200), for flow speed < 219 m/sec and > 283 m/sec, any small disturbance on the wing would be aerodynamically damped. In other words, at (.967, .45, .200) the range of flow speed between 219 and 283 meters per second is unstable and small disturbances could build up through the mechanism of the fluttering wing continuously absorbing energy from the air stream (cf. Fung, reference 3).

Figure 5 illustrates flutter frequency as a function of flow velocity for various reduced frequencies. This is the companion figure to figure 4. Note that these frequency curves are all nearly linear functions of flow velocity. On the other hand, damping coefficient is a nonlinear function of flow velocity; see figure 4 curves. The flutter frequency as a function of flow velocity may be estimated from a very few points. However, reliable predictions of damping coefficient as a function of flow velocity cannot be made.

CONCLUDING REMARKS

- Delta wing flutter in the subsonic range could take place if the wing were flown, for a length of time, inside the flutter parameter space subvolume covered by table 1.
- Critical flutter frequency values summarized in table 1 are well within the expected range of 1-15 Hz for large wings.
- The flutter frequency results (see figure 5) appear not only reasonable but also consistent, indicating that a good flutter calculation has been achieved using the DLM in NASTRAN.

REFERENCES

1. Kuethe, A. M., and Schetzer, J. D.: Foundations of Aerodynamics, John Wiley & Sons, Inc., New York, Second Edition, 1963.
2. Doggett, Robert V., Jr., and Harder, Robert L.: Subsonic Flutter Analysis Addition to NASTRAN. NASTRAN: Users' Experiences. NASA TM X-2893, 1973, pp. 507-529.
3. Fung, Y. C.: The Theory of Aeroelasticity, GALCIT Aeronautical Series, John Wiley & Sons, Inc., London, 1955.

AIR DENSITY RATIO	FLOW MACH NUMBER	REDUCED FREQUENCY	CRITICAL FLOW VELOCITY (m/sec)	CRITICAL FLUTTER FREQUENCY (Hz)
.121	.85	.167	991	12.3
.484	.95	.167	208	2.57
.484	.95	.167	344	4.28
.484	.85	.125	184	1.71
.484	.70	.125	200	1.86
.484	.45	.125	169	1.58
.967	.70	.200	194	2.89
.967	.45	.200	219	3.25
.967	.45	.200	283	4.61
.967	.25	.200	200	3.00

Table 1. — Flutter boundary of delta wing.

