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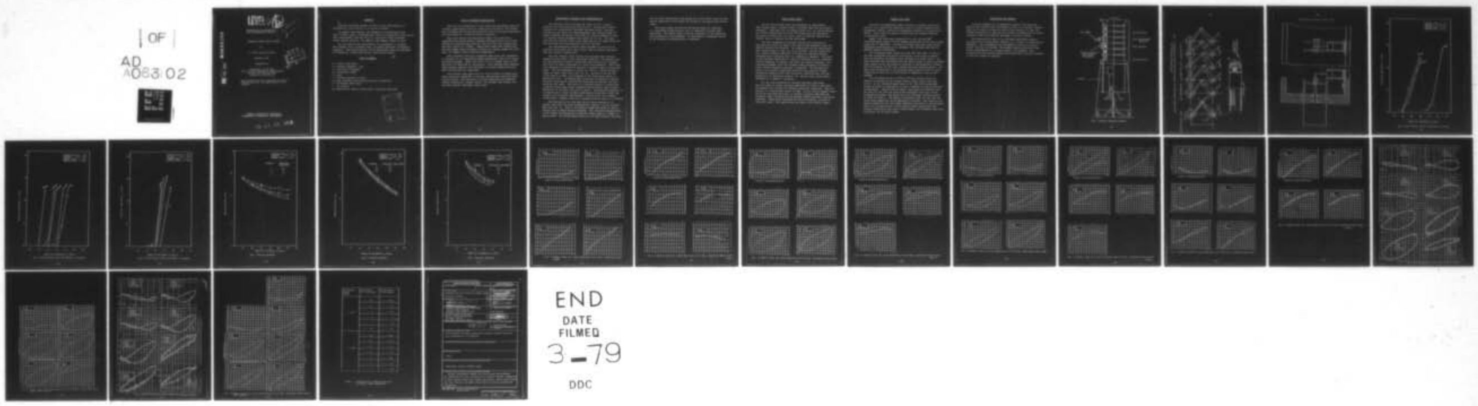

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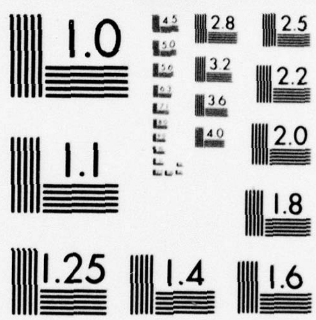

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RESEARCH ON THE FLUTTER OF
AXIAL-TURBOMACHINE BLADING

TECHNICAL REPORT ME-RT 78004

by

F. Sisto and Rich Rossin

November 1978

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STEVENS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING

ABSTRACT

Typical aerodynamic moment and free flutter measurements are presented for thin airfoils in an annular cascade.

For moment measurements, the parameters of significance were mean incidence angle, interblade phase angle and amplitude of oscillation. Since measurements take the form of a continuous record of moment versus angular position, the symbolic name "moment loops" is used.

For the free flutter measurements, the parameters of interest were stagger angle, incidence angle, torsional amplitude, and reduced frequency. The characteristics of the experimental data are discussed and comparison is made with earlier tested thick blades.

LIST OF SYMBOLS

b = airfoil semi-chord

k = reduced frequency = wb/V

ω = oscillation frequency

M = aerodynamic moment

t = time

V = relative approach velocity

α_1 = mean incidence angle measured from V to chordline

σ = interblade phase angle

ρ = air density

θ_o = amplitude of angular displacement (torsional amplitude)

SCOPE OF PRESENT INVESTIGATION

The work to be described in this report was undertaken basically to obtain experimental data for studying the flutter of thin blades and to compare the results obtained with those of previous experiments run with blades of a different profile geometry.

Both free flutter and quasistatic moment loop tests were conducted with blades having a maximum thickness ratio of 4.7% with leading and trailing edge radii of 1/64 and 1/128 inch respectively, and with a chord of 2 inches. These (new) blades were thinner and had less camber than the double circular arc (thick) blades (7% thickness, 15° camber) used in previous experiments.

Mean incidence angle and interblade phase angle were parameters of interest for the quasistatic moment measurement tests with slowly oscillating blades. These tests were run at a stagger angle of 45° and with a 6° amplitude of oscillation. Data obtained with different blade profile geometry were published in previous reports and have been included here for comparison.

Free flutter tests were also run with an effort to obtain data under conditions comparable to earlier compiled data with the thick profile blades. The variation of flutter amplitude with different reduced frequencies, stagger angles, and incident flow angles, was of prime interest throughout these tests.

EXPERIMENTAL APPARATUS AND INSTRUMENTATION

The Stevens vertical cascade Rig, Shown in Fig. 1, has a vertical axis with flow entry from the top. The entrance section consists of a conventional bellmouth and nose bullet. The main sections of the tunnel are interchangeable cast aluminum rings 20" inside diameter and similar rings with 16" outside diameter to form a 2" annular region throughout the length of the rig. Two inlet sections with variable inlet guide vanes cast out of epoxy direct the flow entering the instrumentation and test sections.

The instrumentation section which precedes the test section utilizes a yaw meter and a pitot-static tube to measure flow angle and flow velocity respectively.

The test section, which follows the instrumentation section, depends on the nature of the test being conducted. The section used for determination of moment coefficient data consists of 30 blades, each with its shaft terminated in a 4-bar link mechanism. This 4-bar link mechanism is designed to generate a harmonic motion of the blade shaft. The link mechanism is driven by 4 low H.P. motors through a number of small nylon gears (see fig. 2). Because of the low RPM of the motors (2 RPM), the frequency of the oscillatory motion is essentially zero. Interblade phase angle may be changed by removing the nylon idler gears, positioning the blades accordingly, and then replacing the gears. The shaft of a selected airfoil is fitted with s special strain gage torque transducer which measures the torsional deflection of the shaft and airfoil system. The positional variable (Θ) is supplied by a linear variable differential transformer (LVDT) and linked to the torsional displacement. Thus with all the necessary calibrations, a moment loop can be produced directly with a x-y recorder.

The test section for the free flutter tests consists of 30 blades, each with its shaft terminated by a spring - air pot arrangement (see fig. 3). Thus in the flutter regime each blade is free to vibrate with a damped natural frequency. The vibration characteristics of the blades are determined by mounting strain gages on a number of spring posts. The spring posts deflect in the same manner as the link, and for small oscillations, the spring is in its linear range and thus flutter amplitude of the blades are related to the spring post deflections.

The strain gages attached to the spring posts are connected to a resistance bridge which in turn is connected to strain gage indicators. The output signal from the indicators is then amplified and recorded on an oscillograph. In this manner, a permanent record of the vibration characteristics is obtained.

FREE FLUTTER TESTS

For the free flutter tests the parameters of significance were stagger angle, incidence angle, torsional amplitude and reduced frequency. Tests were run at stagger angles of 0, 30 and 45 degrees for various combinations of inlet flow velocities and directions. Two types of tests were run: first, tests at constant velocity and second, tests at constant flutter amplitudes.

The tests conducted at constant velocity were obtained by adjusting the inlet air rings in the nose of the apparatus until the desired velocity was obtained. The significance of the free flutter test results shown in figs. 4-6 is as follows. The plot shows that for a given torsional amplitude of flutter the reduced frequency increases with increasing angle of incidence as expected. The slope of the torsional amplitude vs. angle of incidence line at a constant reduced frequency is steeper, the lower the reduced frequency. For increasing stagger angle the incidence angle necessary to produce a given reduced frequency decreases as expected. The scattering of data at low torsional amplitudes would not only indicate "noisy" boundaries between flutter and non-flutter conditions but also the possibility of hysteresis effects, viz, flutter being directionally dependent on a number of variables.

For the tests conducted at constant torsional amplitudes, data was taken to obtain torsional amplitudes as close to each other as possible over a range of incidence angles and velocities. Data are plotted in a conventional manner in figs. 7-9 for various stagger angles. As can be seen from the plots, at constant torsional amplitude the incidence angle increases with decreasing reduced frequency (increasing velocity). These plots delineate the flutter boundary, as shown by the solid lines. The region above the lines is the flutter region.

MOMENT LOOP TESTS

Variation of aerodynamic moment acting on a slowly oscillating airfoil is of significant importance since it allows studying static aerodynamic effects, effects of neighboring airfoils in a qualitative manner. Due to the low speed of oscillation the reduced frequency is practically zero.

Moment loop tests were conducted at 0, 60, 120 and 180^{o} interblade phase angles with the blades oscillating at 45^{o} mean stagger angle with 6^{o} amplitude. Variation of moment loop area with various interblade phase angles are in agreement with previous data and the physical nature of stalling.

For interblade phase angles of 0 and 180^{o} (see figs. 10 and 13), the work encountered during the oscillation of one cycle is nearly zero and therefore the moment loops collapse into single lines. The small enclosed area associated with the moment loops at these interblade phase angles can be attributed to backlash in the mechanical linkages and the deviation of the 4-bar linkage from pure harmonic motion. The small work encountered at an interblade phase angle of 180^{o} is accentuated due to the error in link motion as compared to that of zero degrees.

For interblade angles of 60^{o}and 120^{o} the critical nature of phasing is revealed by the larger loops at these angles (see figs. 11-12). At an interblade phase angle of 60 the work encountered during one cycle of oscillation is near a maximum as noted by previous investigators. Similarities in moment loop shapes are observed from the data for the thin and thick blade geometries (see figs. 14-15). Corresponding moment loop shapes occur at different incidence angles as shown in Table 1. The change in incidence angle for the thin and thick blade geometries can be explained as follows: The nature of the profile geometries for the blades themselves attribute to the incidence shift but for both blades to have similar bubble separations and pressure differences near their leading edges, the incidence angle must be greater for the thick blades.

CONCLUSIONS AND REMARKS

A fairly complete set of quasistatic moment loops have been measured and recorded for a particular airfoil in an annular cascade. These can be used to study the stall flutter behavior at very low reduced frequencies or they can be utilized in predictions for finite frequency loops using methods described in earlier reports.

The scattering of data at low torsional amplitudes leads to the possibility of hysteresis effects, i.e., flutter is directionally dependent. This phenomenon will be handled in detail as soon as present testing is finished. The present testing consists of free flutter measurements at a stagger angle of -45 degrees. This configuration has recently become of interest due to flutter problems in the rear stages of turbines.

