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Rotorcraft Aeromechanical Stability–Methodology Assessment: Phase 2 Workshop

William G. Bousman

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ROTORCRAFT AEROMECHANICAL STABILITY - METHODOLOGY ASSESSMENT PHASE 2 WORKSHOP

William G. Bousman

Ames Research Center
and
Aeroflightdynamics Directorate
U.S. Army Research and Technology Activity (AVSCOM)

Introduction

A workshop was held at Ames Research Center August 2-3, 1988 to discuss the results of the Methodology Assessment Phase 2 Continuation. This workshop was a follow-on to the original Methodology Assessment reported in Ref. 1. The present volume contains the predictions that were obtained under the continuation efforts.

The original Integrated Technology Rotor (ITR) Methodology Assessment was a Government-funded study to assess the capability of industry analyses to predict the aeroelastic and aeromechanical stability of rotorcraft. Six different sets of experimental data were used as a baseline ranging from a hingeless rotor model in hover to data on a full-scale bearingless rotor in forward flight as shown in Table 1. For each data set, A through F, several cases or configuration variations were identified to enable comparisons for a range of rotor aeroelastic effects. Analyses from Bell Helicopter Textron, Boeing Helicopters, McDonnell Douglas Helicopter Company, and Sikorsky Aircraft were compared with the data. The first workshop to discuss these results was held in June 1983 at Ames Research Center and was reported in Ref. 1.

Following the original assessment, two data sets were selected for a significantly more detailed comparison in an effort referred to as the Phase 1 Continuation. The first set selected (Data Set A, Case 6) was for the torsionally-soft hingeless rotor model in hover with a soft pitch flexure and negative droop. This particular case had shown the greatest discrepancies in the Methodology Assessment results. The second case (Data Set C, Case 3) was from an aeromechanical rotor-body stability model test where there was extensive data available on modes other than the lead-lag regressing mode. Whereas in the original Methodology Assessment the basis of comparison was the damping of the least stable mode, in the Phase 1 Continuation the damping and frequency of all the rotor modes in the frequency range of the least stable mode were examined.

A Phase 2 Continuation effort followed the Phase 1 work. Additional computations were made with the torsionally-soft hingeless rotor model of Data Set A. The acquisition of frequency data in a vacuum test of this model rotor (Ref. 2) prompted inclusion of new calculations to compare with these data as well. A simplified hypothetical version of the torsionally-soft rotor model was also specified that retained the aeroelastic coupling effects that had caused difficulties in the torsionally-soft rotor comparisons but eliminated the unimportant blade root hardware that complica ' the assessments. Finally, two new matched-stiffness configurations were added for the aeromechanical stability test (Data Set C) that had not been examined previously.

Table 1. – Experimental Data Sets

DATA SET	ROTOR TYPE	FUSELAGE COUPLING	FLIGHT CONDITION	SCALE	SOURCE
A	Hingeless	Isolated	Hover	Model	Aeroflightdynamics
B	Hingeless	Rotor-Body	Hover	Model	Aeroflightdynamics
C	Hingeless	Rotor-Body	Hover	Model	Aeroflightdynamics
D	Bearingless	Isolated	Hover	Model	Aeroflightdynamics
E	Bearingless	Rotor-Body	Hover/Fwd Flt	Model	Boeing Helicopters
F	Bearingless	Rotor-Body	Hover/Fwd Flt	Full	Boeing Helicopters

The purpose of this report was to collect and publish the results of the Phase 1 and Phase 2 Methodology Assessment Continuation efforts for use by future investigators. Discussion of these results is not provided in this document; conclusions about the relative merits of the various prediction codes, the quality of the predicted results, or explanation of the sources of differences between predicted and measured data are left to the reader. A full description of the experimental data sets, the experiments themselves, and the prediction codes can be found in Ref. 1. Although the analysis results presented in the figures contained herein should be self-explanatory, additional discussion of some details may be found in Ref. 1. This report is intended to be a companion to that report.

The report is organized into four sections presenting the results for the predictions of the four data sets addressed in the Phase 1 and Phase 2 Continuations.

Torsionally-Soft Hingeless Rotor Model

The damping predictions shown in the original Methodology Assessment for the torsionally-soft rotor model (Data Set A) were obtained for six different cases or configurations. For the Phase 1 and 2 Continuations, more detailed predictions were made for Cases 2 and 6, and these predictions included the damping and frequency of the flap, lead-lag, and torsion modes as well as the blade equilibrium flap, lead-lag, and torsional deflections. The additional parameters calculated in the continuation were intended to help understand the variations in the original lead-lag damping results. The two cases studied, both with the soft pitch-flexure configuration, were Case 2 without precone or droop and Case 6 with -5° droop and no precone. The Case 6 configuration has the largest aeroelastic coupling and showed the widest variations in predicted lead-lag damping. The calculations shown here are outlined in Table 2. The task numbers shown in Table 2 refer to the tasks listed in the continuation statement of work. The calculations are shown on the pages indicated in the table. A symbol is shown on the torsionally-soft rotor plots that represents the case plotted. The middle section of the symbol represents the root configuration and is open for cases with a soft pitch-flexure (Cases 2 and 6). The right hand section of the symbol represents the blade and is horizontal for Case 2 (no precone or droop) and is canted upwards for Case 6 (-5° droop).

Table 2. – Torsionally-Soft Rotor Hover Test (Data Set A)

CASE	PITCH FLEXURE	PRECONE β_{pc}, deg	DROOP β_d, deg	PHASE 2	PAGES
1	stiff	0.0	0.0	–	–
2	soft	0.0	0.0	Tasks 86d, 86e	10-107
3	stiff	5.0	0.0	–	–
4	soft	5.0	0.0	–	–
5	stiff	0.0	-5.0	–	–
6	soft	0.0	-5.0	Tasks 86f, 86g	108-205

The same model properties were used for the Phase 2 calculations as were used in the original Methodology Assessment (Ref. 1) except the analysts were instructed to adjust the the chordwise structural properties so that the predicted nonrotating lead-lag frequency matched the measured Case 2 value. The chordwise properties were then fixed for the rest of the torsionally-soft rotor cases. For the Case 2 configuration without precone or droop, the Phase 2 comparisons of theory and experiment for Task 86d are shown on pages 10 to 44. Nonlinear aerodynamic section properties were used for these calculations, that is,

$$c_\ell = 6\alpha - (\mathrm{sgn}\alpha)\,10\,\alpha^2$$

$$c_d = 0.01 + 11.1|\alpha|^3$$

The same comparisons were made in Task 86e except that linear aerodynamic section properties were used

$$c_\ell = 2\pi\alpha$$

$$c_d = 0.008$$

The pitching moment was assumed to be zero and the section properties were assumed independent of Mach number for both tasks. The Task 86e calculations are shown on pages 45 to 107. Included in these calculations are comparisons of the linear and nonlinear predictions for each analyst.

Calculations made with nonlinear section properties for Case 6 (Task 86f) are given on pages 108 to 142. The predictions made with linear aerodynamic section properties (Task 86g) are on pages 143 to 205. Again, these latter calculations include comparisons of the linear and nonlinear predictions for each analyst.

Torsionally-Soft Hingeless Rotor Model in Vacuum

Calculations of flap, lead-lag, and torsion frequencies in vacuum were made during the Phase 2 continuation and these are compared here to experimental measurements that have been obtained on the torsionally-soft rotor model (Ref. 2). These results provide an opportunity to compare basic rotor structural and inertial analyses without the additional uncertainties of aerodynamic modeling. The calculations are shown for the cases outlined in Table 3. The comparisons for Case 2 (Task 86b) are on pages 206 to 215. The Case 6 comparisons (Task 86c) are on pages 216 to 225.

Table 3. – Torsionally-Soft Rotor Vacuum Test

CASE	PITCH FLEXURE	PRECONE β_{pc}, deg	DROOP β_d, deg	PHASE 2	PAGES
2	soft	0.0	0.0	Task 86b	206-215
6	soft	0.0	-5.0	Task 86c	216-225

Hypothetical Torsionally-Soft Hingeless Rotor

Although the torsionally-soft hingeless rotor model represents an almost ideal configuration intended for research purposes, several physical details such as the pitch flexure and blade root retention hardware require some care to properly represent in prediction codes. To remove these complications and provide a more unambiguous basis for analysis comparisons, a hypothetical rotor model was specified for the Phase 2 calculations. This rotor shows a number of simplifications from the actual torsionally-soft rotor model. A sketch of the hypothetical model is shown in Fig. 1 to illustrate the coordinate system that defines the blade pitch and precone angles. The blade of the hypothetical rotor model is defined in a coordinate system $\underline{b}_j^F$, where the blade axis system is defined relative to the coordinate system by

$$\underline{b}_i^P = [C_{ij}]\underline{b}_j^F$$

$$[C_{ij}] = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix}$$

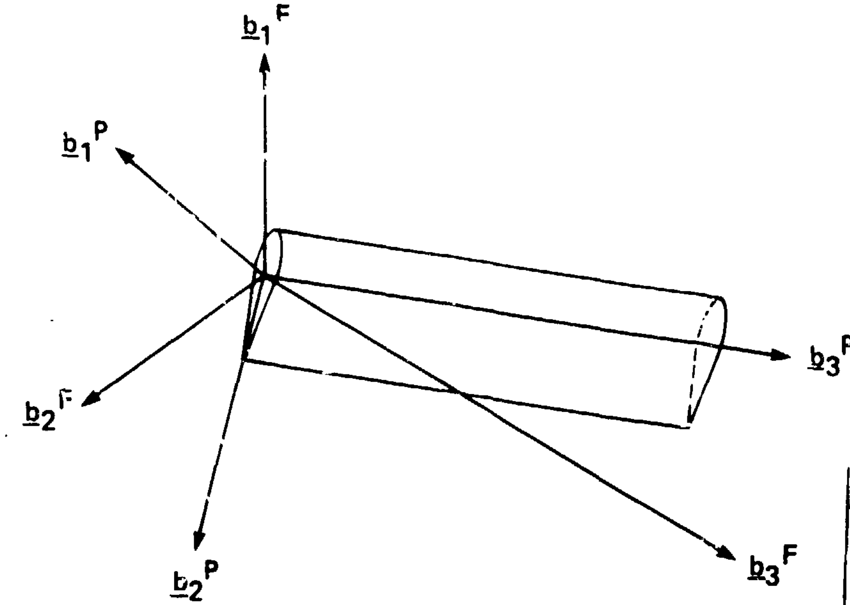


Figure 1. – Schematic of hypothetical rotor model.

Table 4. – Hypothetical Rotor Properties

Radius, in	36.0
Chord, in	3.5
Blade mass, lb_m/in	0.0167
Blade inertia about elastic axis, lb_m-in^2/in	0.0167
Flap stiffness, lb-in^2	6000.
Chord stiffness, lb-in^2	100000.
Torsional stiffness, lb-in^2	1800.
Lift curve slope	6.28
Drag coefficient	0.01
Structural damping	0.0

where θ is the blade pitch angle and β is the precone angle. The blade properties are given in Table 4. The blade c.g., and the elastic and tensile axes are at the 25% chord.

Two cases were calculated for the hypothetical rotor as shown in Table 5. The calculations are shown on pages 226-231 for the case without precone (Task 86h) and on pages 232-237 for the case with 5° precone (Task 86i). As in the case of the torsionally-soft rotor calculations a symbol is used on the plots to represent the case being examined. As the hypothetical rotor does not have a pitch flexure there is no middle section to the symbol. The right hand section is either horizontal for zero precone cases or canted up for cases with precone.

Table 5. – Hypothetical Rotor

PRECONE β_{pc}, deg	PHASE 2	PAGES
0.0	Task 86h	226-231
5.0	Task 86i	232-237

Hingeless Rotor Body Model

Calculations of modal frequency and damping have been compared to the coupled rotor-body experimental model data of Ref. 3 in the Phase 1 and 2 Continuations. Calculations have been made for Case 3 of the original Methodology Assessment as well for configurations not previously examined. The calculation cases are outlined in Table 6. Tabulated parameters in Table 6 include the pitch-lag coupling, θ_ζ, and the elastic coupling, R.

Table 6. – Aeromechanical Stability

CONF. (Ref. 3)	FLAP & LAG STIFFNESSES	θ_ζ	R	METHODOLOGY ASSESSMENT CASES	PHASE 1	PHASE 2	PAGES
1	$\omega_{\beta o} < \omega_{\zeta o}$	0.0	0	1,2	–	–	–
2	$\omega_{\beta o} < \omega_{\zeta o}$	-0.4	0	3	Task 84-2	–	238-249
3	$\omega_{\beta o} < \omega_{\zeta o}$	-0.4	1	–	–	–	–
4	$\omega_{\beta o} \approx \omega_{\zeta o}$	0.0	0	–	–	–	–
5	$\omega_{\beta o} \approx \omega_{\zeta o}$	-0.4	0	–	–	Tasks 86j, 86k	250-267

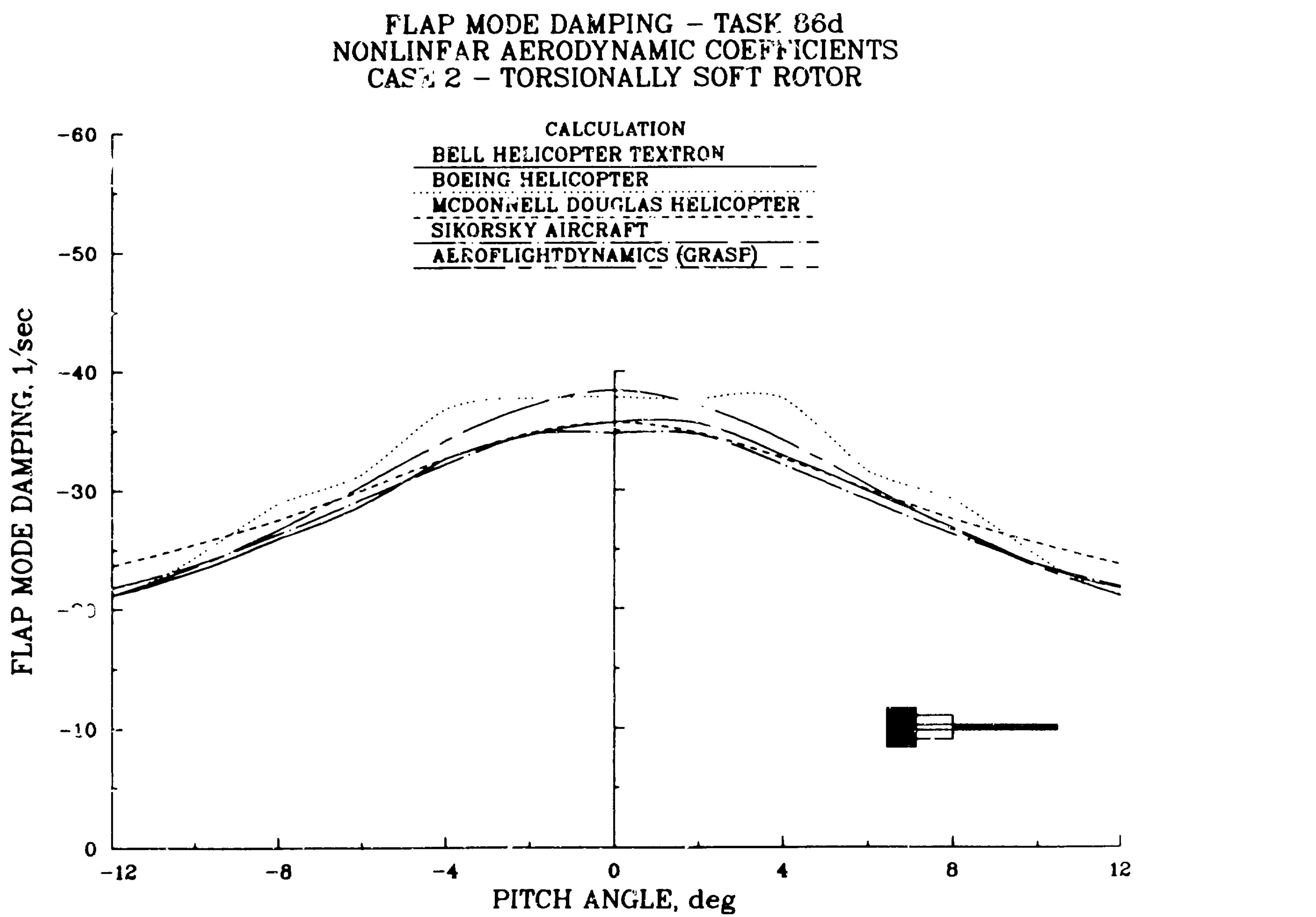
The Task 84-2 calculations were made for a blade pitch angle of 9° and are compared to the data on pages 238 to 249. These results include frequency and damping of several modes in addition to the least stable mode that was presented in the original Methodology Assessment. The Phase 2 Continuation addressed a model configuration having roughly equal flap and lead-lag flexure bending stiffness levels. This "matched stiffness" configuration revealed evidence of a dynamic inflow mode that was later confirmed by analysis (Ref. 4). The Task 86j and 86k calculations were addressed to this matched stiffness configuration and included dynamic inflow models where available. For Task 86j the flap and lead-lag flexure thicknesses were adjusted from the Methodology Assessment model parameters to yield nonrotating flap and lead-lag frequencies of 7.04 and 6.64 Hz respectively. For Task 86k the adjustments were made to provide values of 6.73 and 6.64 Hz for the nonrotating flap and lead-lag frequencies. The Task 86j calculations were run for a pitch angle of 9° and are shown on pages 250 to 258. The Task 86k calculations were run for zero pitch and are shown on pages 259 to 267.

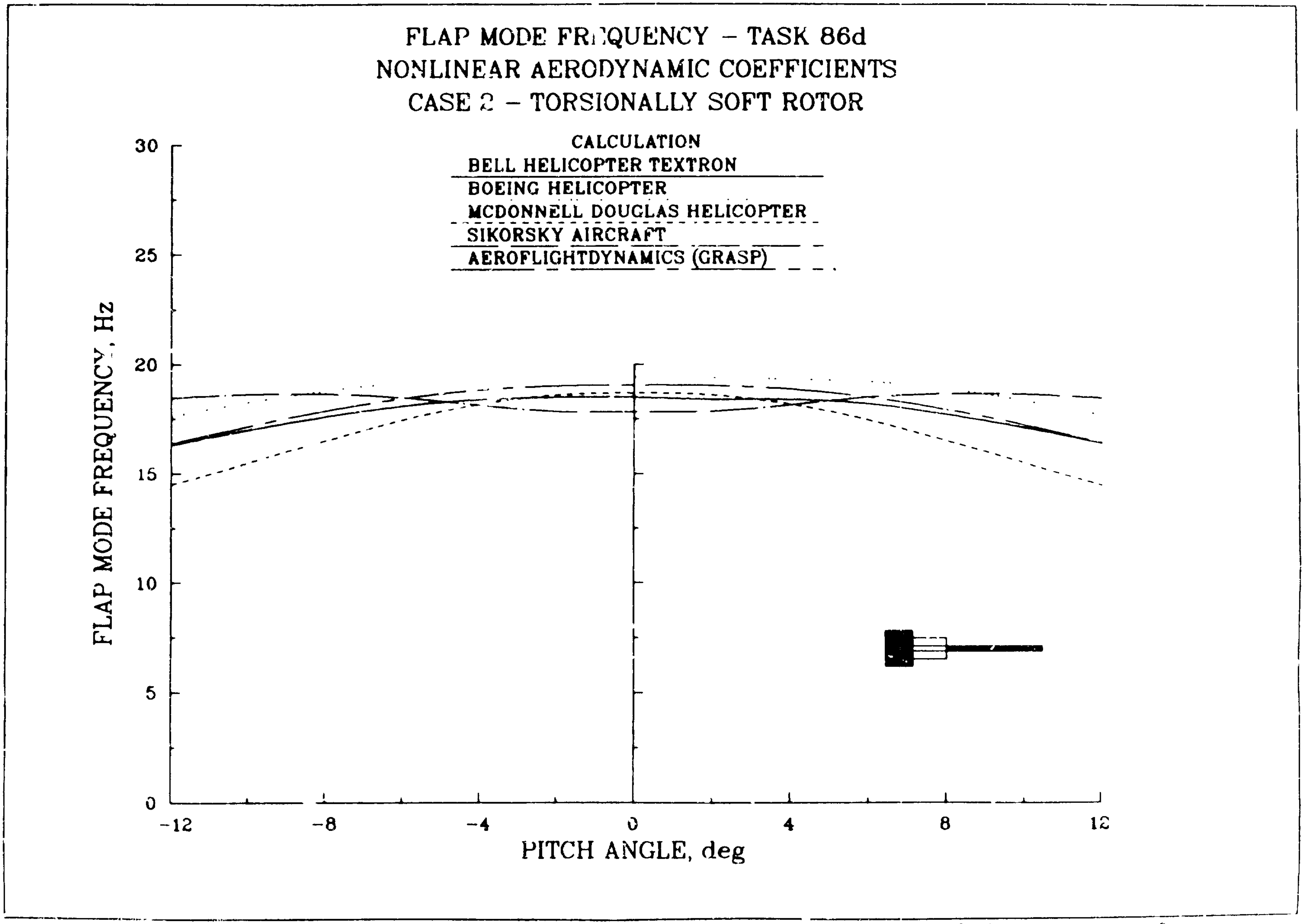
References

1. Michael J. McNulty and William G. Bousman (eds.), "Integrated Technology Rotor Methodology Assessment Workshop," NASA CP-10007, June 1983.
2. A. V. Srinivasan, D. G. Cutts, and H. T. Shu, "An Experimental Investigation of a Torsionally Soft Rotor in Vacuum," NASA CR-177418, July 1986.
3. William G. Bousman, "An Experimental Investigation of the Effects of Aeroelastic Couplings on Aeromechanical Stability of a Hingeless Rotor Helicopter," *Journal of the American Helicopter Society*, Vol. 26, No. 1, Jan. 1981, pp. 46-54.
4. W. Johnson, "Influence of Unsteady Aerodynamics on Hingeless Rotor Ground Resonance," *J. Aircraft*, Vol. 29, No. 8, Aug. 1982, pp. 668-673.

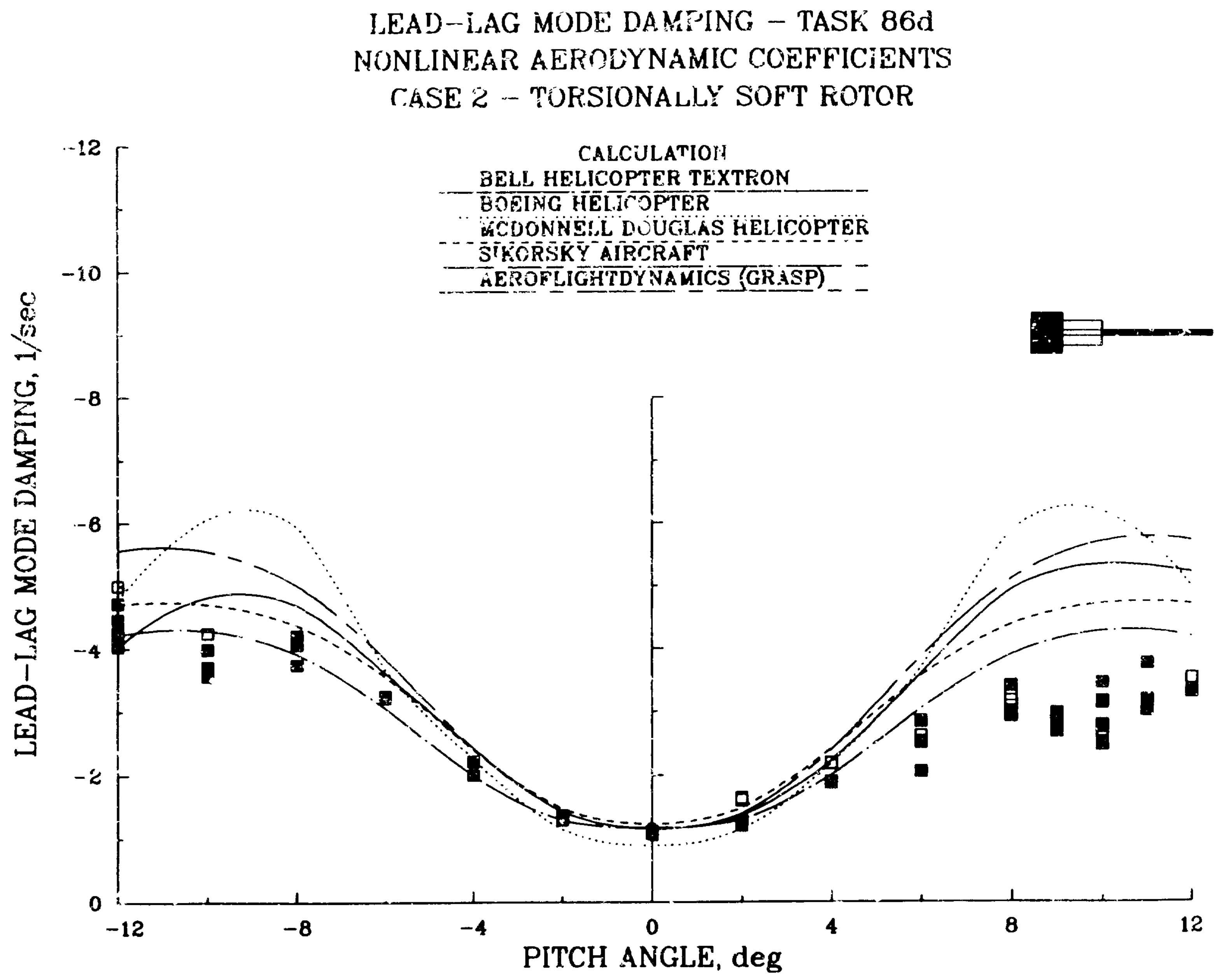
APPENDIX

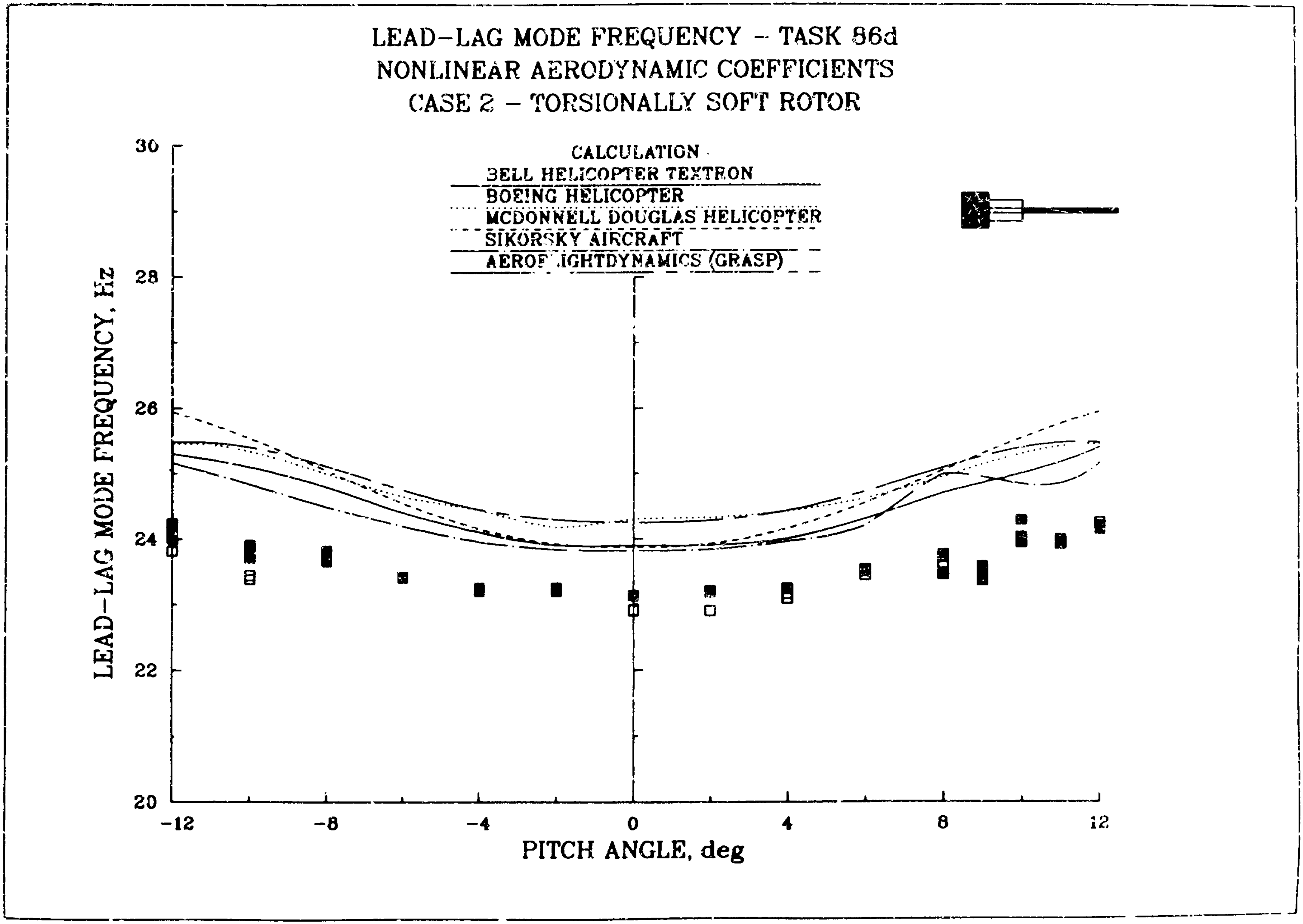
ROTOR CONFIGURATION ANALYSIS DATA


FLAP MODE DAMPING – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
FLAP MODE DAMPING, 1/sec
-60
-50
-40
-30
-10
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

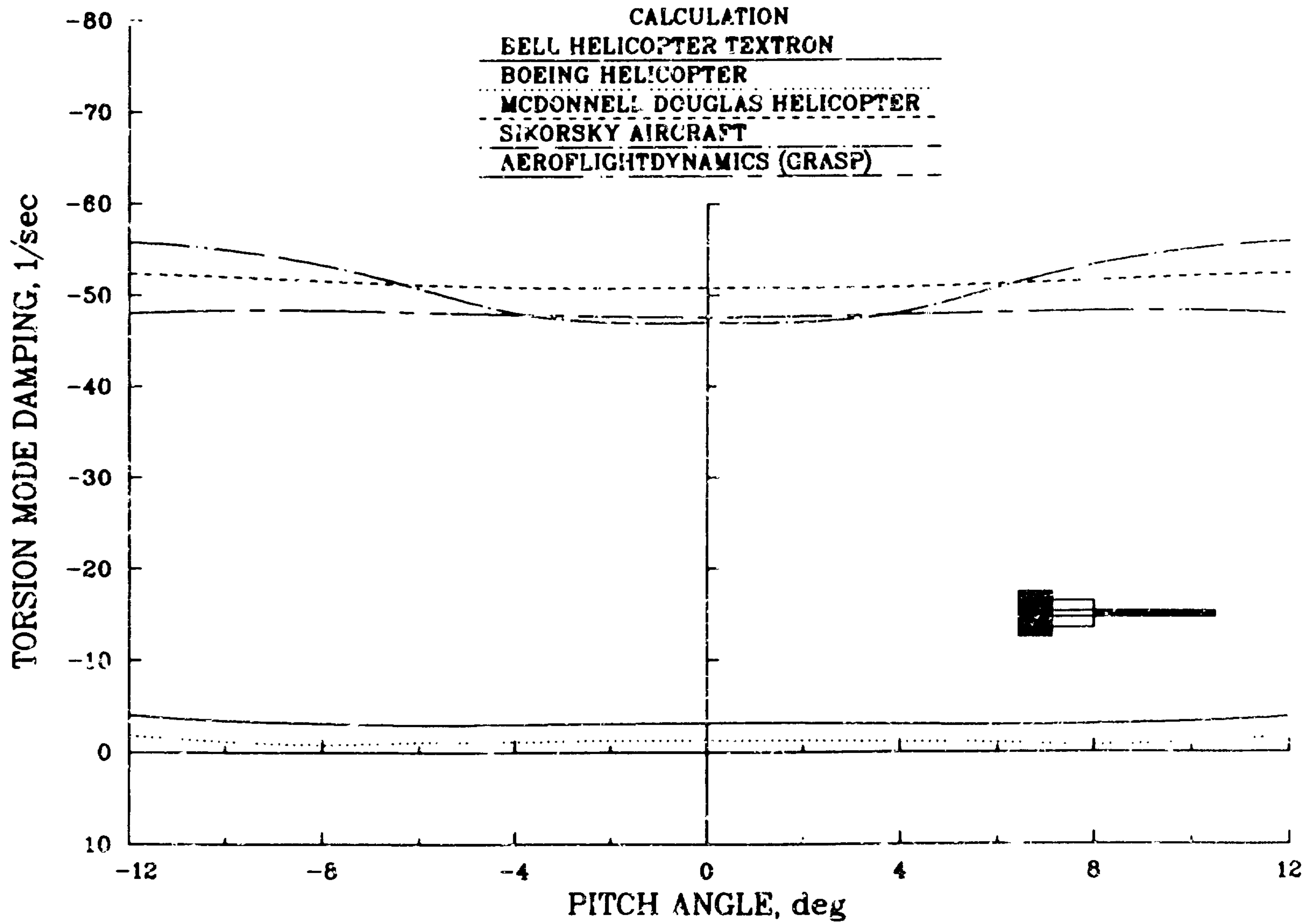


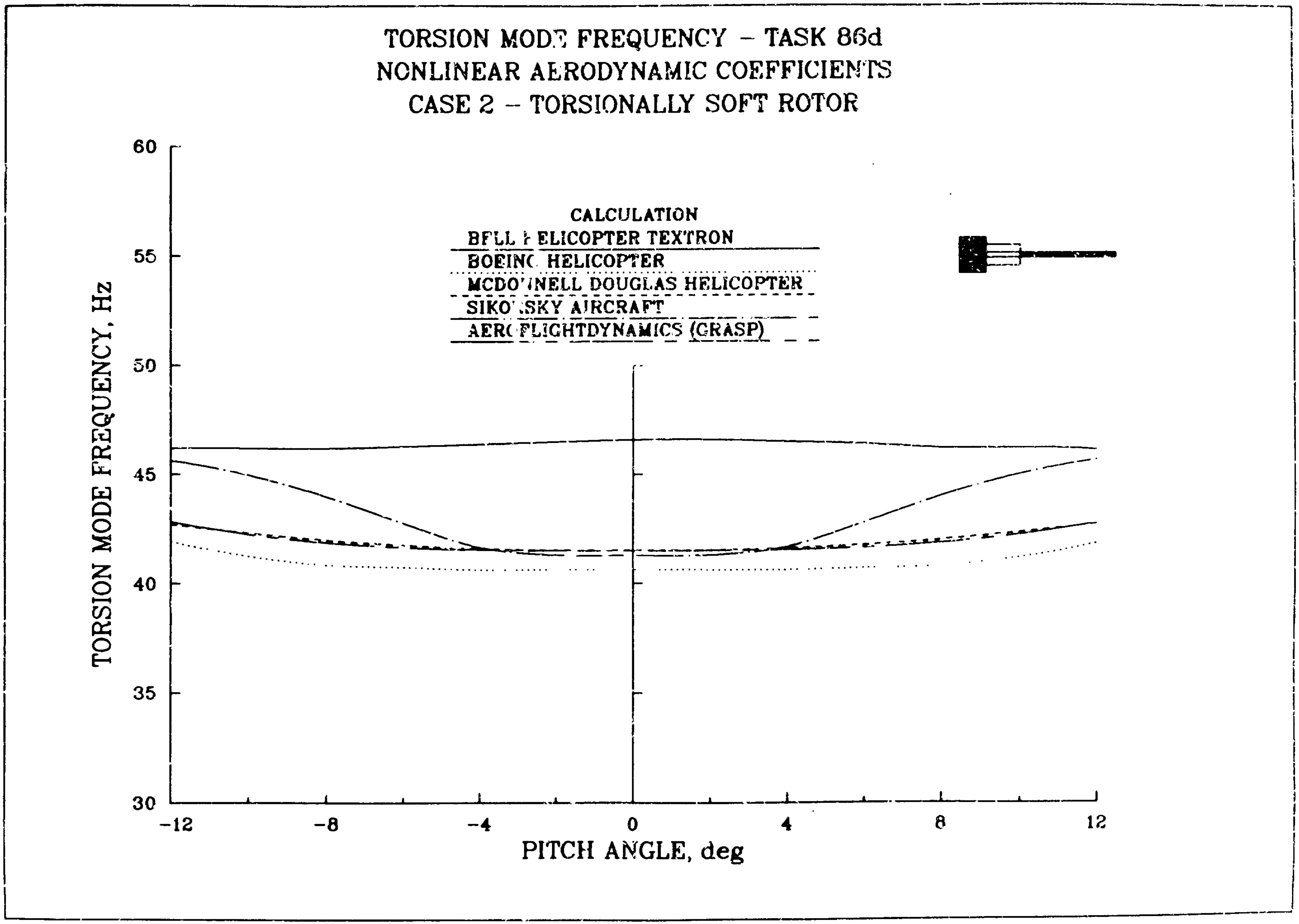
FLAP MODE FREQUENCY – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
FLAP MODE FREQUENCY, Hz
0
5
10
15
20
25
30
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


LEAD–LAG MODE DAMPING – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
LEAD–LAG MODE DAMPING, 1/sec
-12
-10
-8
-6
-4
-2
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

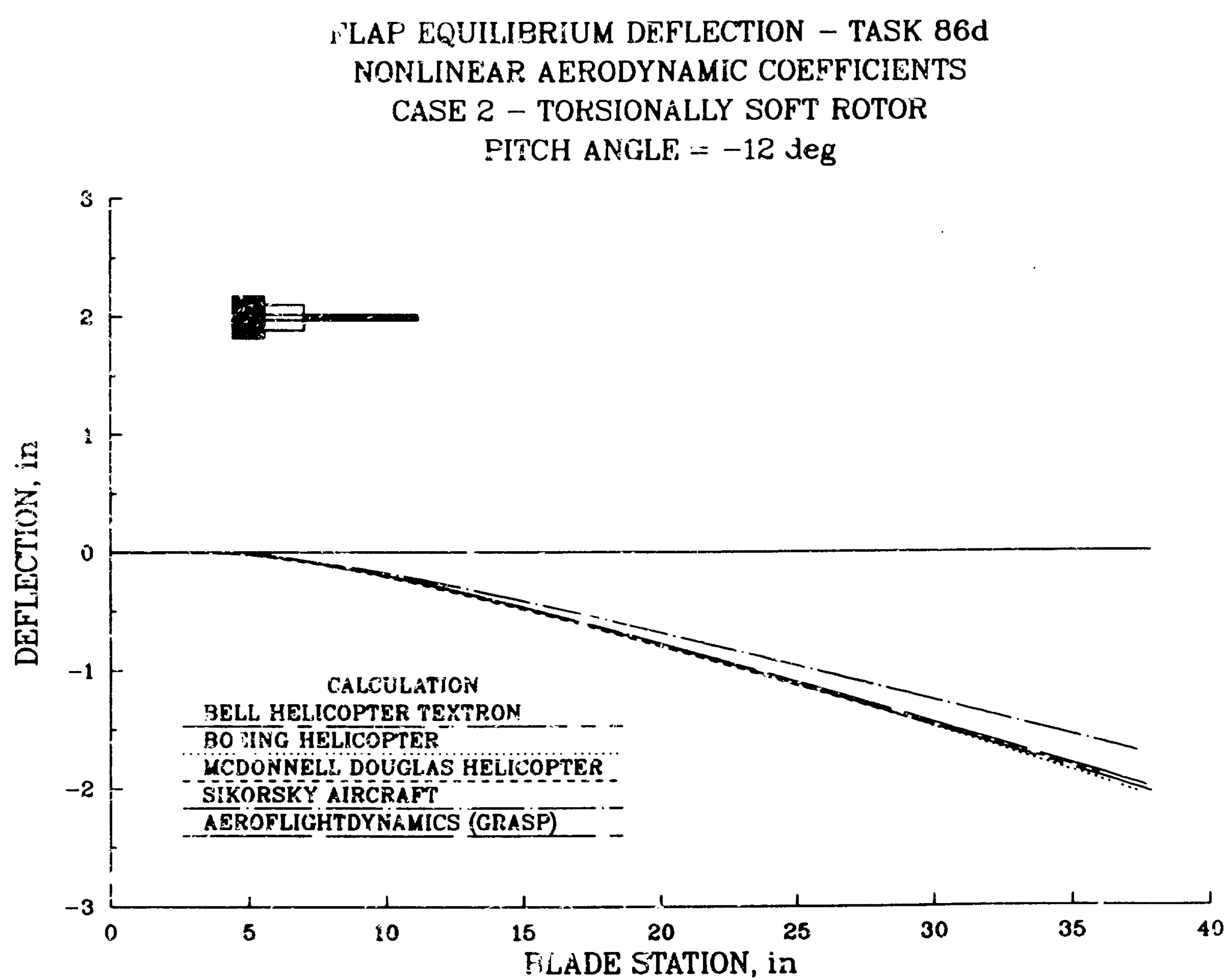

LEAD–LAG MODE FREQUENCY – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
LEAD–LAG MODE FREQUENCY, Hz
30
28
26
24
22
20
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

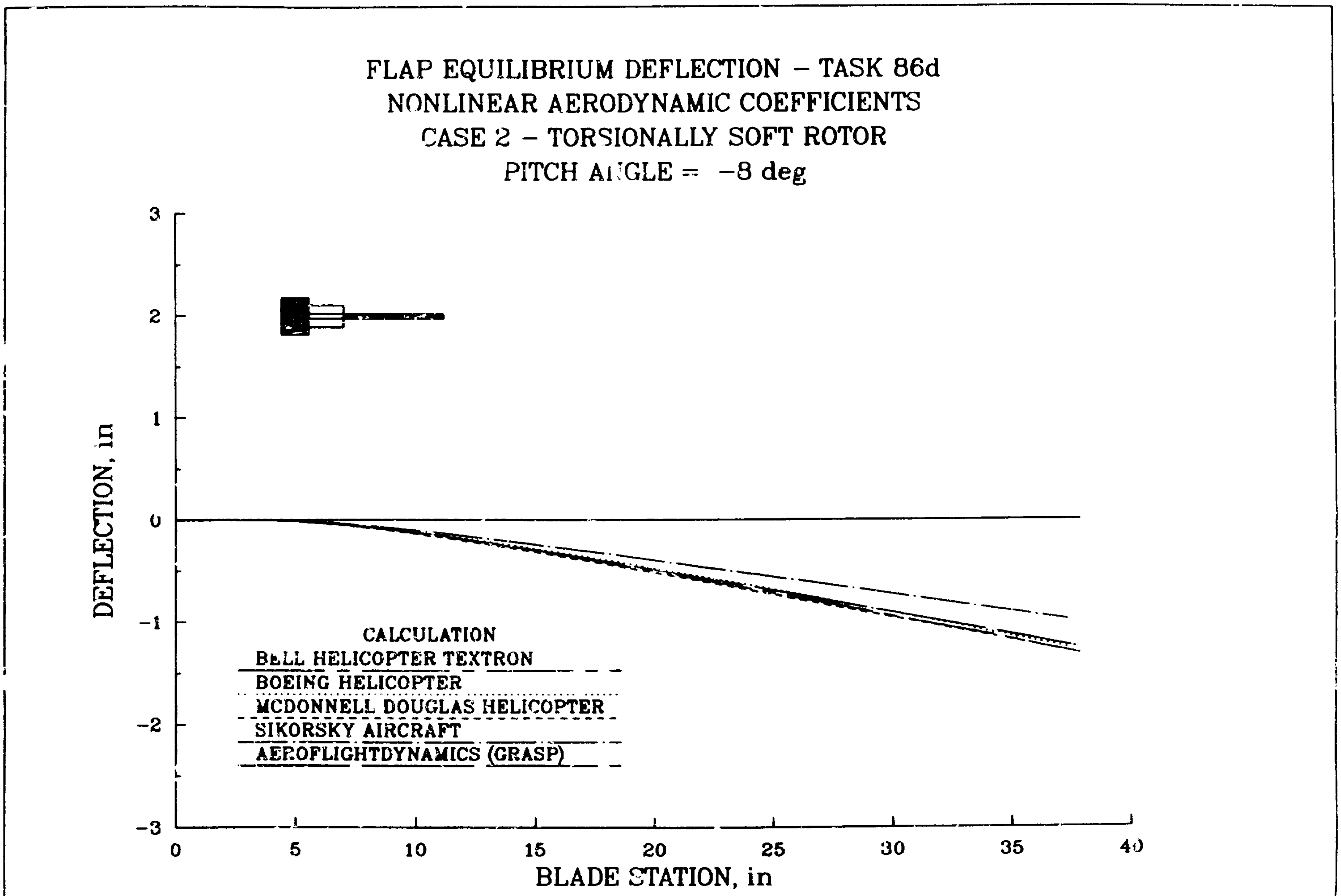
TORSION MODE DAMPING – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR

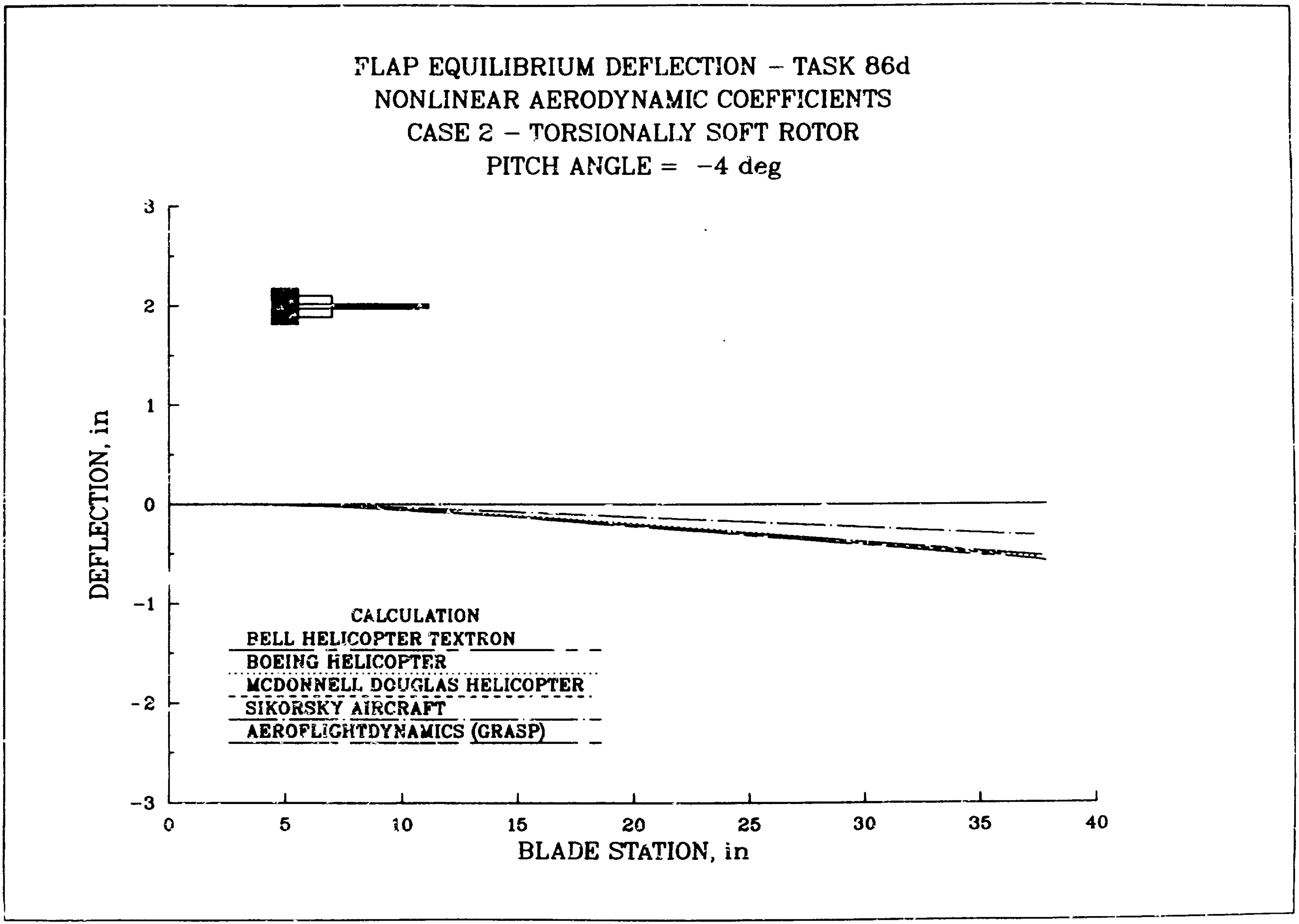




TORSION MODE FREQUENCY – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
TORSION MODE FREQUENCY, Hz
60
55
50
45
40
35
30
–12
–8
–4
0
4
8
12
PITCH ANGLE, deg


FLAP EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg
DEFLECTION, in
3
2
1
0
–1
–2
–3
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in


FLAP EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg
DEFLECTION, in
3
2
1
0
−1
−2
−3
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in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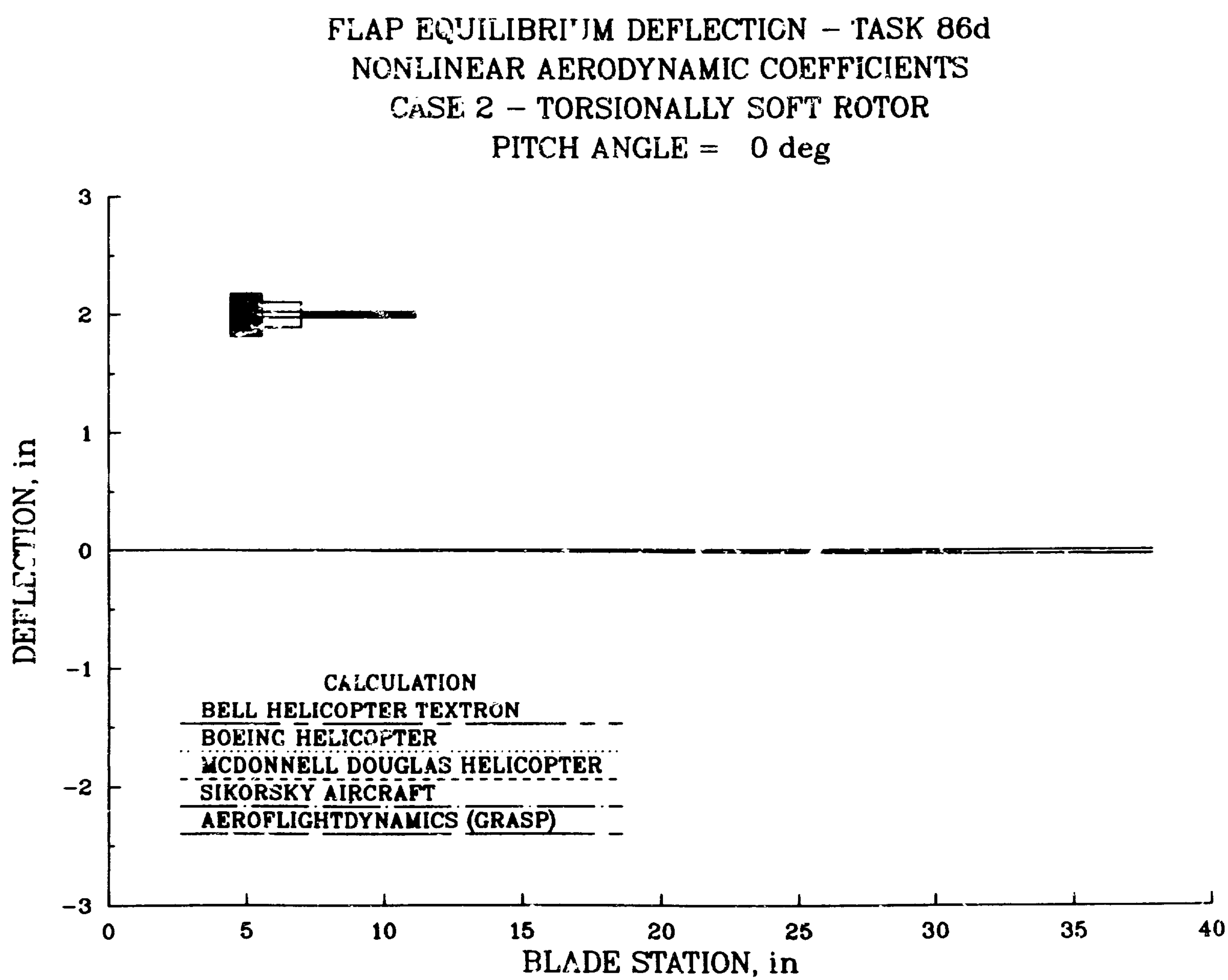
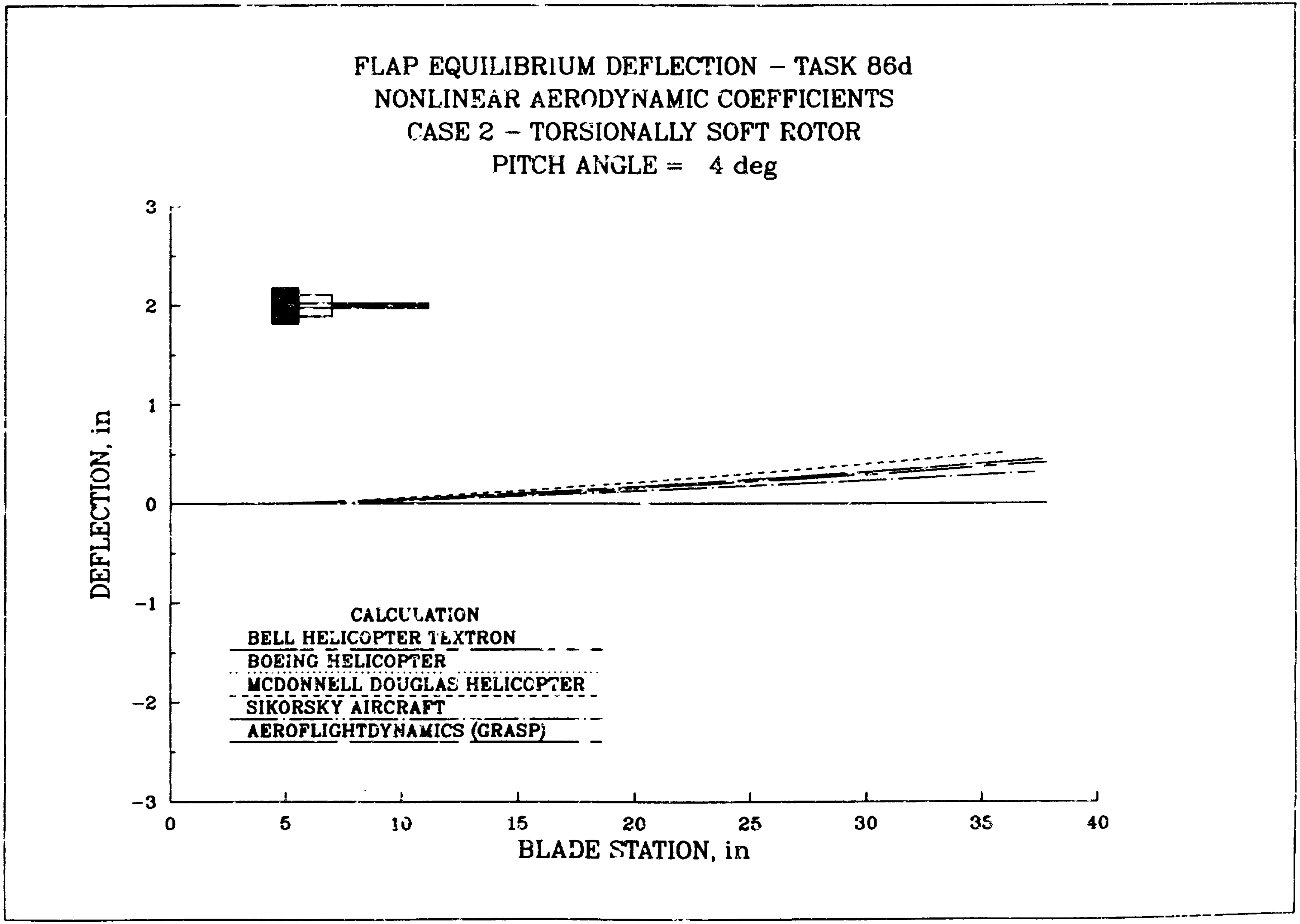
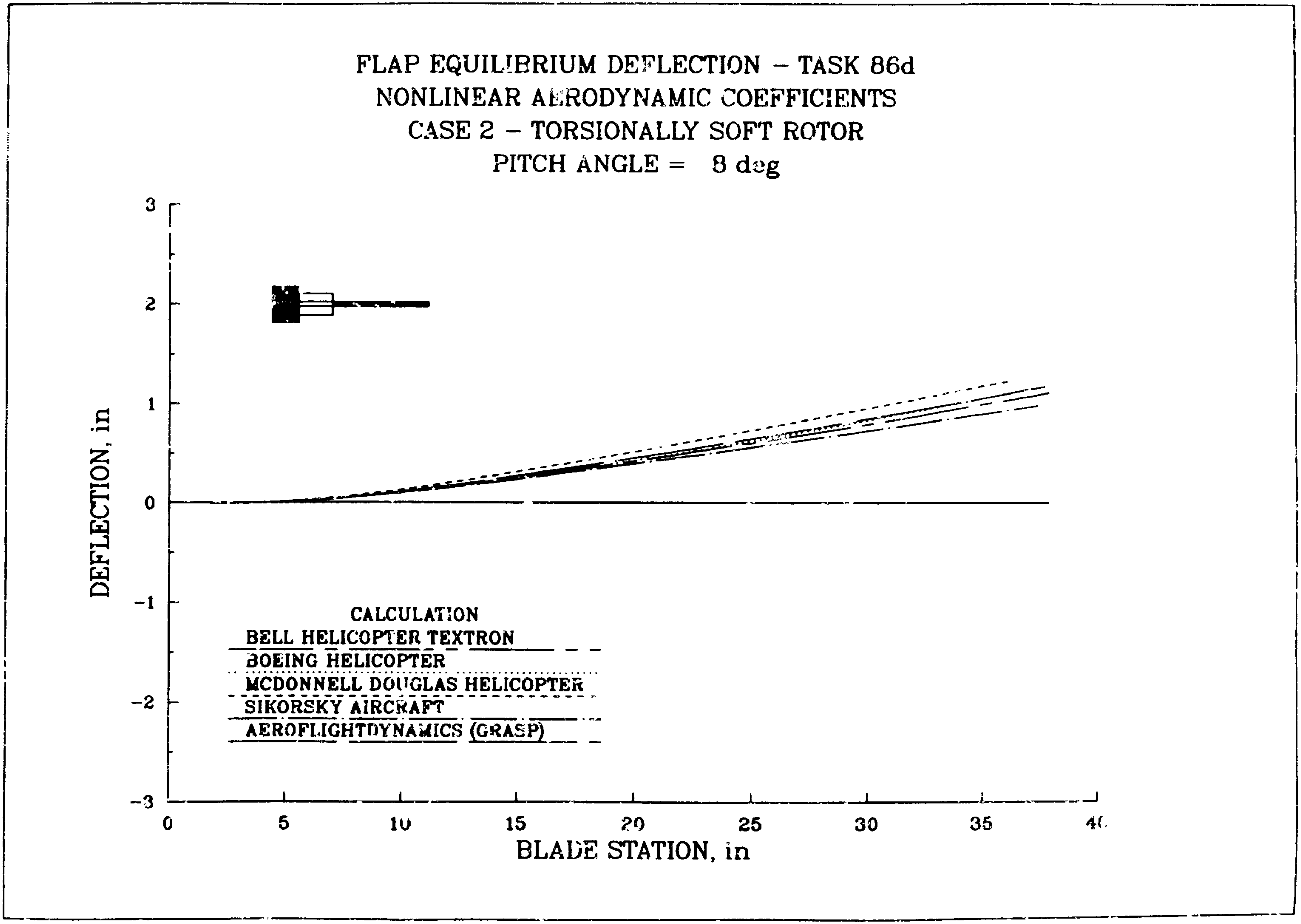
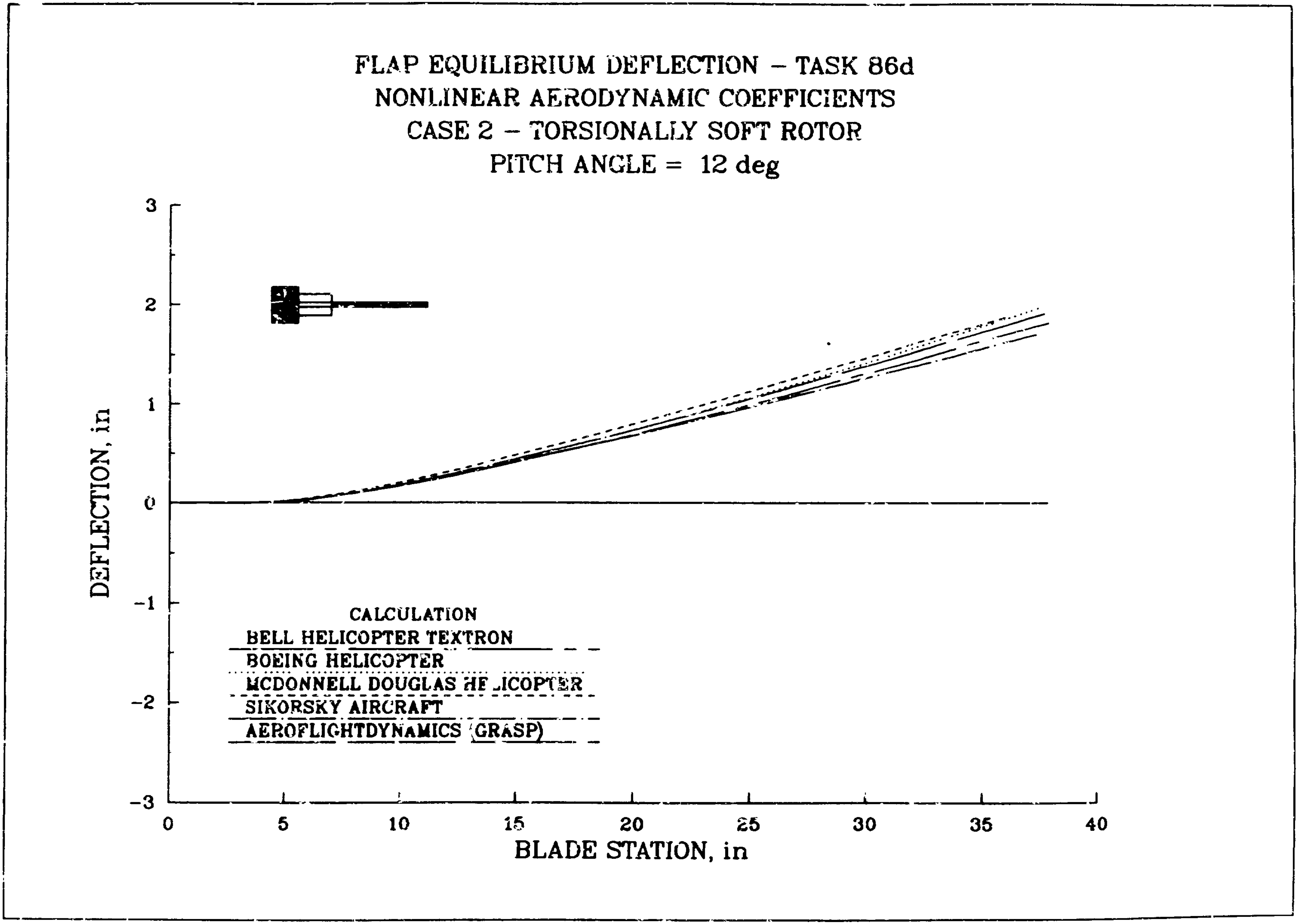
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −4 deg
DEFLECTION, in
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)


FLAP EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
DEFLECTION, in
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)


FLAP EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
DEFLECTION, in
3
2
1
0
−1
−2
−3
BLADE STATION, in
0
5
10
15
20
25
30
35
40
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)


FLAP EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
DEFLECTION, in
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)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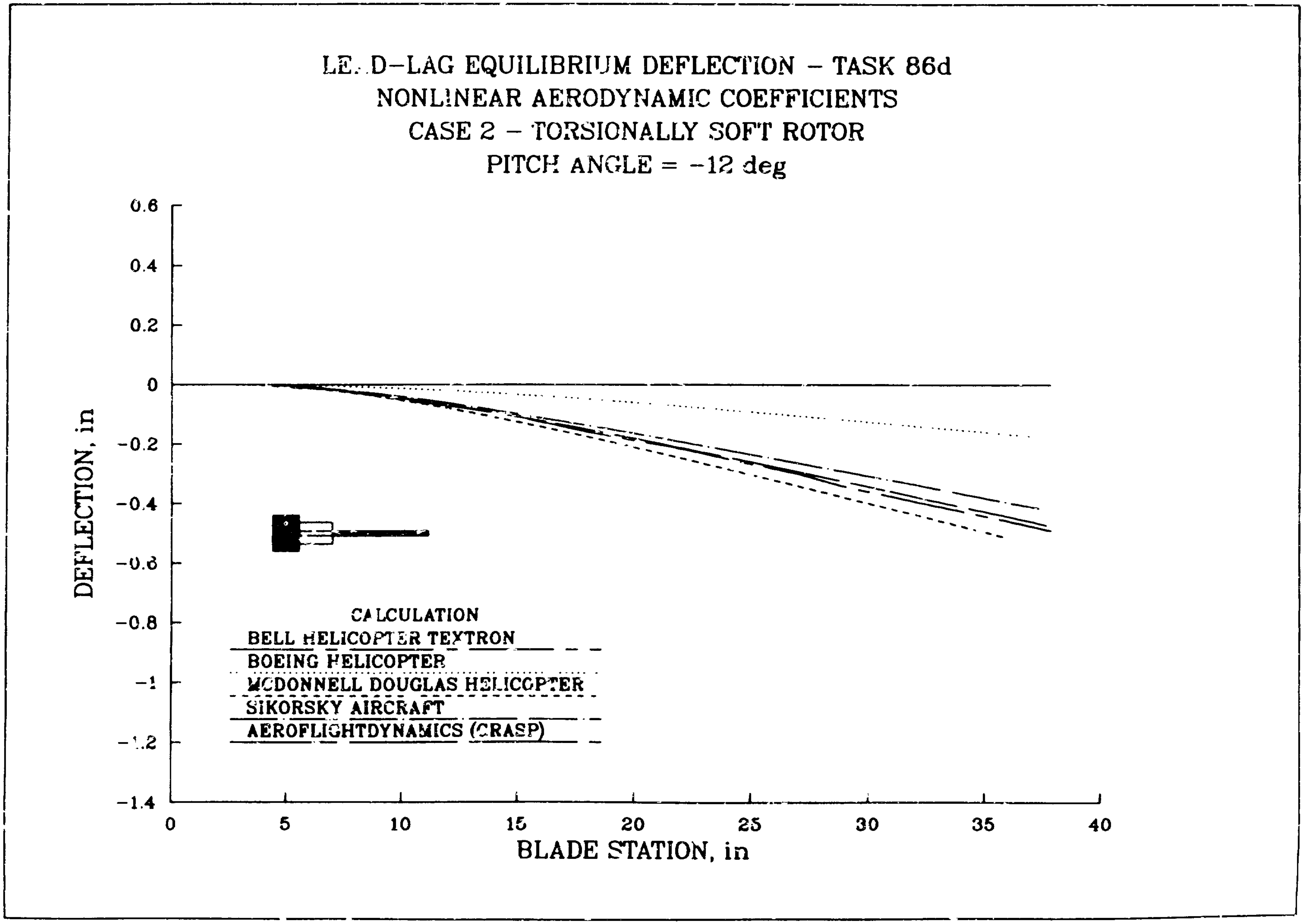
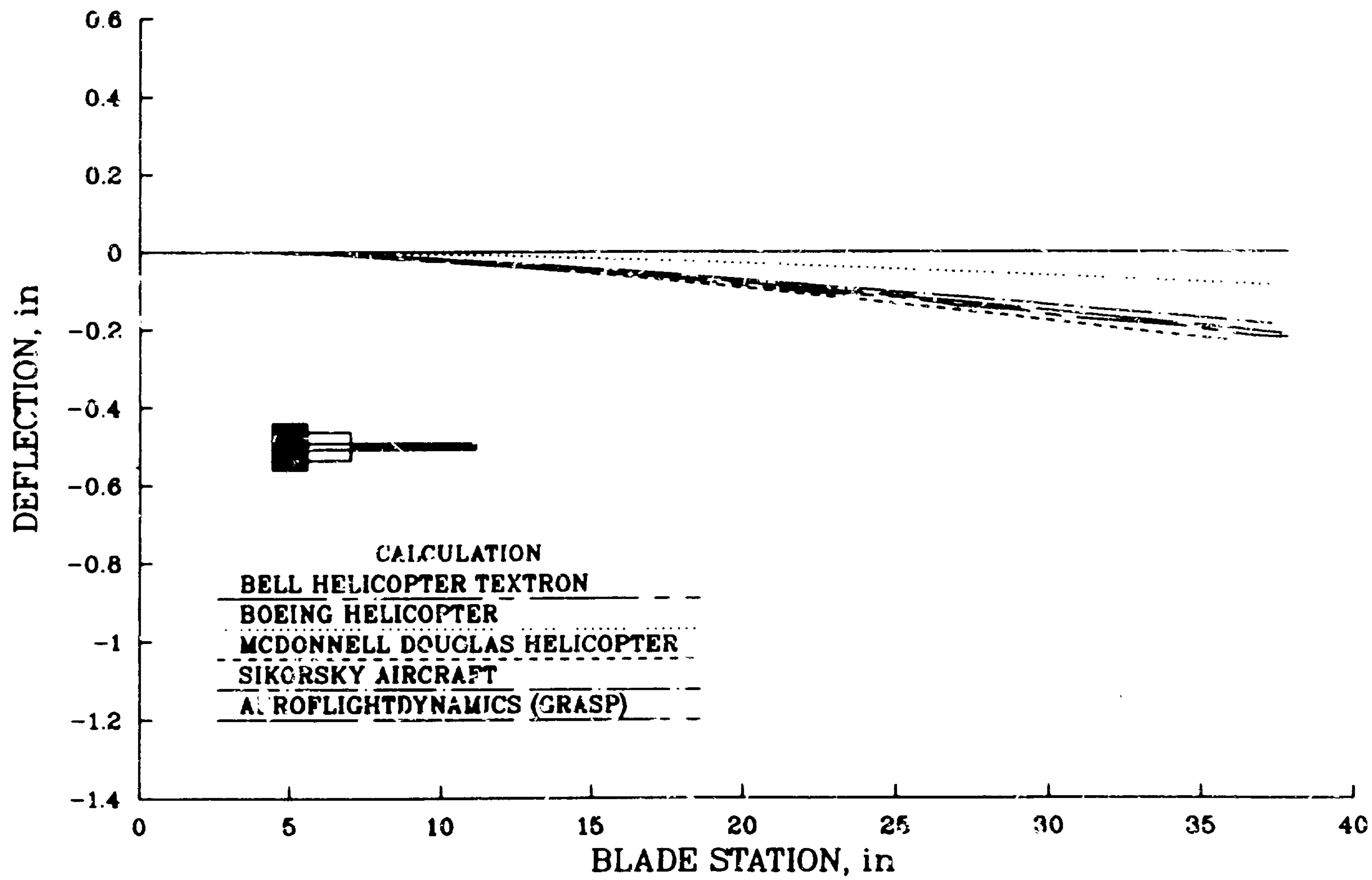
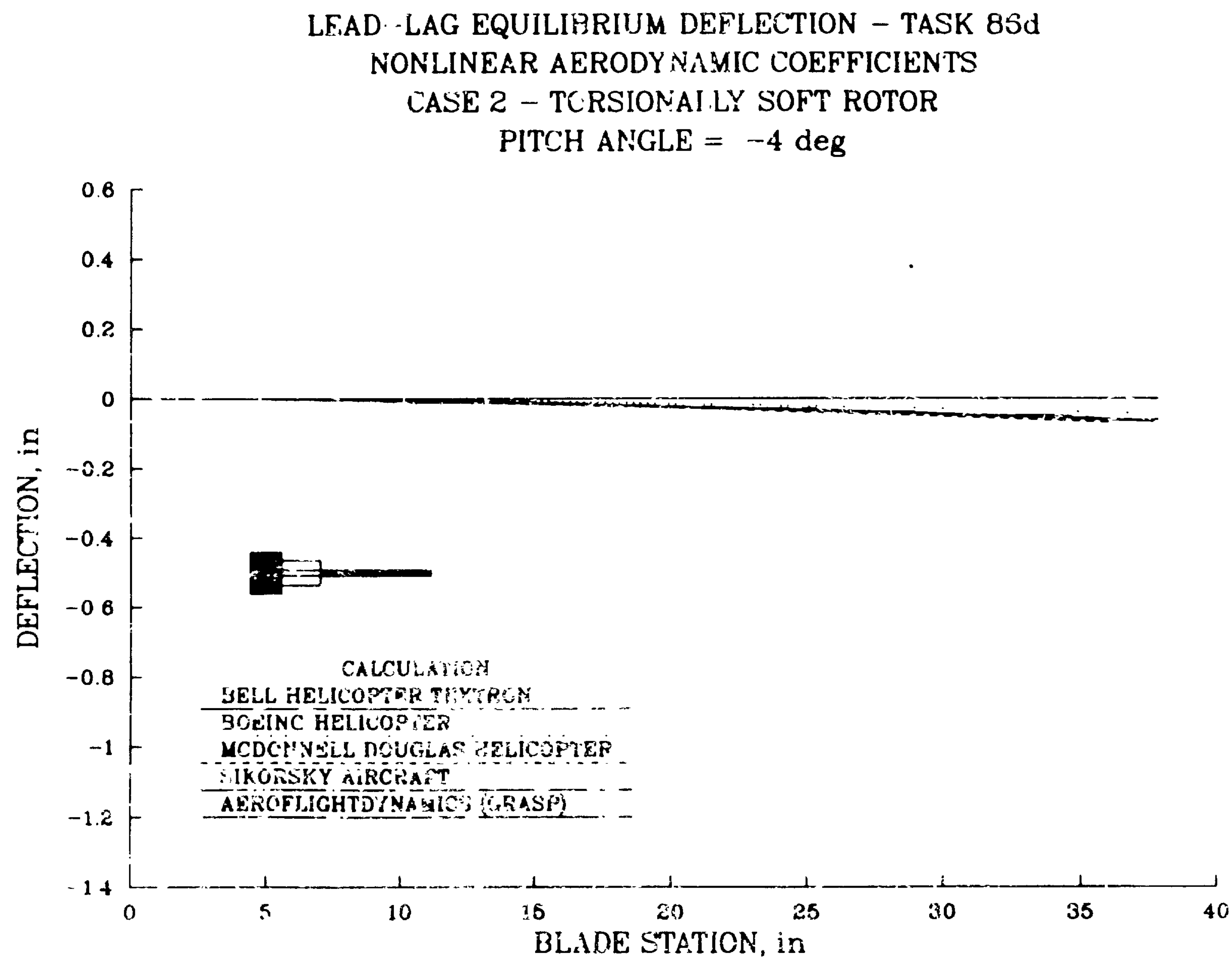
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
DEFLECTION, in
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40

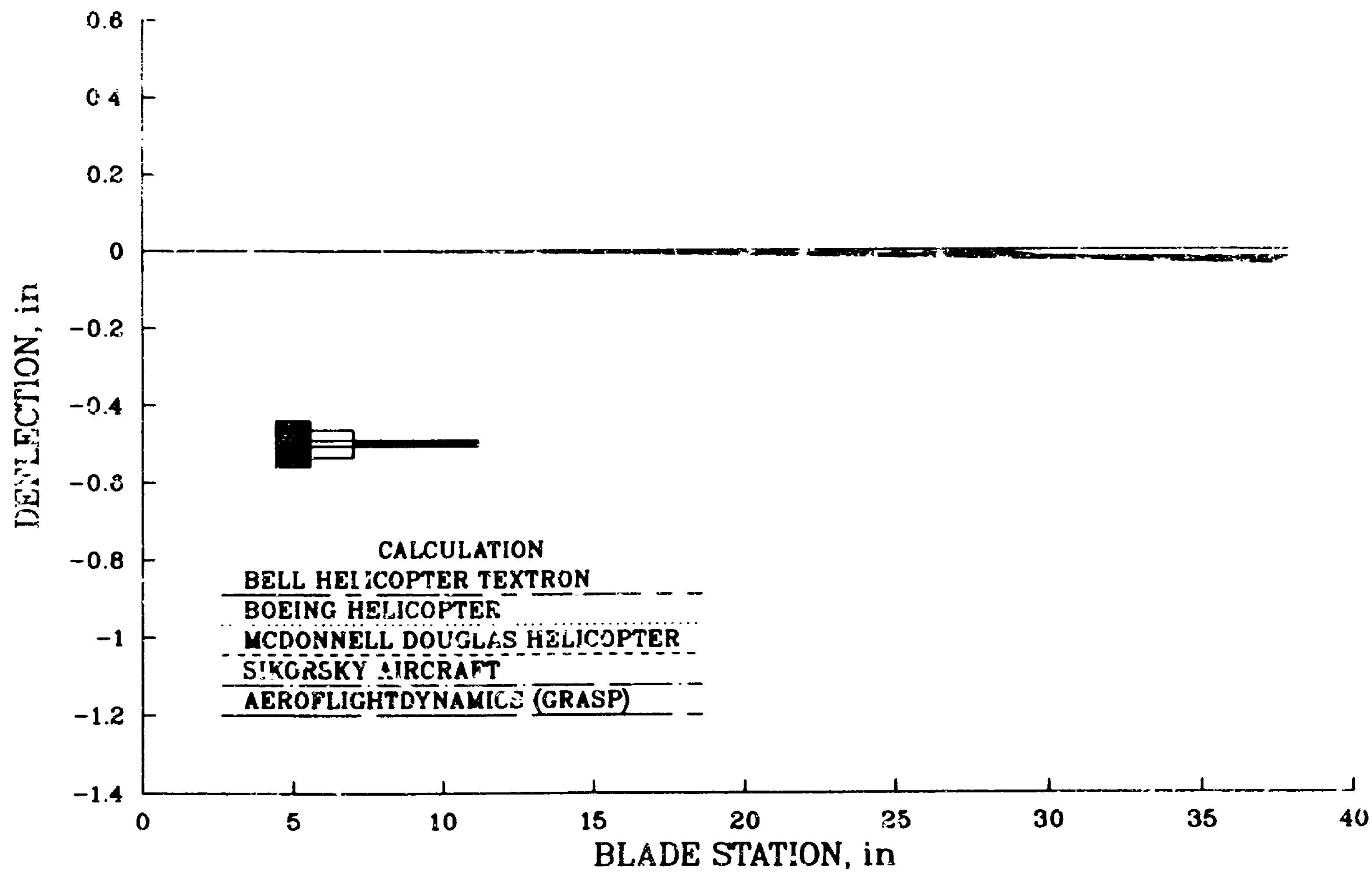

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
DEFLECTION, in
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
BLADE STATION, in
0
5
10
15
20
25
30
35
40
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (CRASP)

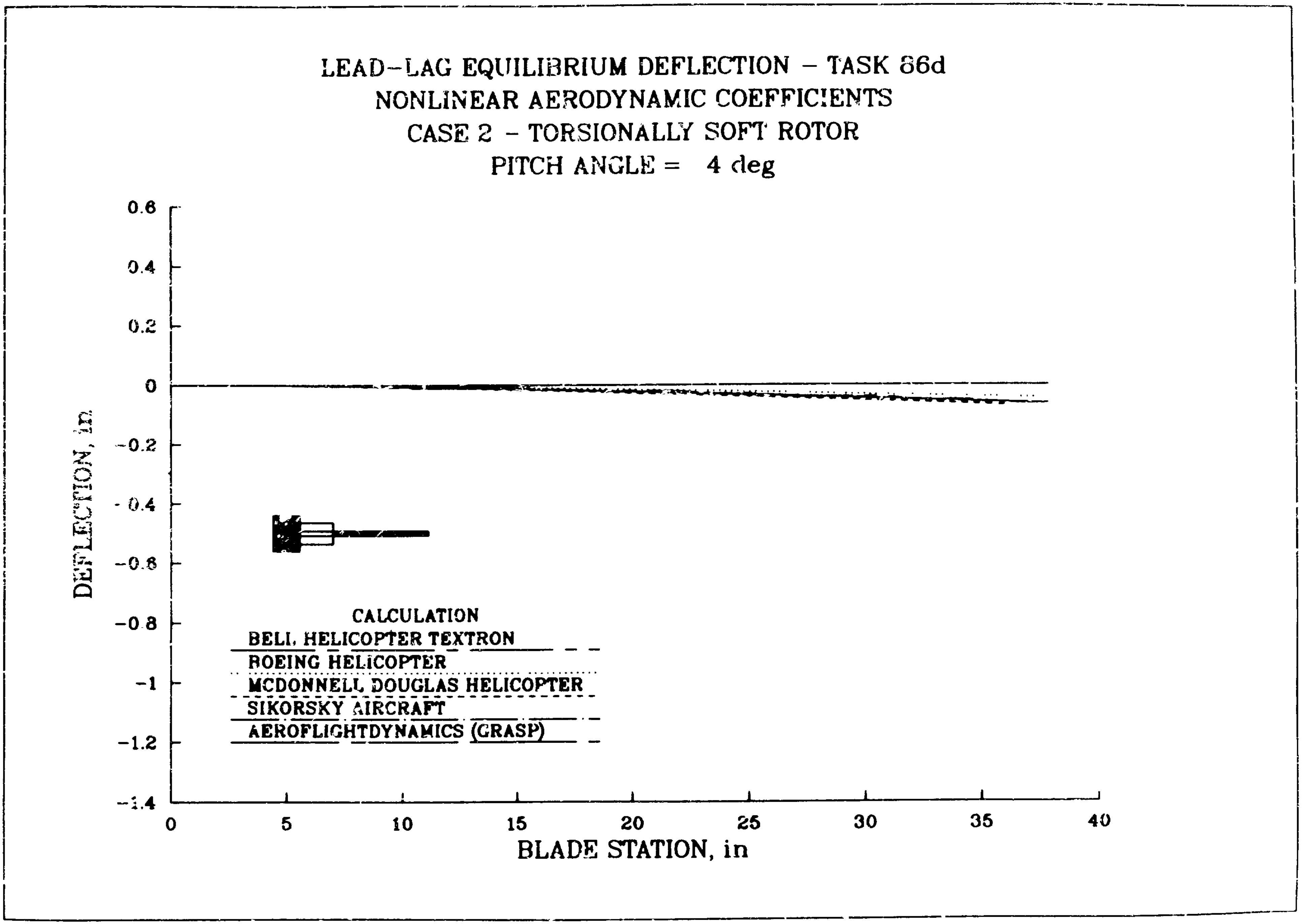
LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg

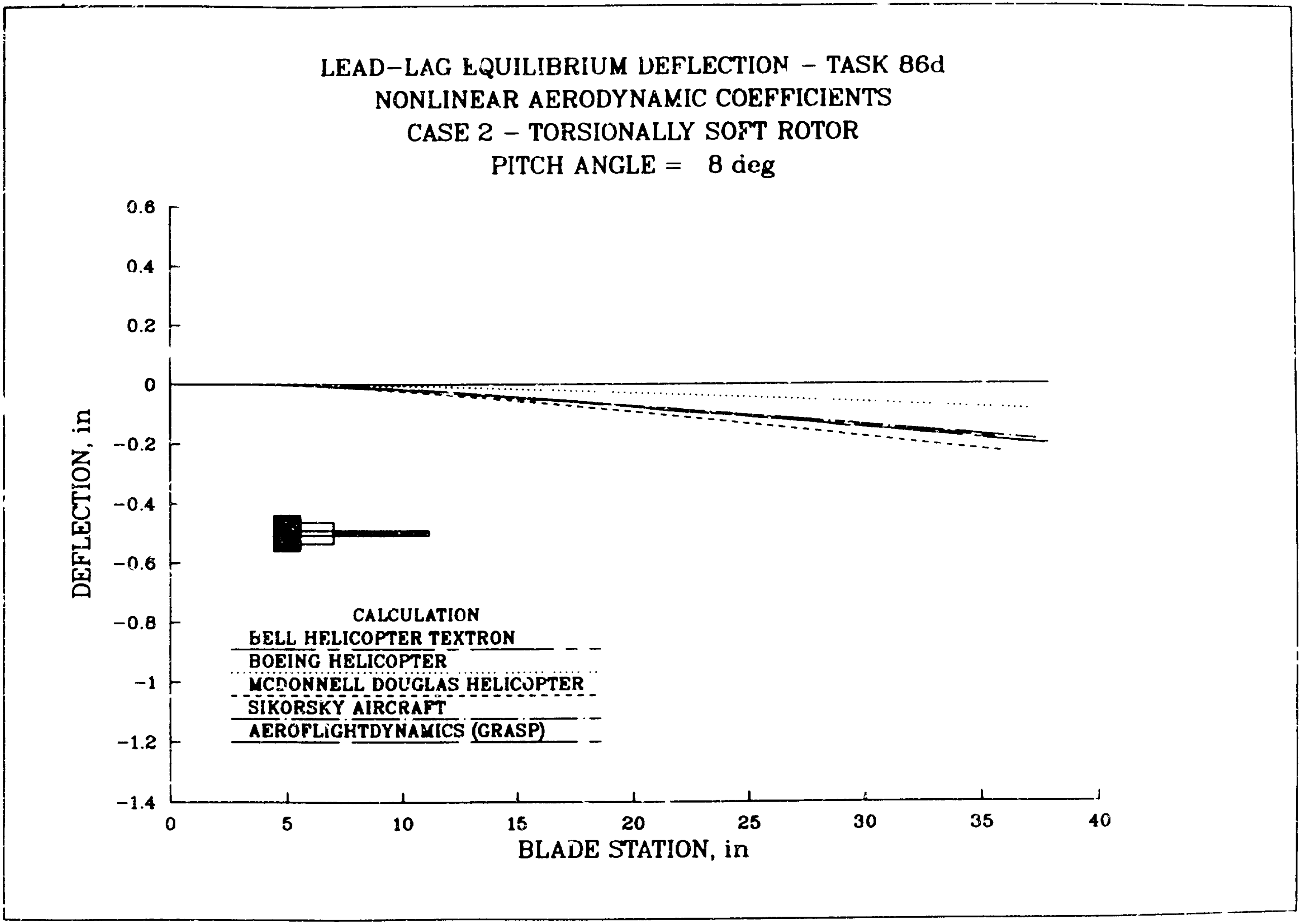



LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 85d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −4 deg
DEFLECTION, in
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

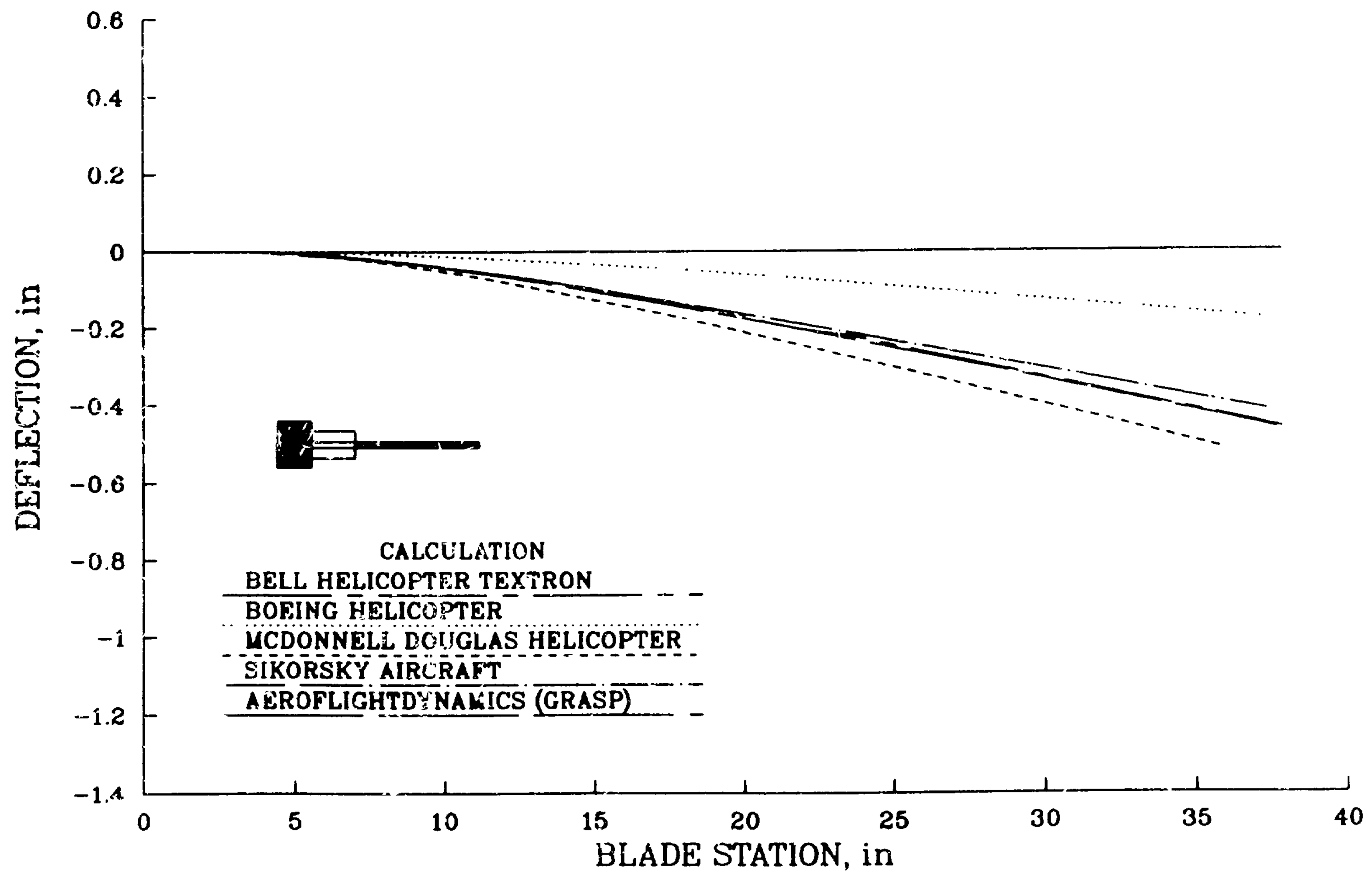
LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg

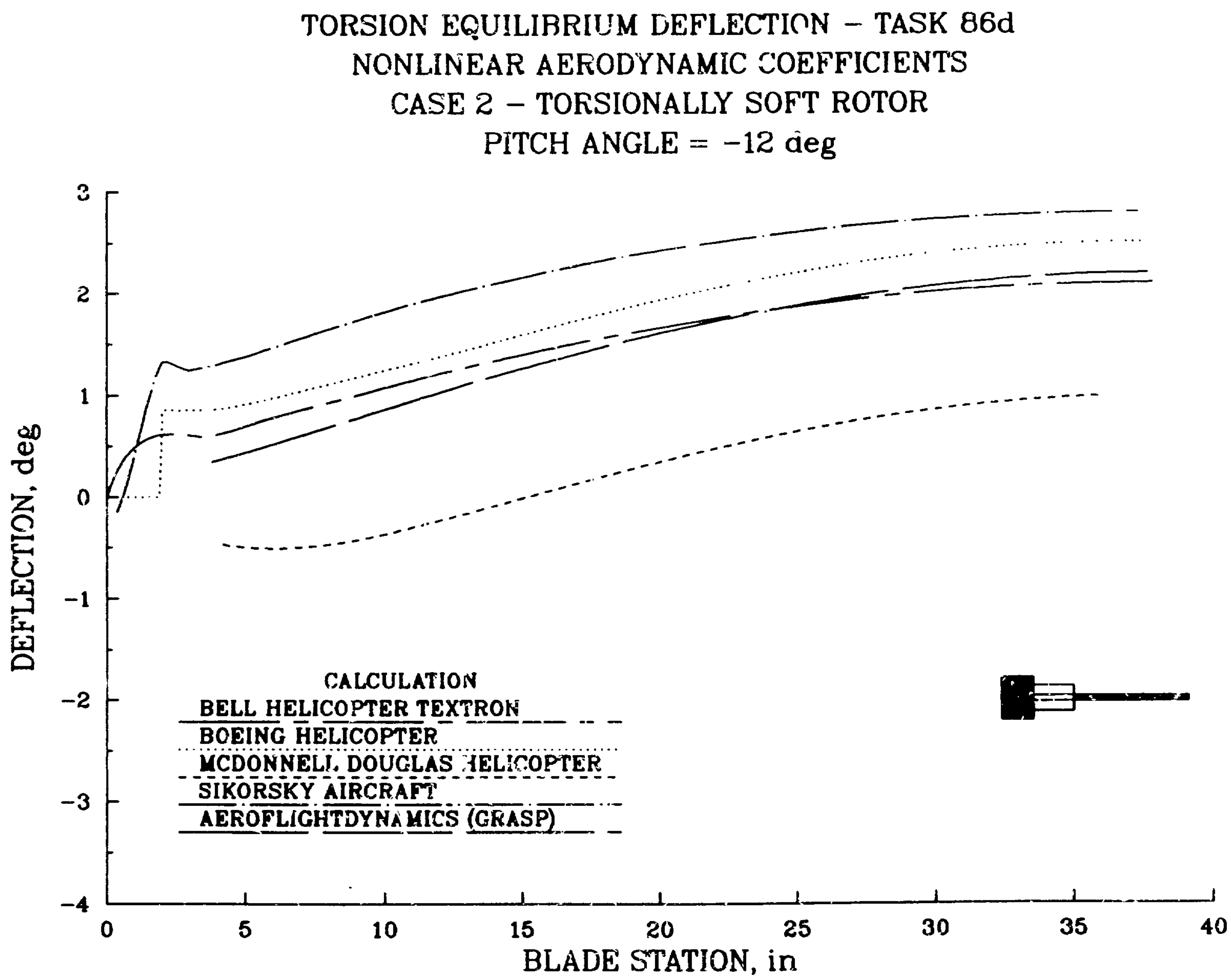


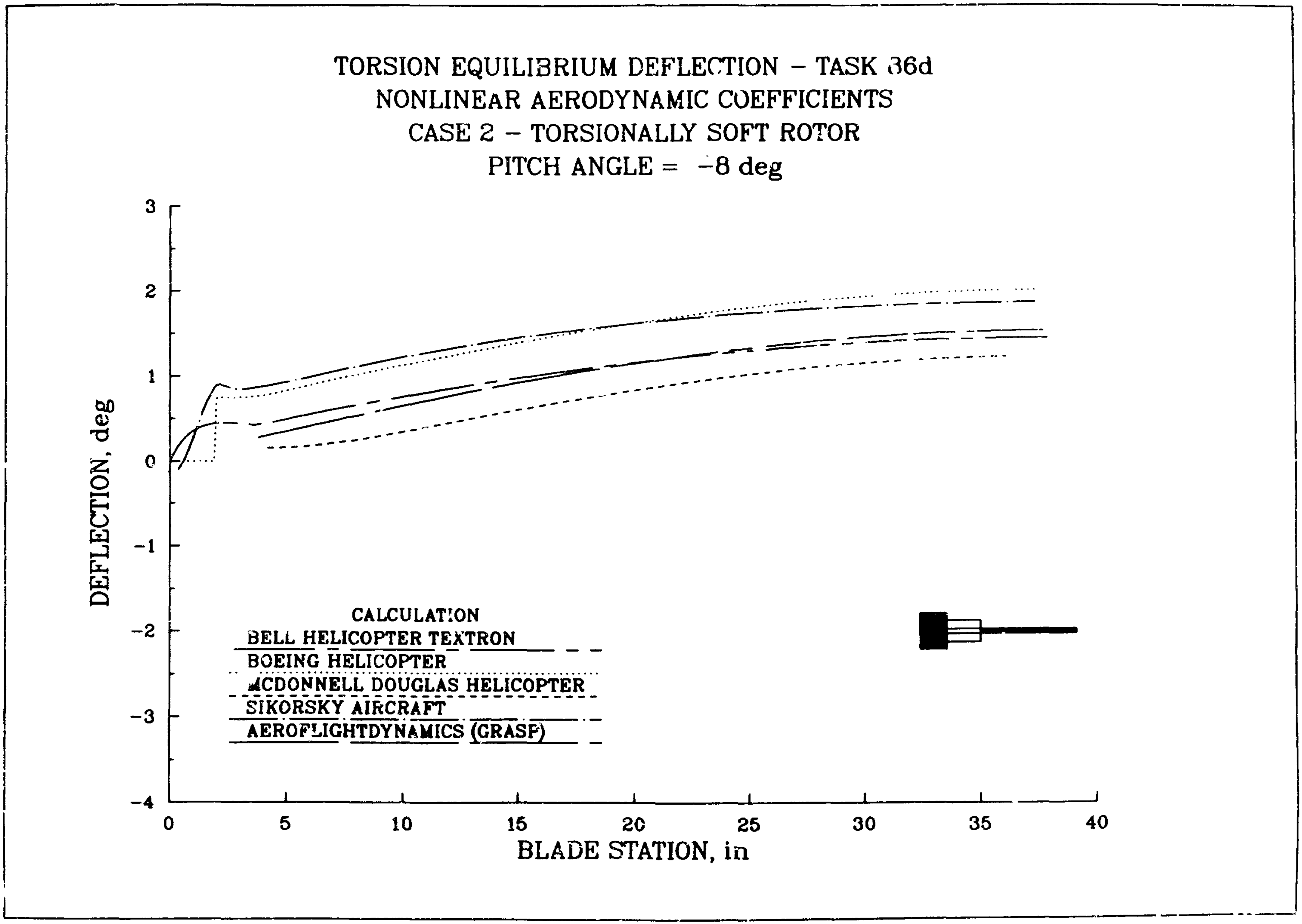

LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
DEFLECTION, in
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in