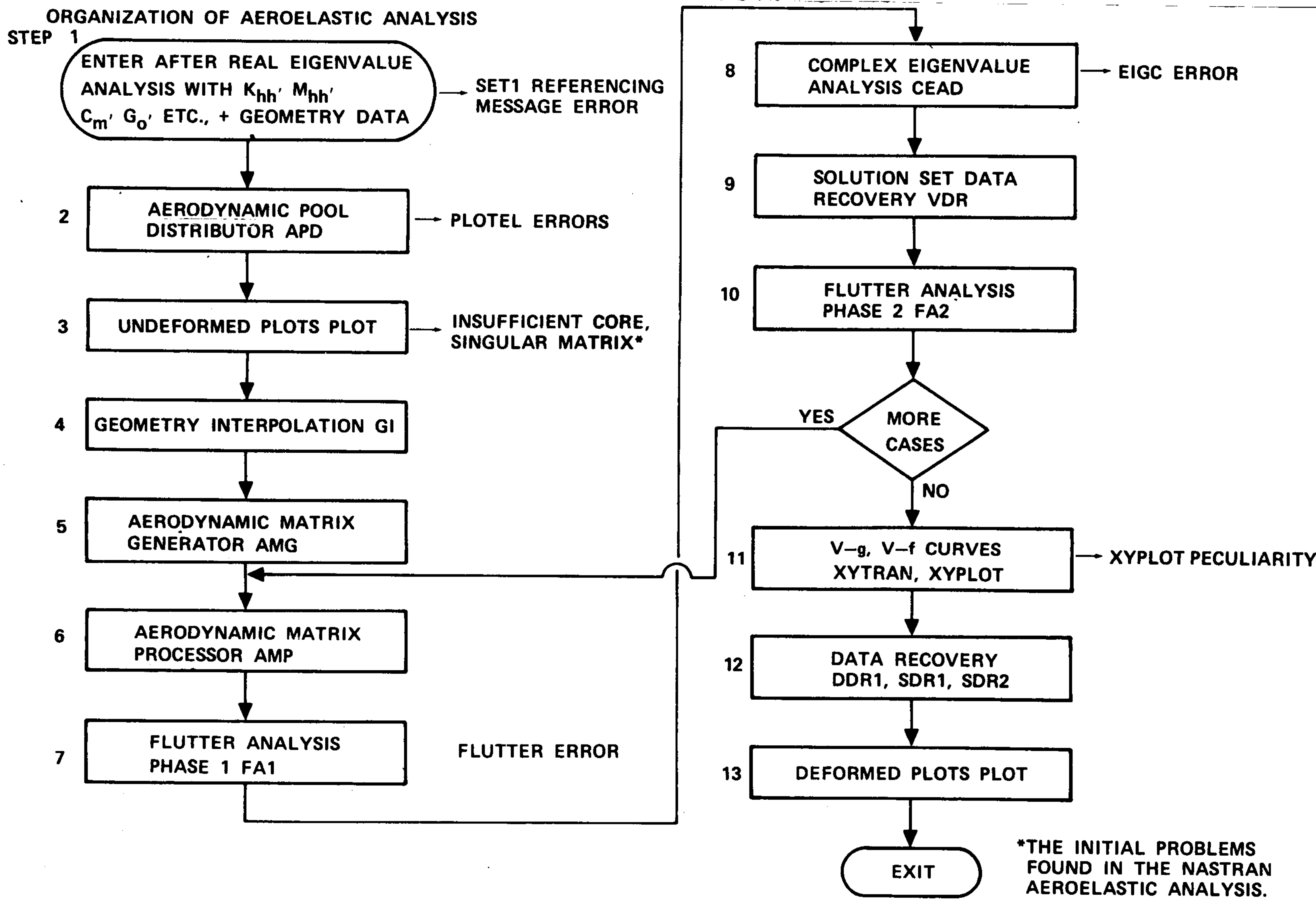

Figure 1. — Modal flutter analysis rigid format 45.