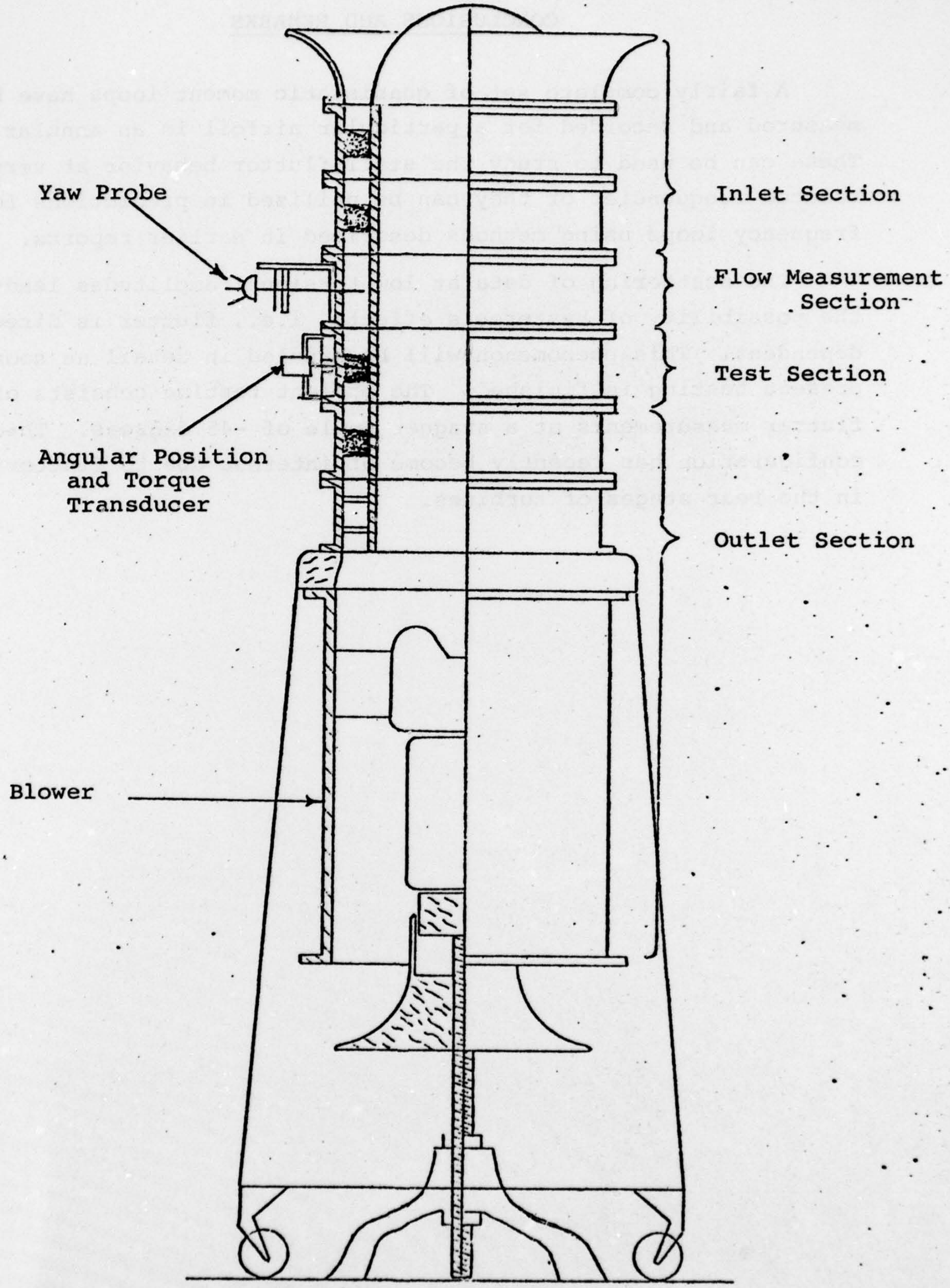

Fig. 1 General Assembly Drawing

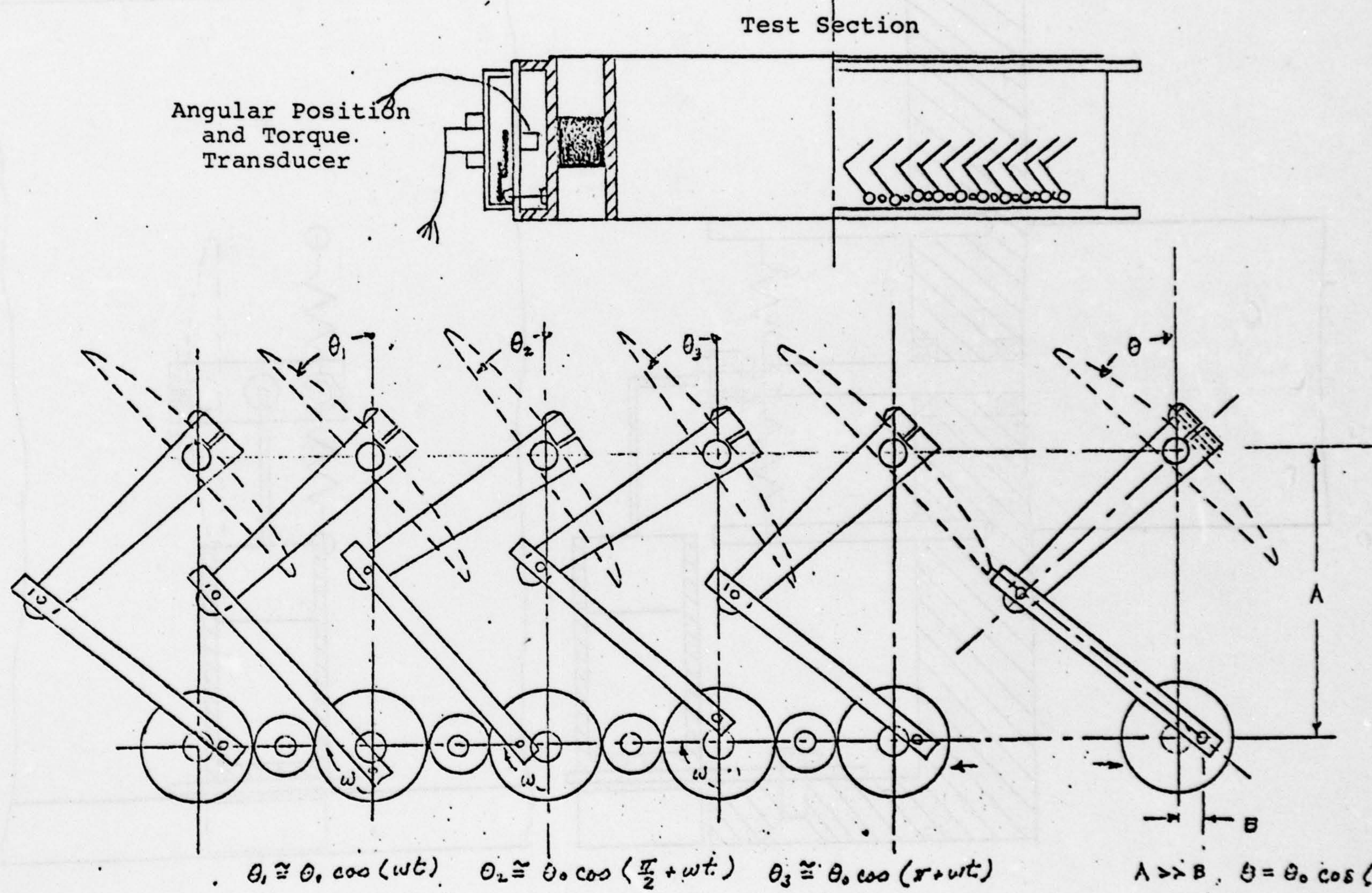

Fig. 2 Linkages and Gear Train Arrangement for Sinusoidal Motion with 90° Interblade Phase Angle.