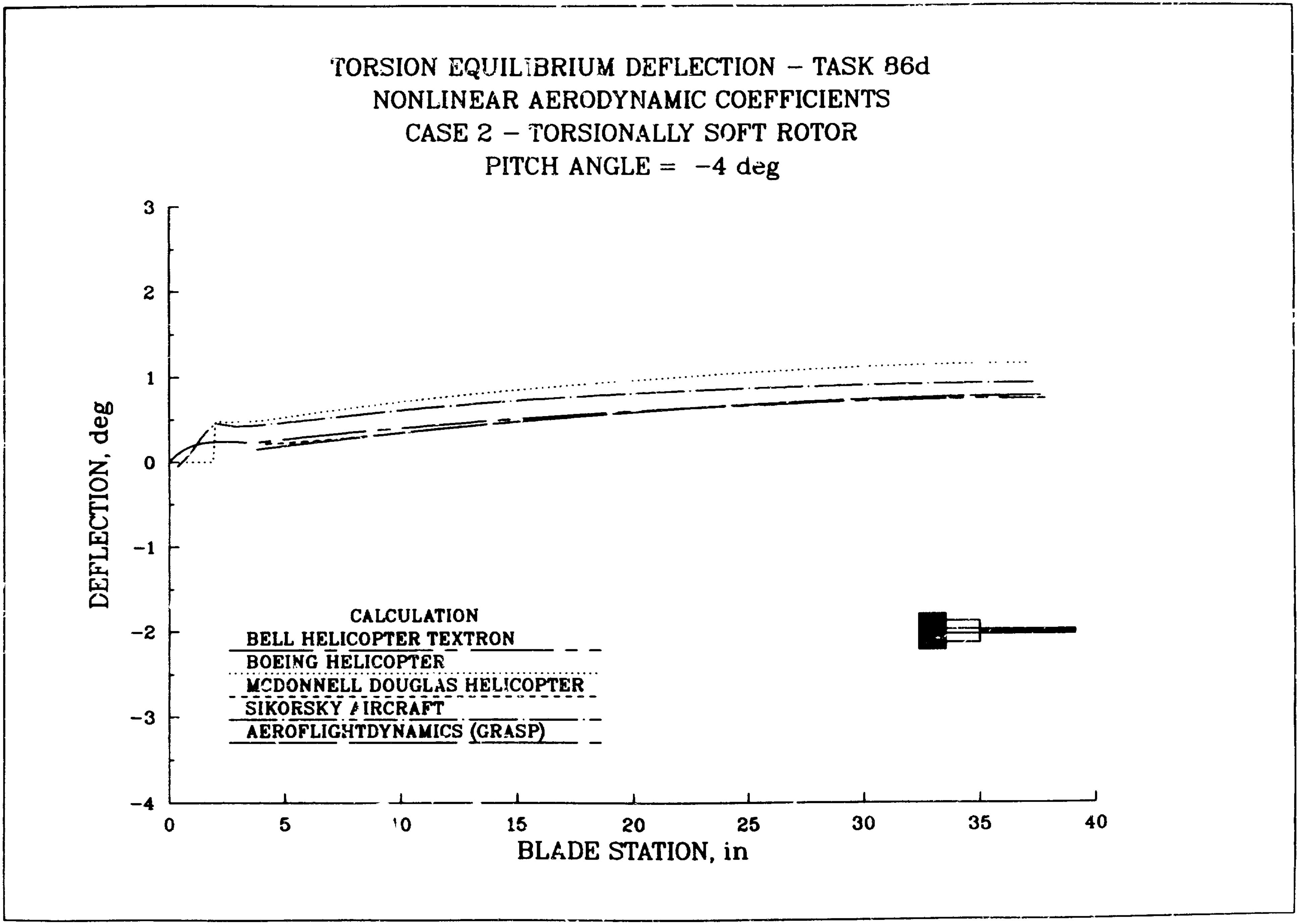

LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
DEFLECTION, in
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
BLADE STATION, in
0
5
10
15
20
25
30
35
40
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 36d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg

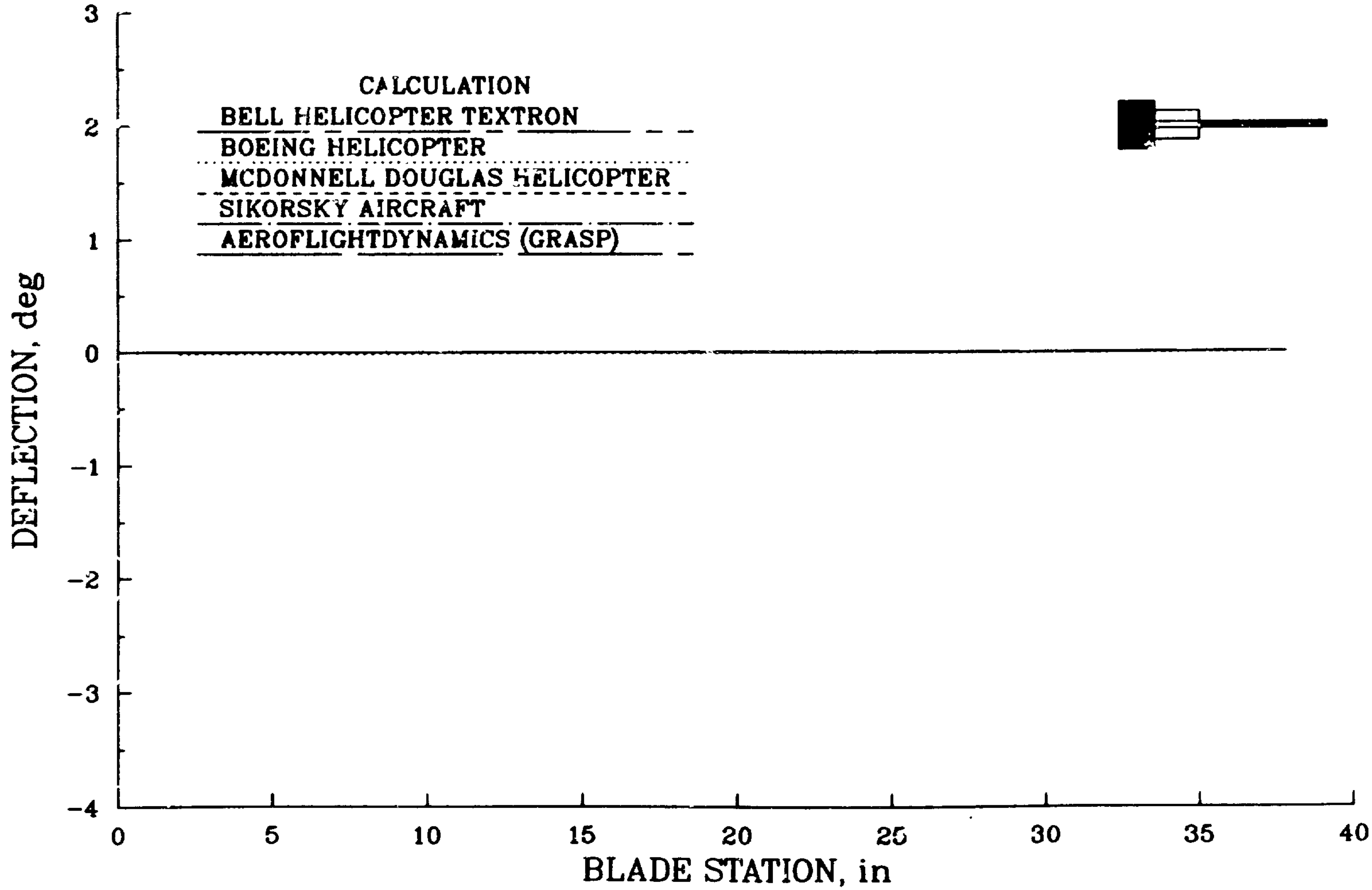



TORSION EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
DEFLECTION, deg
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

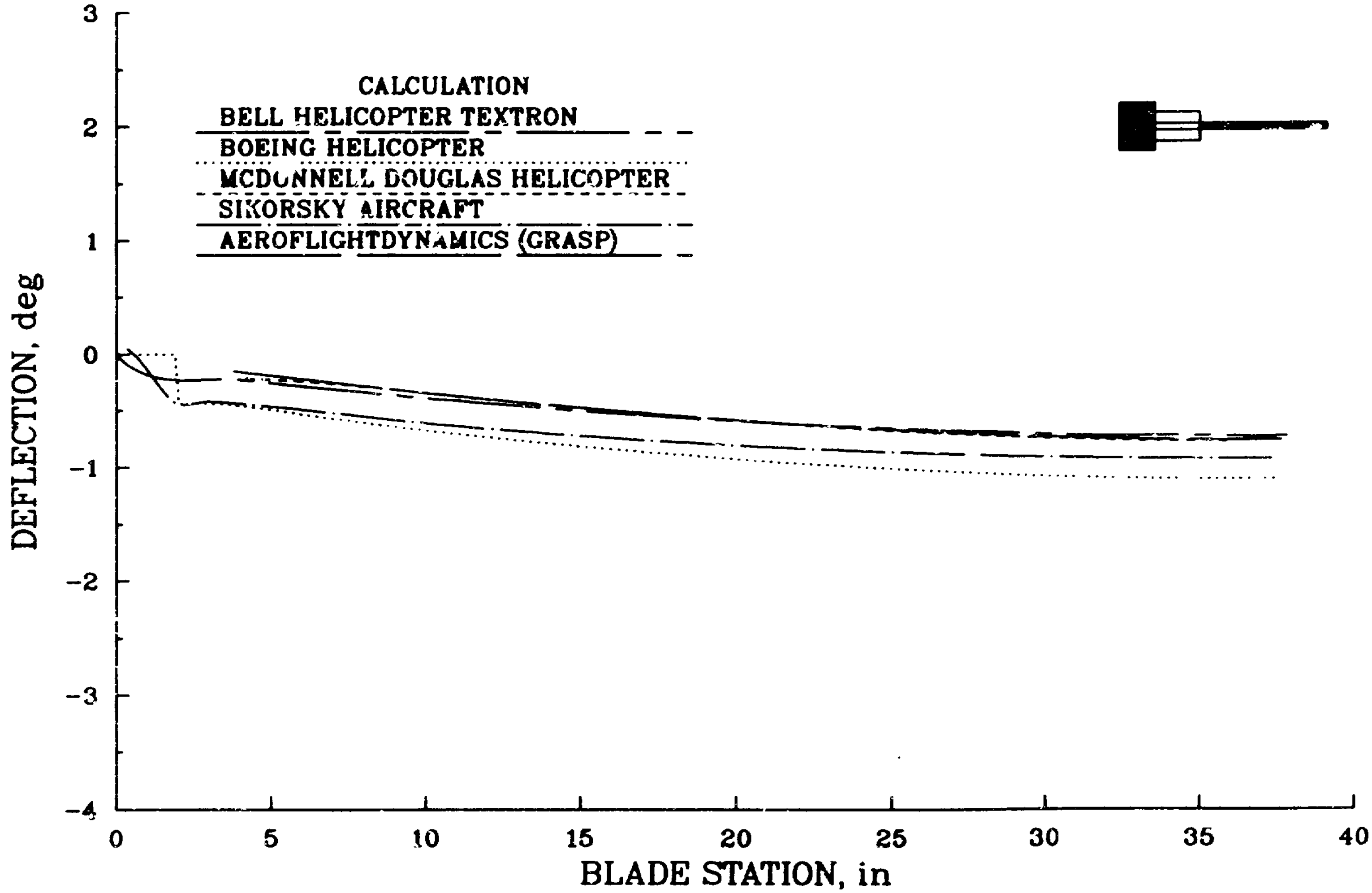

TORSION EQUILIBRIUM DEFLECTION – TASK 36d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –8 deg
DEFLECTION, deg
3
2
1
0
–1
–2
–3
–4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

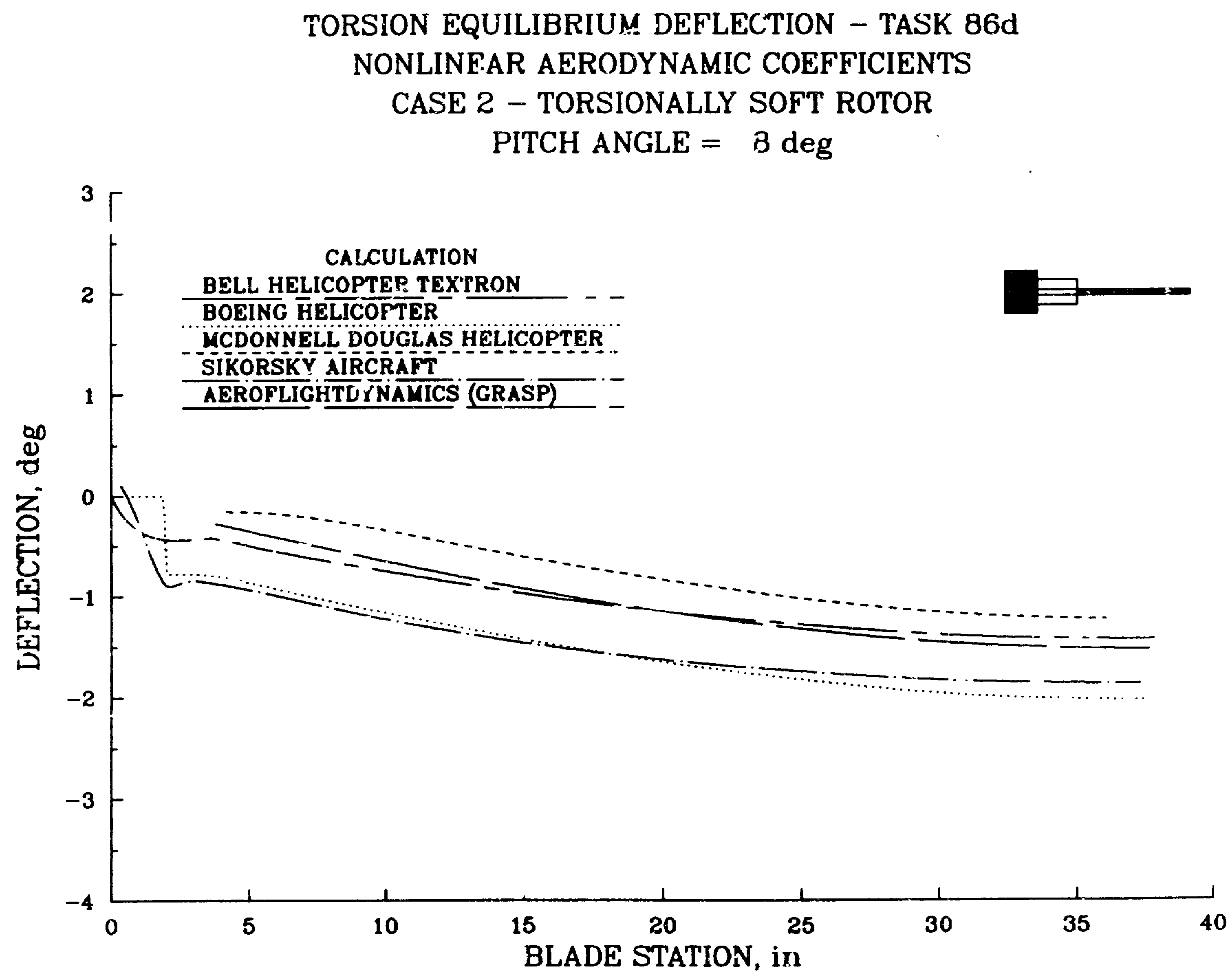

TORSION EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg
DEFLECTION, deg
3
2
1
0
–1
–2
–3
–4
BLADE STATION, in
0
5
10
15
20
25
30
35
40
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

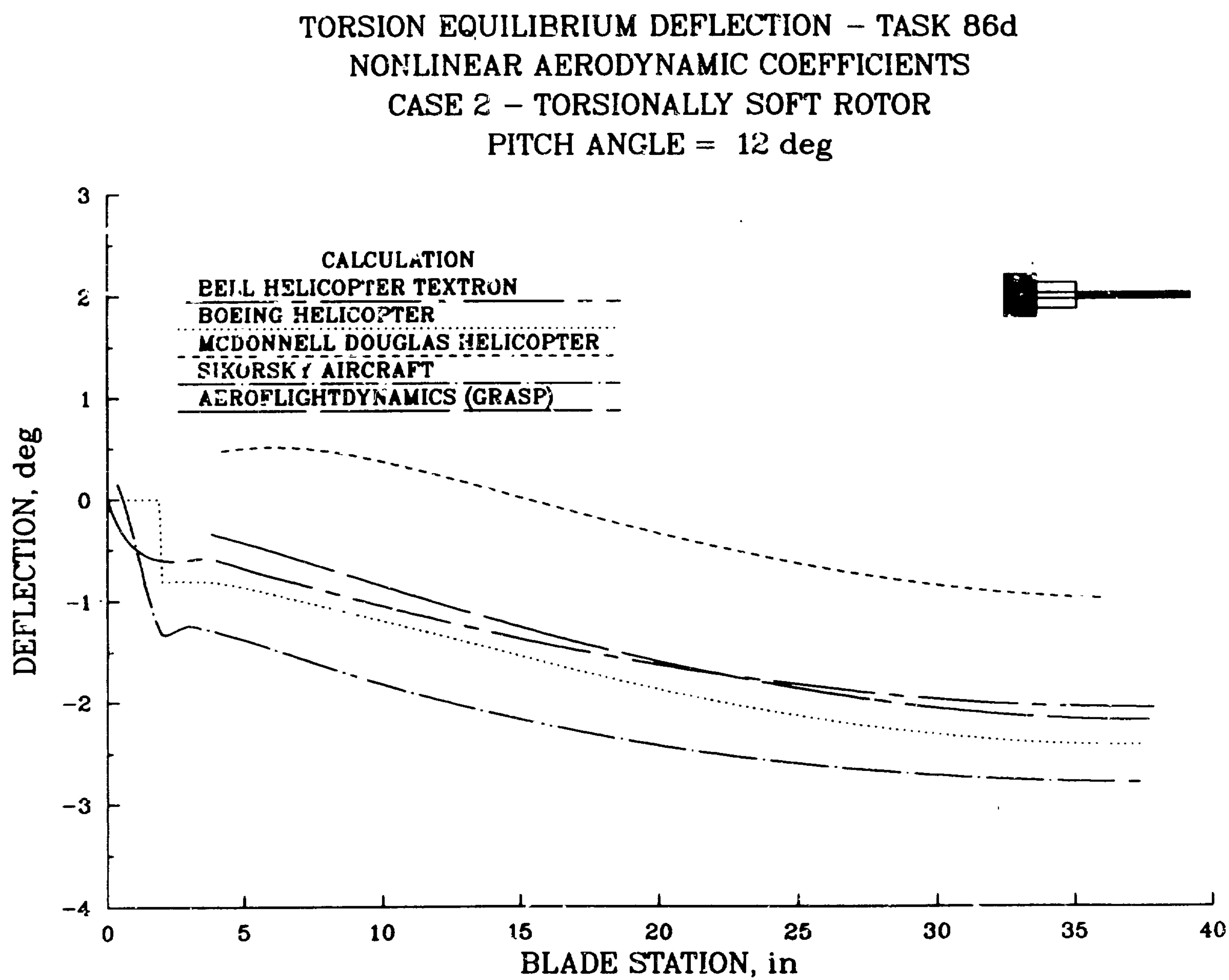
TORSION EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg

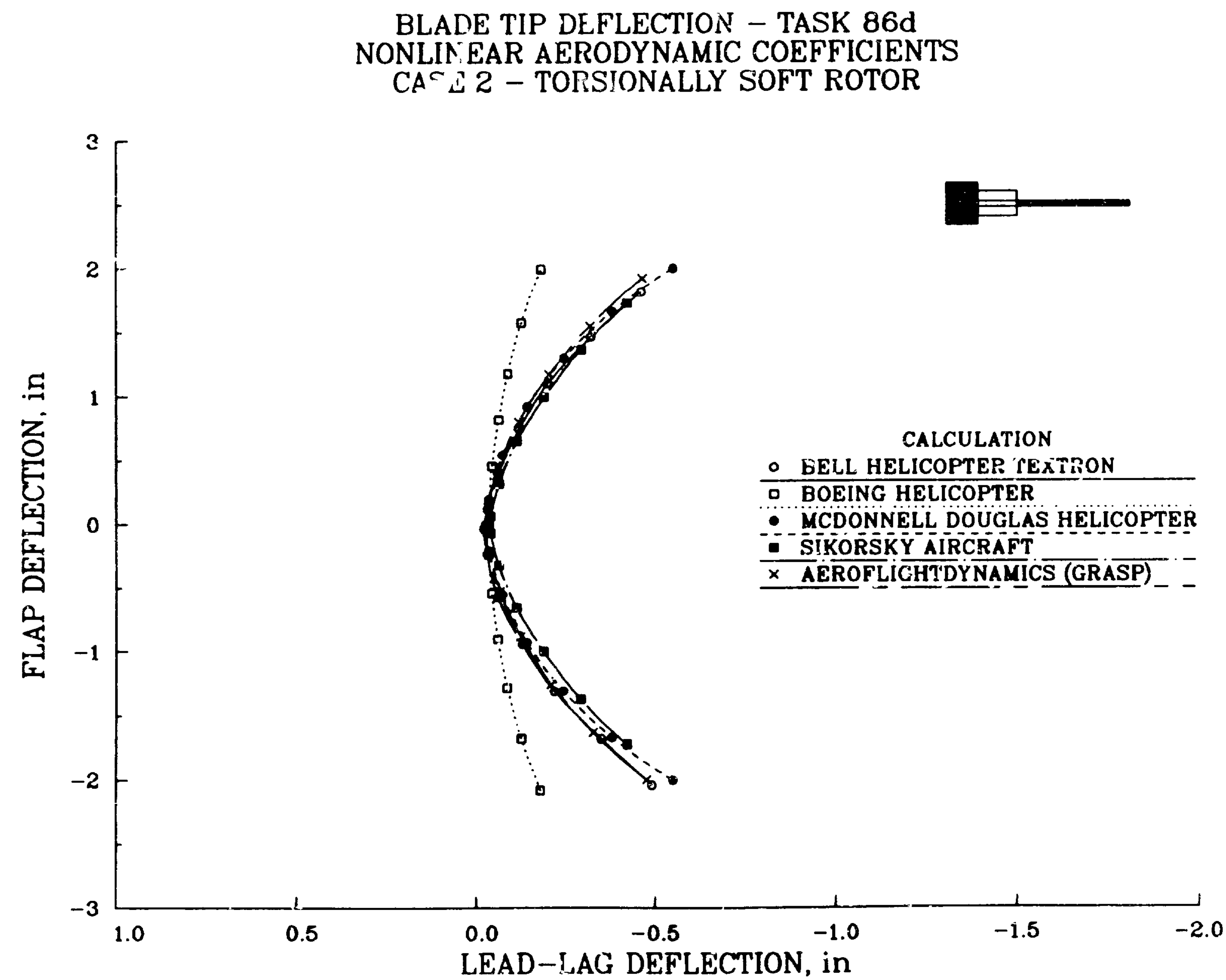


TORSION EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg

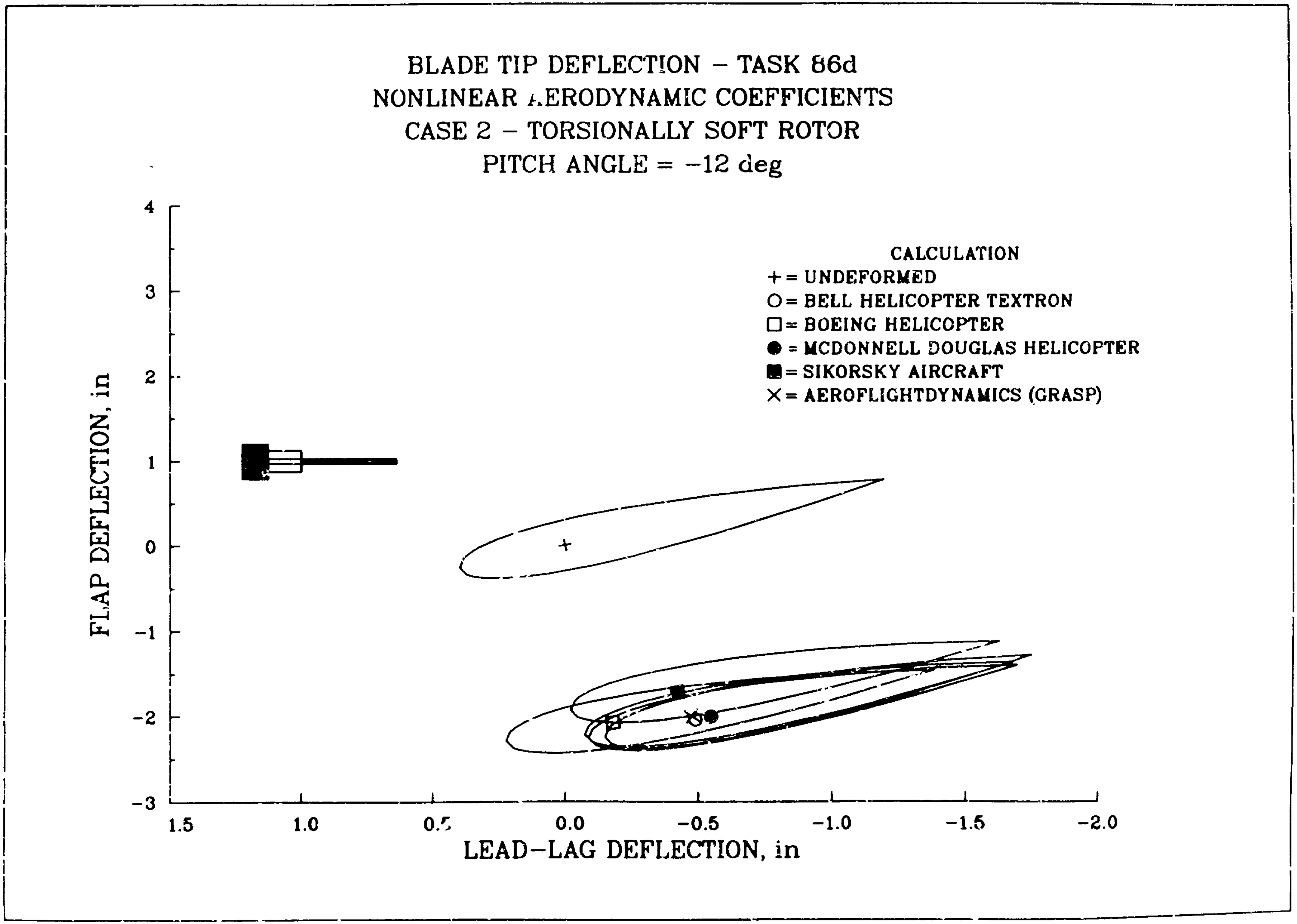



TORSION EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AERODYNAMICS (GRASP)
DEFLECTION, deg
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
BLADE STATION, in

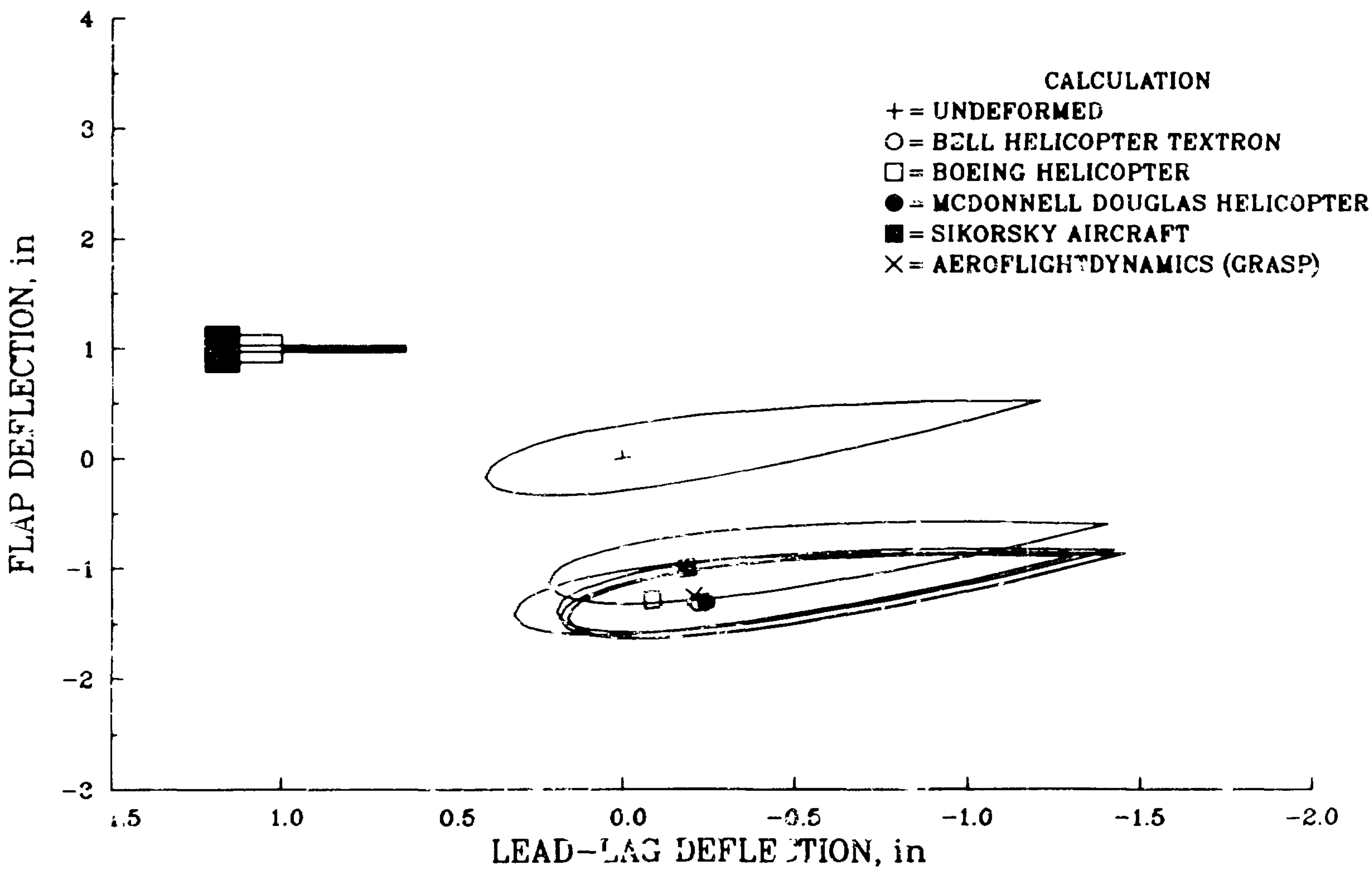

TORSION EQUILIBRIUM DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
DEFLECTION, deg
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
BLADE STATION, in

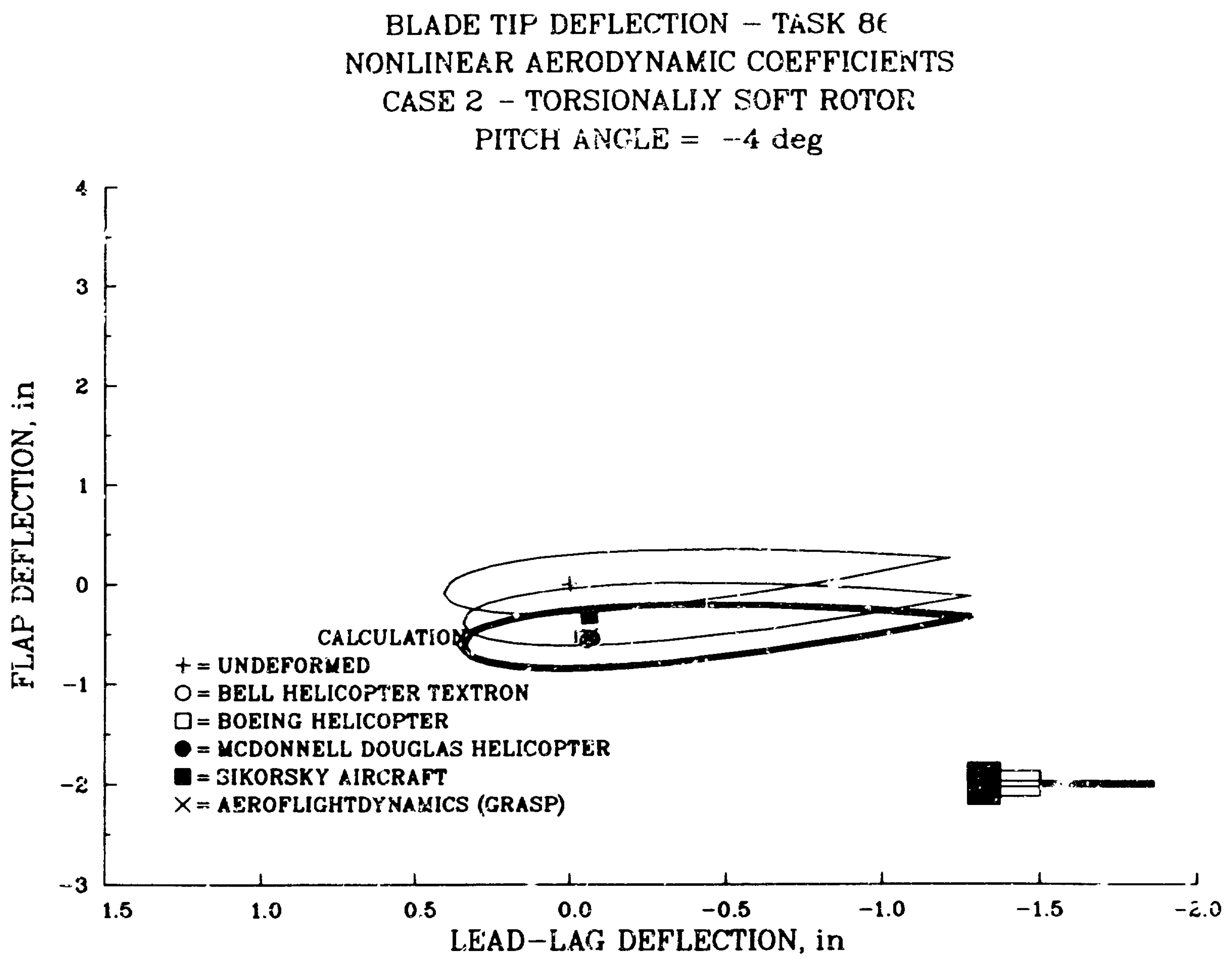


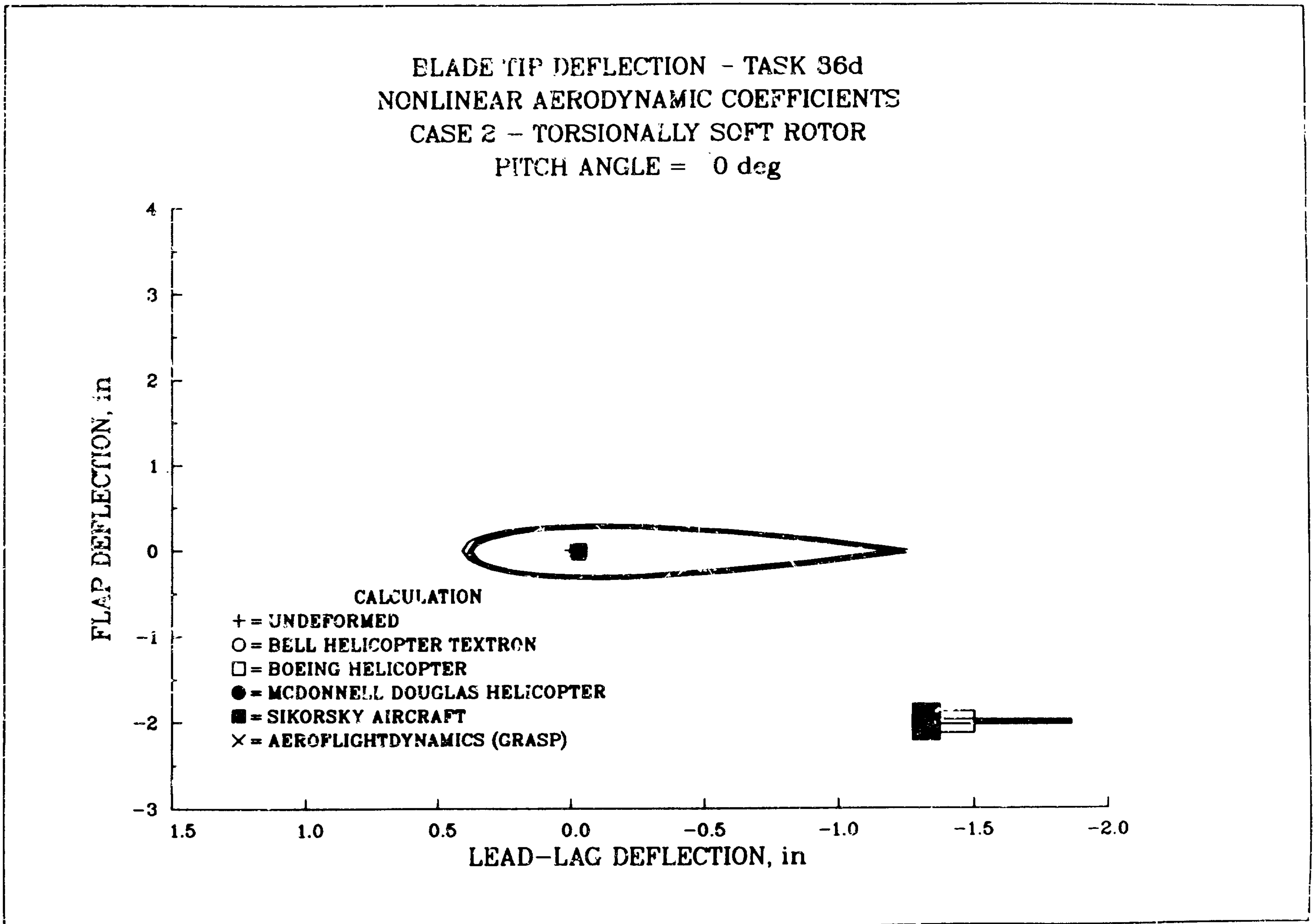
BLADE TIP DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)


BLADE TIP DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in

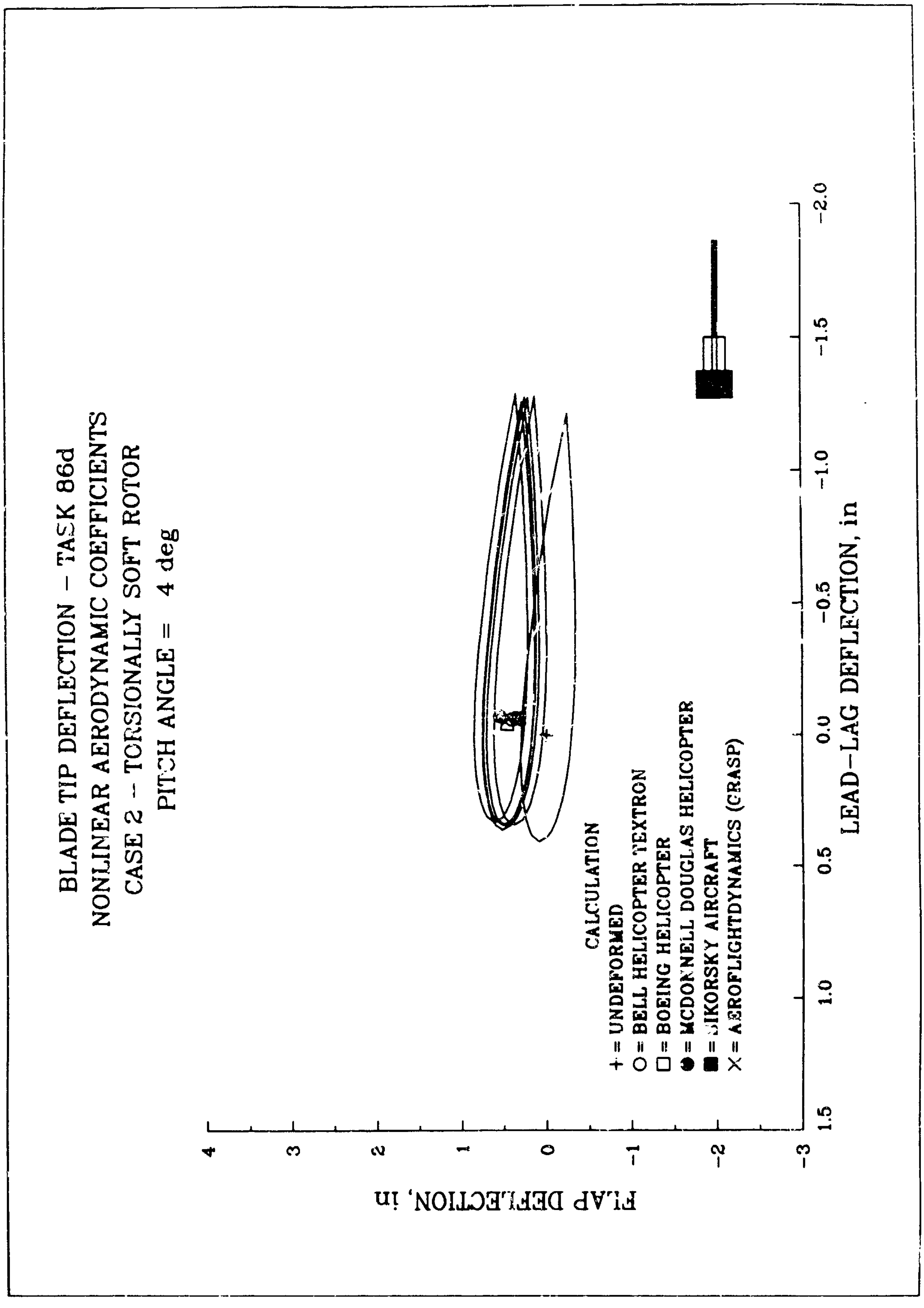
BLADE TIP DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg

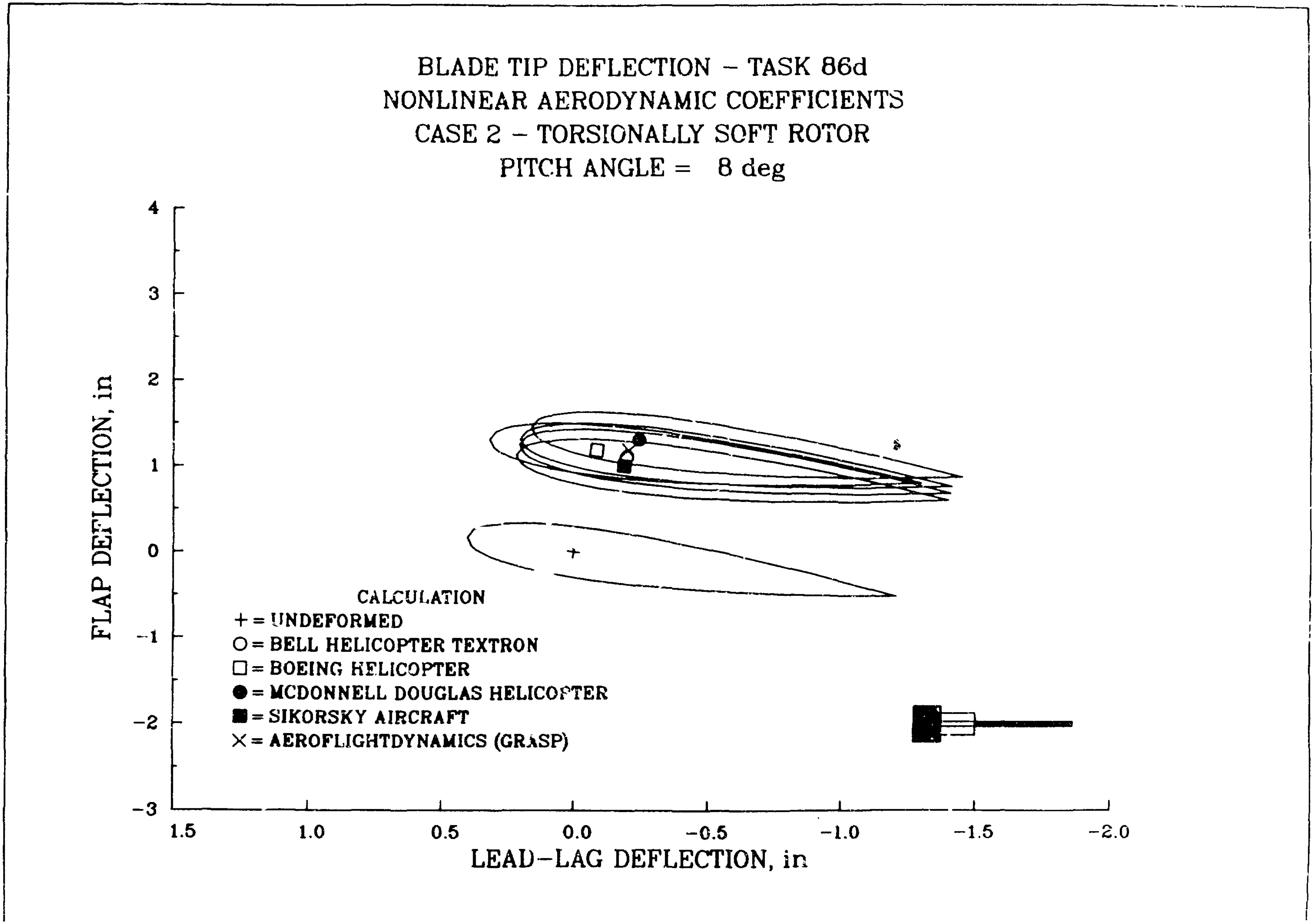


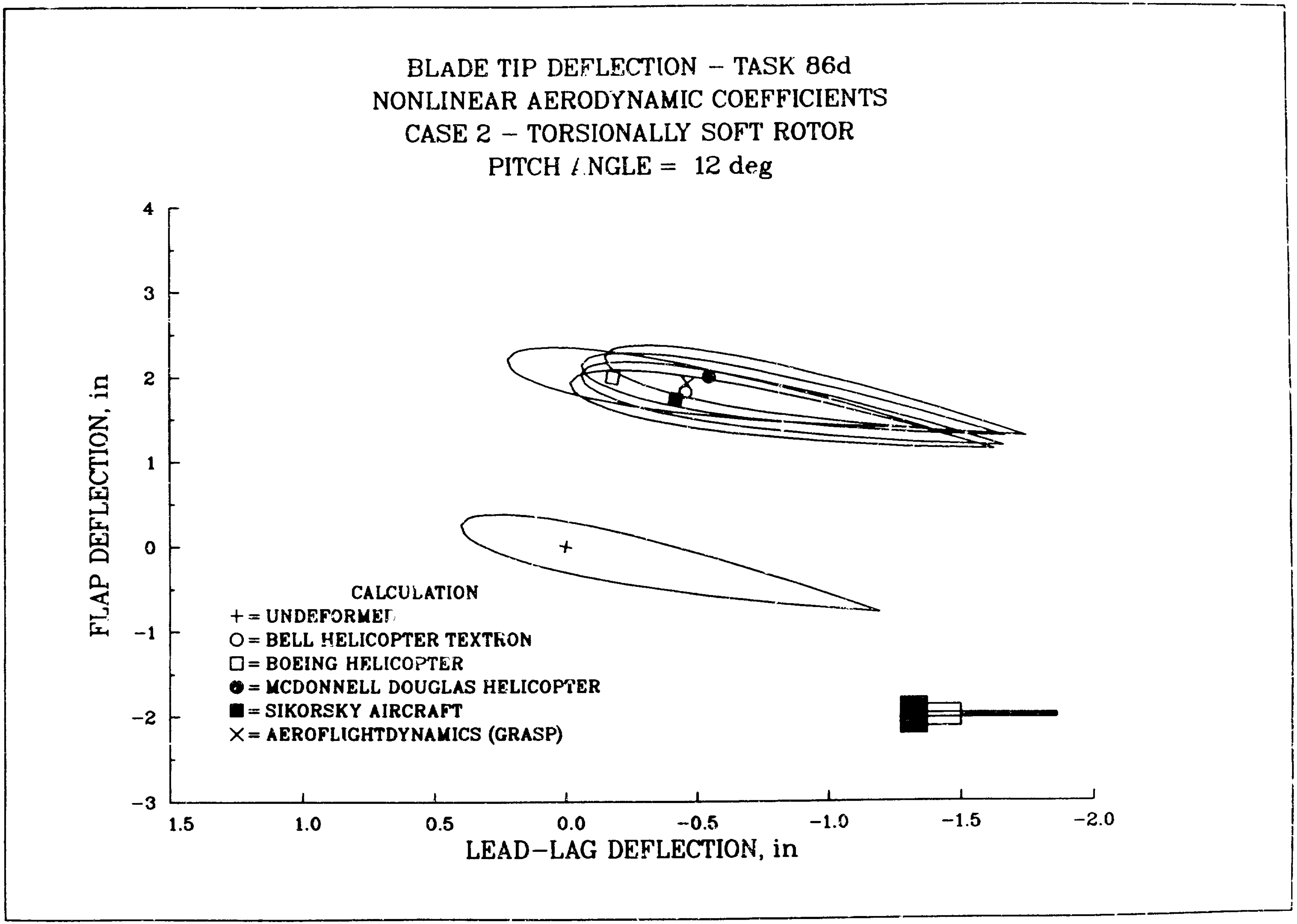

BLADE TIP DEFLECTION – TASK 8(
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
LEAD–LAG DEFLECTION, in
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)

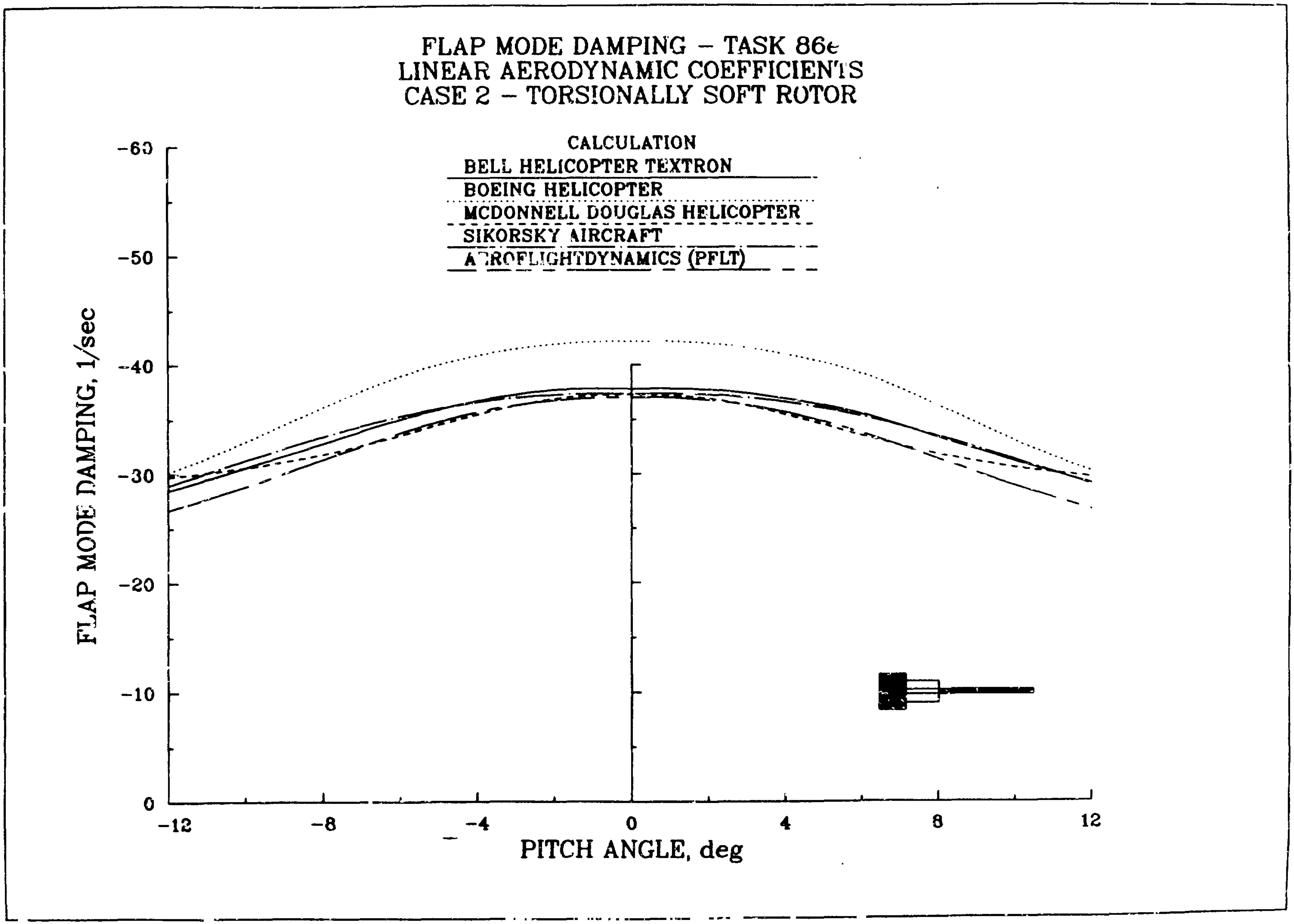


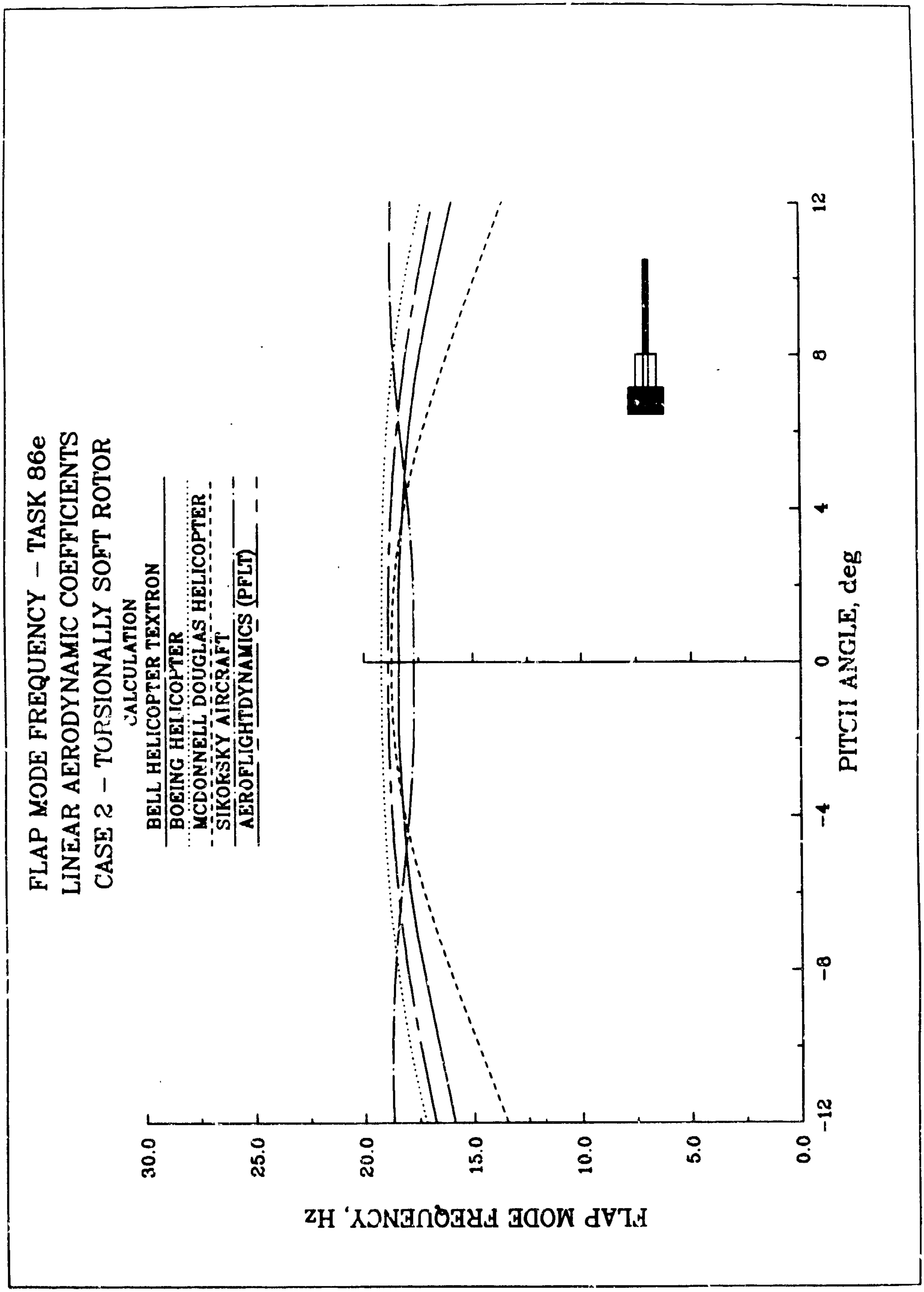
BLADE TIP DEFLECTION - TASK 36d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD−LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)

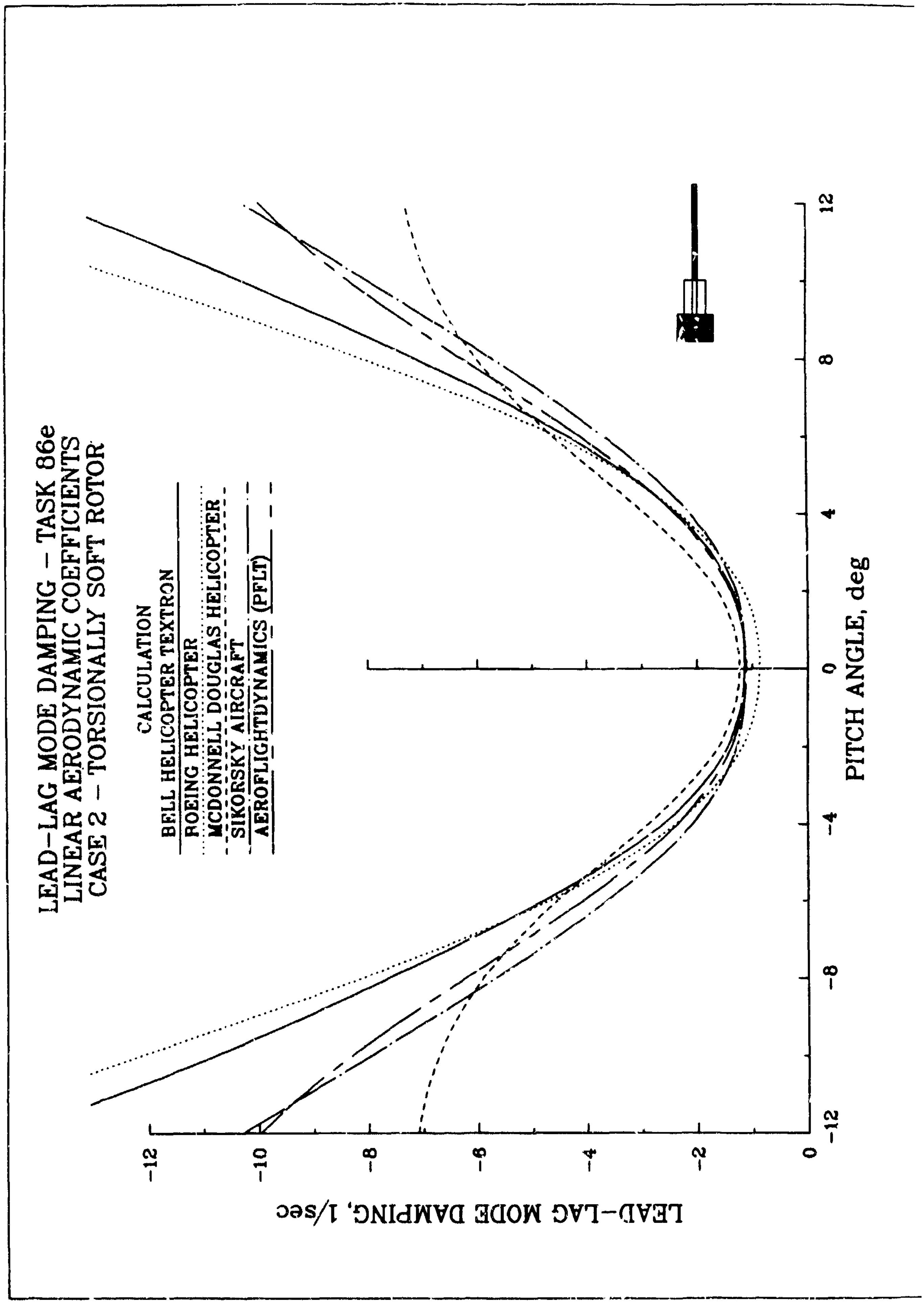

BLADE TIP DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (CRASP)
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0


BLADE TIP DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)

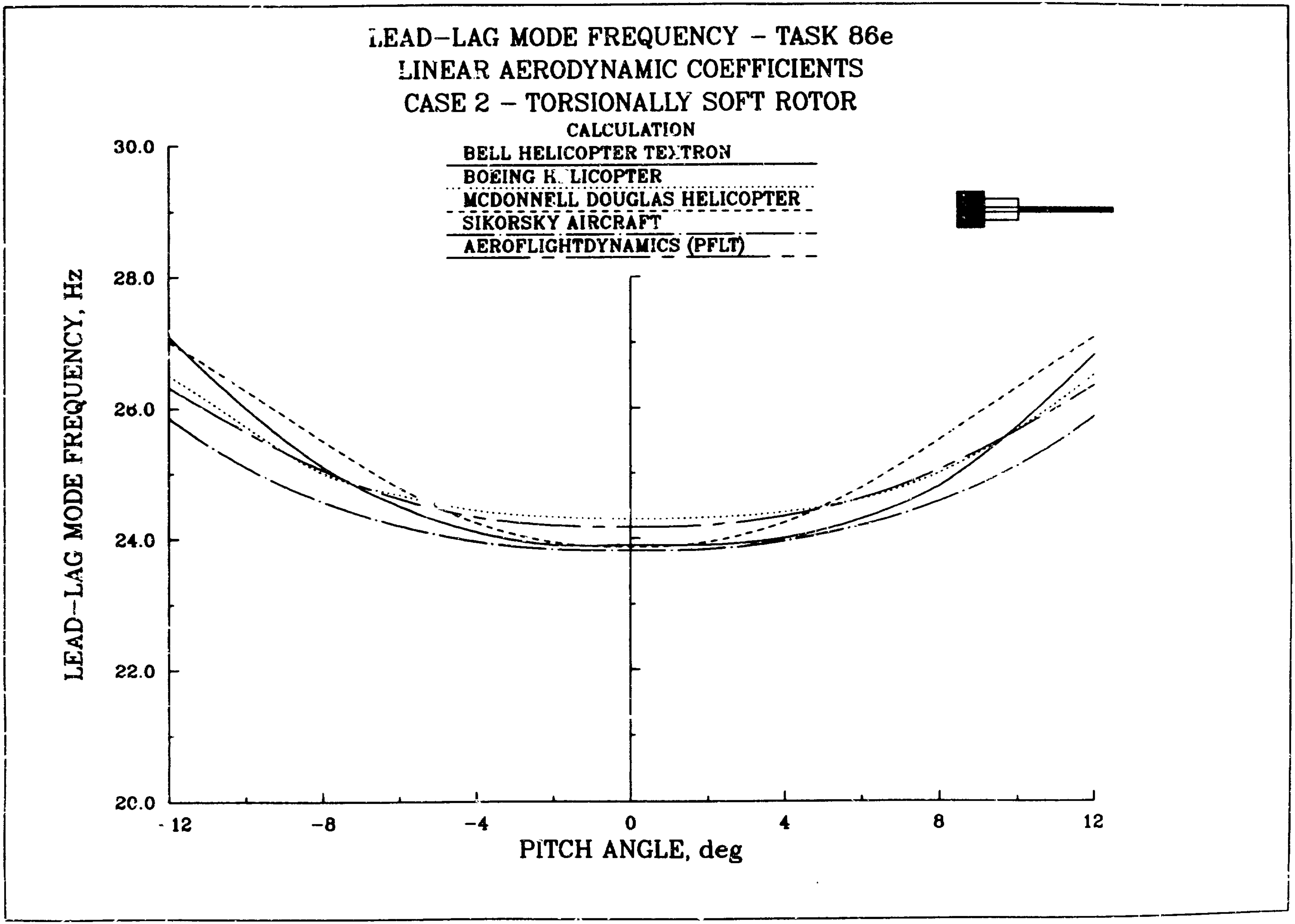

BLADE TIP DEFLECTION – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)


FLAP MODE DAMPING – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
FLAP MODE DAMPING, 1/sec
-60
-50
-40
-30
-20
-10
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


FLAP MODE FREQUENCY – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
FLAP MODE FREQUENCY, Hz
PITCH ANGLE, deg
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−12
−8
−4
0
4
8
12

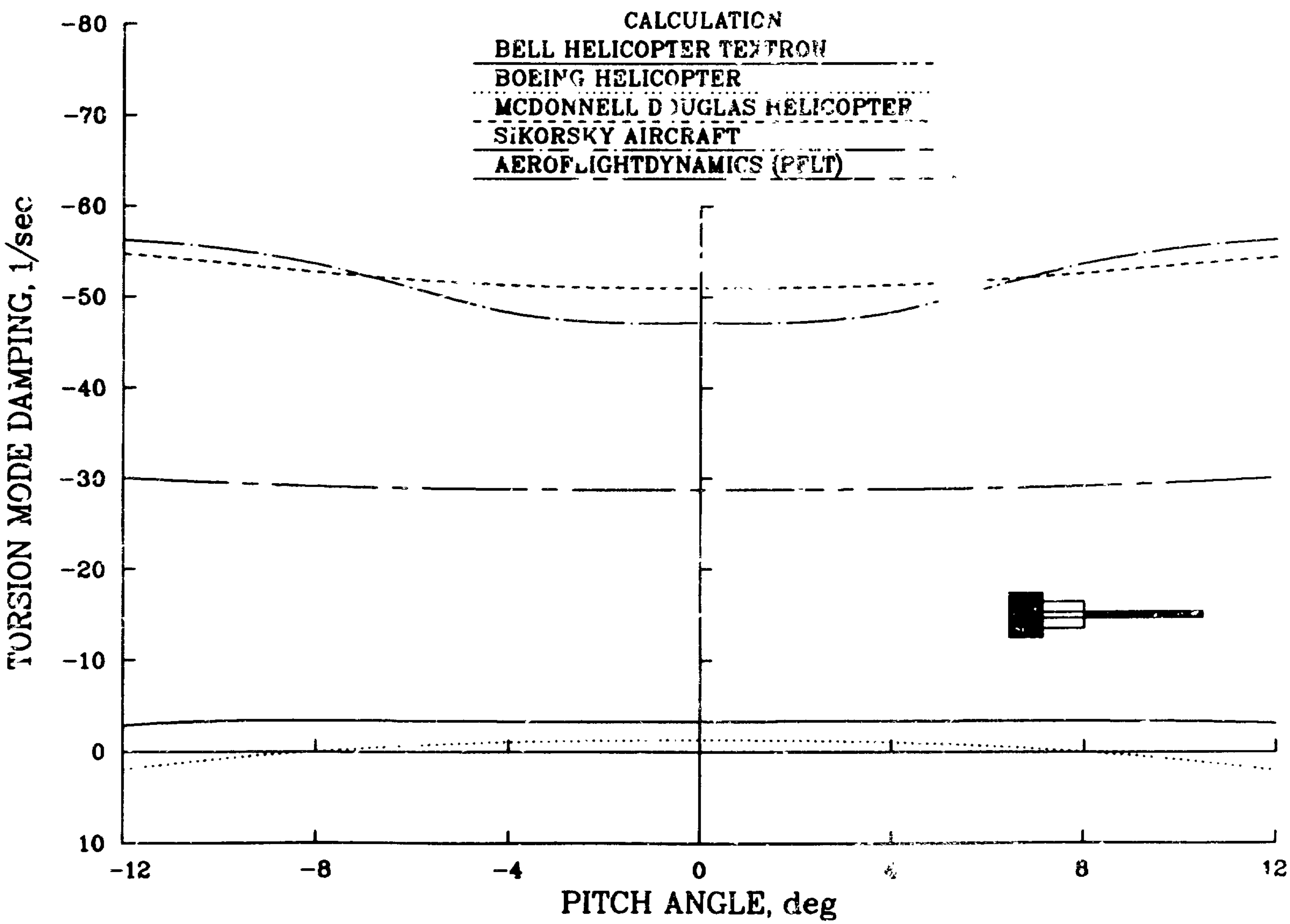


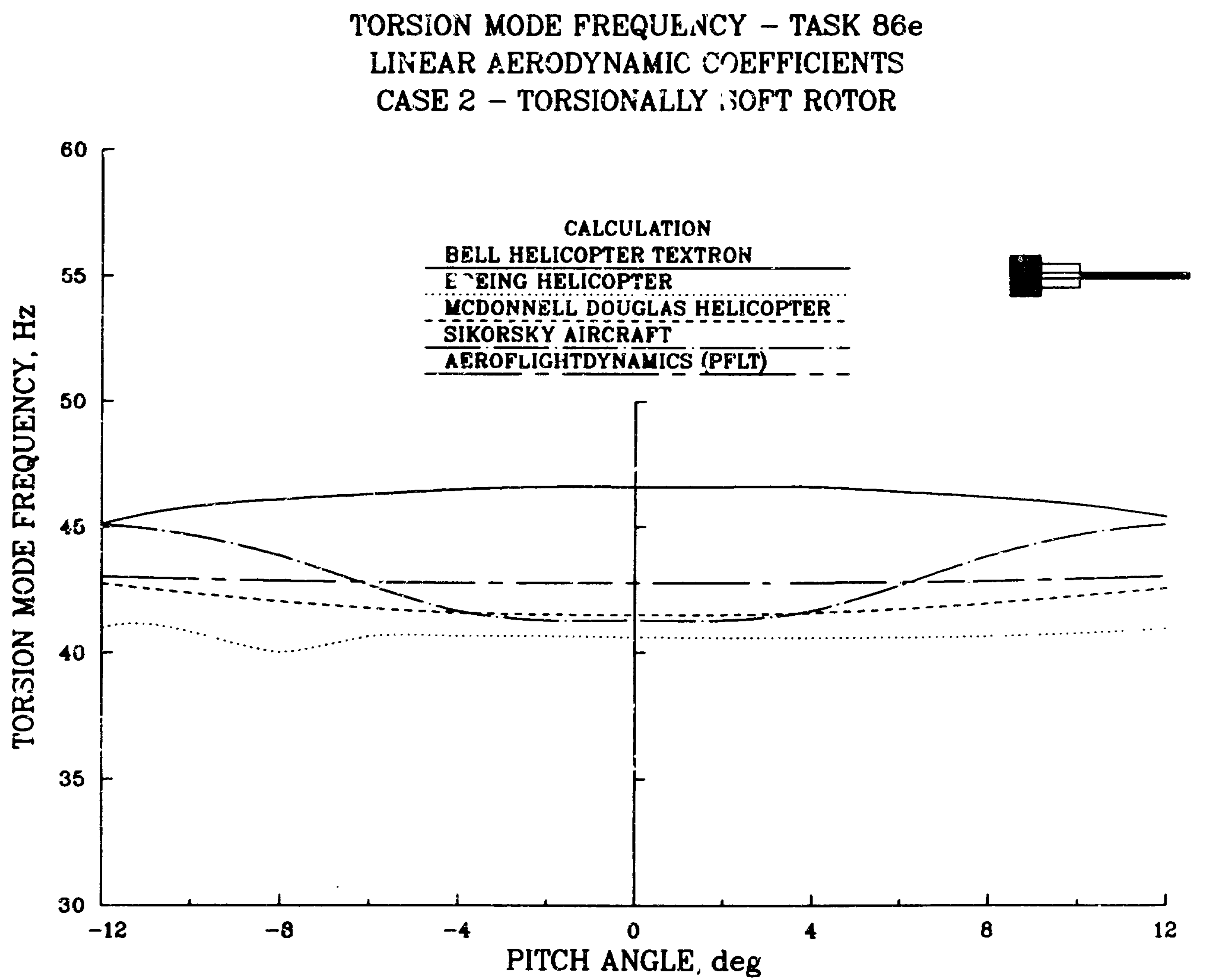
LEAD–LAG MODE DAMPING – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
LEAD–LAG MODE DAMPING, 1/sec
PITCH ANGLE, deg
-12
-10
-8
-6
-4
-2
0
-12
-8
-4
0
4
8
12

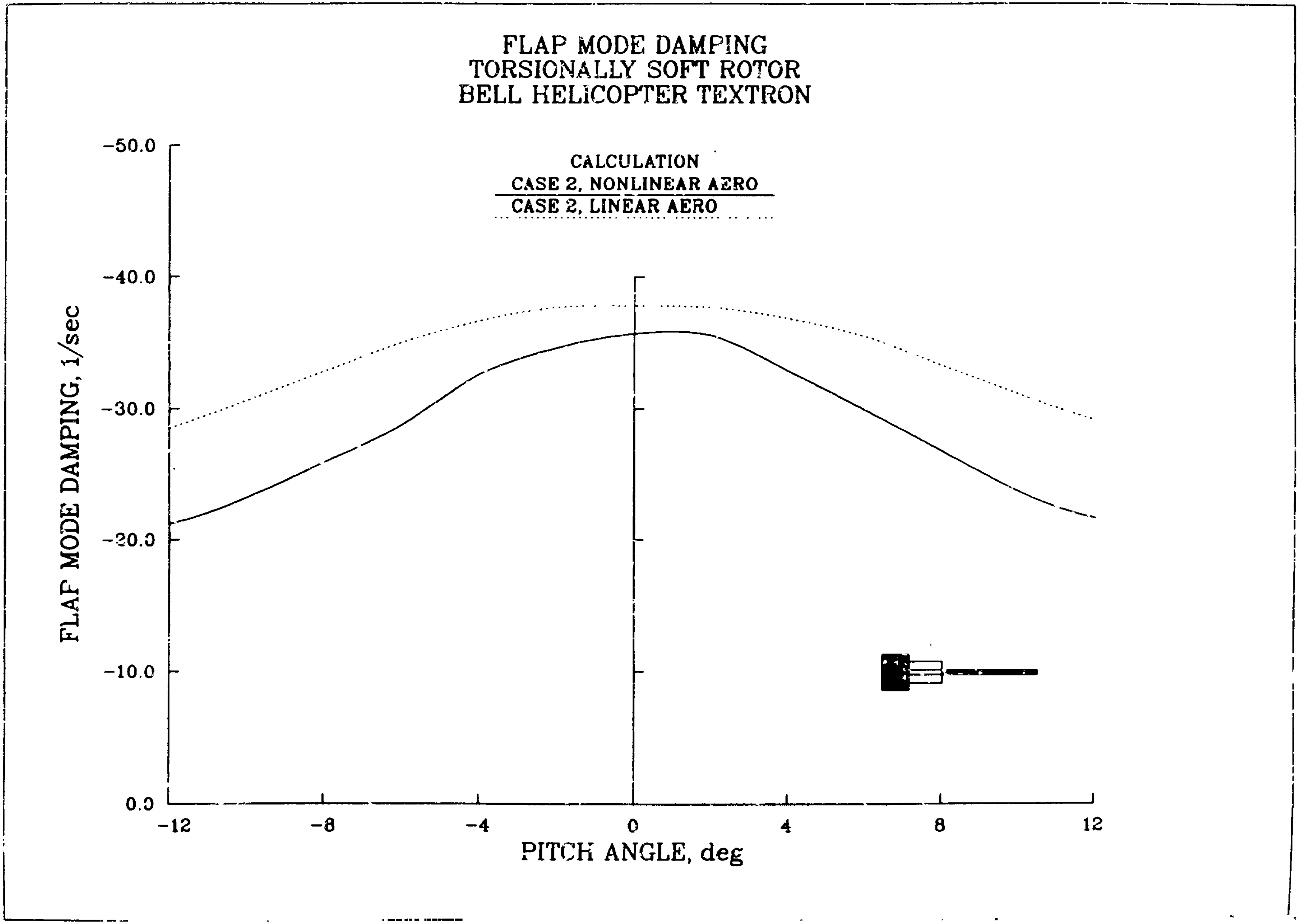


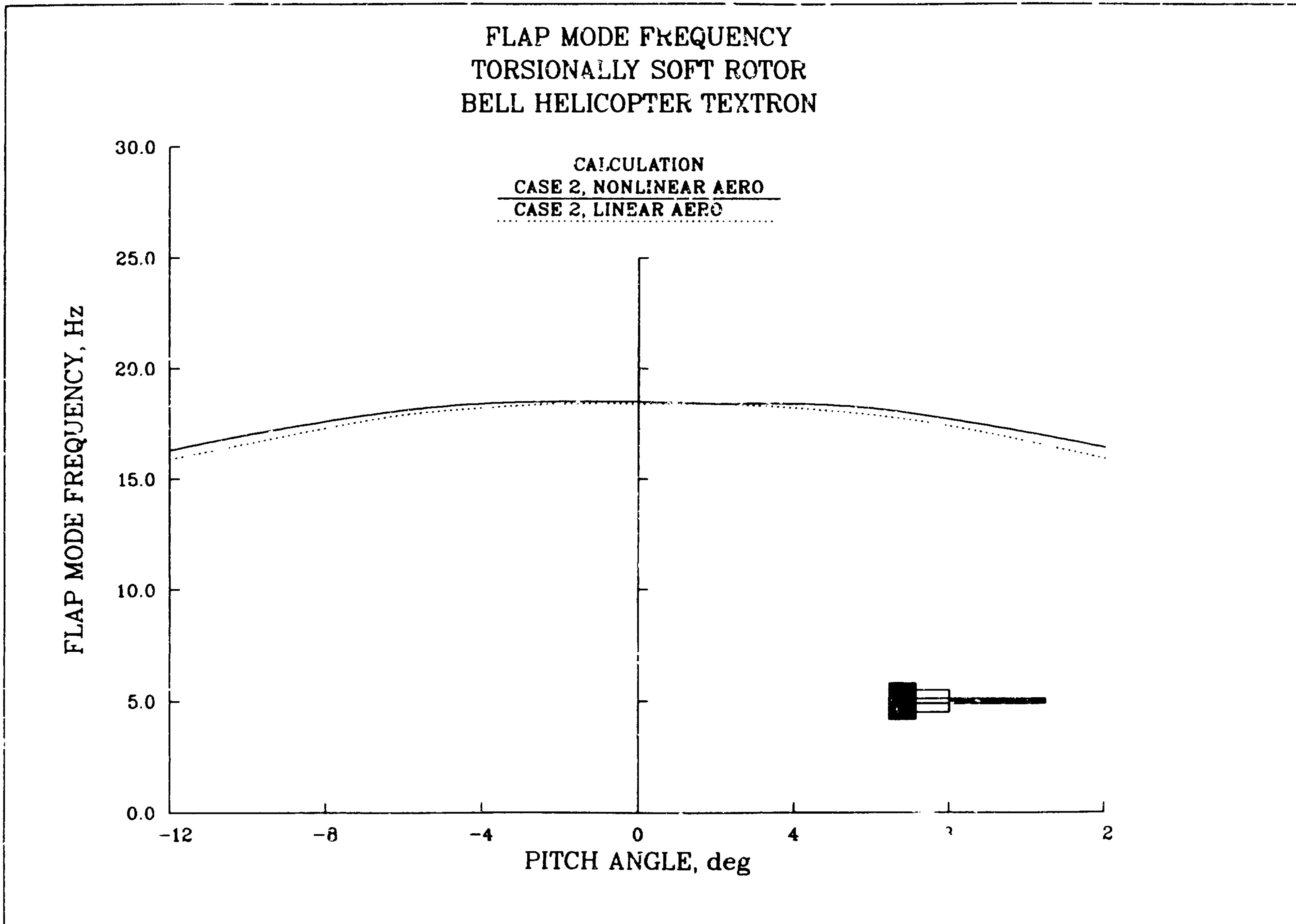
LEAD–LAG MODE FREQUENCY – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
30.0
28.0
26.0
24.0
22.0
20.0
LEAD–LAG MODE FREQUENCY, Hz
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

TORSION MODE DAMPING – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR

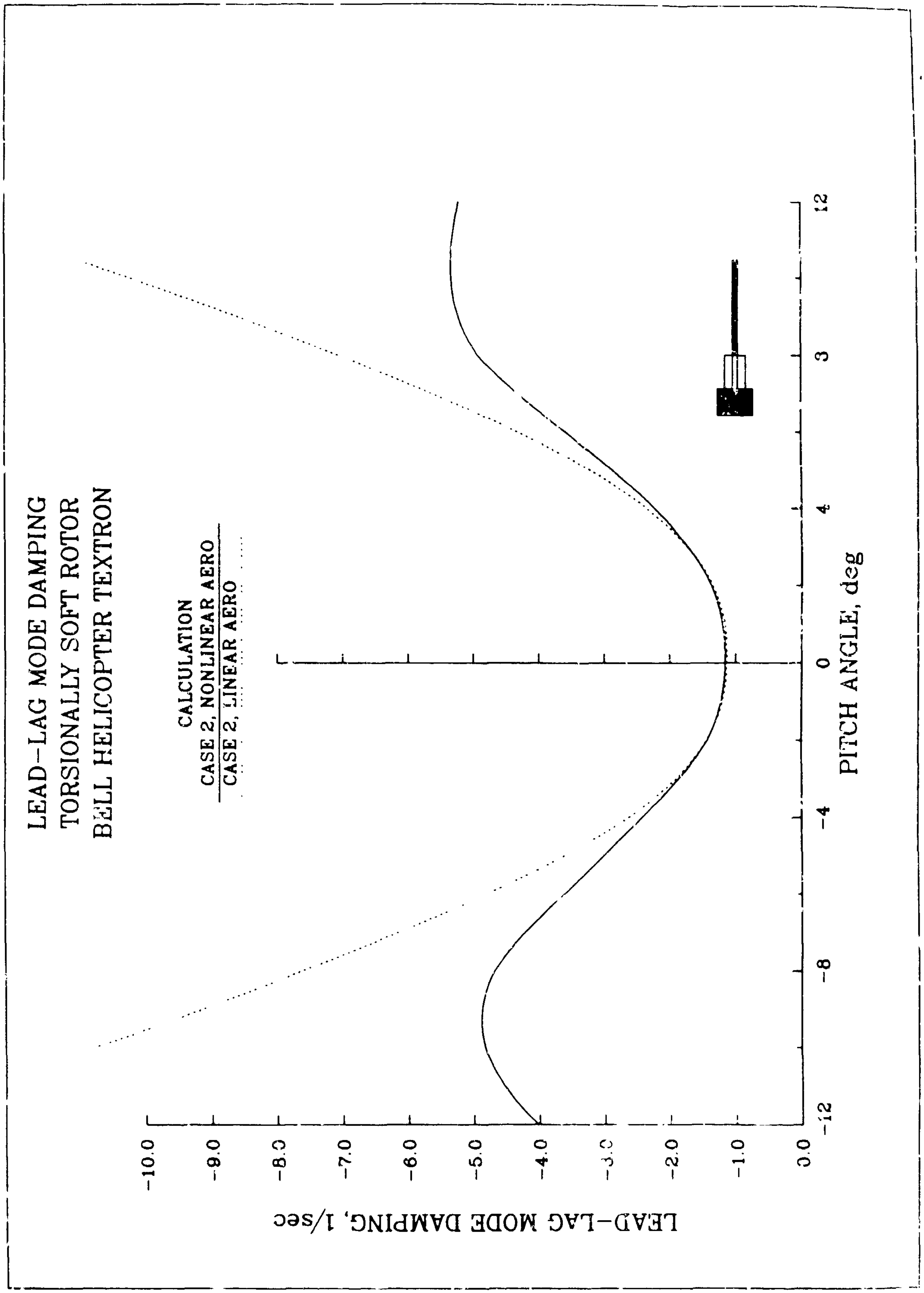


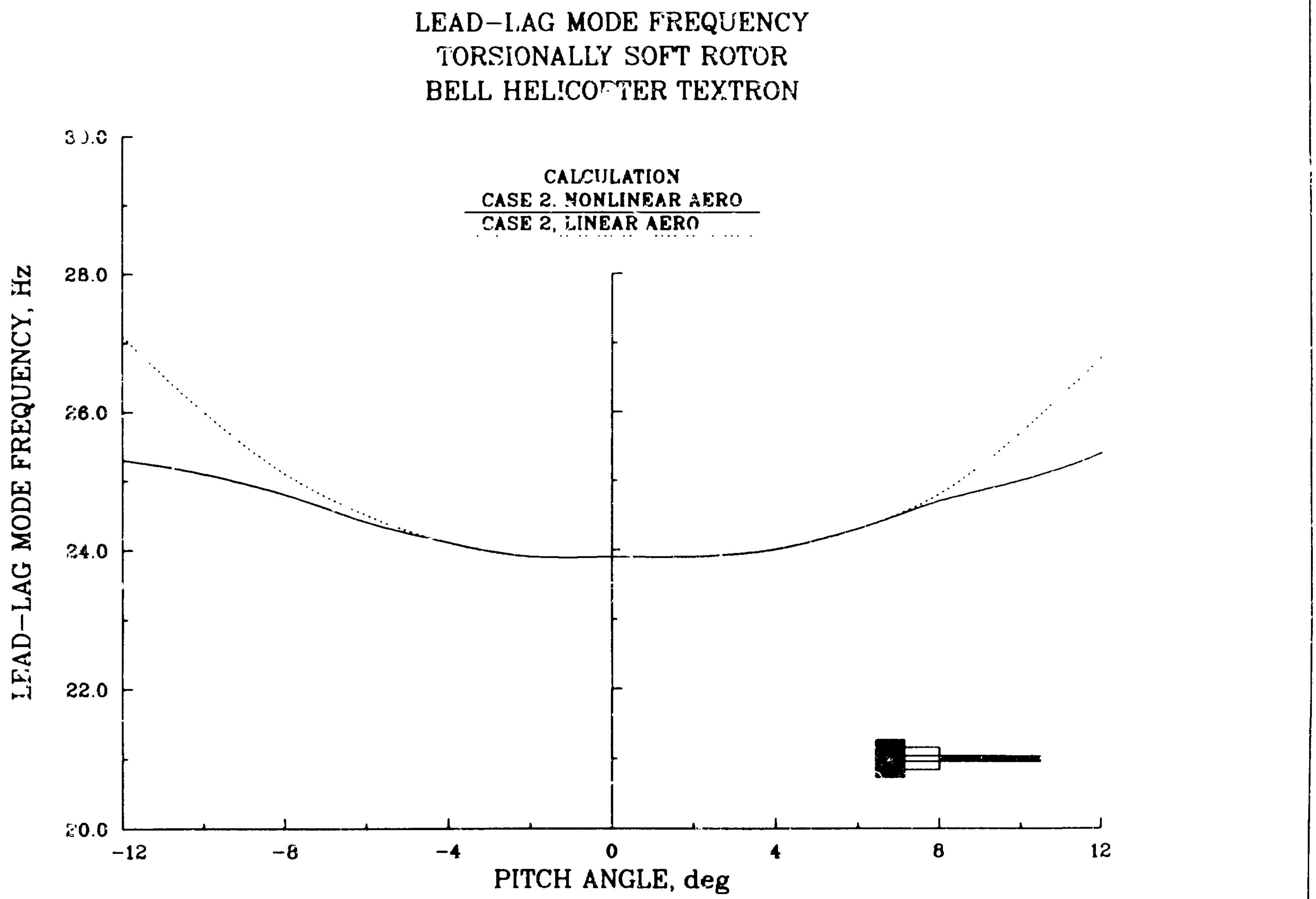

TORSION MODE FREQUENCY – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
TORSION MODE FREQUENCY, Hz
60
55
50
45
40
35
30
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

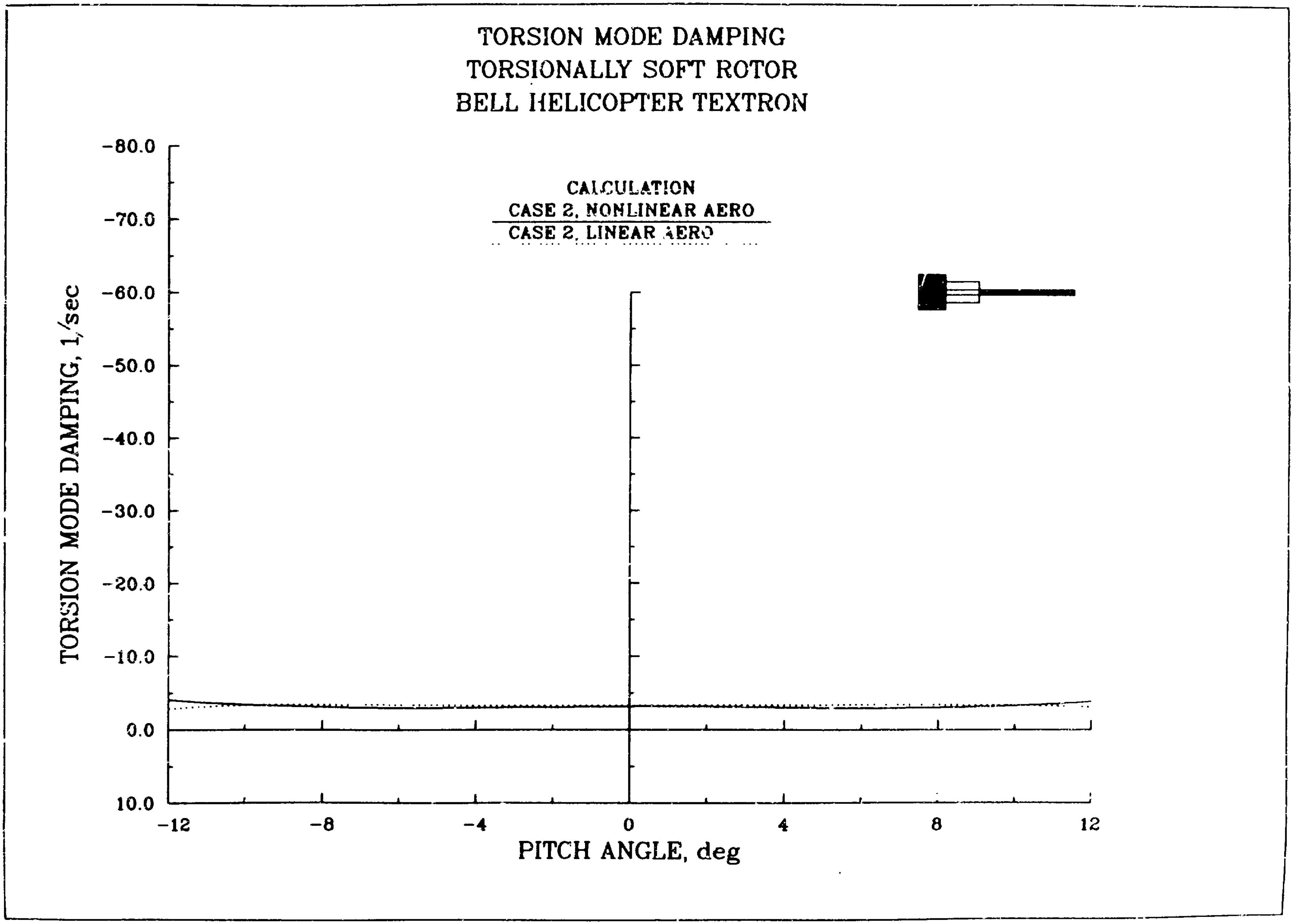

FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE DAMPING, 1/sec
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

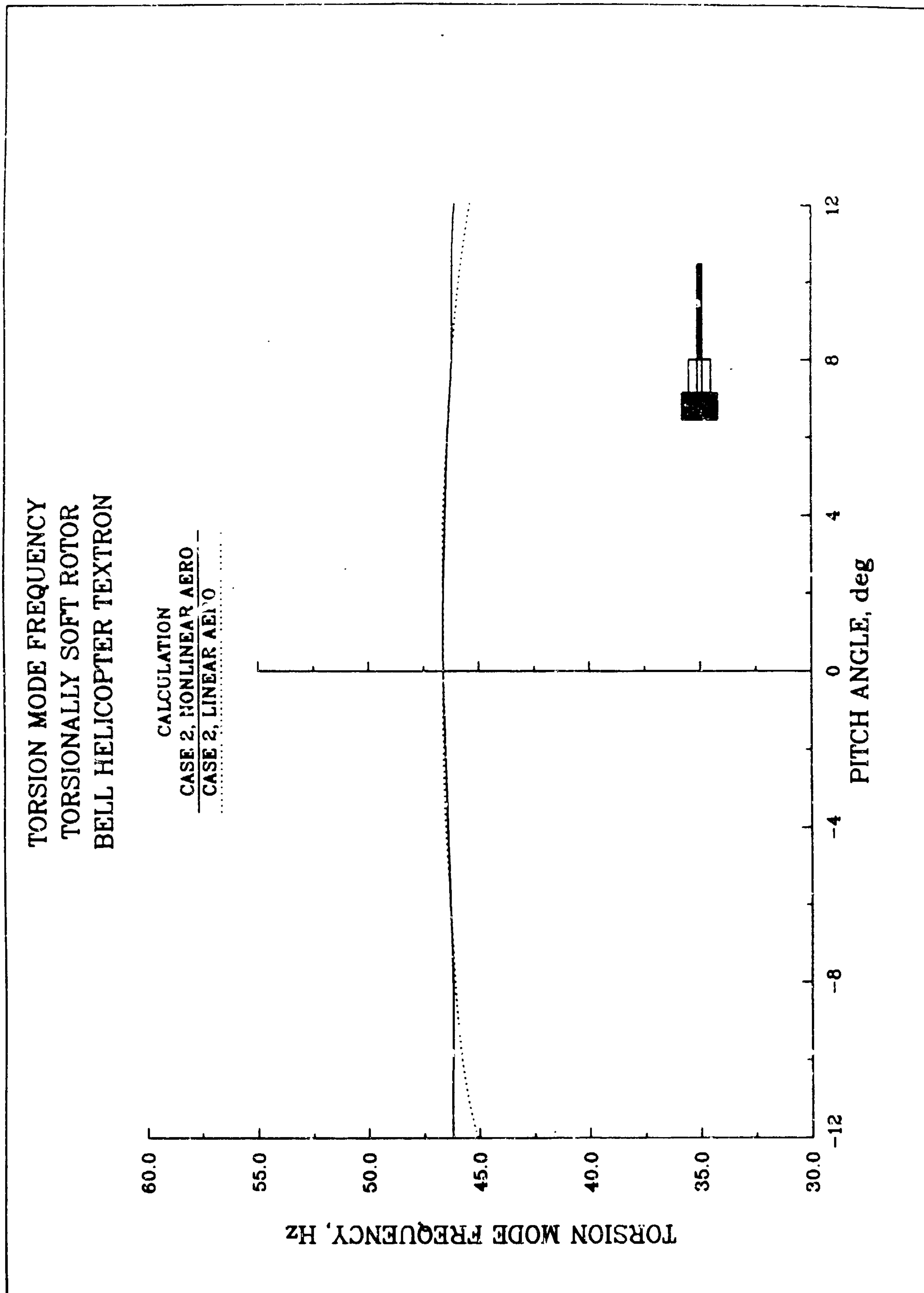


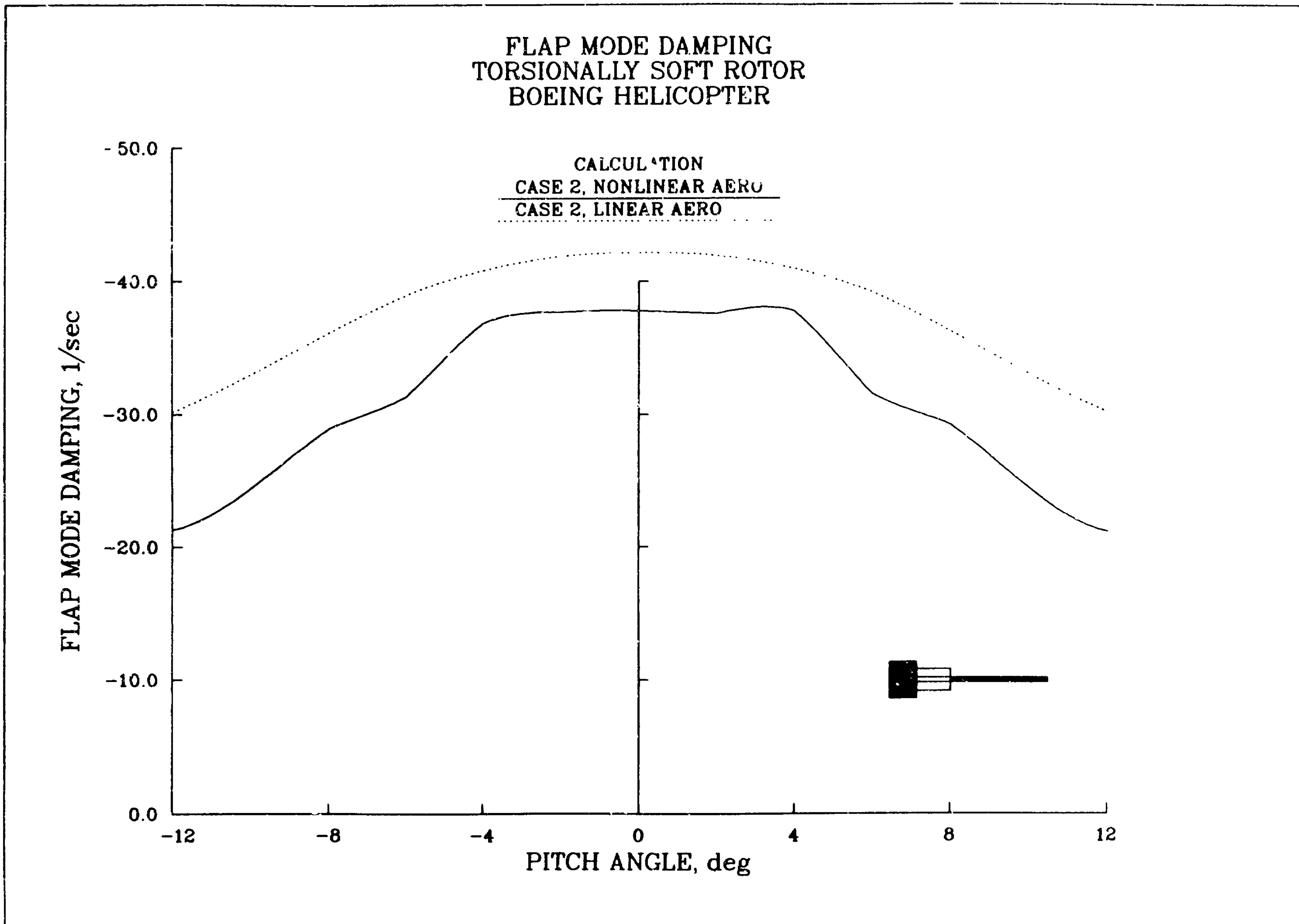
FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−12
−8
−4
0
4
2
PITCH ANGLE, deg


LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
PITCH ANGLE, deg
LEAD–LAG MODE DAMPING, 1/sec
-12
-8
-4
0
4
8
12
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0

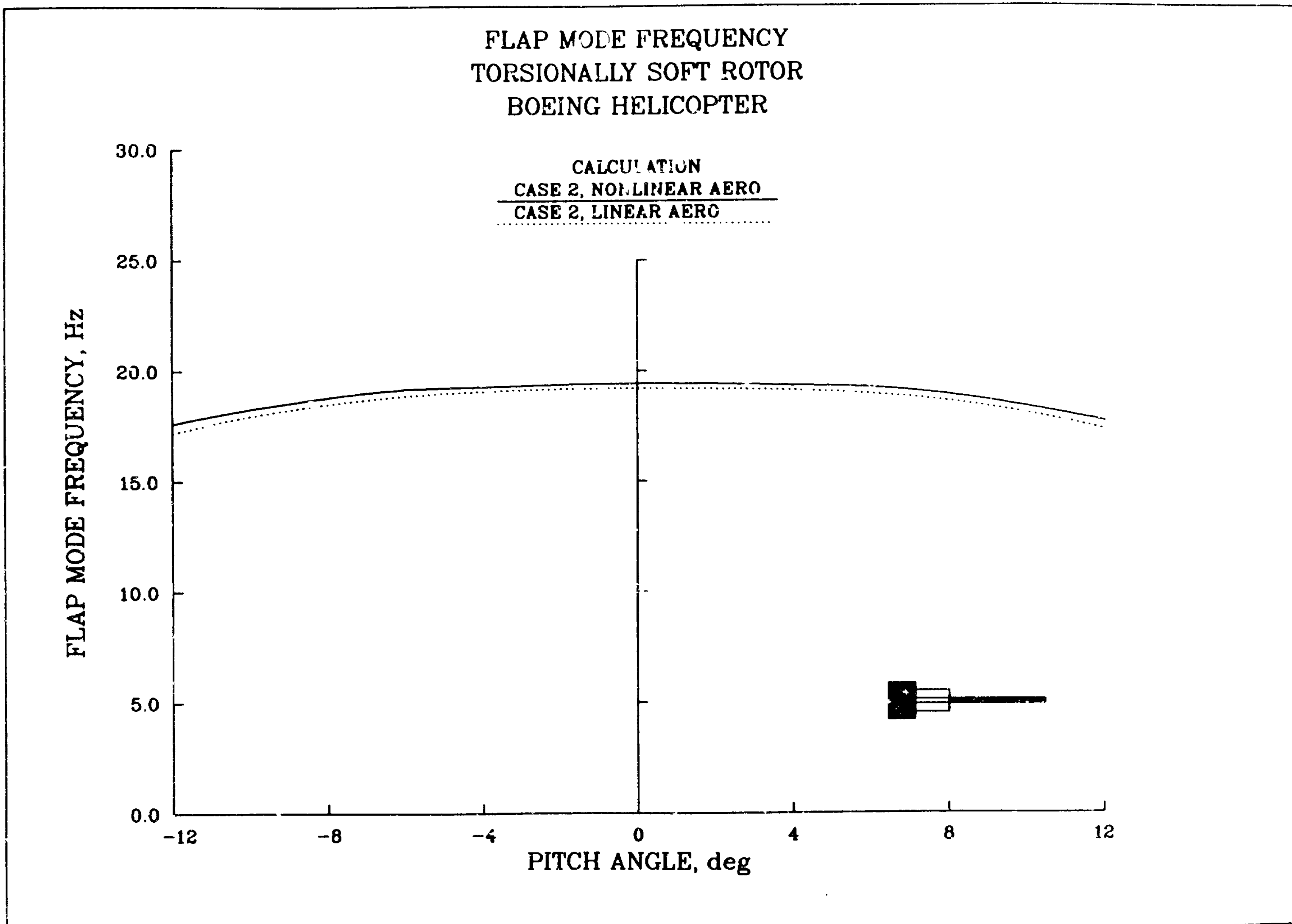

LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
LEAD–LAG MODE FREQUENCY, Hz
30.0
28.0
26.0
24.0
22.0
20.0
–12
–8
–4
0
4
8
12
PITCH ANGLE, deg

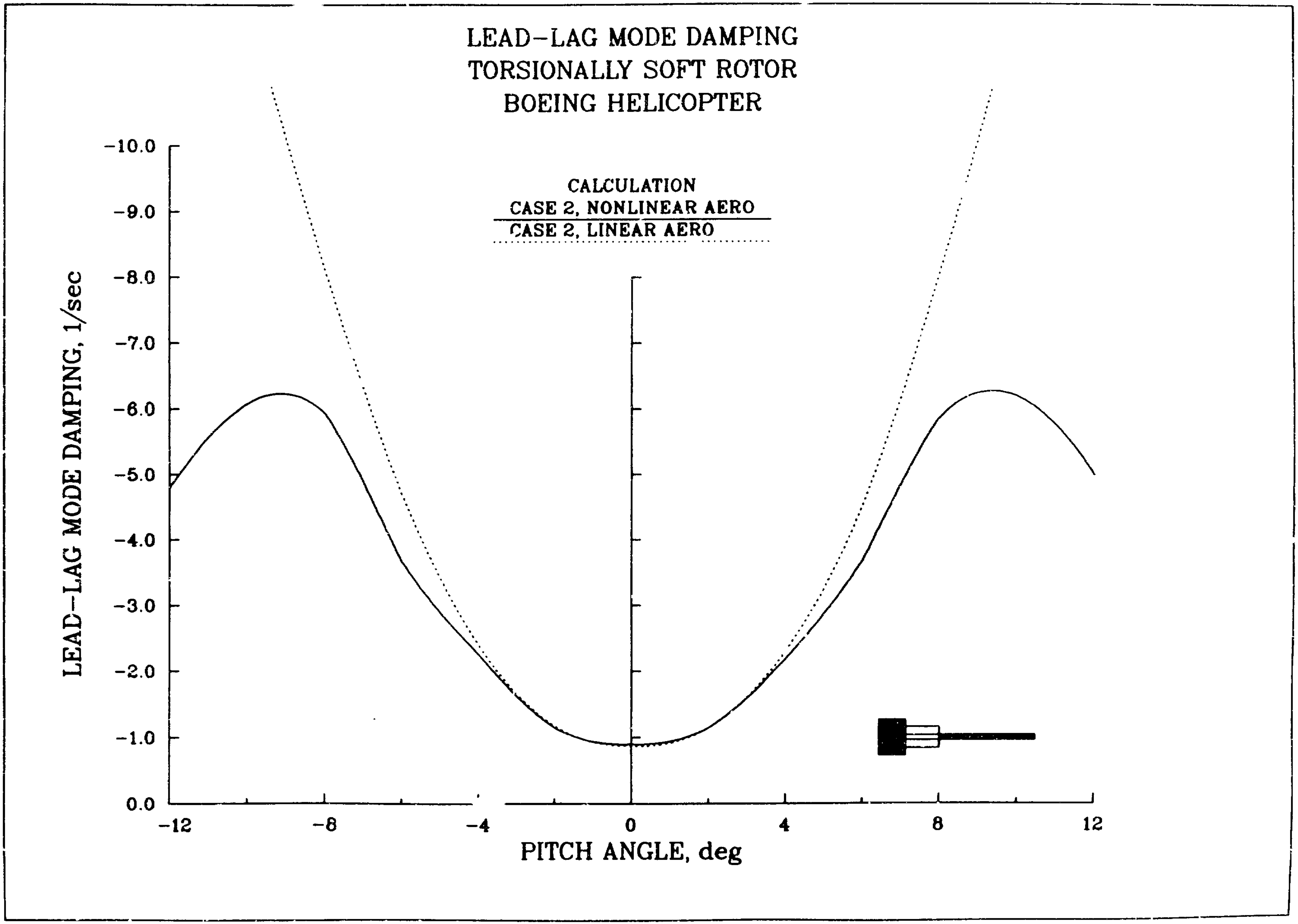

TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

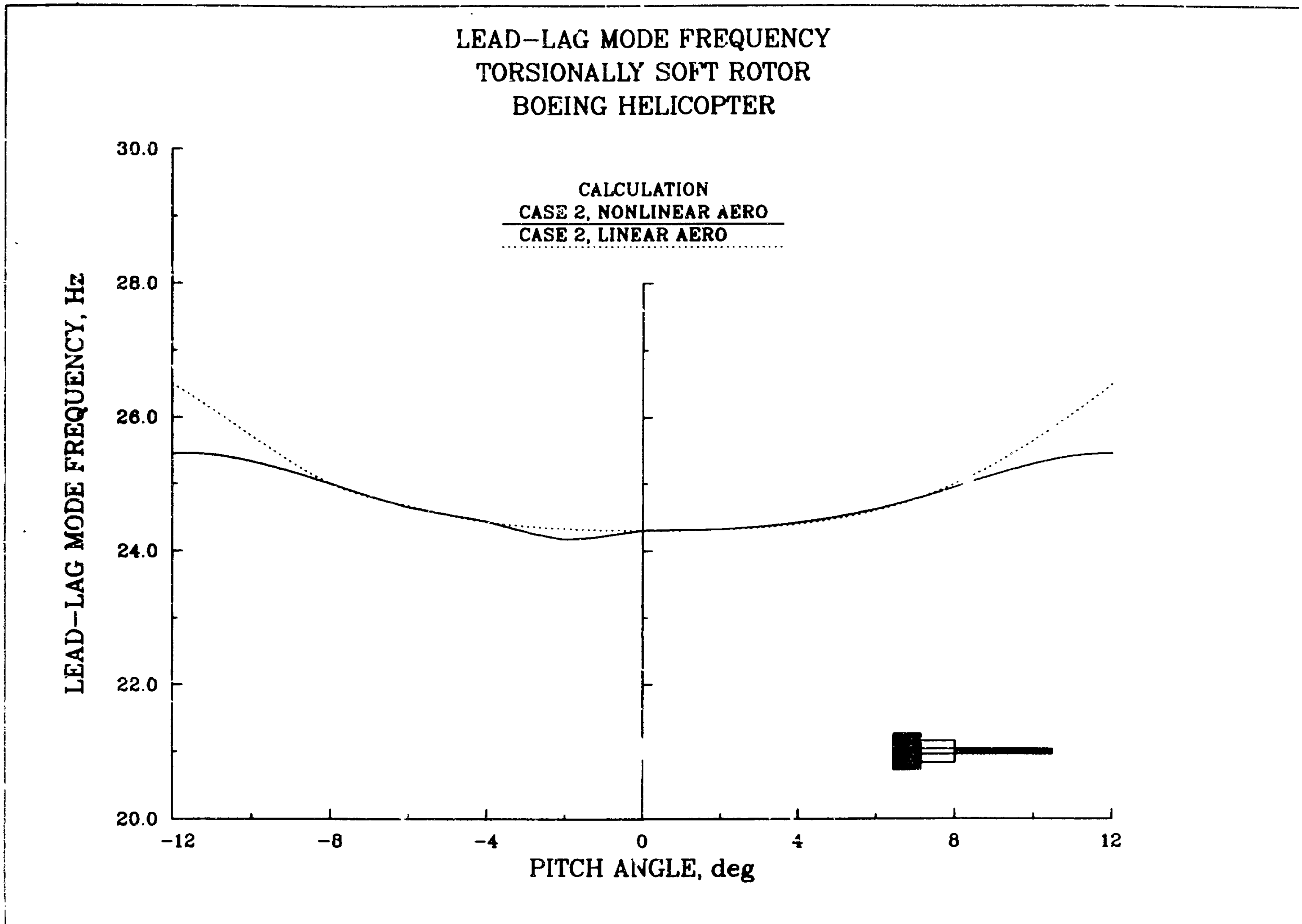

TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
PITCH ANGLE, deg
−12
−8
−4
0
4
8
12

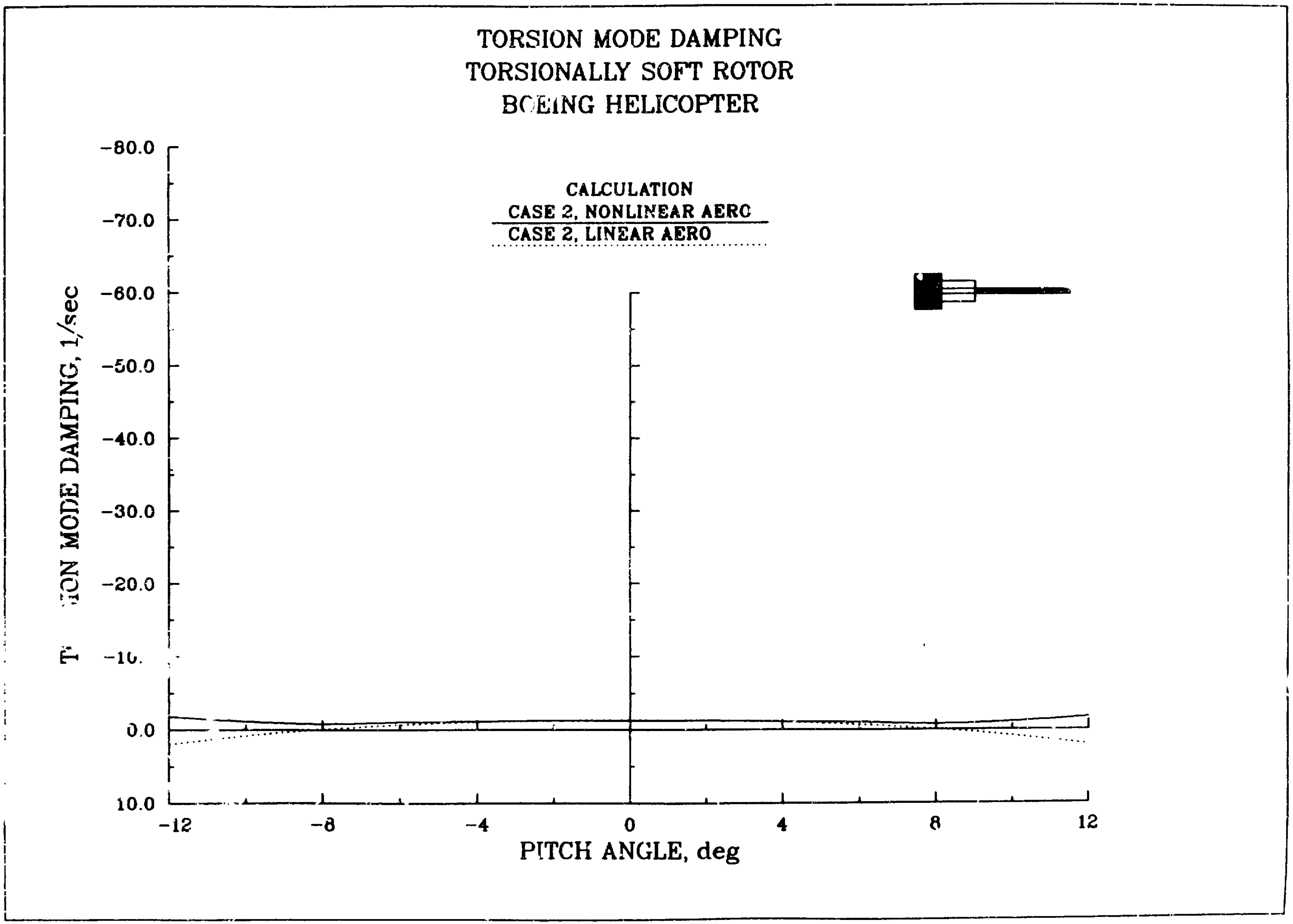


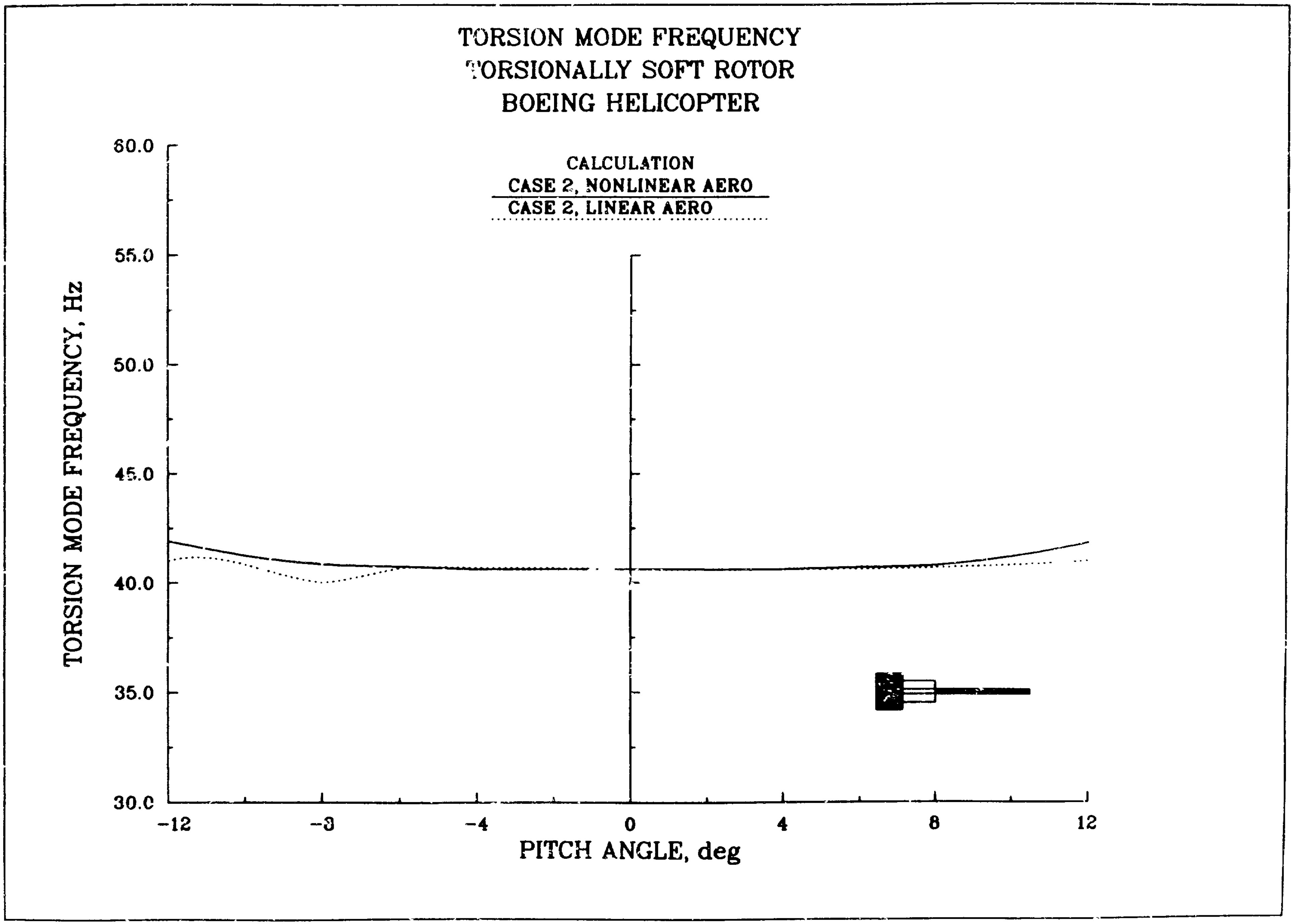
FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
FLAP MODE DAMPING, 1/sec
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

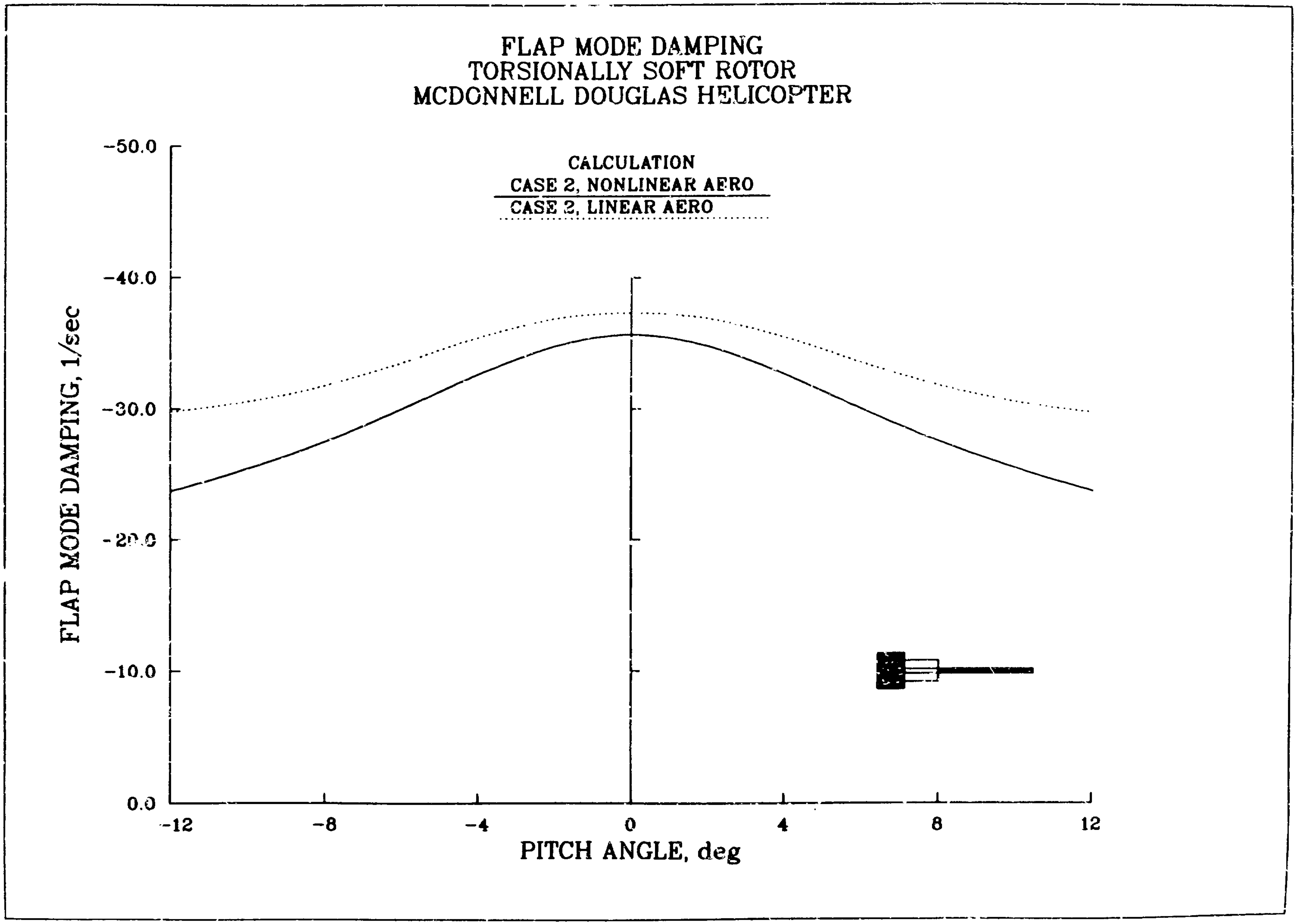

FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

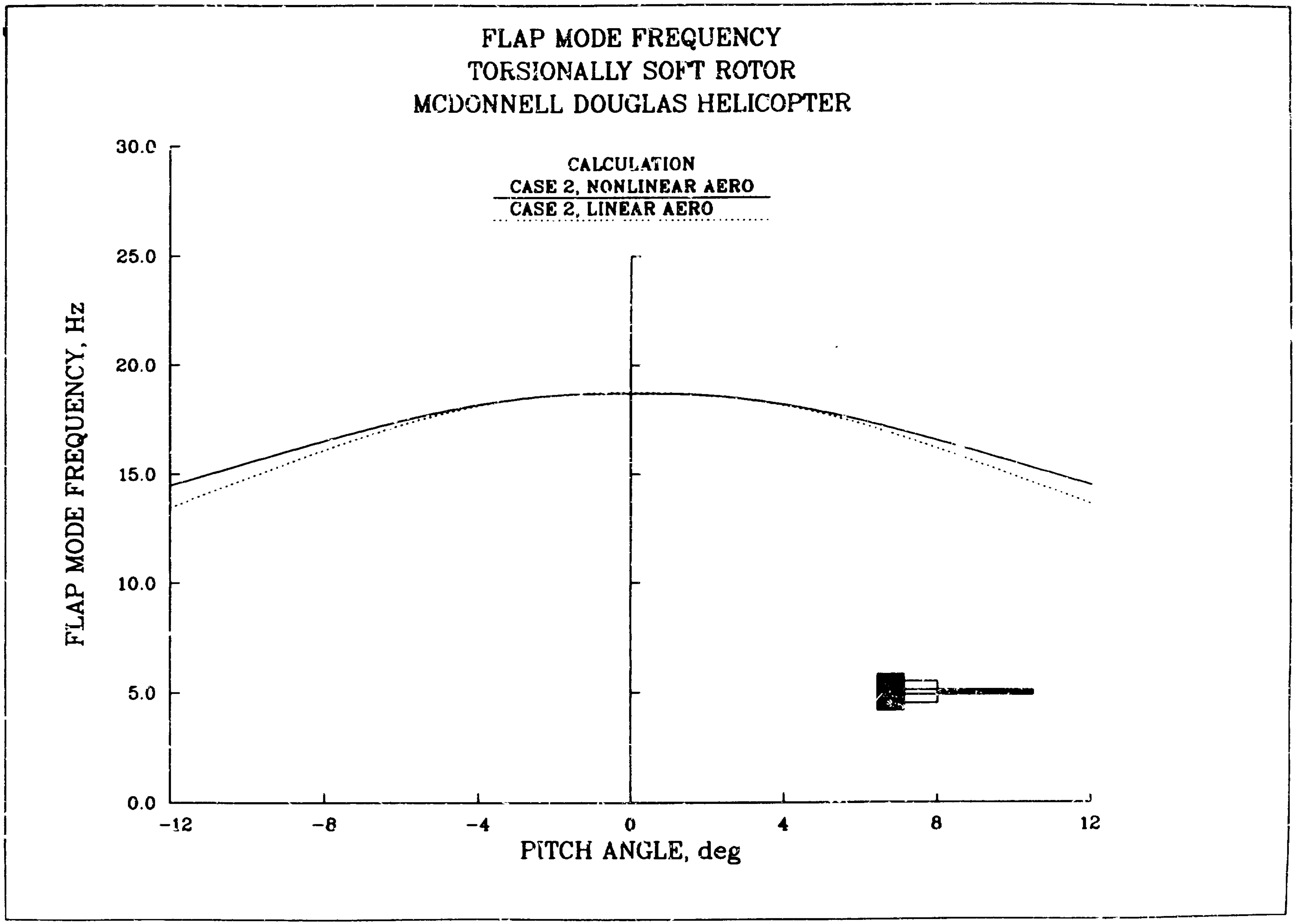

LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
LEAD–LAG MODE DAMPING, 1/sec
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

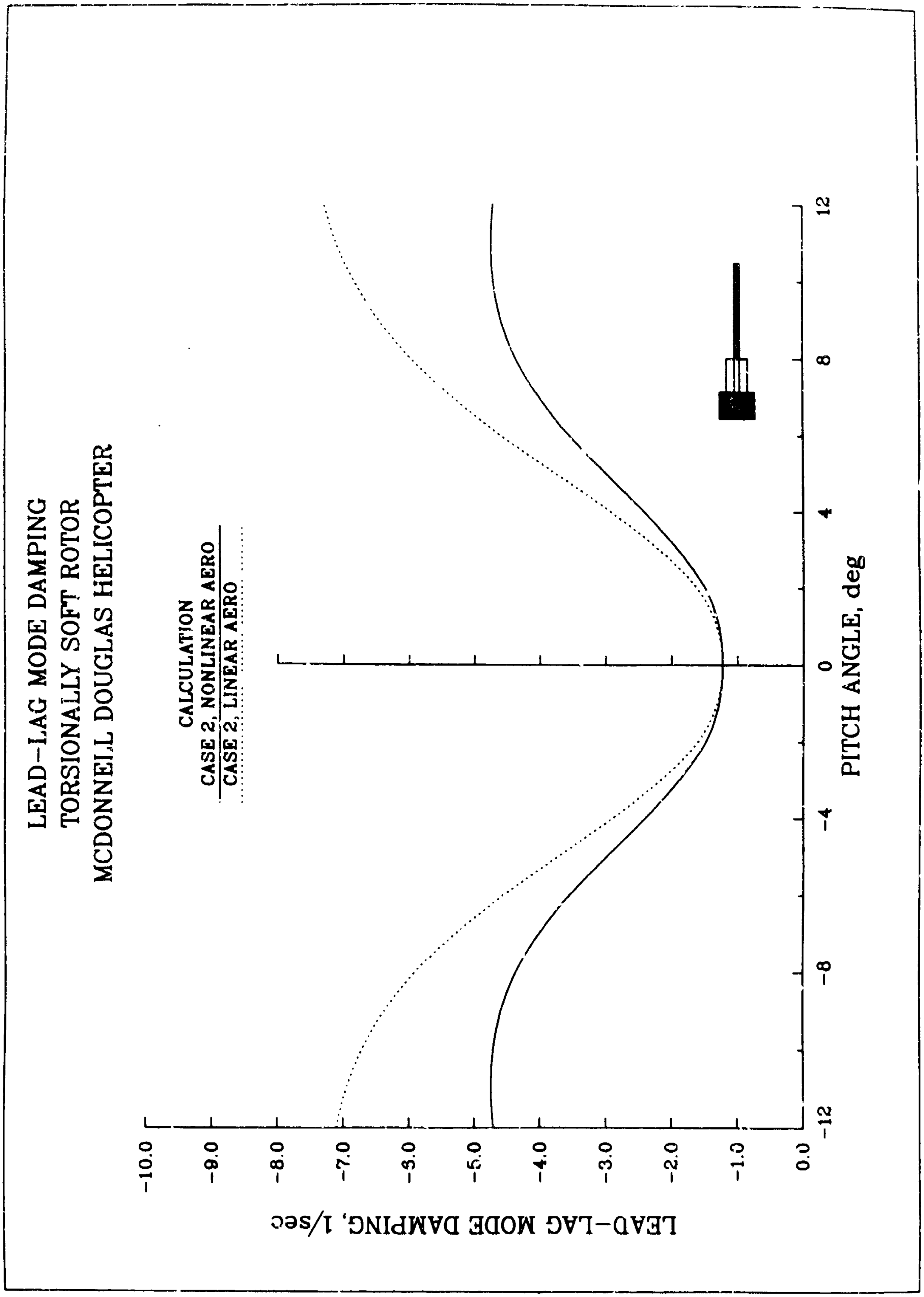

LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
LEAD–LAG MODE FREQUENCY, Hz
30.0
28.0
26.0
24.0
22.0
20.0
–12
–8
–4
0
4
8
12
PITCH ANGLE, deg


TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

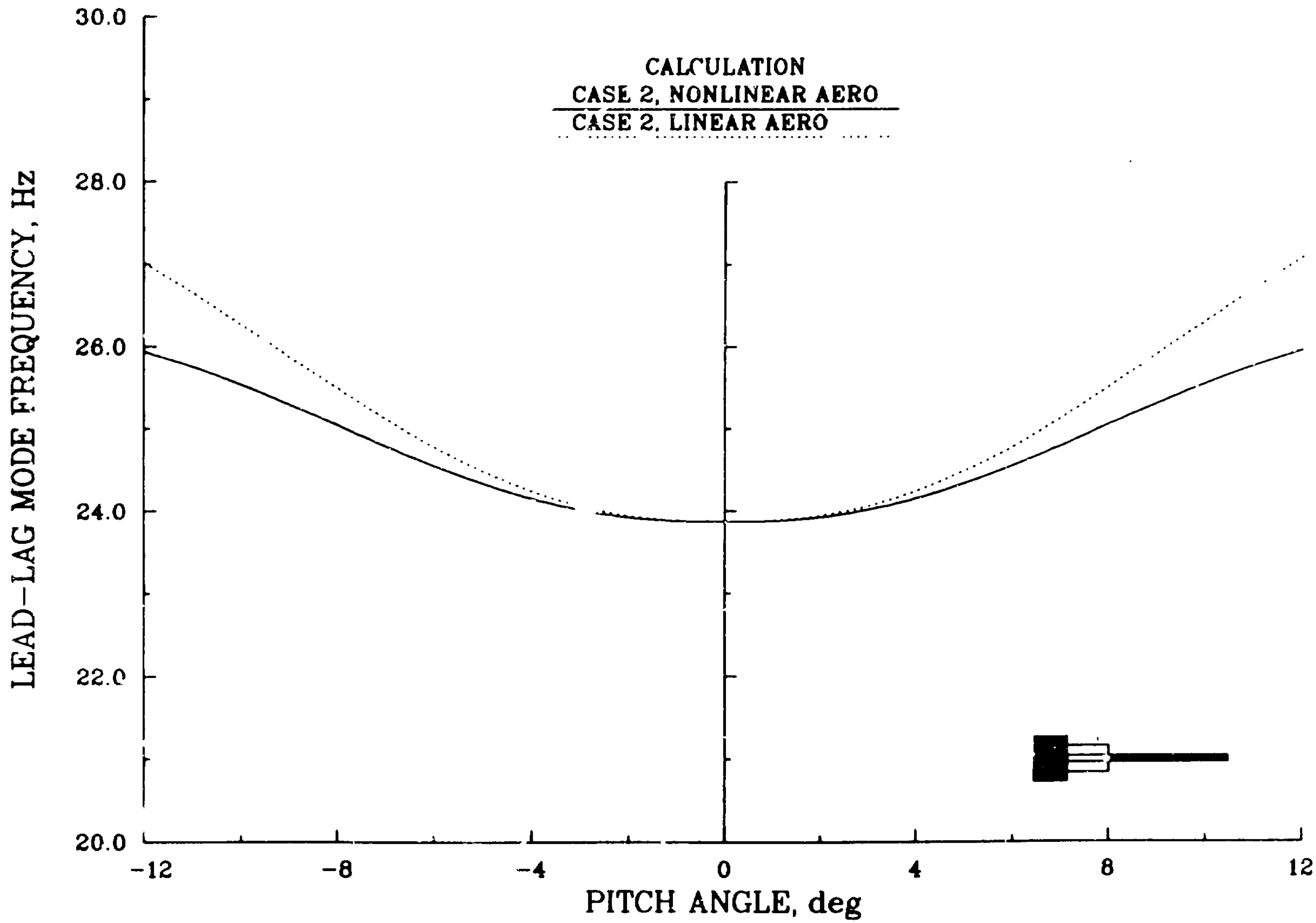

TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
−12
−3
−4
0
4
8
12
PITCH ANGLE, deg

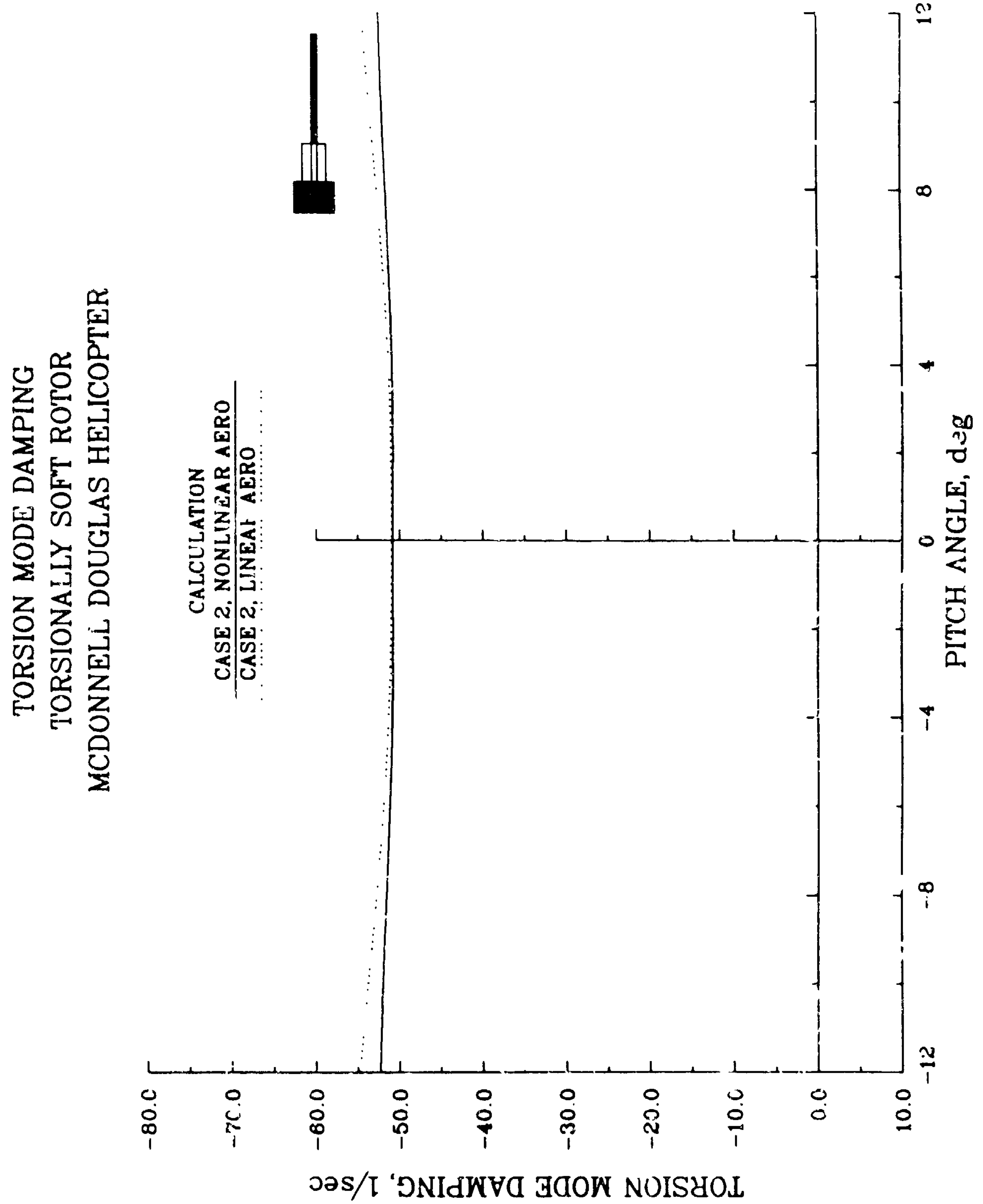

FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE DAMPING, 1/sec
-50.0
-40.0
-30.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

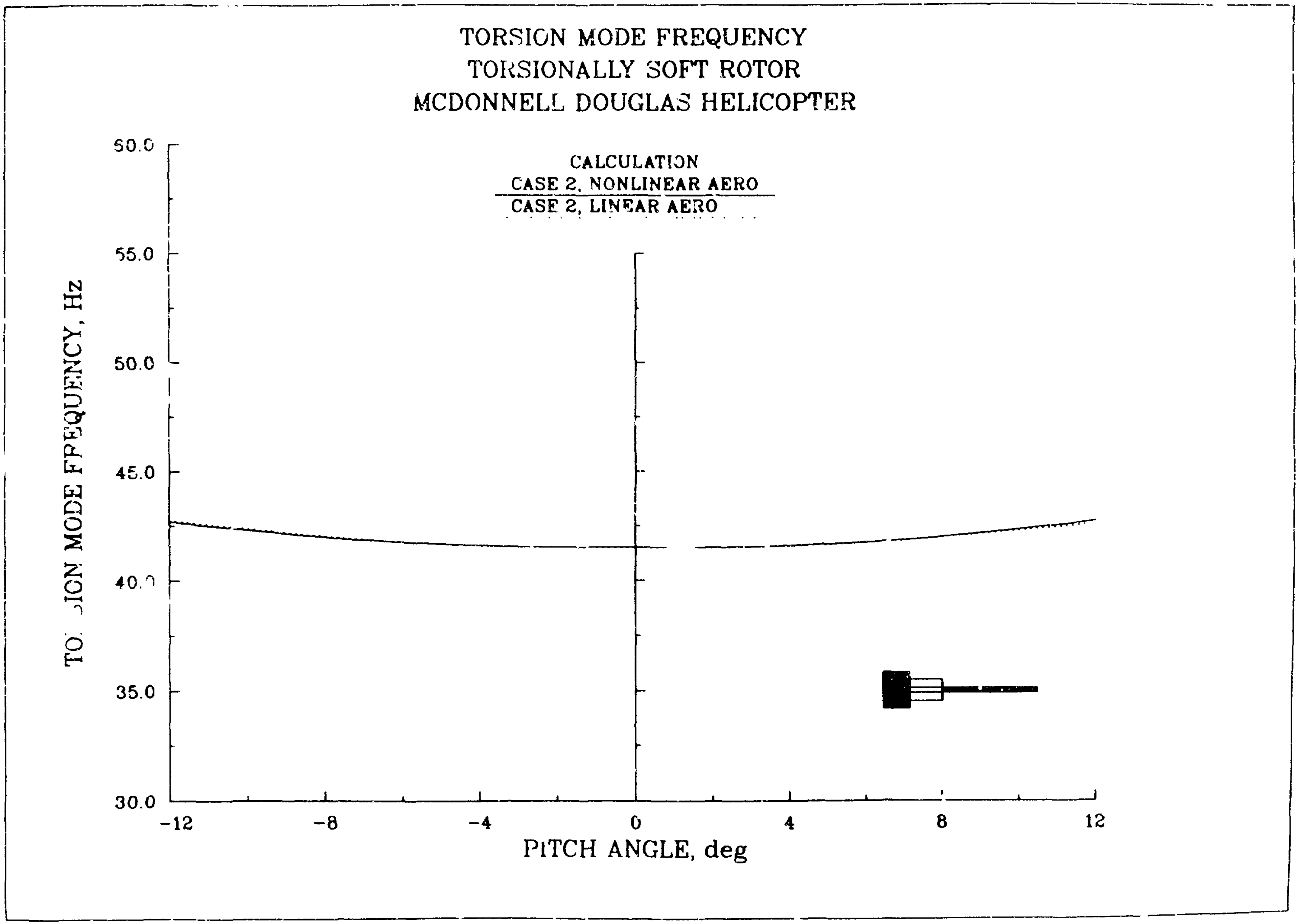

FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

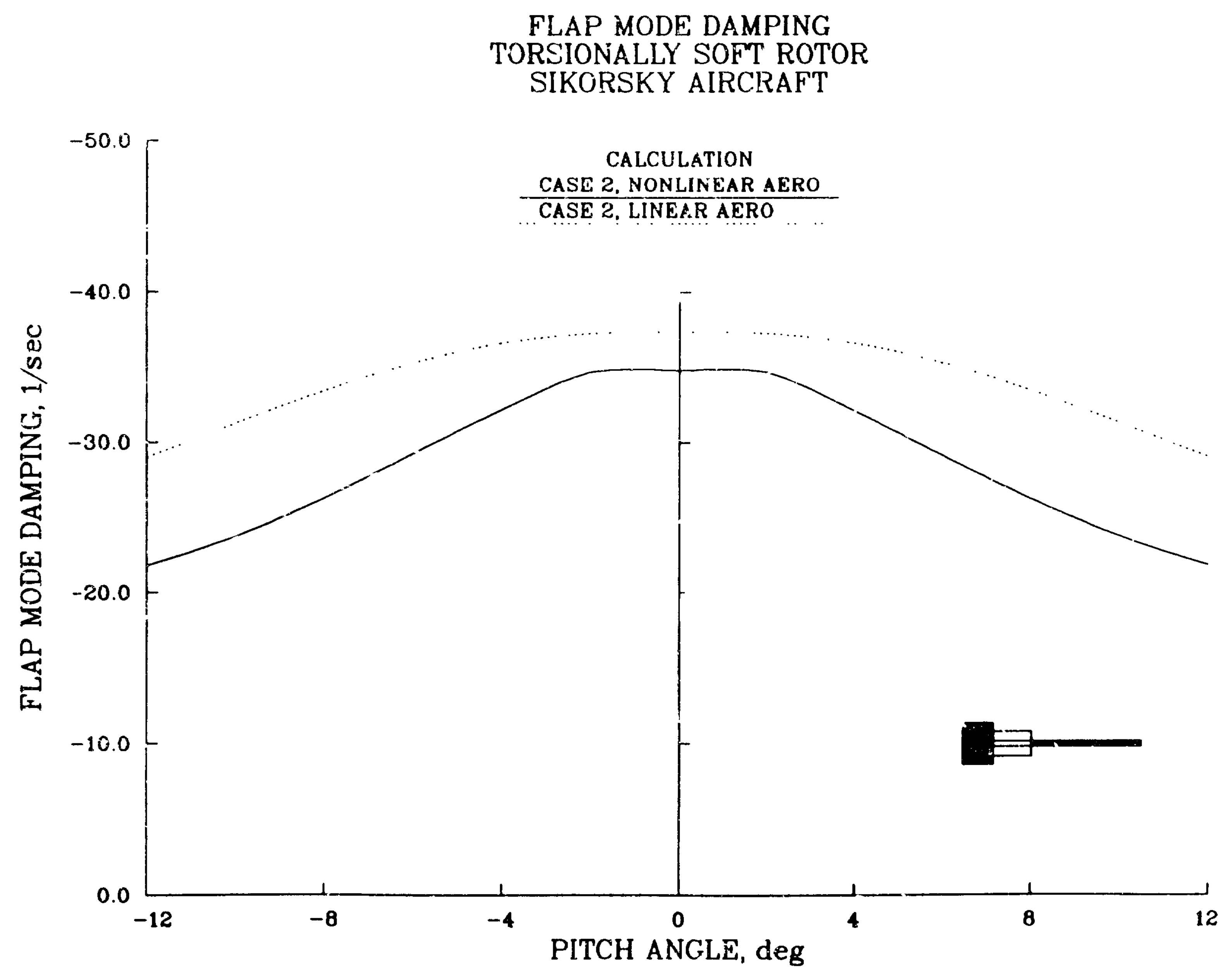

LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
LEAD–LAG MODE DAMPING, 1/sec
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
PITCH ANGLE, deg
-12
-8
-4
0
4
8
12

LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER

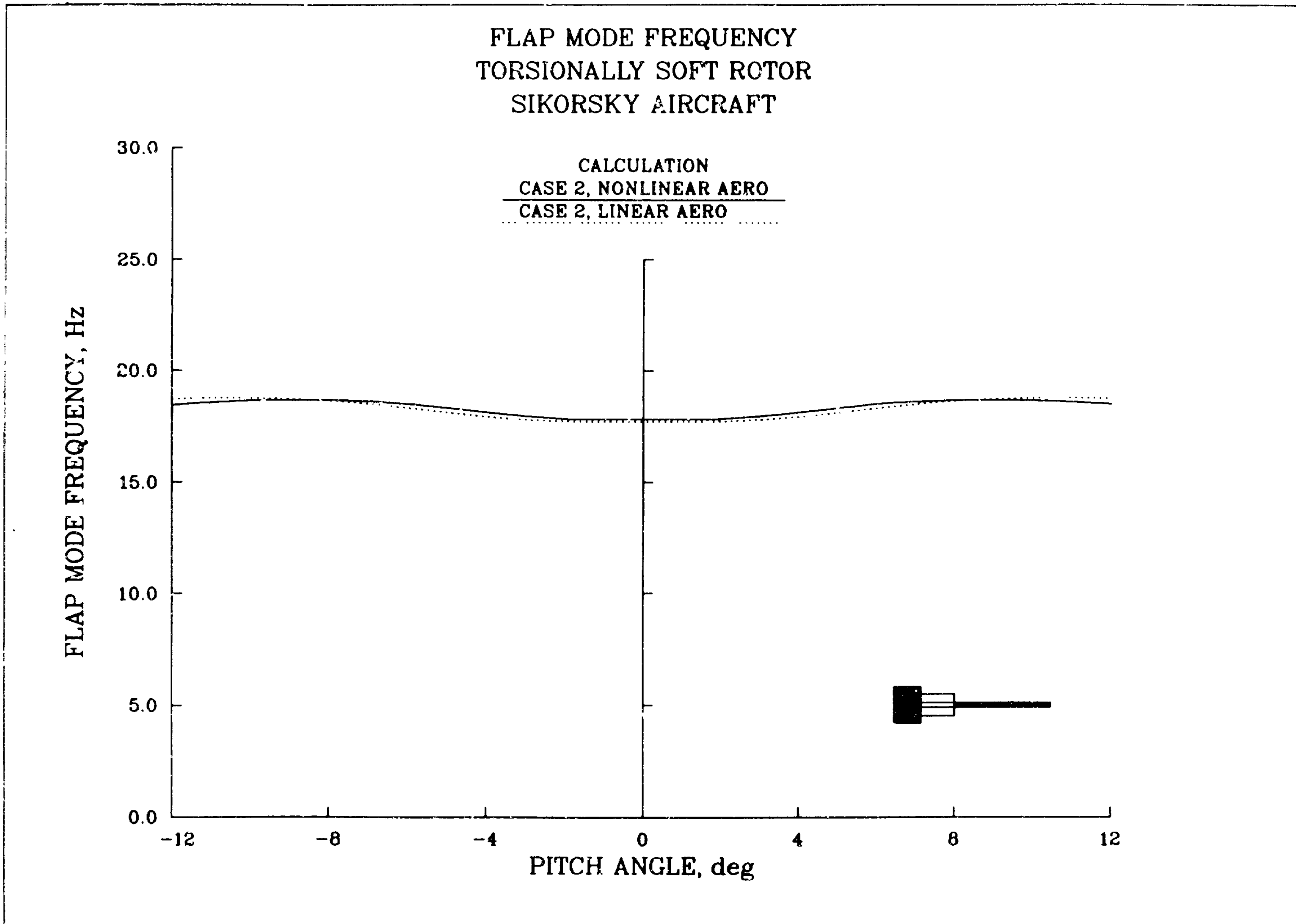


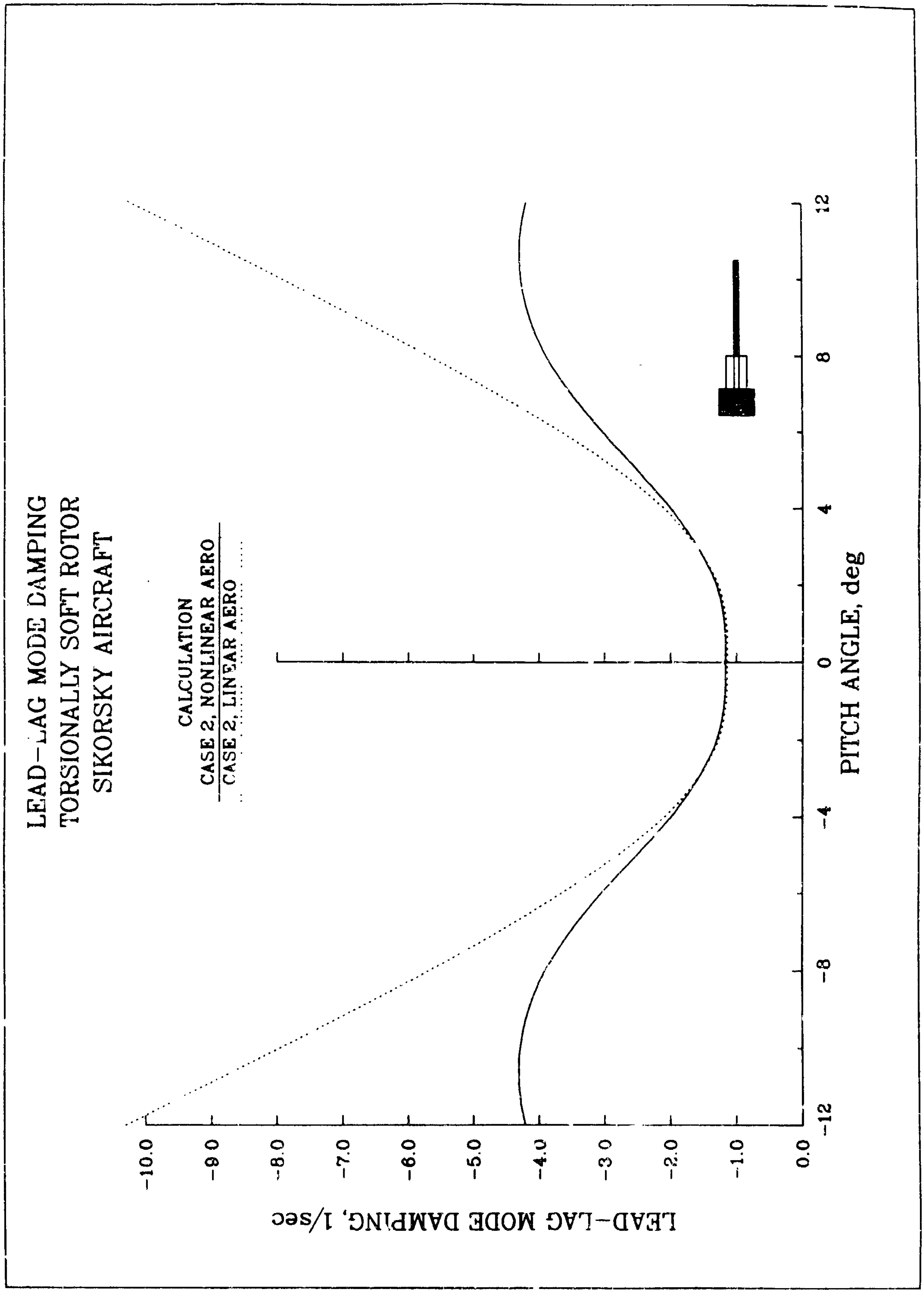

TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
35.0
30.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

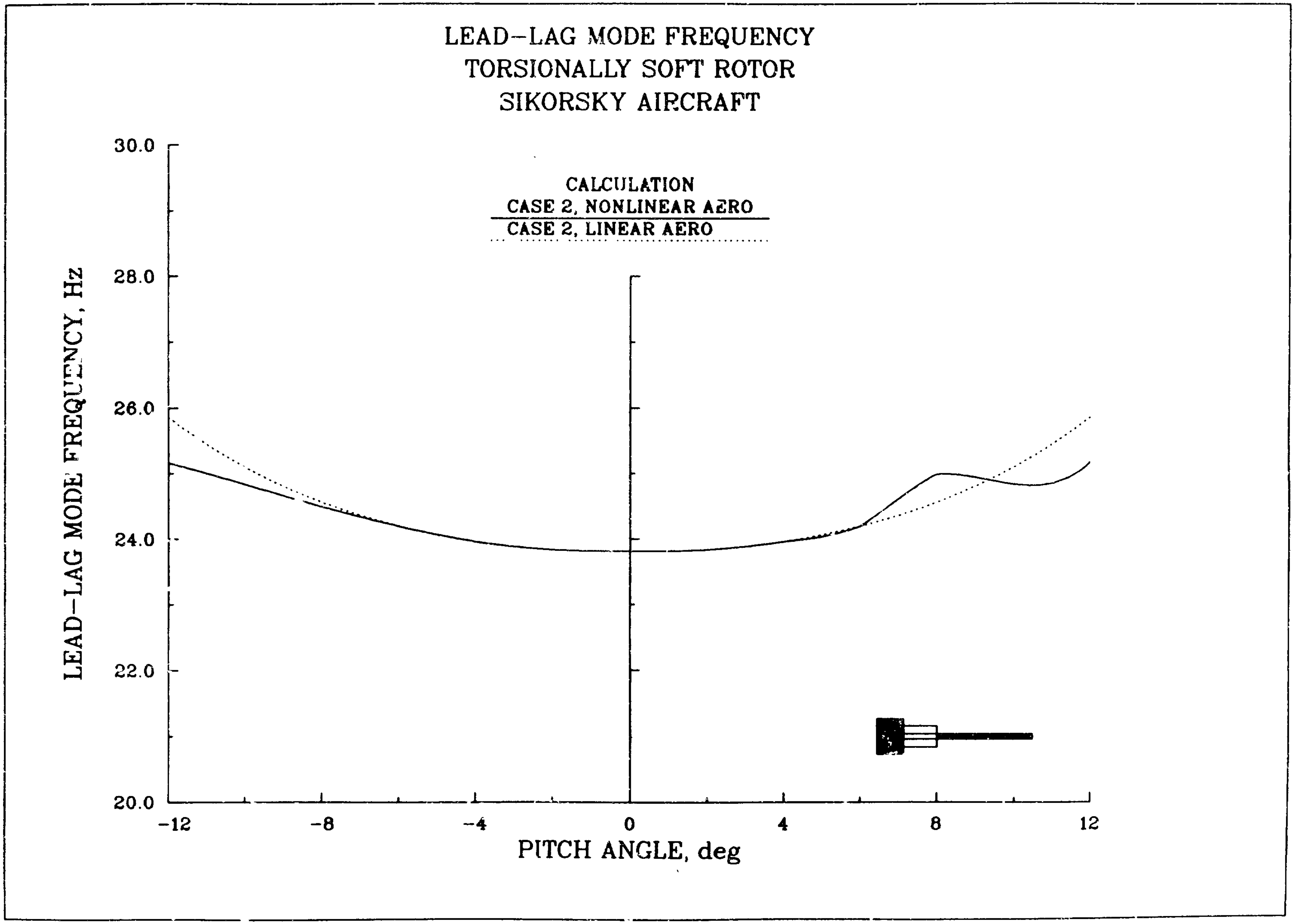


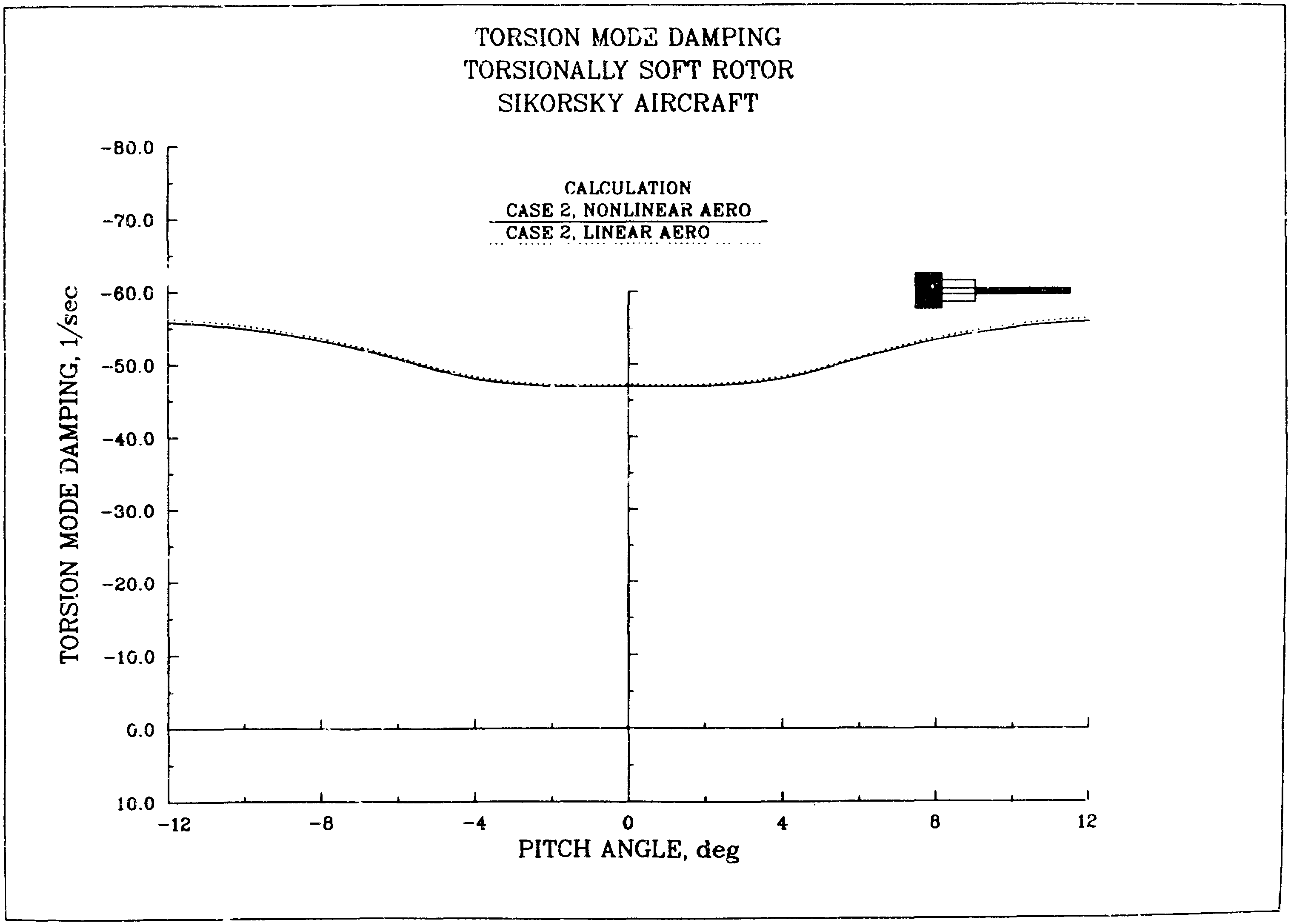
FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE DAMPING, 1/sec
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

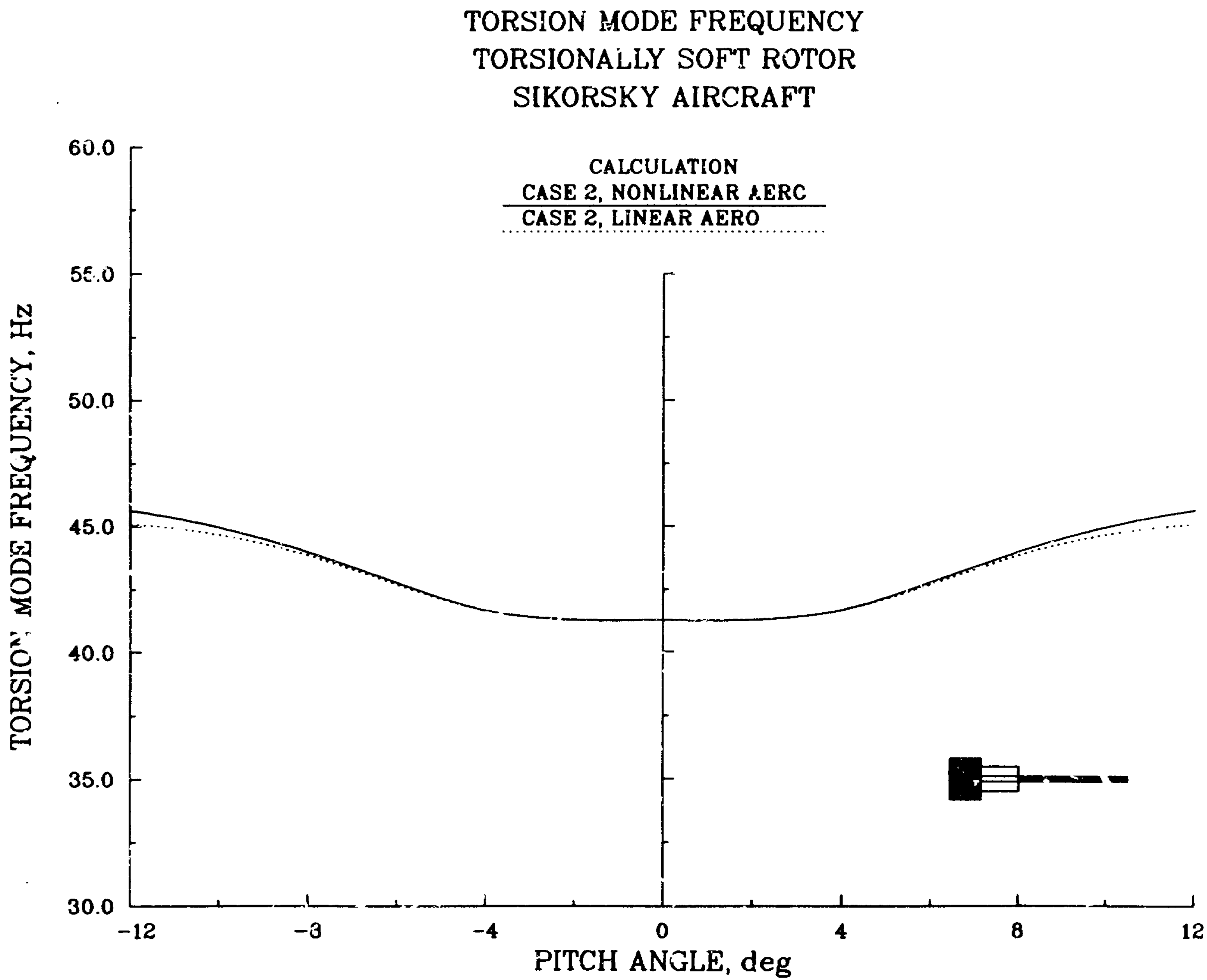

FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

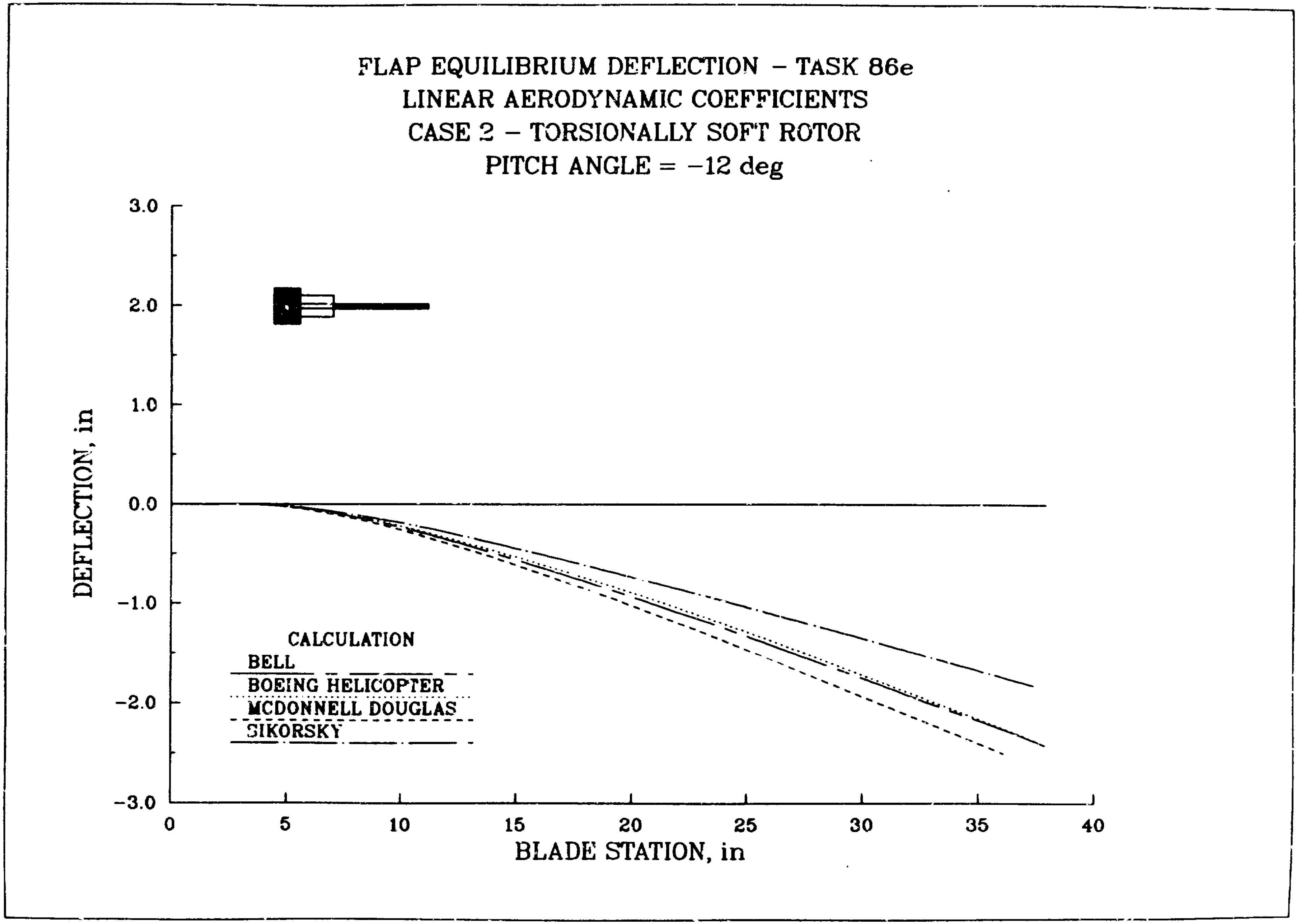


LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
LEAD–LAG MODE DAMPING, 1/sec
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
PITCH ANGLE, deg
-12
-8
-4
0
4
8
12

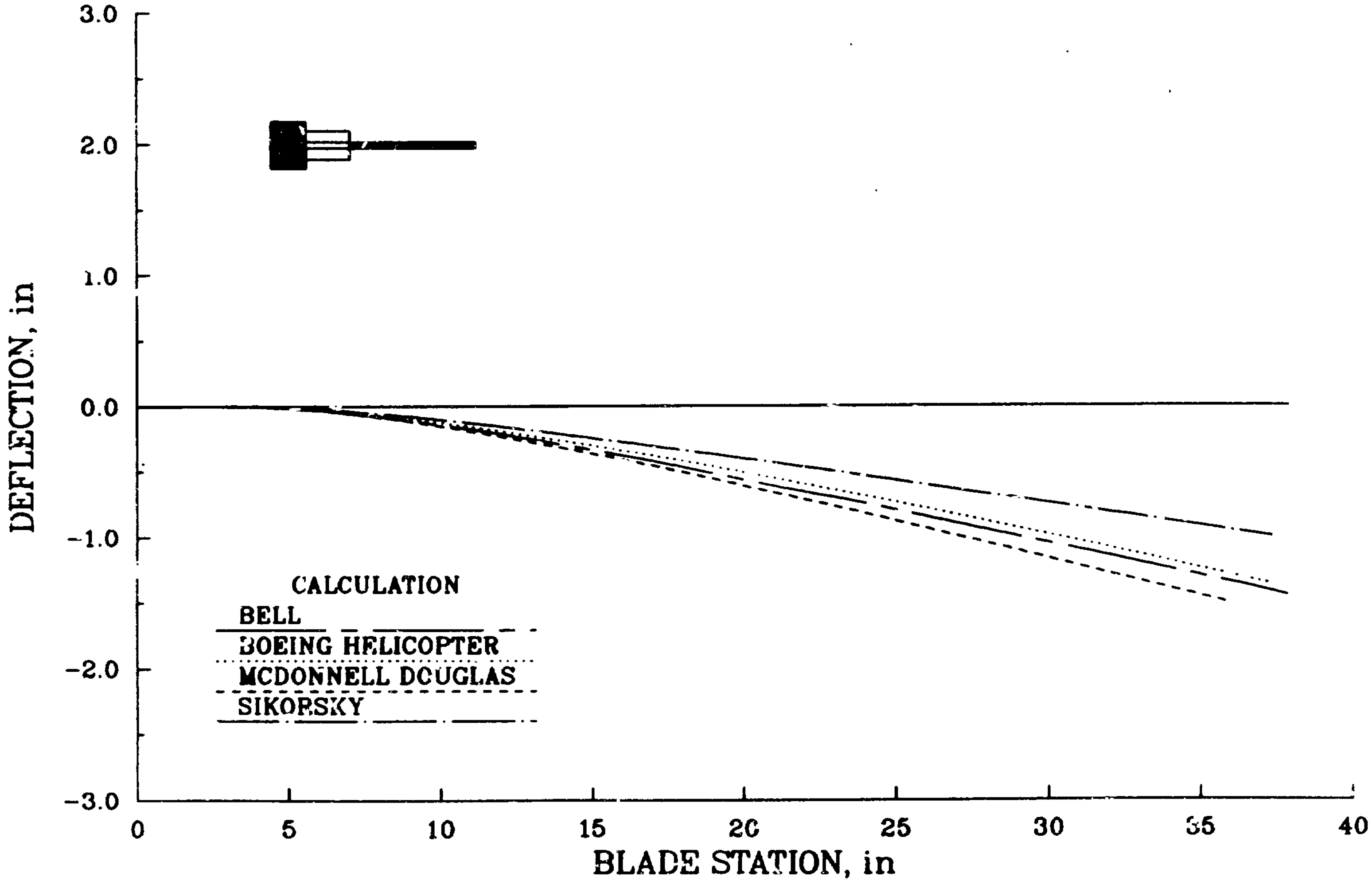

LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
30.0
28.0
26.0
24.0
22.0
20.0
LEAD–LAG MODE FREQUENCY, Hz
–12
–8
–4
0
4
8
12
PITCH ANGLE, deg

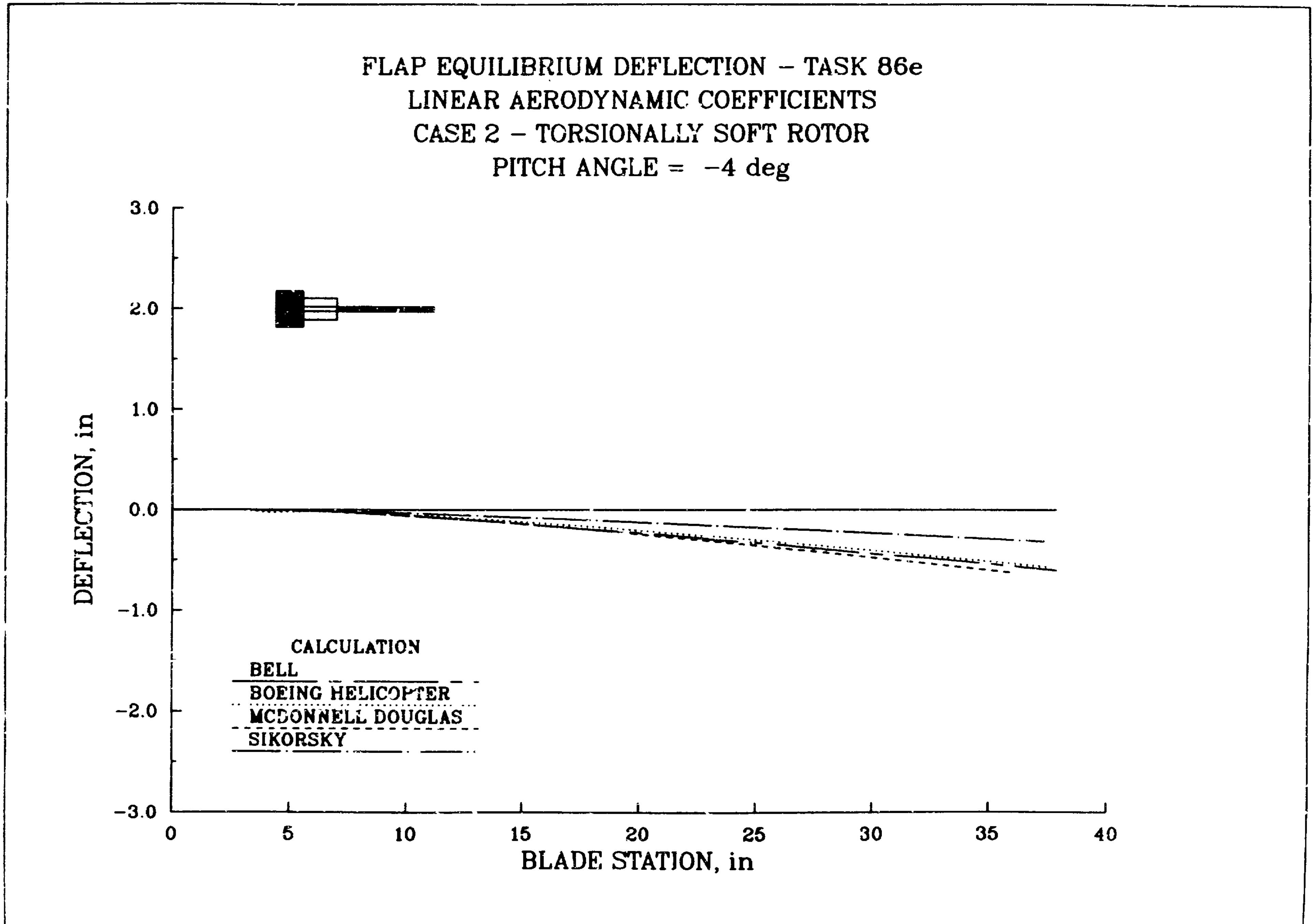

TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
PITCH ANGLE, deg
-12
-3
-4
0
4
8
12


FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
DEFLECTION, in
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

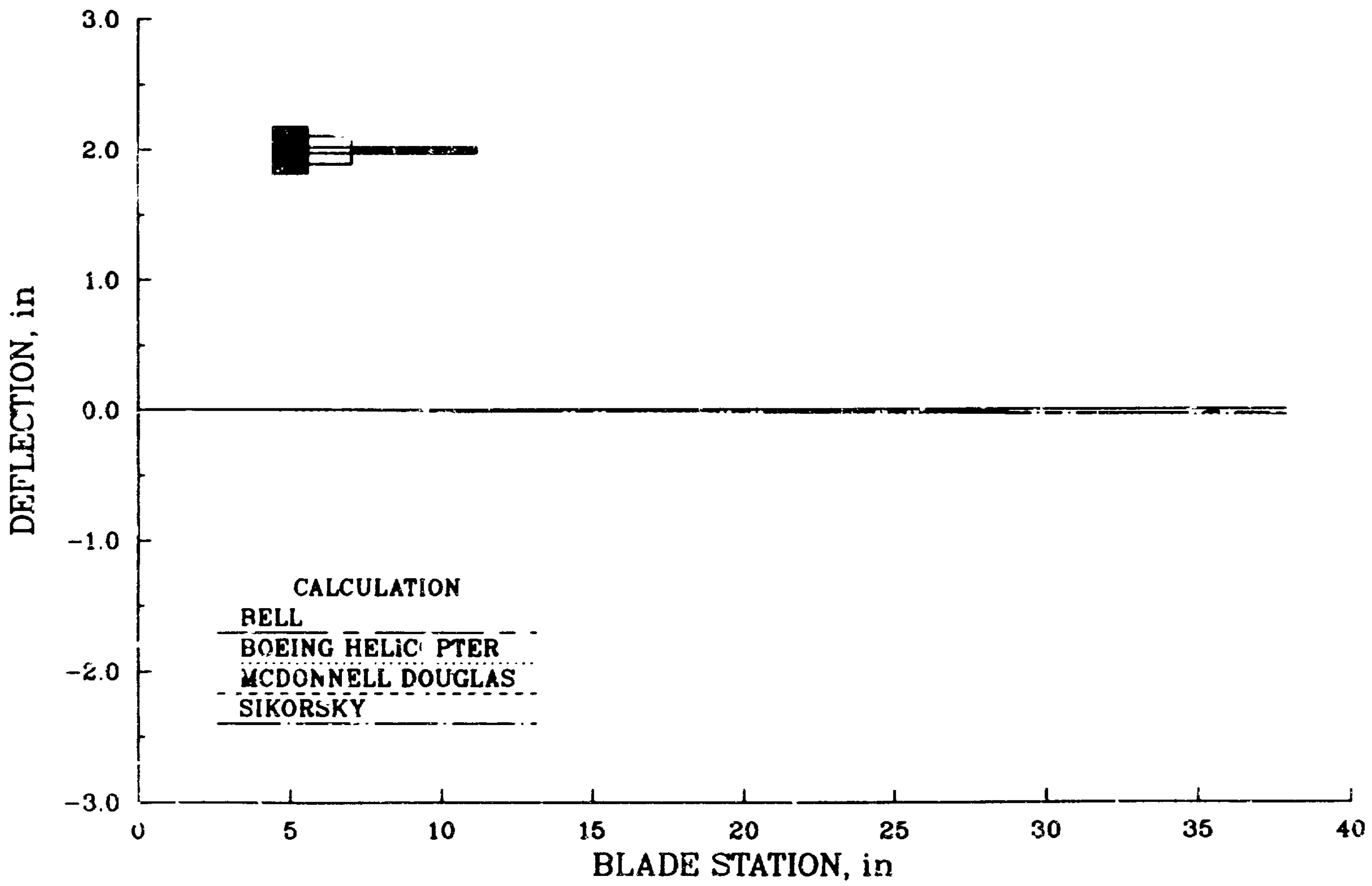
FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg

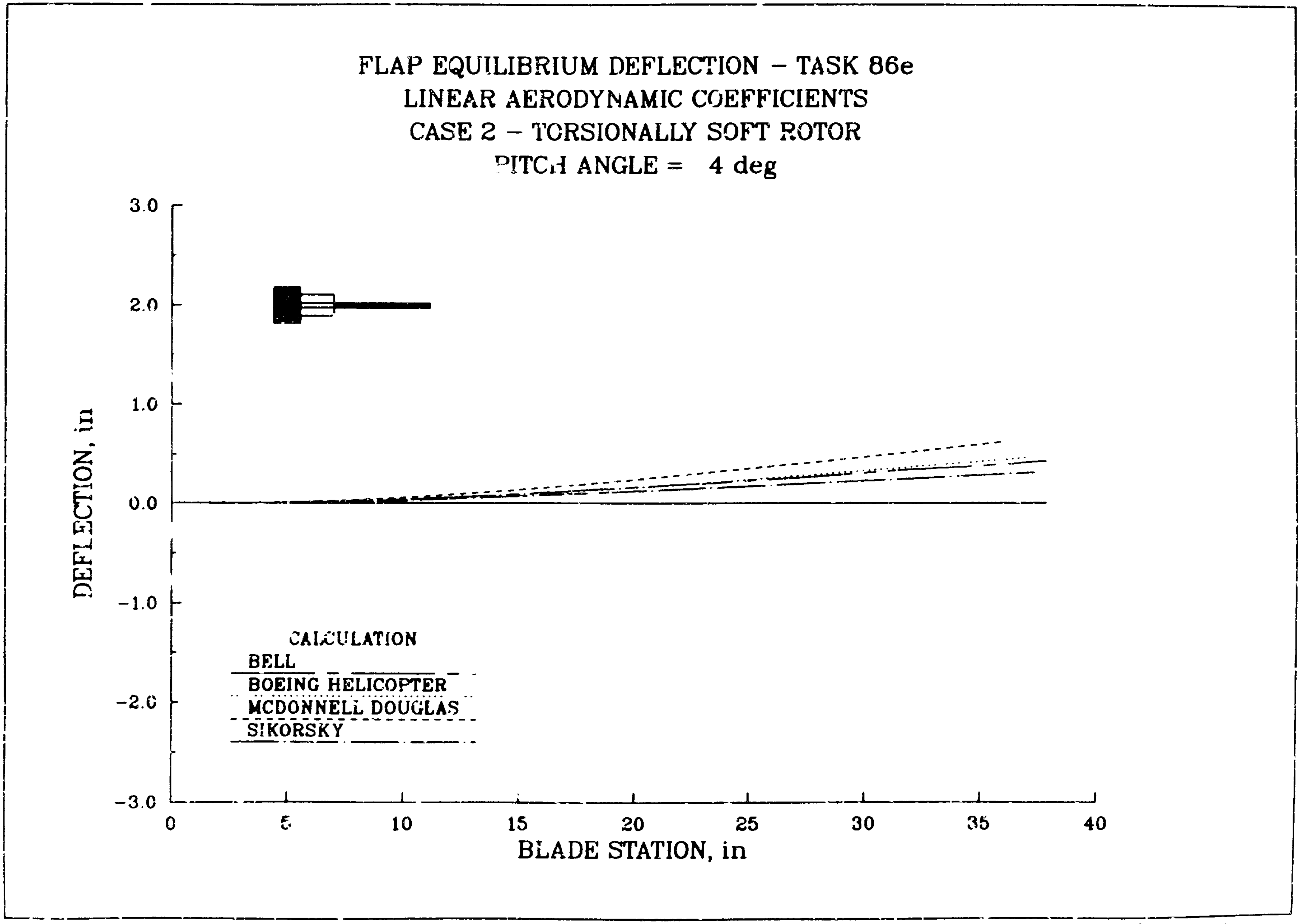


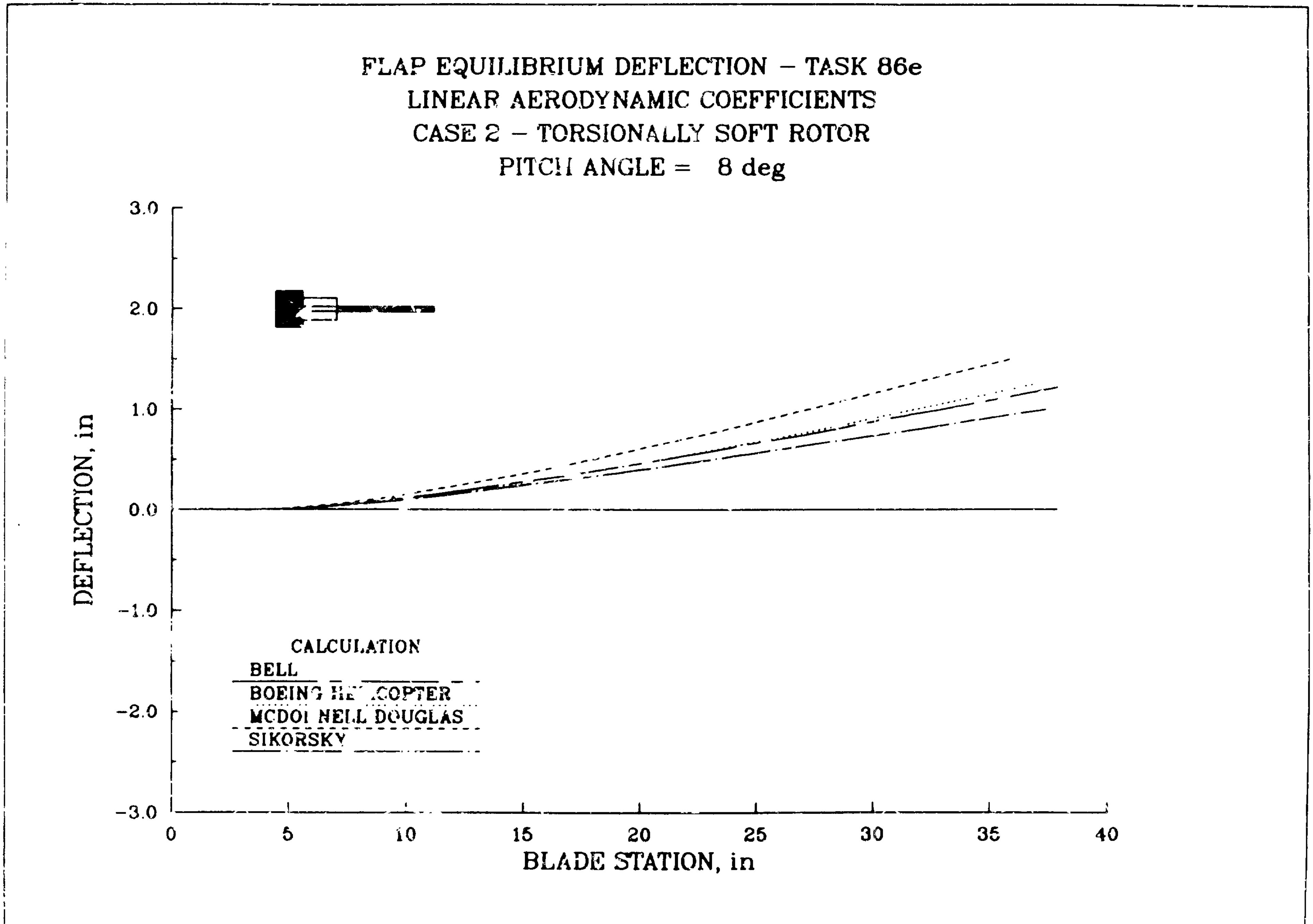


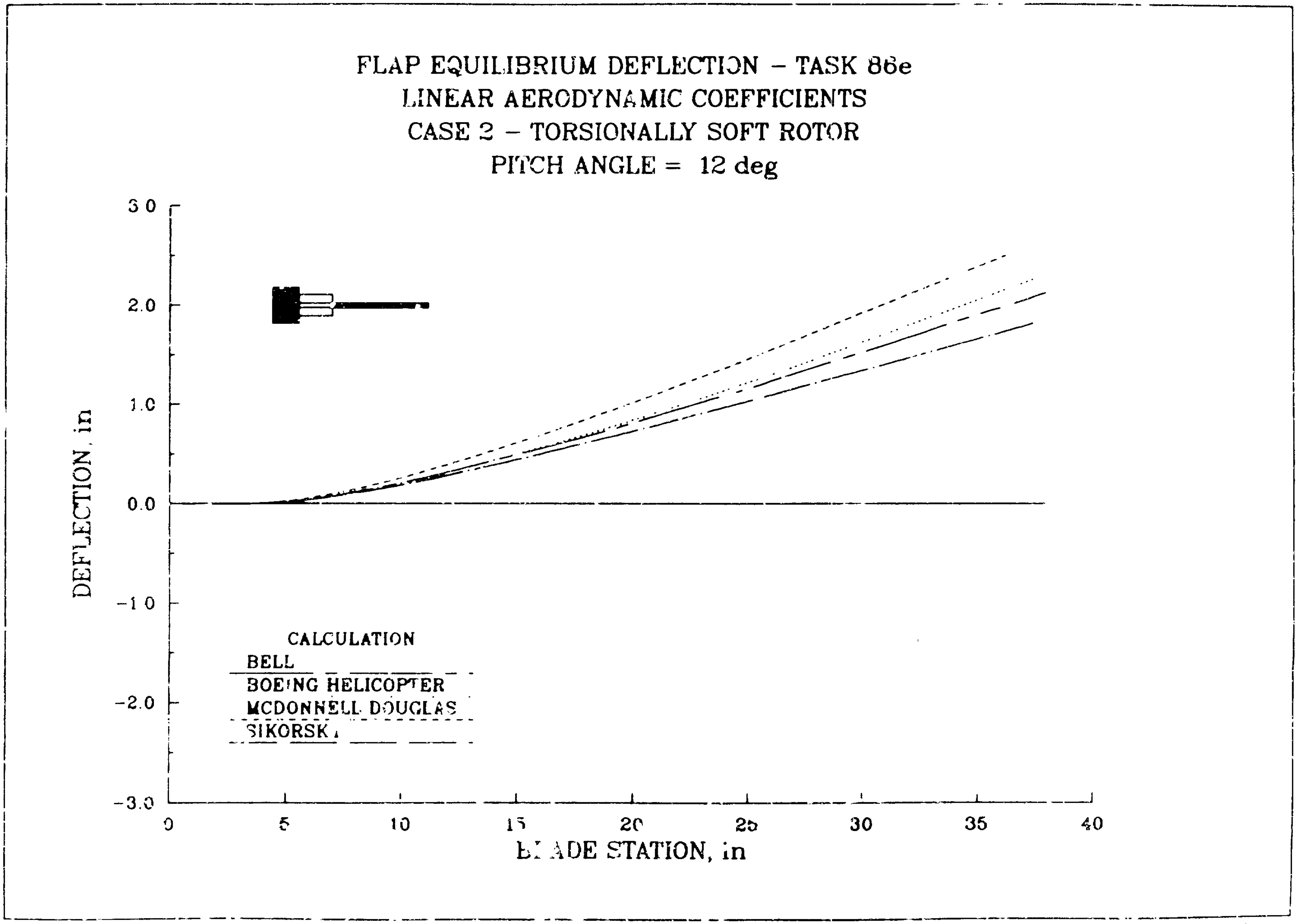
FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
–1.0
–2.0
–3.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg

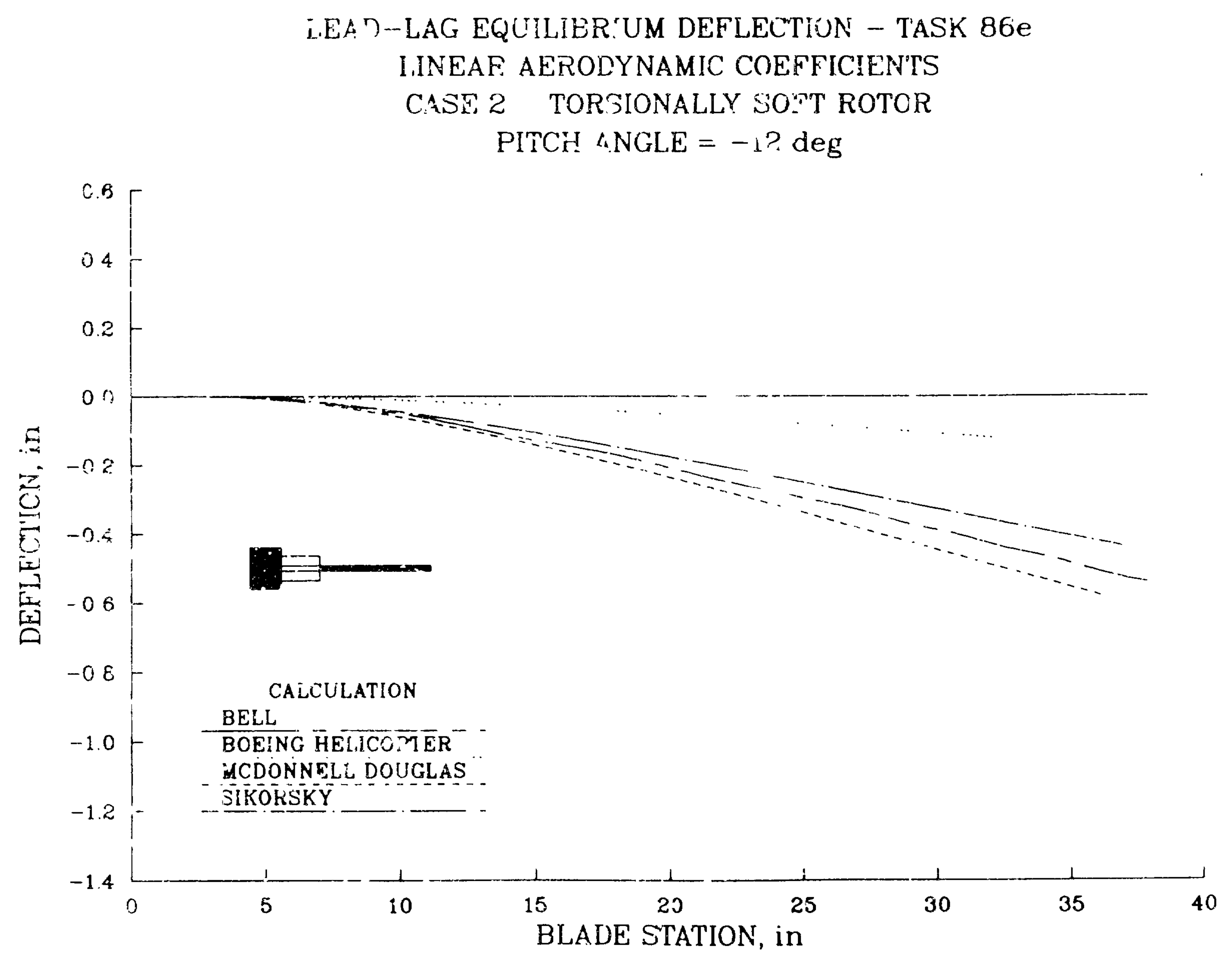



FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
DEFLECTION, in
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