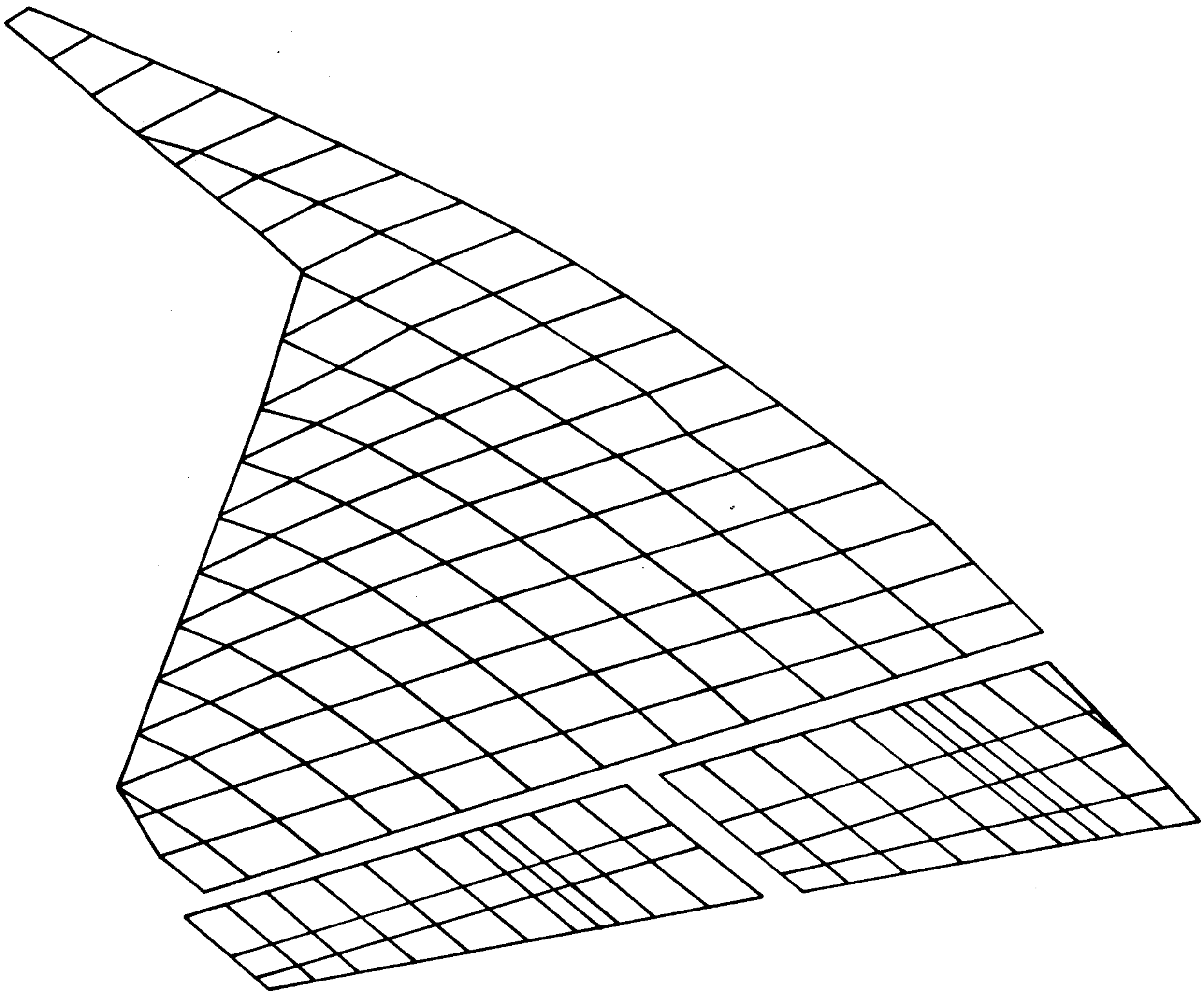

Figure 2. – Structural model of delta wing.