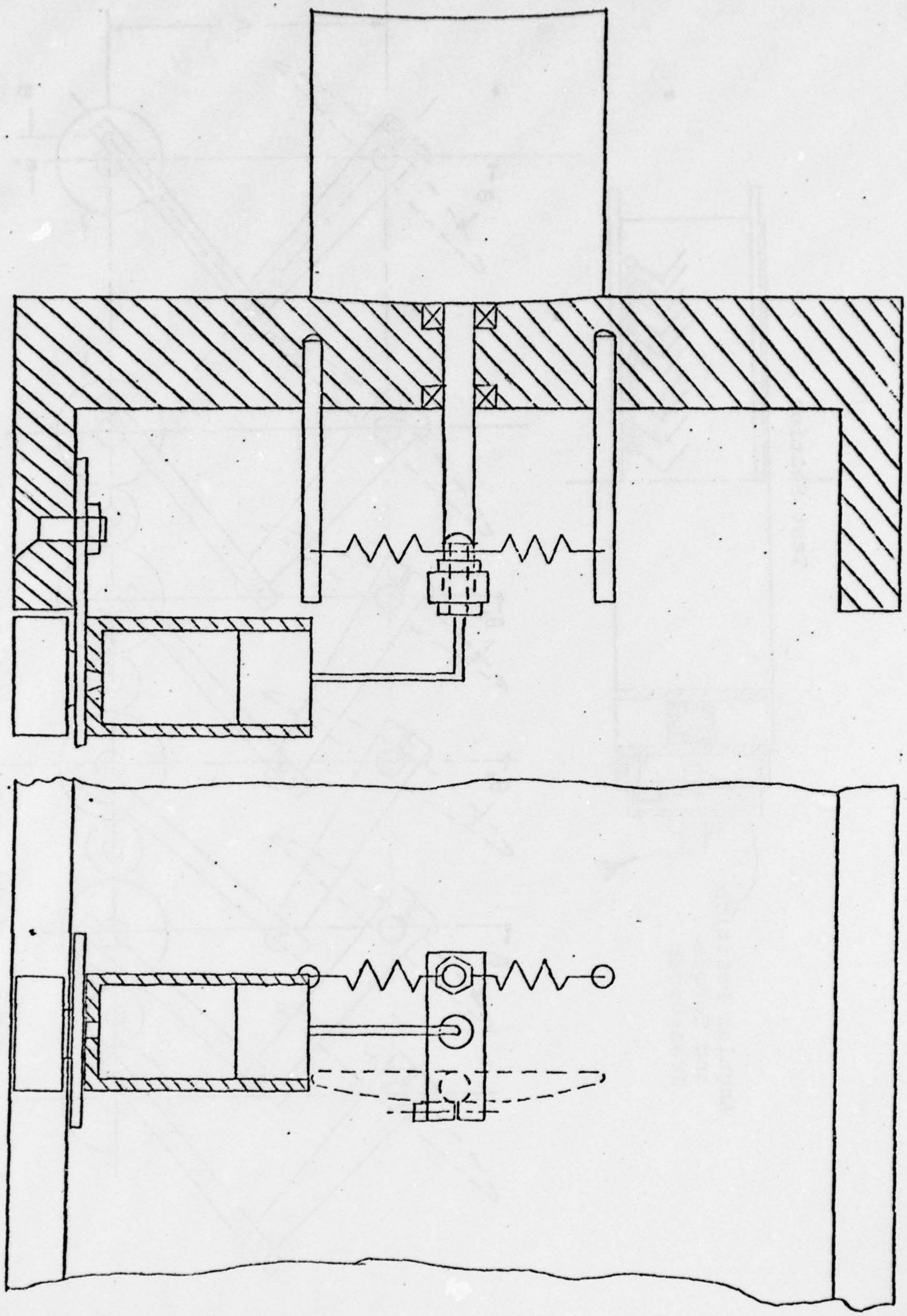

Fig. 3 Free Flutter Test Section

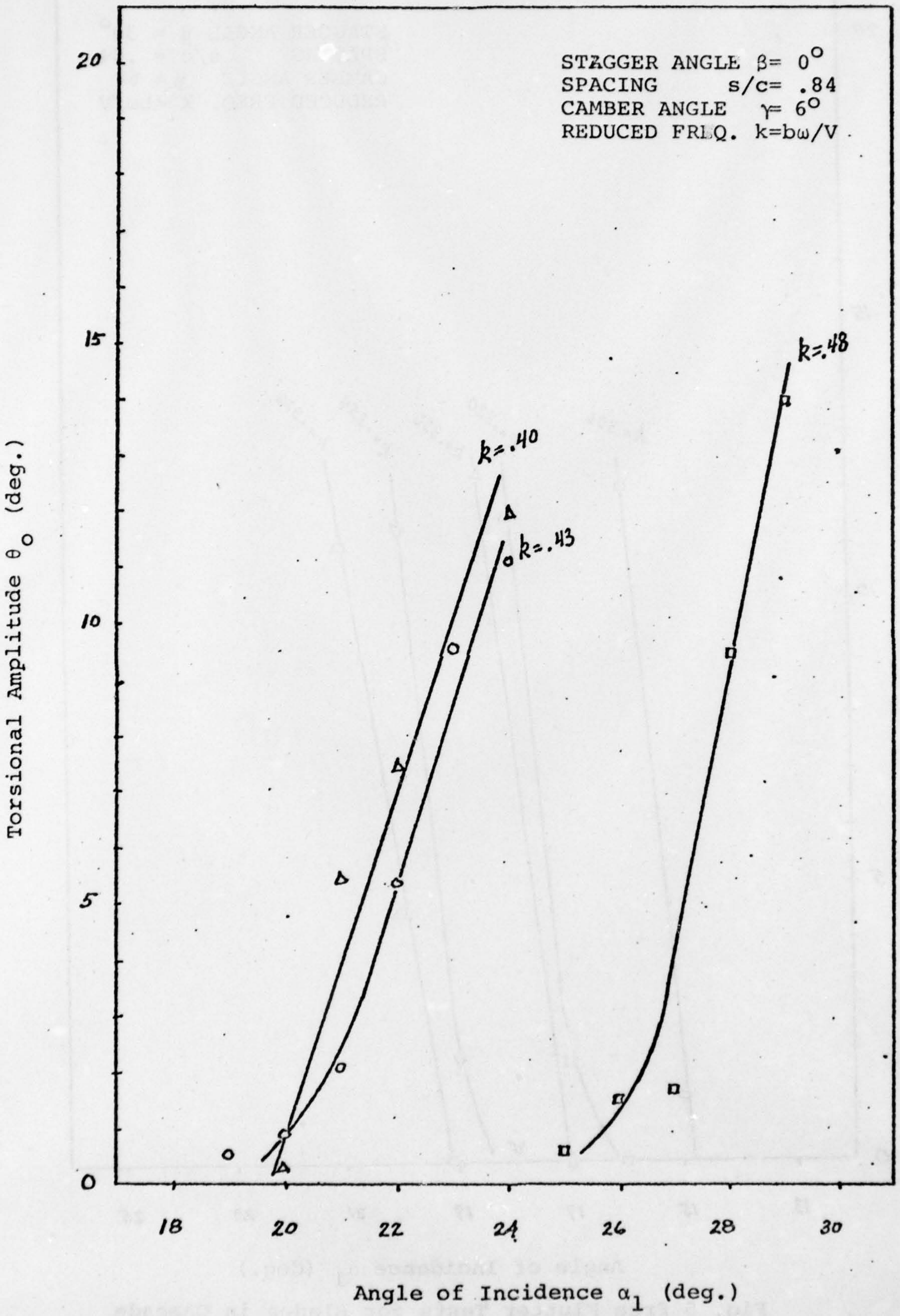

Fig. 4 Free Flutter Tests for Blades in Cascade

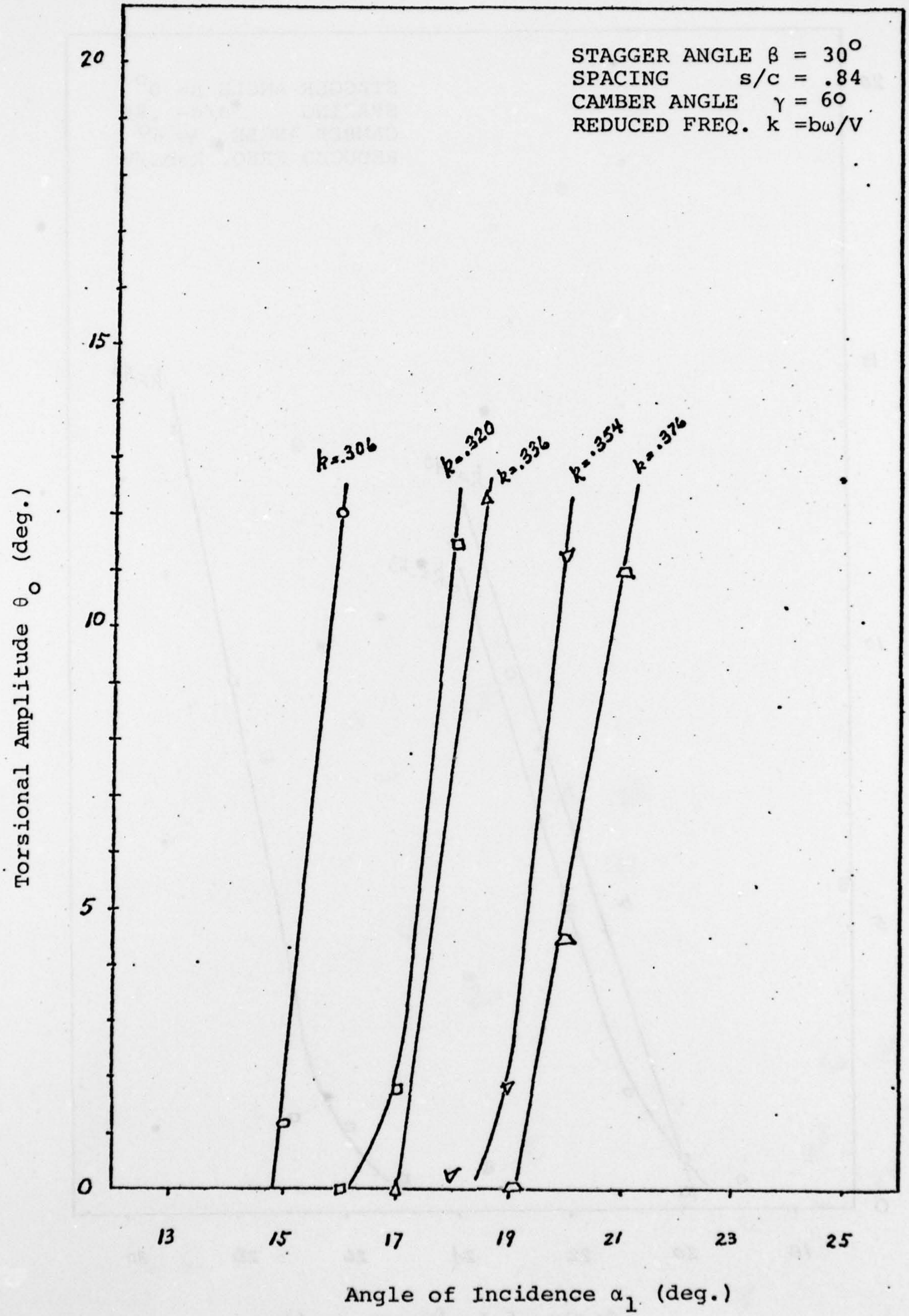

Fig. 5 Free Flutter Tests for Blades in Cascade