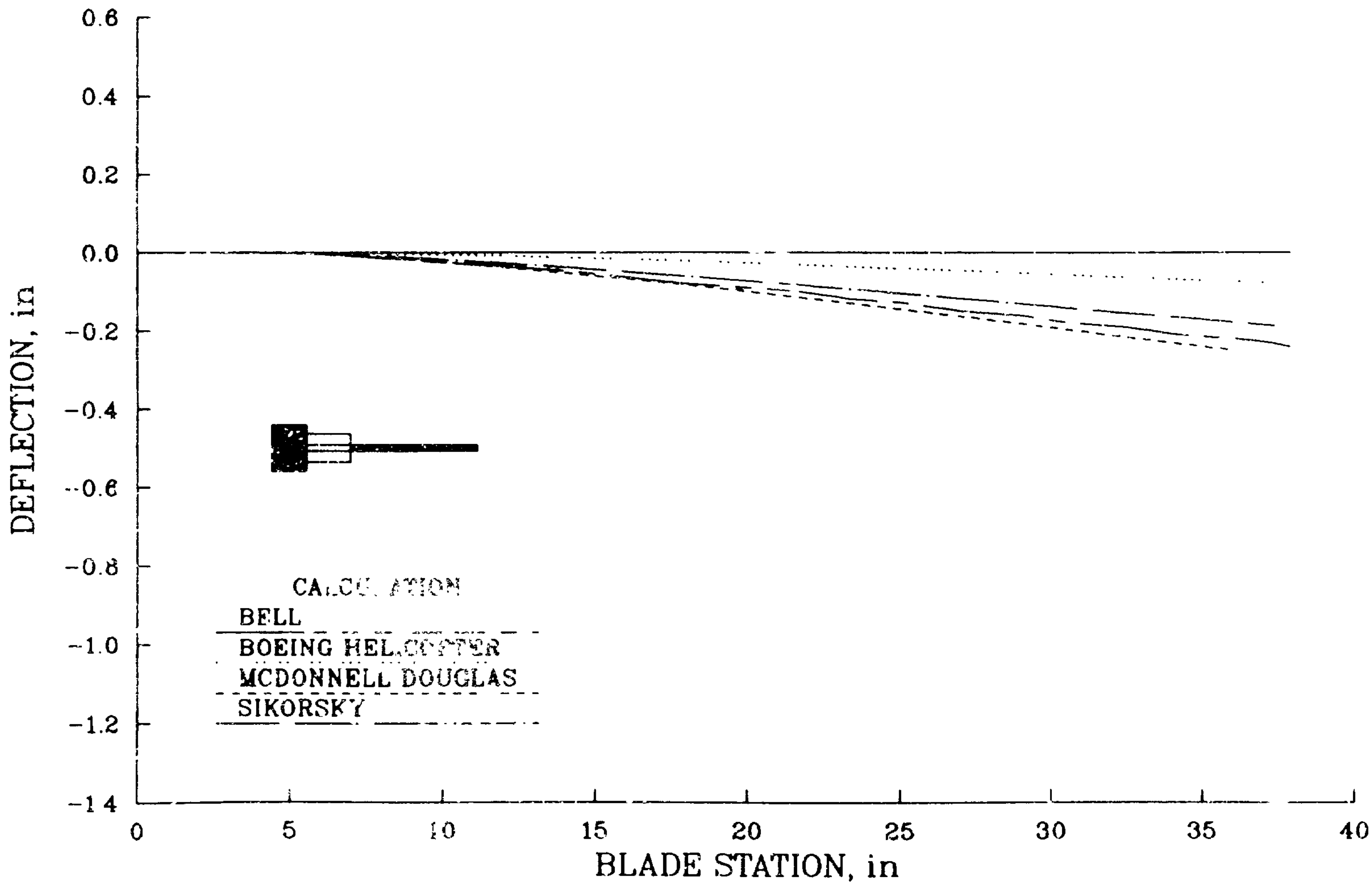

FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
DEFLECTION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY
0
5
10
15
20
25
30
35
40
BLADE STATION, in

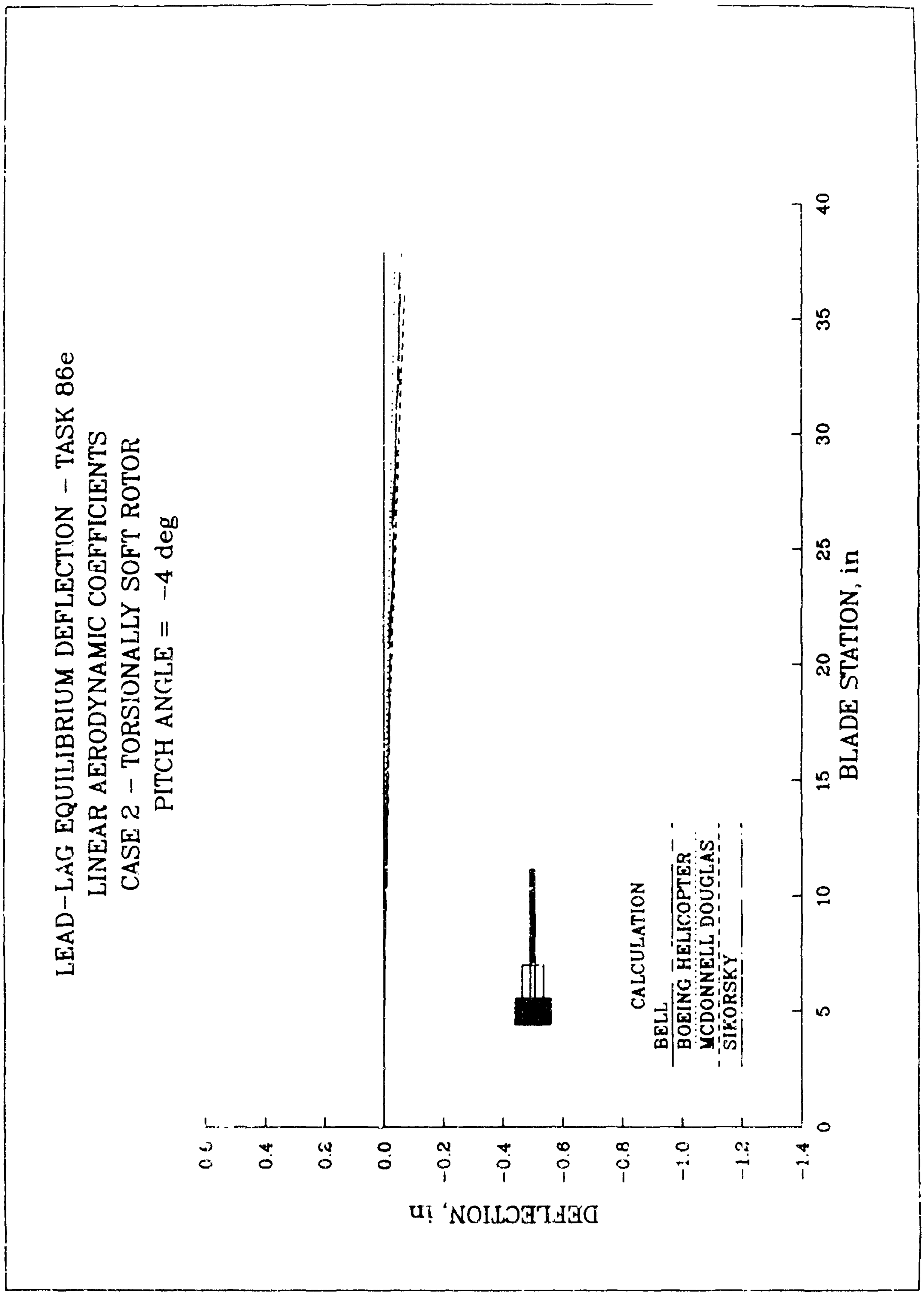


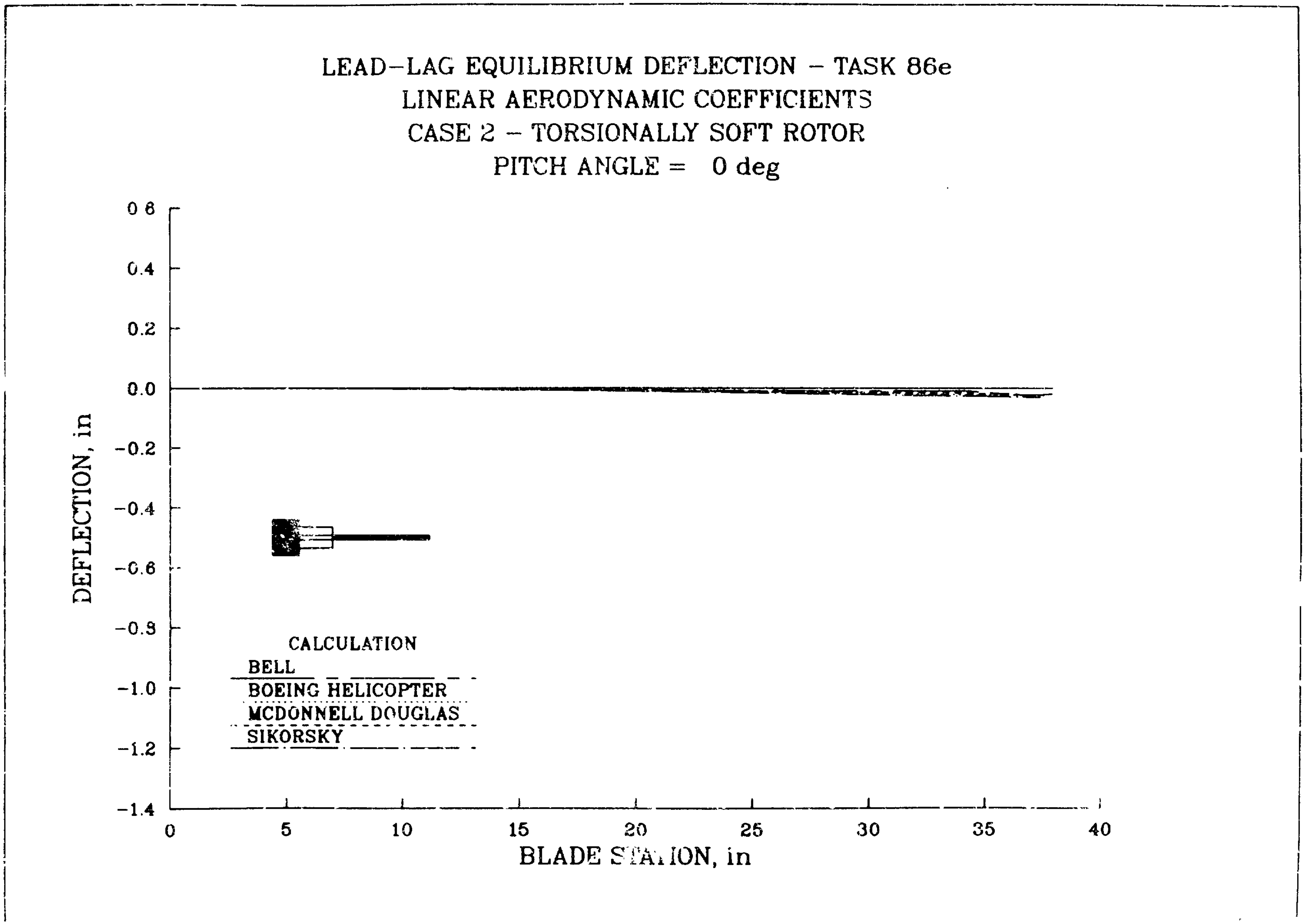
FLAP EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0
5
10
20
30
35
40
STATION, in
CALCULATION
BELL
MCDONNELL DOUGLAS

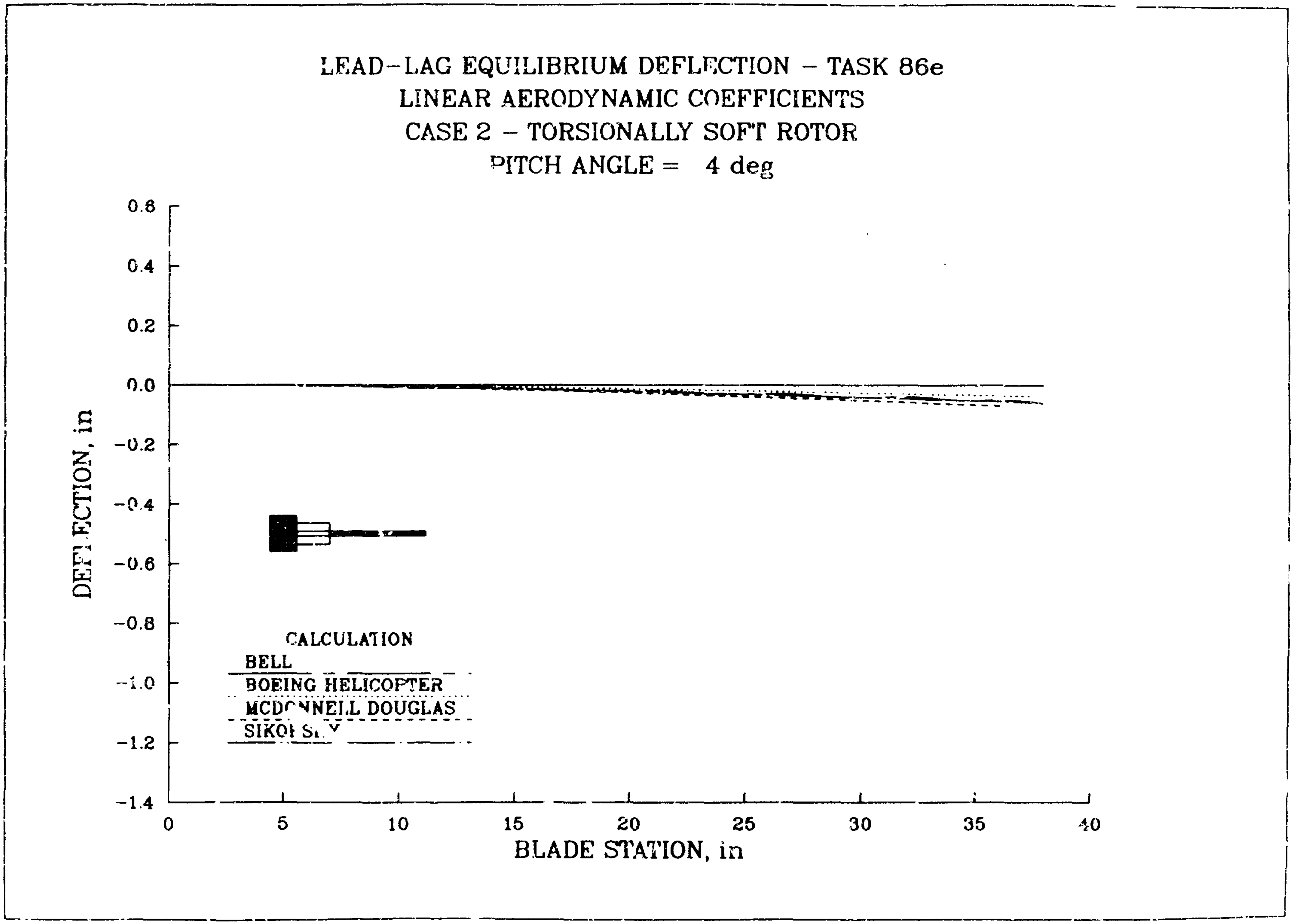

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
–0.2
–0.4
–0.6
–0.8
–1.0
–1.2
–1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

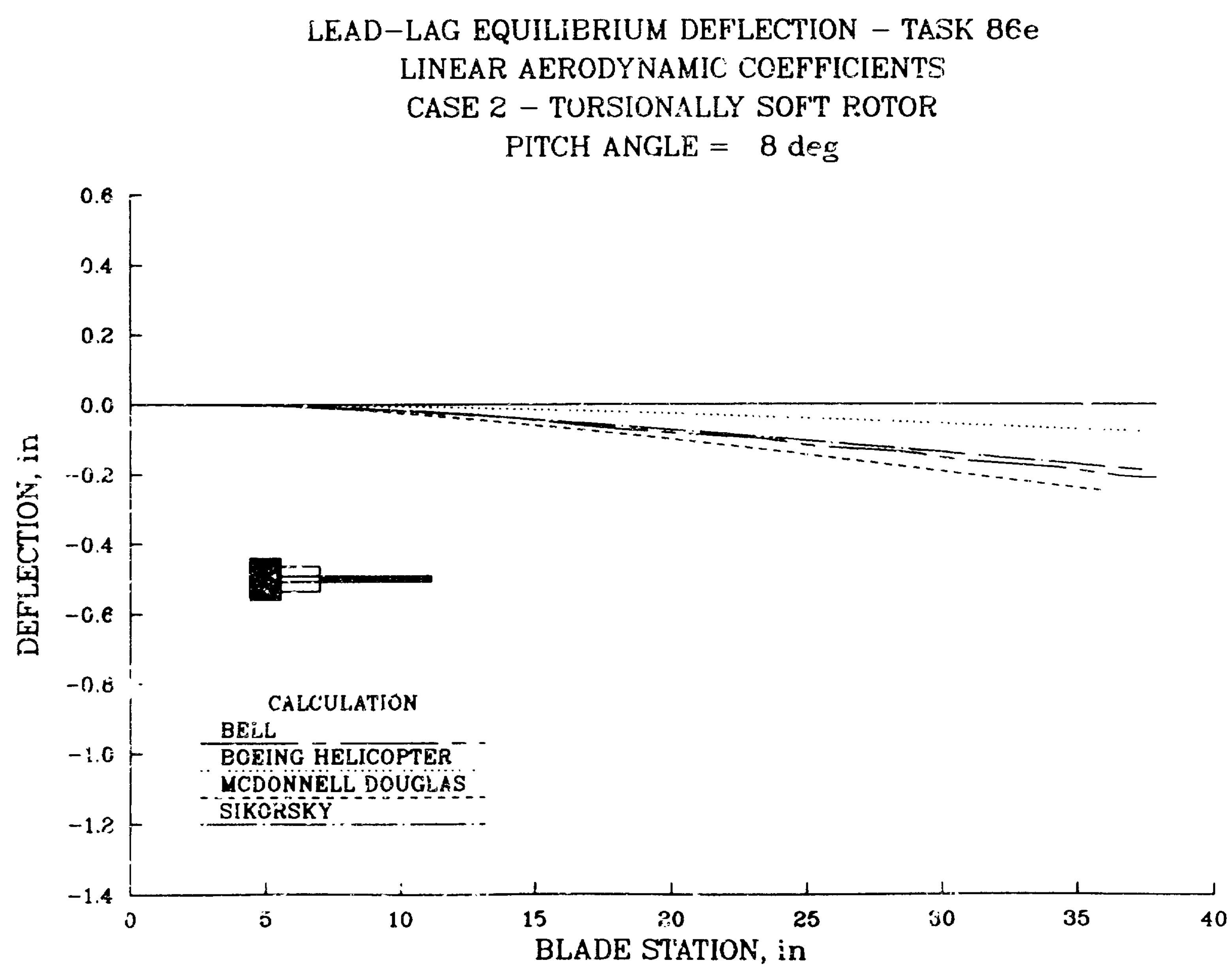
LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg



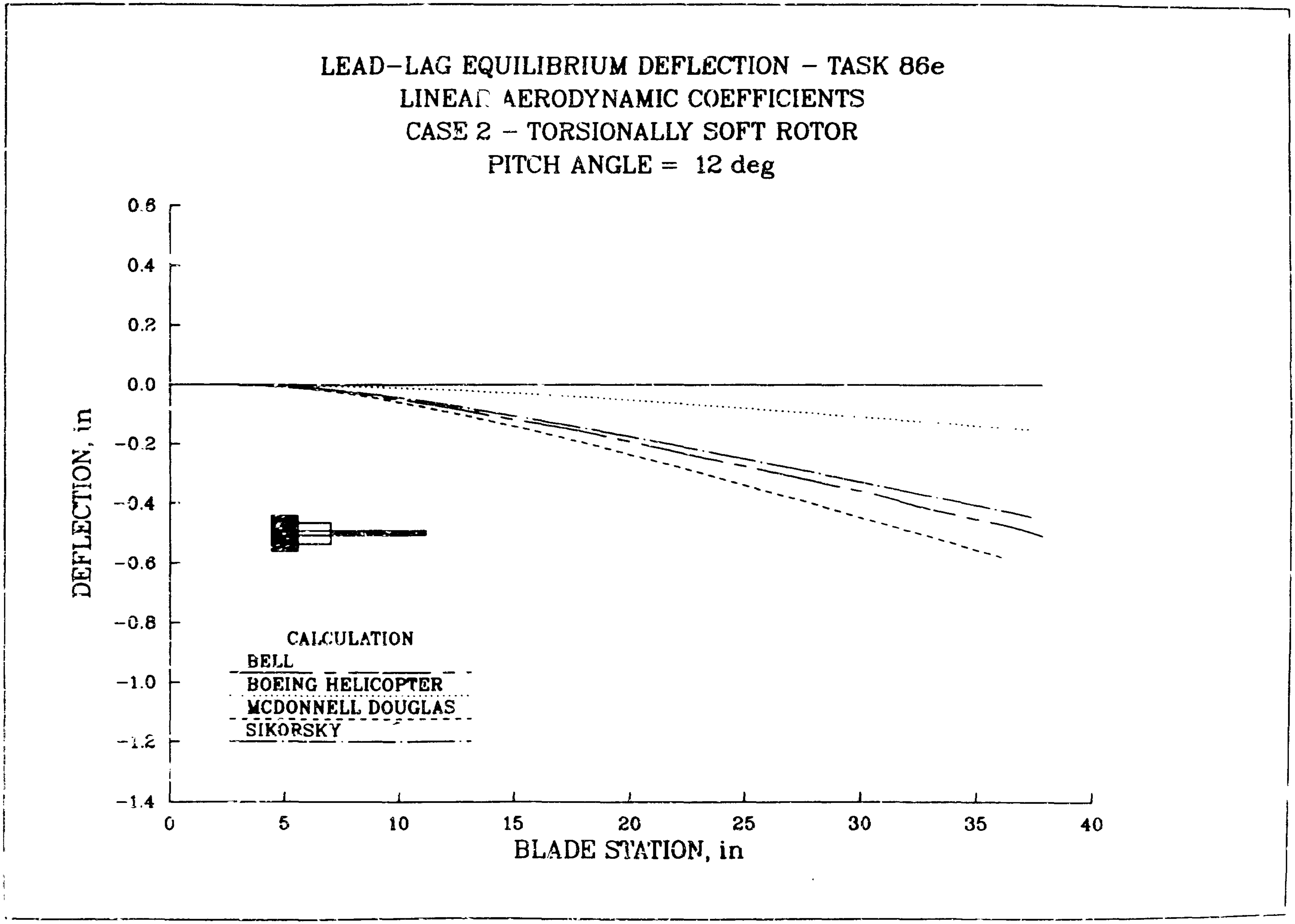

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = -4 deg
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY
DEFLECTION, in
BLADE STATION, in
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
0
5
10
15
20
25
30
35
40

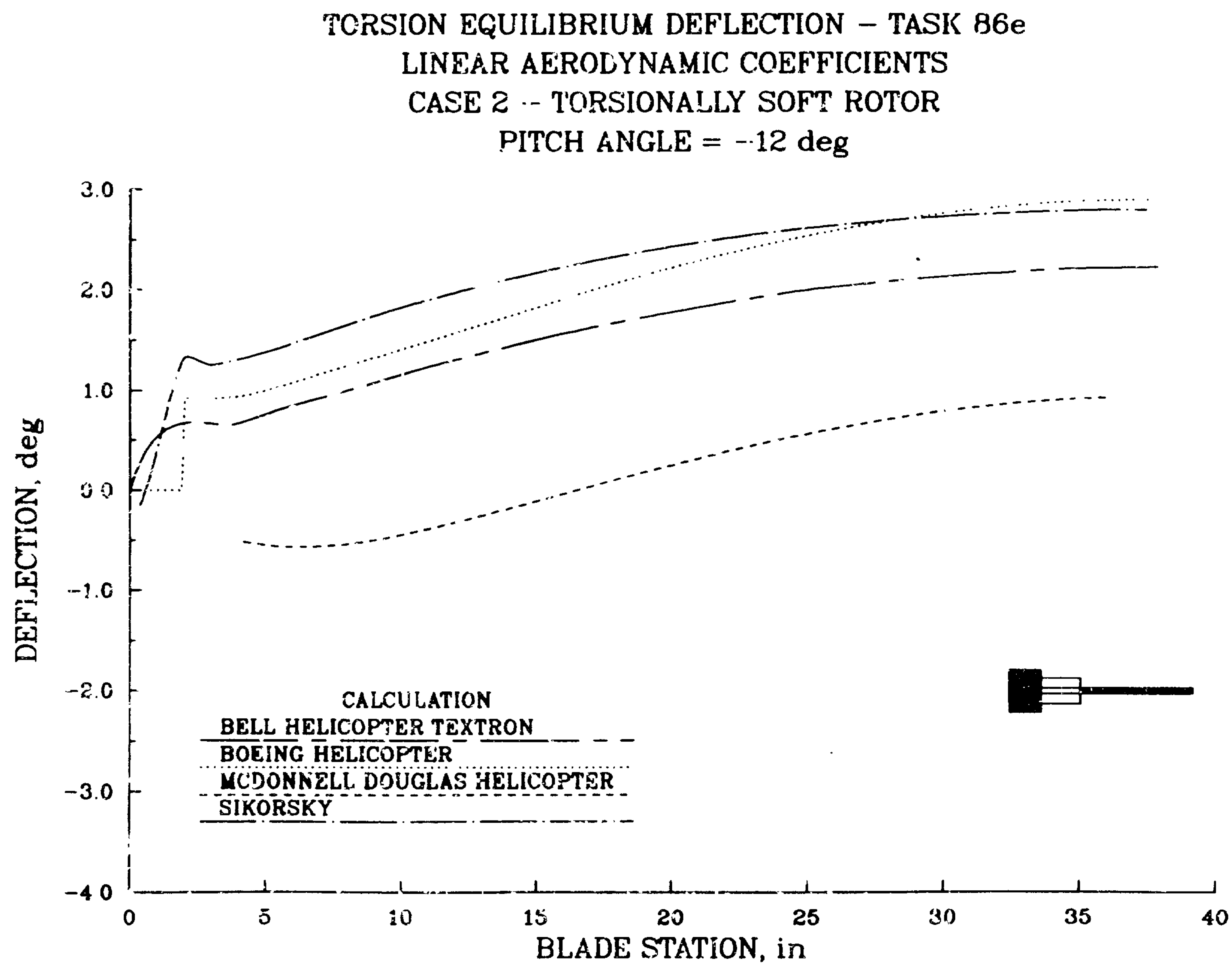

LEAD-LAG EQUILIBRIUM DEFLECTION - TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 - TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY
0
5
10
15
20
25
30
35
40
BLADE STATION, in

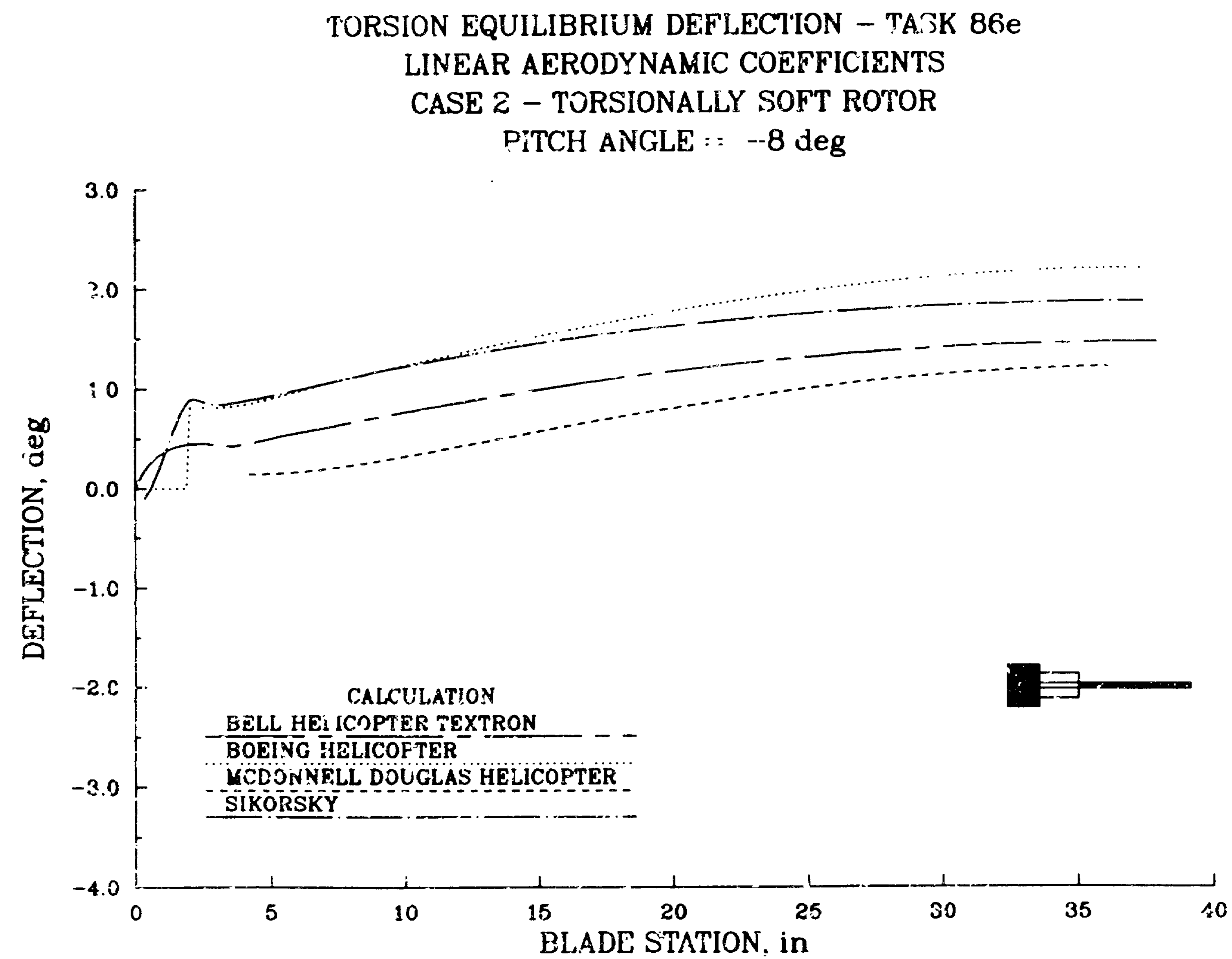

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS

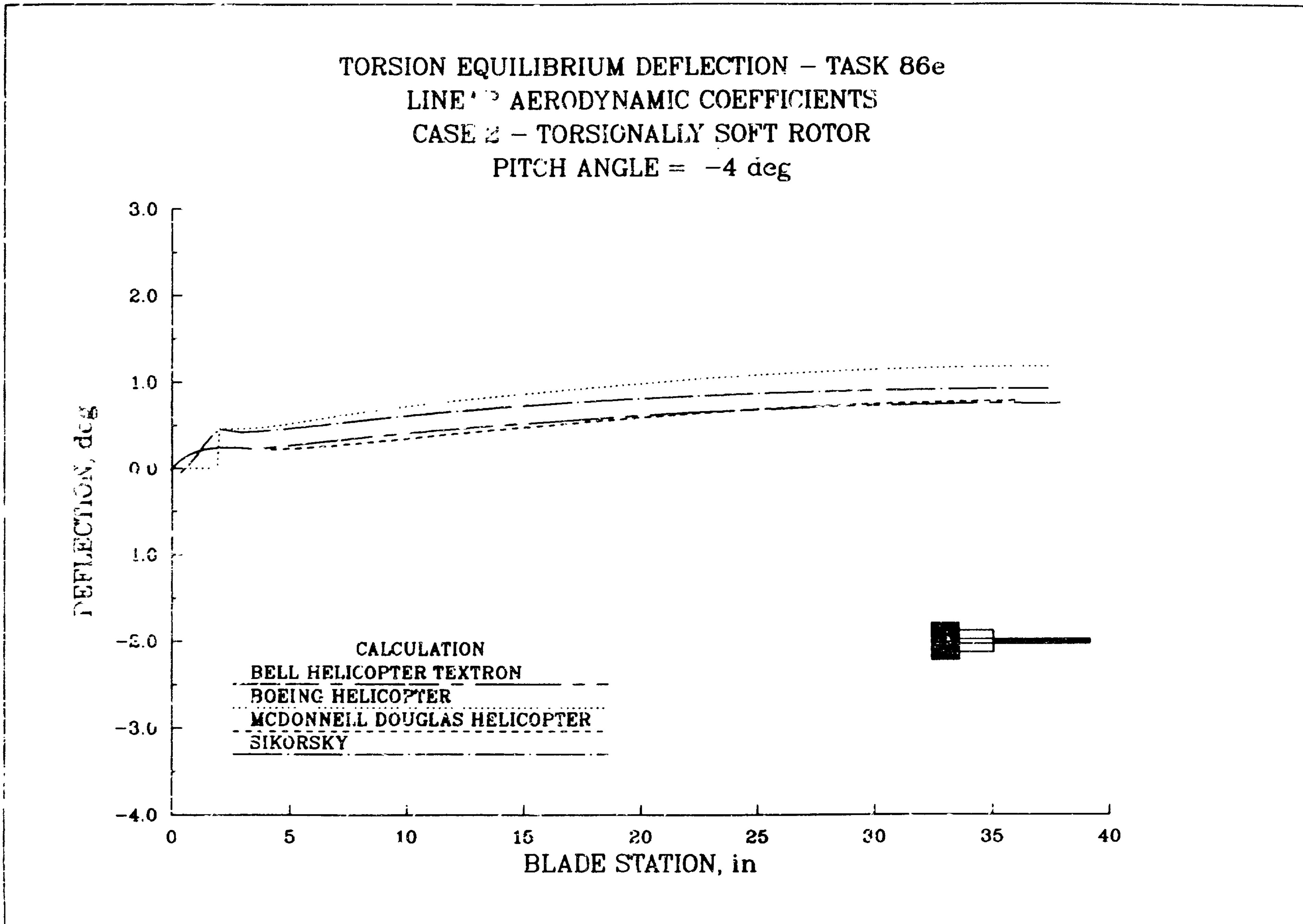


LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

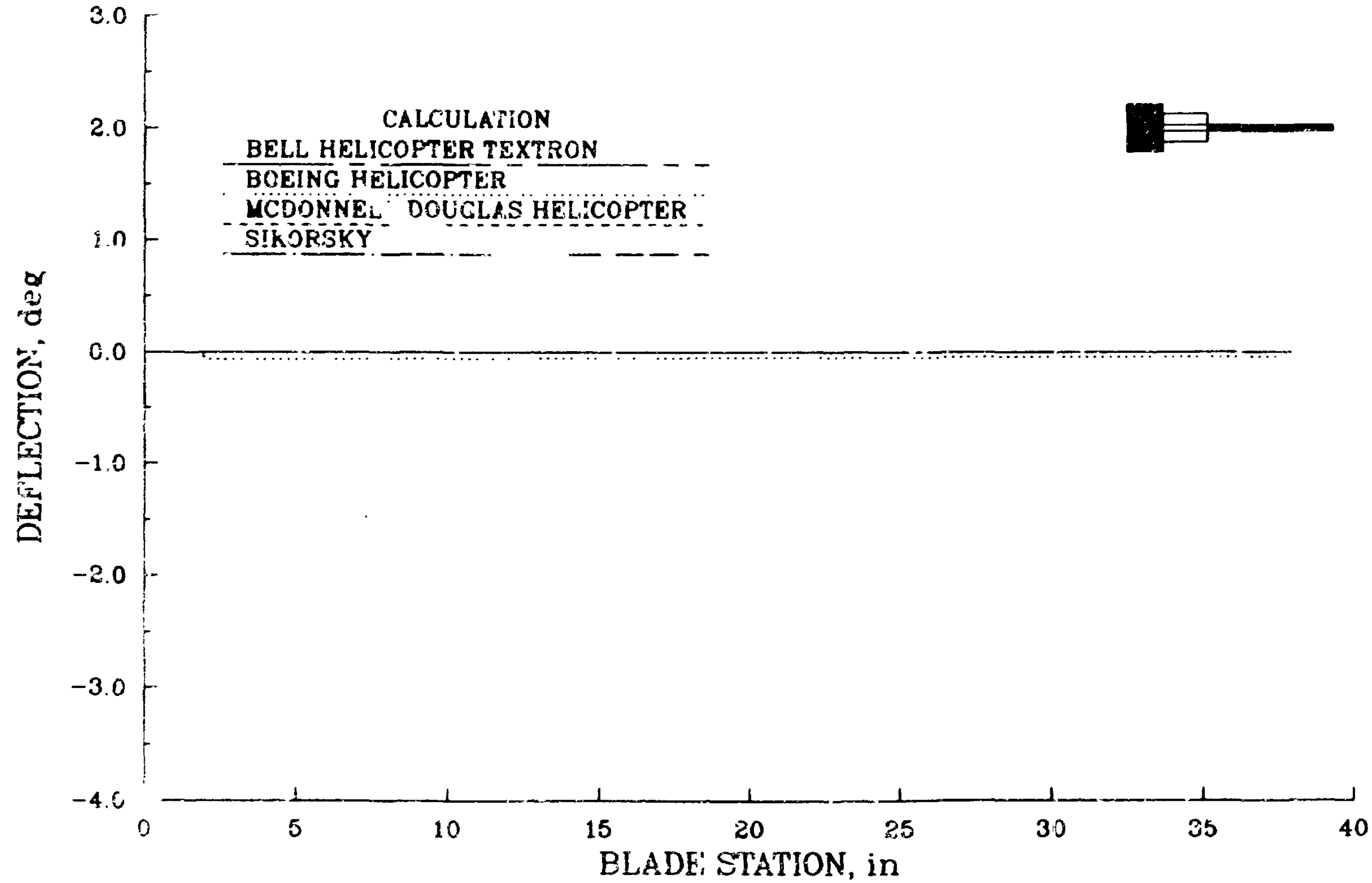

LEAD-LAG EQUILIBRIUM DEFLECTION - TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 - TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
DEFLECTION, in
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY


TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 -- TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg
DEFLECTION, deg
3.0
2.0
1.0
0.0
–1.0
–2.0
–3.0
–4.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY

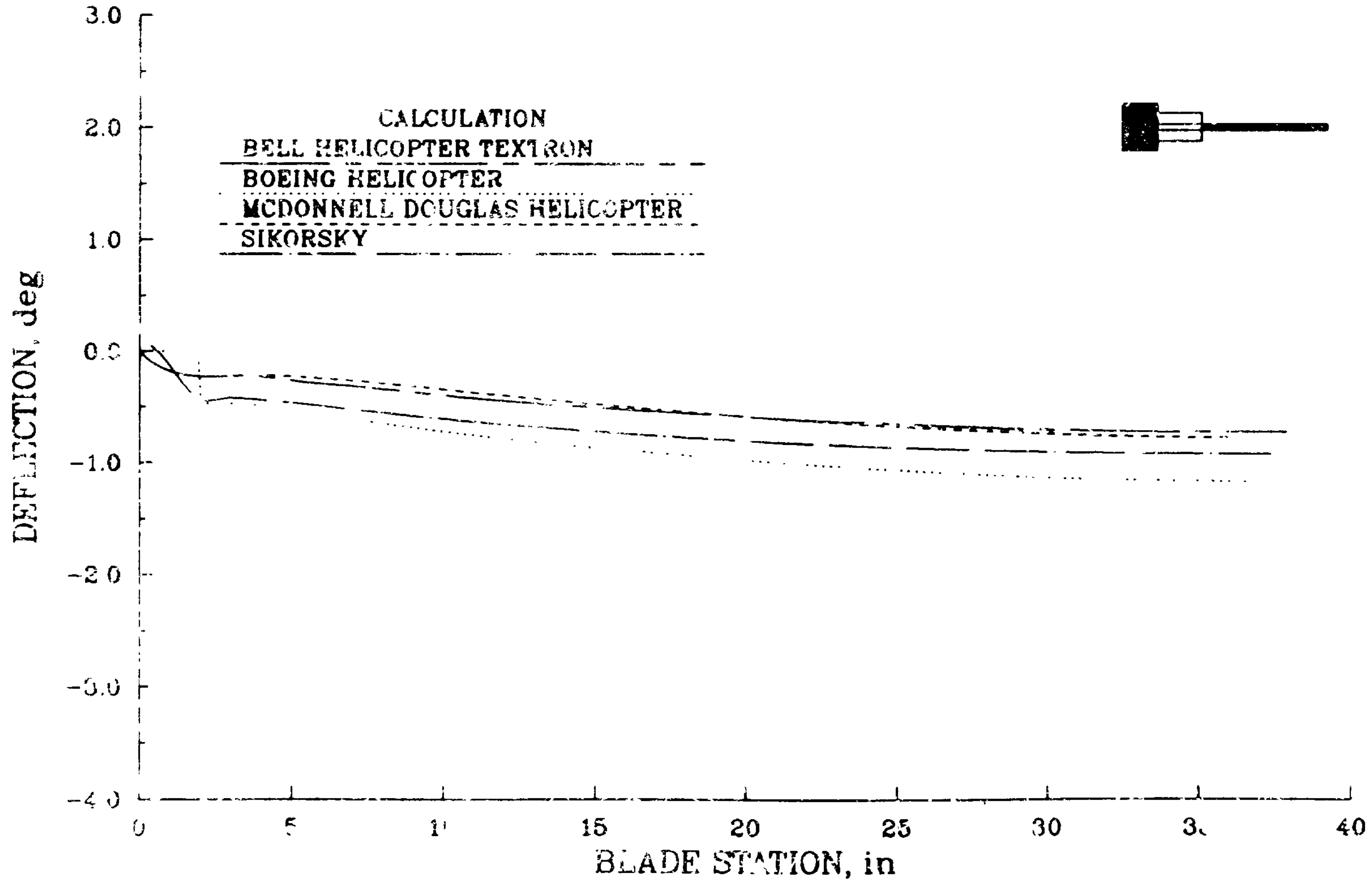

TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = -8 deg
DEFLECTION, deg
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY

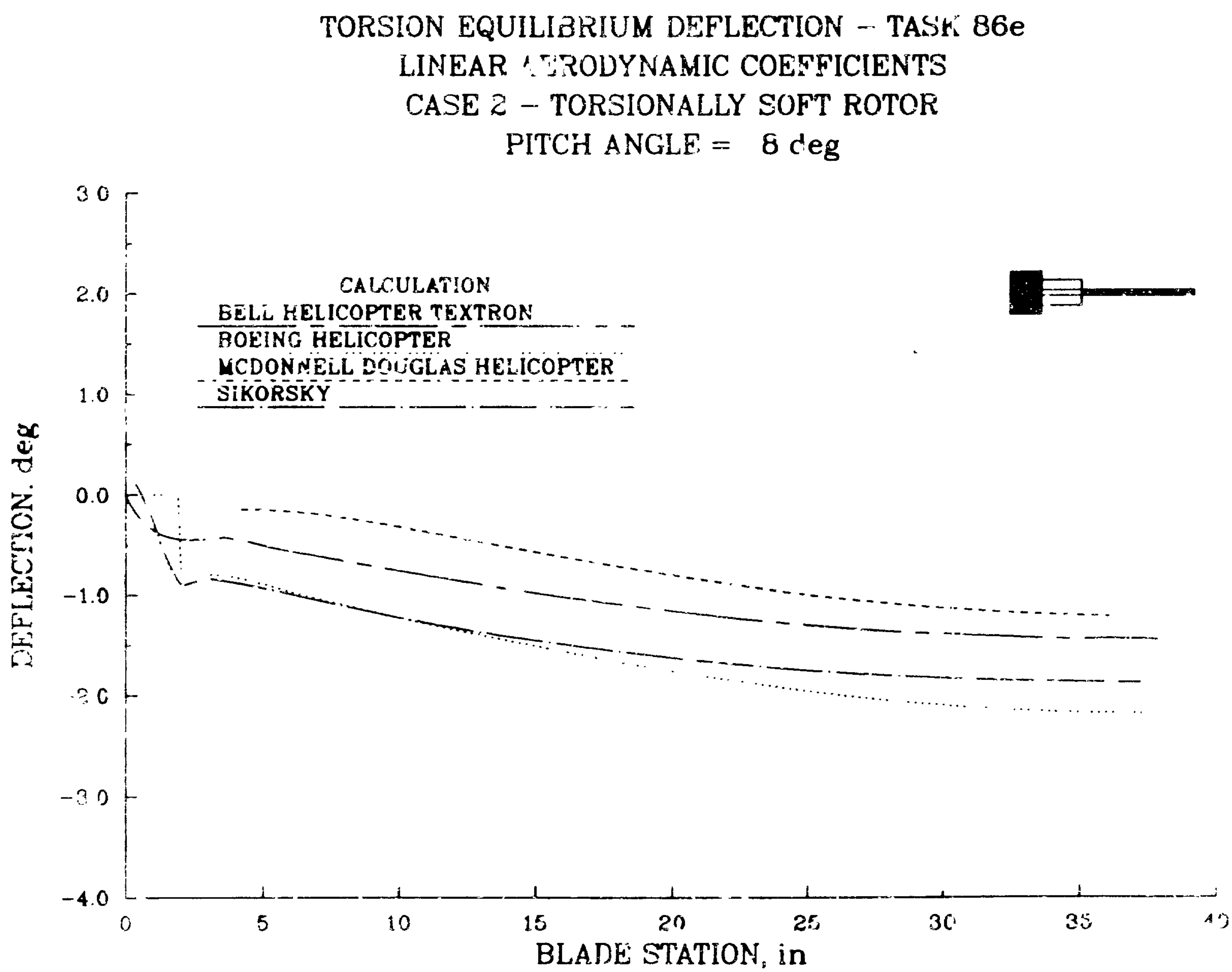

TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −4 deg
DEFLECTION, deg
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY

TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg



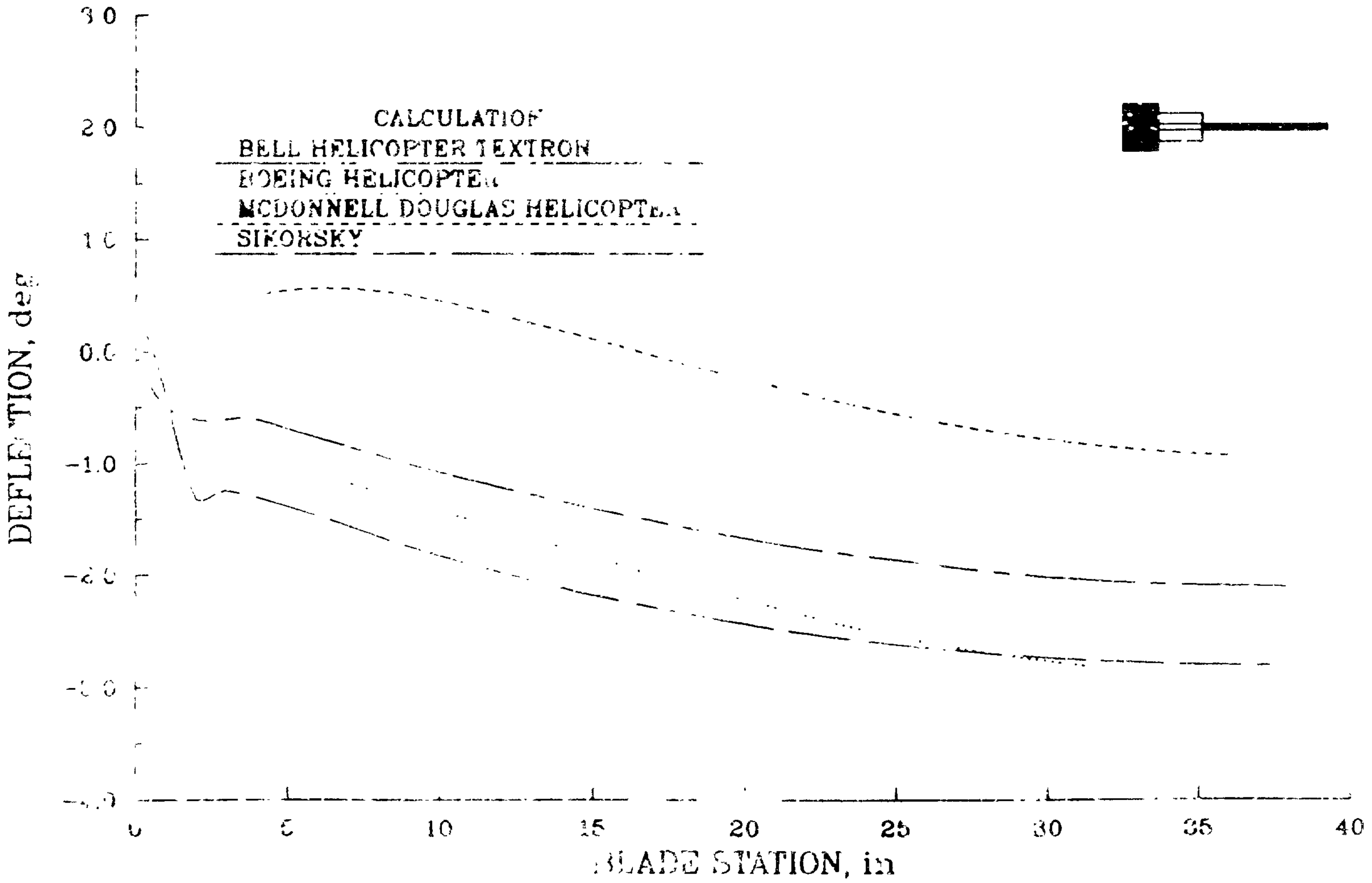
TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg

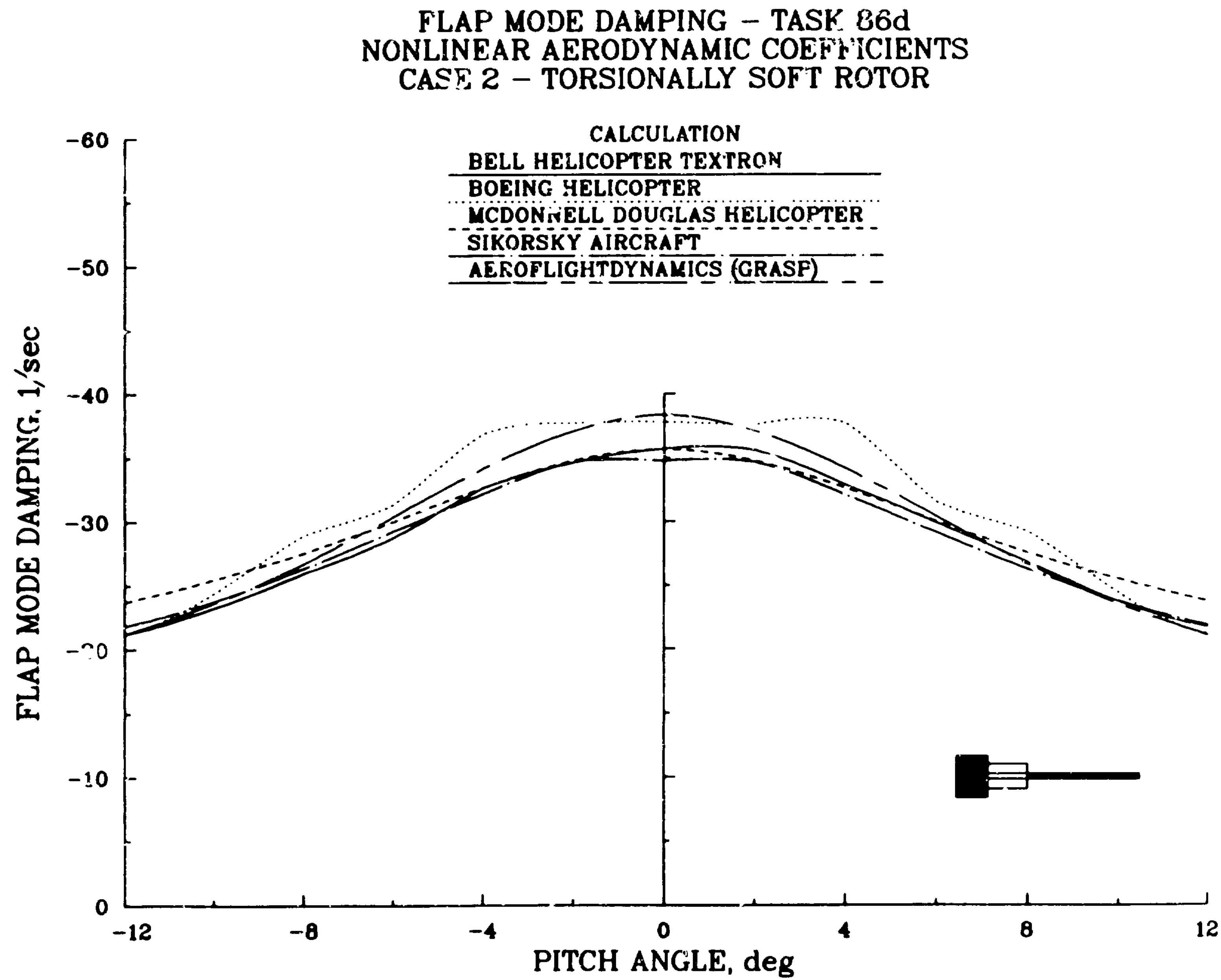




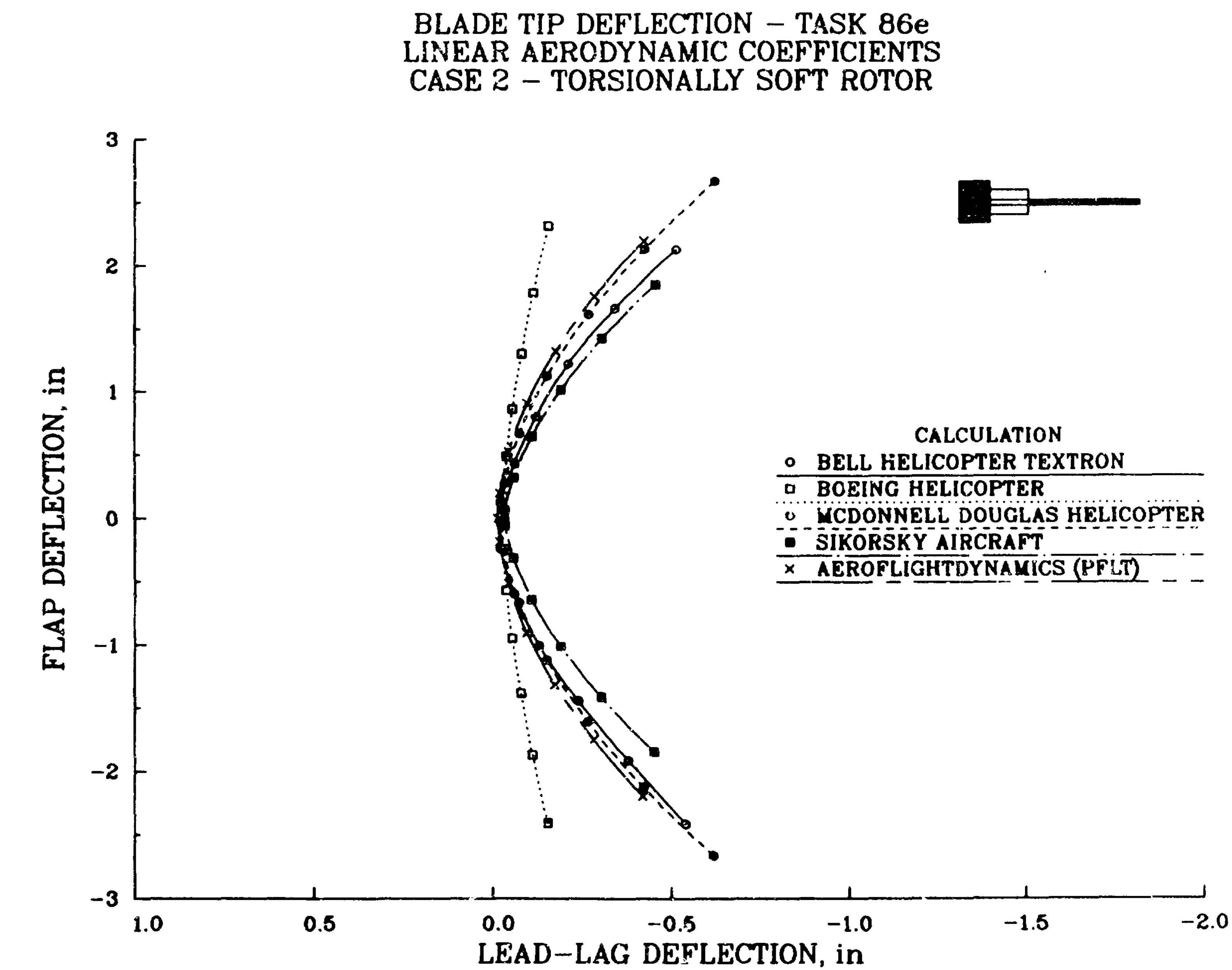
TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY
DEFLECTION, deg
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in

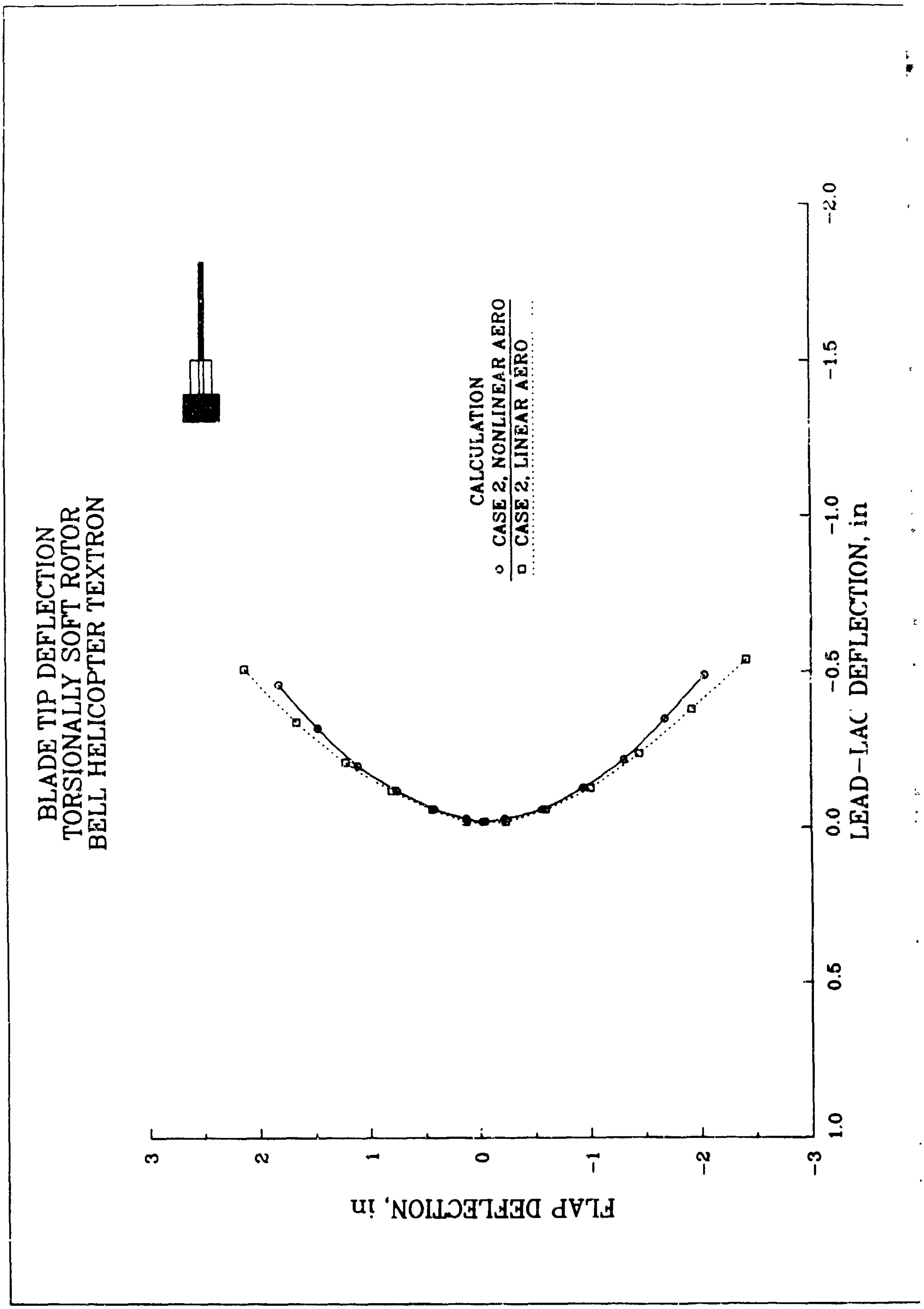
TORSION EQUILIBRIUM DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg

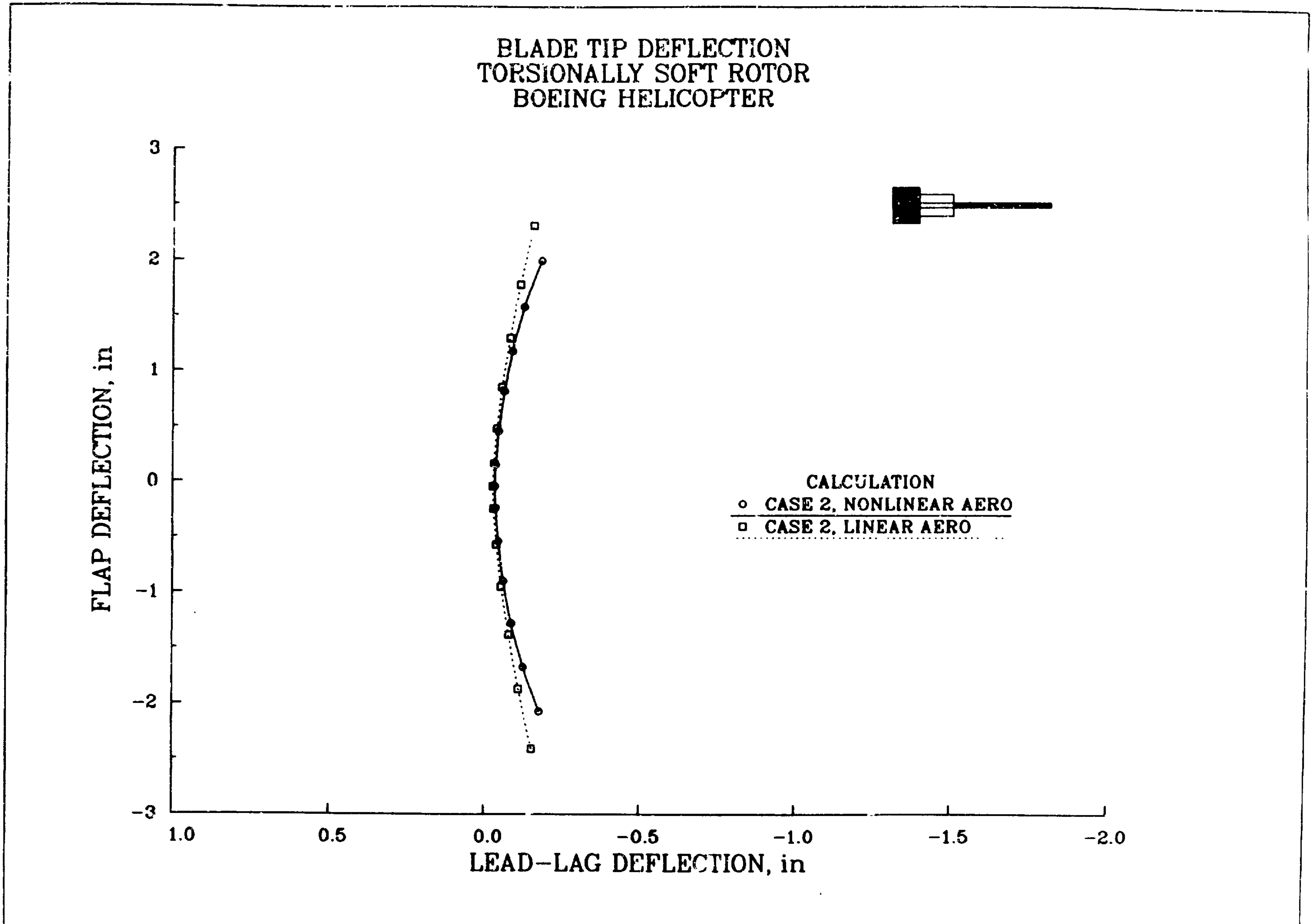


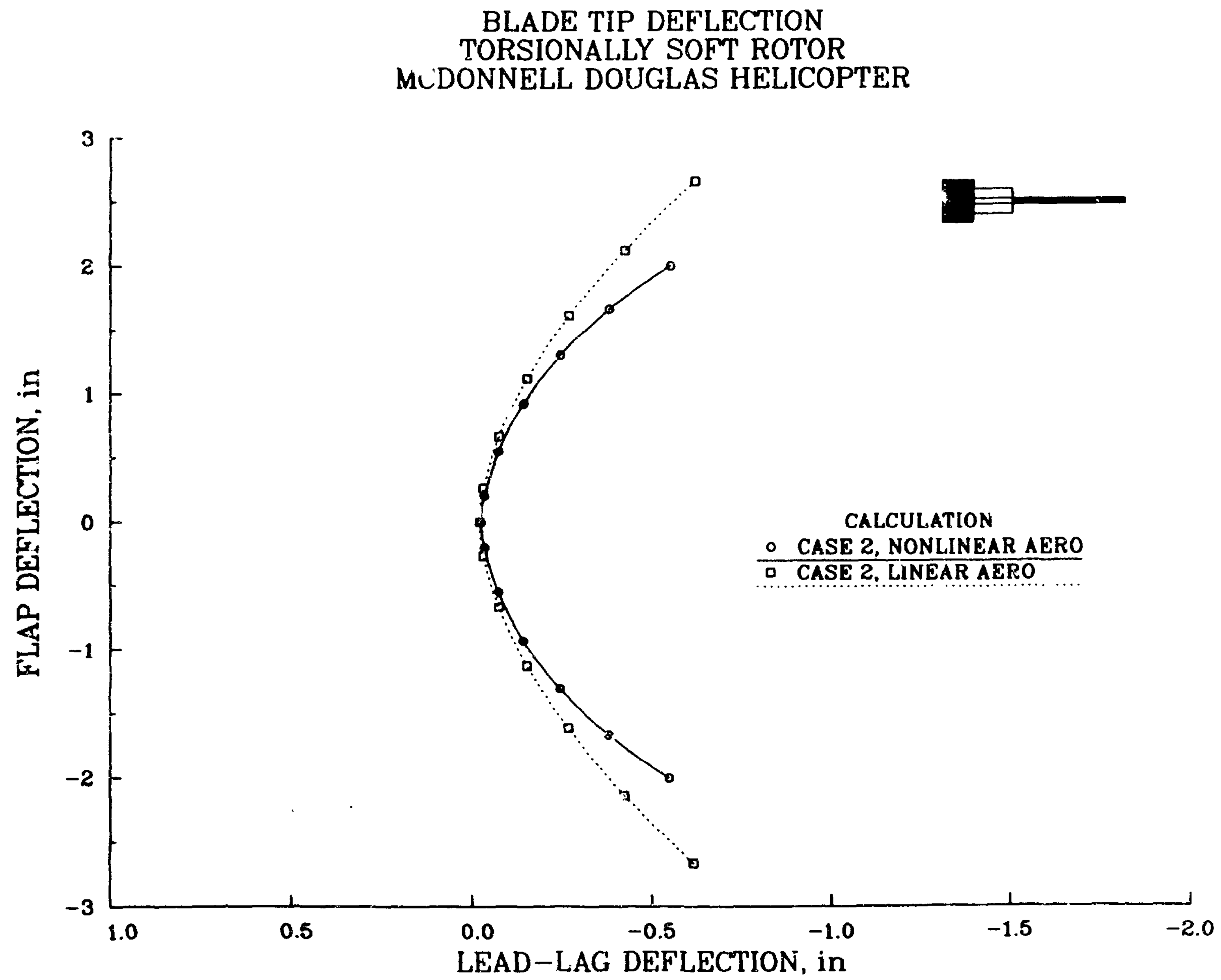


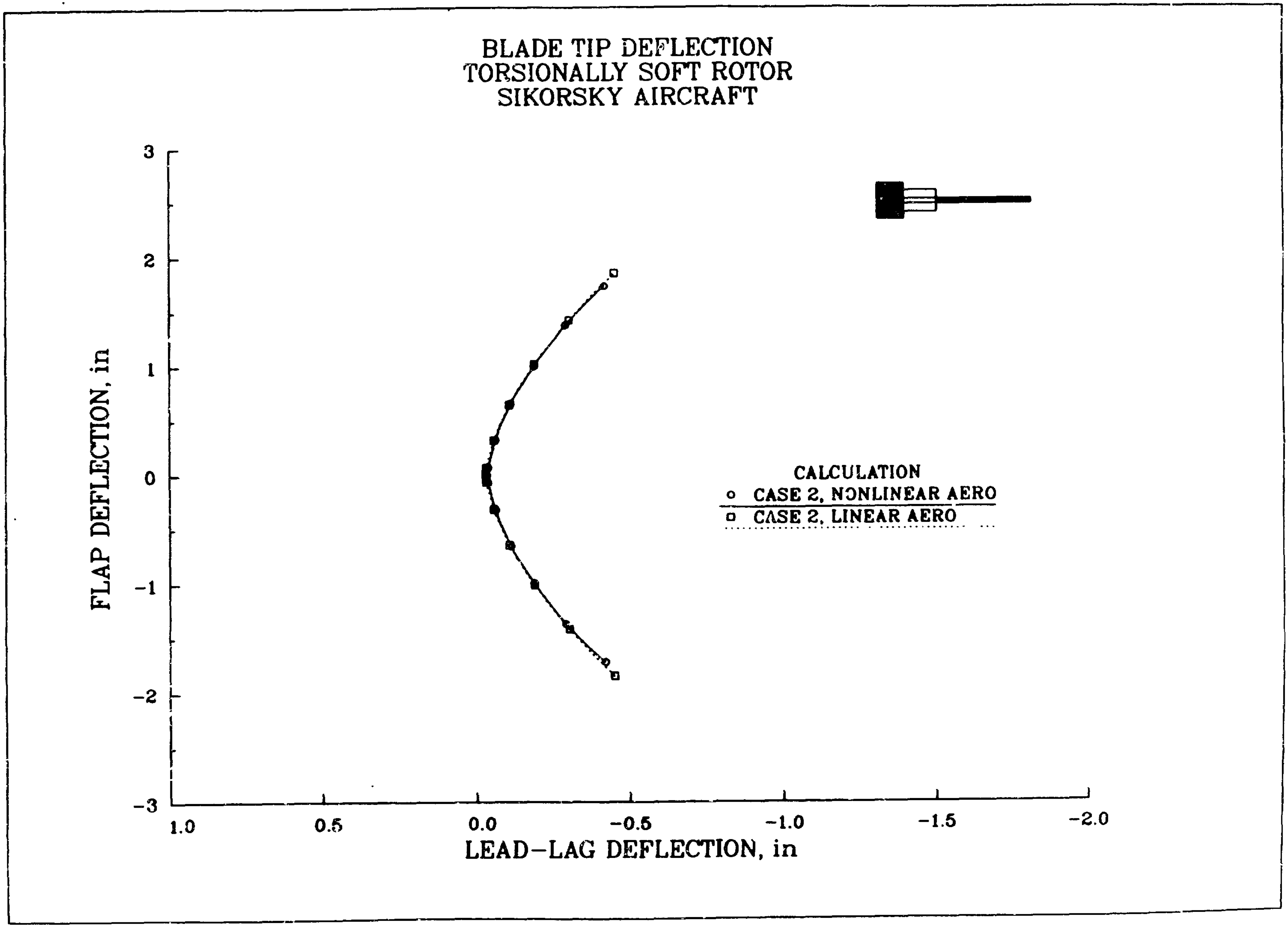
FLAP MODE DAMPING – TASK 86d
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
FLAP MODE DAMPING, 1/sec
-60
-50
-40
-30
-20
-10
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
FLAP DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)

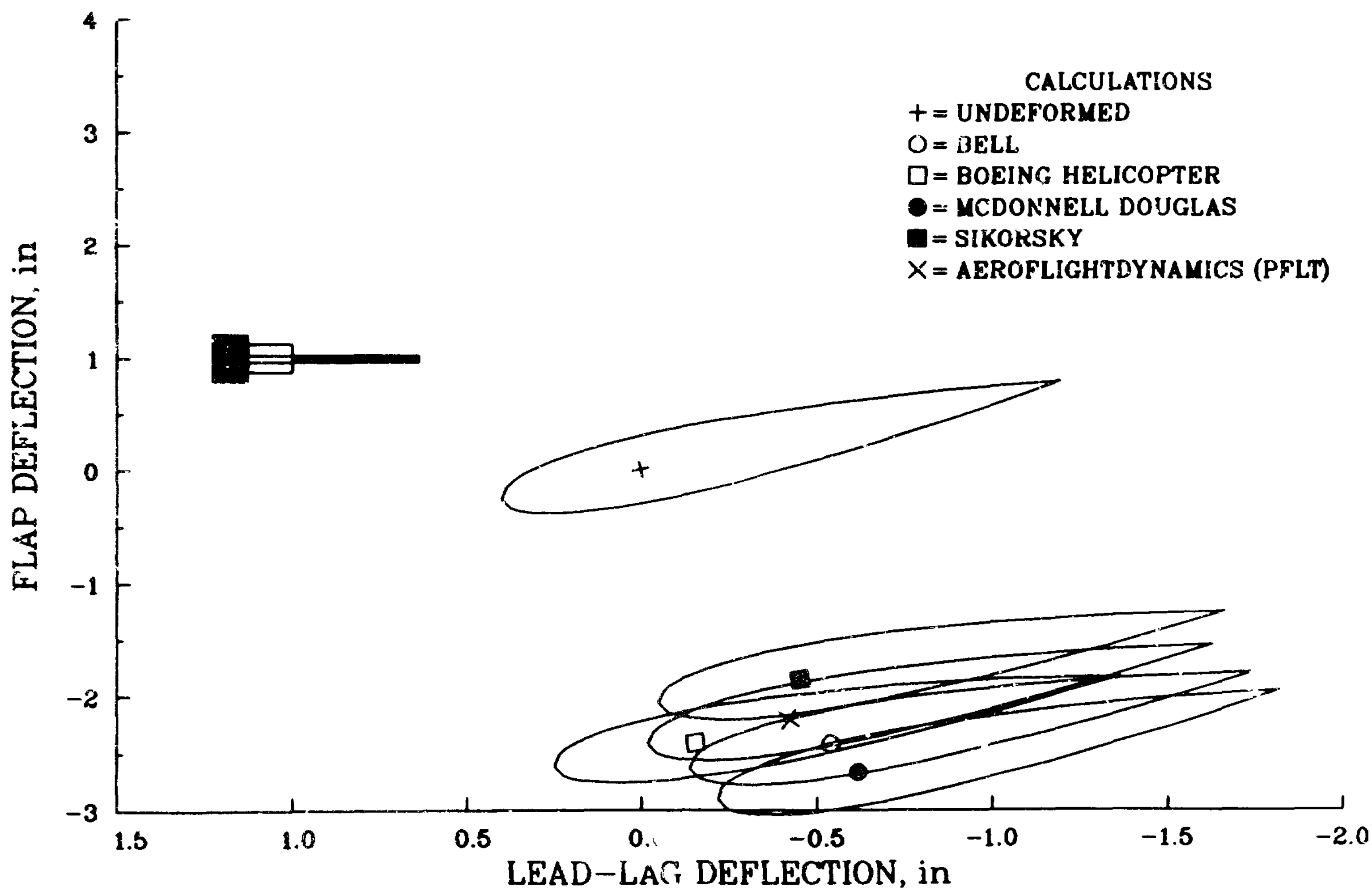

BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0


BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
FLAP DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD−LAG DEFLECTION, in
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO

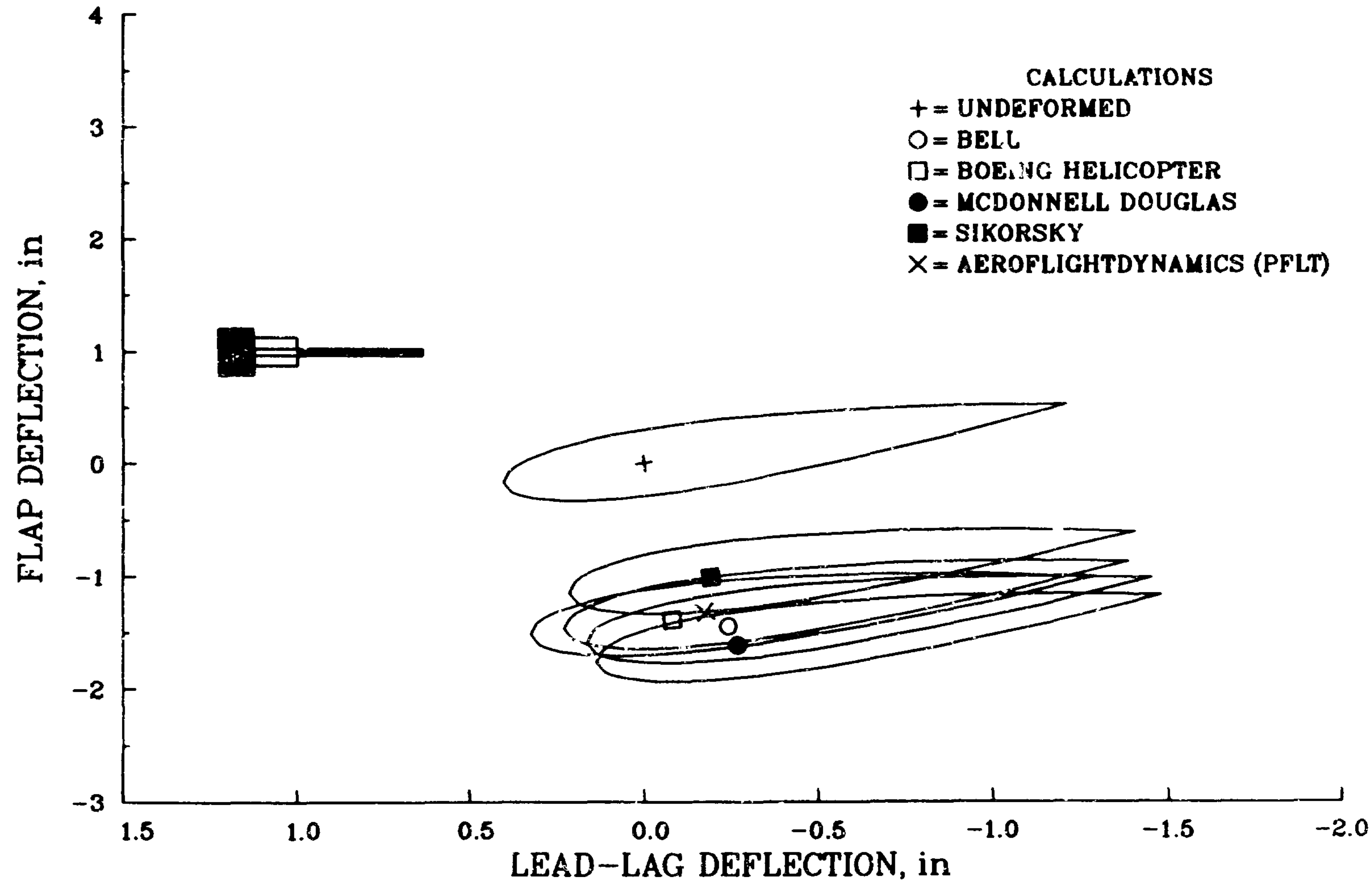

BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
McDONNELL DOUGLAS HELICOPTER
3
2
1
0
−1
−2
−3
FLAP DEFLECTION, in
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD−LAG DEFLECTION, in
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO


BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 2, NONLINEAR AERO
CASE 2, LINEAR AERO
FLAP DEFLECTION, in
LEAD−LAG DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

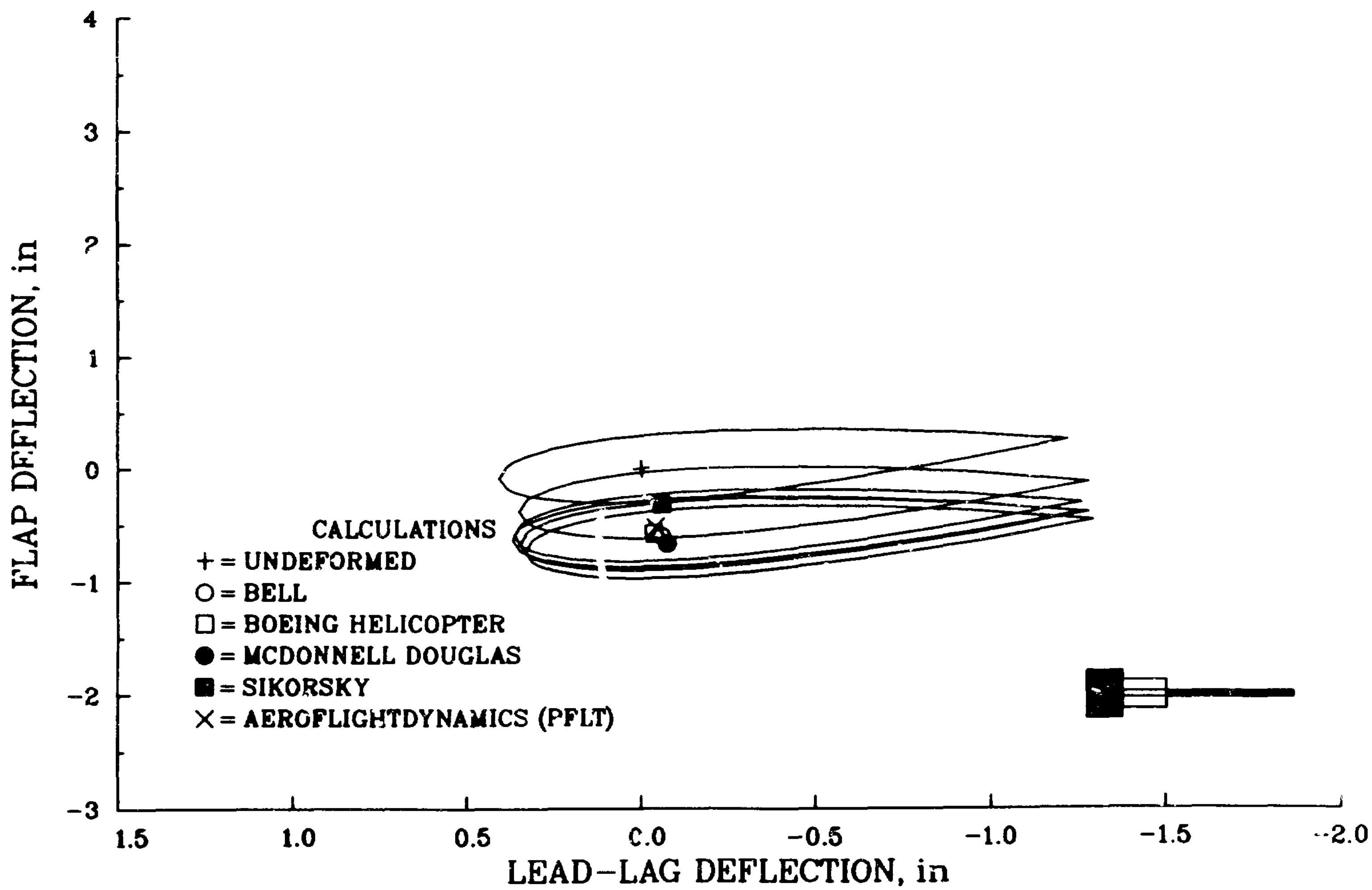
BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg

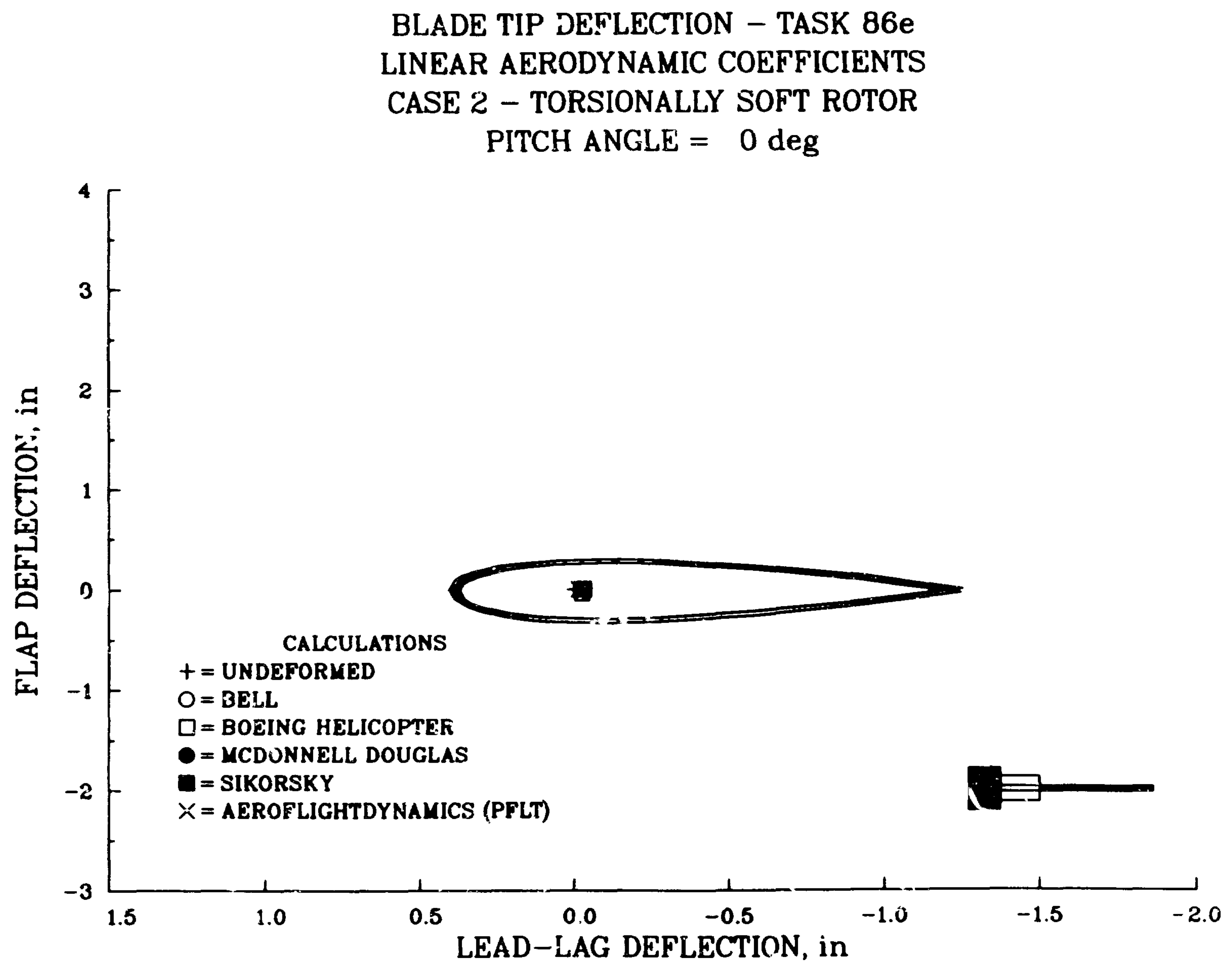


BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg

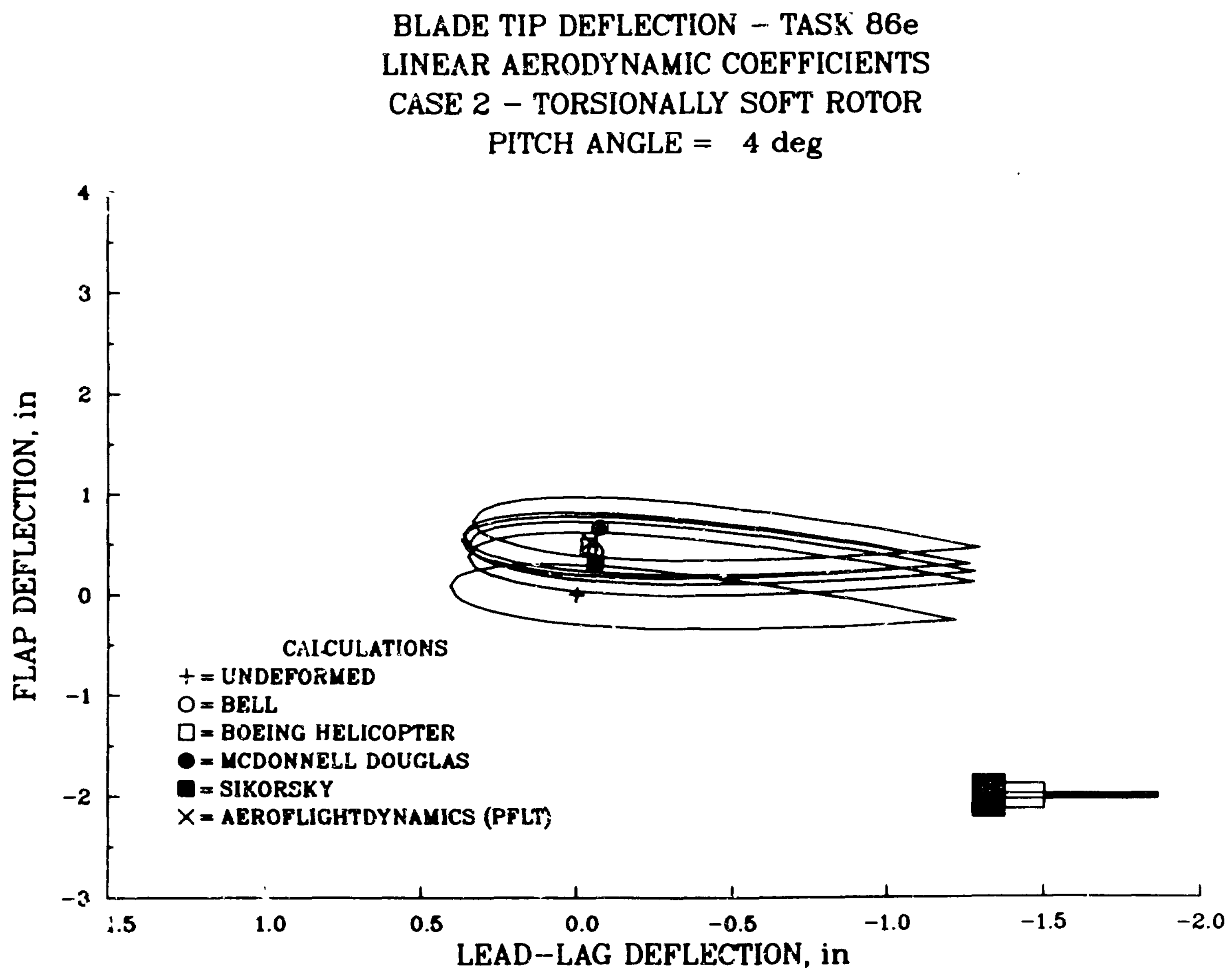


BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg

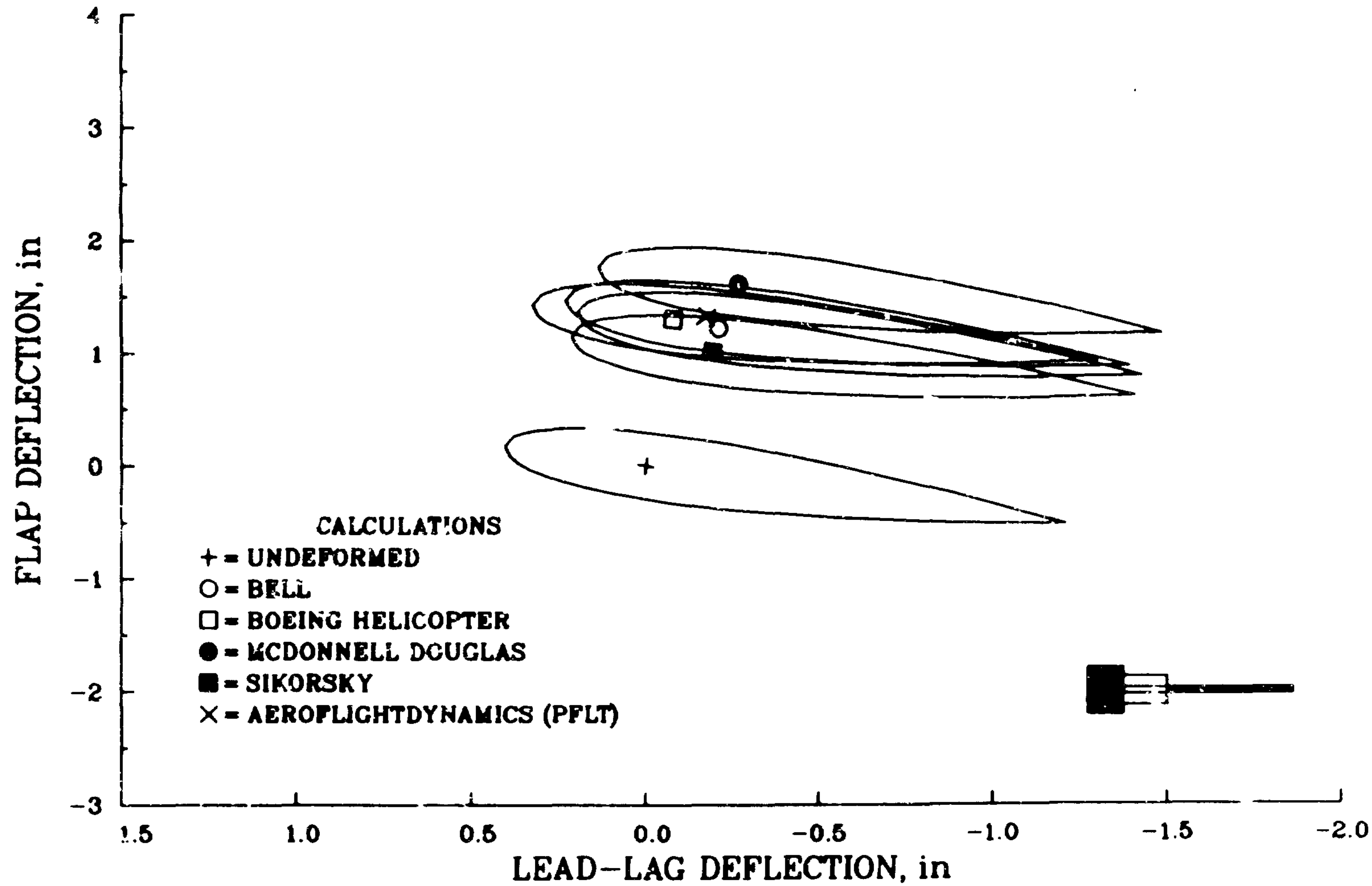


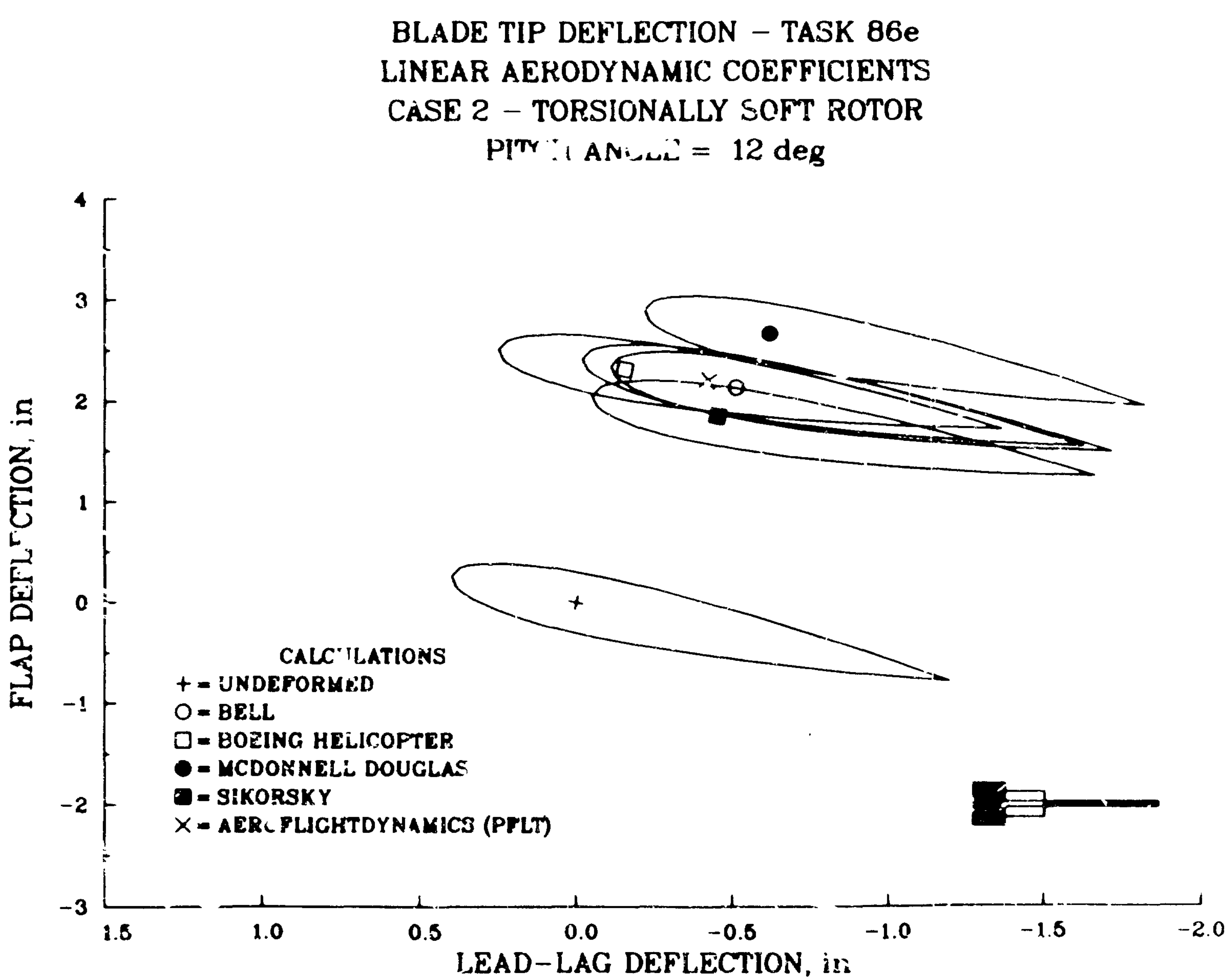


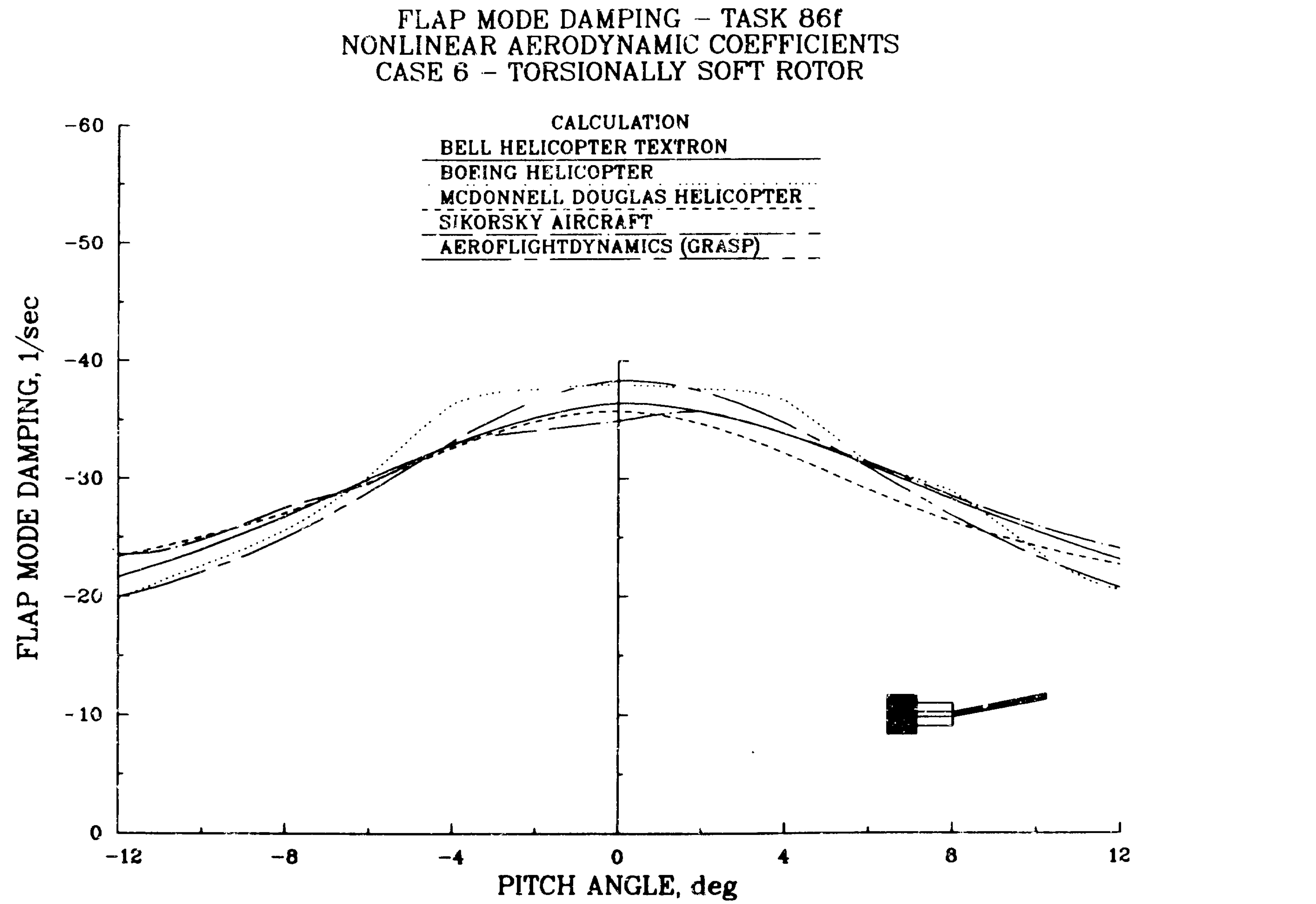
BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)