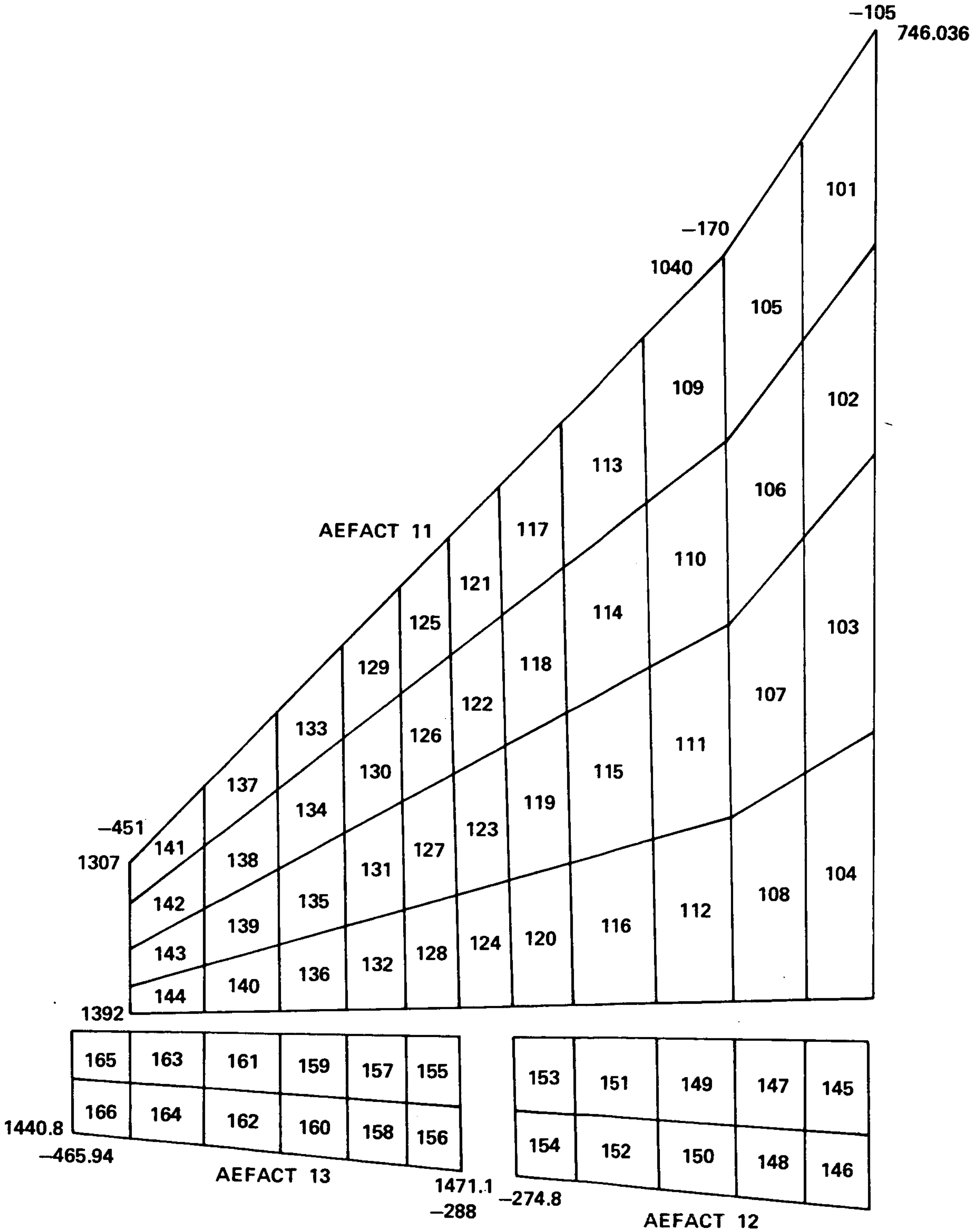

Figure 3. — 66 Aero-box model of delta wing.

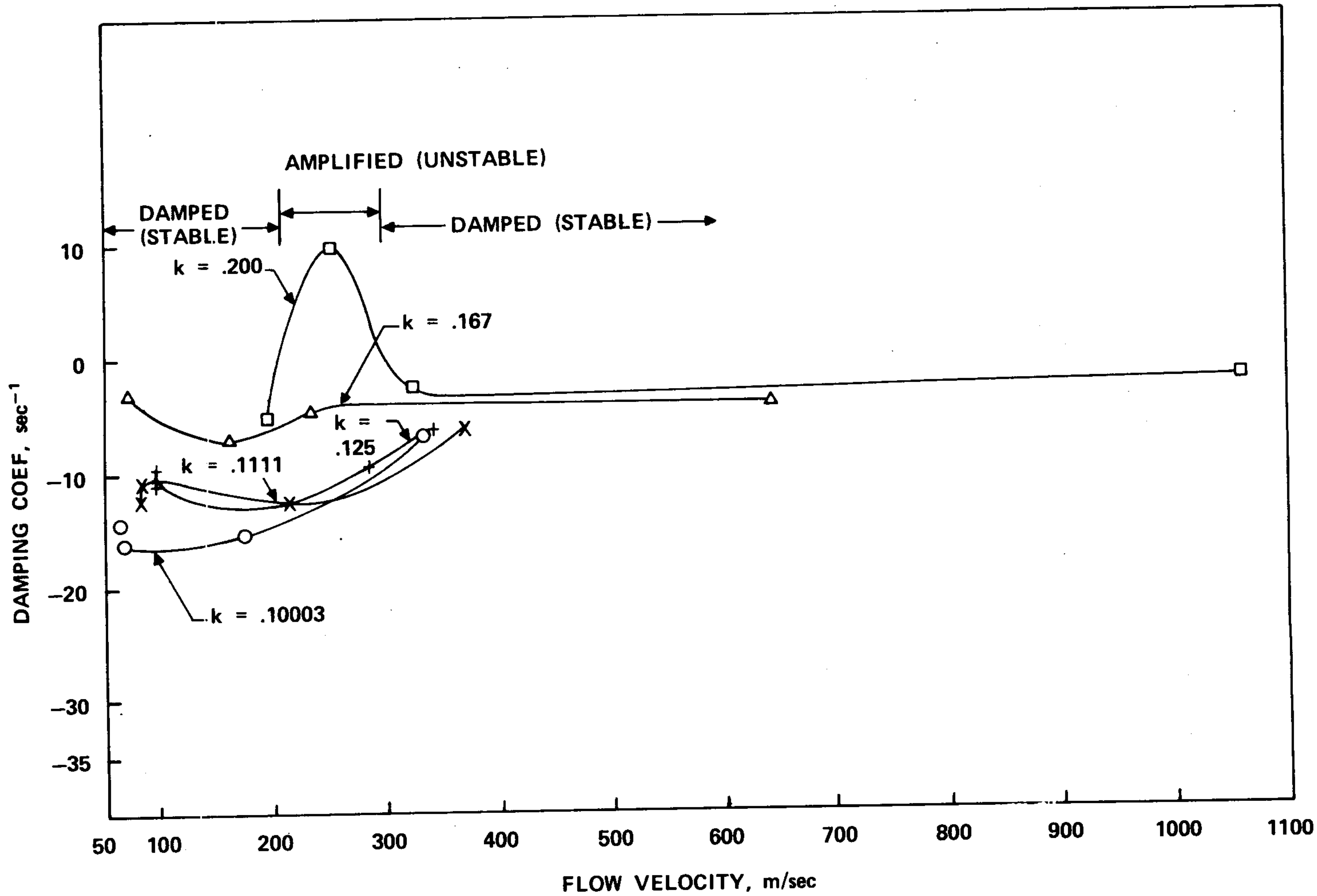

Figure 4. — Damping coefficient versus flow velocity at AIR DENSITY RATIO = .967 FLOW MACH NUMBER = .45