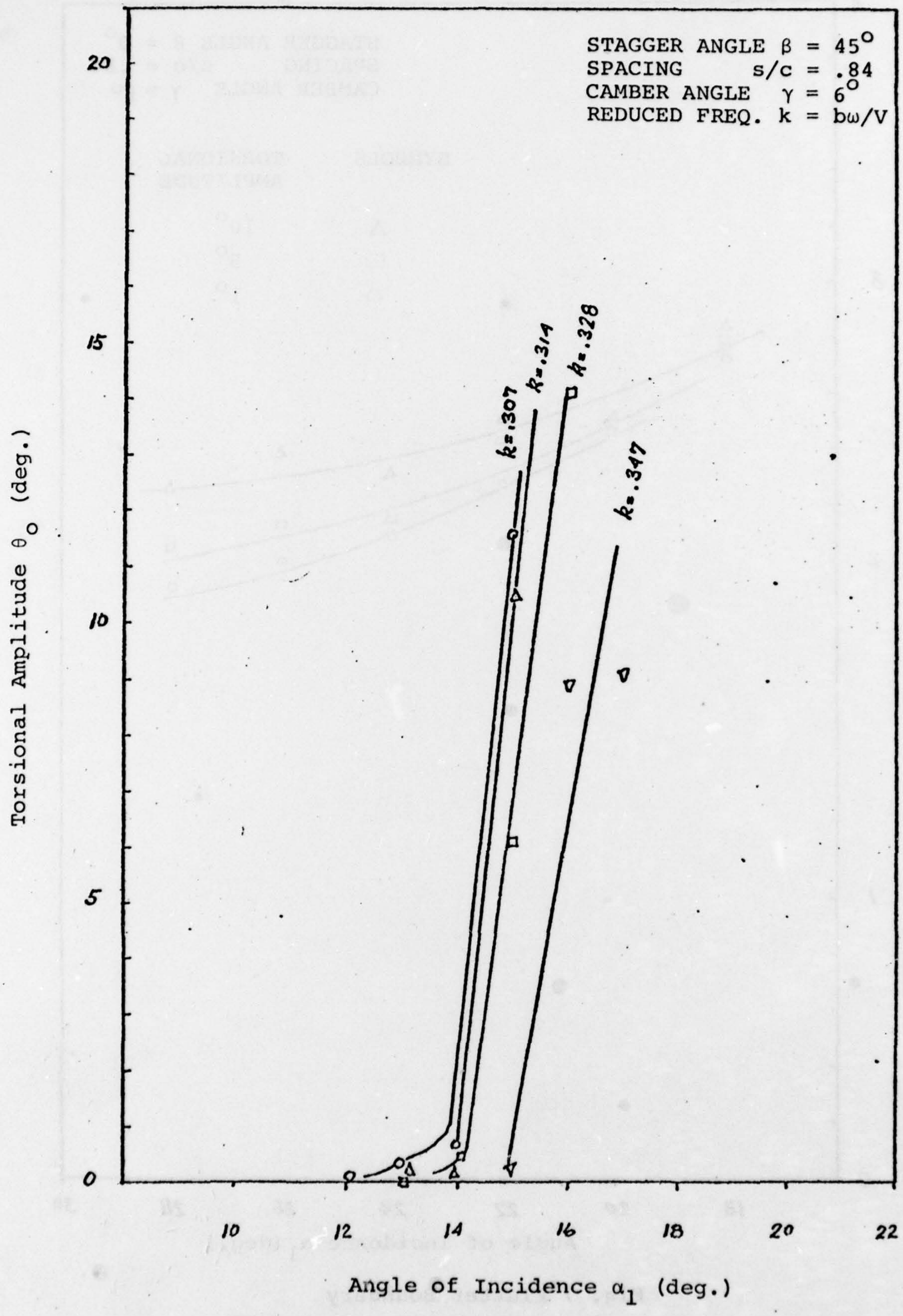

Fig. 6 Free Flutter Tests for Blades in Cascade

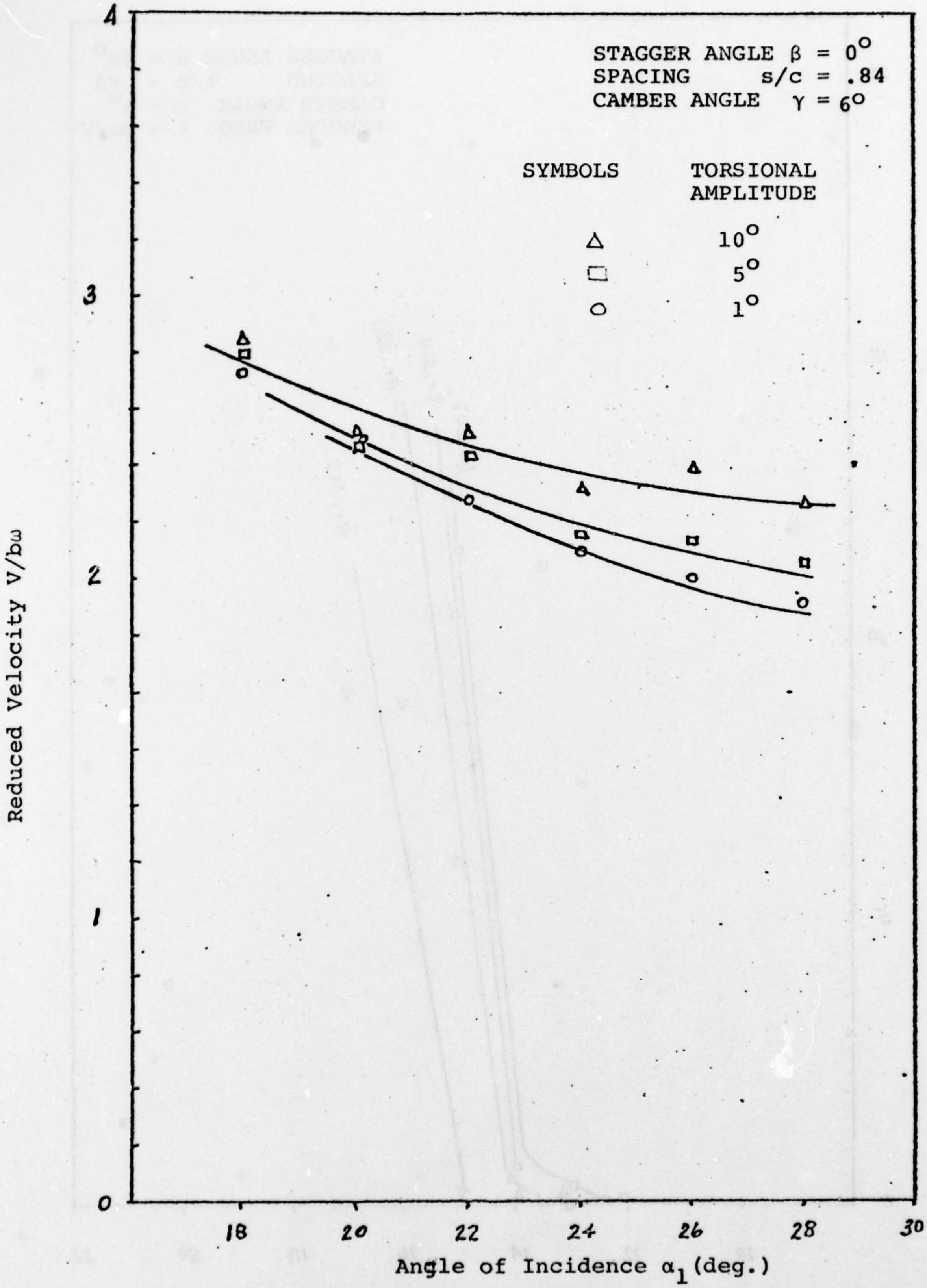

Fig. 7 Flutter Boundary

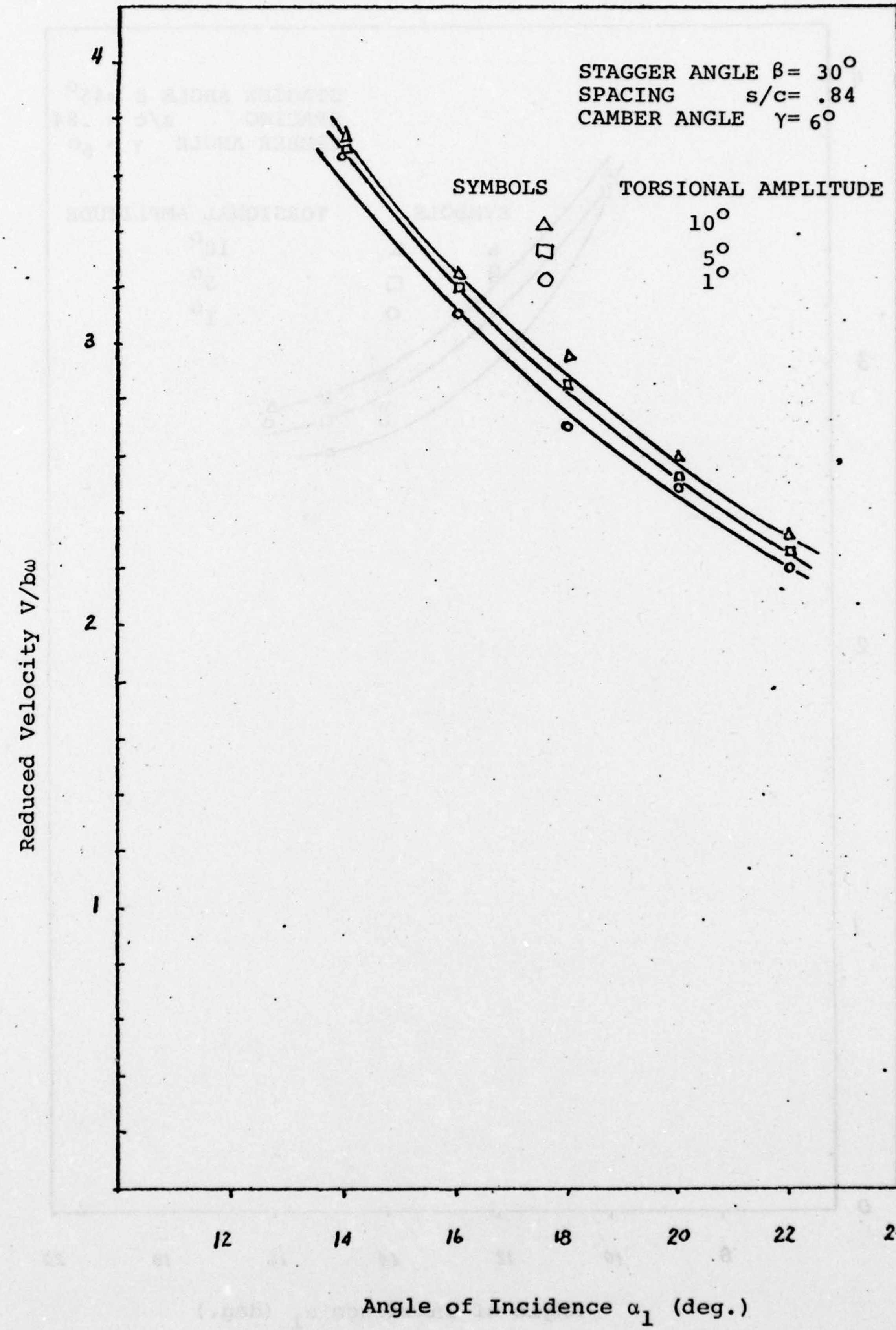

Fig. 8 Flutter Boundary

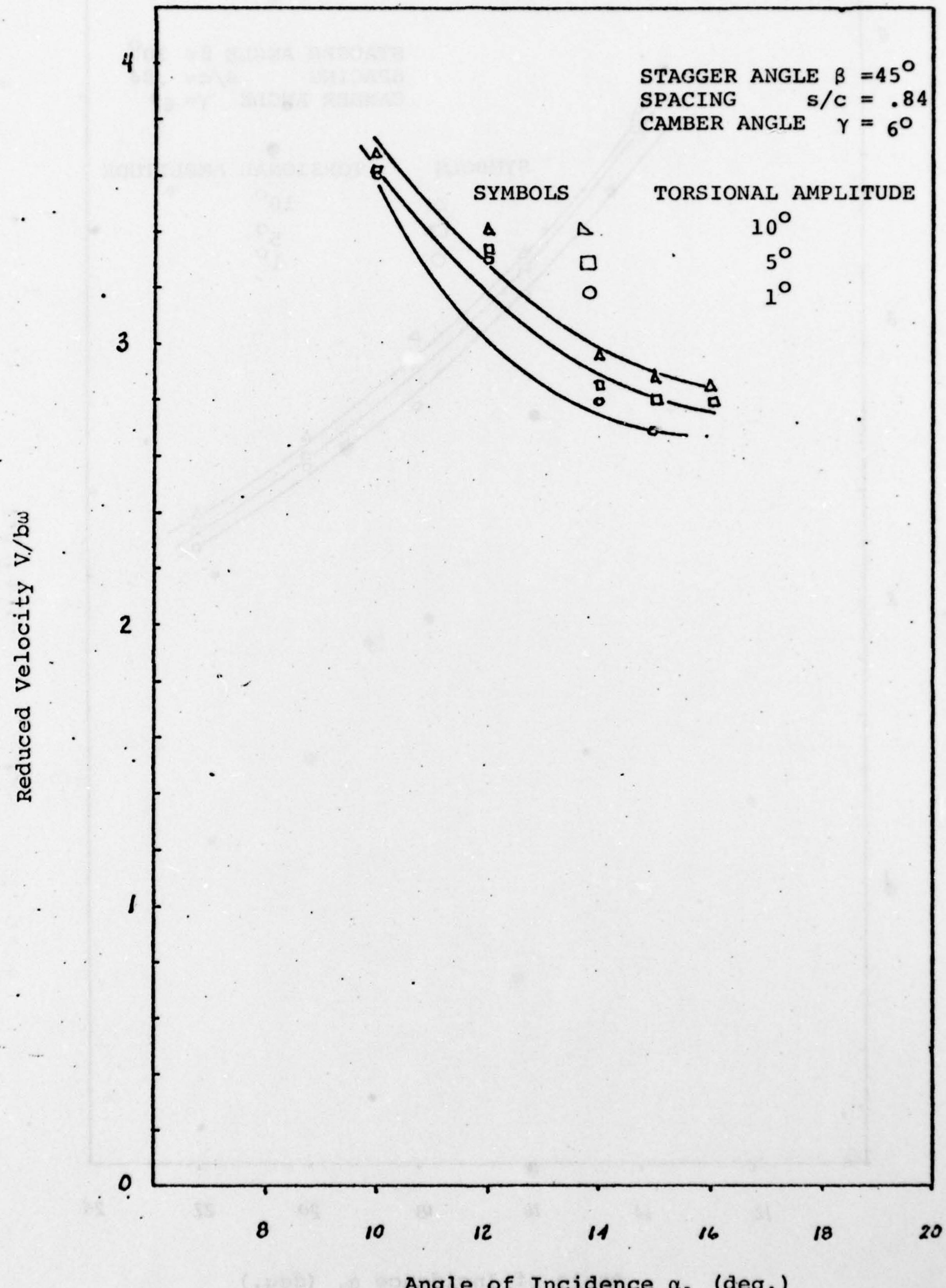