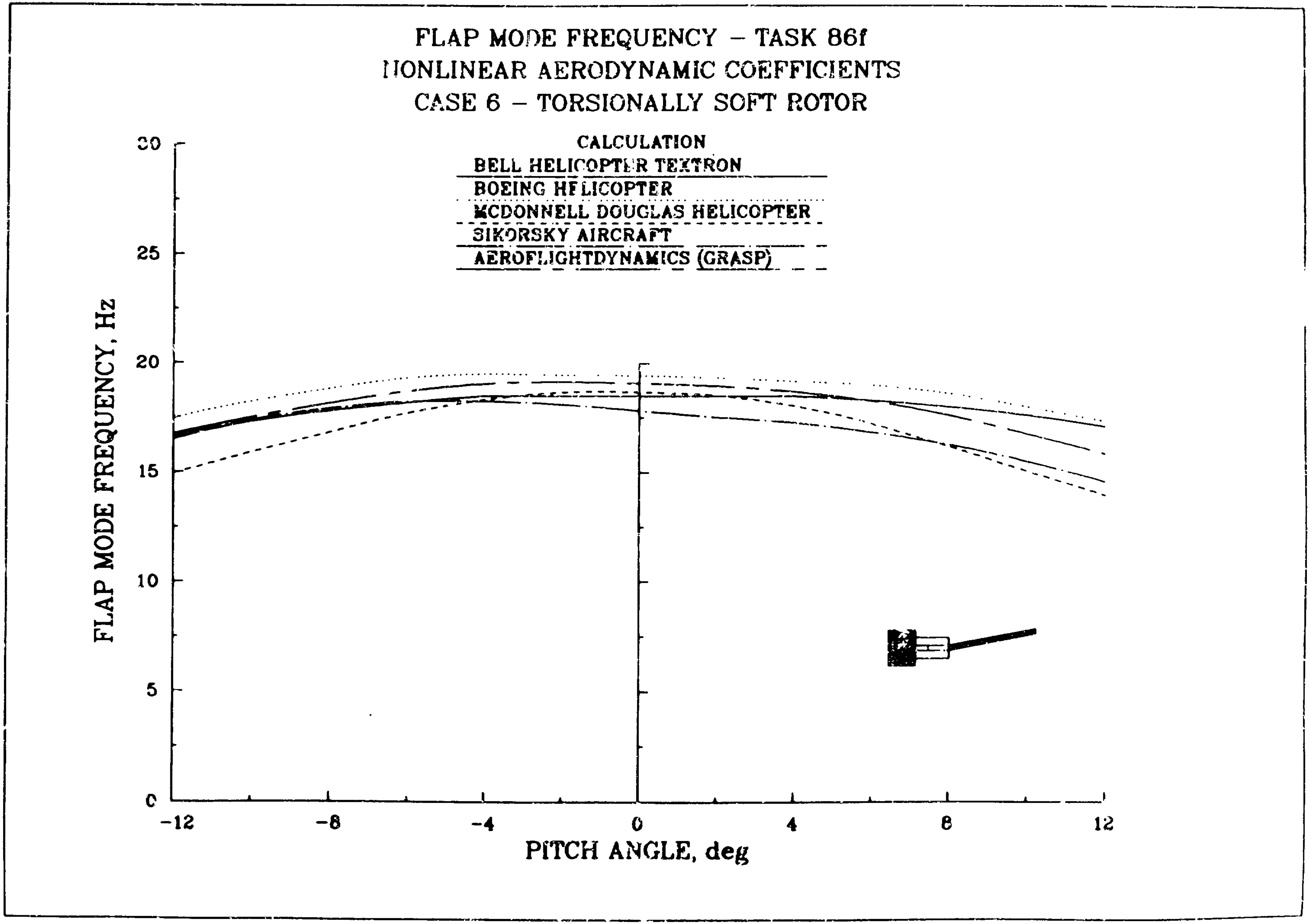

BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)

BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg

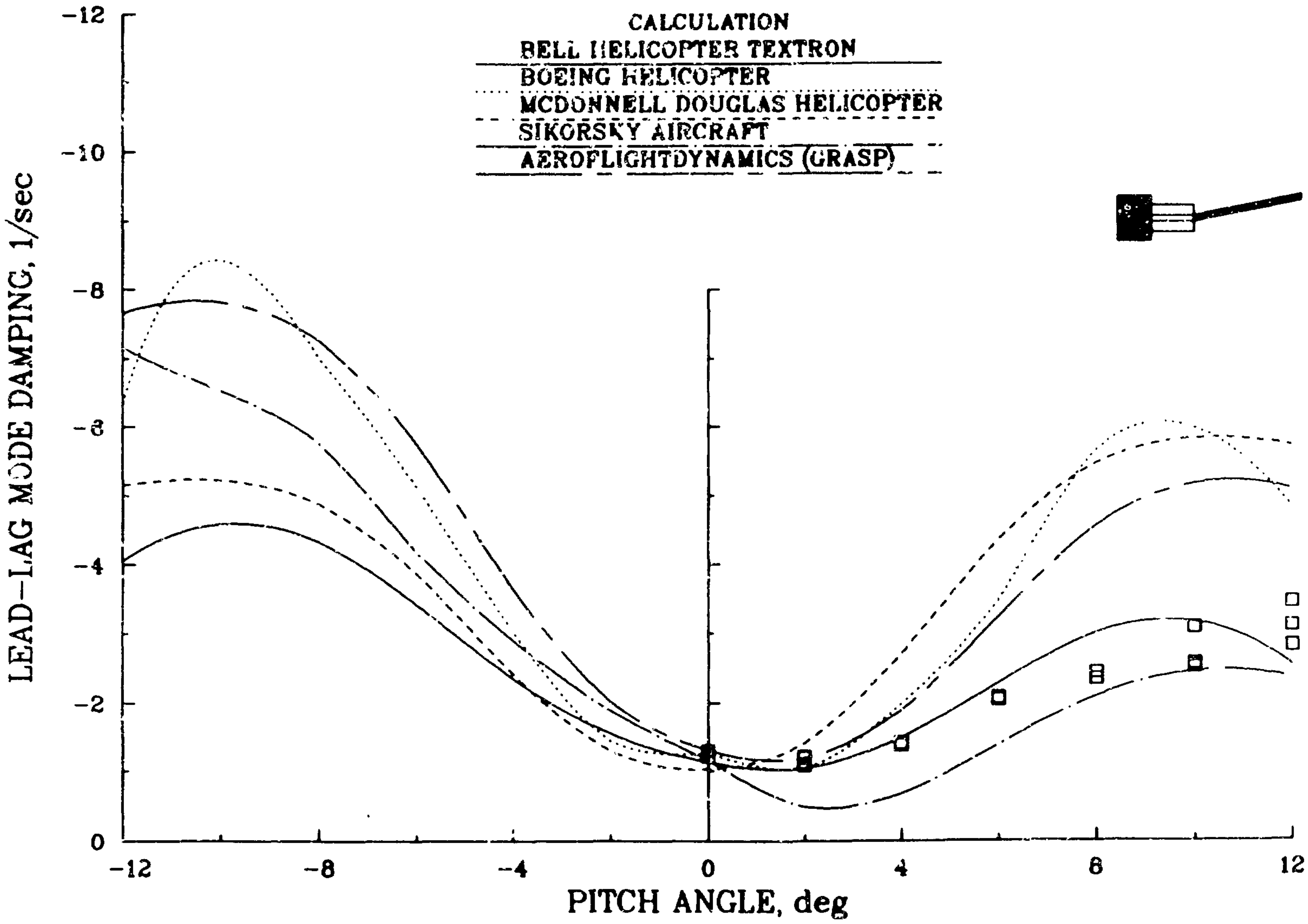


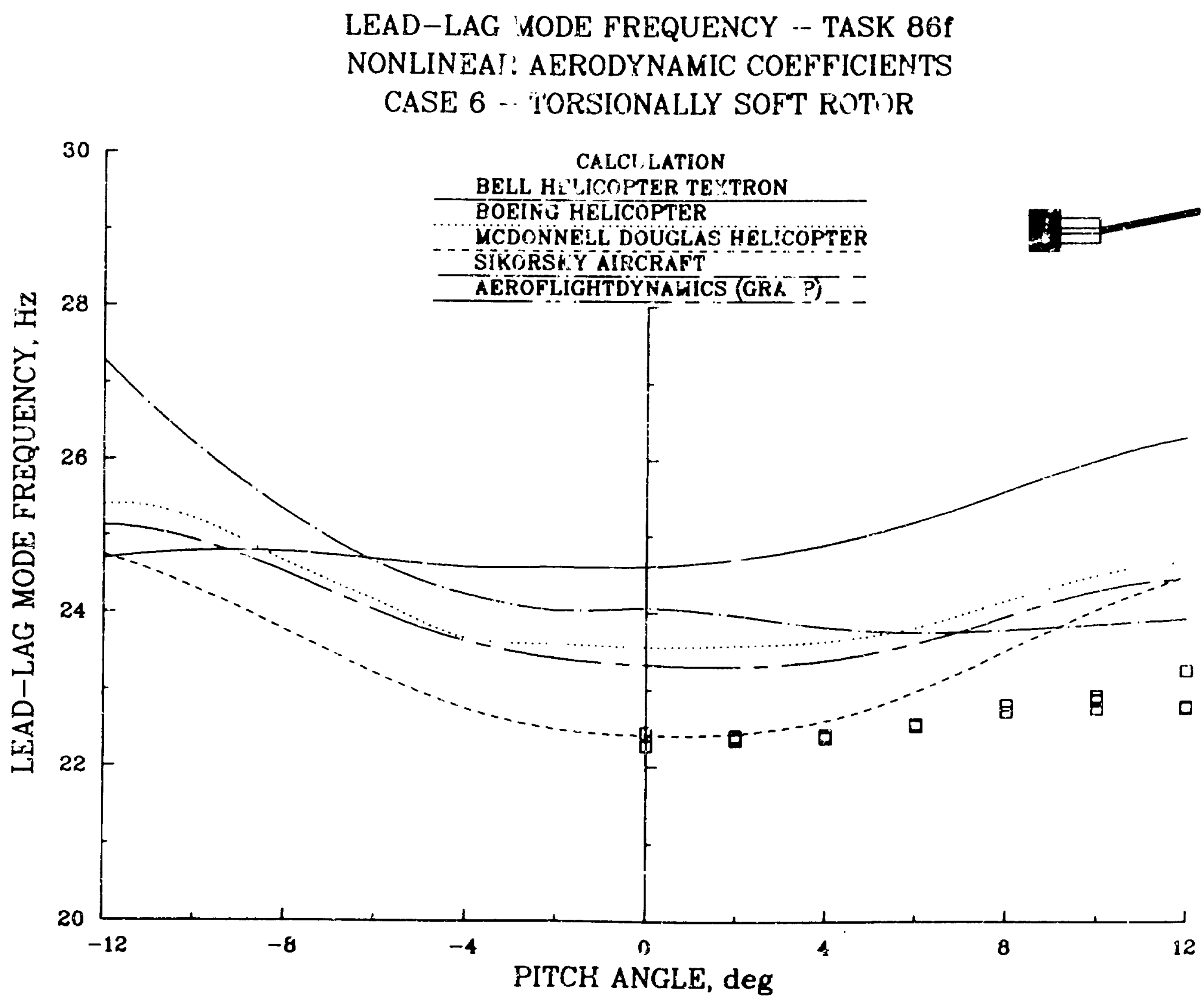

BLADE TIP DEFLECTION – TASK 86e
LINEAR AERODYNAMIC COEFFICIENTS
CASE 2 – TORSIONALLY SOFT ROTOR
= 12 deg
FLAP DEFL
CTION, in
LEAD–LAG DEFLECTION, in
CALC
LATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AER
FLIGHTDYNAMICS (PFLT)
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0


FLAP MODE DAMPING – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
FLAP MODE DAMPING, 1/sec
-60
-50
-40
-30
-20
-10
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


FLAP MODE FREQUENCY – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
FLAP MODE FREQUENCY, Hz
PITCH ANGLE, deg
0
5
10
15
20
25
30
–12
–8
–4
0
4
8
12

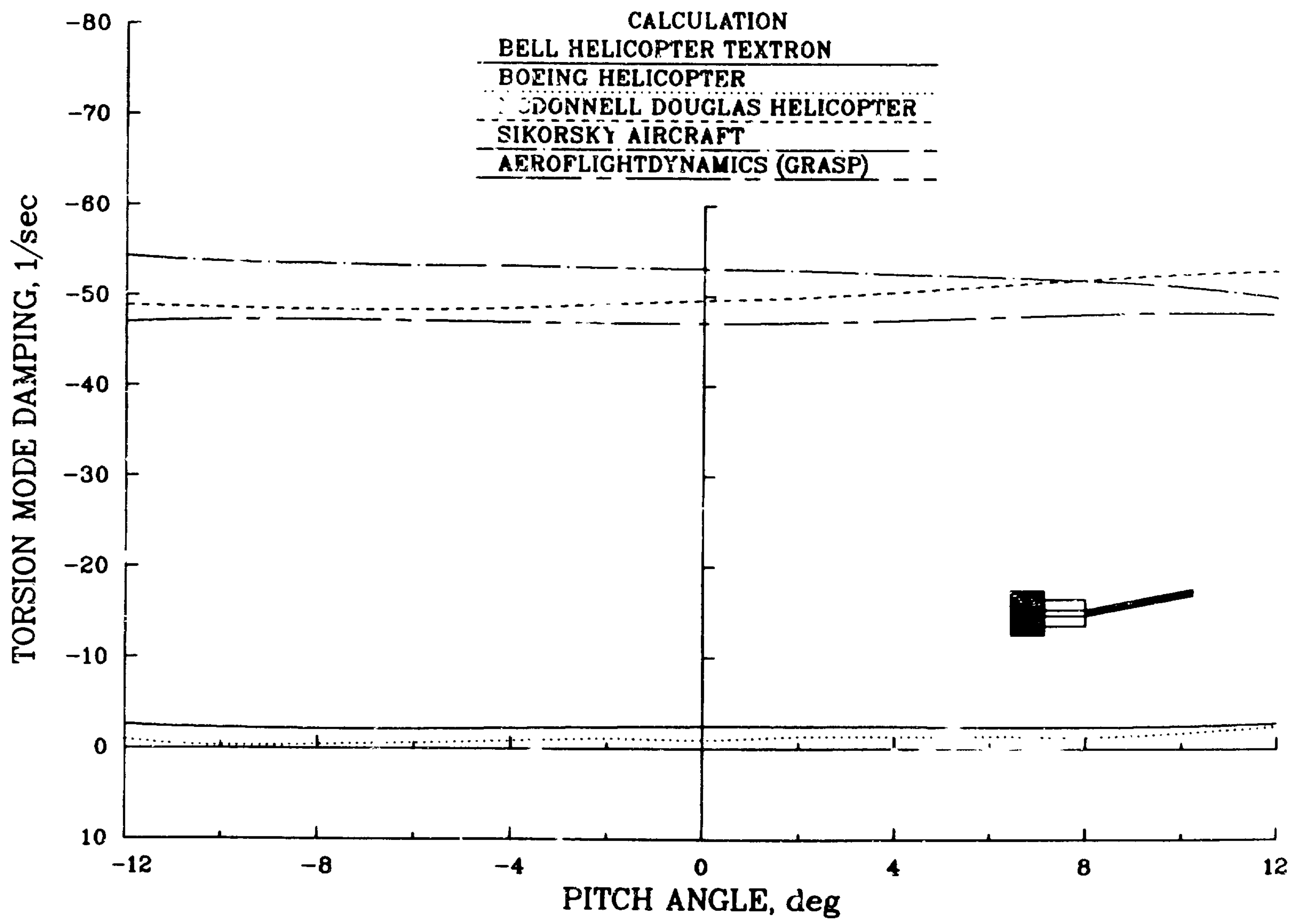
LEAD–LAG MODE DAMPING – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR



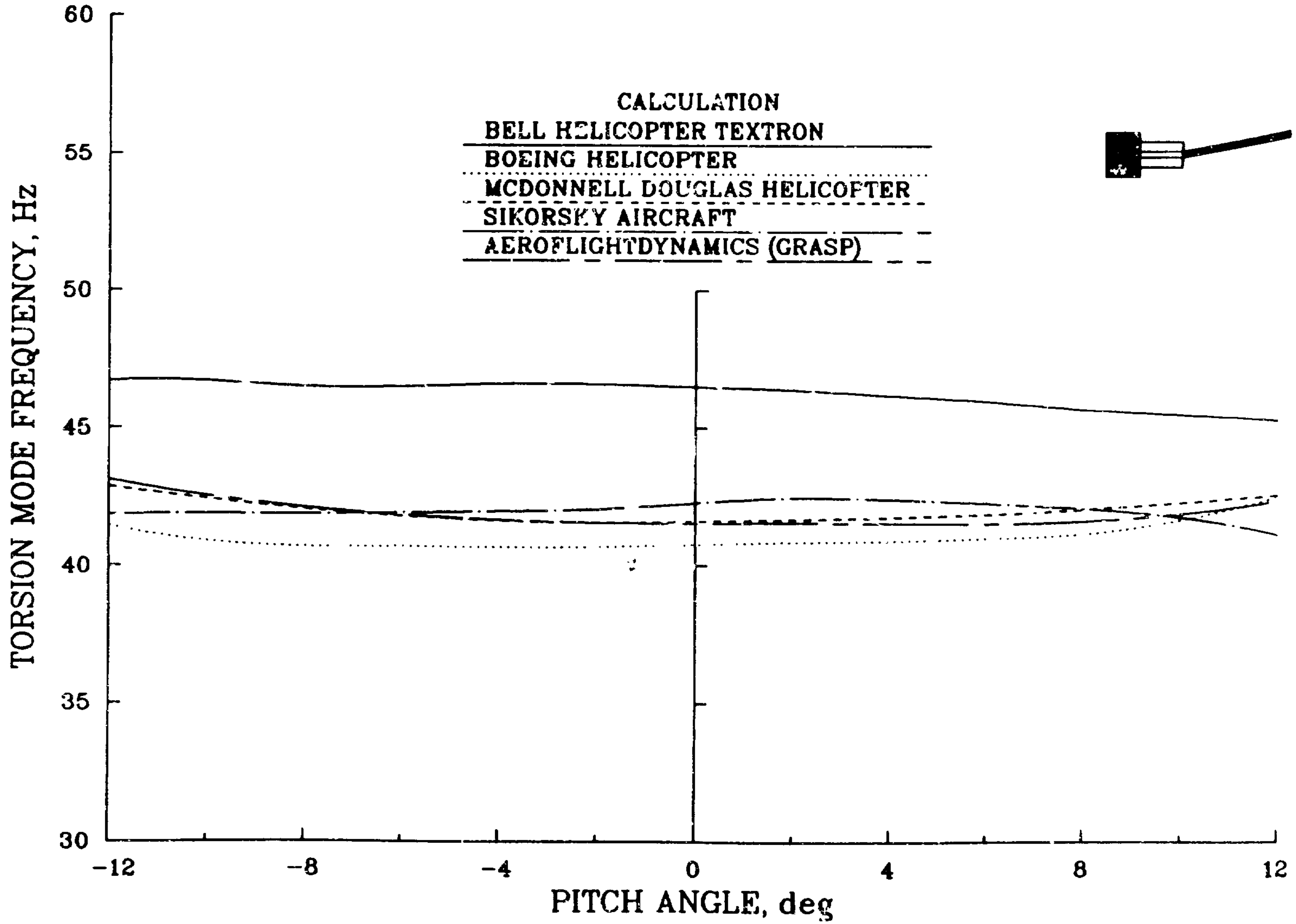


LEAD–LAG MODE FREQUENCY -- TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 -- TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GROUP)
LEAD–LAG MODE FREQUENCY, Hz
PITCH ANGLE, deg
30
28
26
24
22
20
–12
–8
–4
0
4
8
12

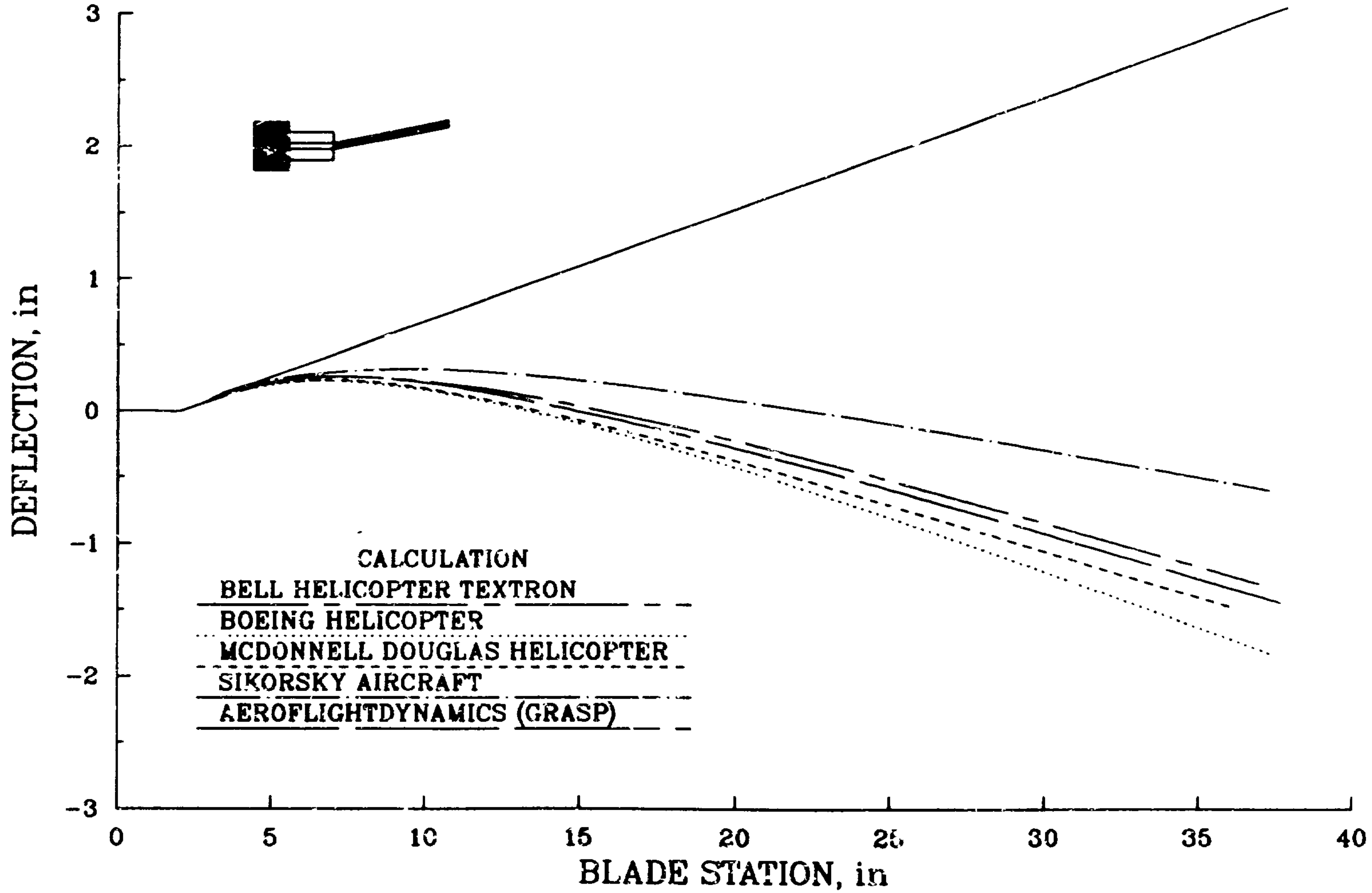
TORSION MODE DAMPING – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR



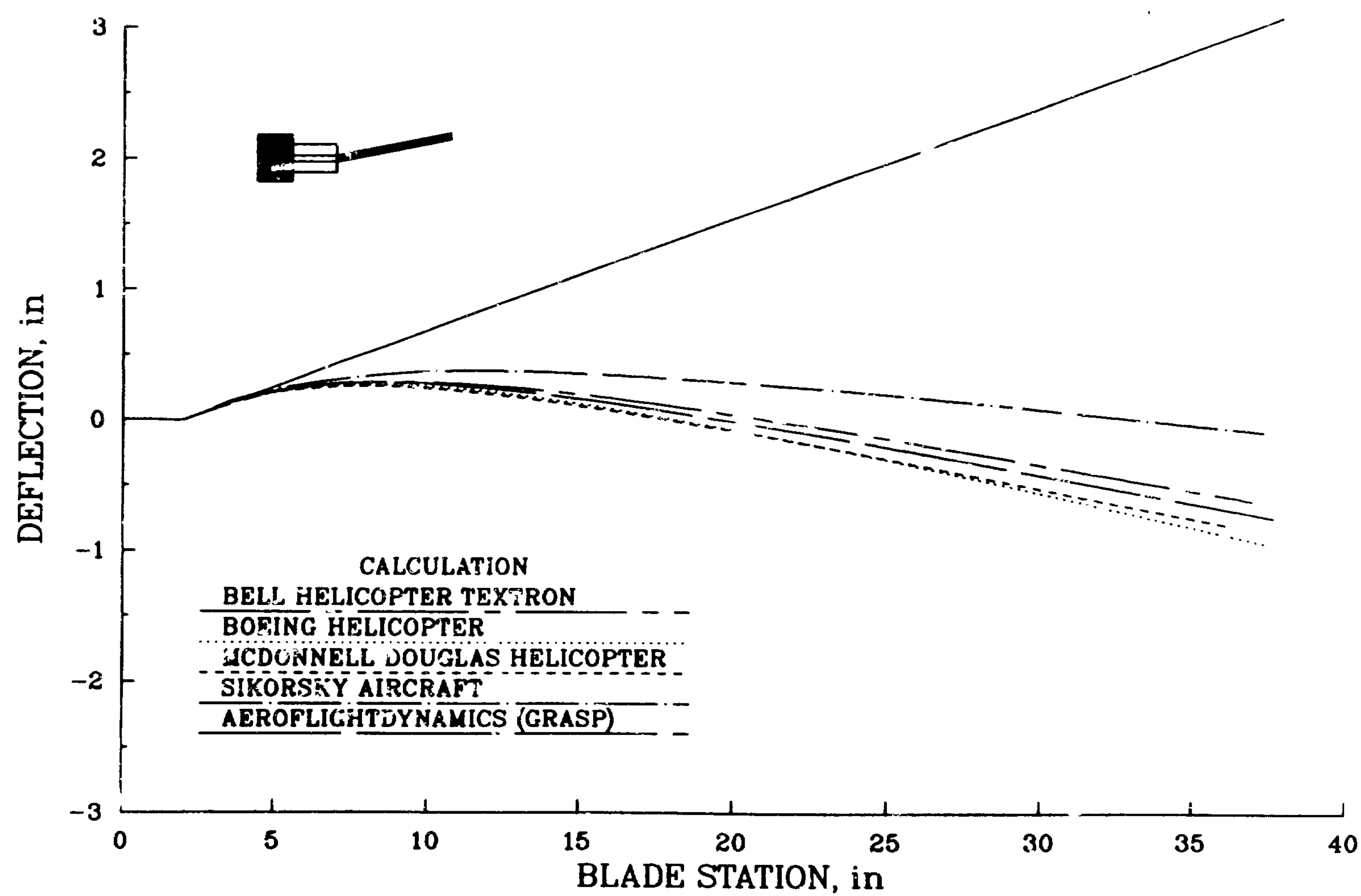
TORSION MODE FREQUENCY – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR



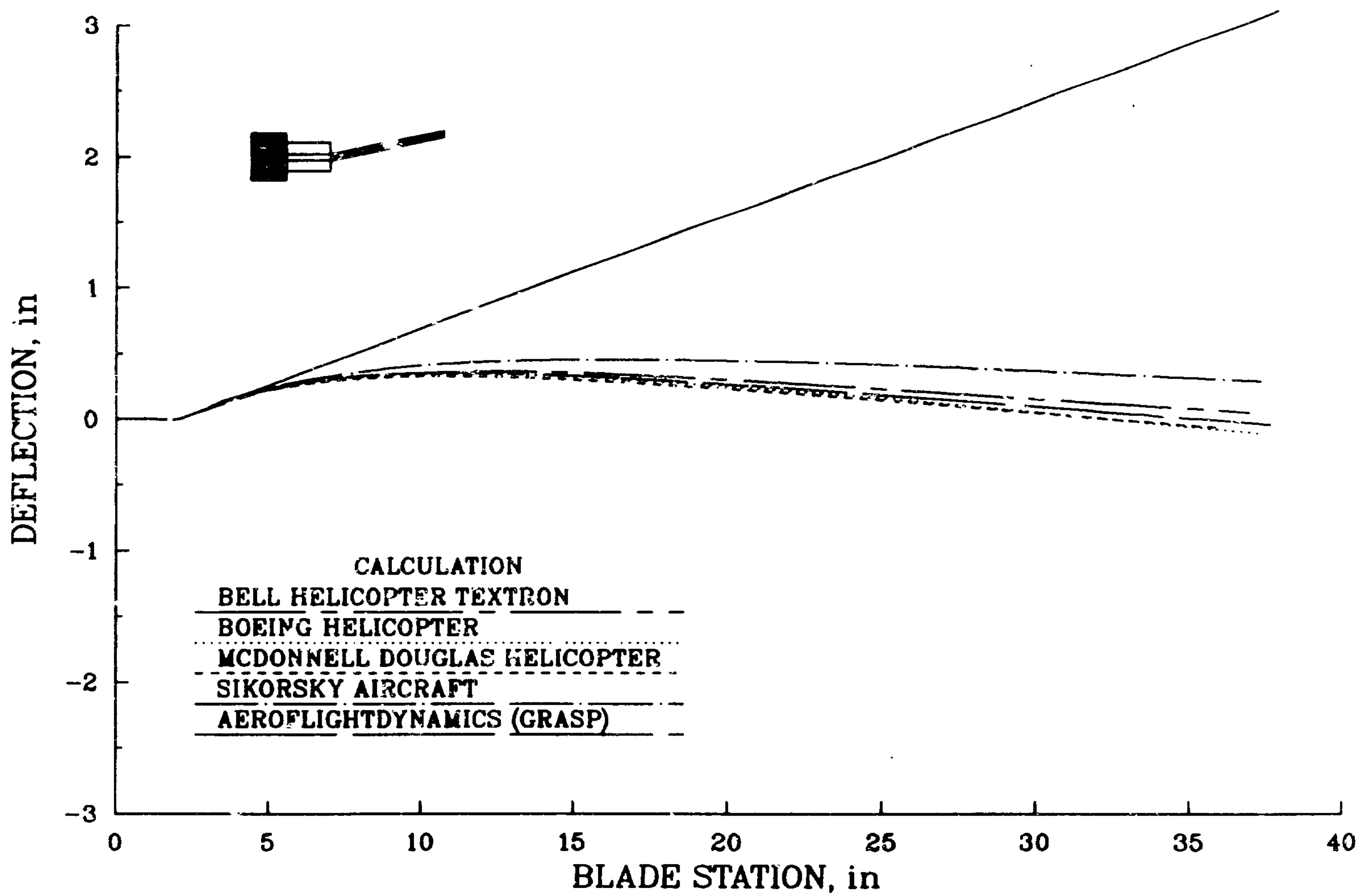
FLAP EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg

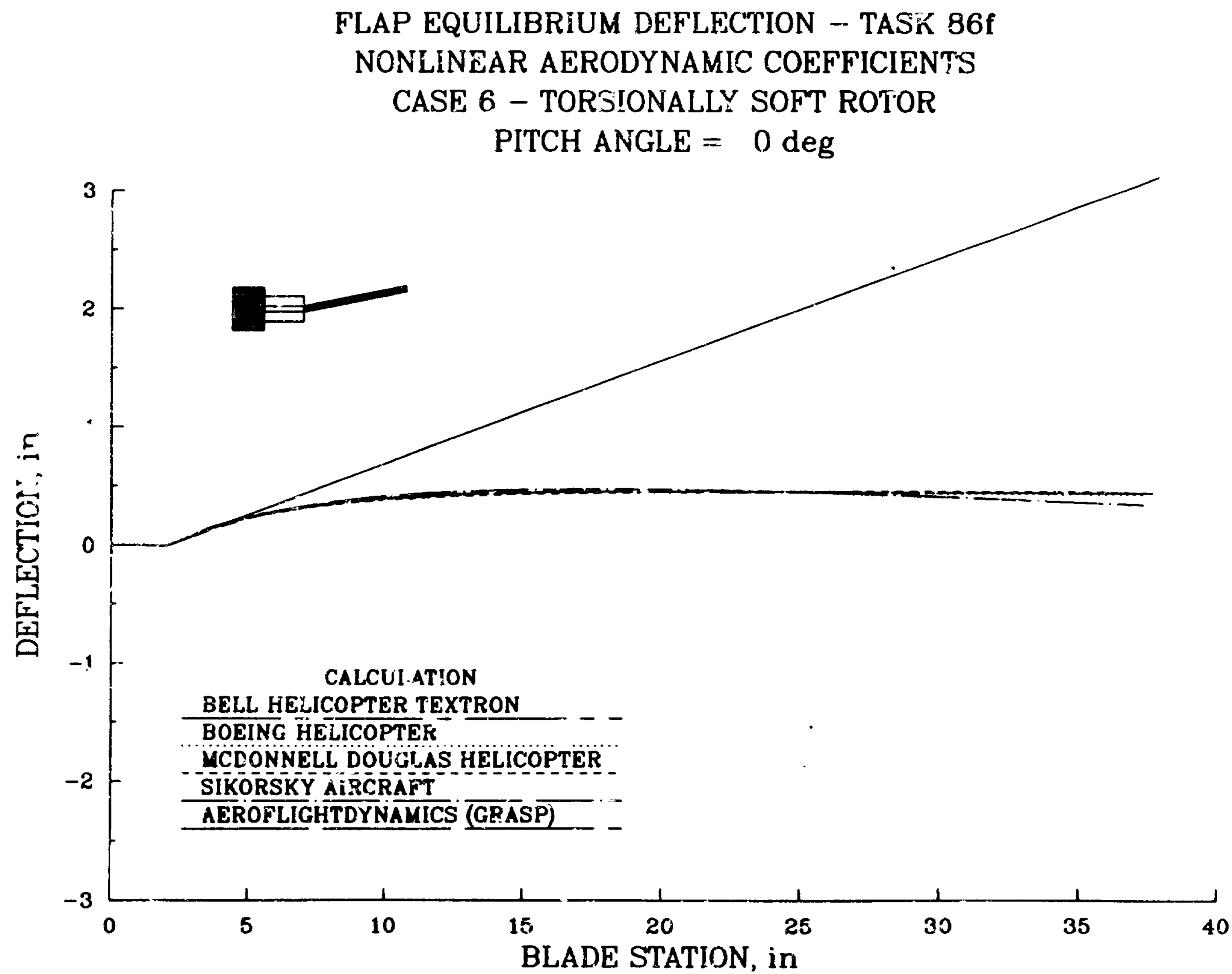


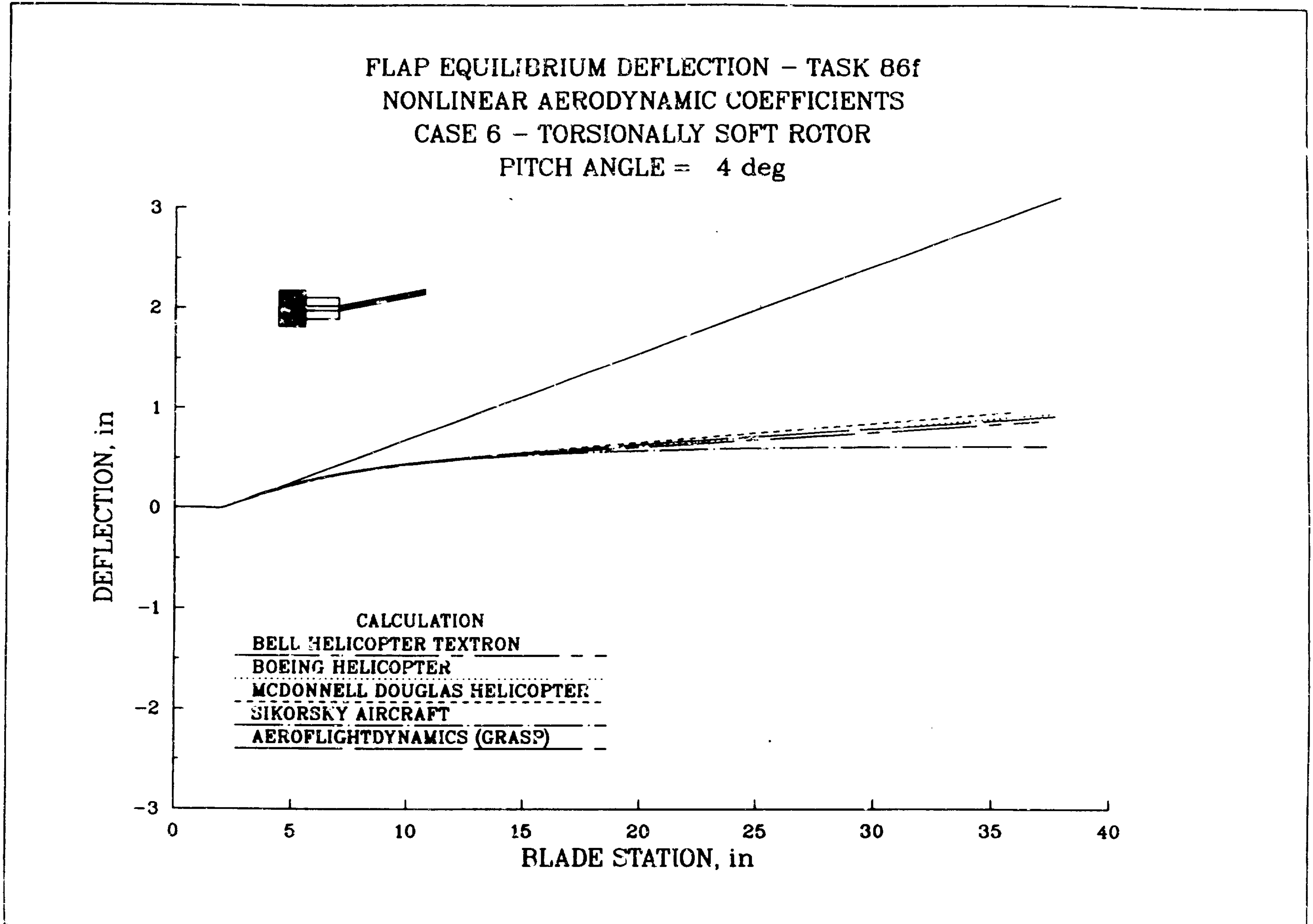
FLAP EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg



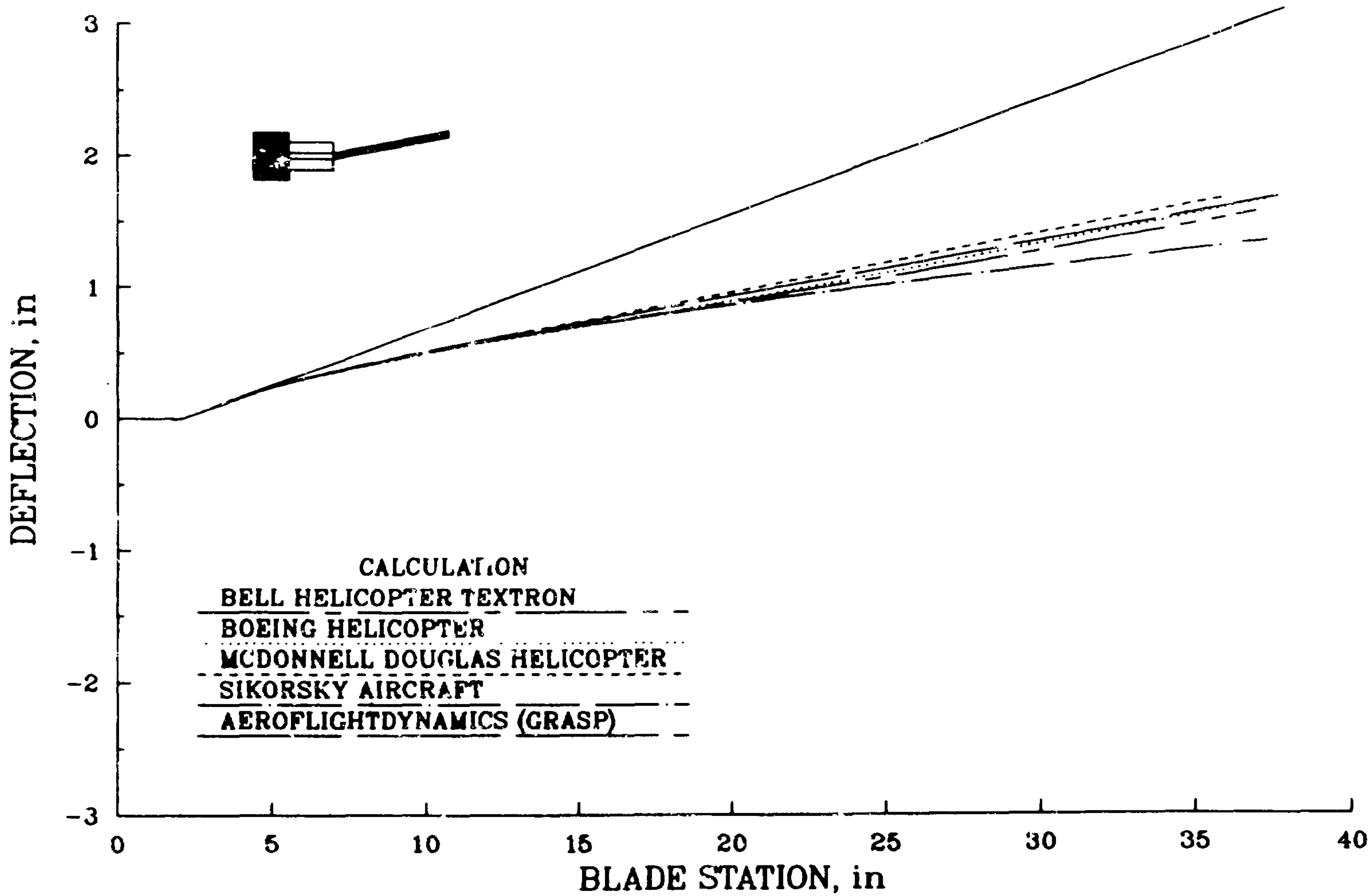
FLAP EQUILIBRIUM DEFLECTION -- TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −4 deg

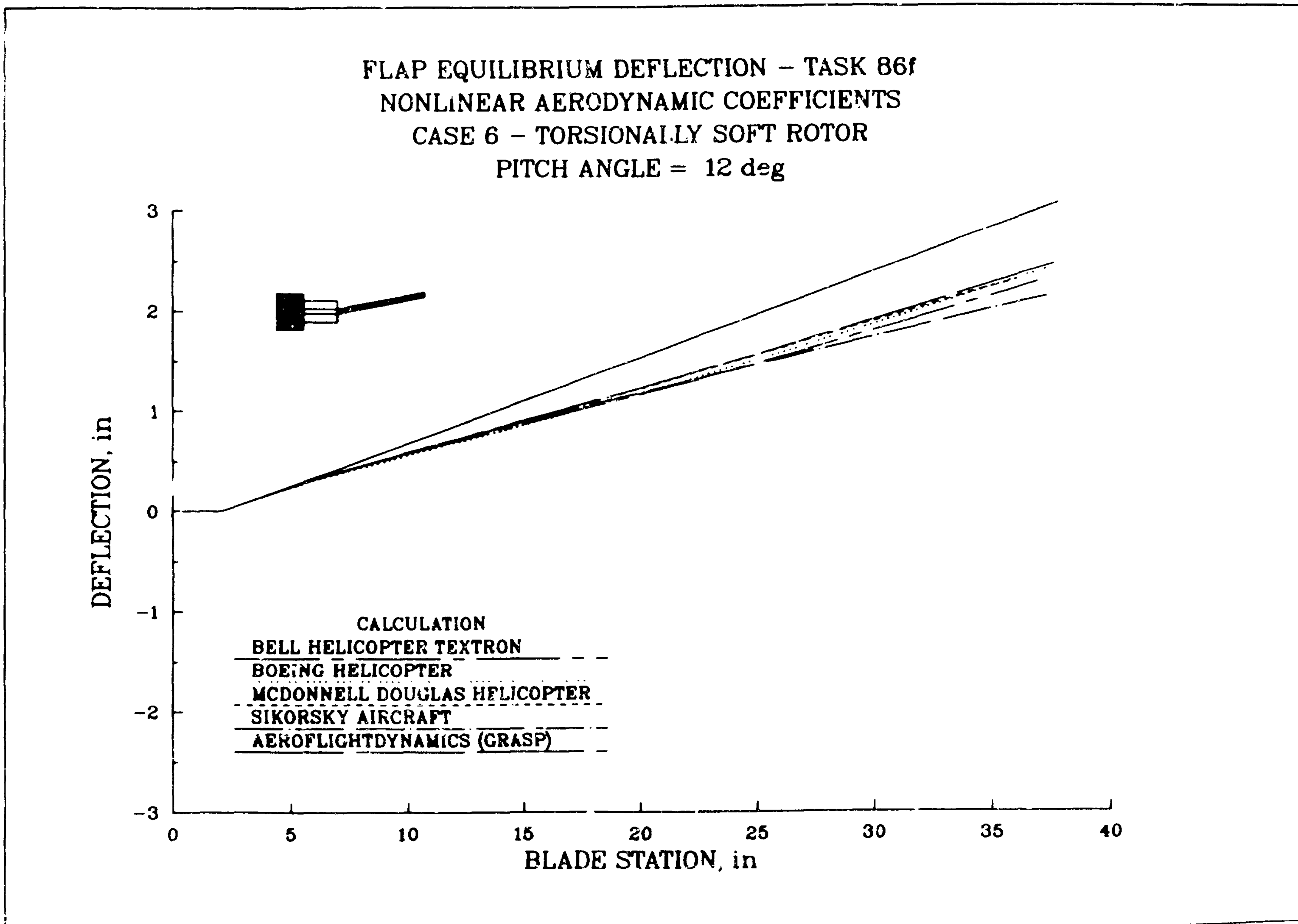


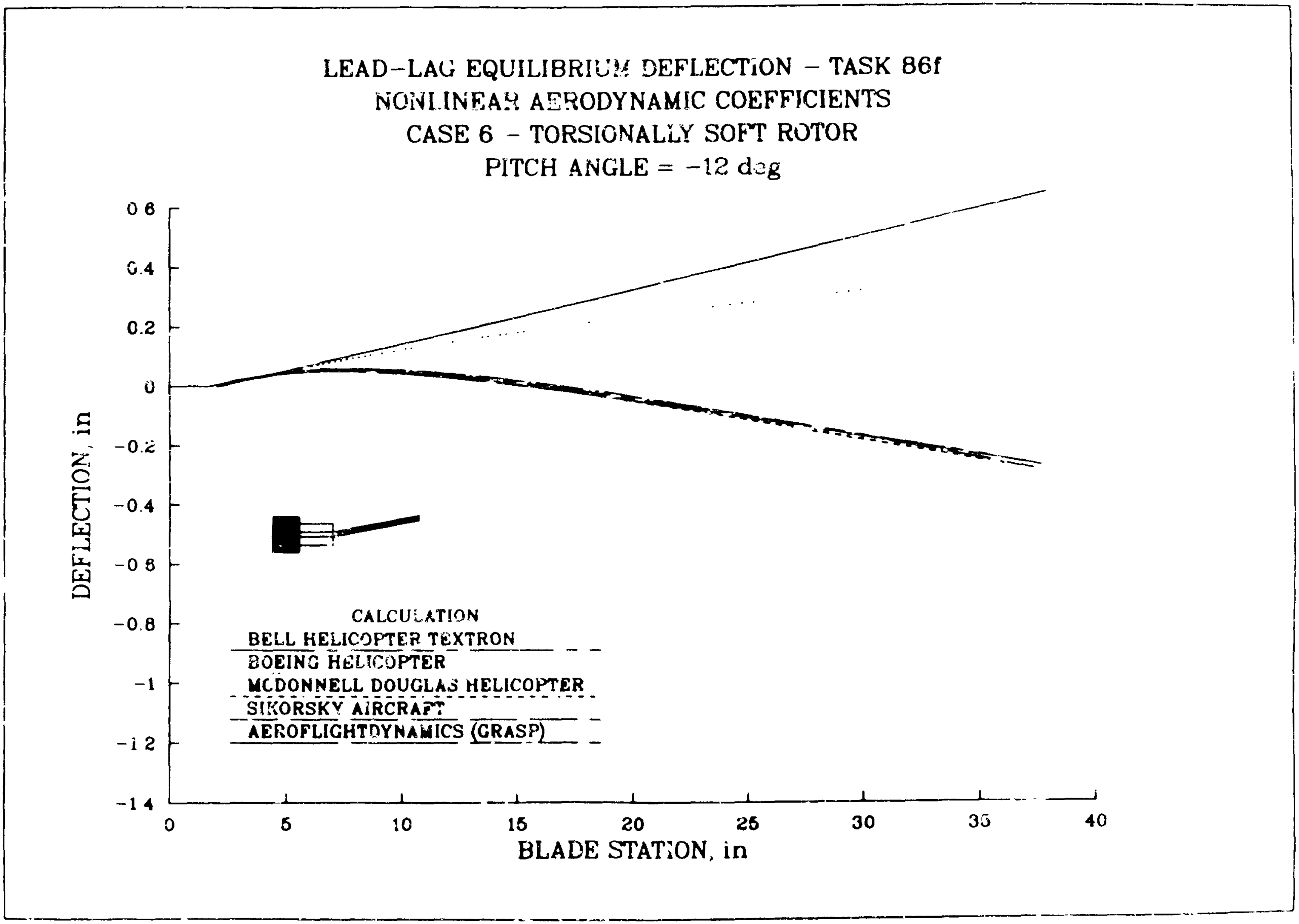

FLAP EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
DEFLECTION, in
3
2
0
-1
-2
-3
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)


FLAP EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
DEFLECTION, in
BLADE STATION, in
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

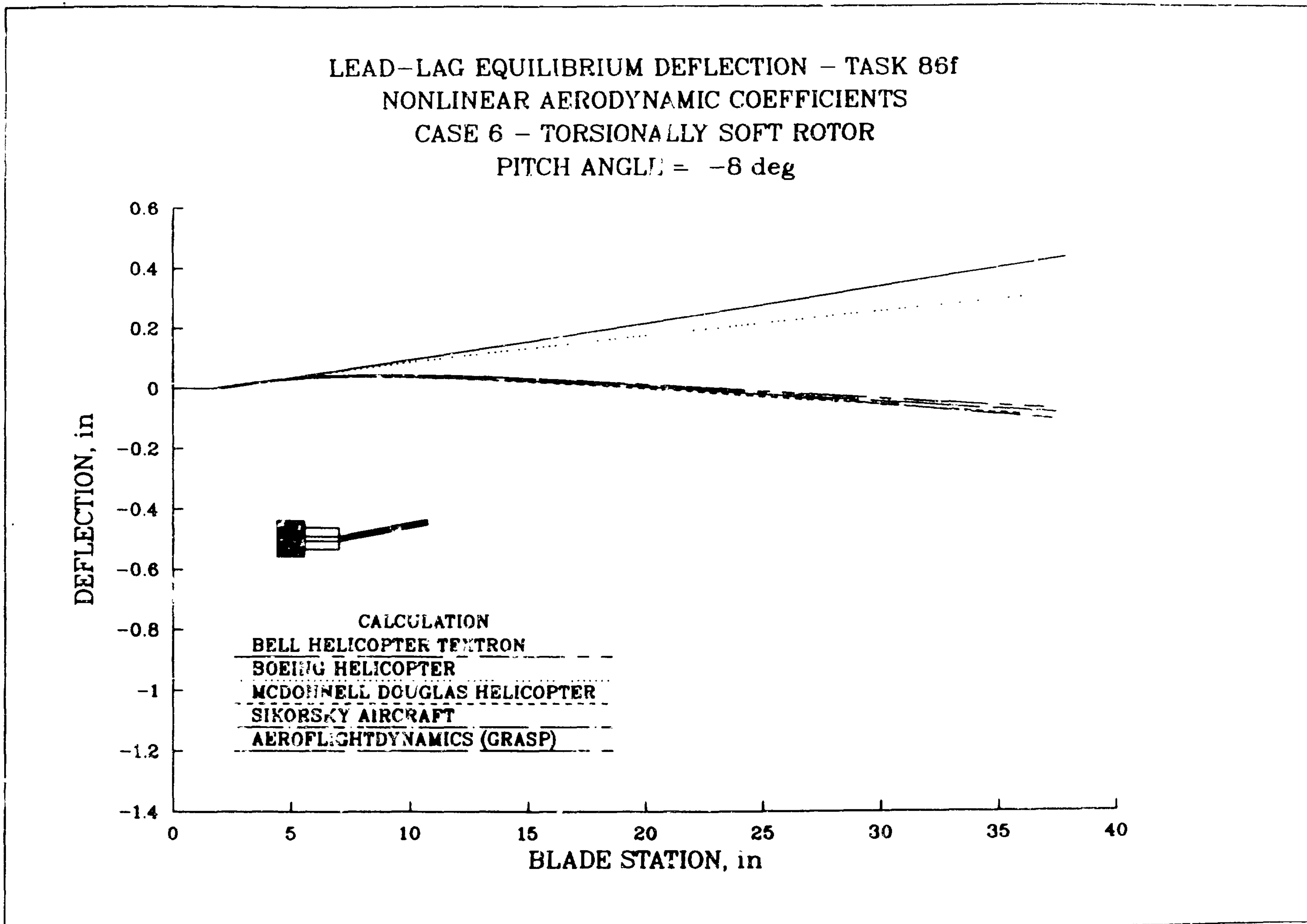
FLAP EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg



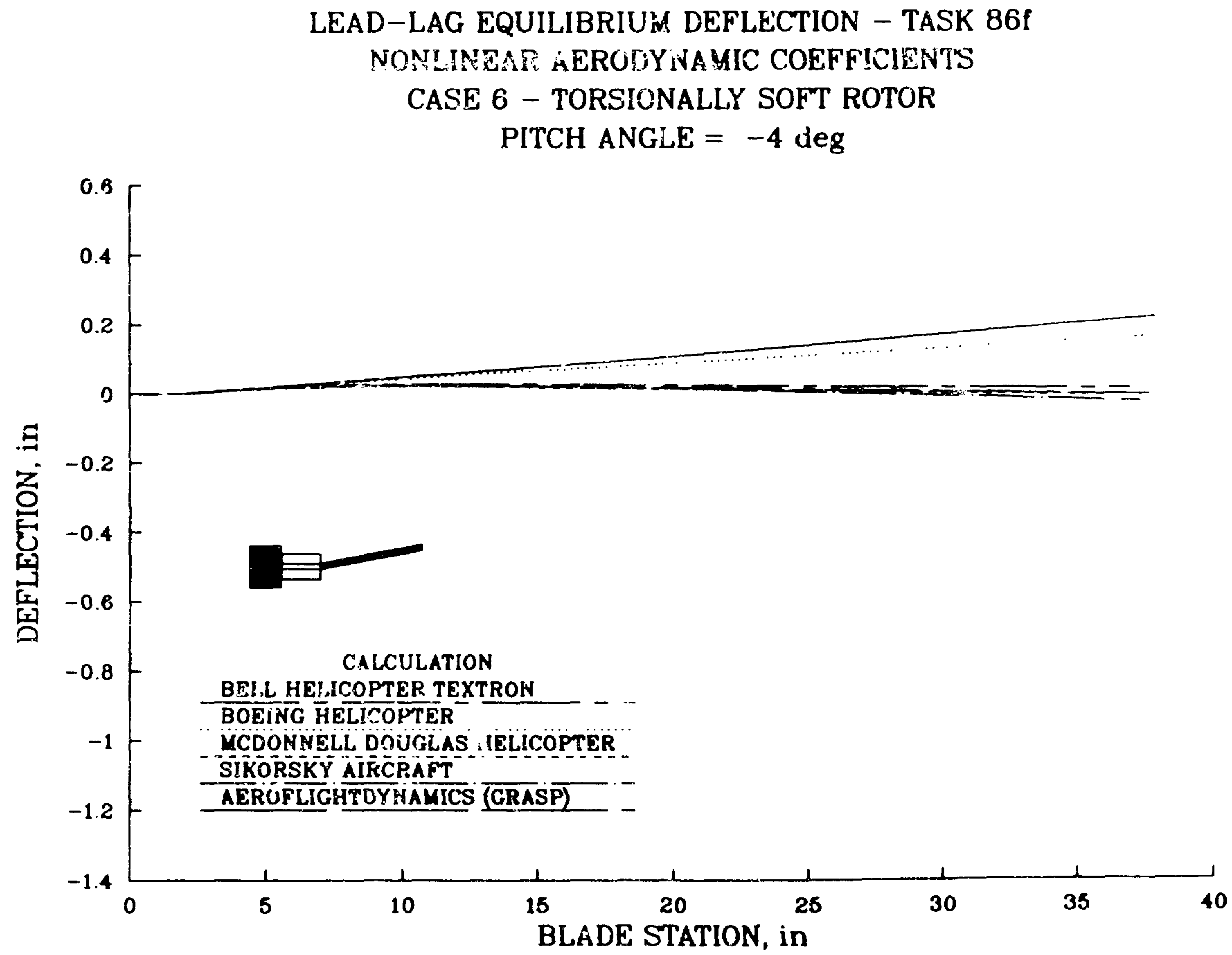

FLAP EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
3
2
1
0
−1
−2
−3
DEFLECTION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in



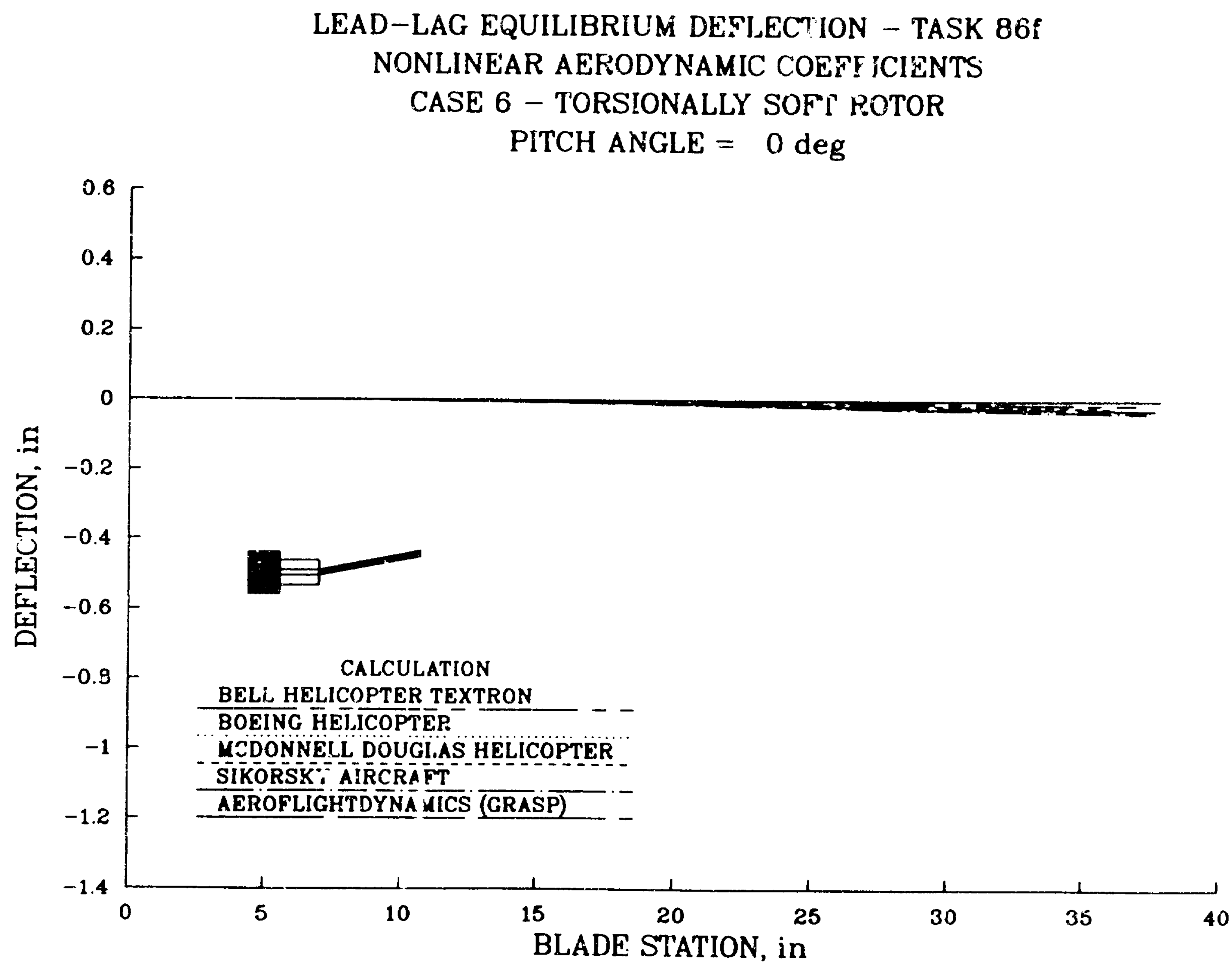
LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg
0.6
0.4
0.2
0
–0.2
–0.4
–0.6
–0.8
–1
–1.2
–1.4
DEFLECTION, in
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)



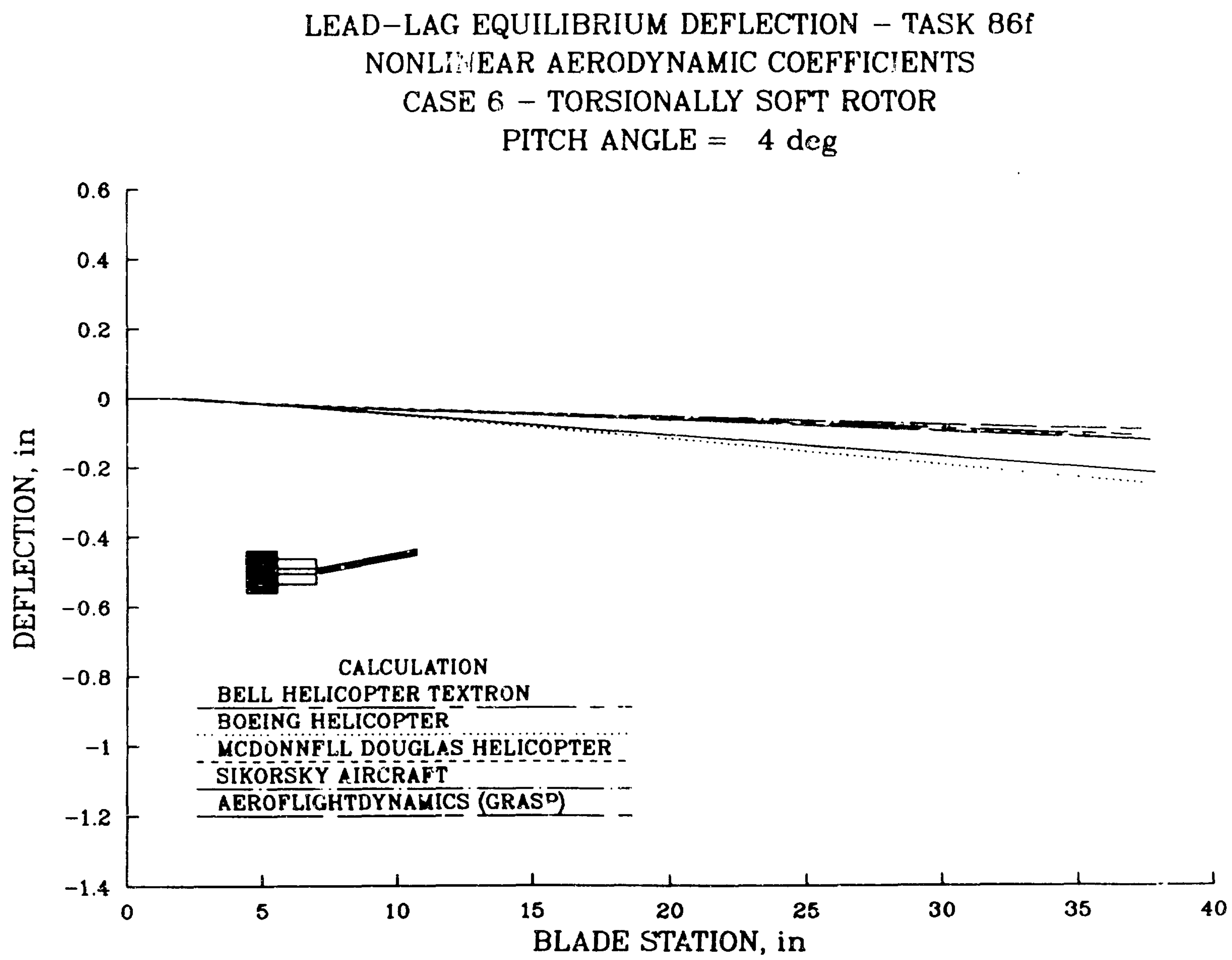
LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = -8 deg
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
DEFLECTION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in



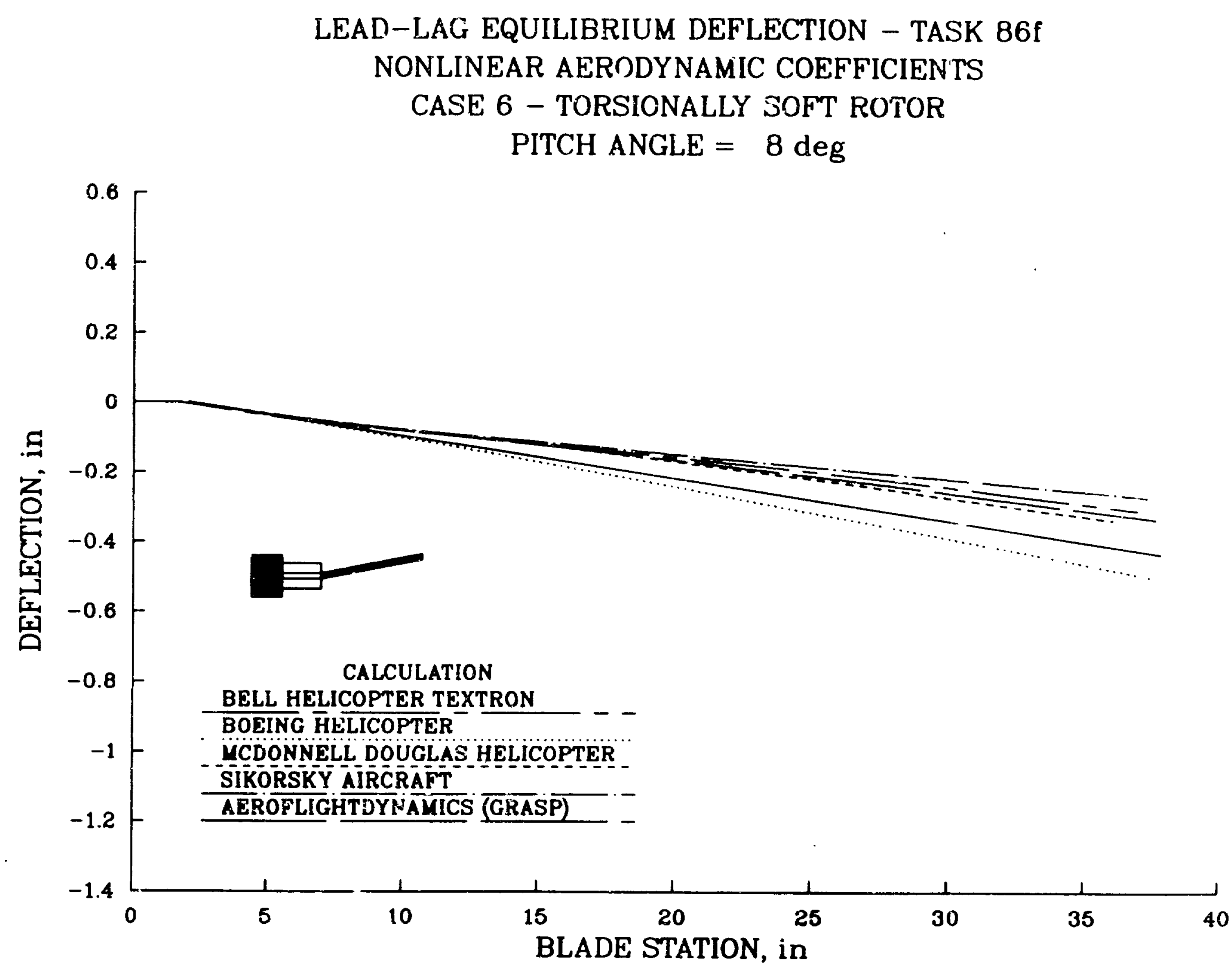
LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = -4 deg
DEFLECTION, in
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in



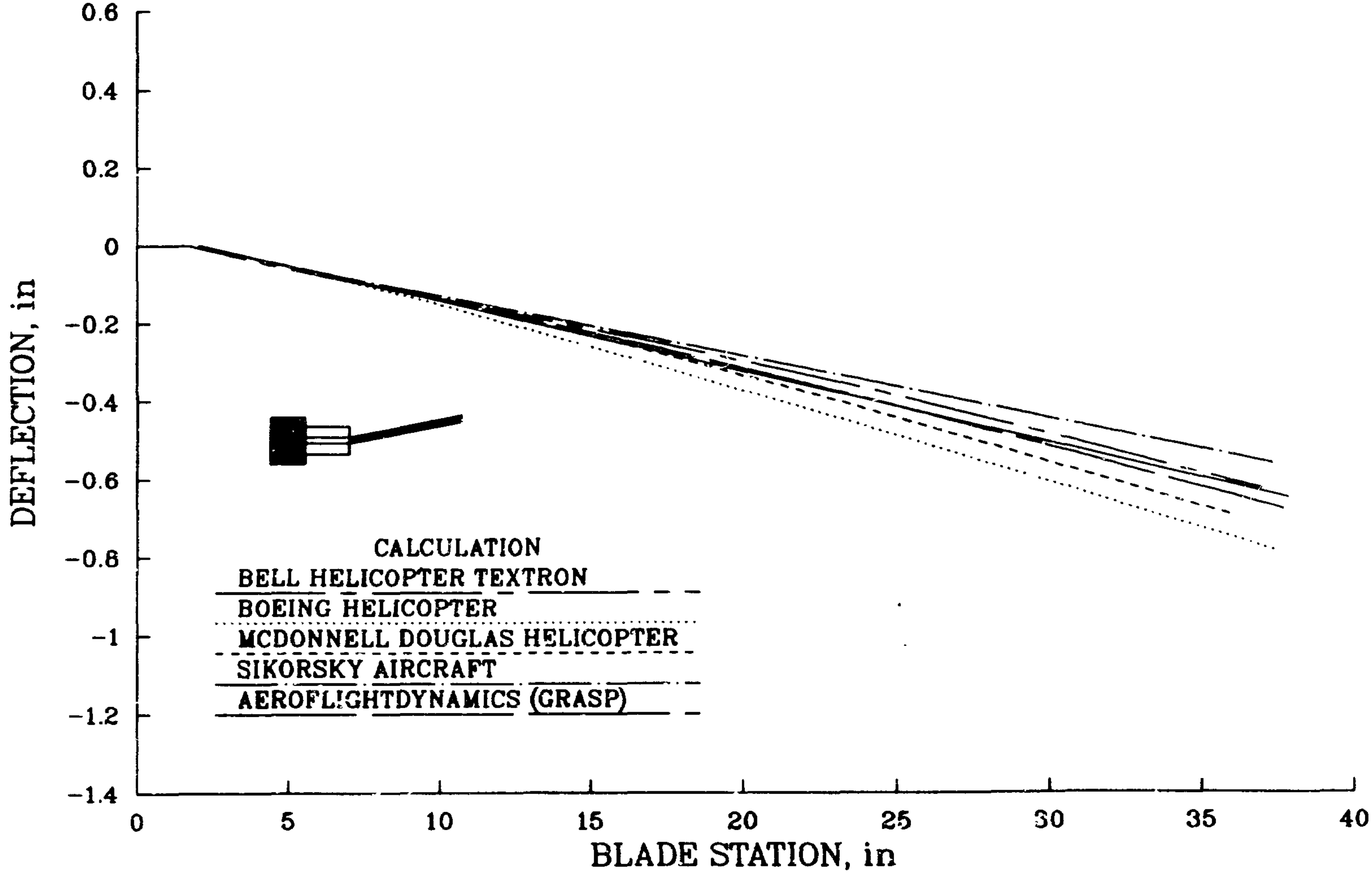
LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
DEFLECTION, in
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in



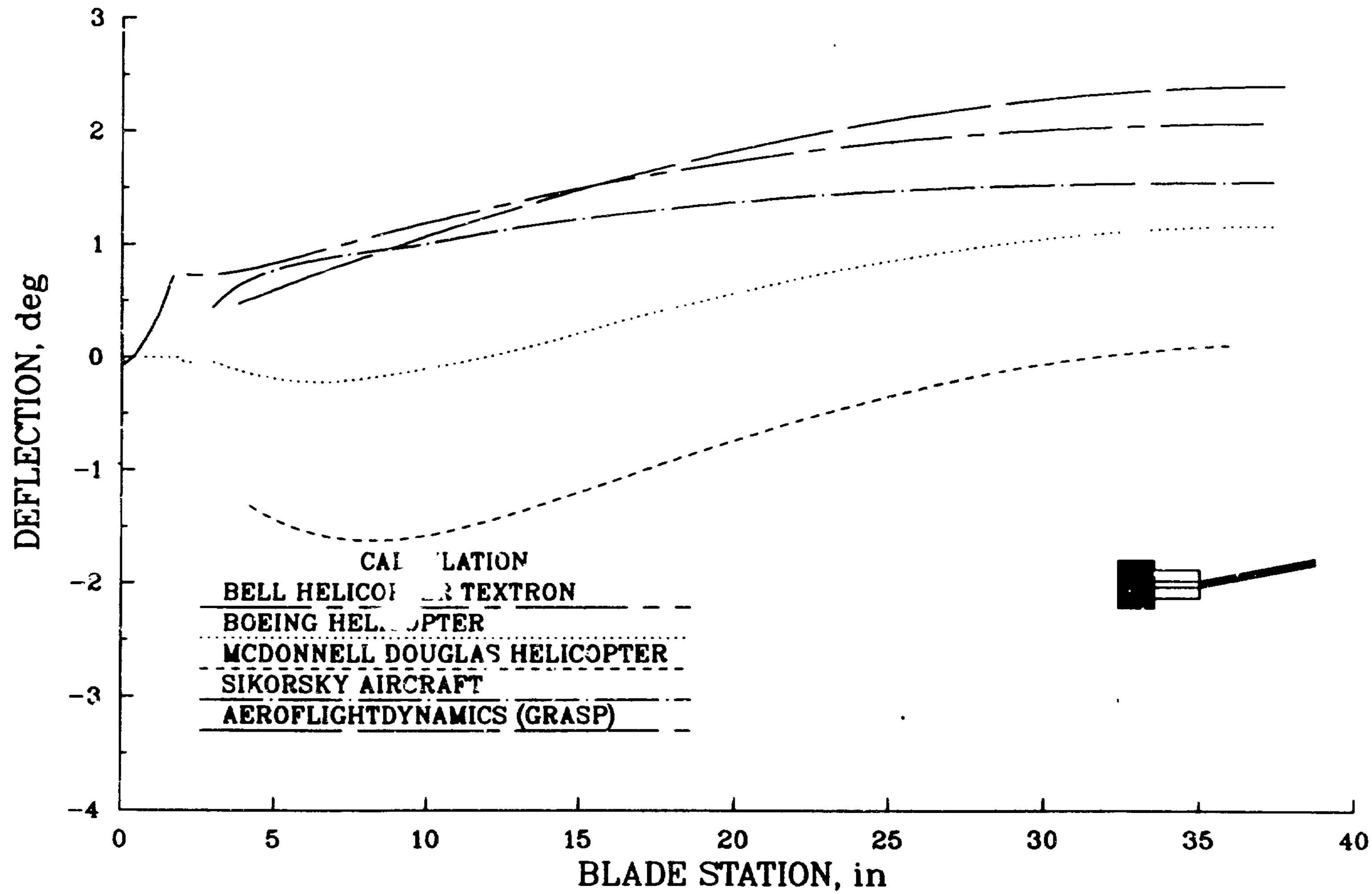
LEAD-LAG EQUILIBRIUM DEFLECTION - TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 - TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
DEFLECTION, in
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

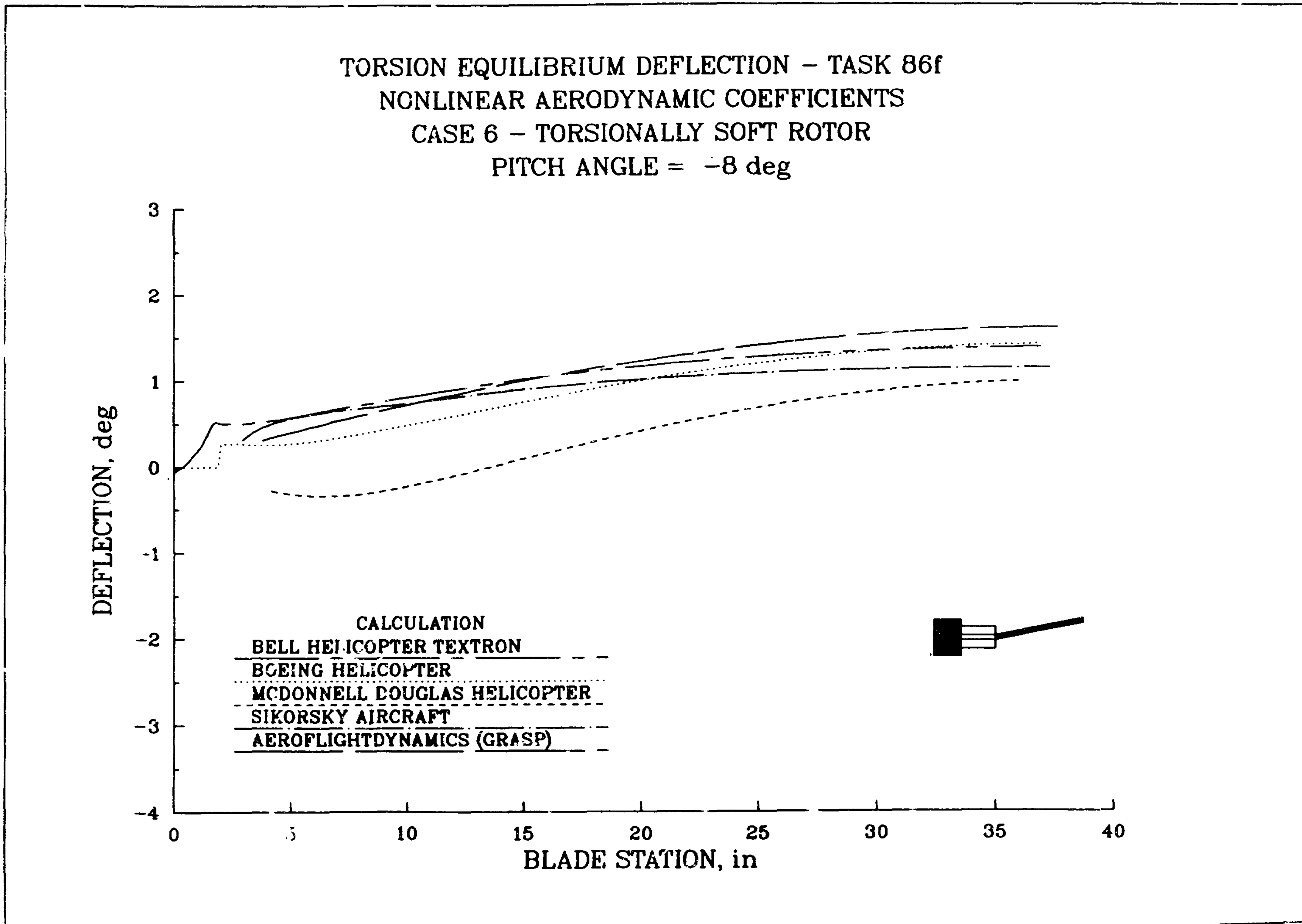

LEAD-LAG EQUILIBRIUM DEFLECTION - TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 - TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
DEFLECTION, in
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
0
5
10
15
20
25
30
35
40
BLADE STATION, in

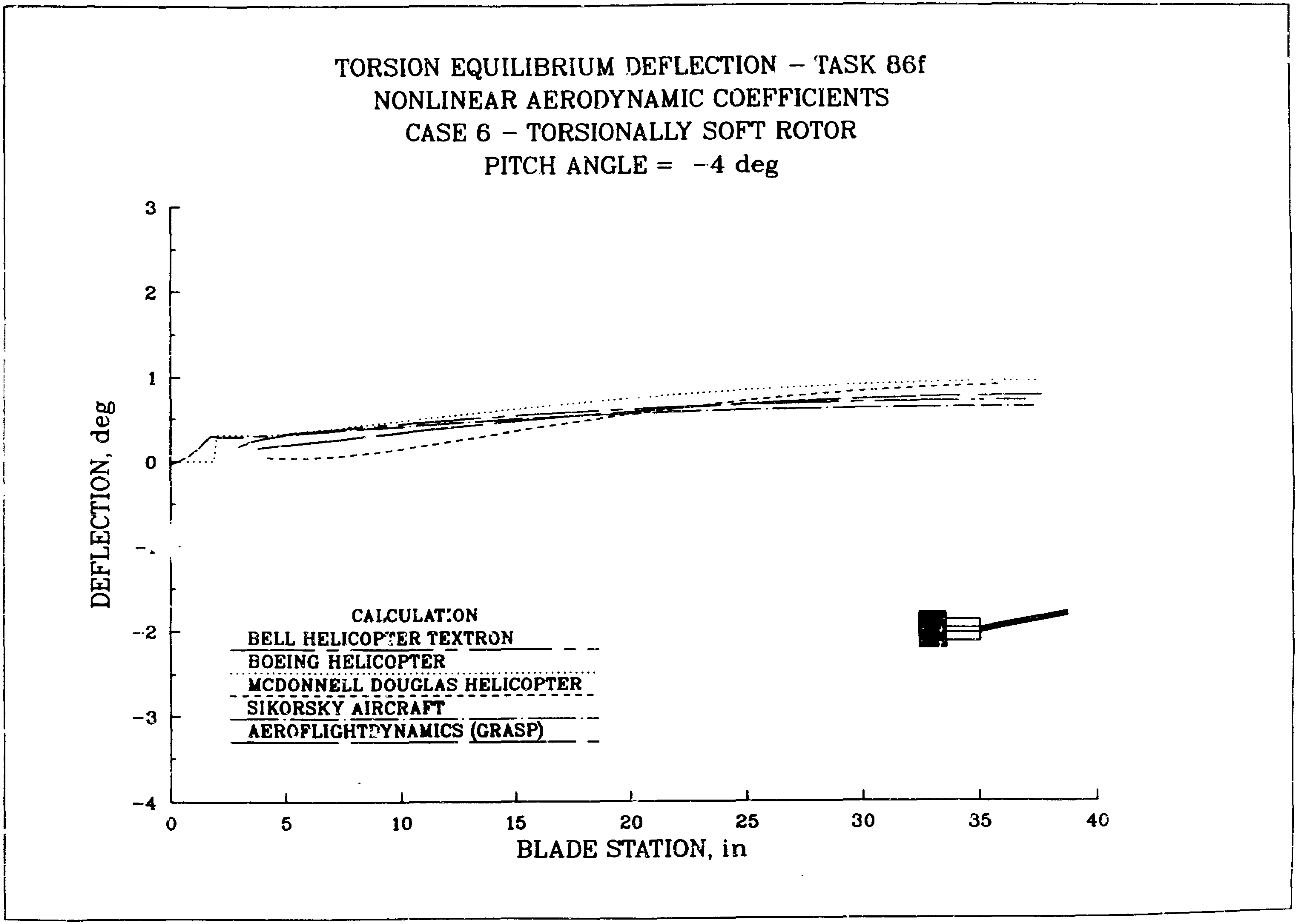
LEAD–LAG EQUILIBRIUM DEFLECTION -- TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg

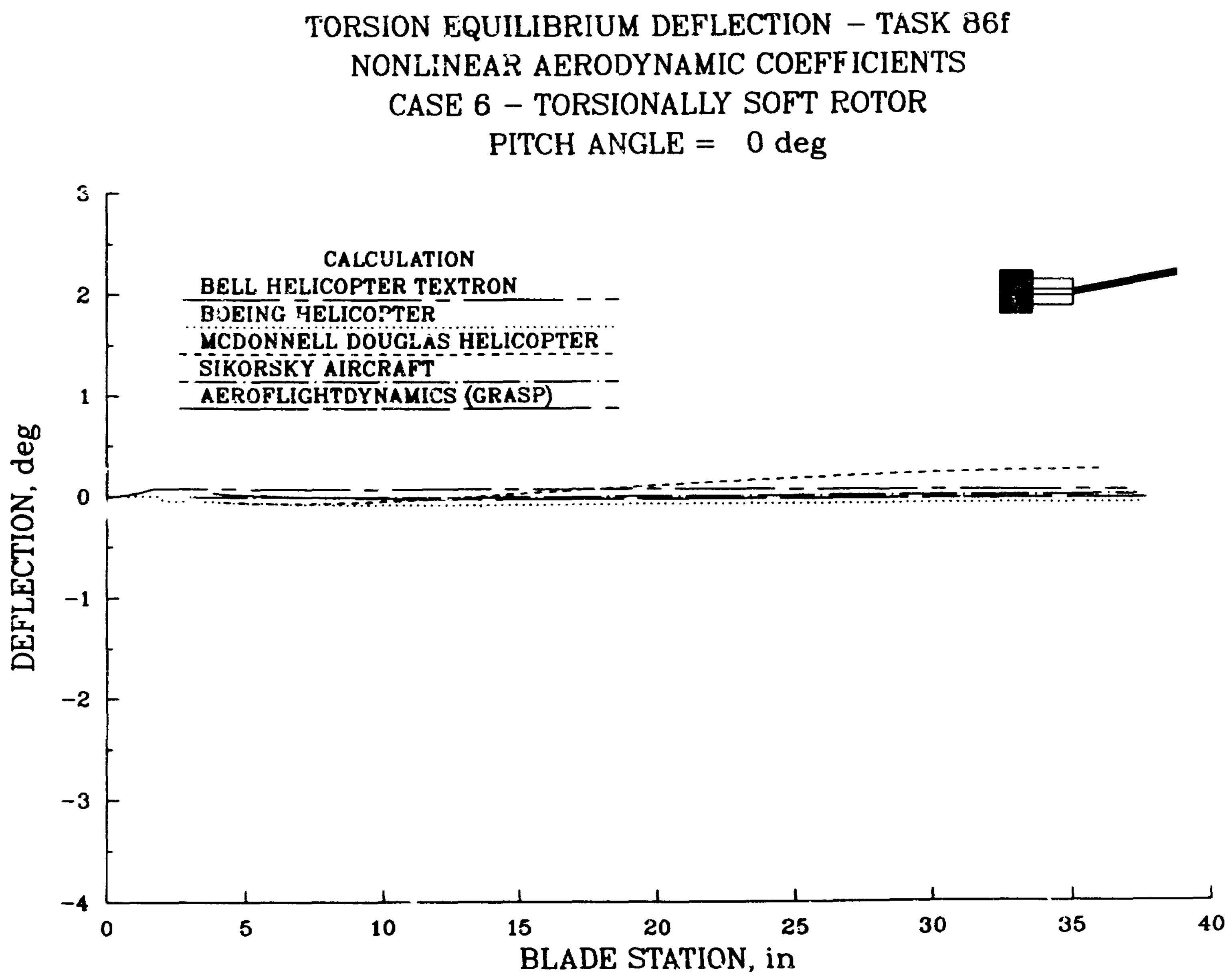


TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg

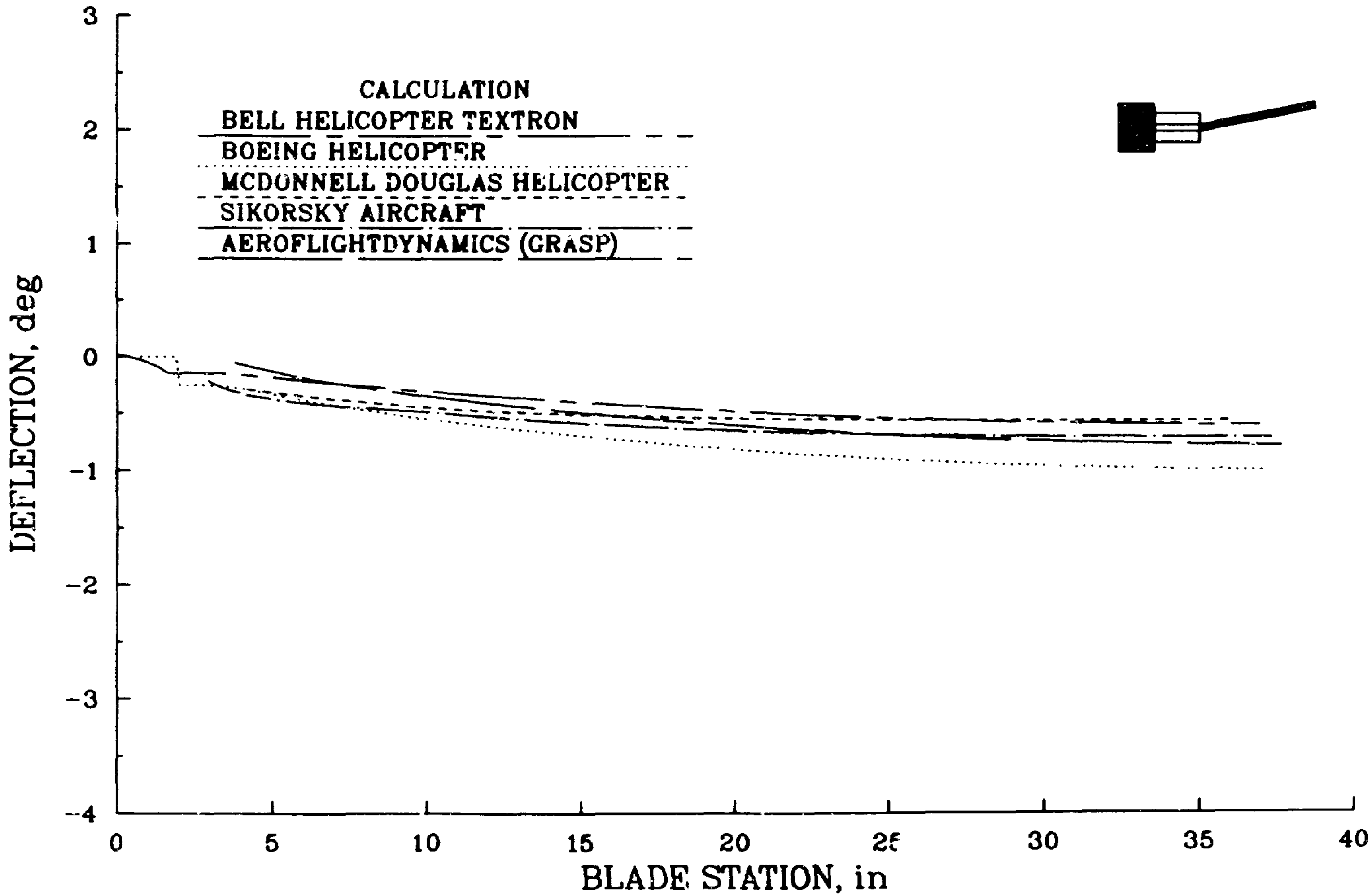


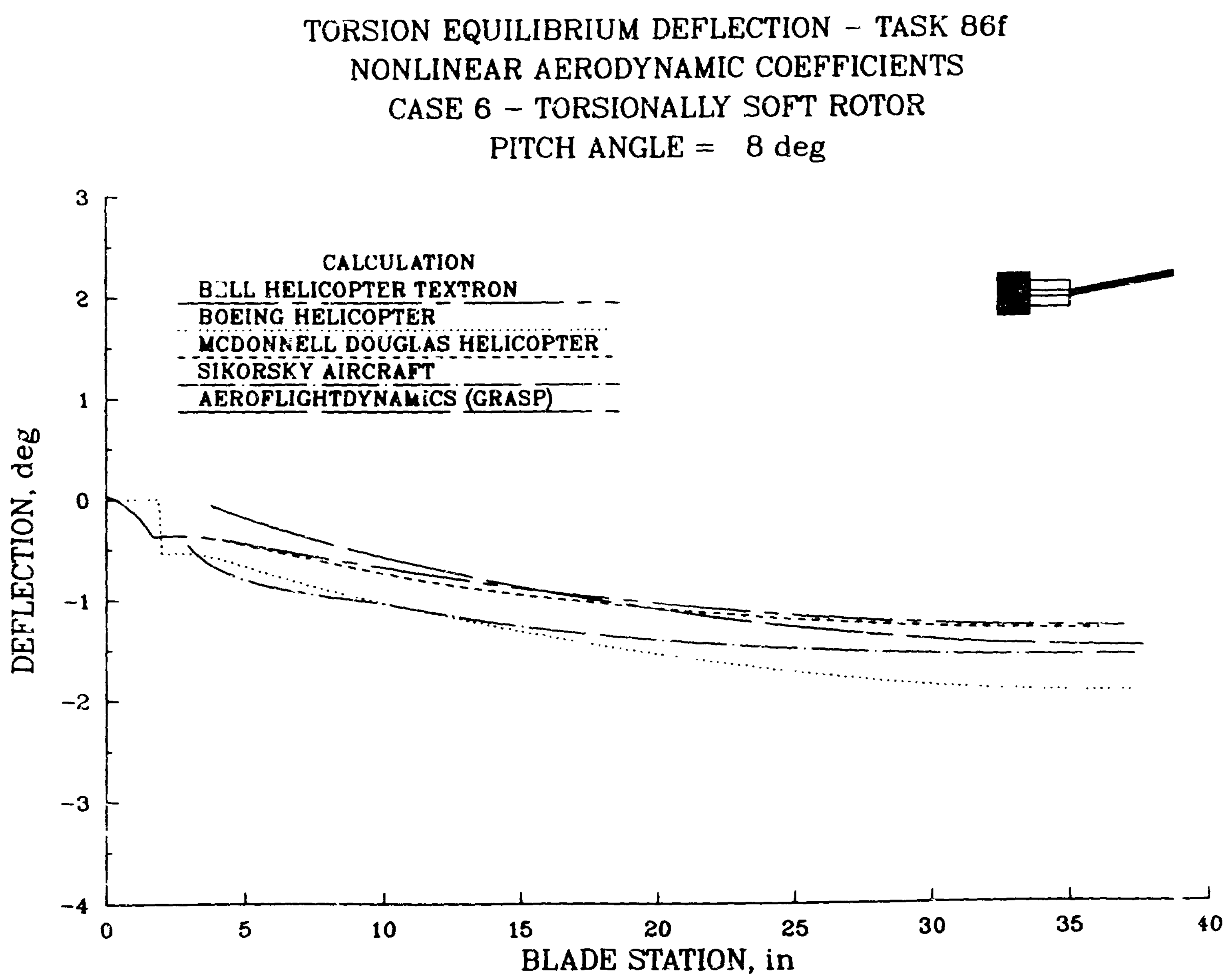

TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –8 deg
DEFLECTION, deg
3
2
1
0
-1
–2
–3
–4
0
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)


TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg
DEFLECTION, deg
3
2
1
0
-2
-3
-4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)

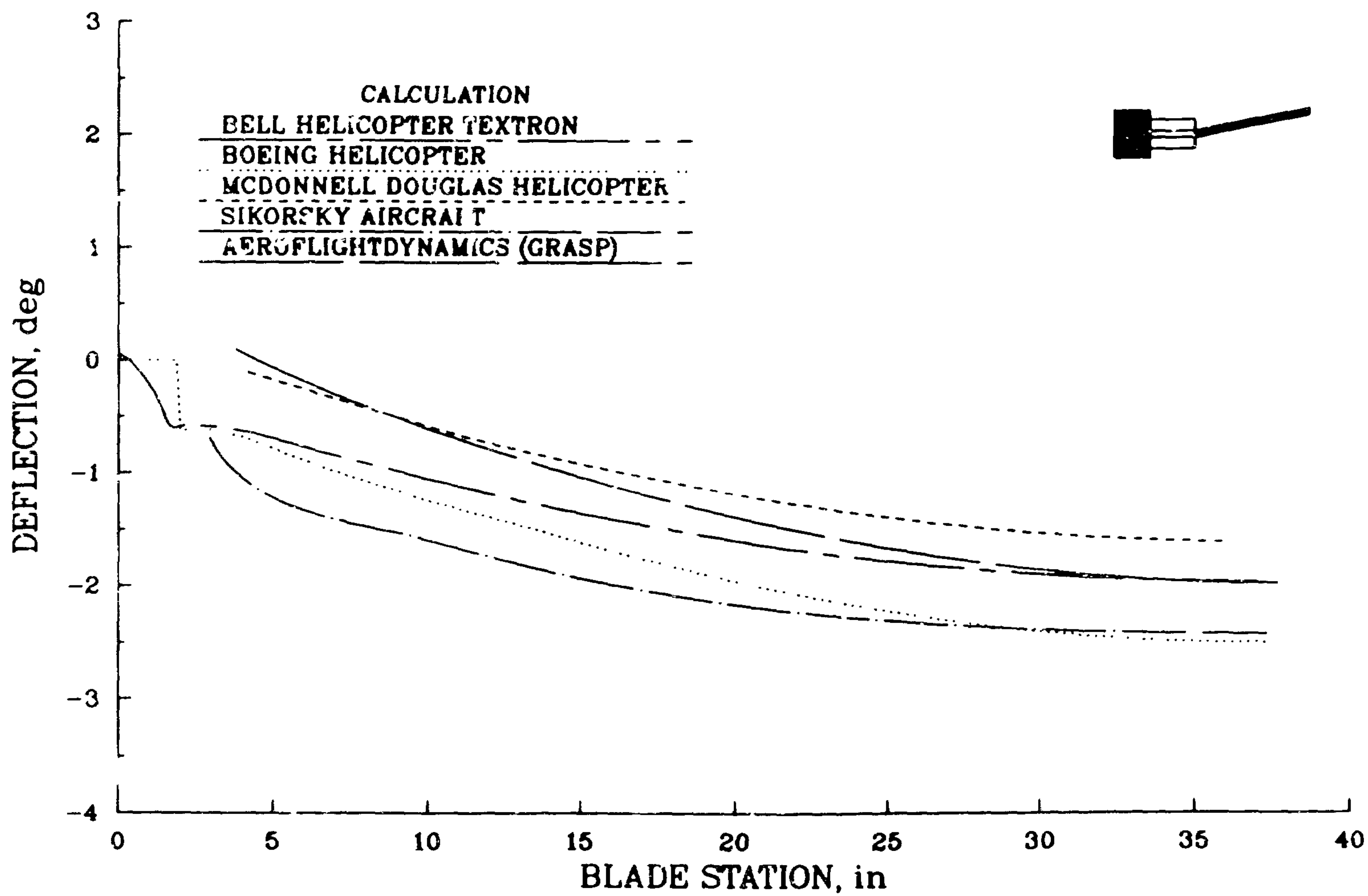

TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
DEFLECTION, deg
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
BLADE STATION, in

TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg

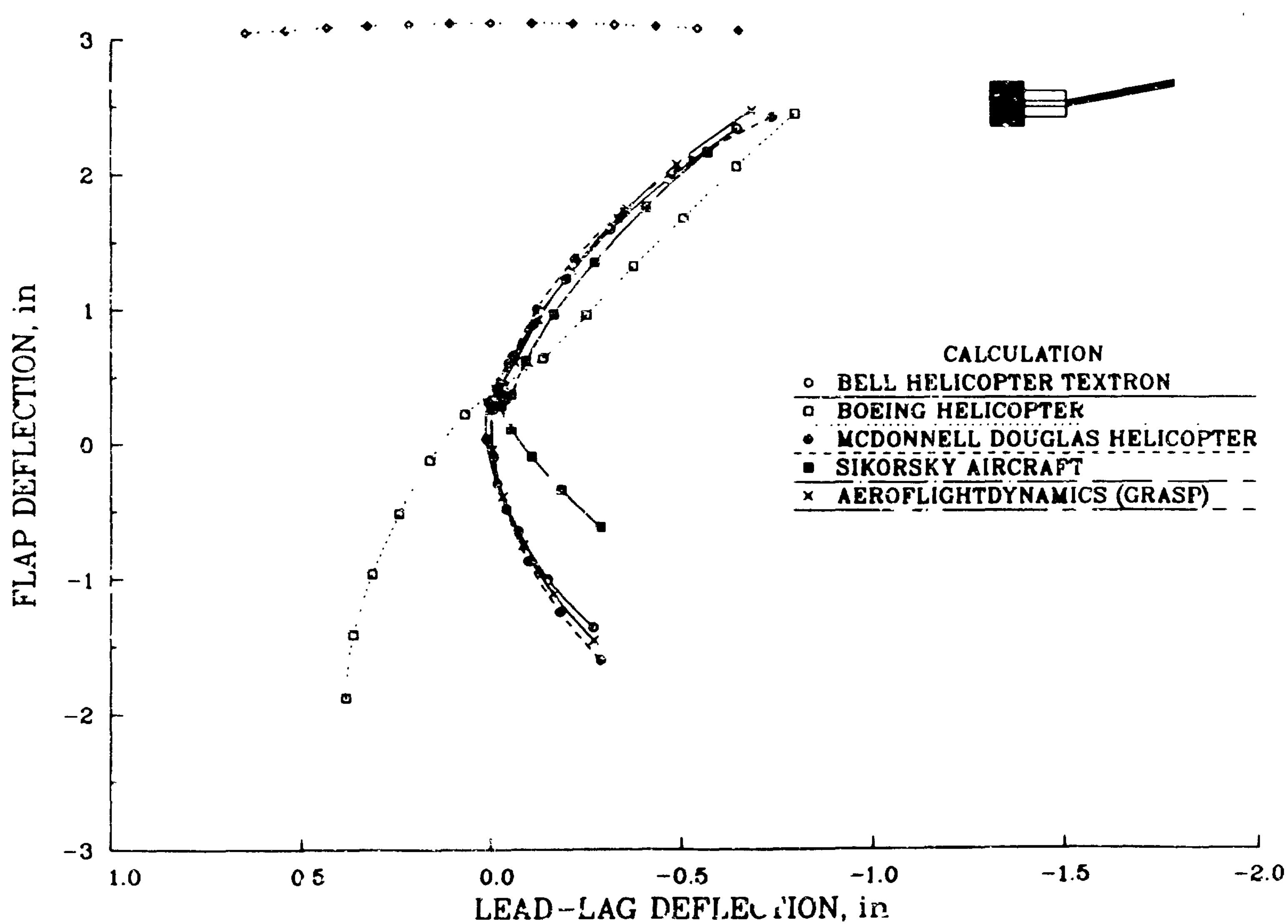


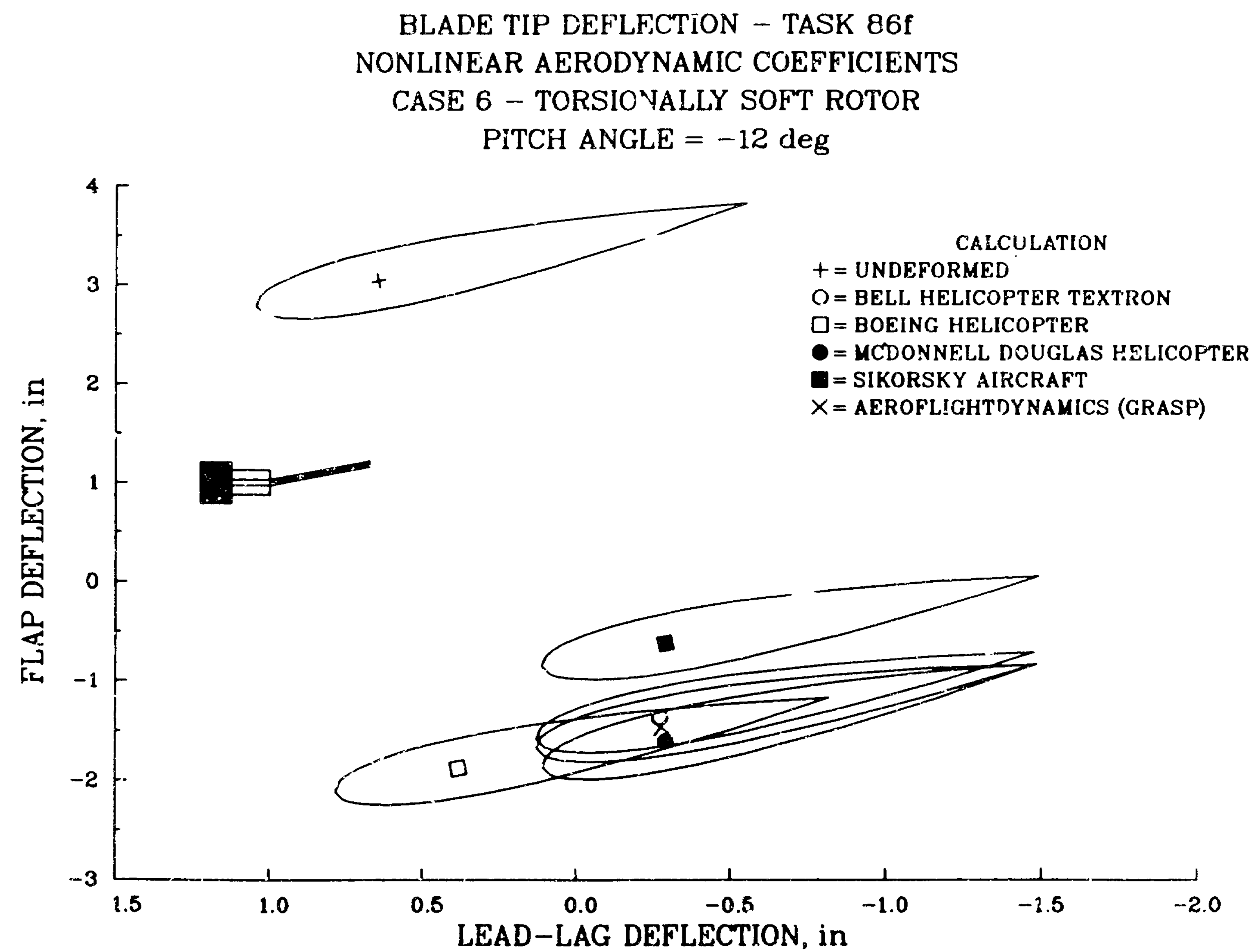

TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (GRASP)
DEFLECTION, deg
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
BLADE STATION, in

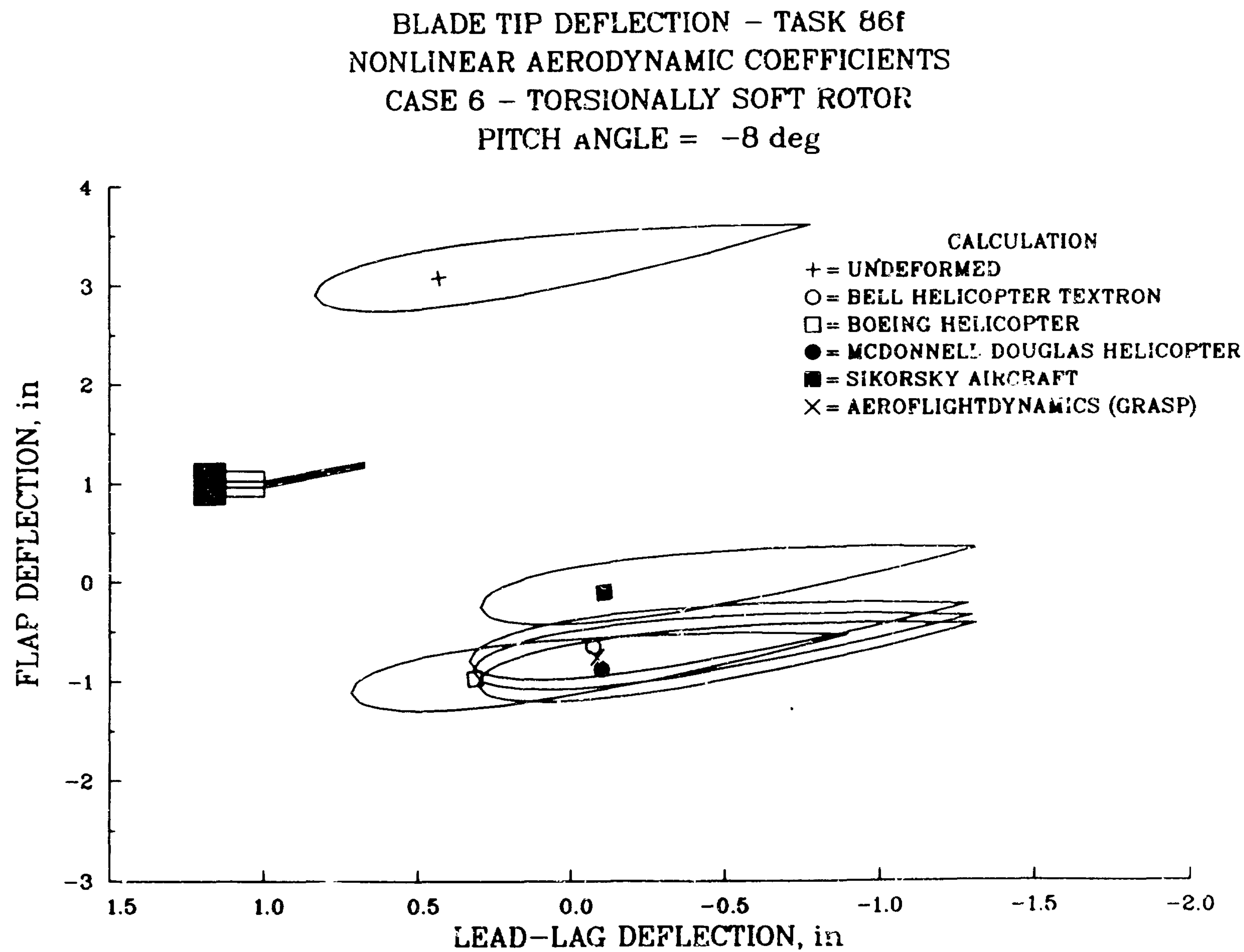
TORSION EQUILIBRIUM DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg

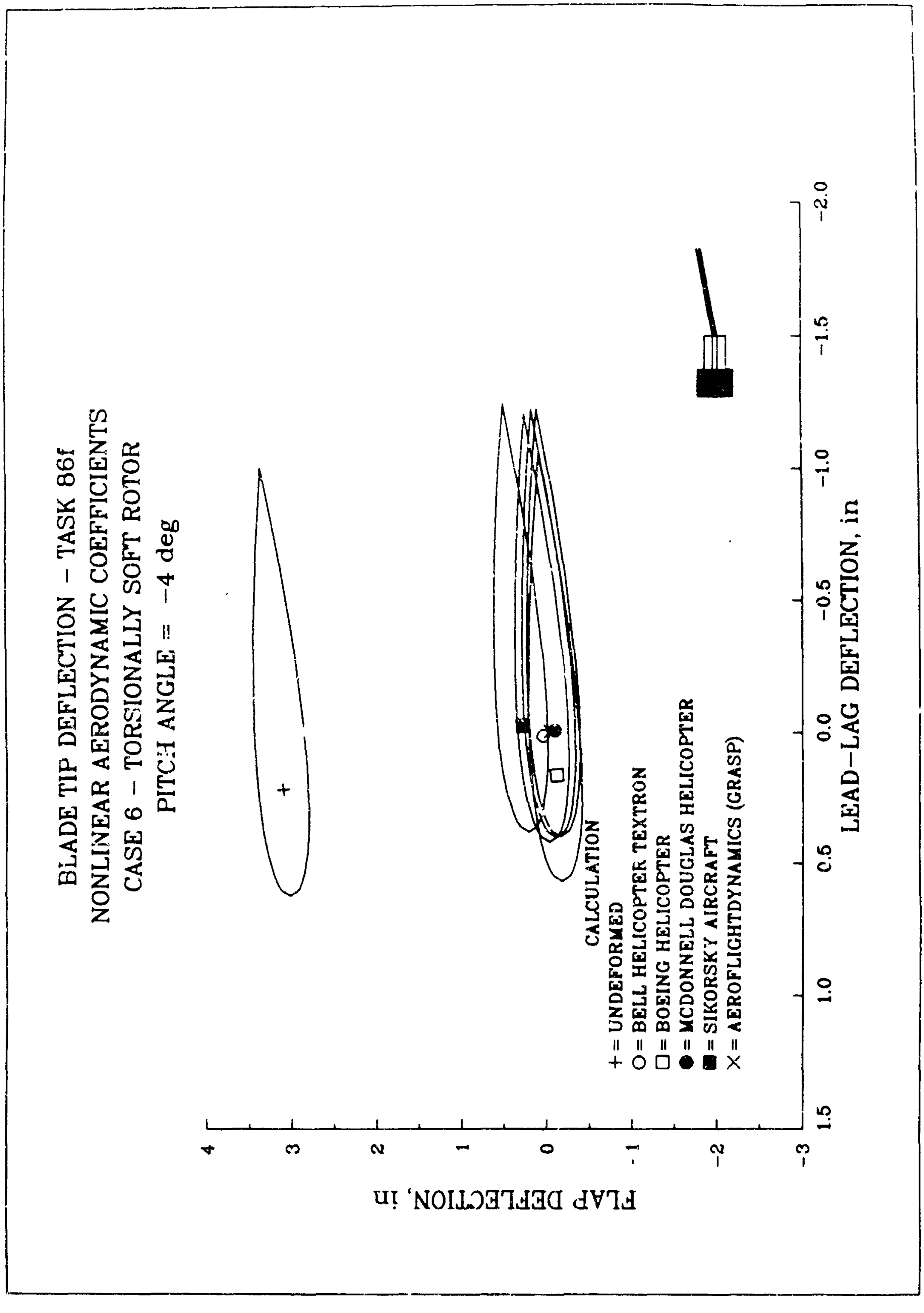


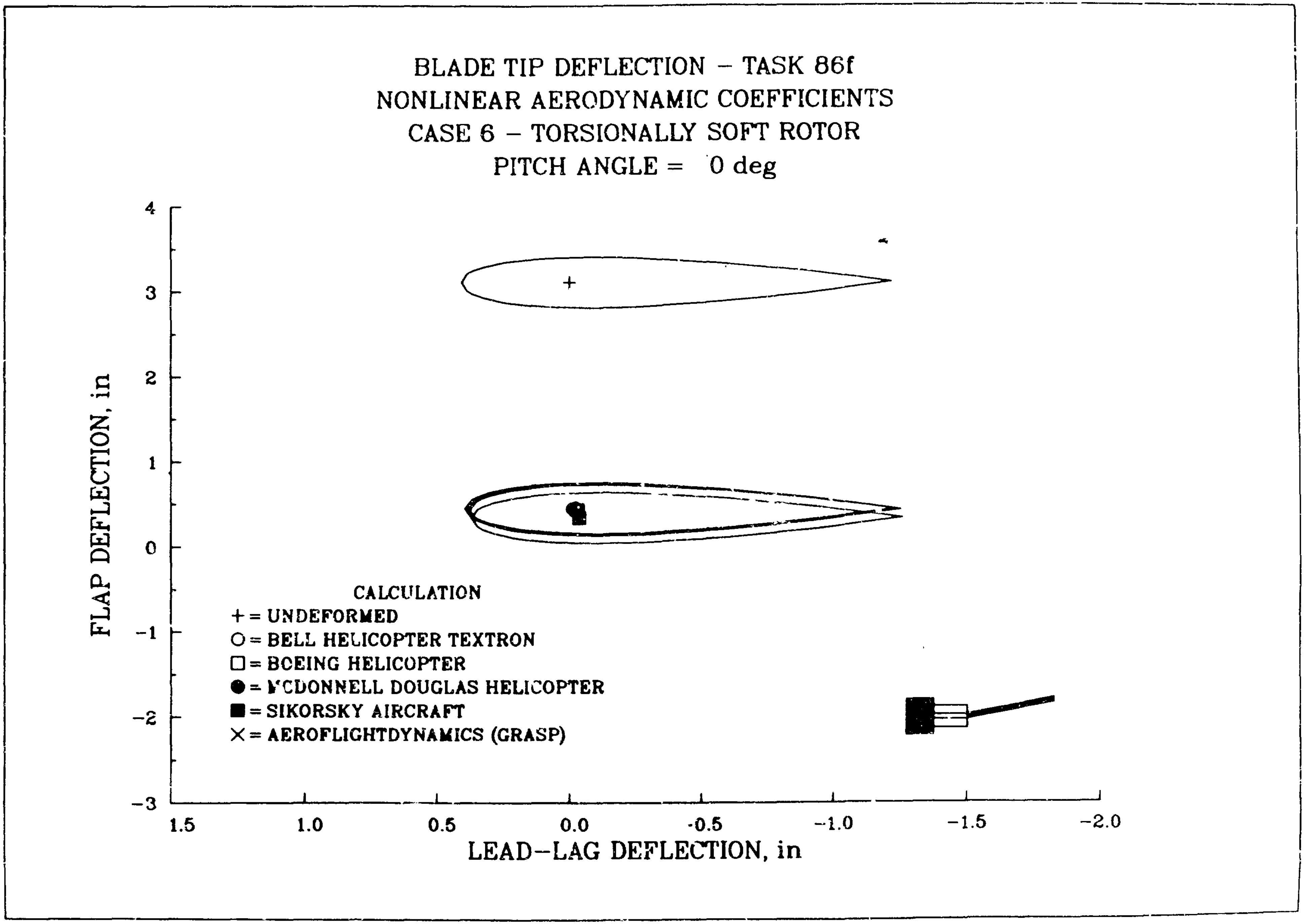
BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR

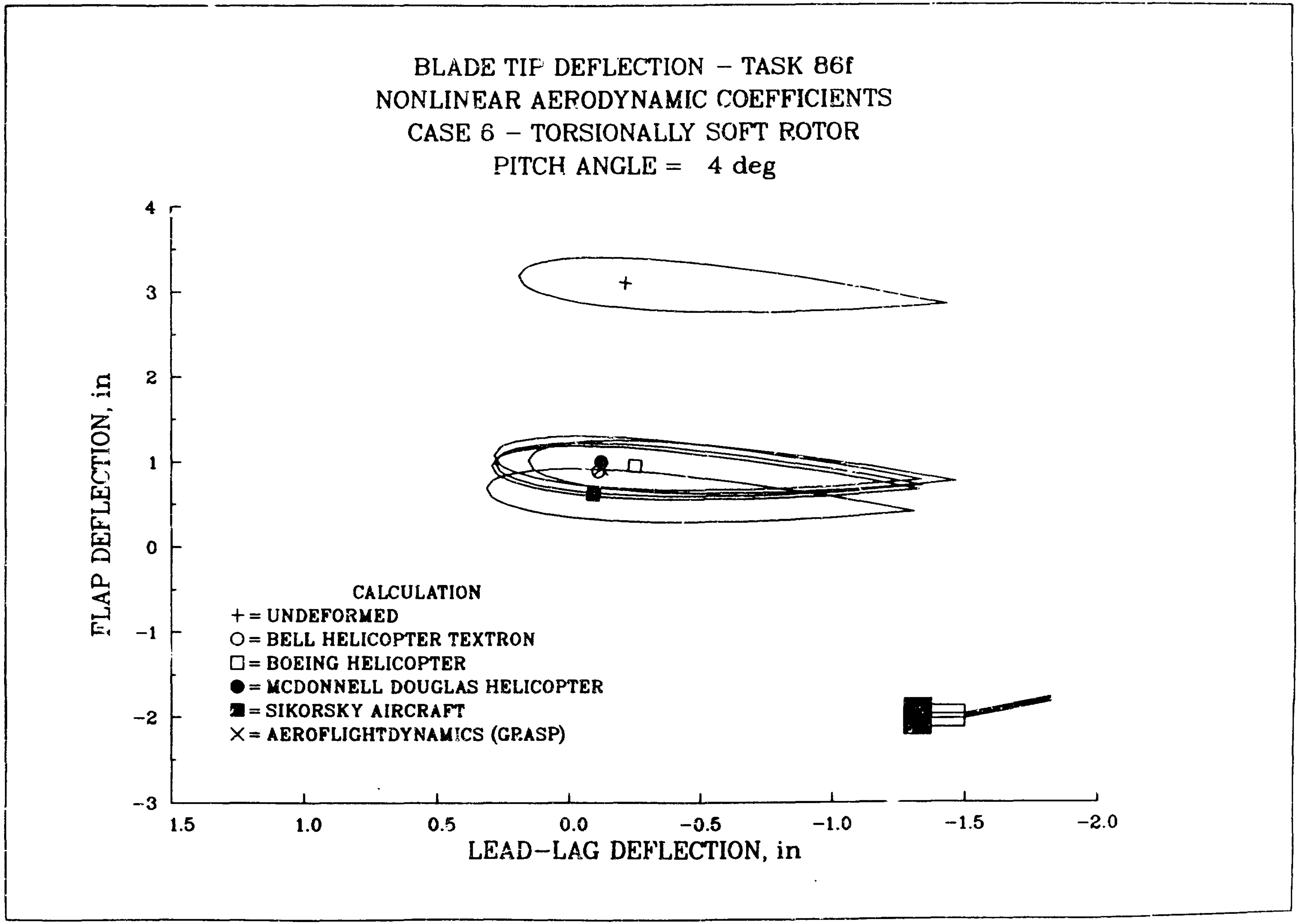


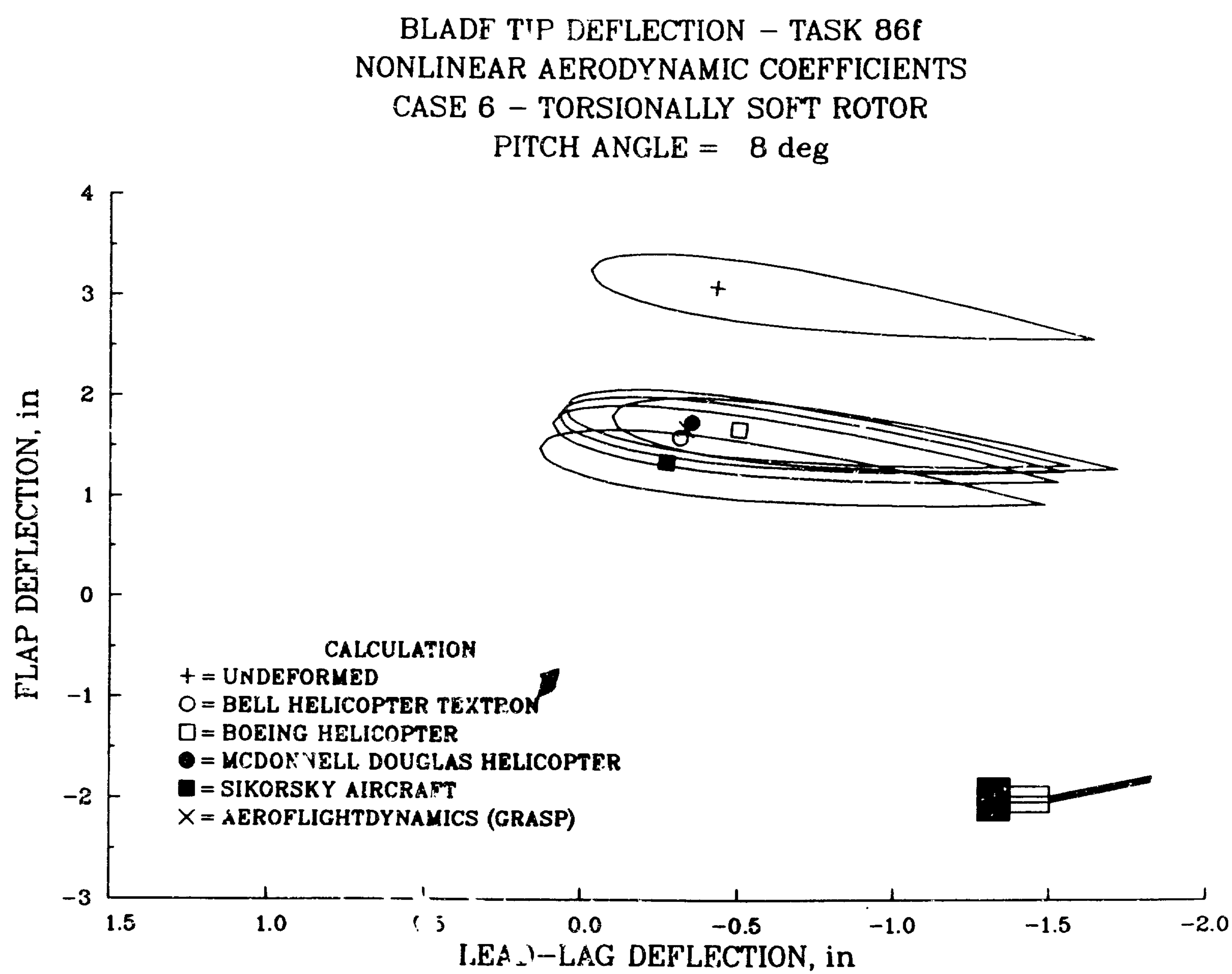

BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in


BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –8 deg
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)
FLAP DEFLECTION, in
4
3
2
1
0
–1
–2
–3
1.5
1.0
0.5
0.0
–0.5
–1.0
–1.5
–2.0
LEAD–LAG DEFLECTION, in


BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)
4
3
2
1
0
-1
-2
-3
1.5
1.0
0.5
0.0
–0.5
–1.0
–1.5
–2.0

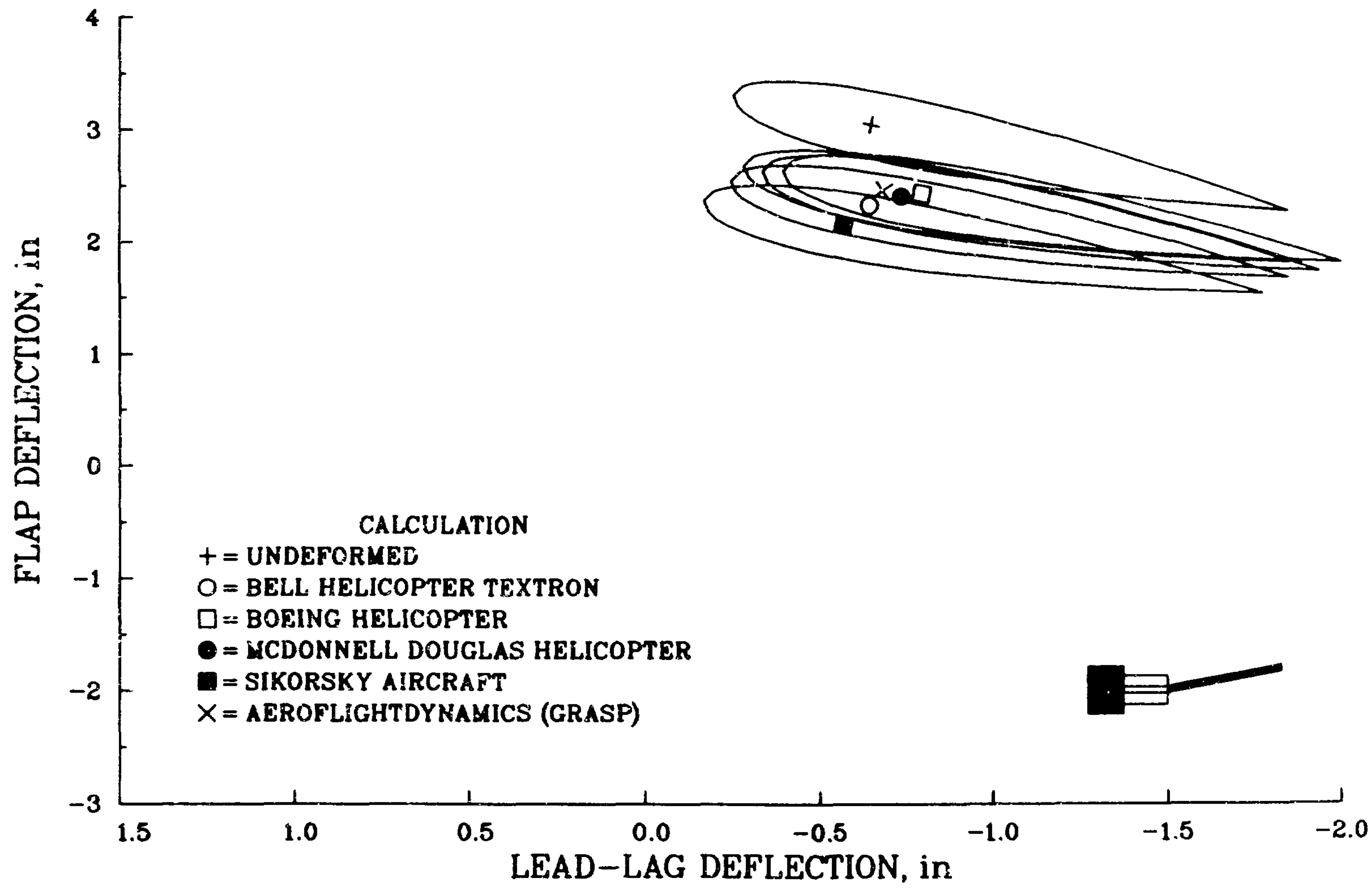

BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
-0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)

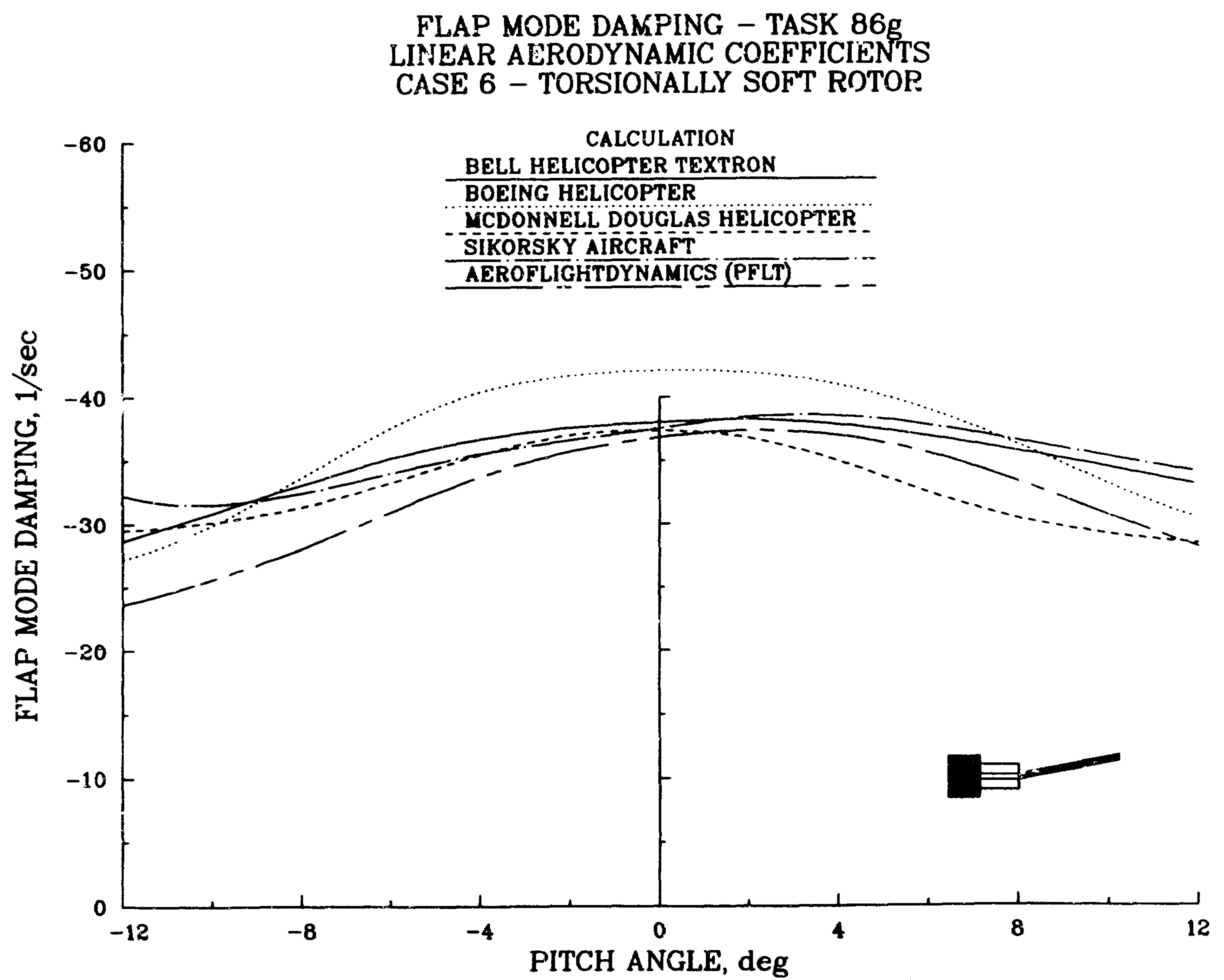

BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)

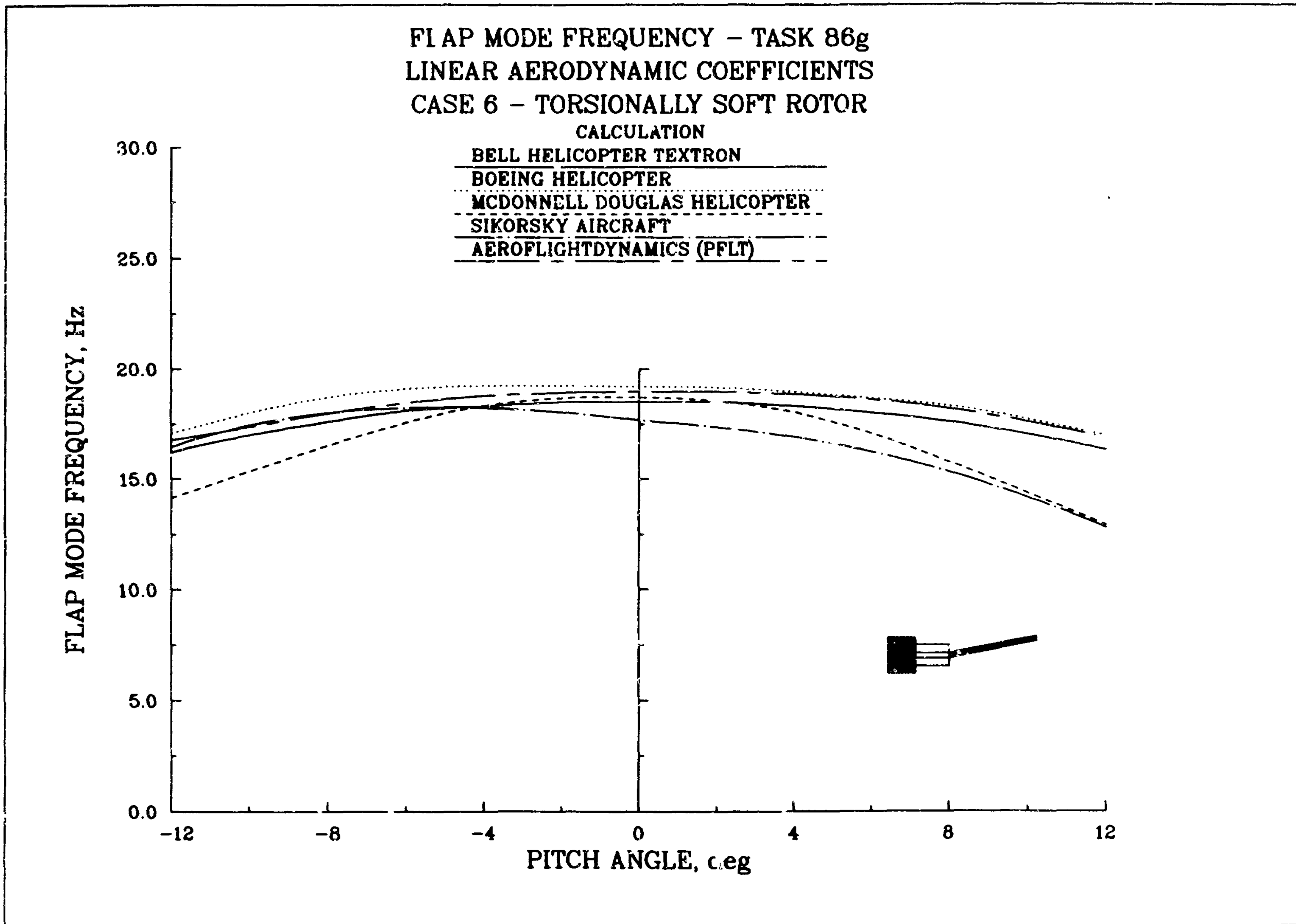


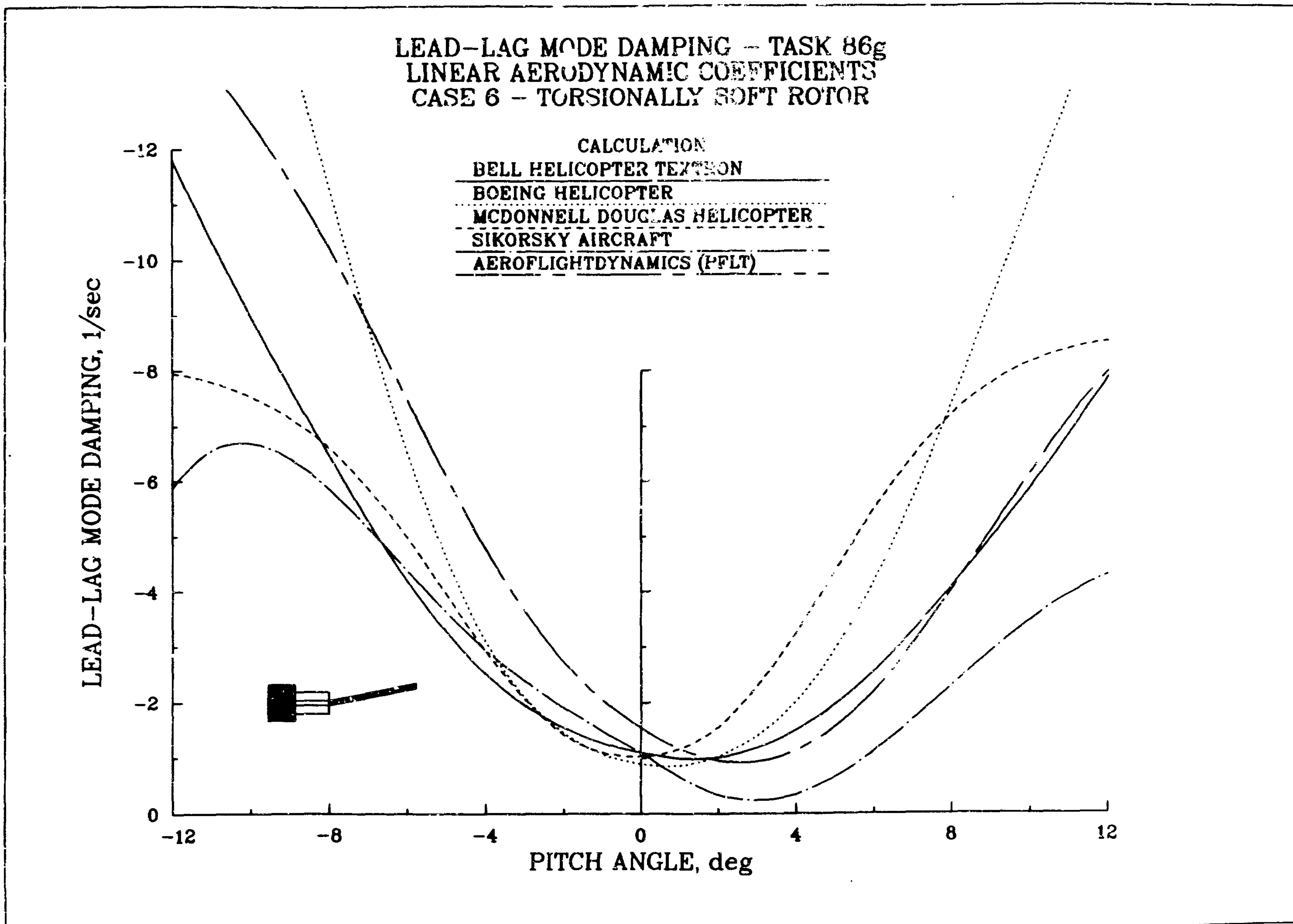
BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
CALCULATION
+ = UNDEFORMED
○ = BELL HELICOPTER TEXTRON
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS HELICOPTER
■ = SIKORSKY AIRCRAFT
× = AEROFLIGHTDYNAMICS (GRASP)
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.0
−0.5
−1.0
−1.5
−2.0

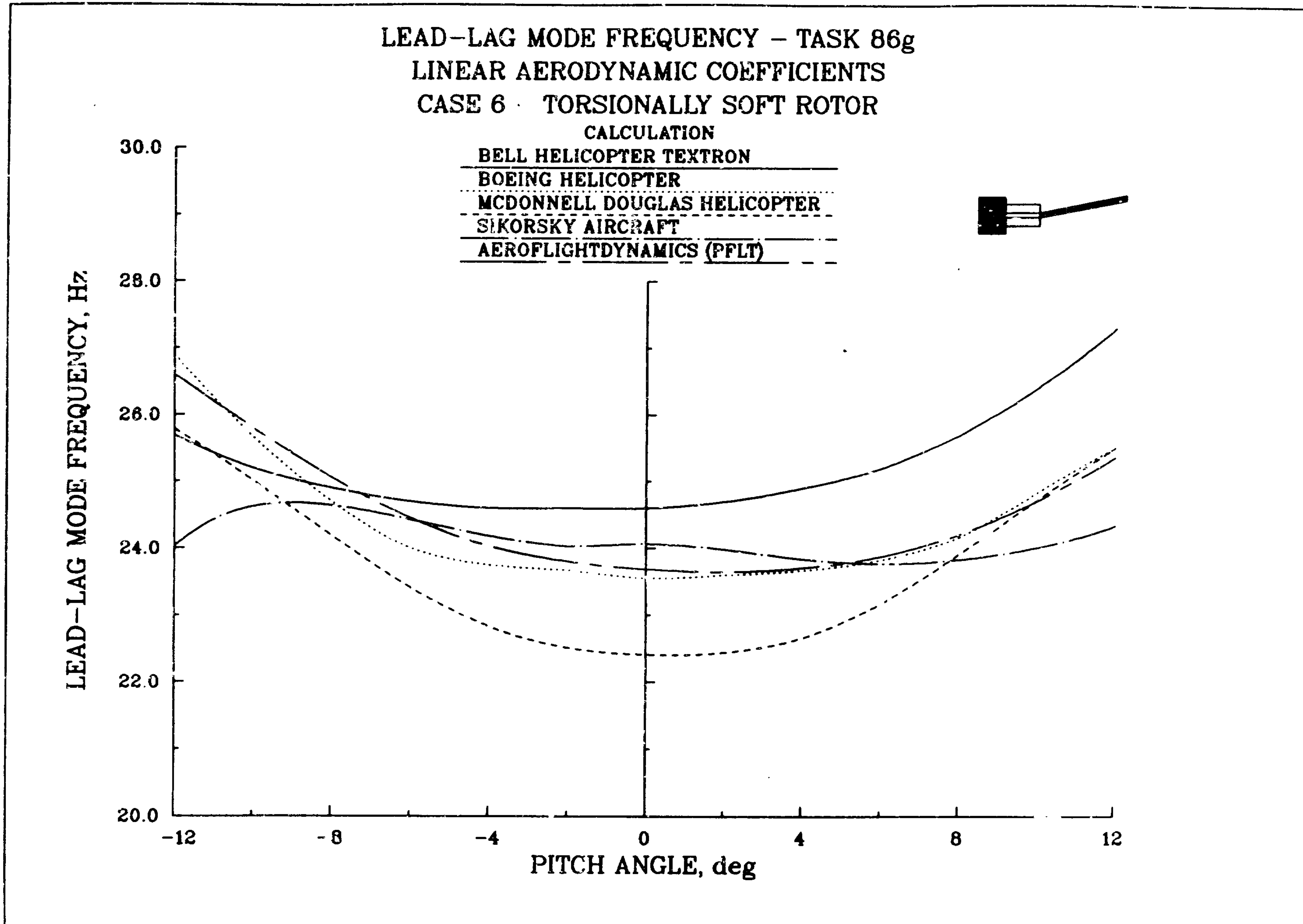
BLADE TIP DEFLECTION – TASK 86f
NONLINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg



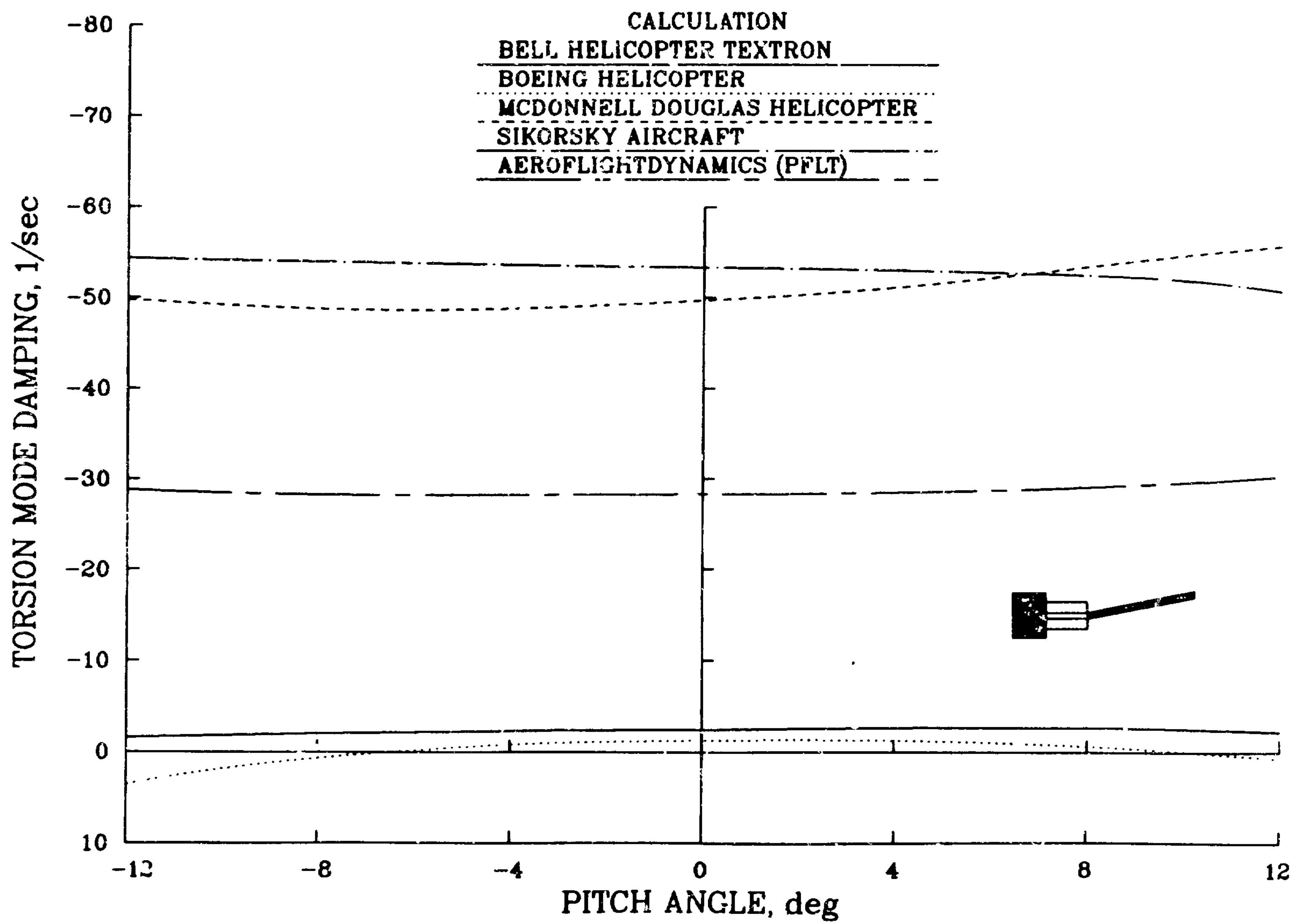

FLAP MODE DAMPING – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
FLAP MODE DAMPING, 1/sec
-60
-50
-40
-30
-20
-10
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

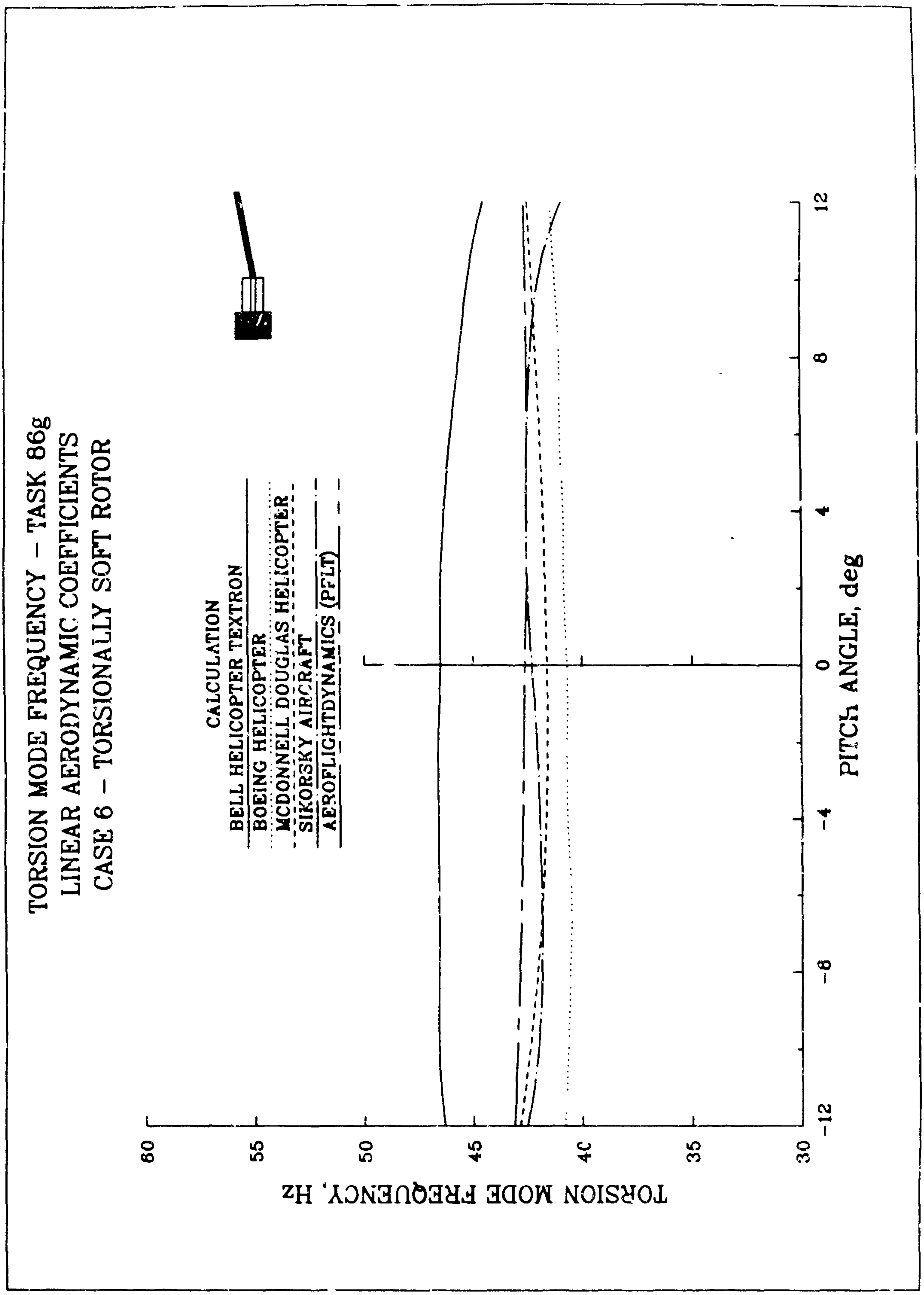

FI AP MODE FREQUENCY – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, c.eg


LEAD–LAG MODE DAMPING – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
LEAD–LAG MODE DAMPING, 1/sec
-12
-10
-8
-6
-4
-2
0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

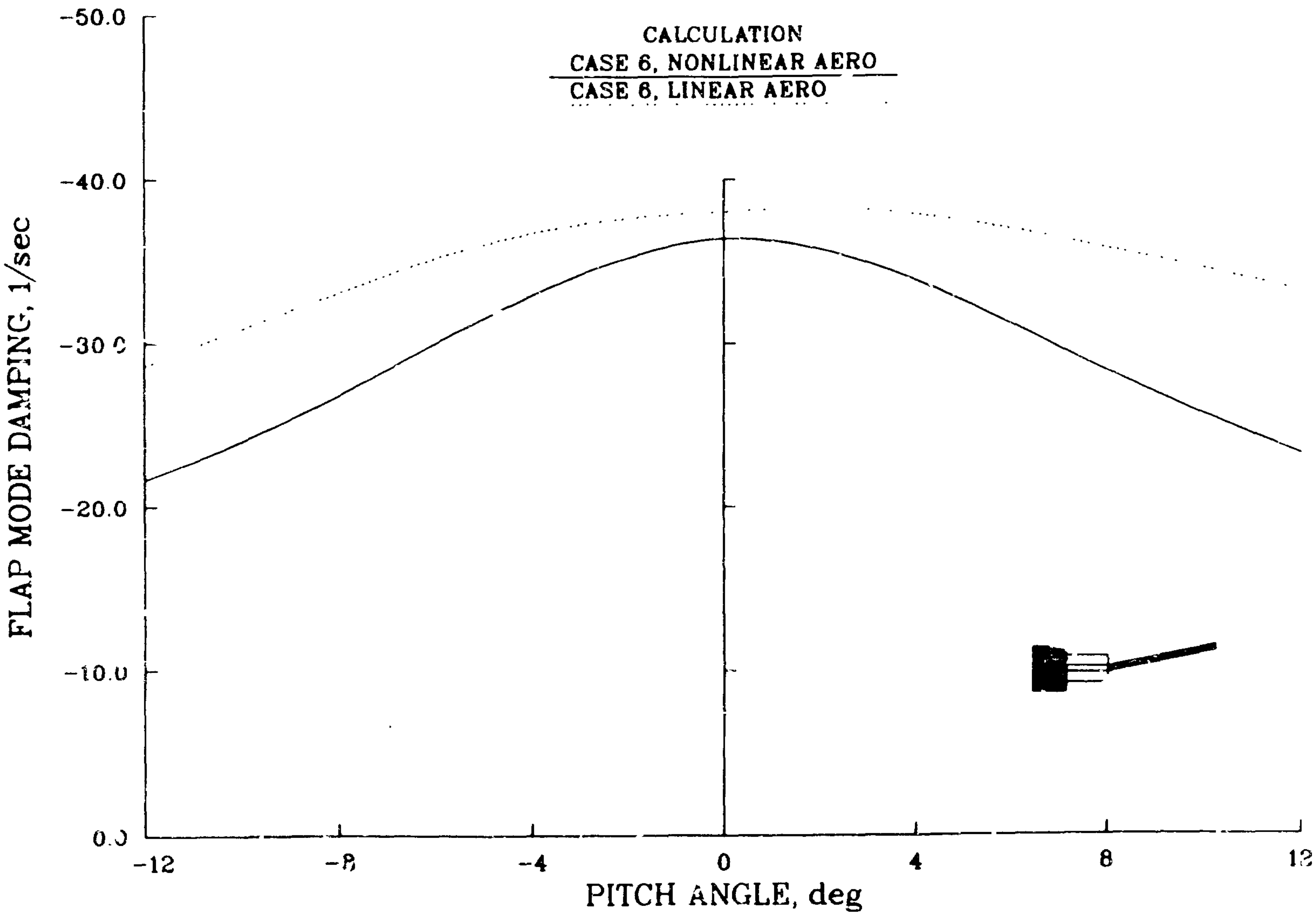

LEAD–LAG MODE FREQUENCY – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 · TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AERO FLIGHTDYNAMICS (PFLT)
LEAD–LAG MODE FREQUENCY, Hz
30.0
28.0
26.0
24.0
22.0
20.0
–12
-8
–4
0
4
8
12
PITCH ANGLE, deg

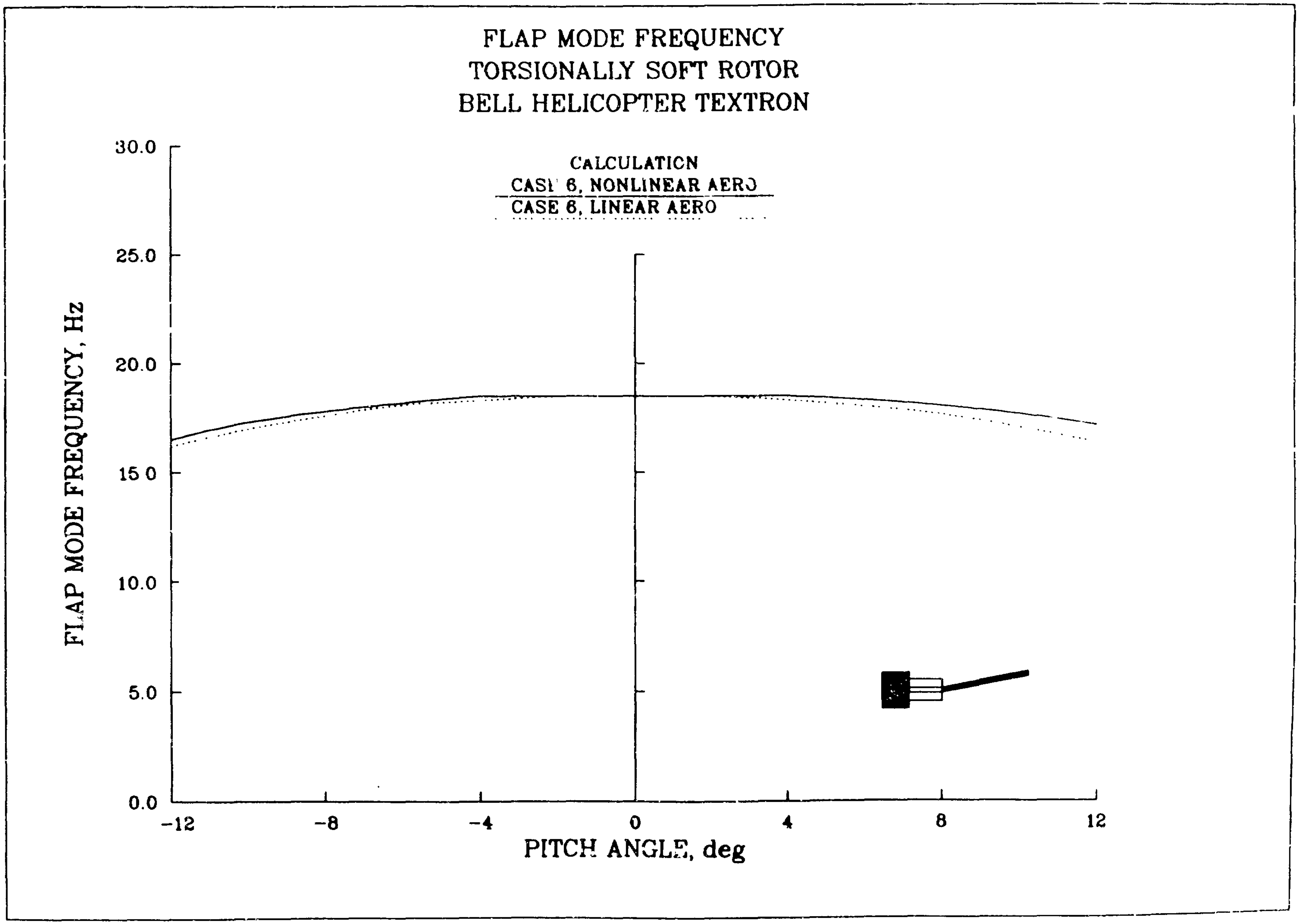
TORSION MODE DAMPING – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR

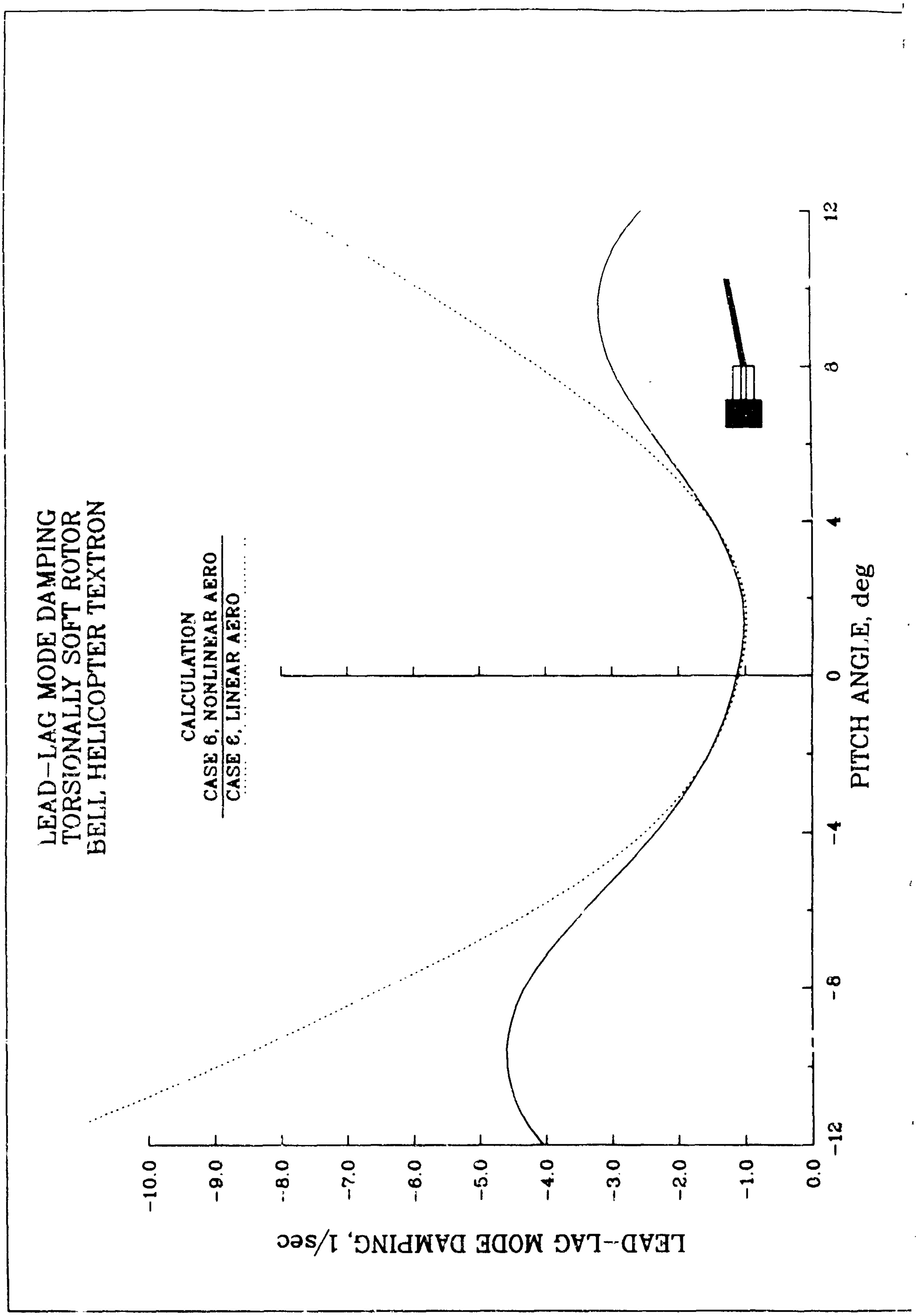



TORSION MODE FREQUENCY – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
TORSION MODE FREQUENCY, Hz
60
55
50
45
40
35
30
PITCH ANGLE, deg
–12
–8
–4
0
4
8
12

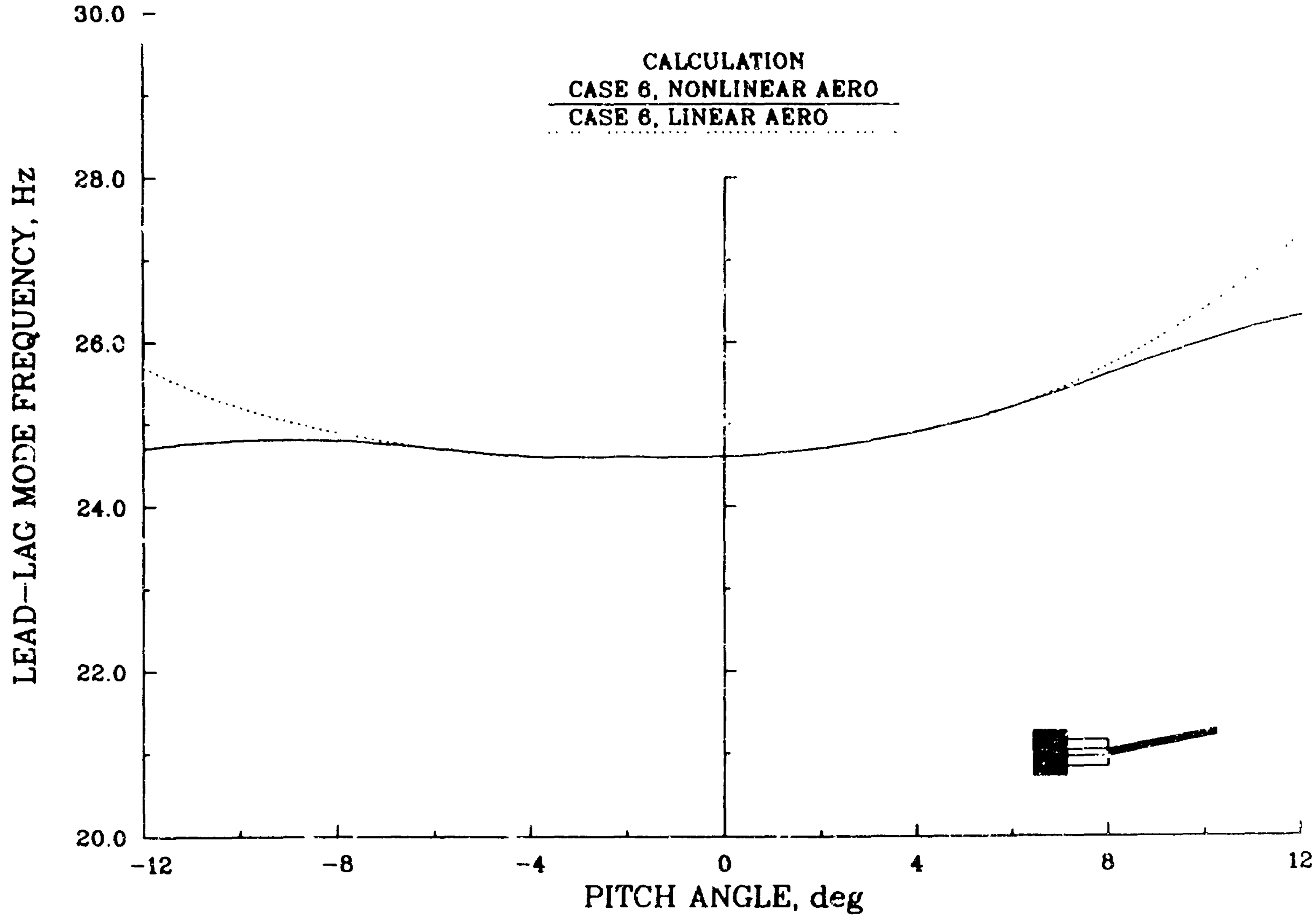
FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON

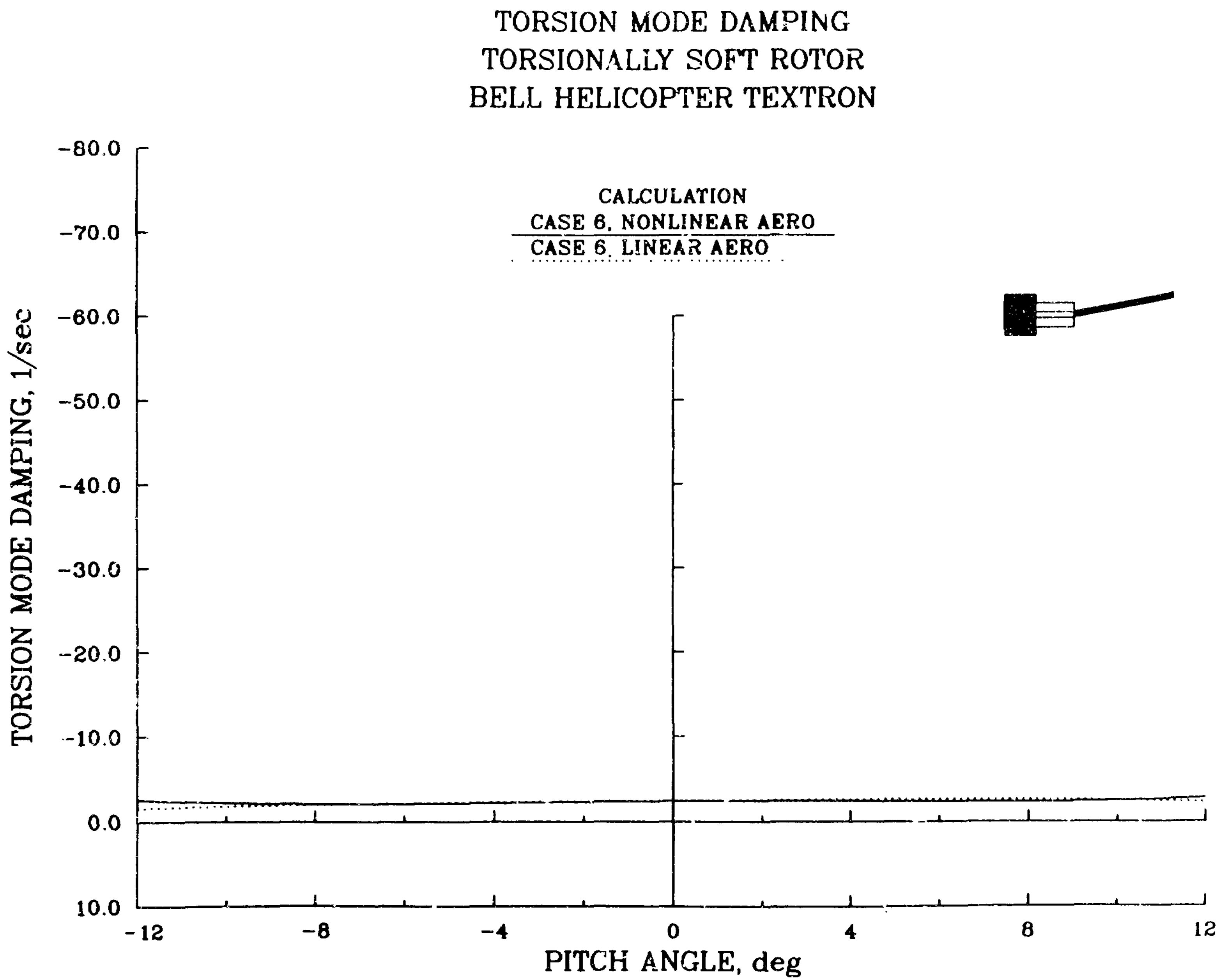


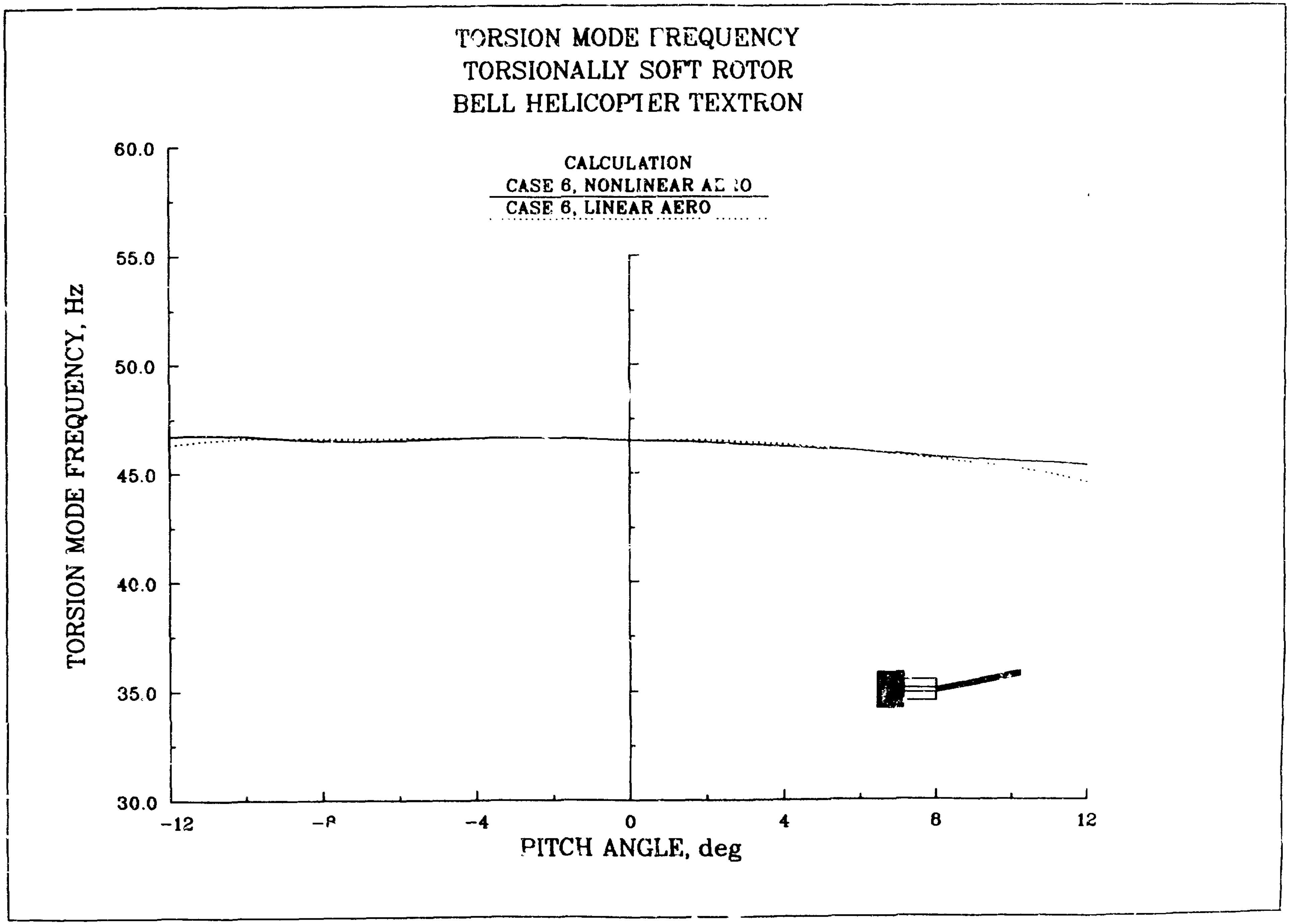

FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP MODE FREQUENCY, Hz
0.0
5.0
10.0
15.0
20.0
25.0
30.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

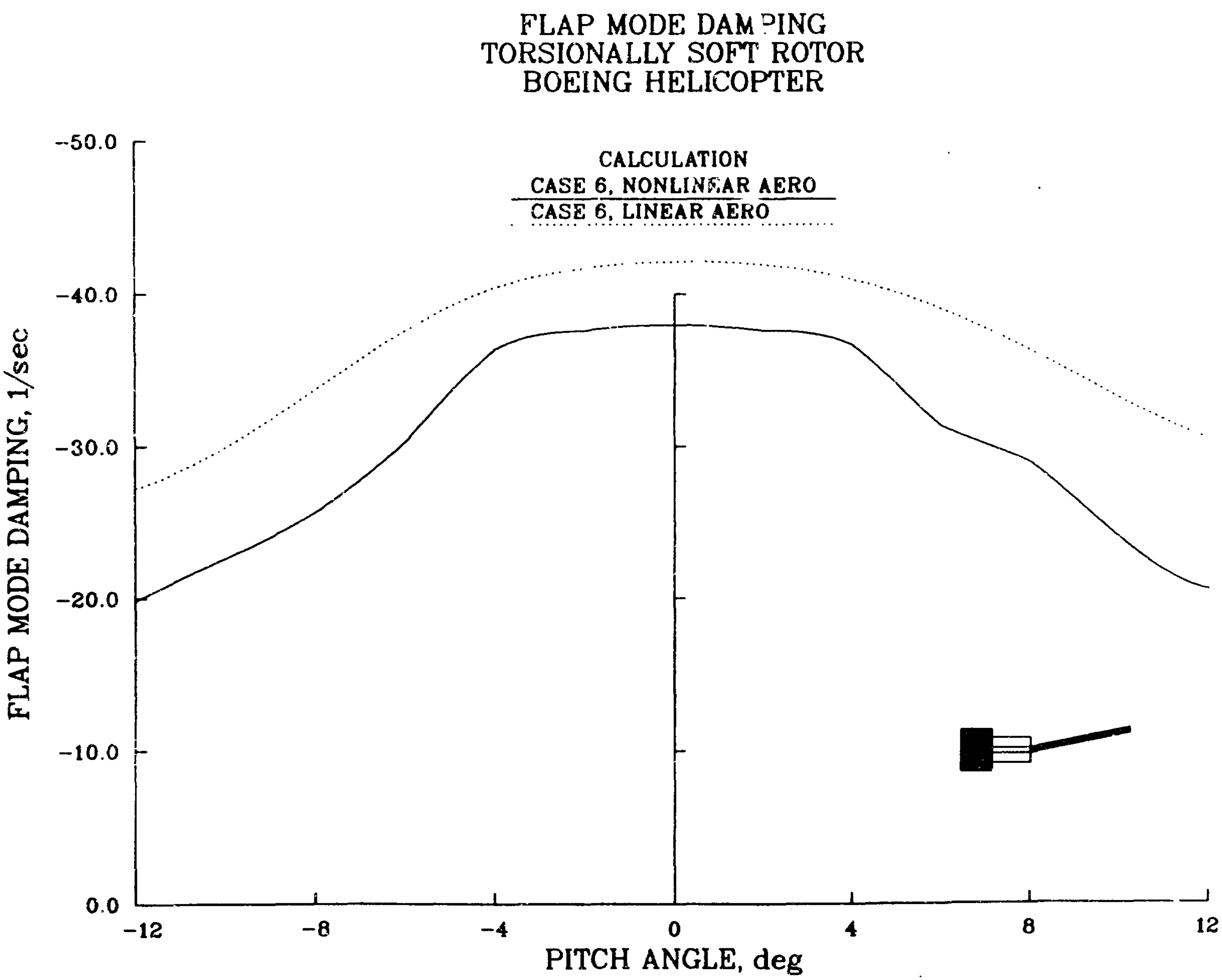

LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
LEAD–LAG MODE DAMPING, 1/sec
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

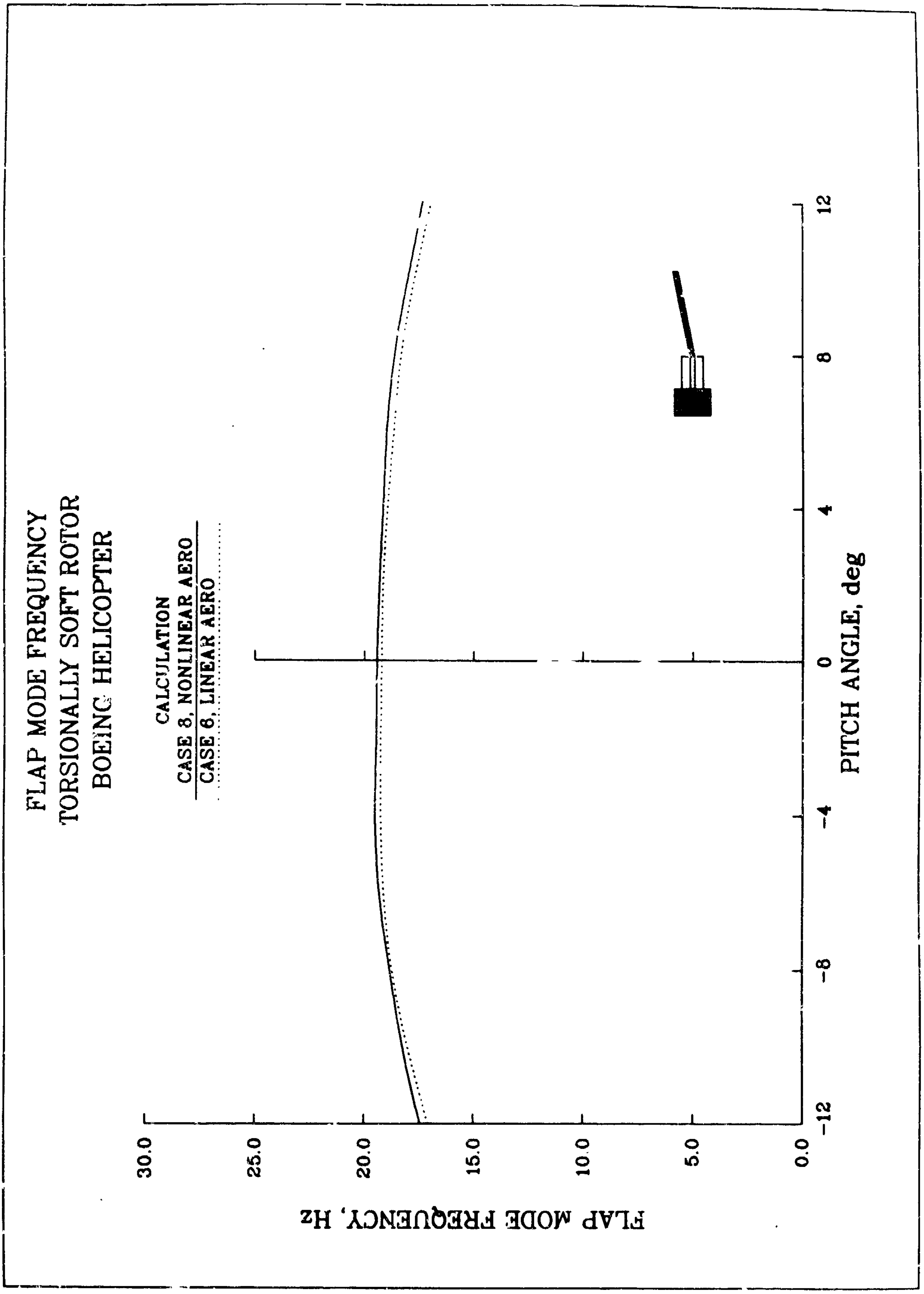
LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON

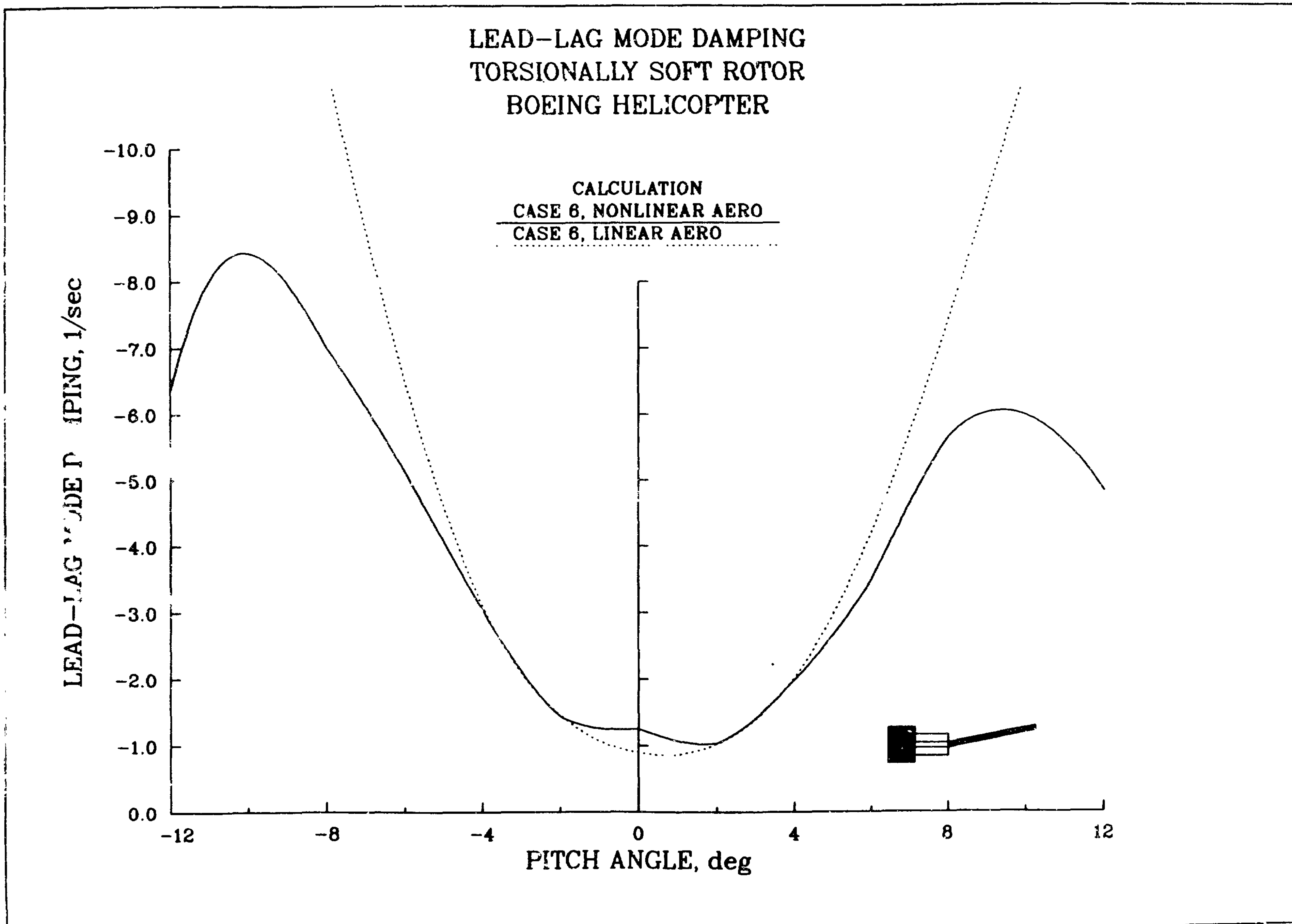



TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

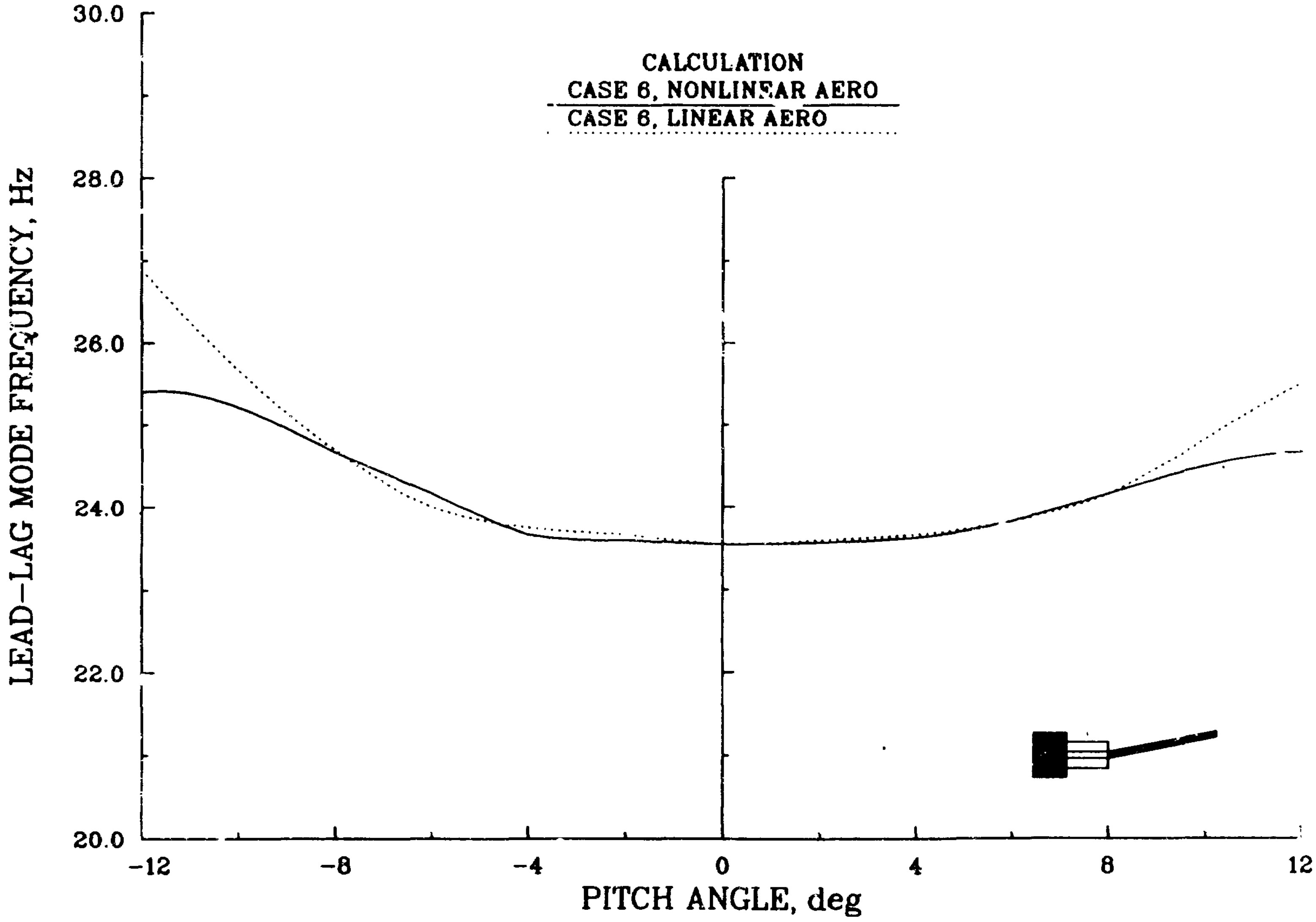

FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP MODE DAMPING, 1/sec
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