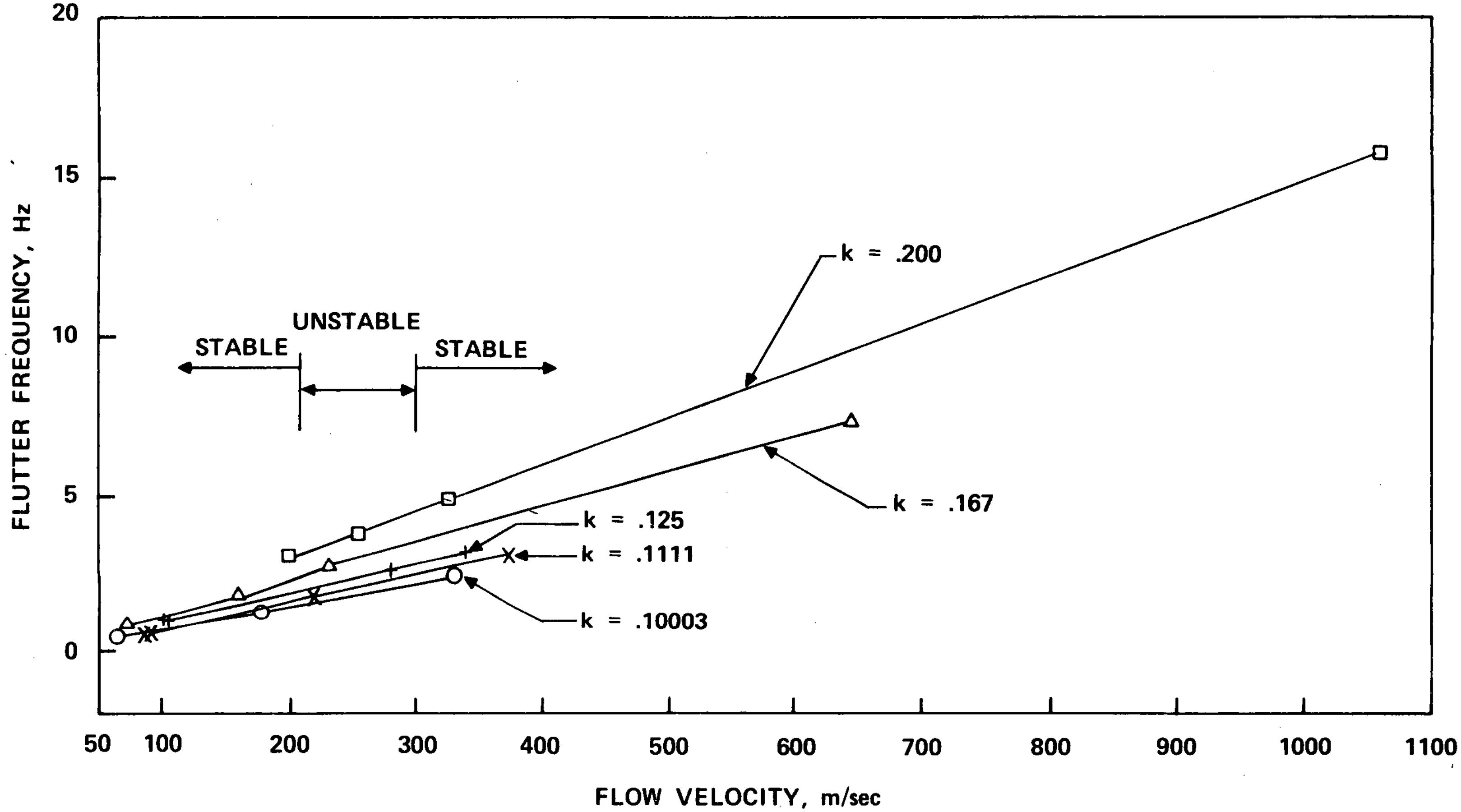

Figure 5. — Flutter frequency versus flow velocity at
AIR DENSITY RATIO = .967
FLOW MACH NUMBER = .45