Fig. 9 Flutter Boundary

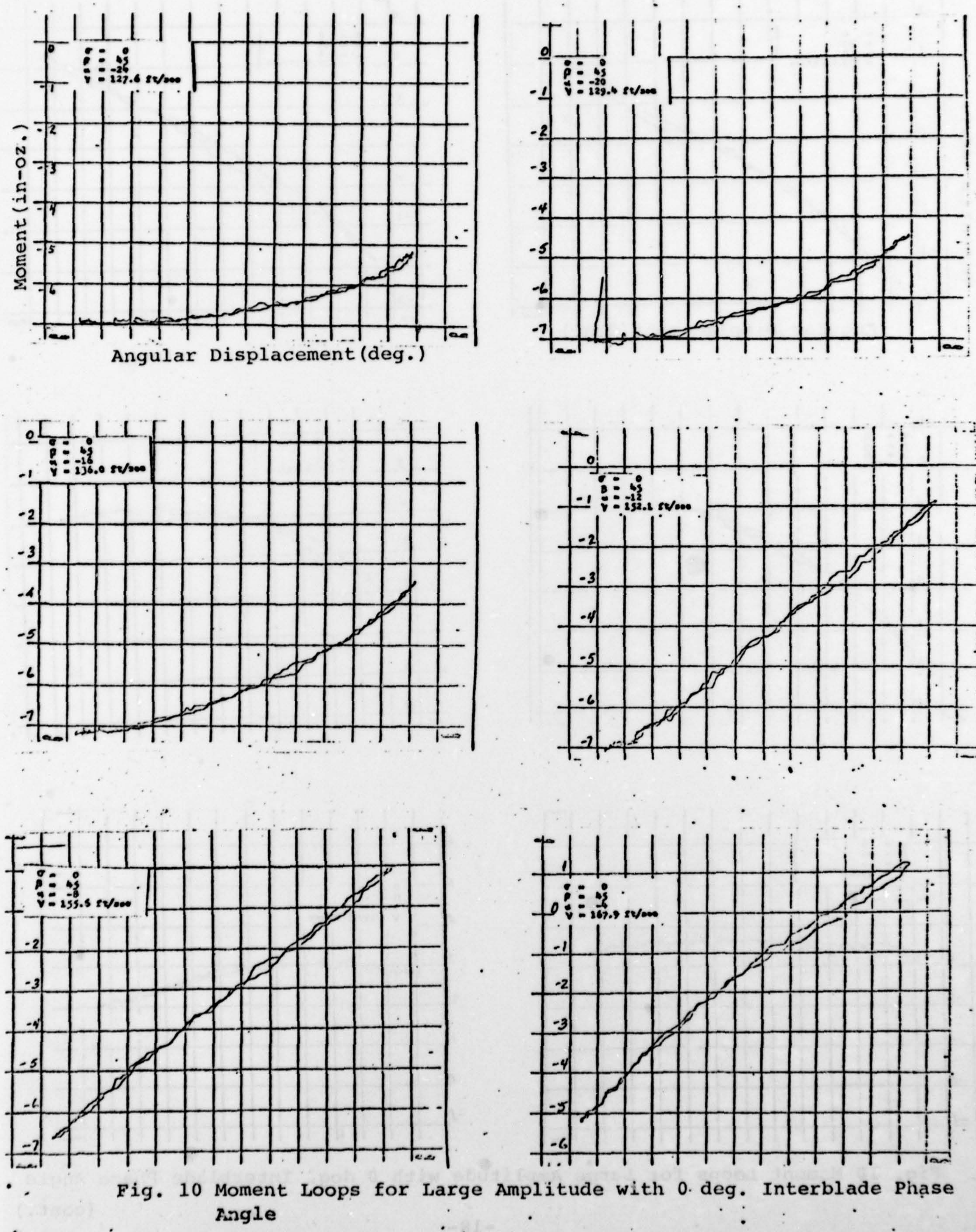

Fig. 10 Moment Loops for Large Amplitude with 0 deg. Interblade Phase Angle

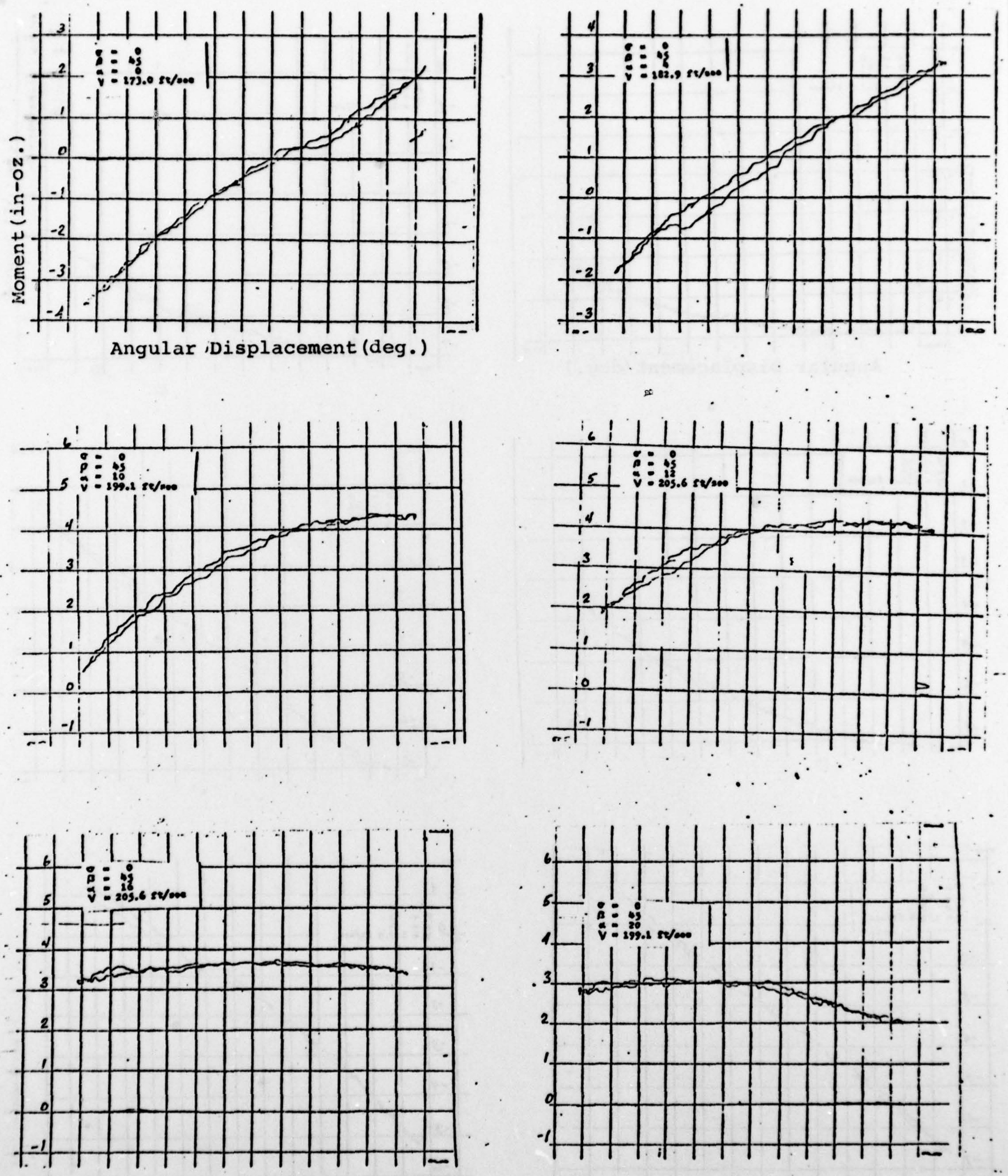

Fig. 10 Moment Loops for Large Amplitude with 0 deg. Interblade Phase Angle (cont.)