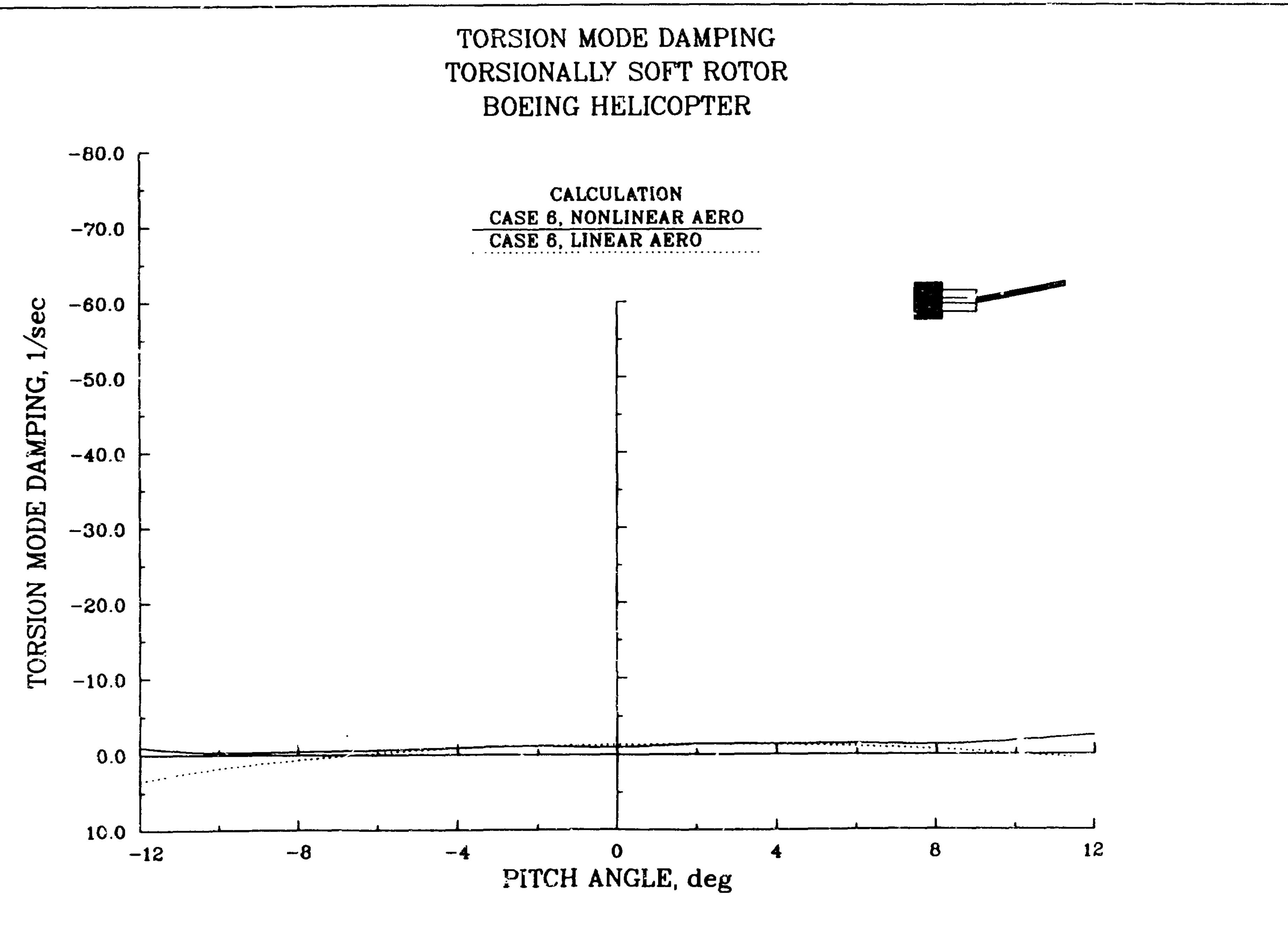

FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 8, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP MODE FREQUENCY, Hz
0.0
5.0
10.0
15.0
20.0
25.0
30.0
PITCH ANGLE, deg
−12
−8
−4
0
4
8
12



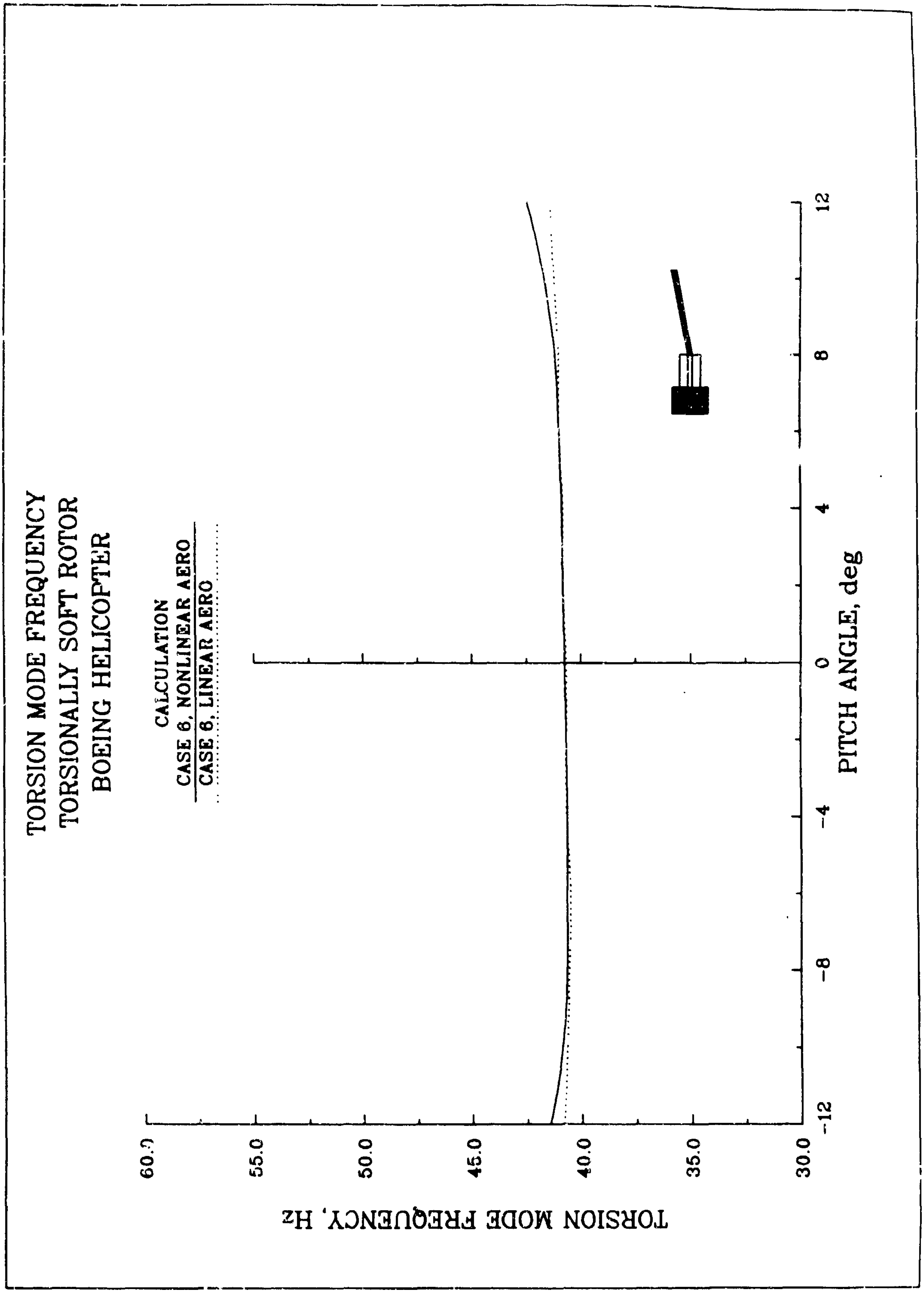
LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

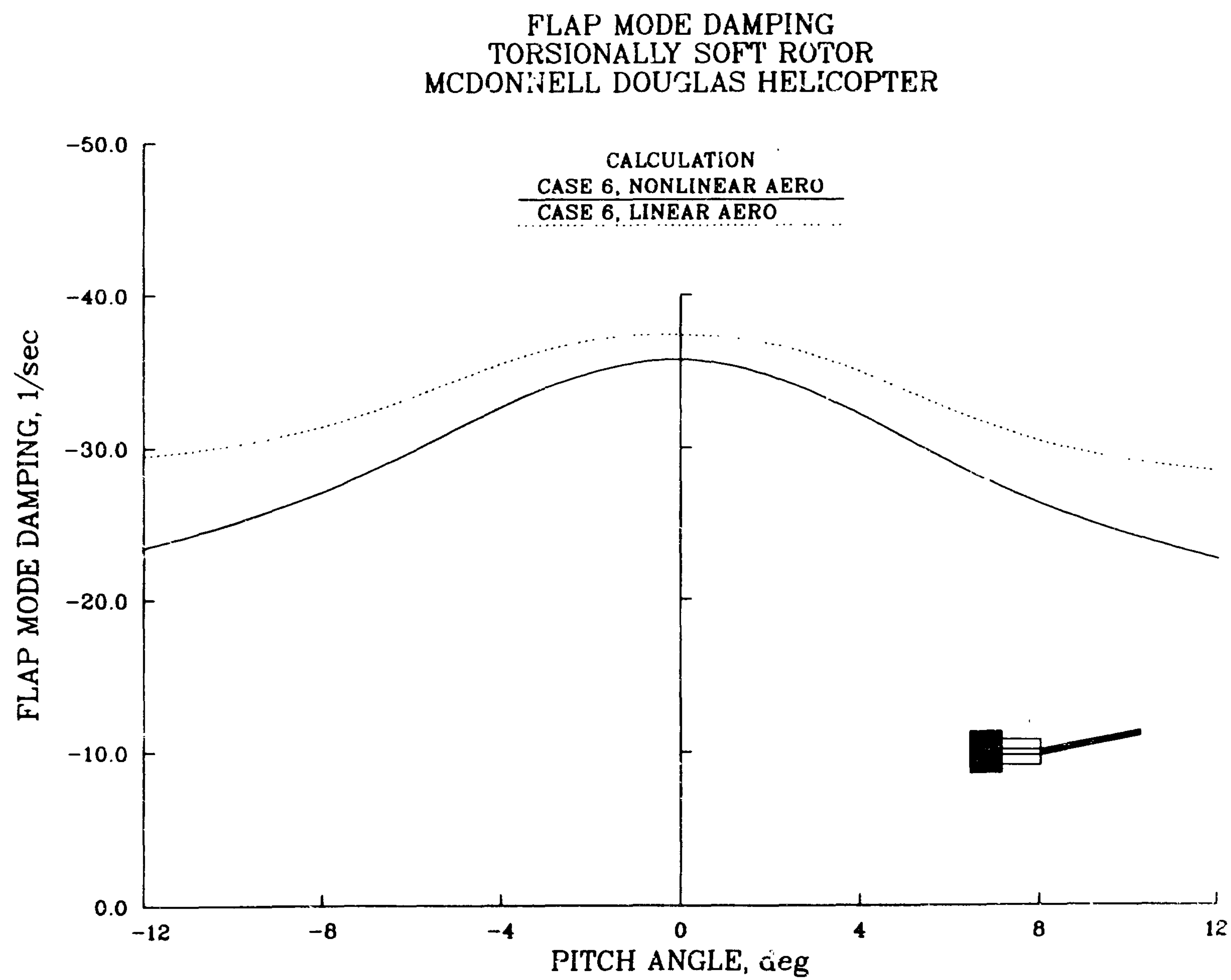
LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER



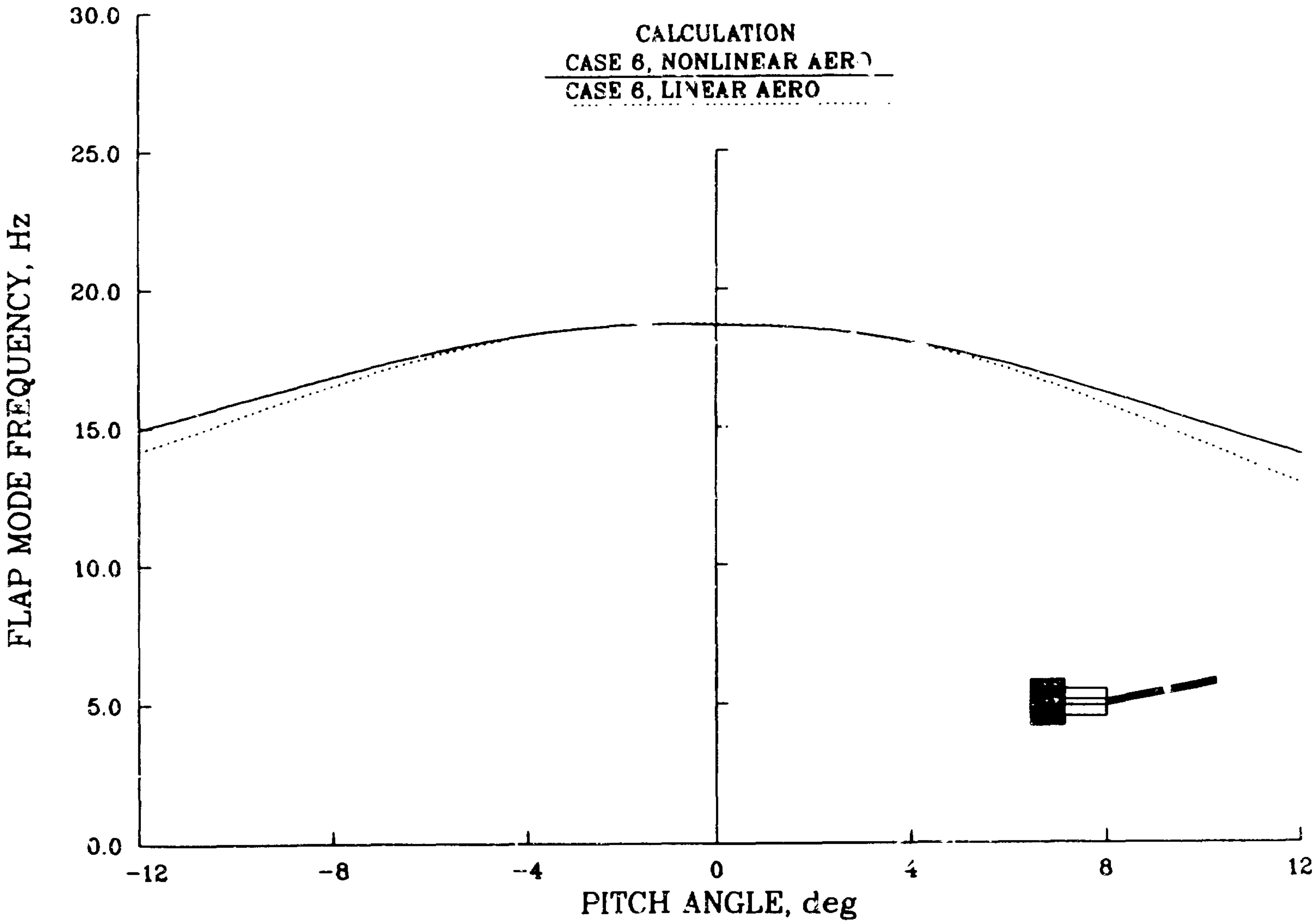


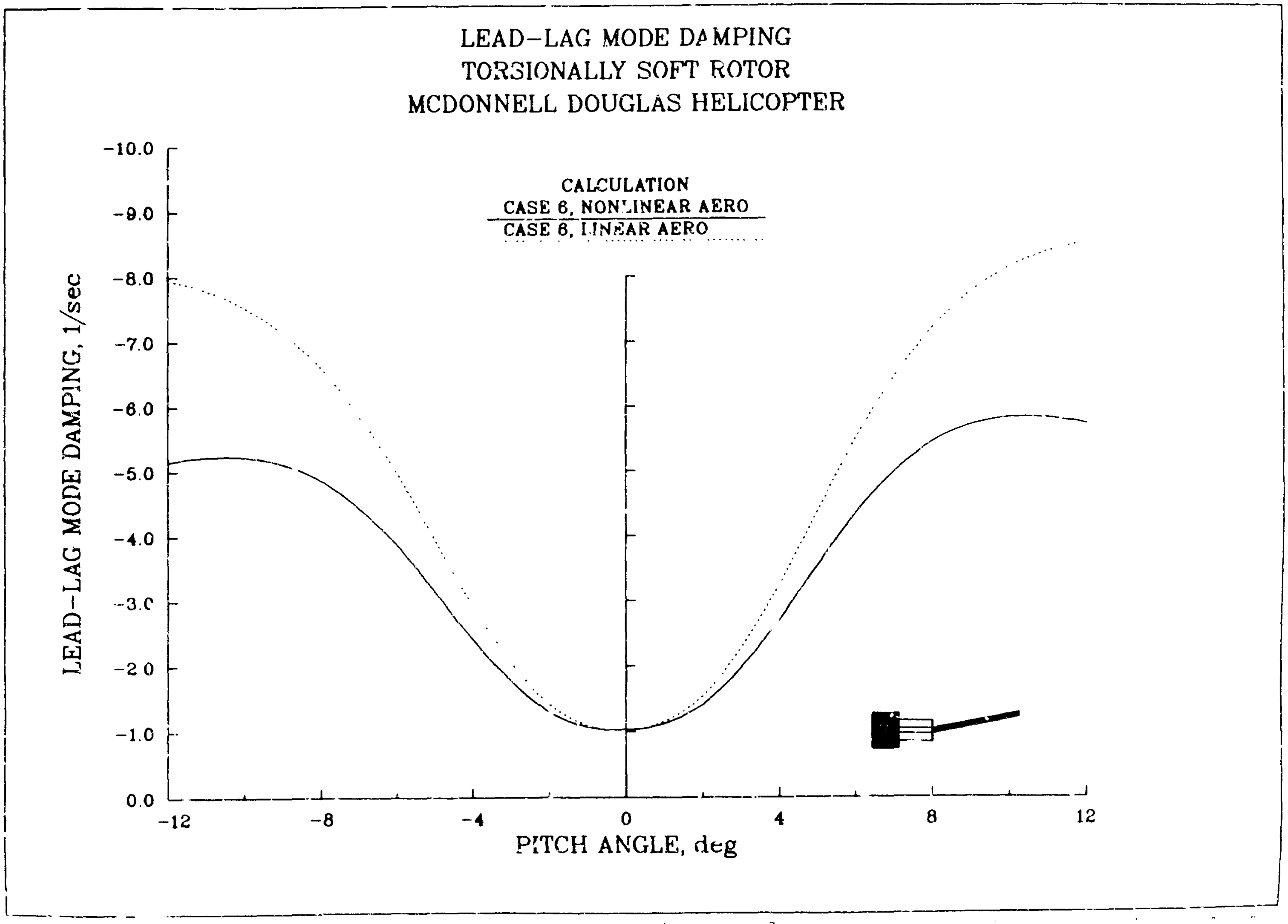
TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE FREQUENCY, Hz
PITCH ANGLE, deg
60.0
55.0
50.0
45.0
40.0
35.0
30.0
-12
-8
-4
0
4
8
12

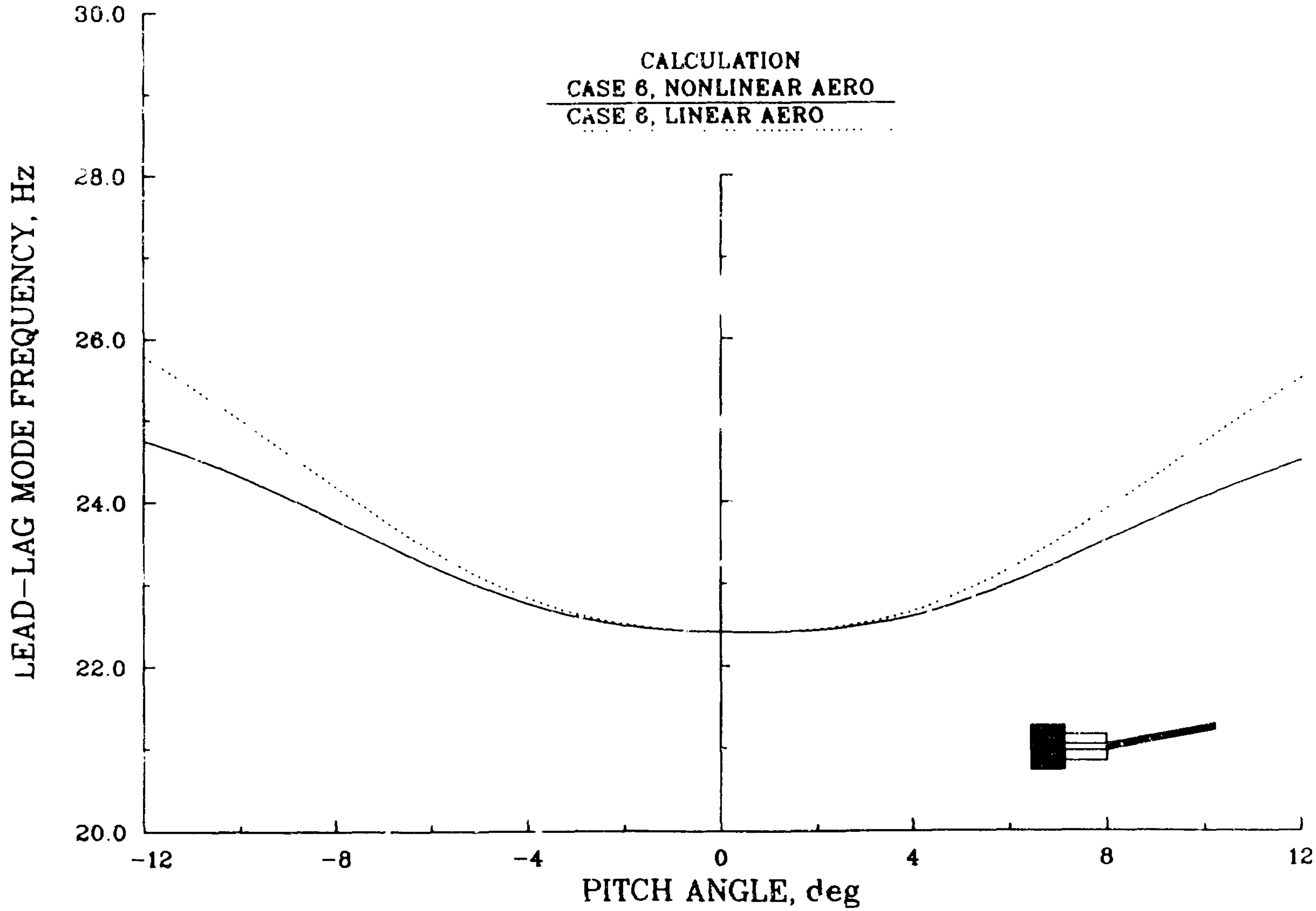

FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP MODE DAMPING, 1/sec
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

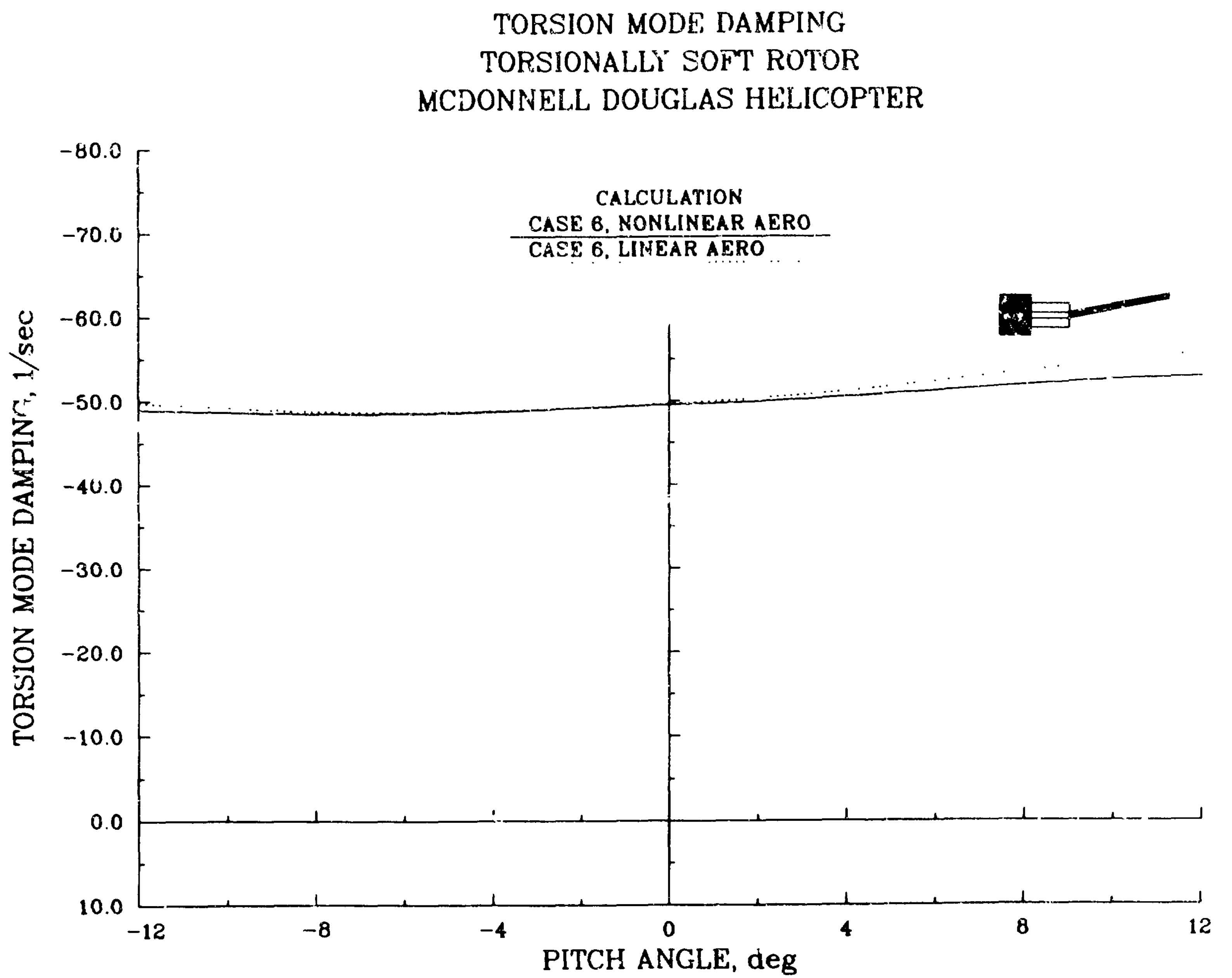
FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER

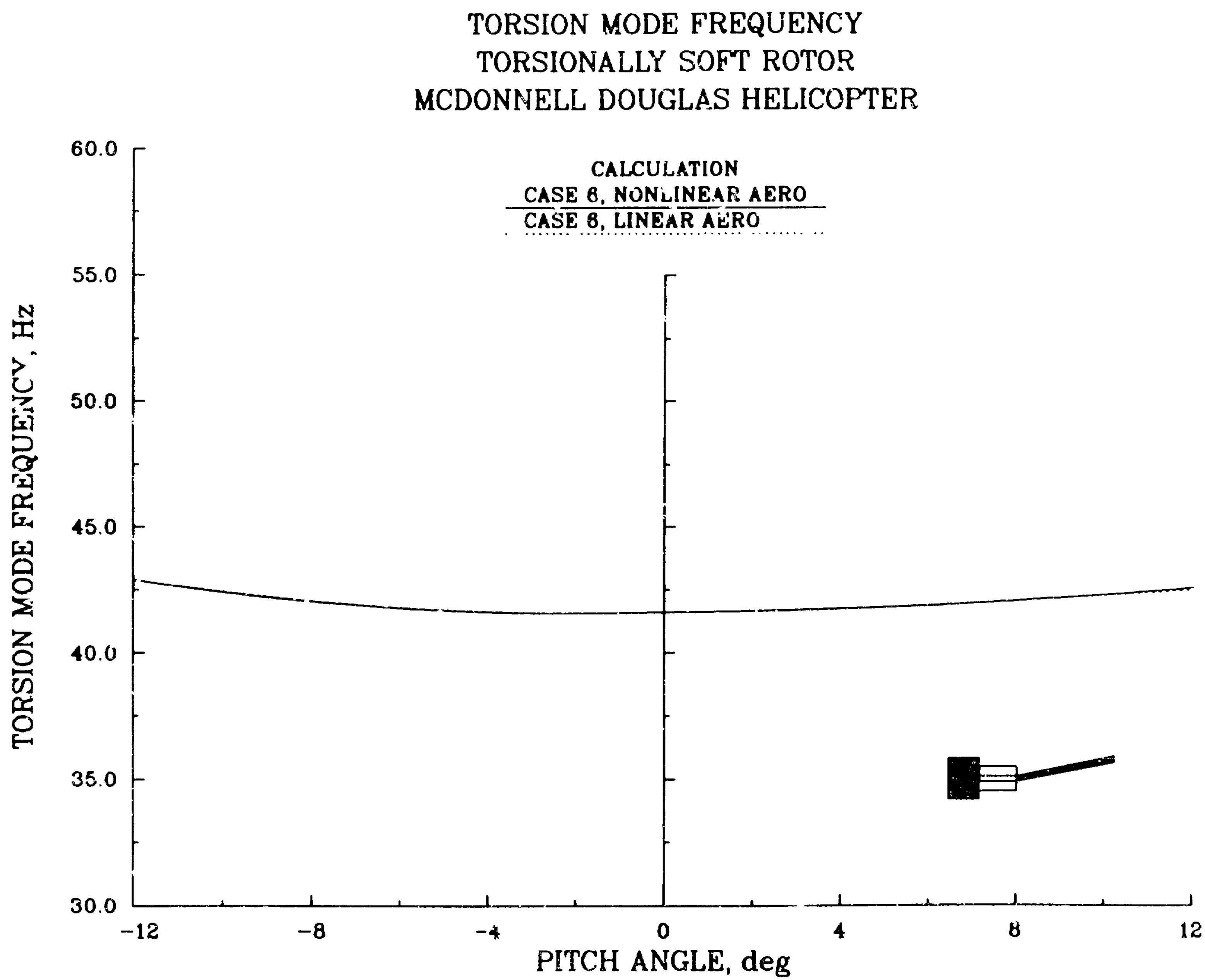


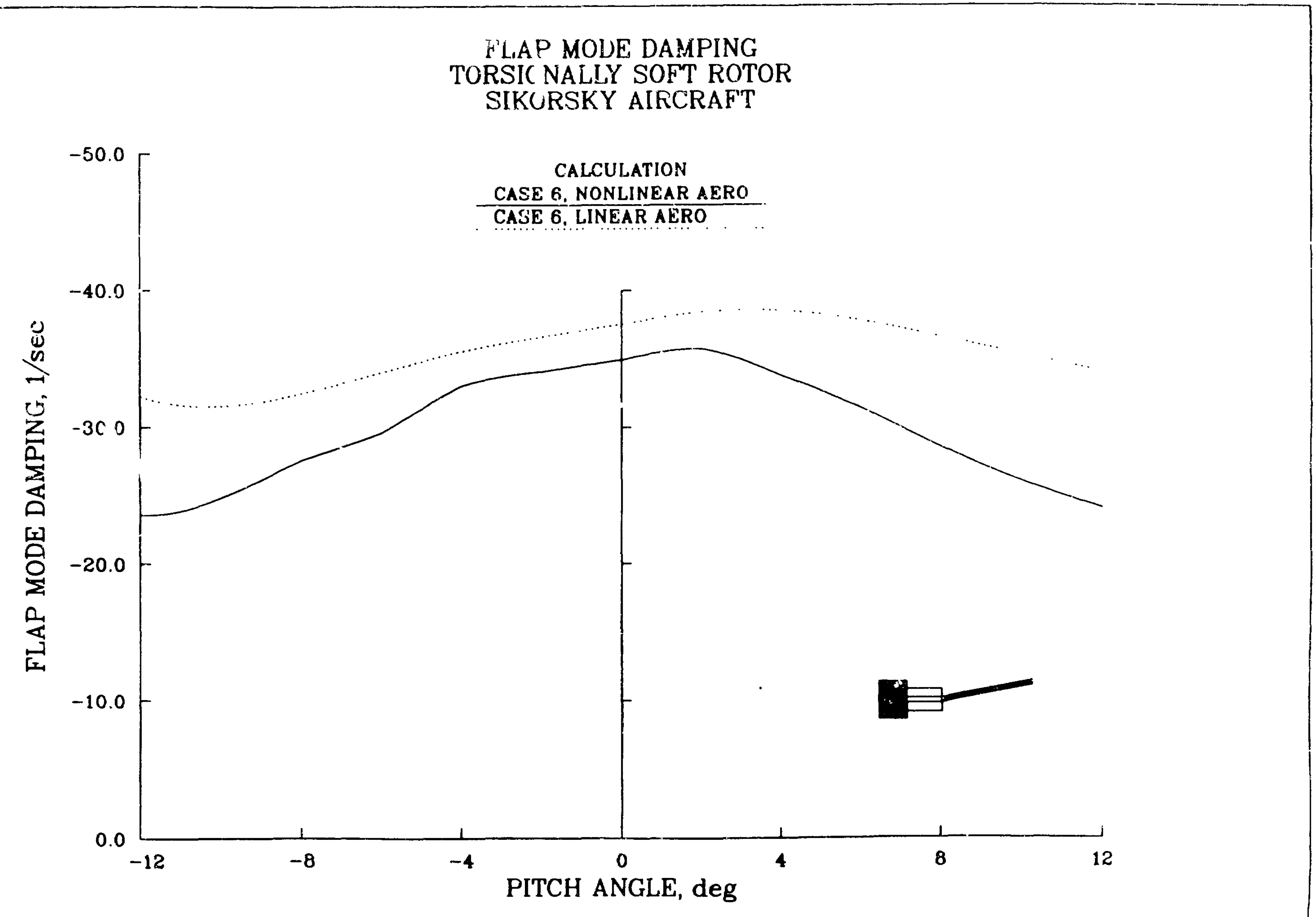

LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
LEAD–LAG MODE DAMPING, 1/sec
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

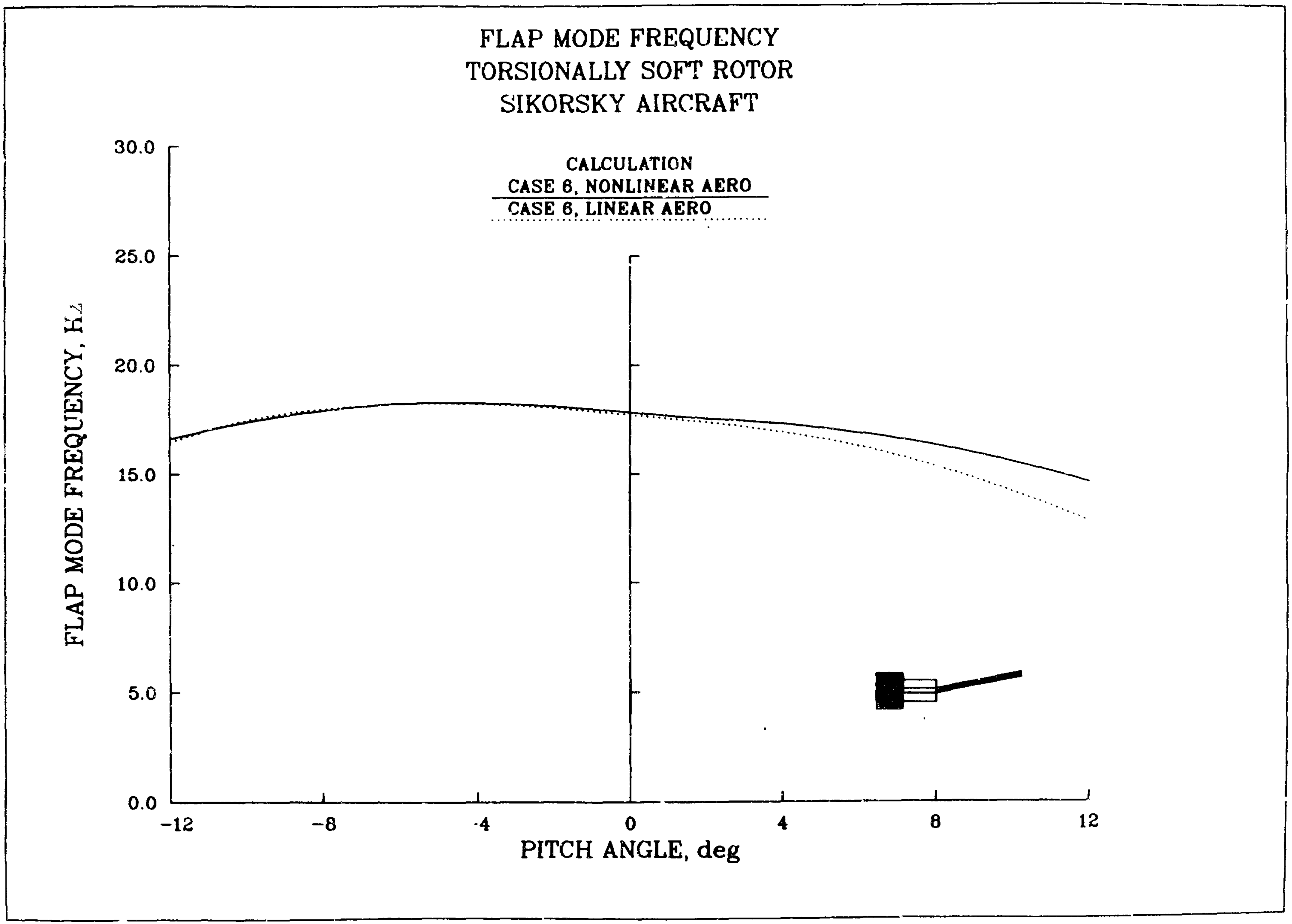
LEAD-LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER

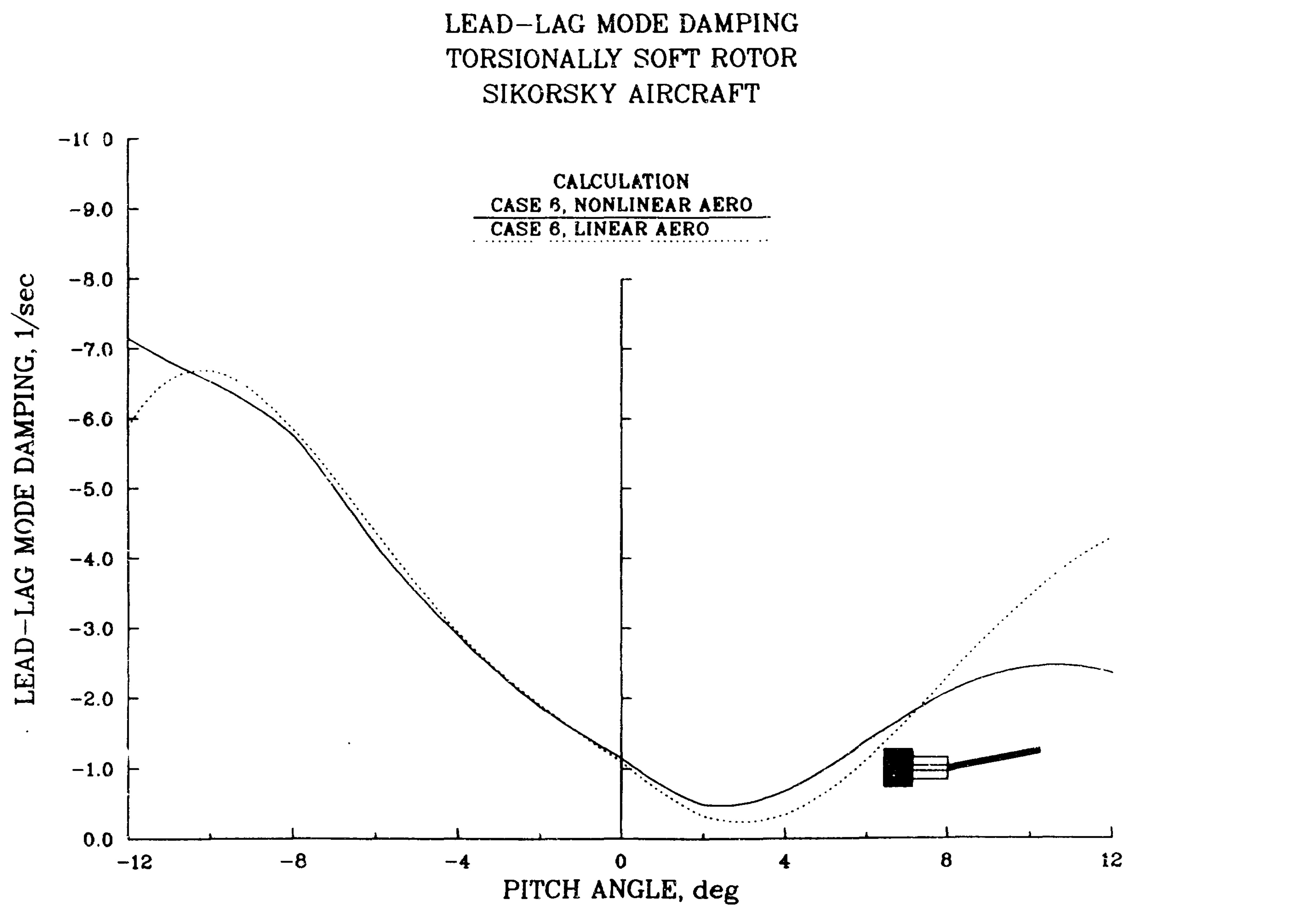


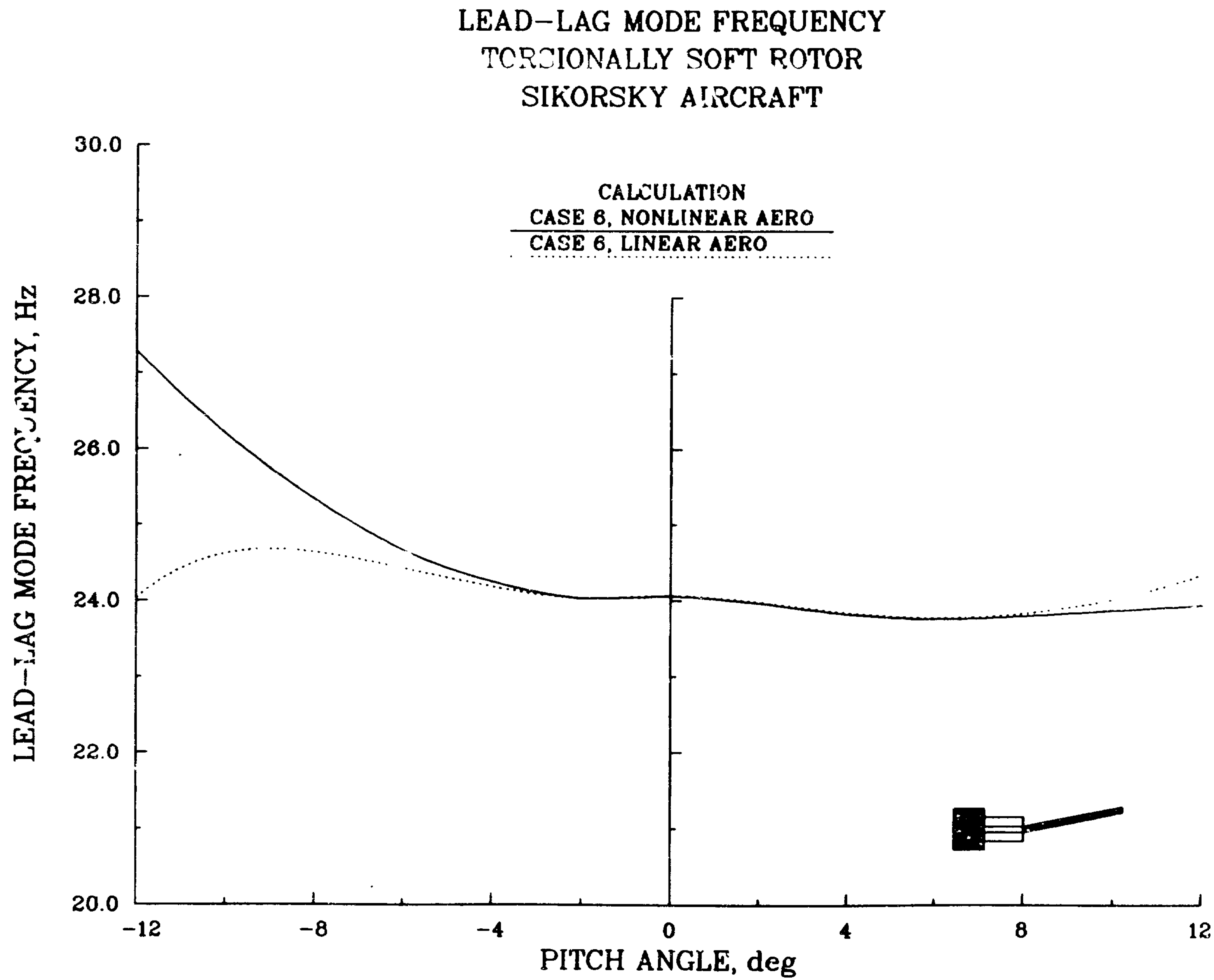

TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

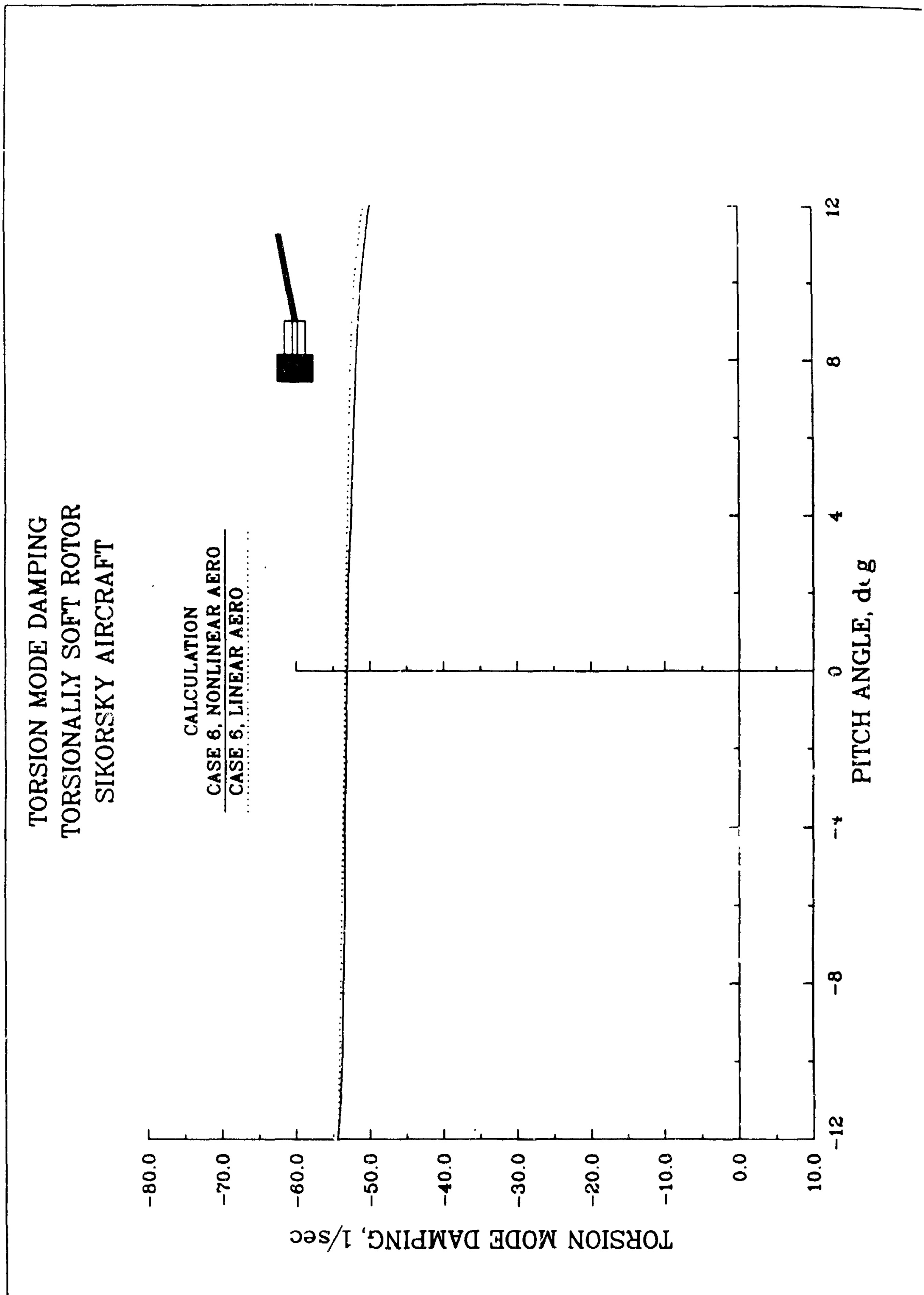

TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


FLAP MODE DAMPING
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP MODE DAMPING, 1/sec
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

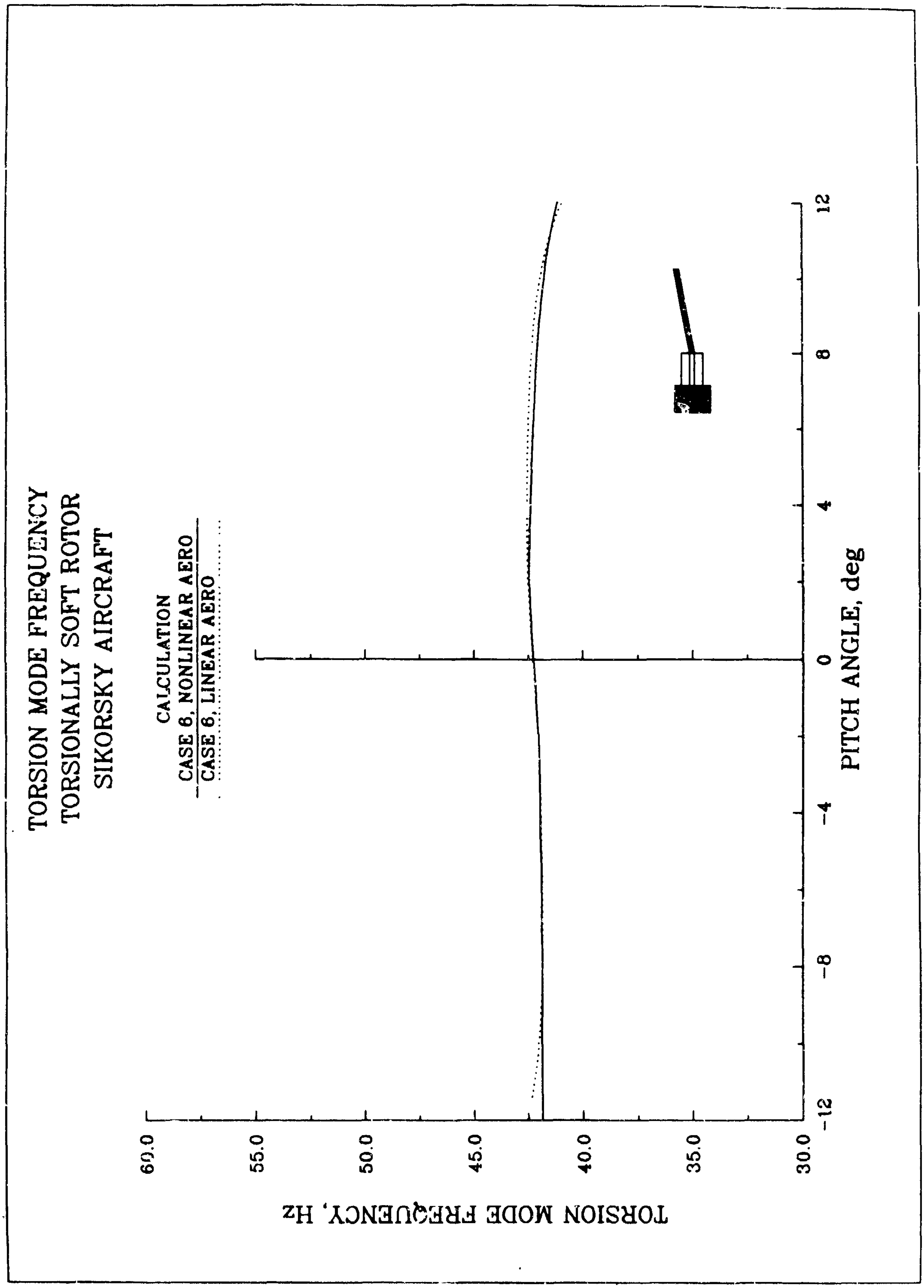

FLAP MODE FREQUENCY
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


LEAD–LAG MODE DAMPING
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
LEAD–LAG MODE DAMPING, 1/sec
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

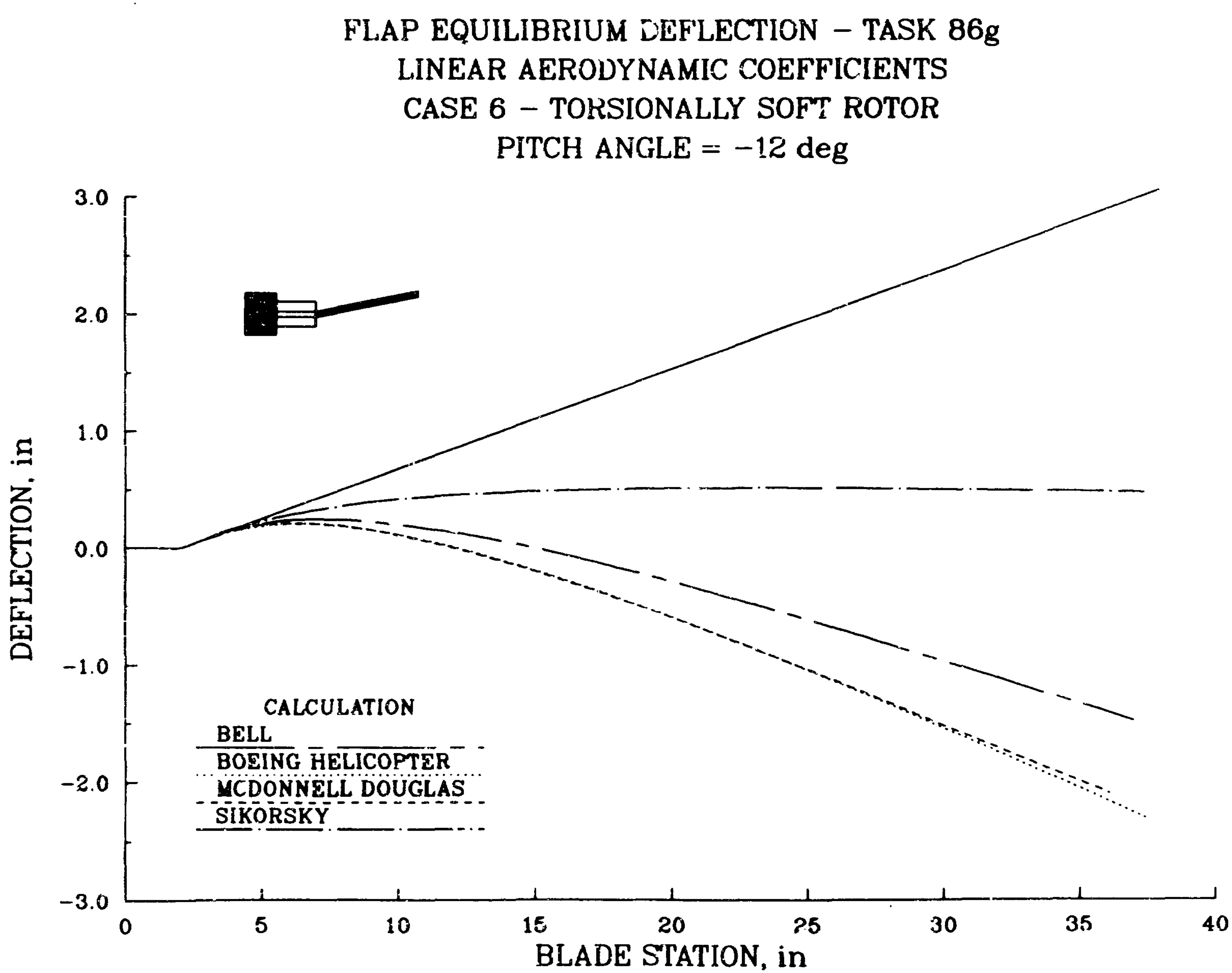

LEAD–LAG MODE FREQUENCY
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
30.0
28.0
26.0
24.0
22.0
20.0
LEAD–LAG MODE FREQUENCY, Hz
–12
–8
–4
0
4
8
12
PITCH ANGLE, deg

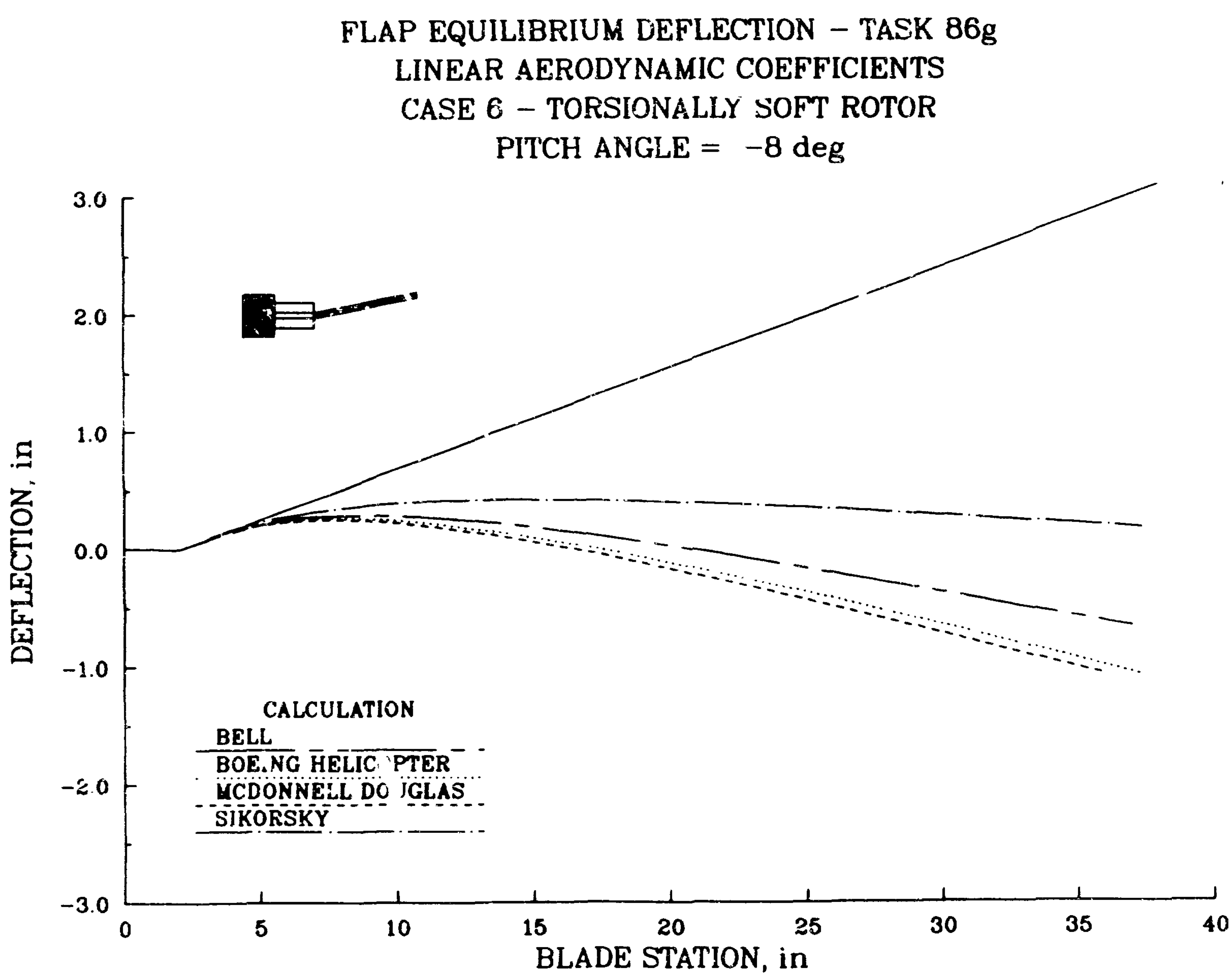


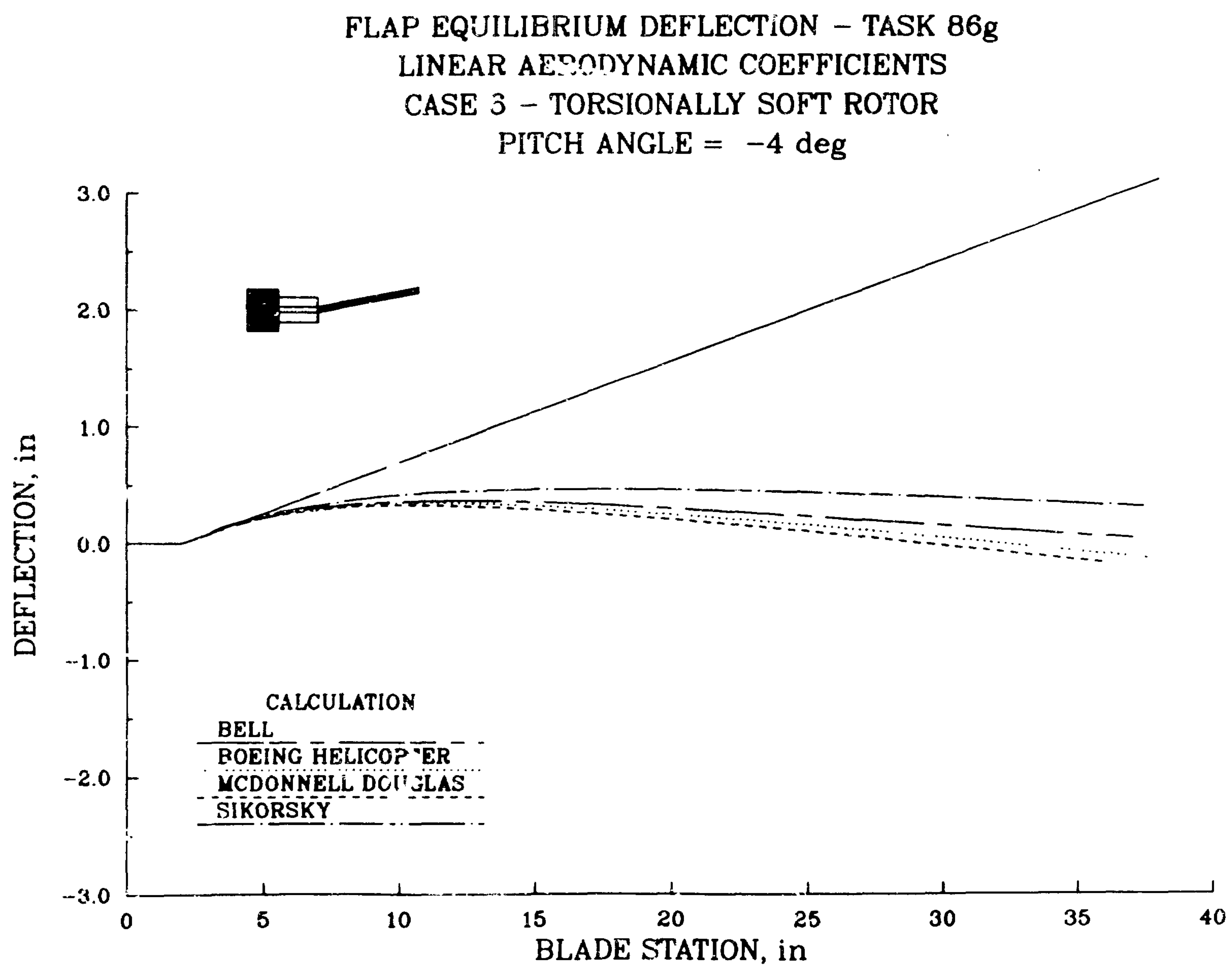
TORSION MODE DAMPING
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 5, LINEAR AERO
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
PITCH ANGLE, deg
-12
-8
-4
0
4
8
12



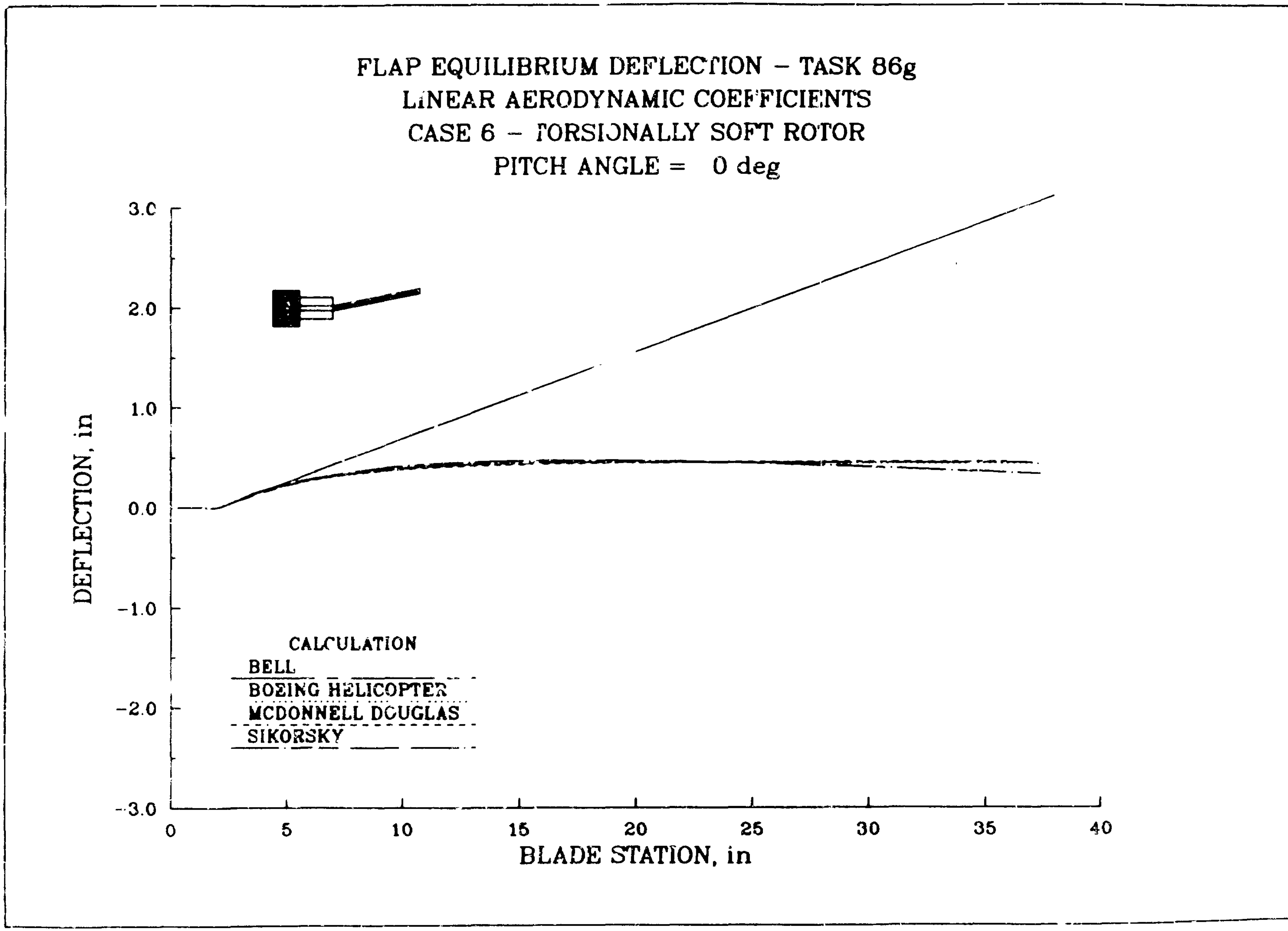
TORSION MODE FREQUENCY
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
PITCH ANGLE, deg
-12
-8
-4
0
4
8
12


FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

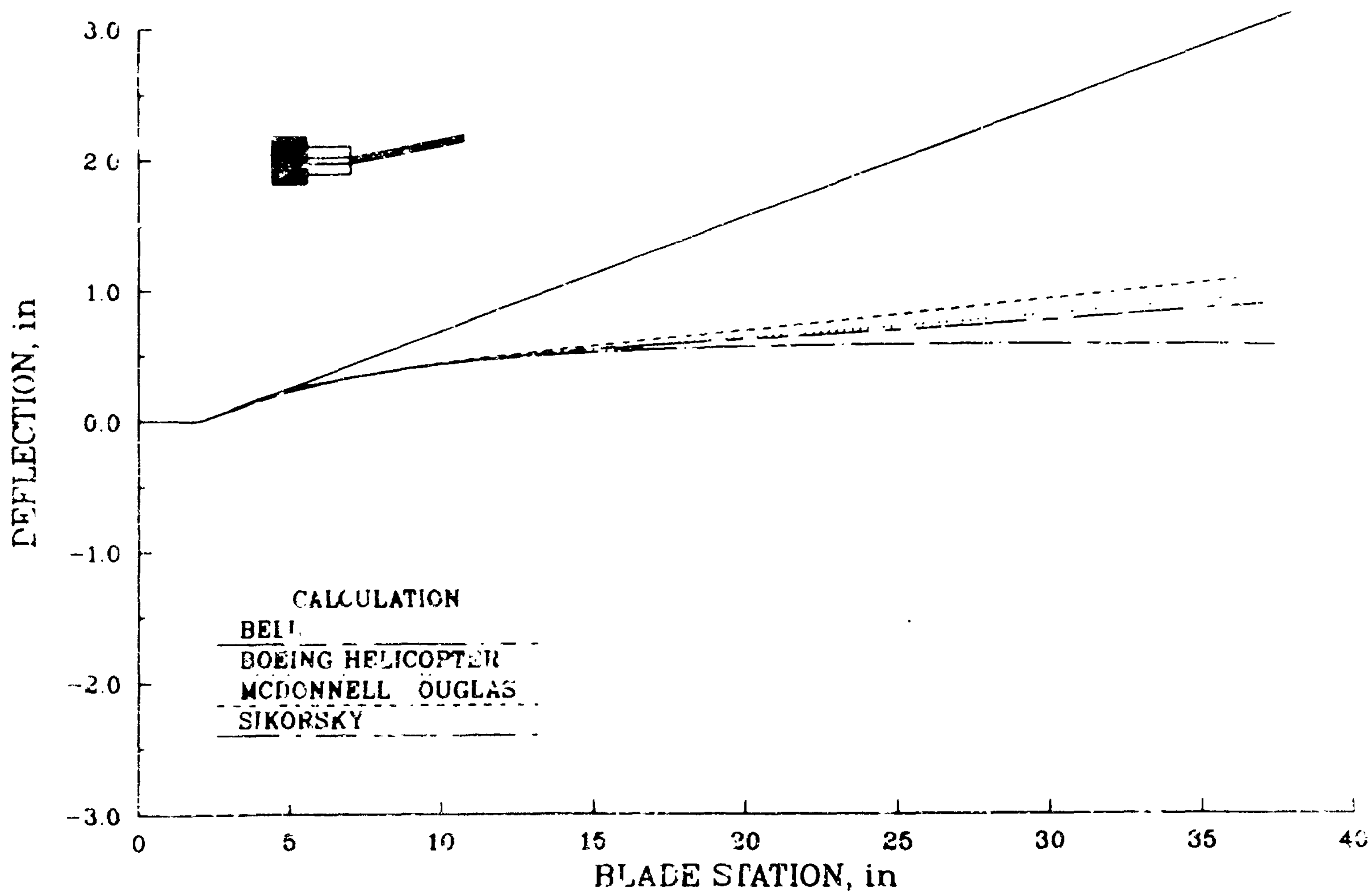

FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –8 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
–1.0
–2.0
–3.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOE.NG HELIC PTER
MCDONNELL DO JGLAS
SIKORSKY

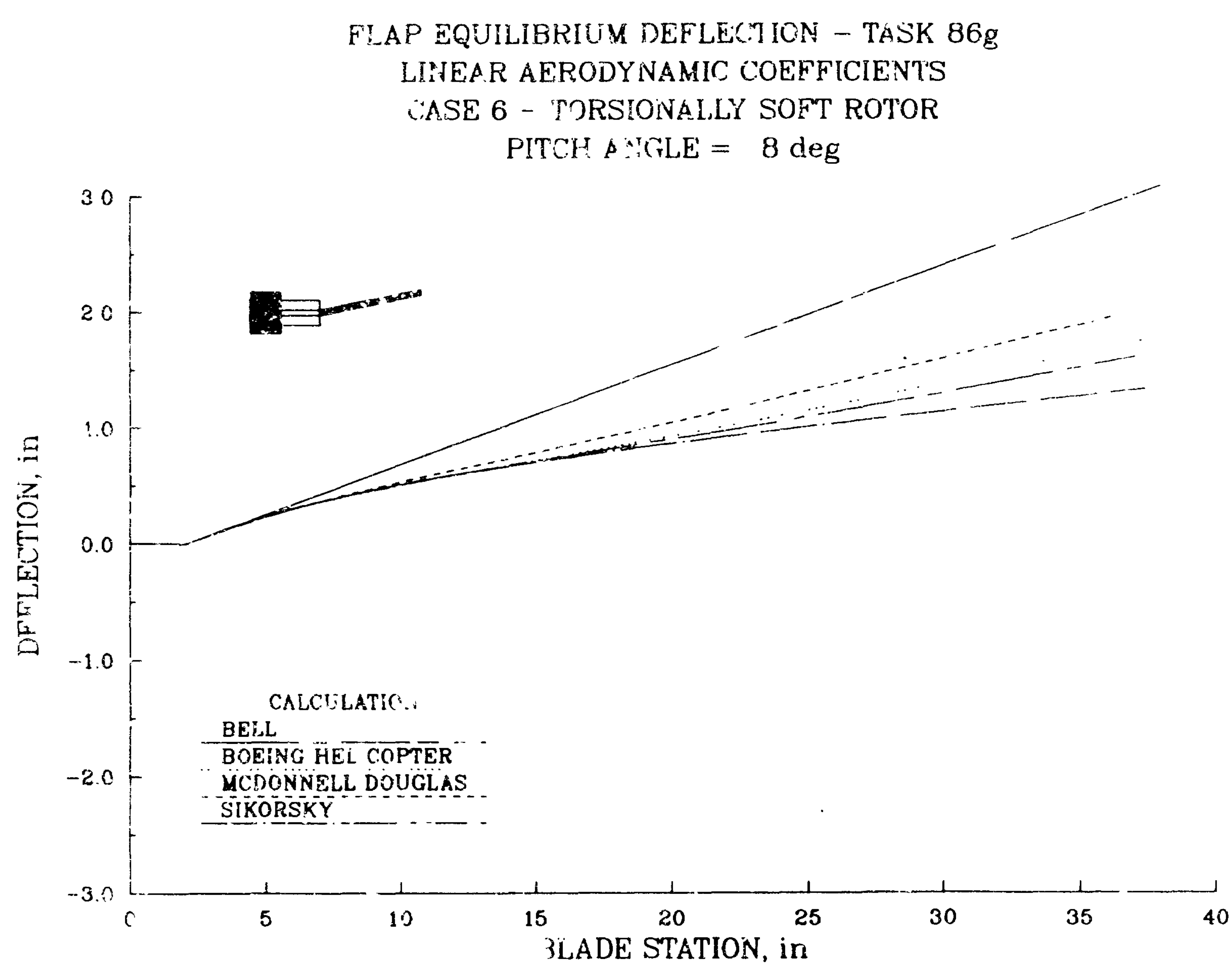


FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 3 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −4 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
MCDONNELL
SIKORSKY

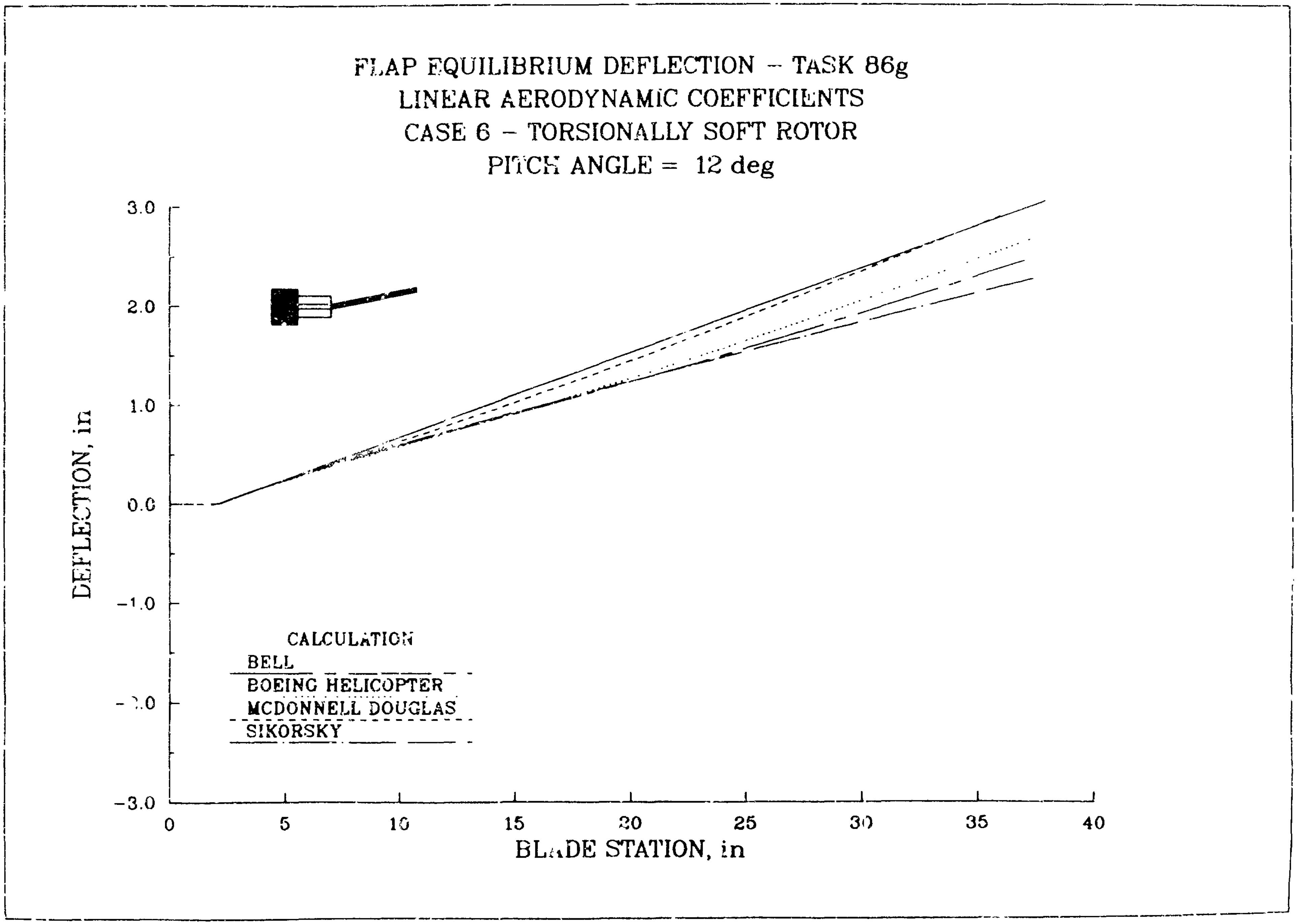

FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
DEFLECTION, in
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg

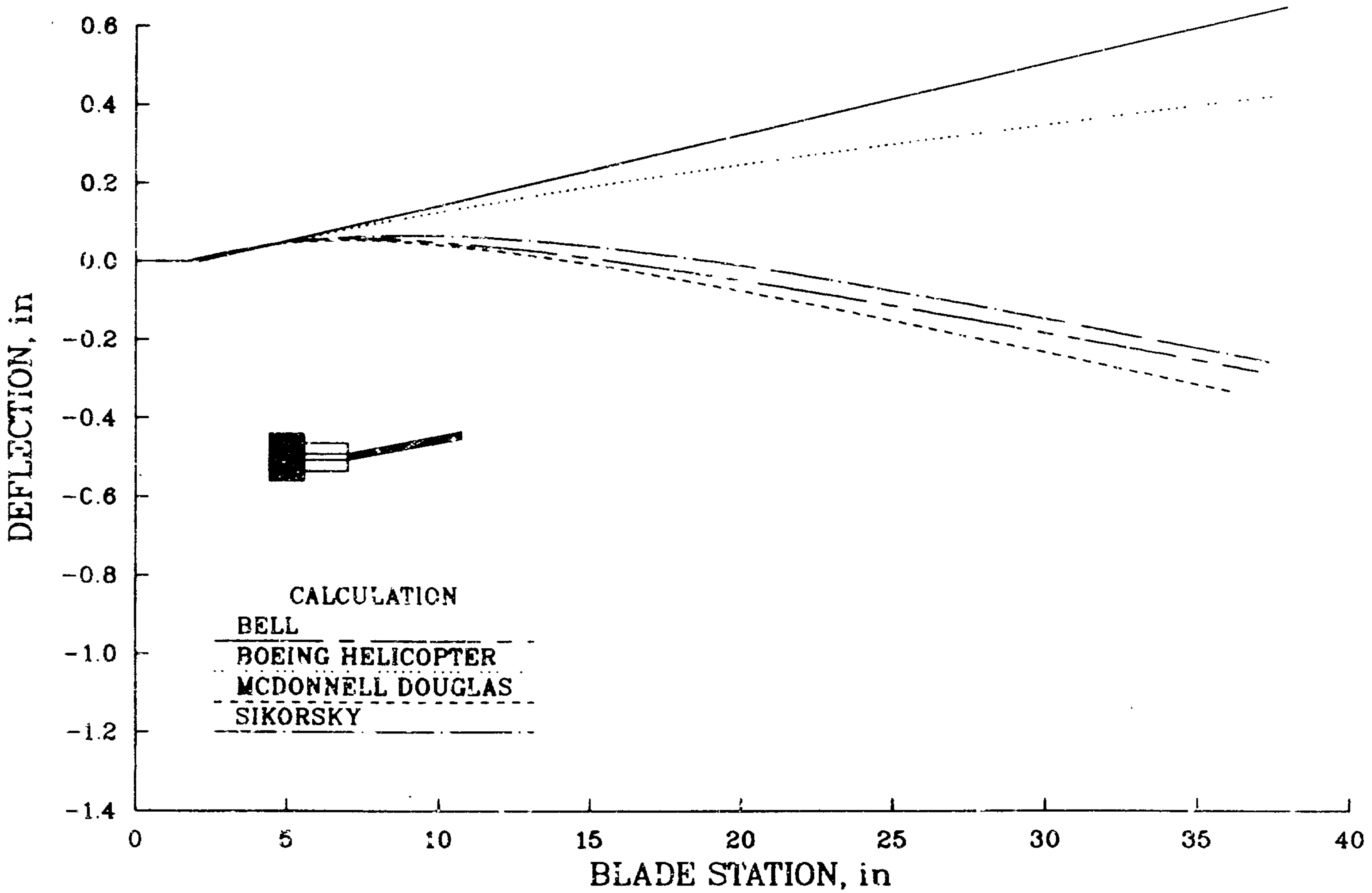


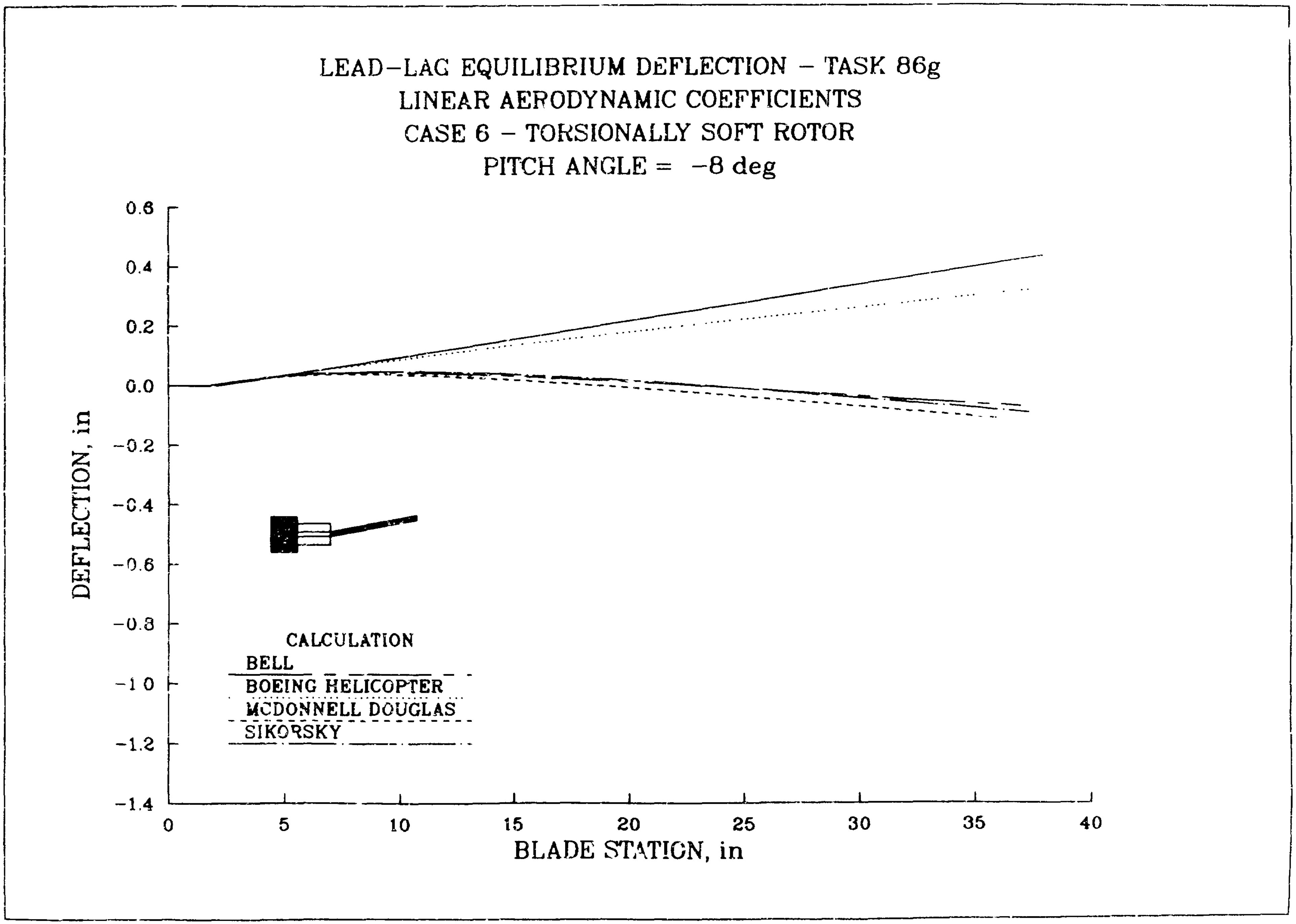


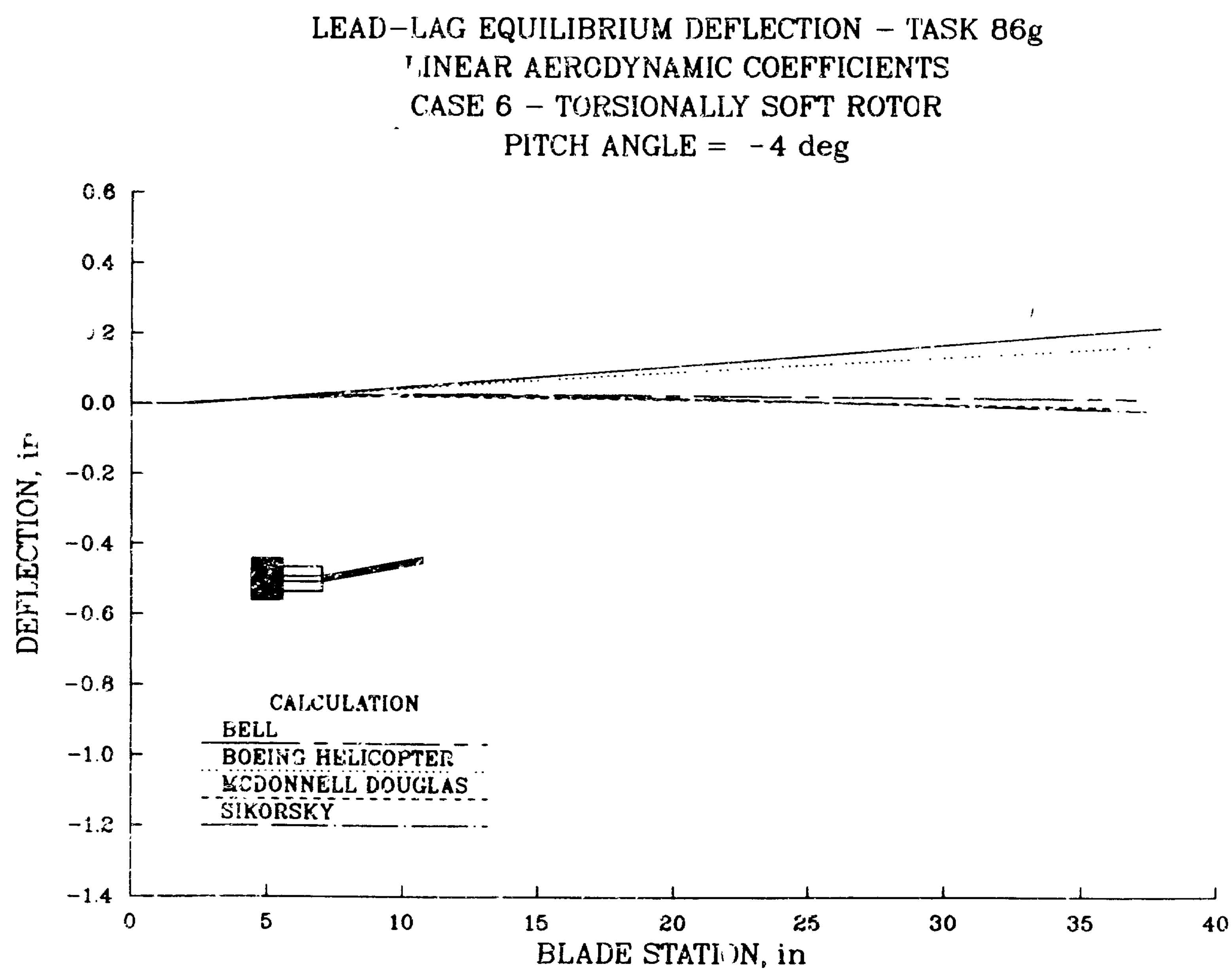
FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

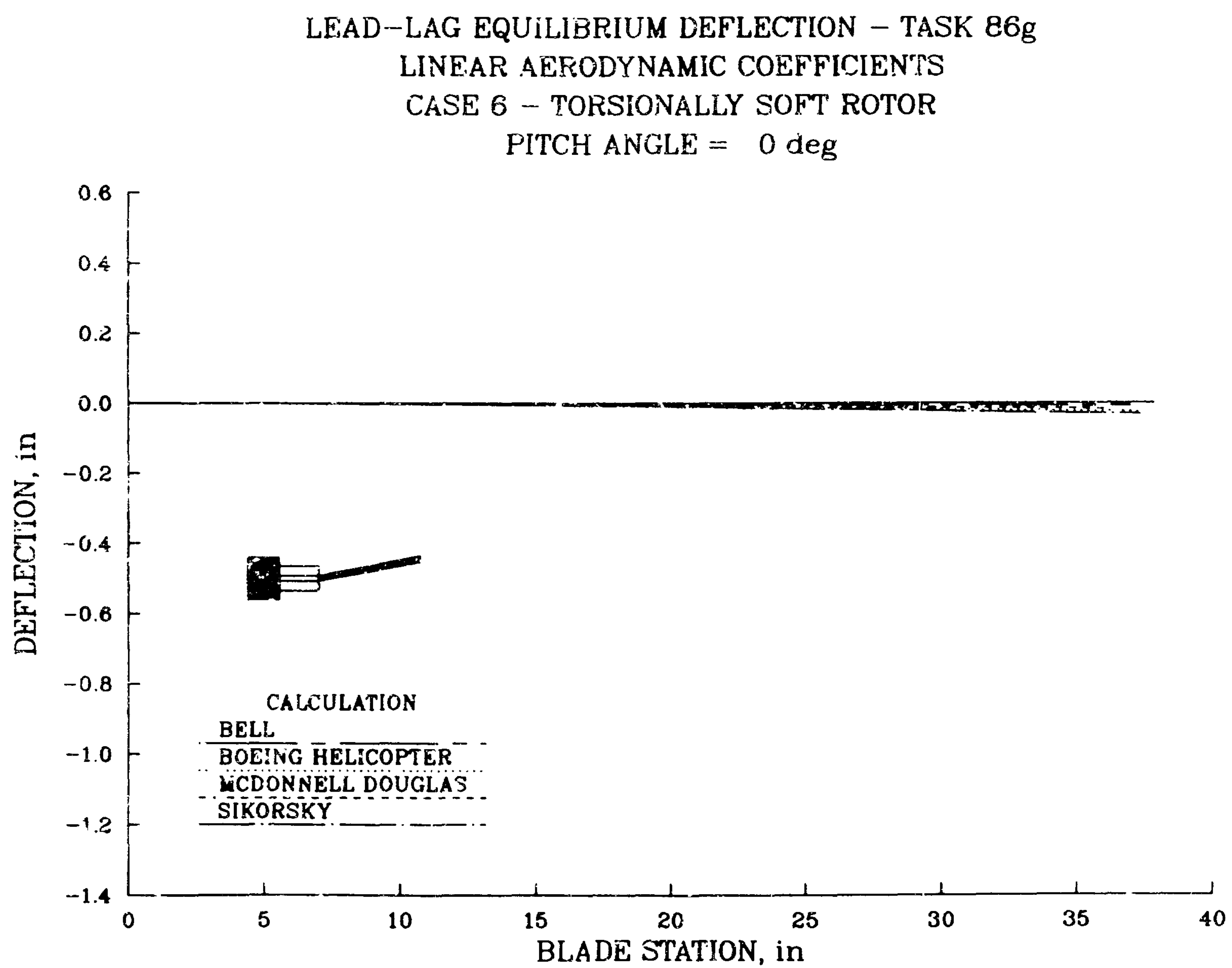

FLAP EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
DEFLECTION, in
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

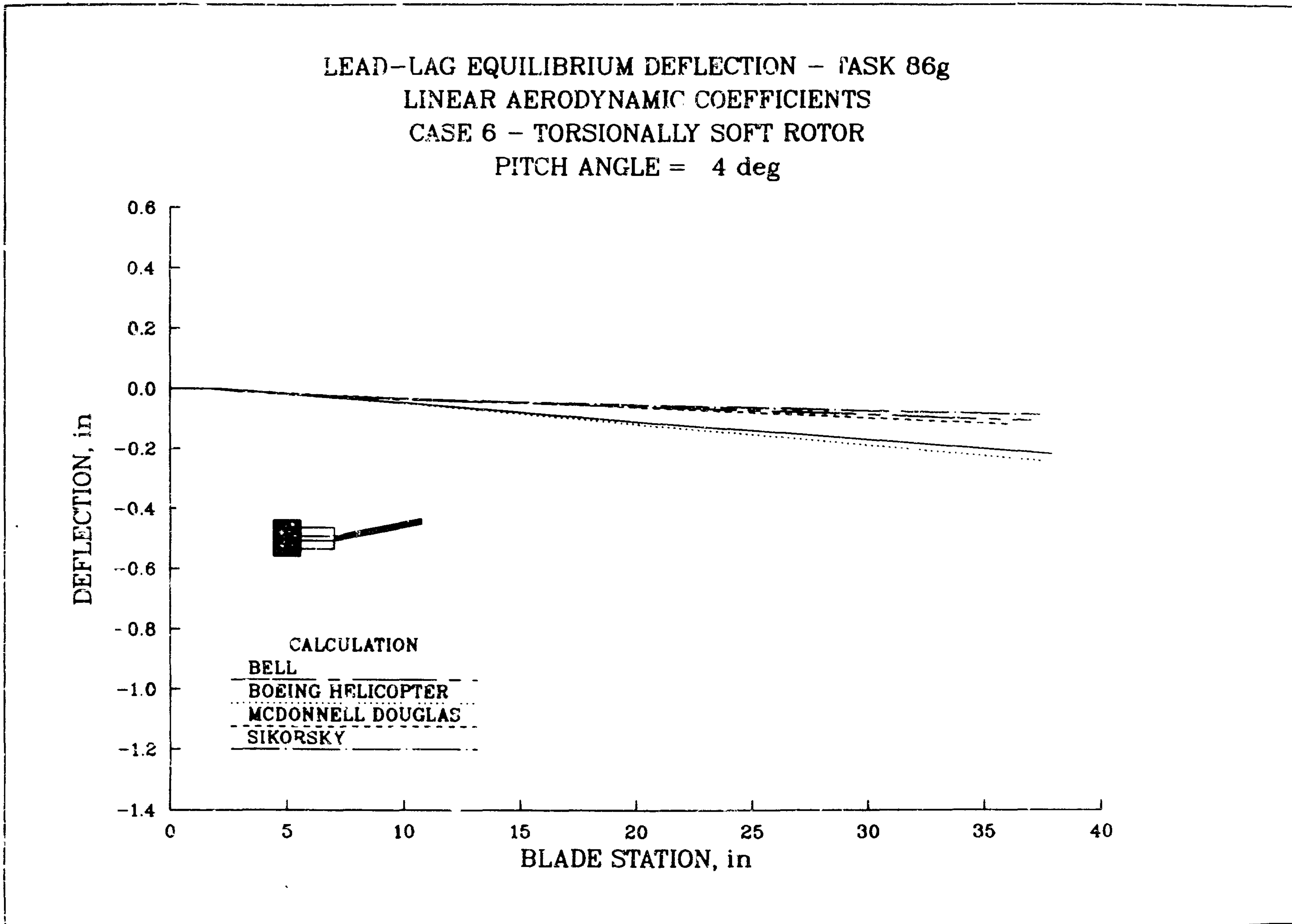
LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg