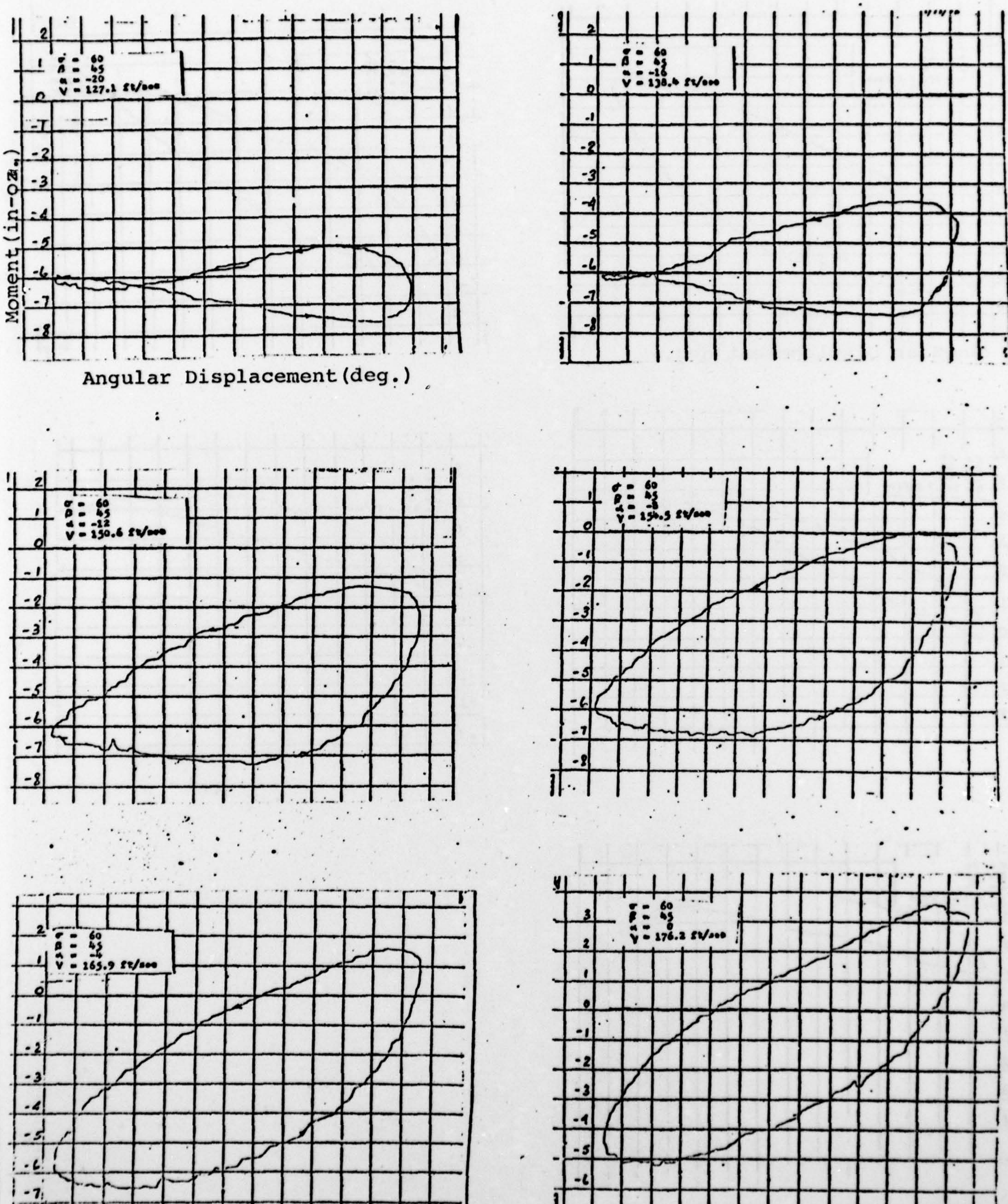

Fig. 11 Moment Loops for Large Amplitude with 60 deg. Interblade Phase Angle

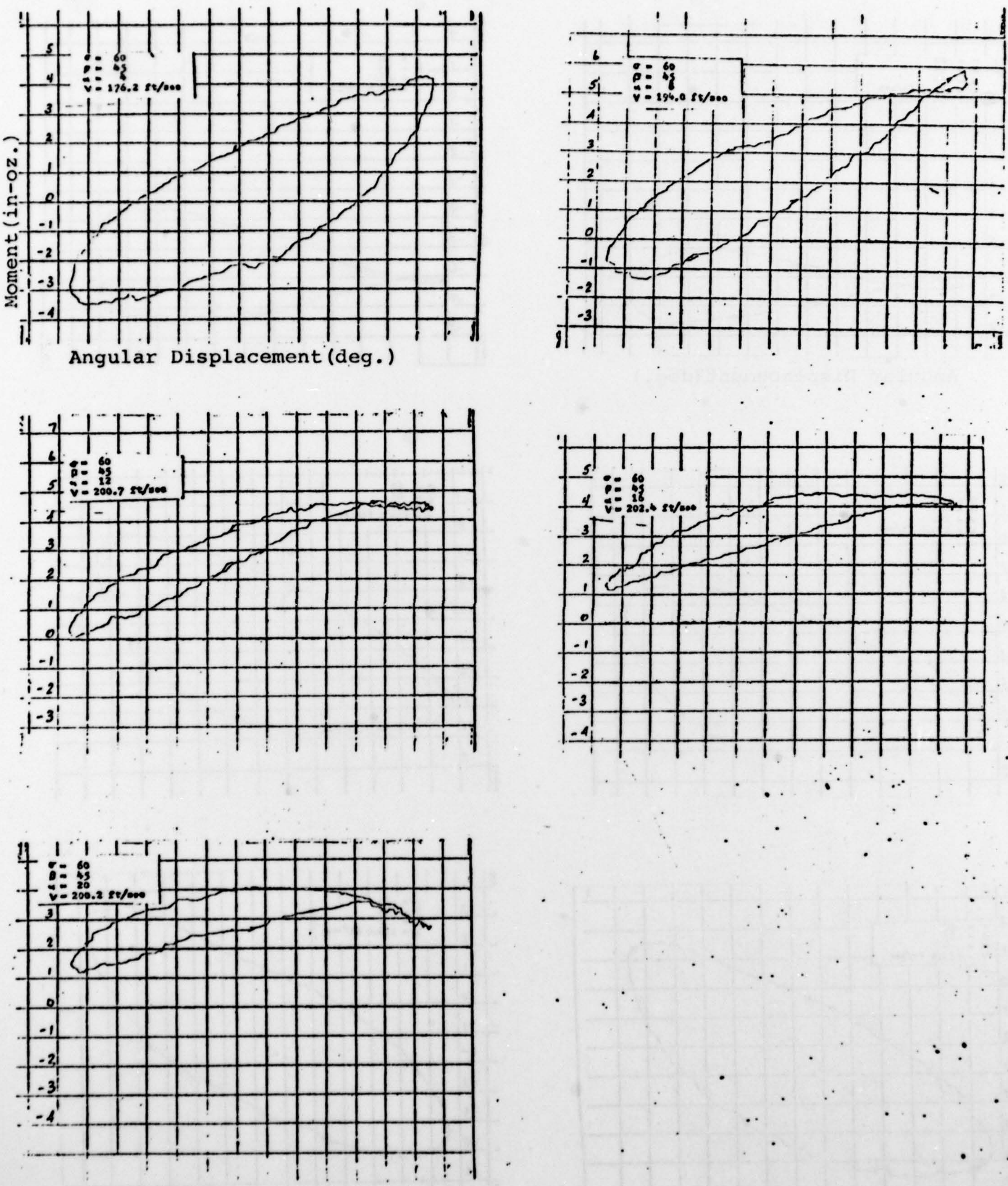

Fig. 11 Moment Loops for Large Amplitude with 60 deg. Interblade Phase Angle (cont.)

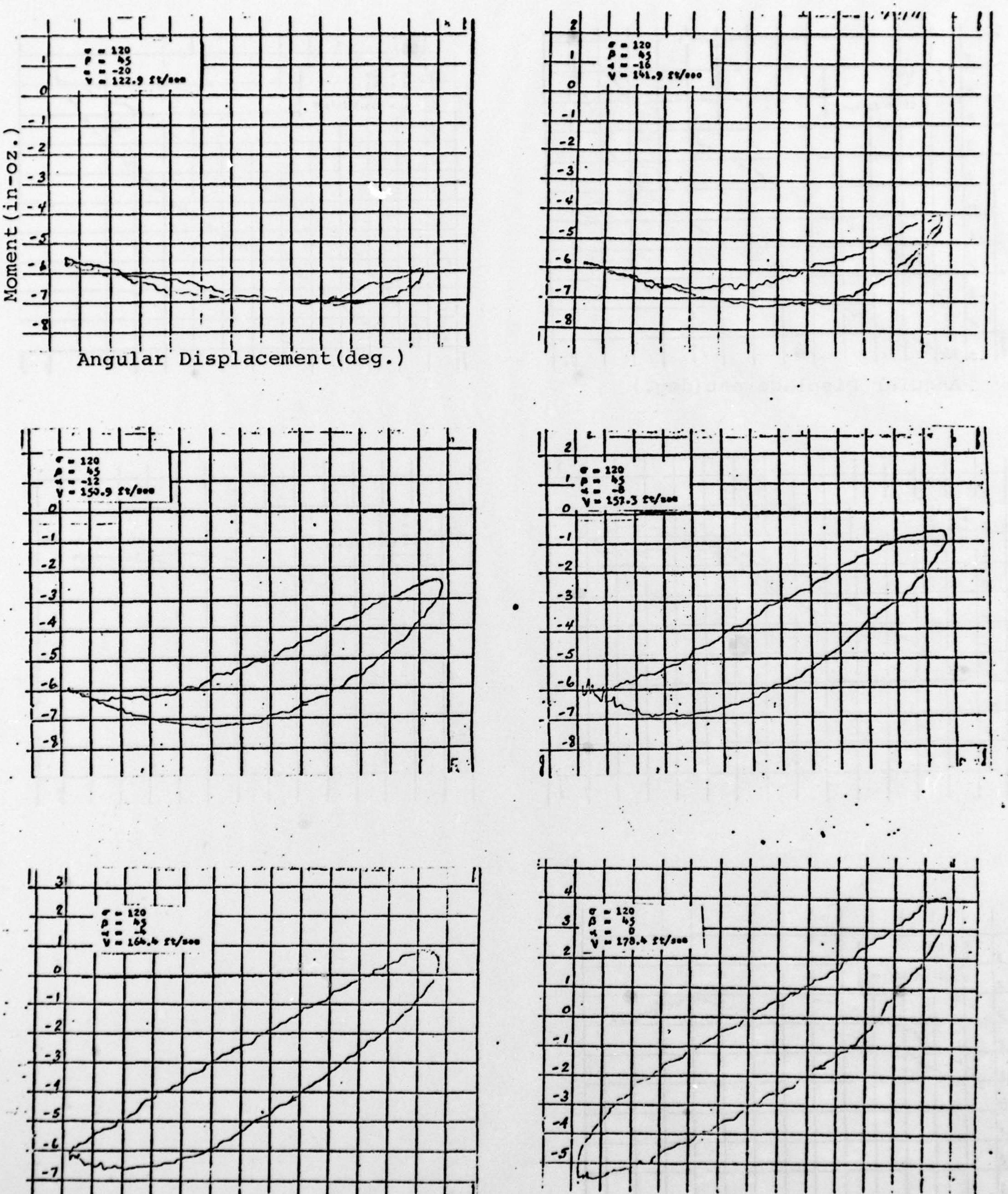

Fig. 12 Moment Loops for Large Amplitude with 120 deg. Interblade Phase Angle

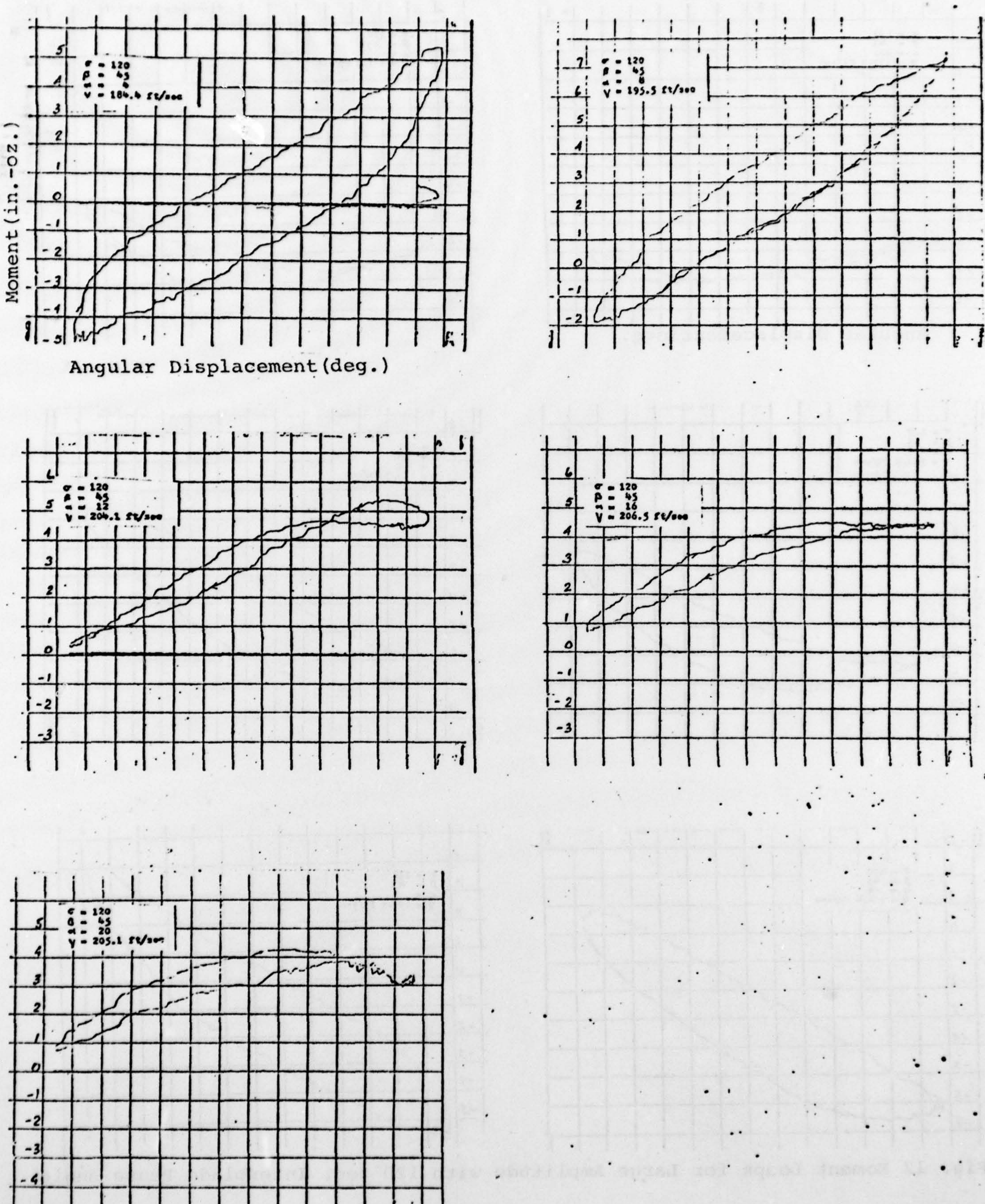

Fig. 12 Moment Loops for Large Amplitude with 120 deg. Interblade Phase Angle. (cont.)

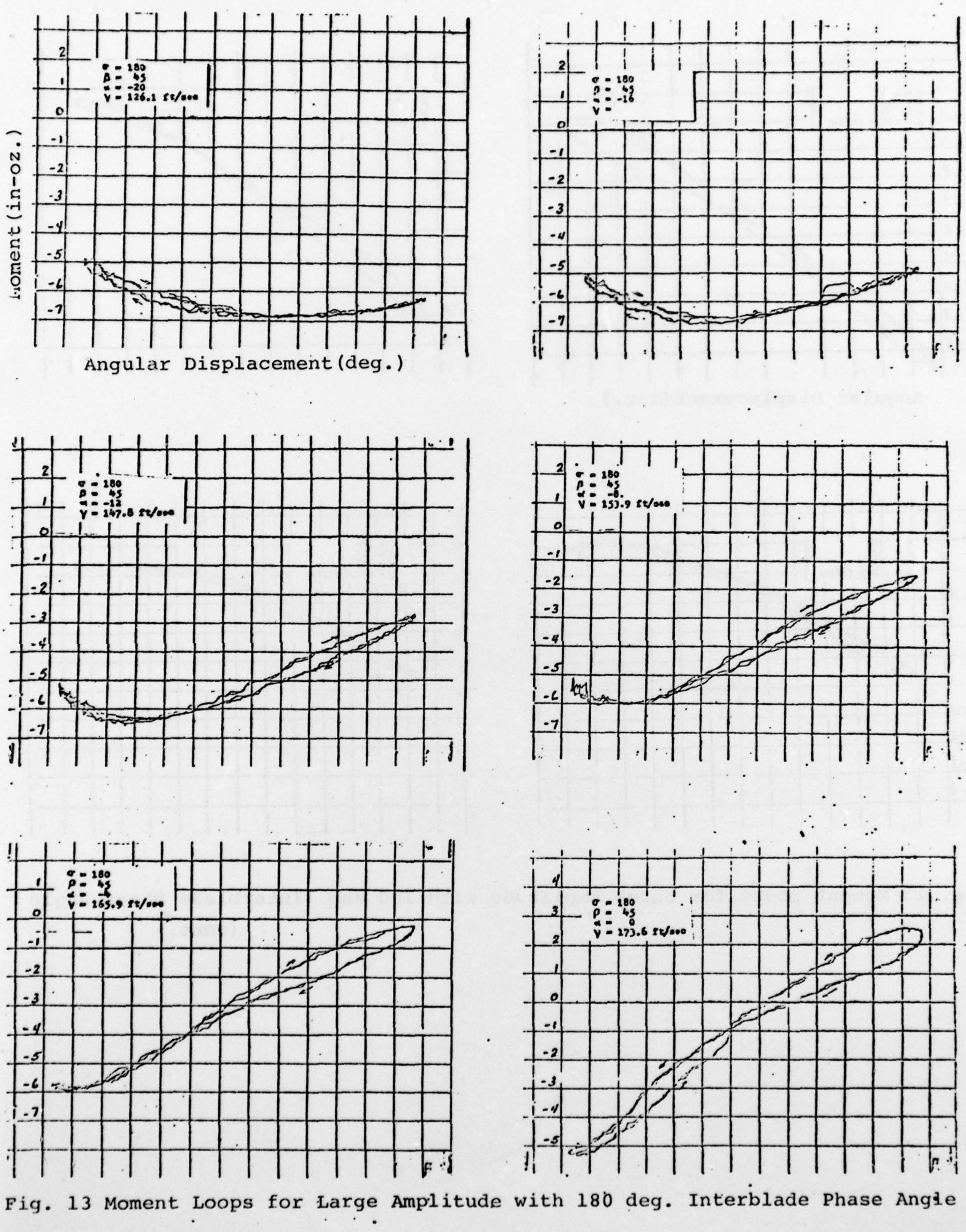

Fig. 13 Moment Loops for Large Amplitude with 180 deg. Interblade Phase Angle

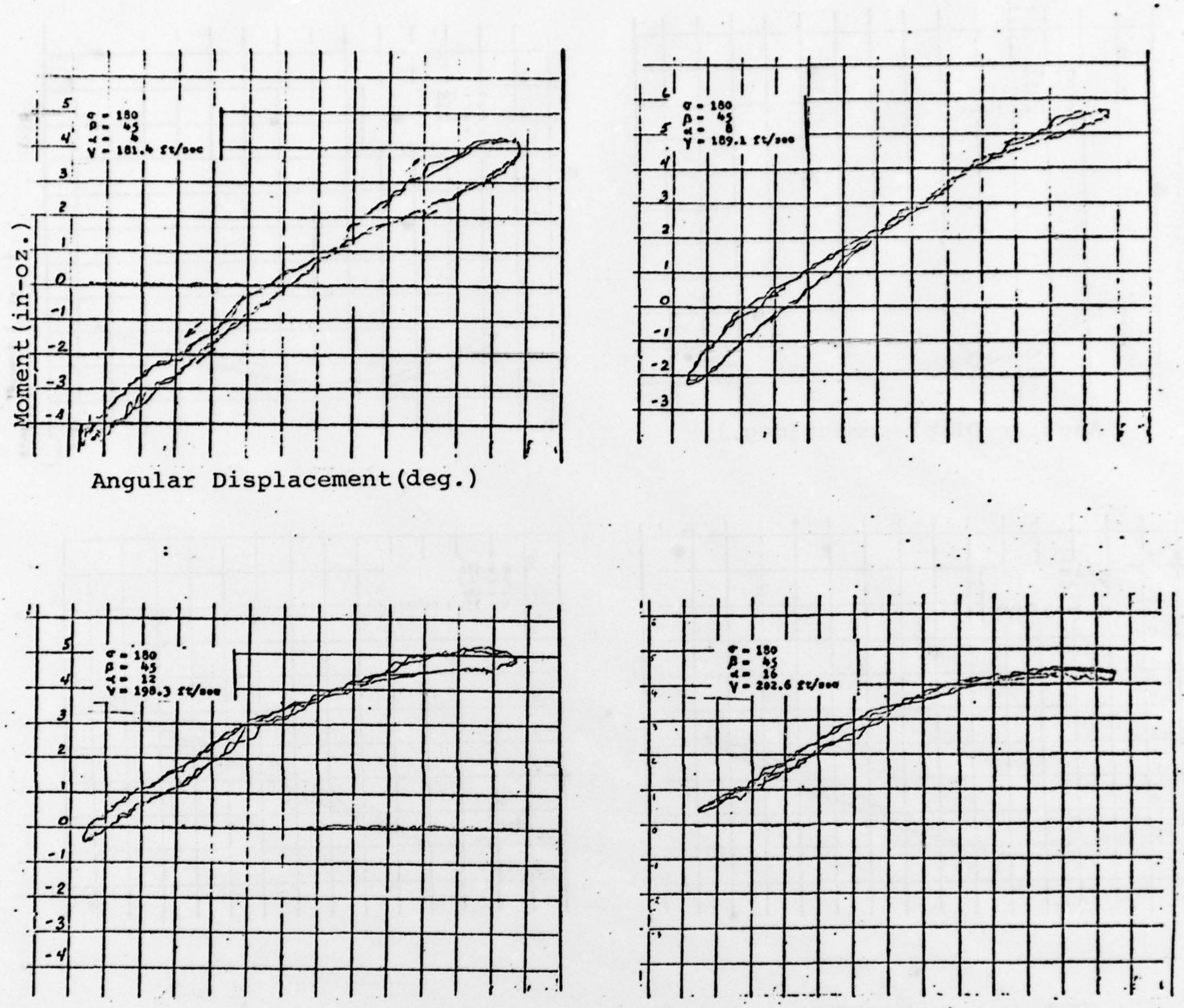

Fig. 13 Moment Loops for Large Amplitude with 180 deg. Interblade Phase Angle (cont.)

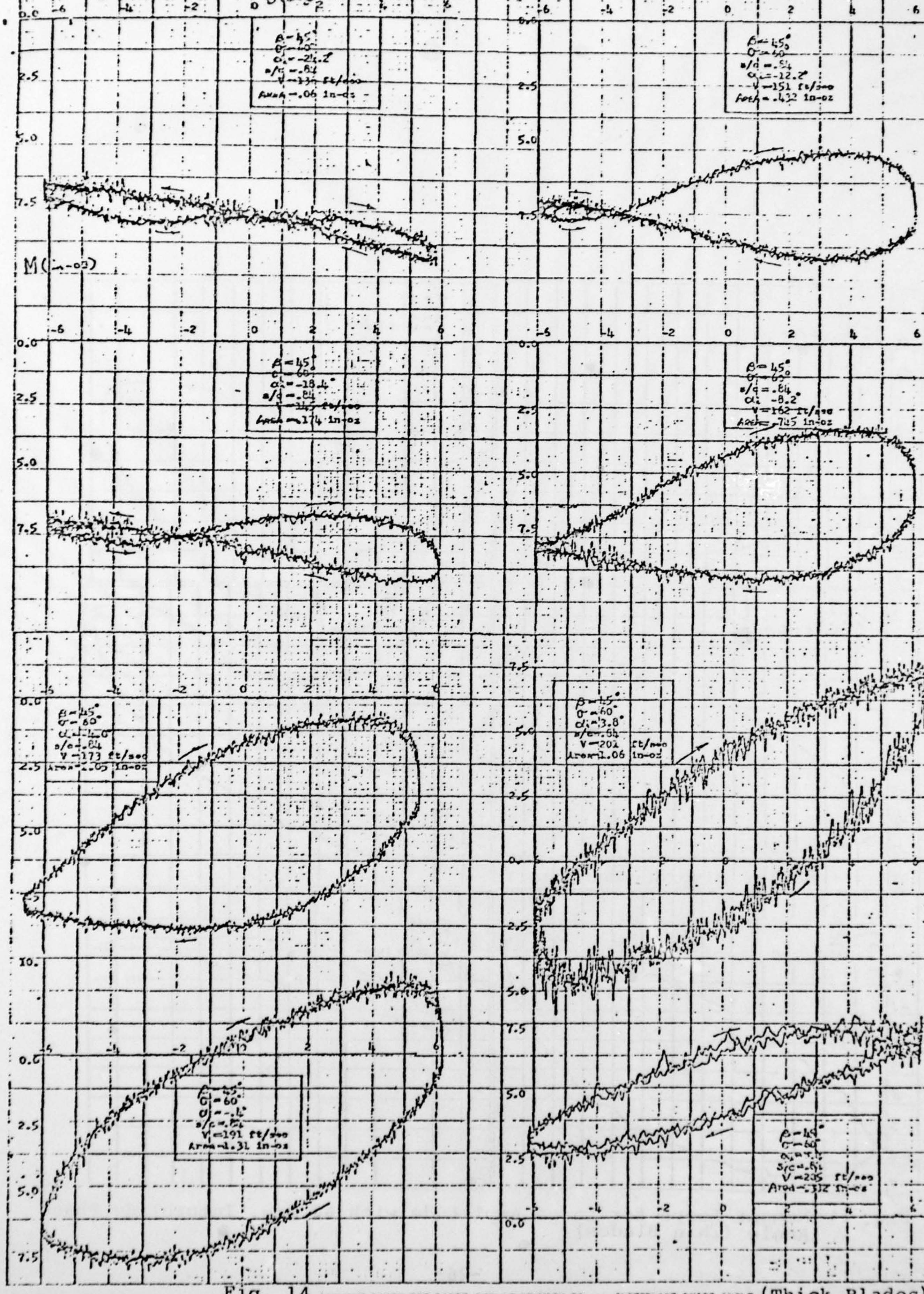

Fig. 14 MOMENT LOOPS FOR LARGE AMPLITUDE WITH 60 deg INTERBLADE PHASE ANGLE (Thick Blades)

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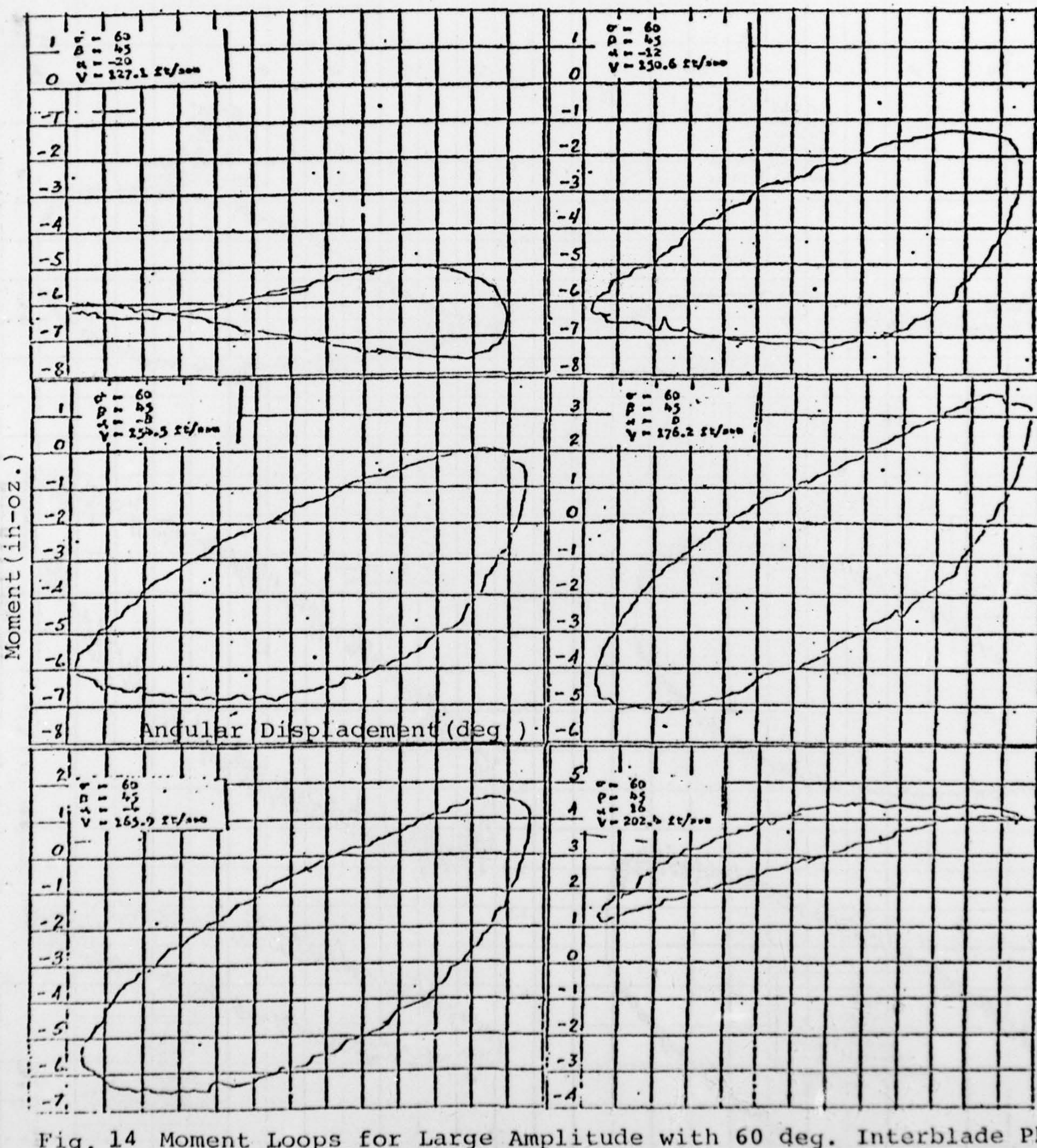

Fig. 14 Moment Loops for Large Amplitude with 60 deg. Interblade Phase Angle (Thin Blades)

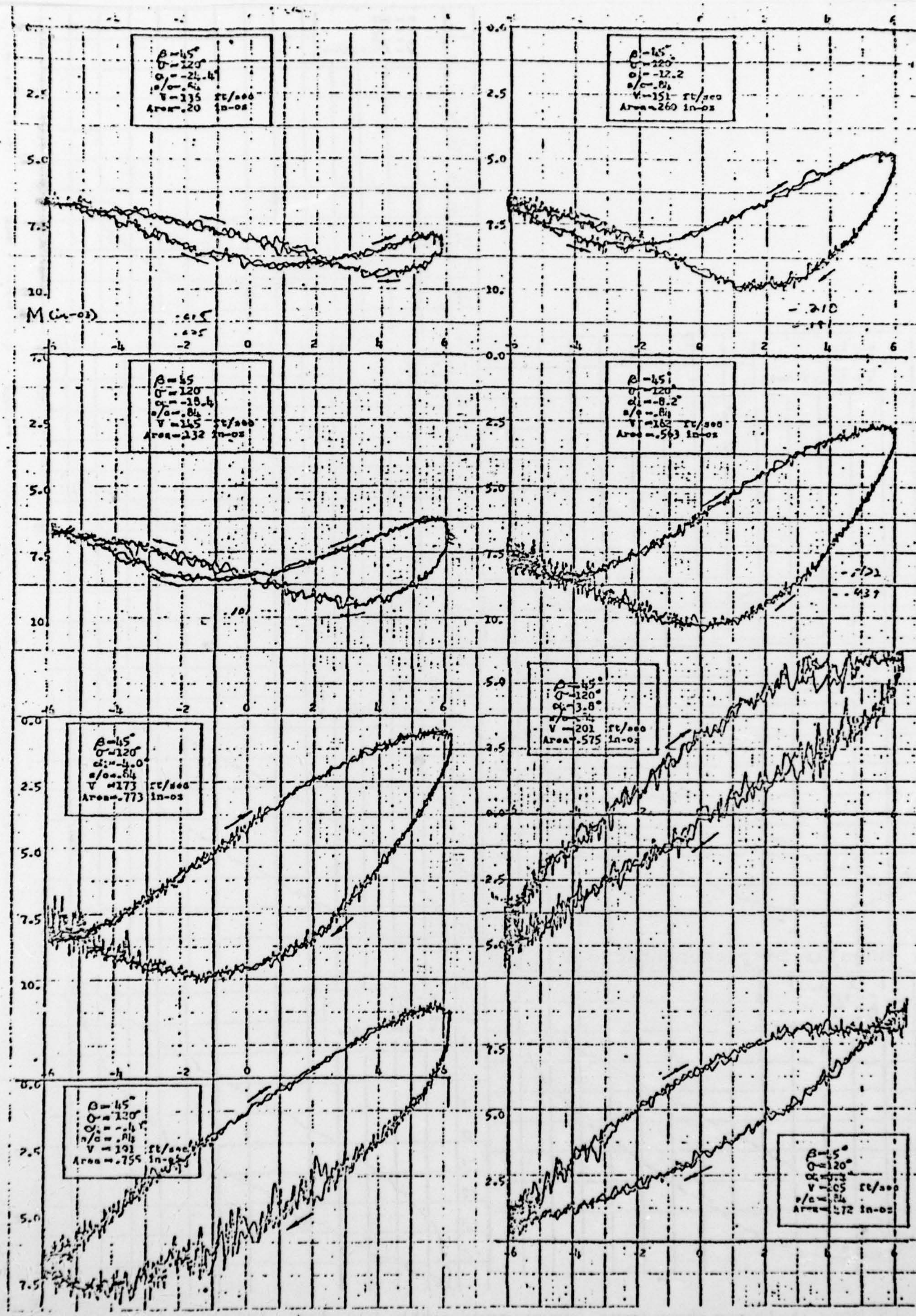

Fig. 15 MOMENT LOOPS FOR LARGE AMPLITUDE WITH 120 DEG INTERBLADE PHASE ANGLE (Thick Blades)

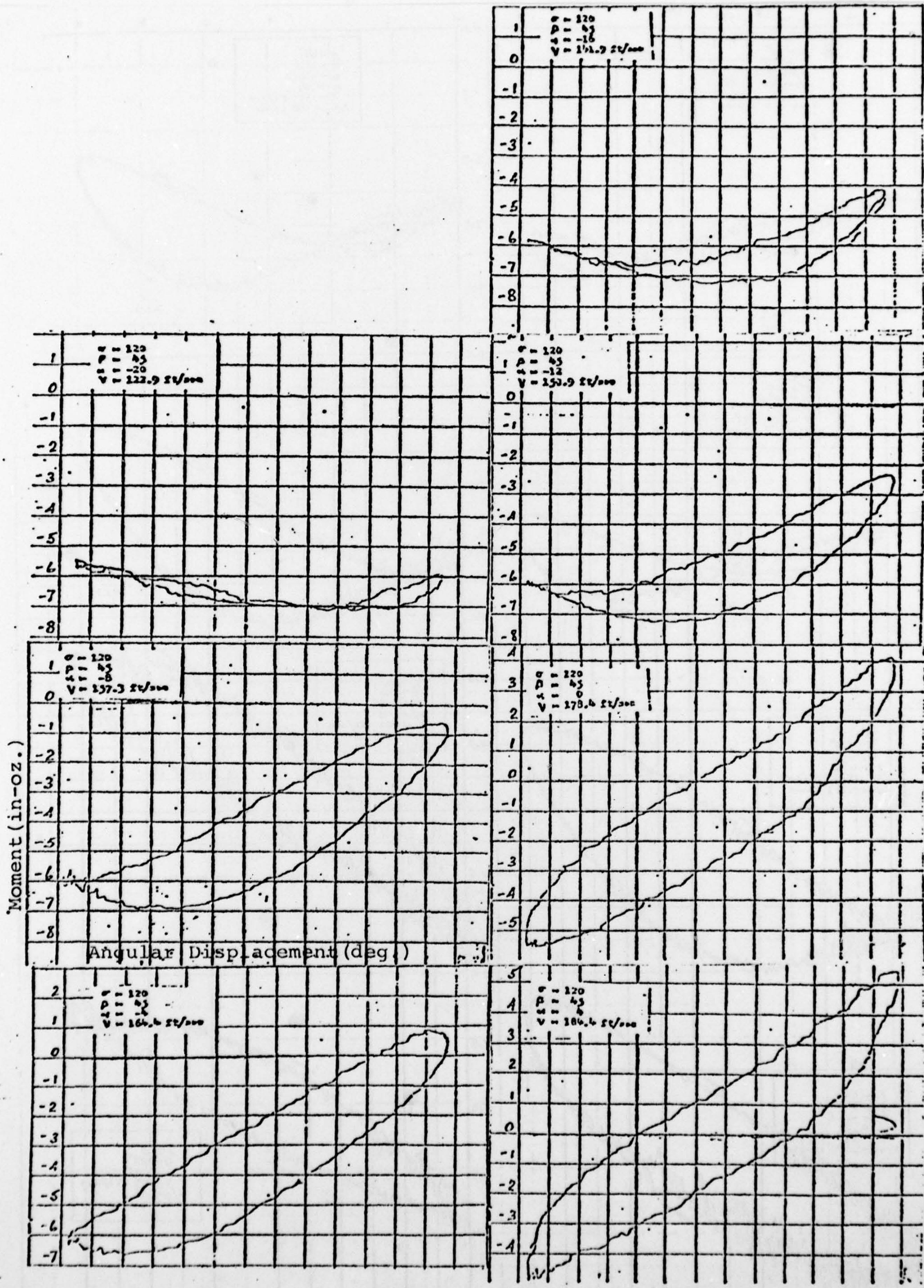

Fig. 15 Moment Loops for Large Amplitude with 120 deg. Interblade Phase Angle (Thin Blades)

Interblade Phase Angle	Thin Blade 4.7% Thickness	Thick Blade 7% Thickness
$\sigma = 60^{\circ}$	α = -20	α = -18.4
	α = -12	α = - 8.2
	α = - 8	α = - 4.0
	α = - 4	α = - .4
	α = 0	α = 3.8
	α = 16	α = 8.4
$\sigma = 120^{\circ}$	α = -20	α = -18.4
	α = -16	α = -12.2
	α = -12	α = - 8.2
	α = - 8	α = - 4.0
	α = - 4	α = -.40
	α = 0	α = 3.8
	α = 4	α = 8.4

Table 1 - Similarities in Moment Loops for Different Blade Geometries

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Typical aerodynamic moment and free flutter measurements are presented for thin airfoils in an annular cascade. Comparison is made between these thin blades and earlier tested thick blades for free flutter and moment loop tests by varying significant parameters.

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