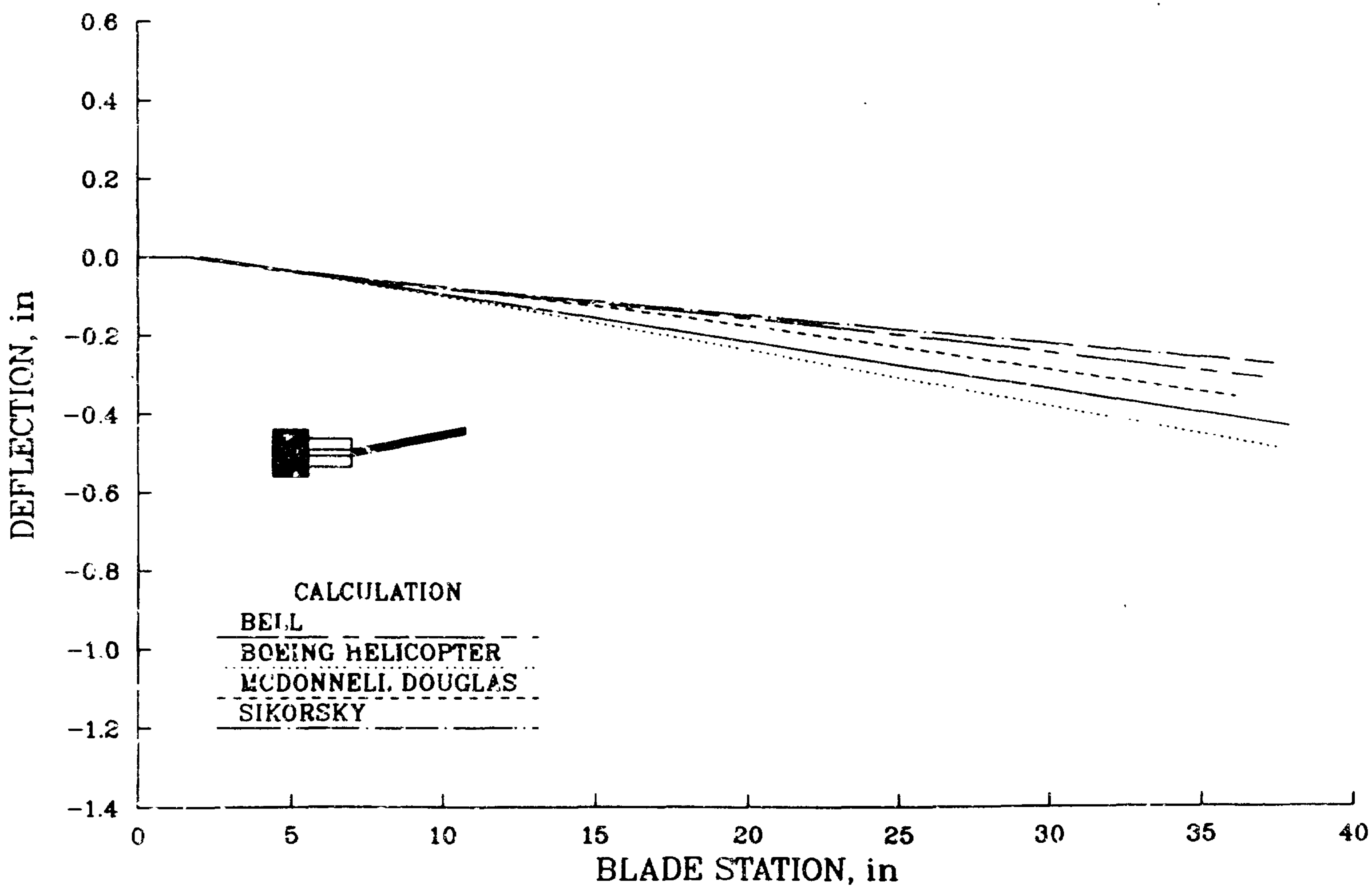

LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −8 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY
0
5
10
15
20
25
30
35
40
BLADE STATION, in

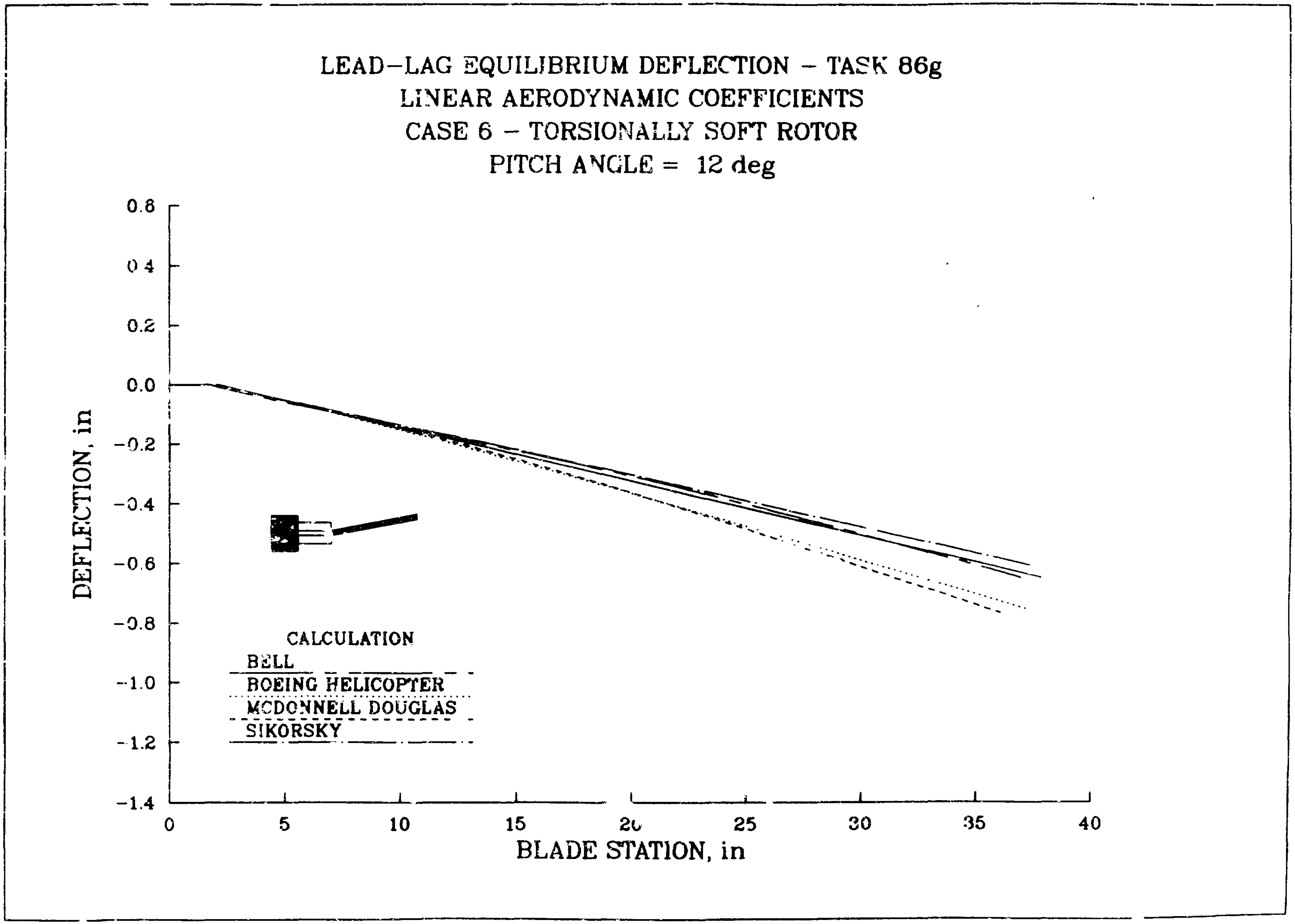

LEAD-LAG EQUILIBRIUM DEFLECTION - TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 - TORSIONALLY SOFT ROTOR
PITCH ANGLE = -4 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

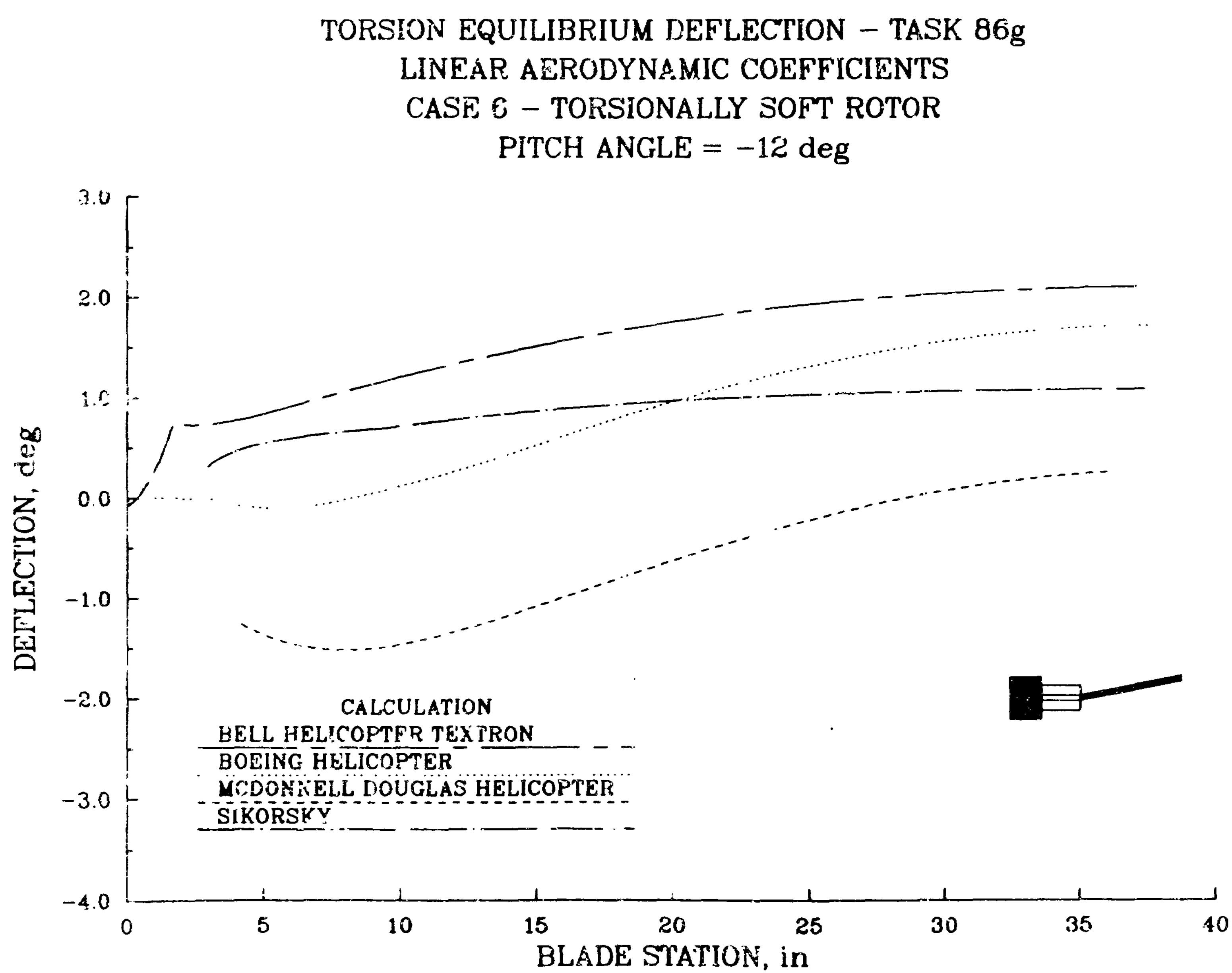

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
DEFLECTION, in
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

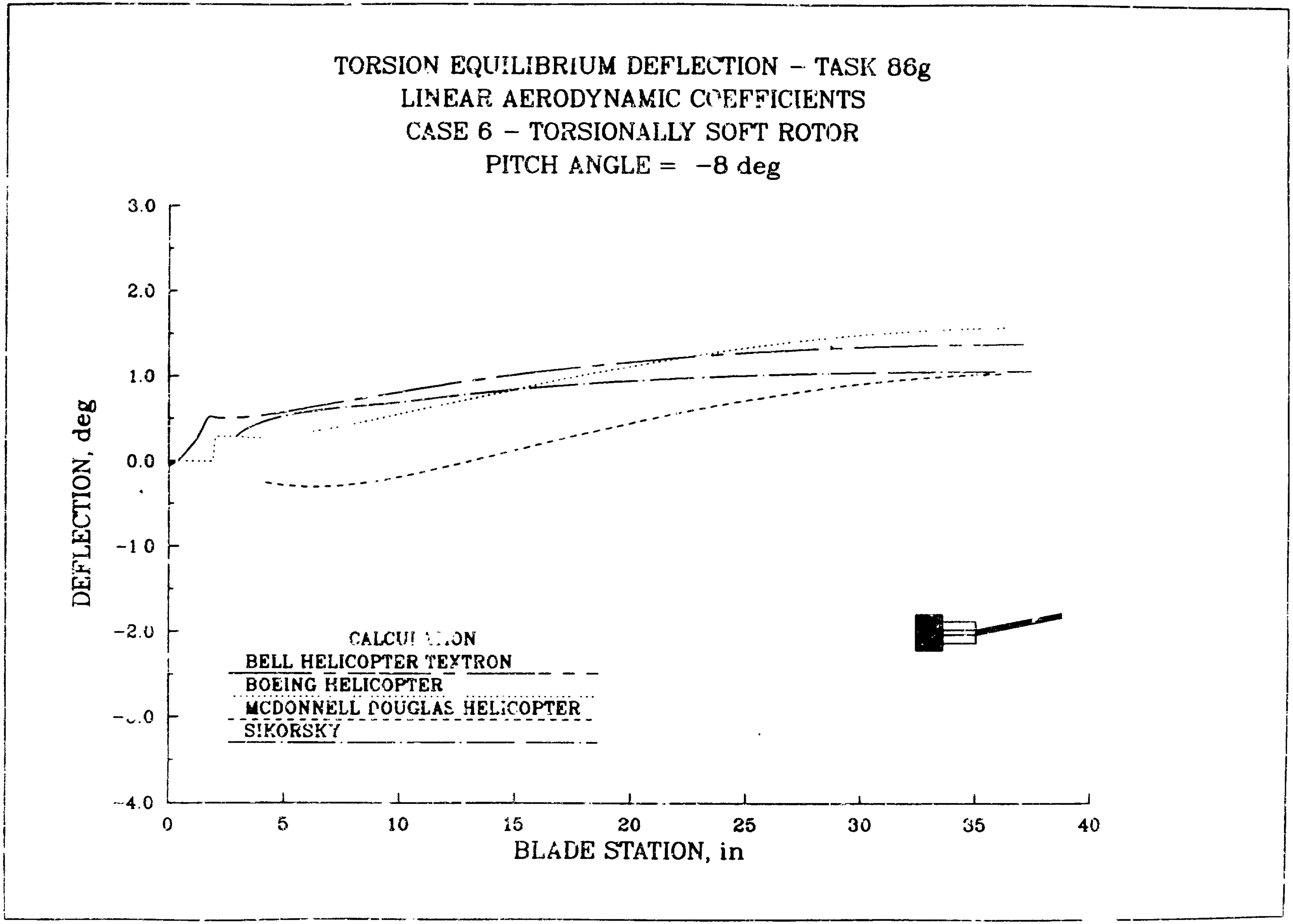

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
DEFLECTION, in
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

LEAD-LAG EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg

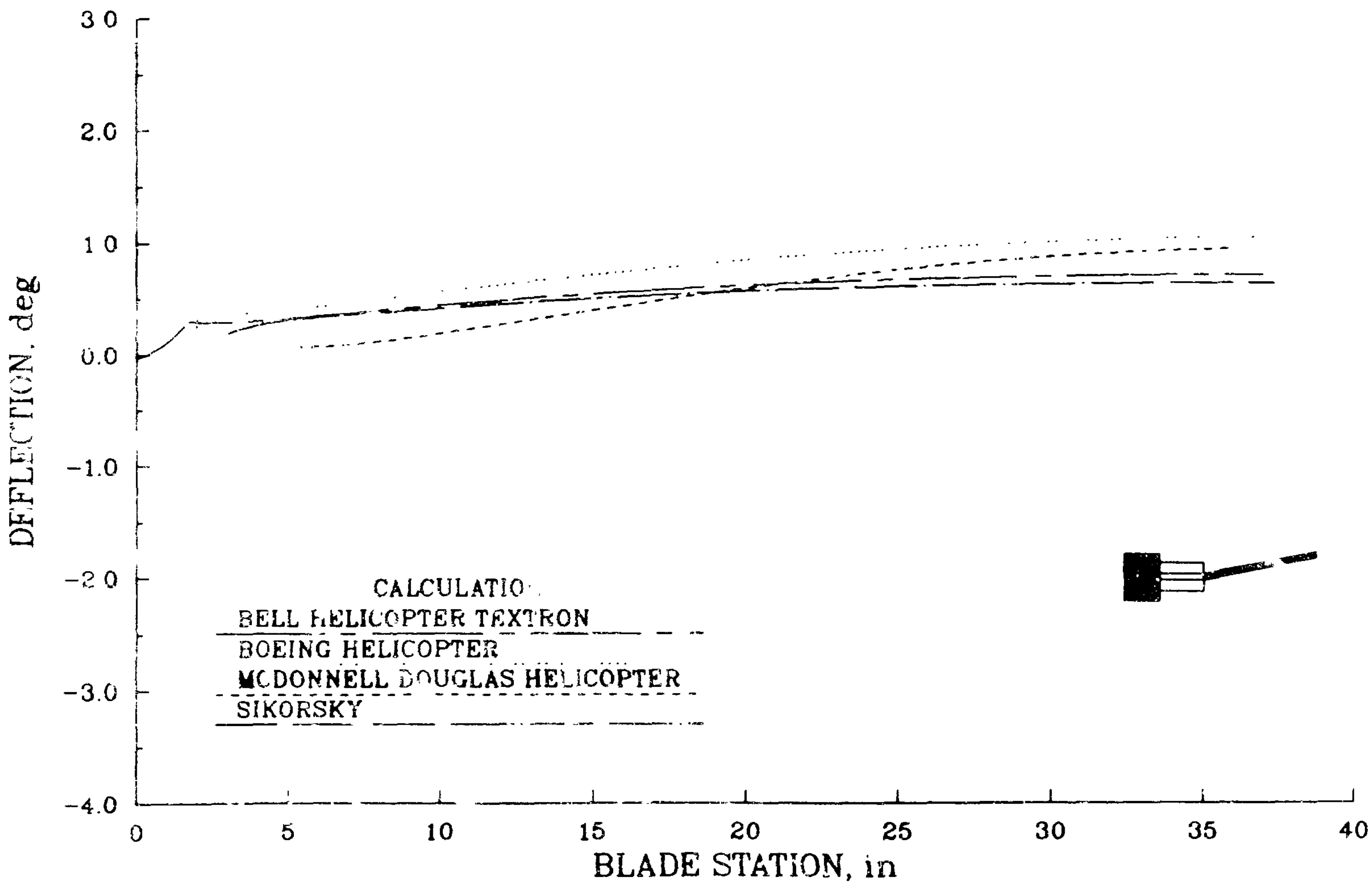



LEAD–LAG EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
DEFLECTION, in
0.8
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
0
5
10
15
25
30
35
40
BLADE STATION, in
CALCULATION
BELL
BOEING HELICOPTER
MCDONNELL DOUGLAS
SIKORSKY

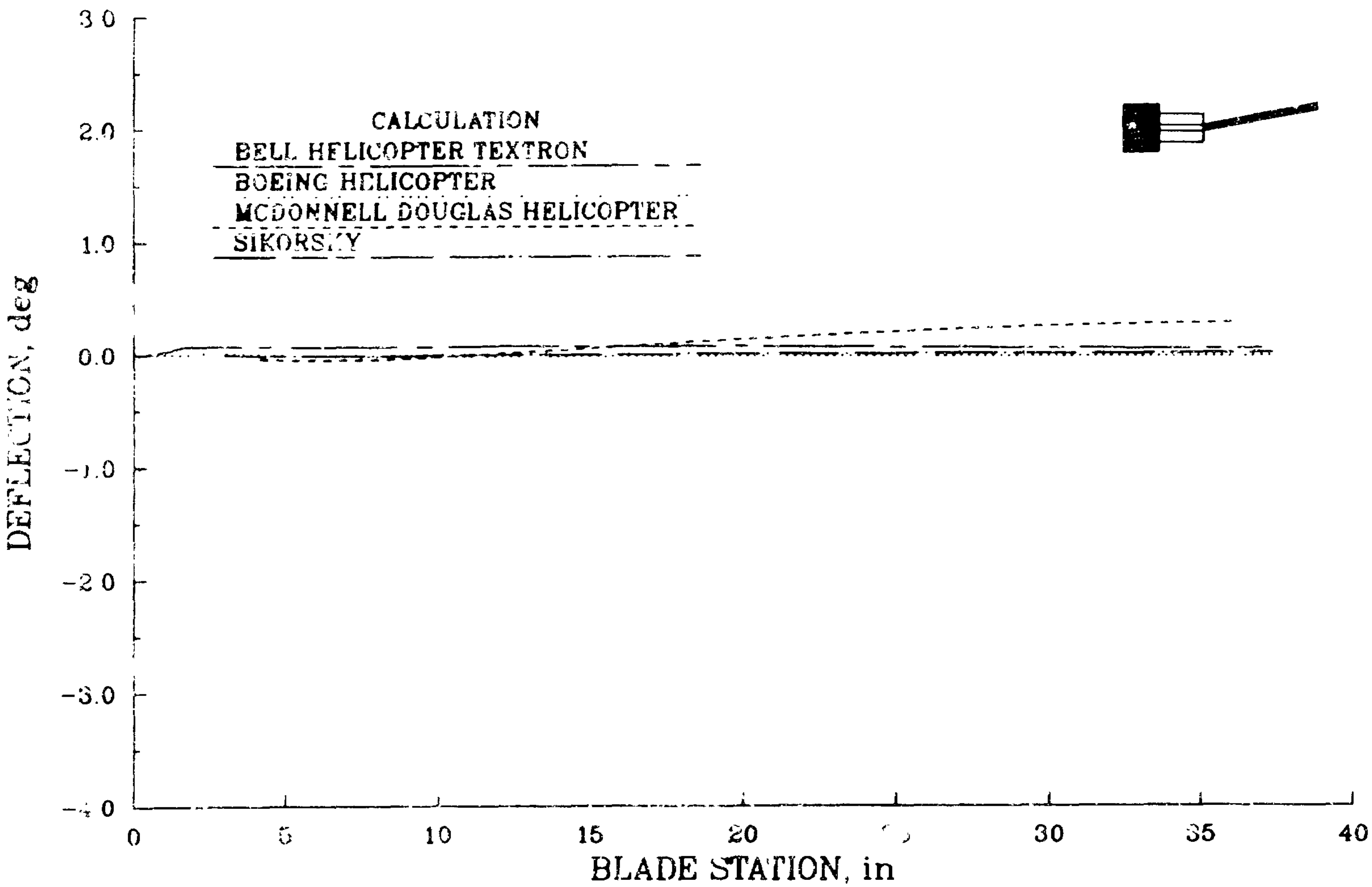

TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = −12 deg
DEFLECTION, deg
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY


TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –8 deg
DEFLECTION, deg
3.0
2.0
1.0
0.0
–1.0
–2.0
–4.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY

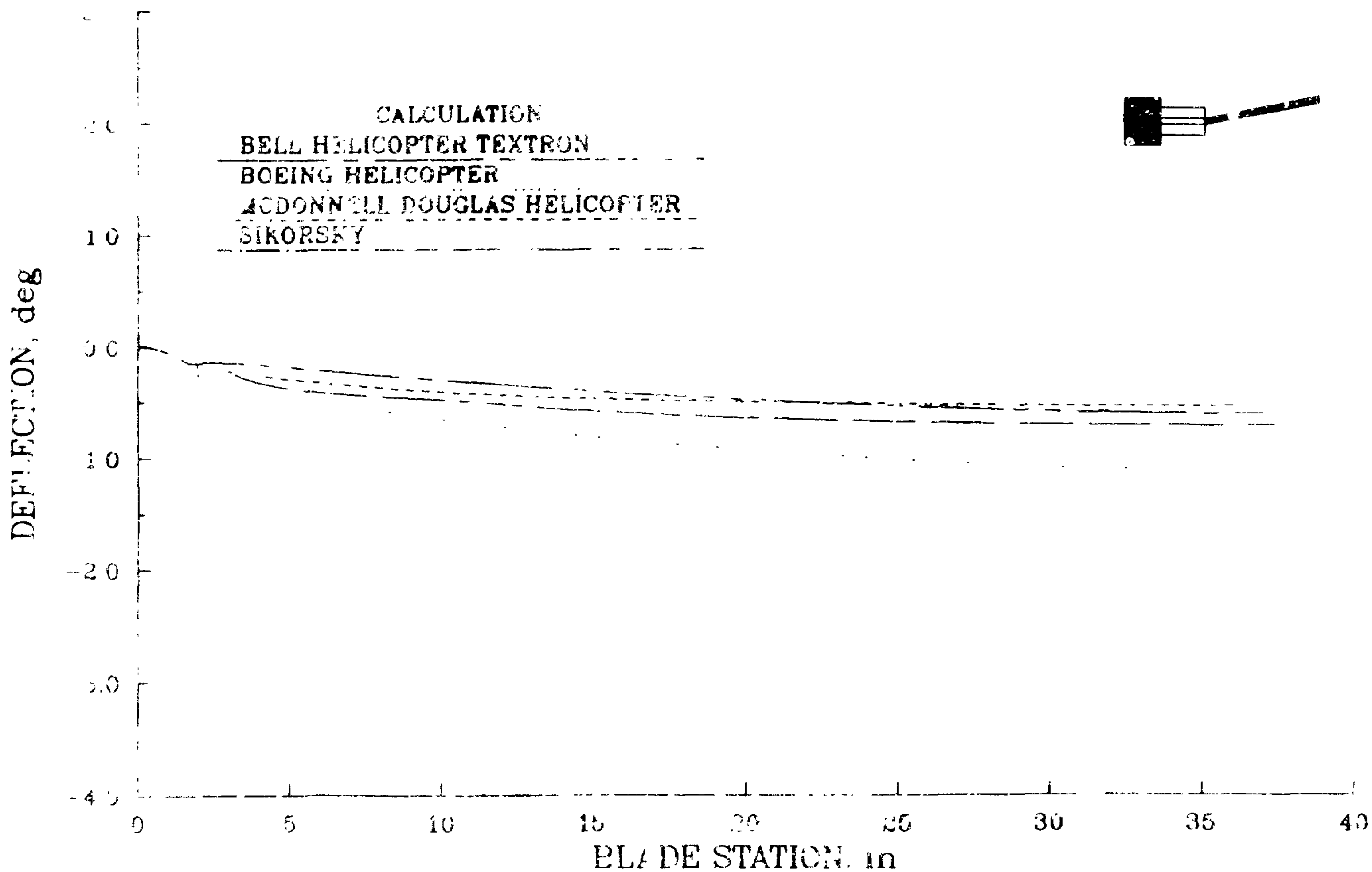
TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg

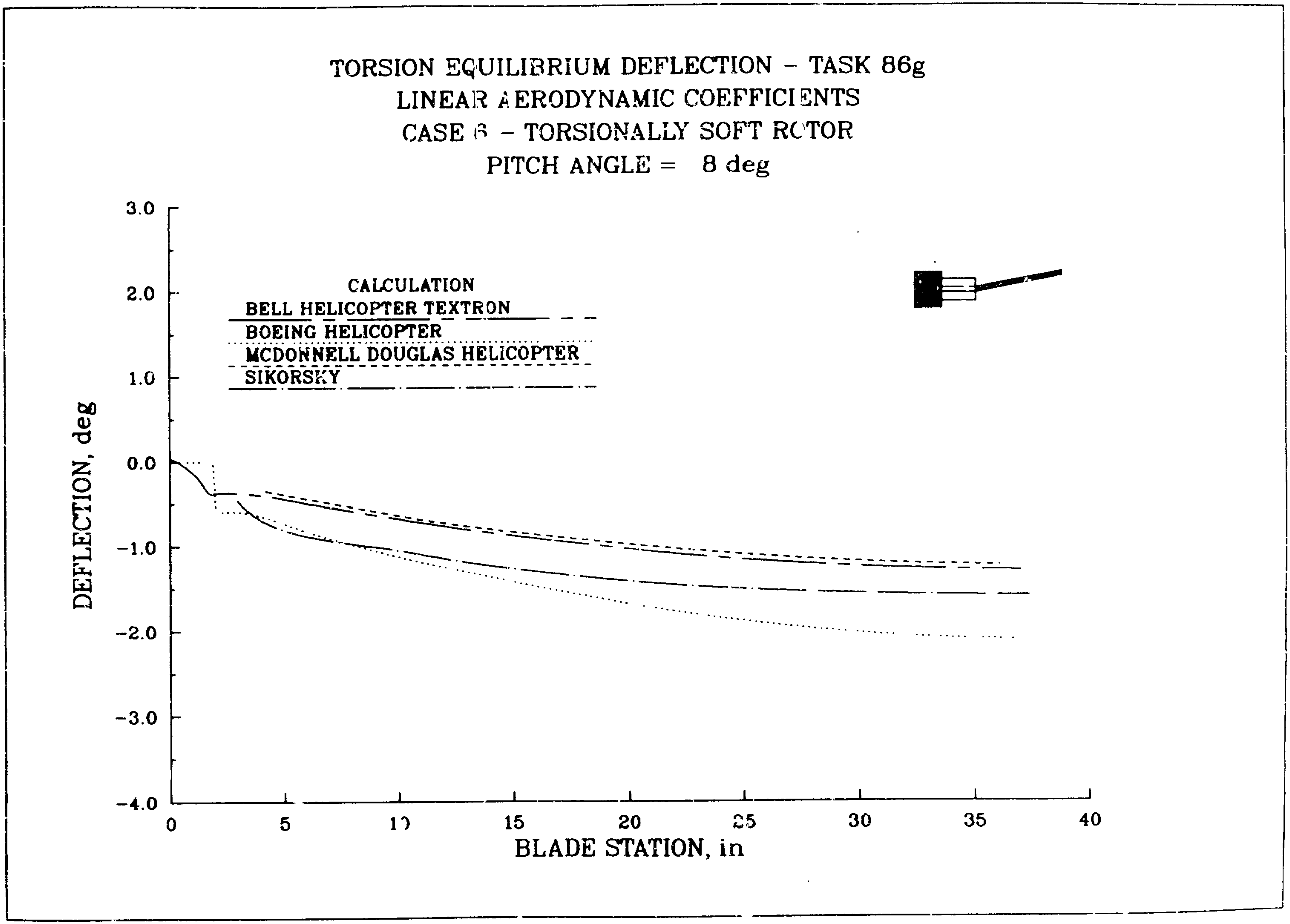


TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg

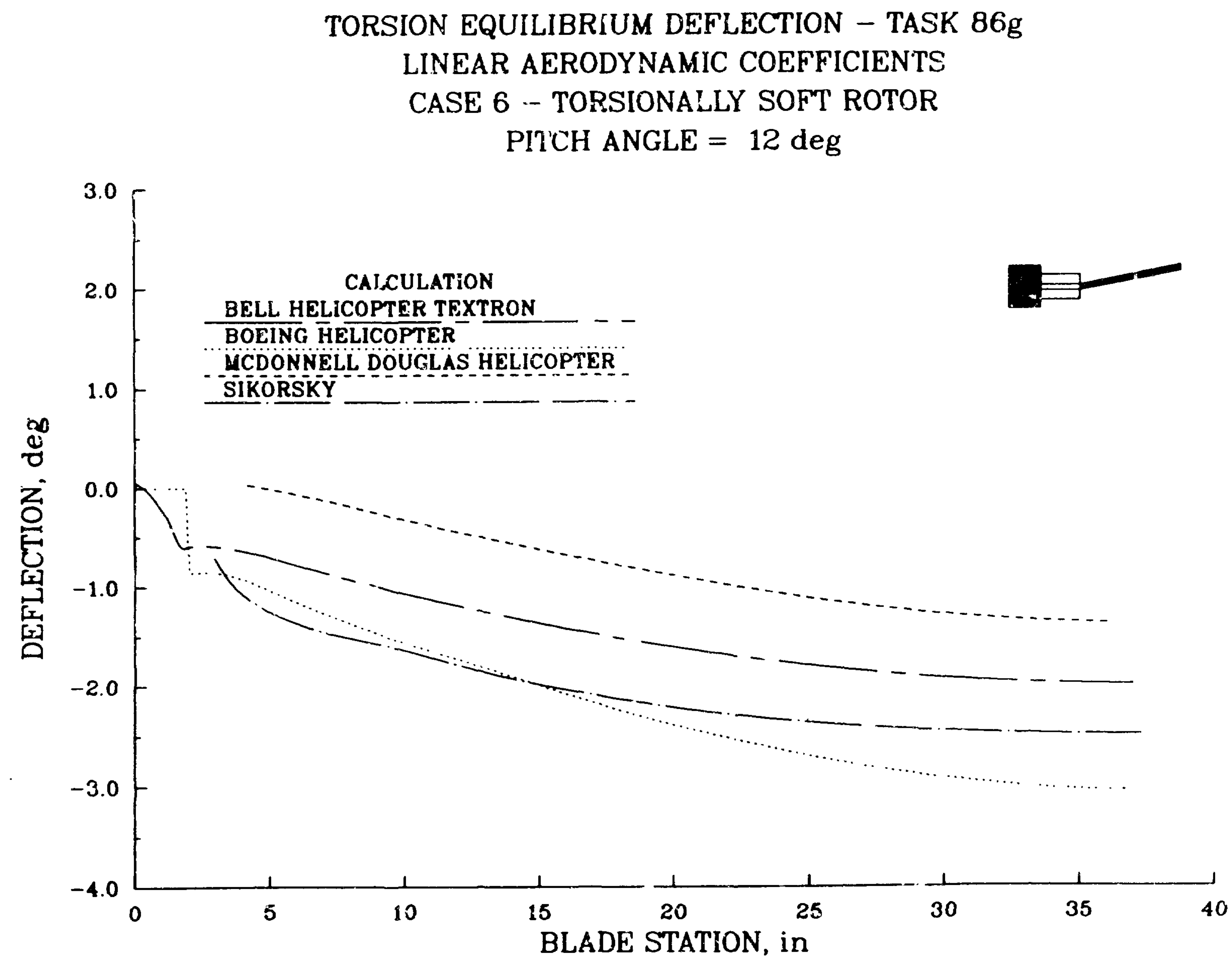


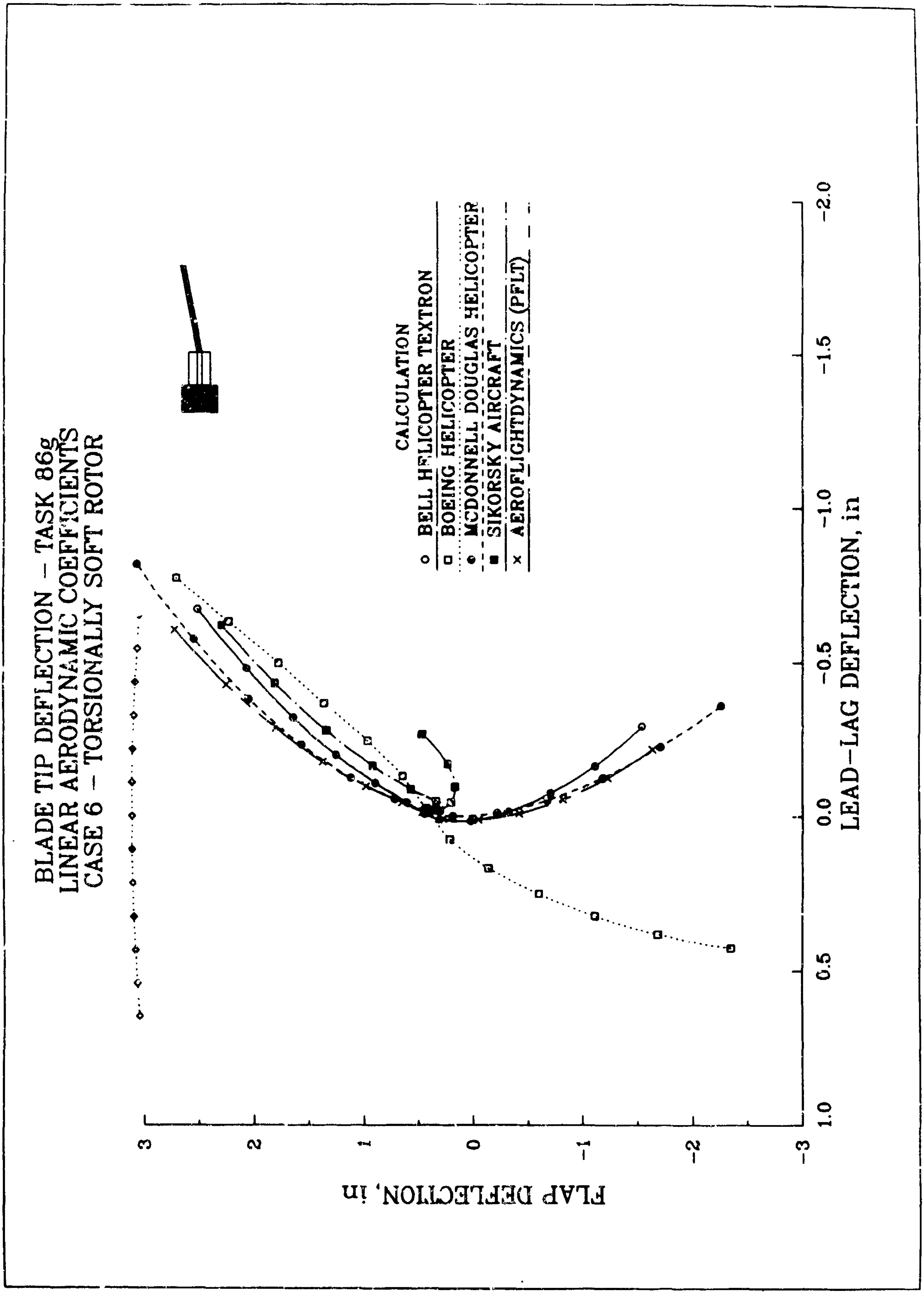
TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg



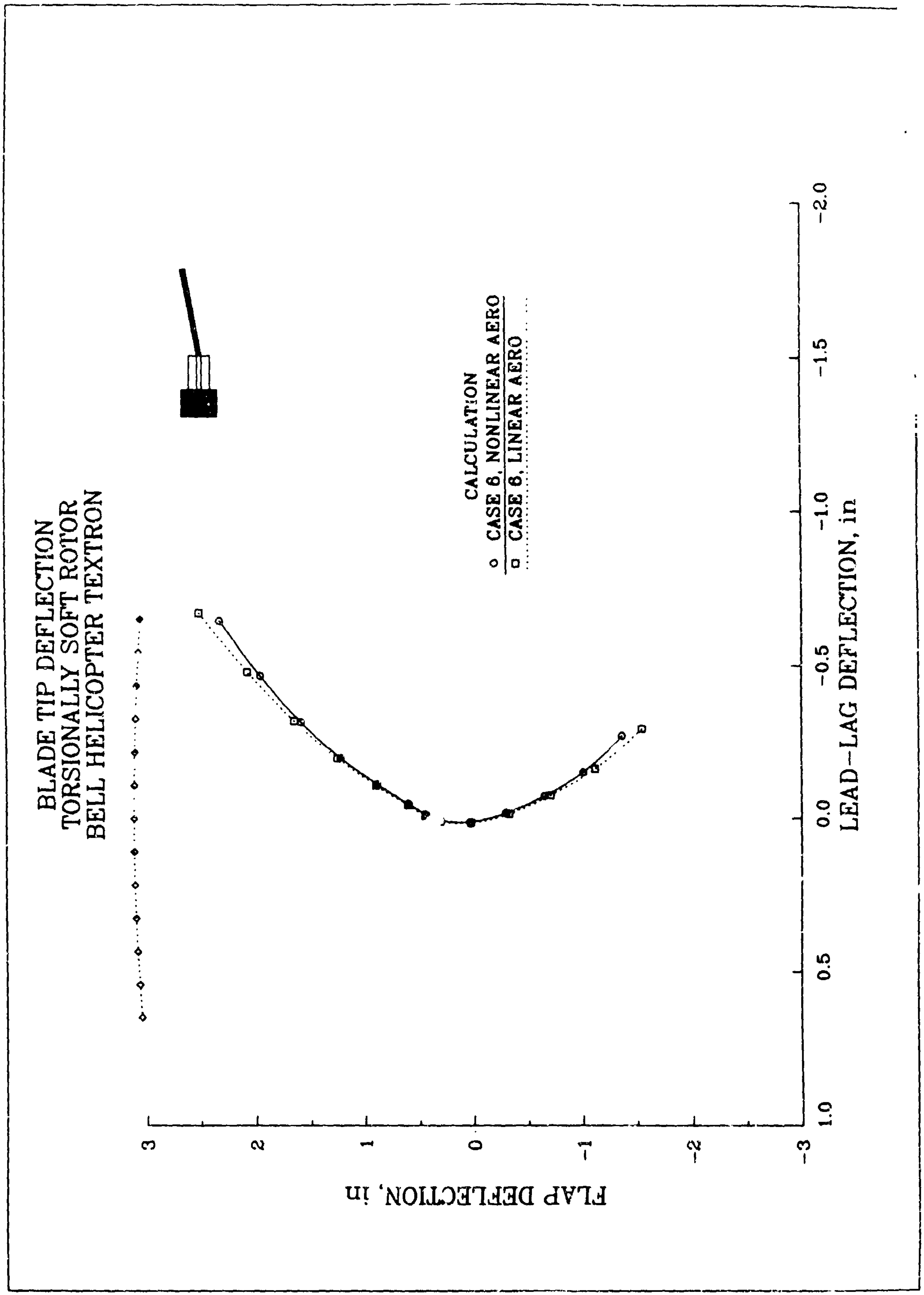


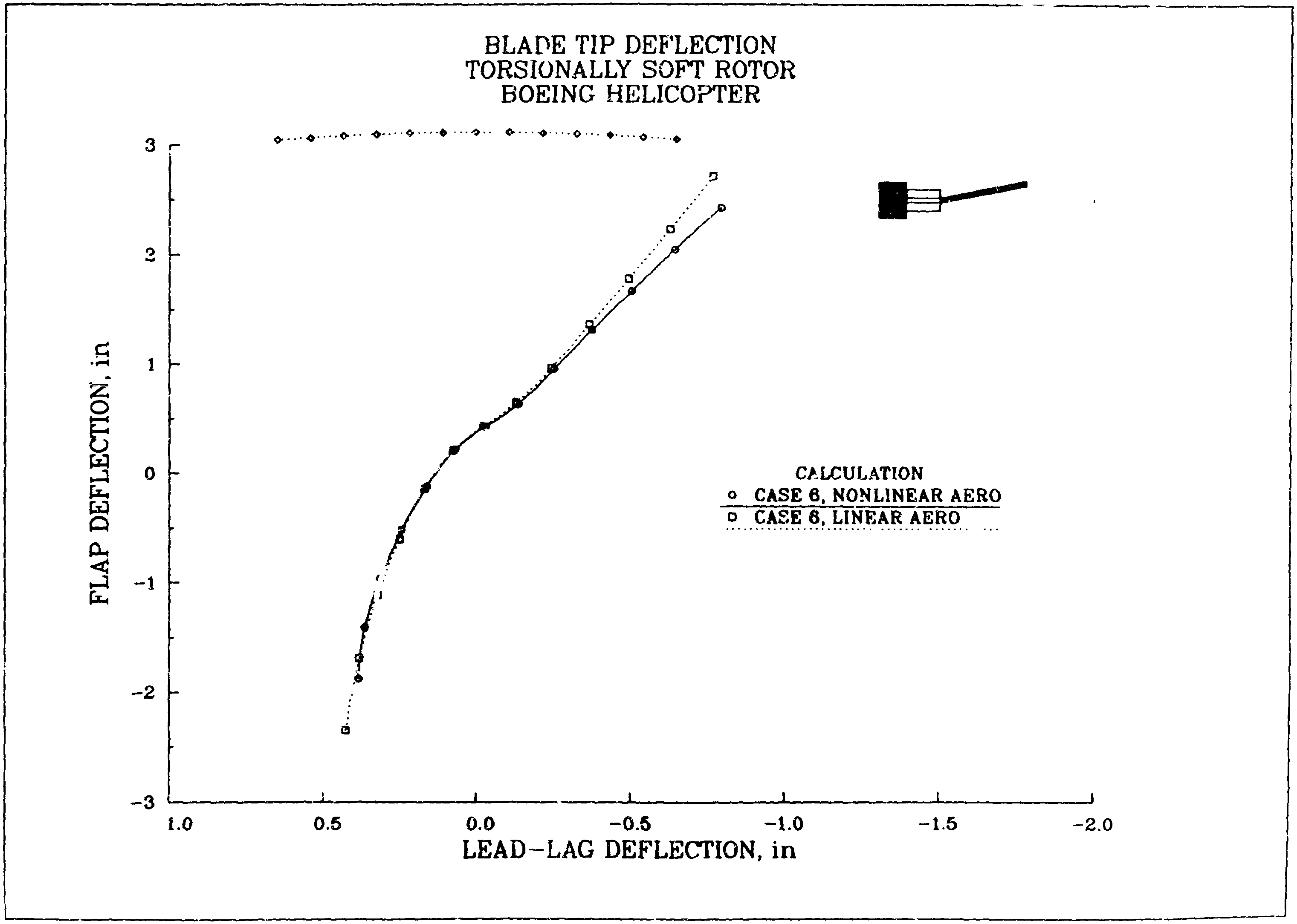
TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY
DEFLECTION, deg
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
0
5
15
20
30
35
40
BLADE STATION, in

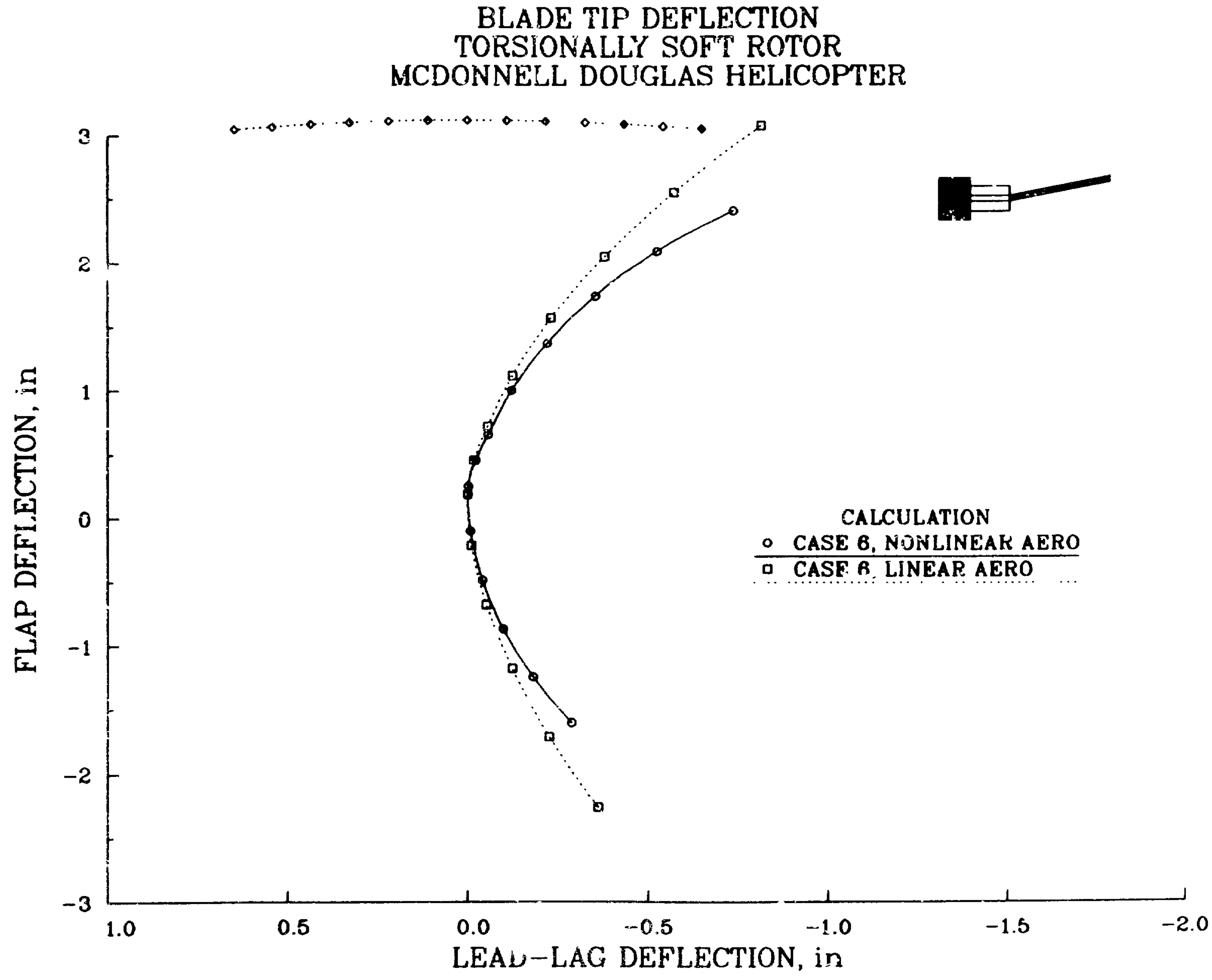

TORSION EQUILIBRIUM DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY
DEFLECTION, deg
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
0
5
10
15
20
25
30
35
40
BLADE STATION, in

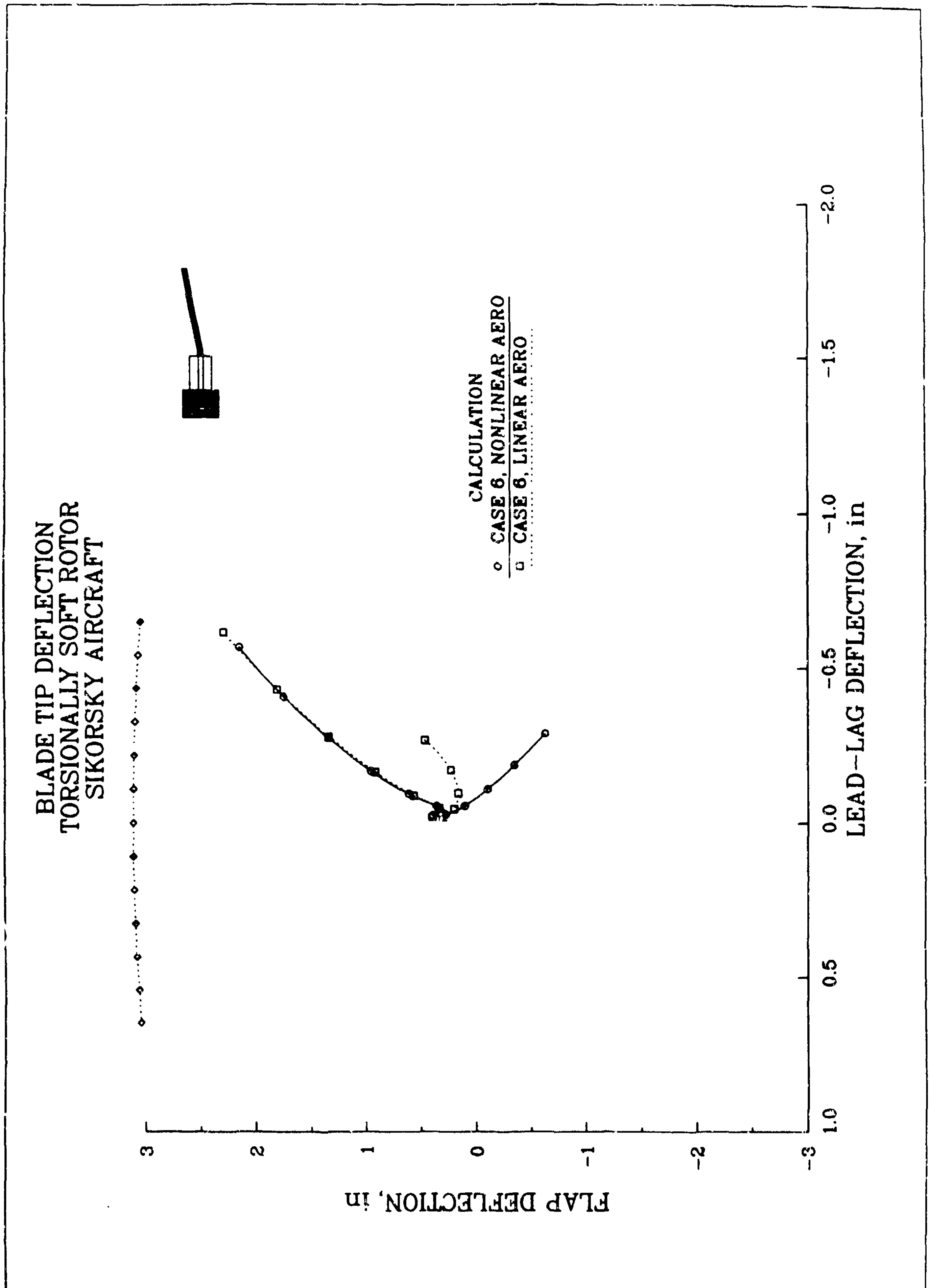


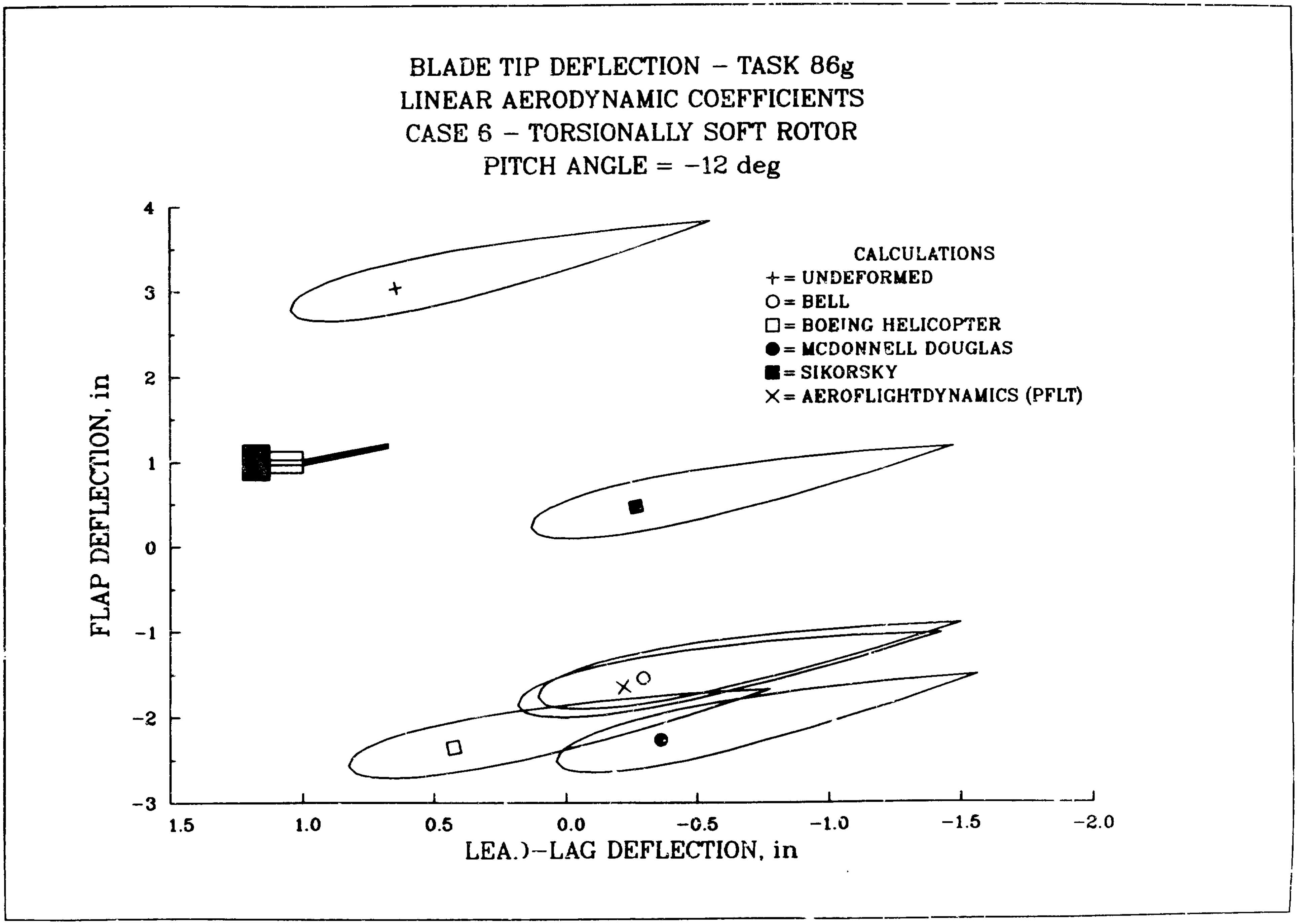
BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
3
2
1
0
−1
−2
−3

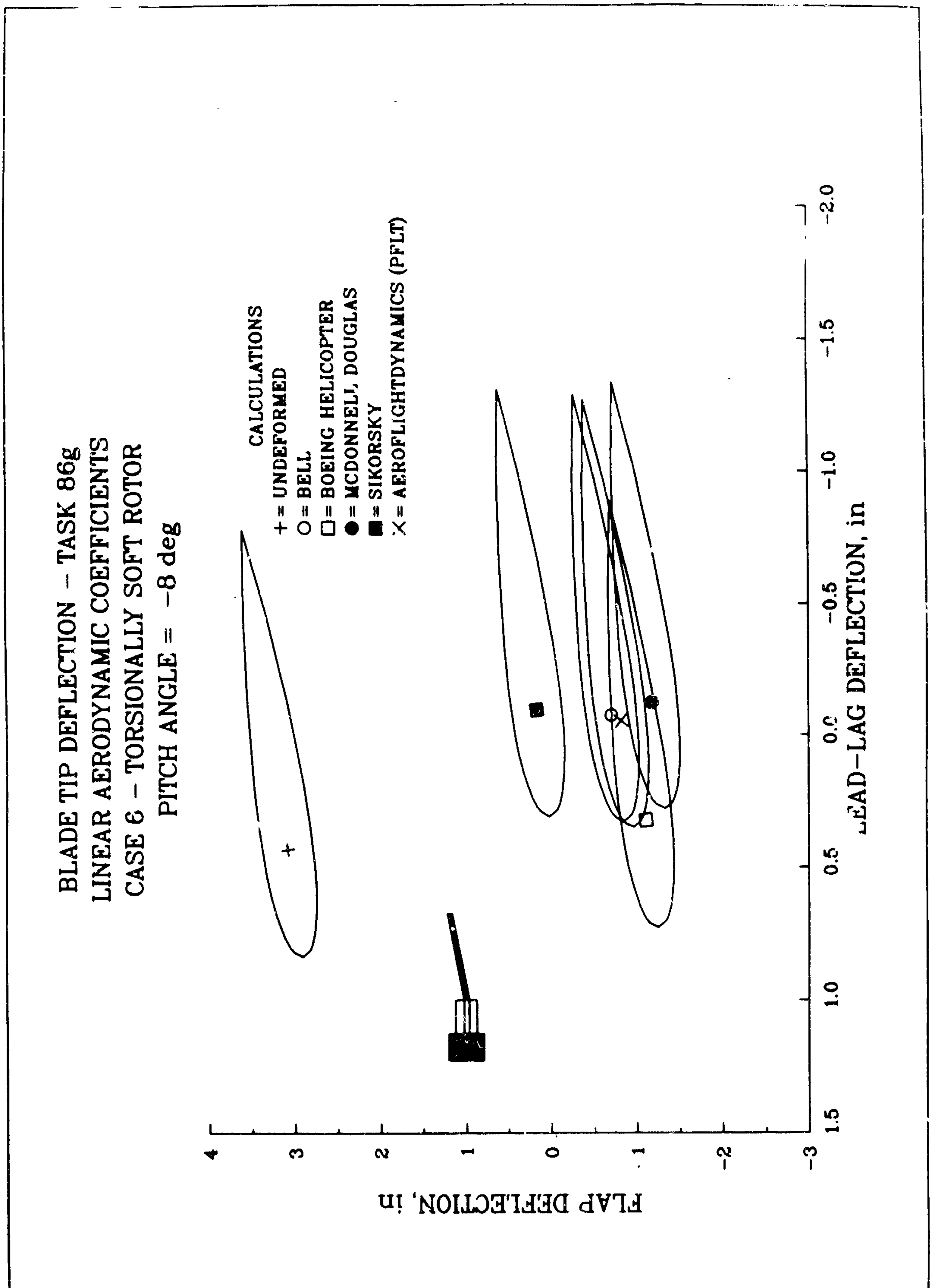

BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
LEAD–LAG DEFLECTION, in
FLAP DEFLECTION, in
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
3
2
1
0
−1
−2
−3


BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

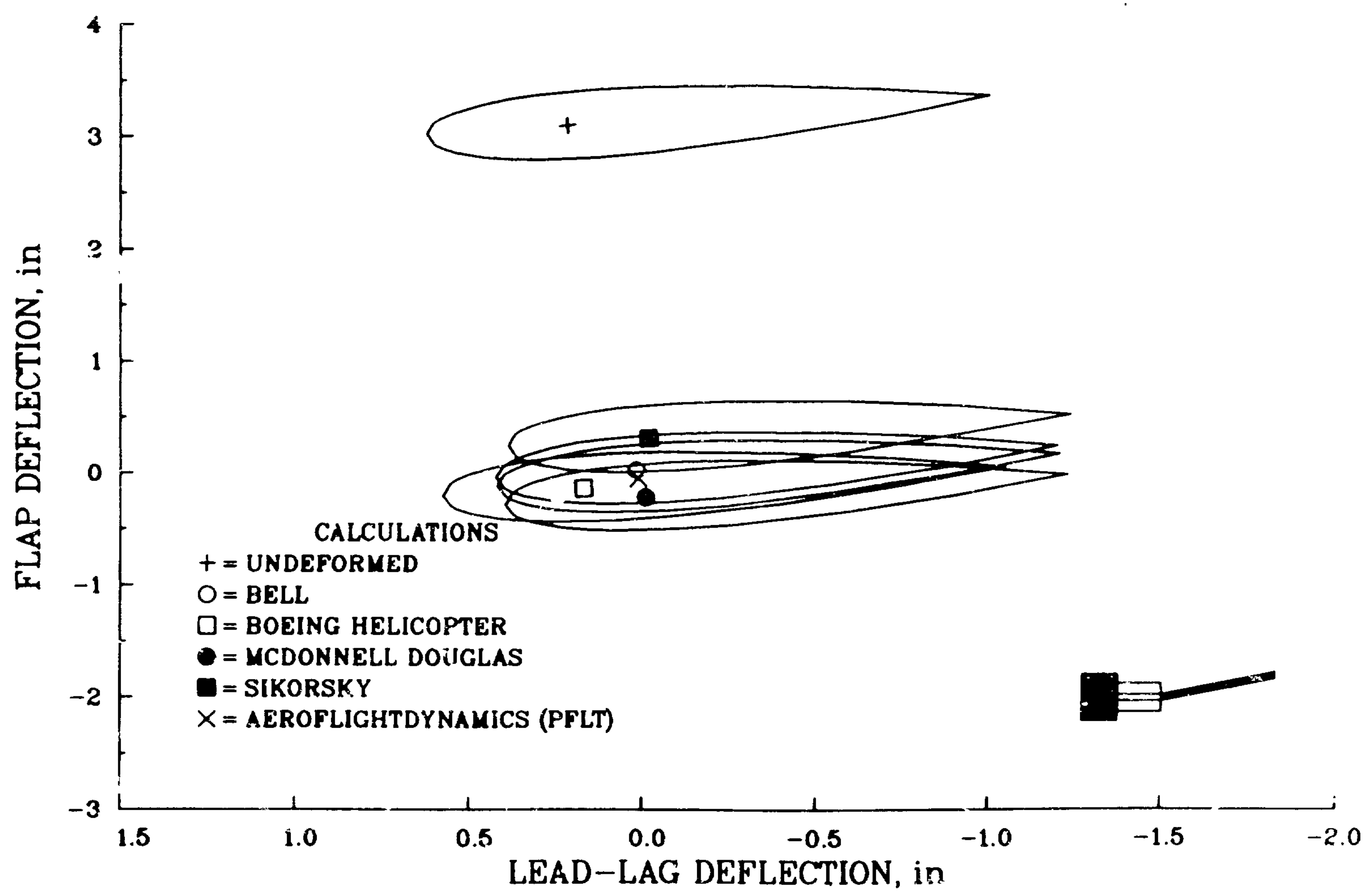

BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
3
2
1
0
−1
−2
−3
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

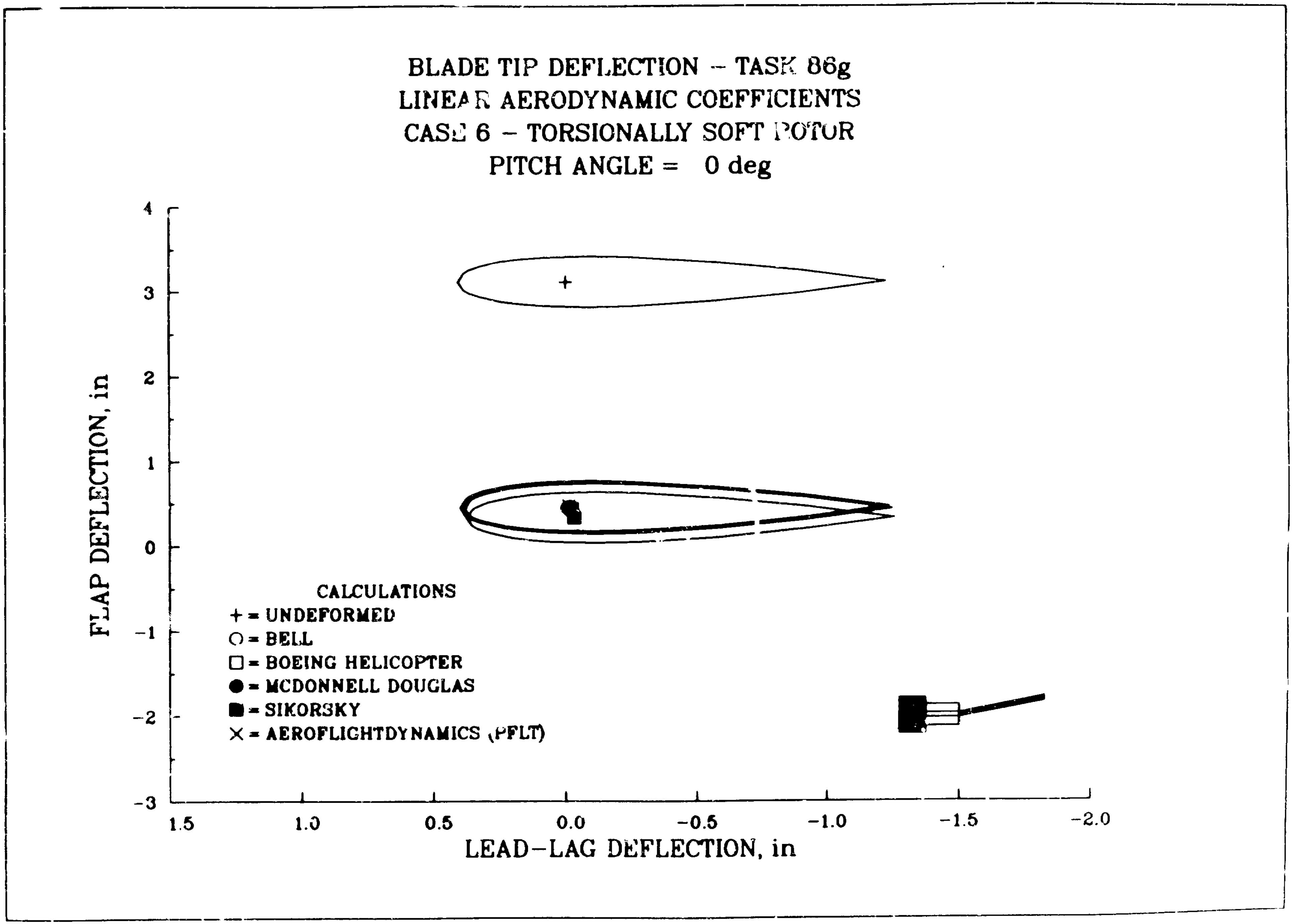

BLADE TIP DEFLECTION
TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
CALCULATION
CASE 6, NONLINEAR AERO
CASE 6, LINEAR AERO
FLAP DEFLECTION, in
LEAD—LAG DEFLECTION, in
3
2
1
0
-1
-2
-3
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0

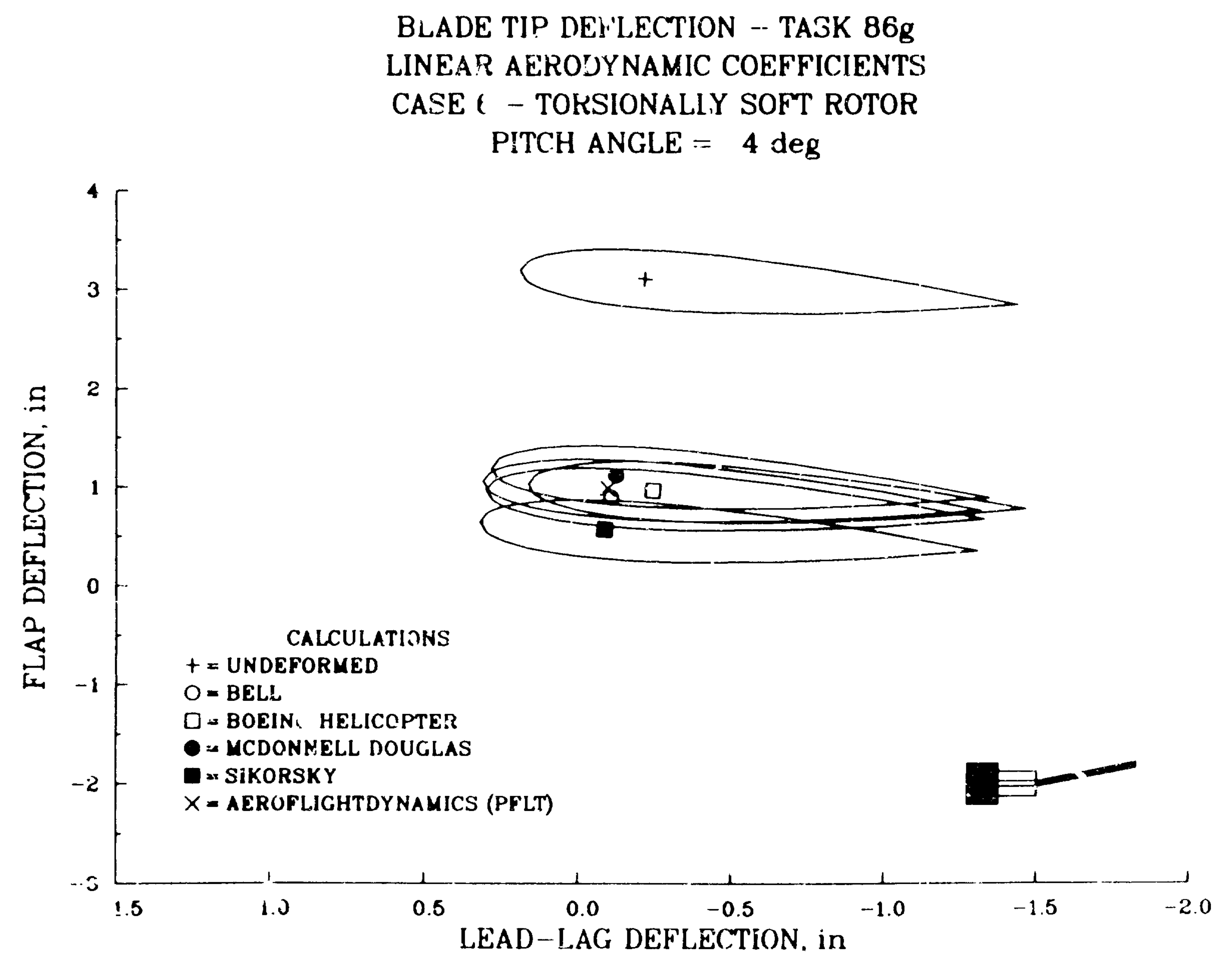

BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –12 deg
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)
FLAP DEFLECTION, in
LEA.)–LAG DEFLECTION, in
4
3
2
1
0
–1
–2
–3
1.5
1.0
0.5
0.0
–0.5
–1.0
–1.5
–2.0

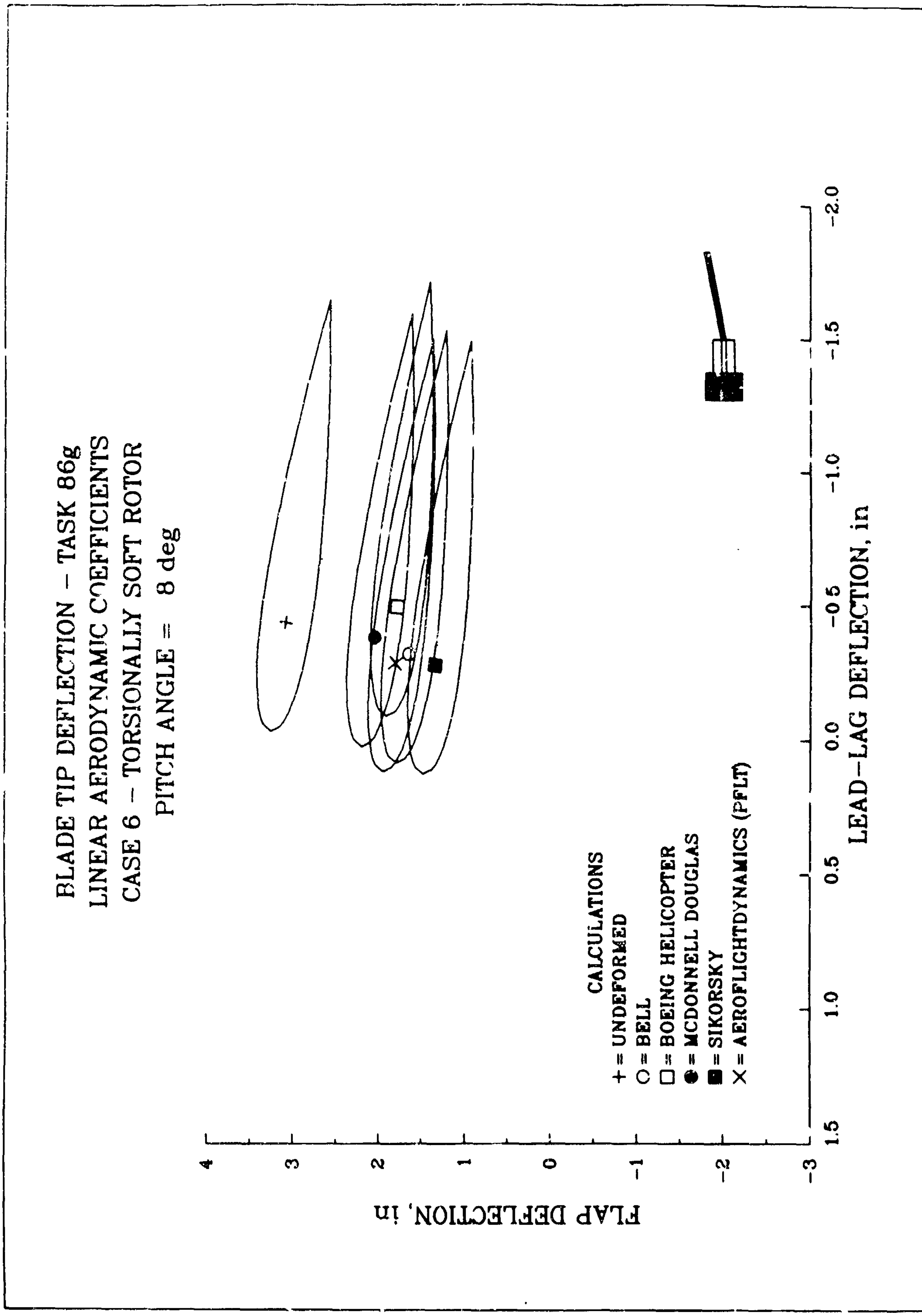

BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –8 deg
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
4
3
2
1
0
-1
-2
-3
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0

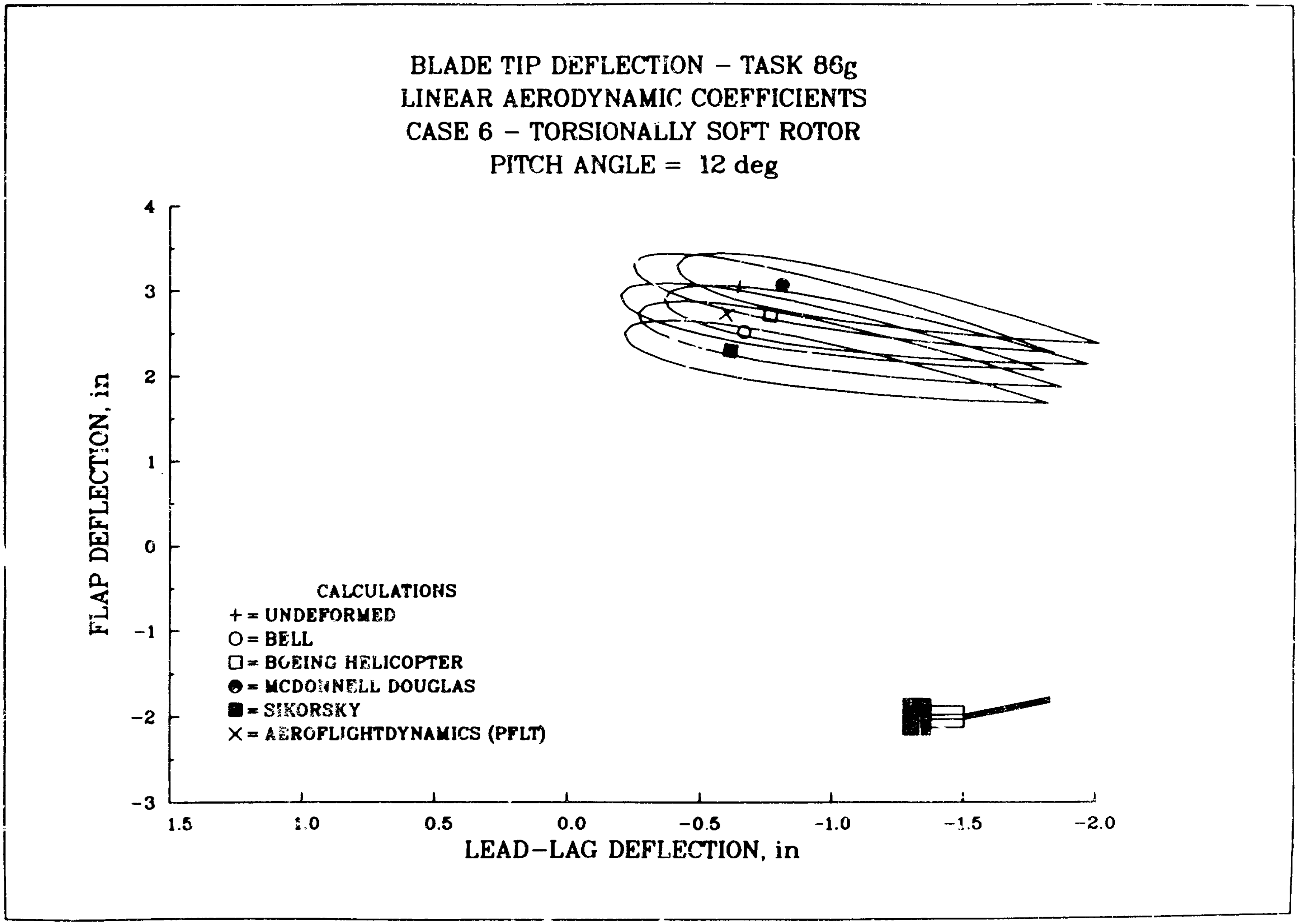
BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = –4 deg

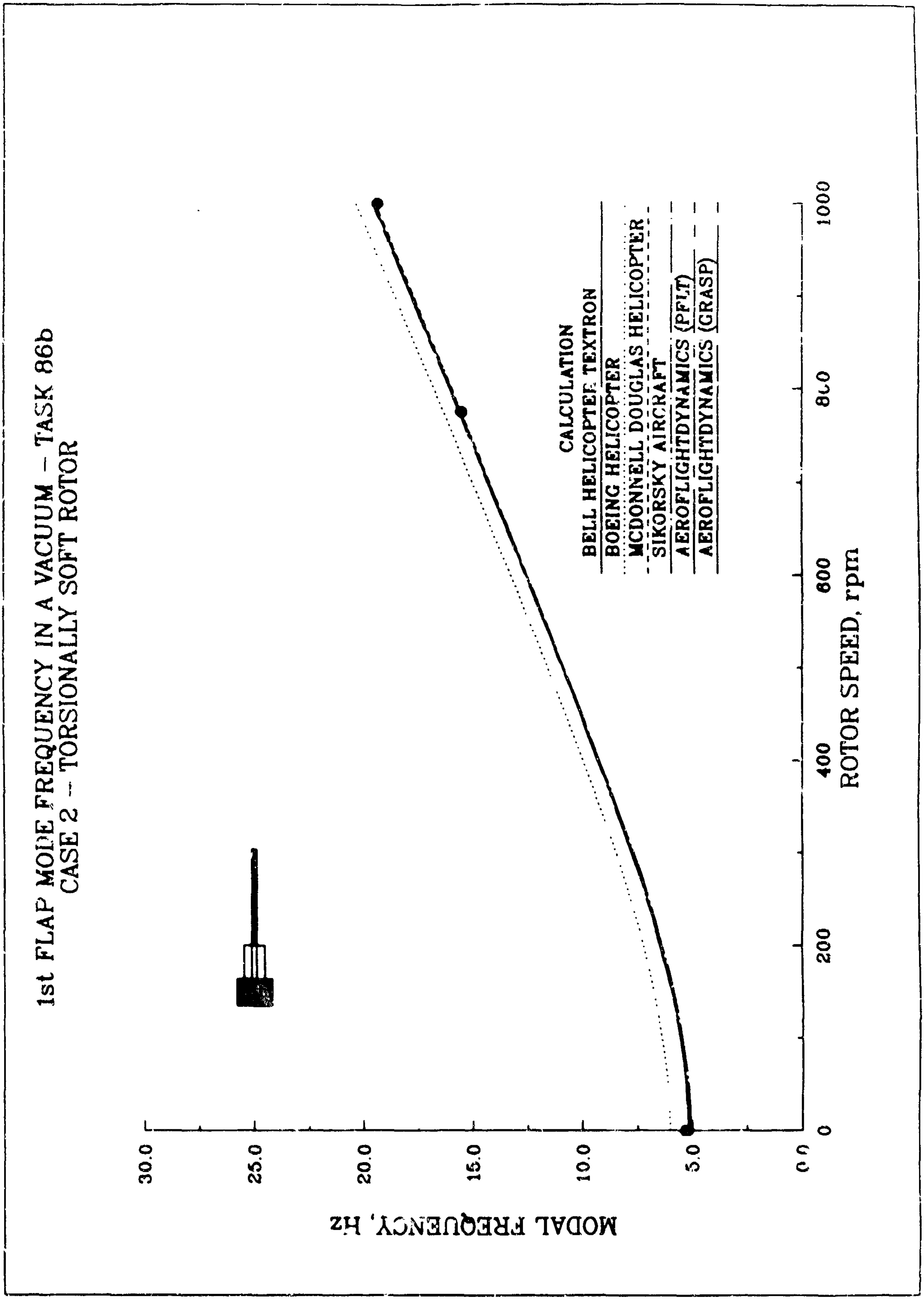


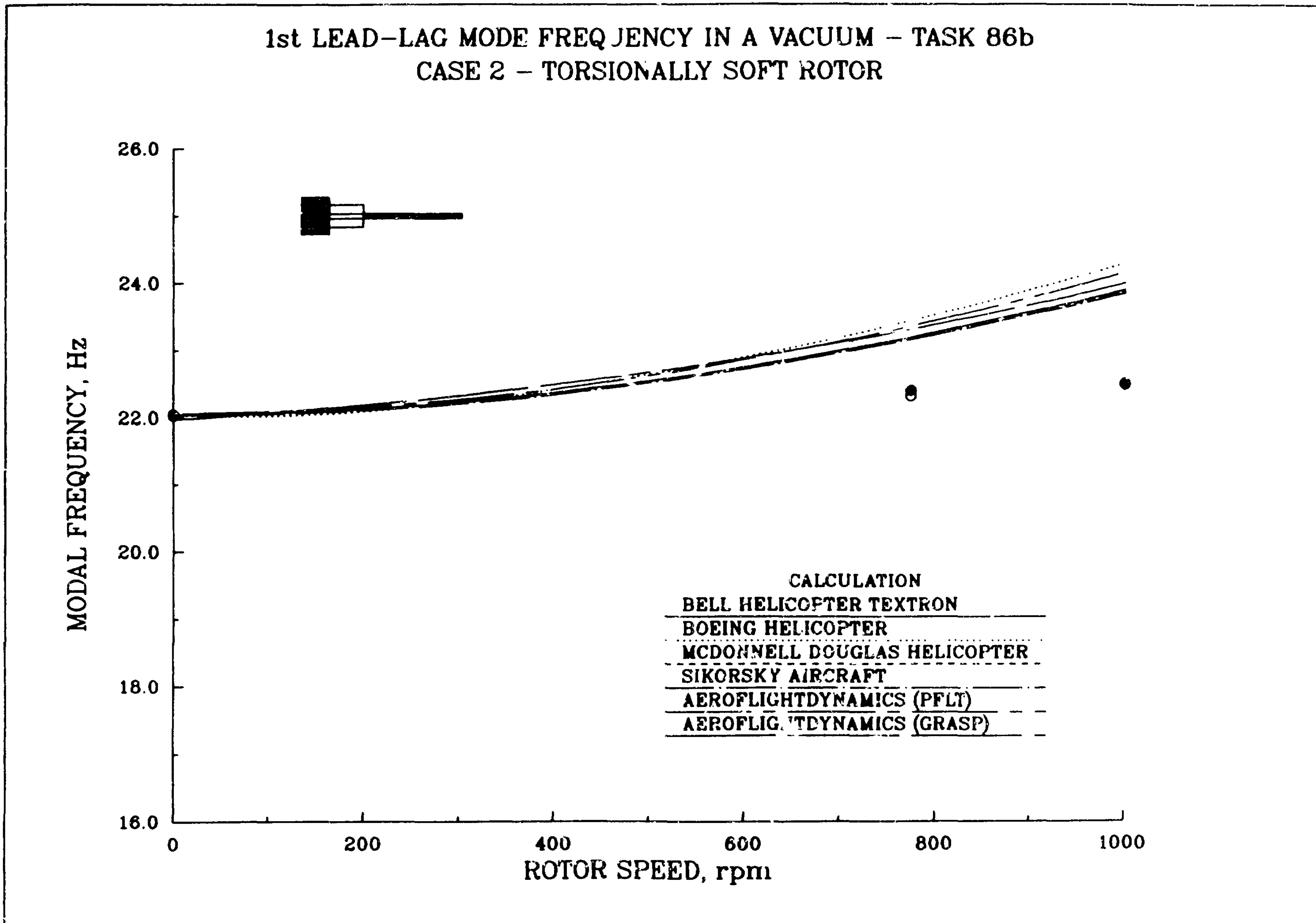

BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 0 deg
FLAP DEFLECTION, in
4
3
2
1
0
−1
−2
−3
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
LEAD–LAG DEFLECTION, in
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
X = AEROFLIGHTDYNAMICS (PFLT)

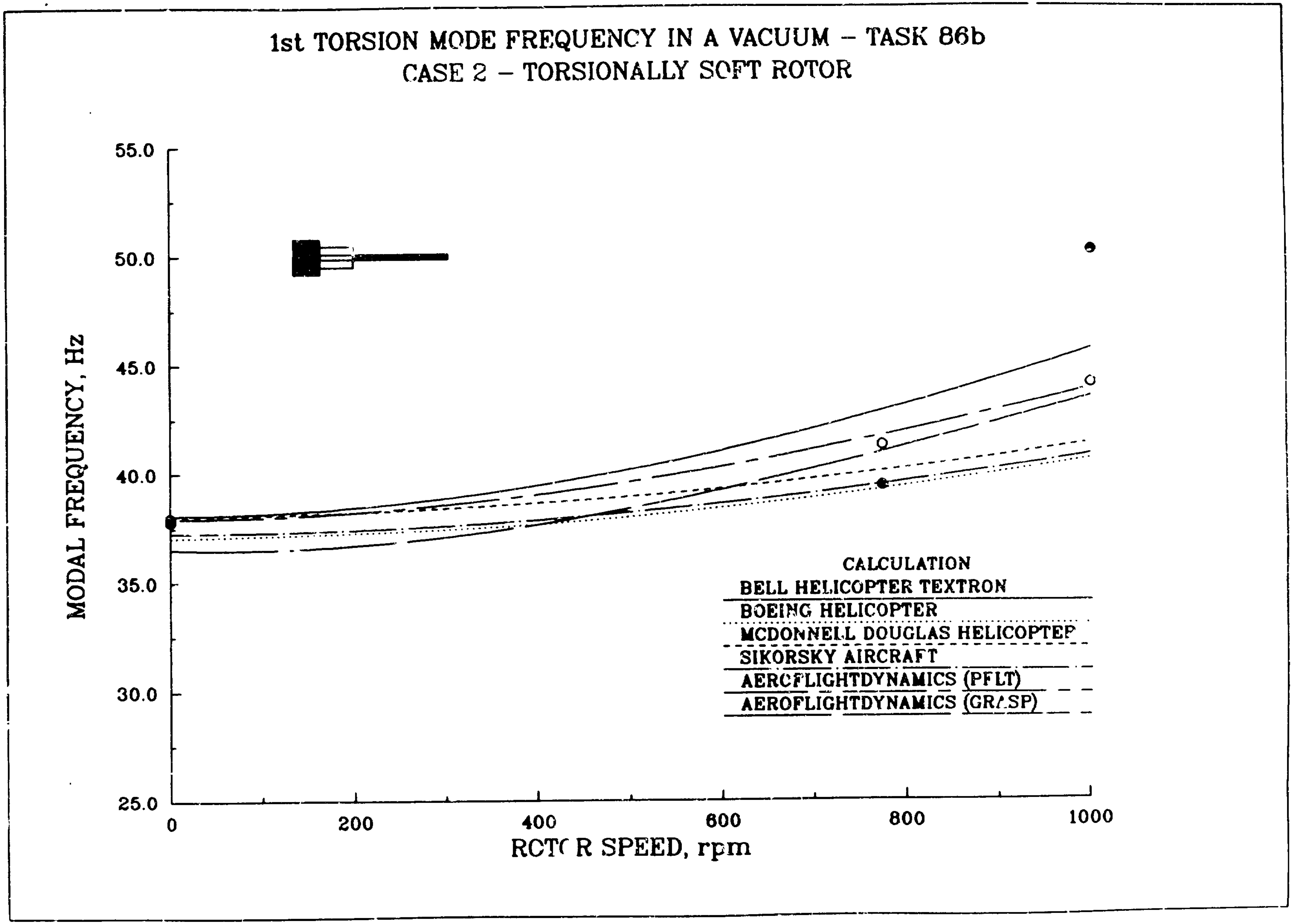

BLADE TIP DEFLECTION -- TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 - TORSIONALLY SOFT ROTOR
PITCH ANGLE = 4 deg
FLAP DEFLECTION, in
4
3
2
1
0
-1
-2
-3
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
LEAD-LAG DEFLECTION, in
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)

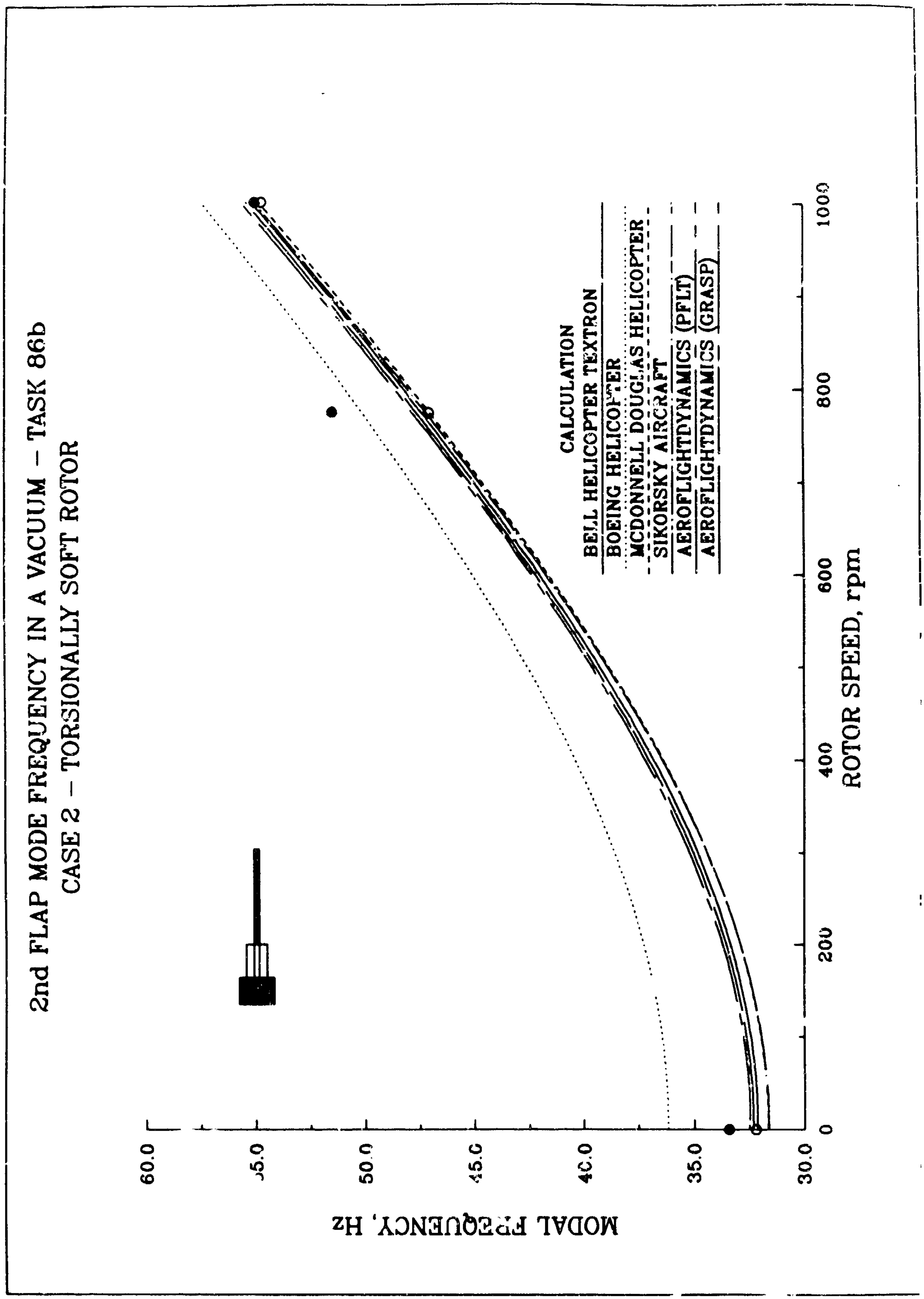

BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 8 deg
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
4
3
2
1
0
–1
–2
–3
1.5
1.0
0.5
0.0
–0.5
–1.0
–1.5
–2.0

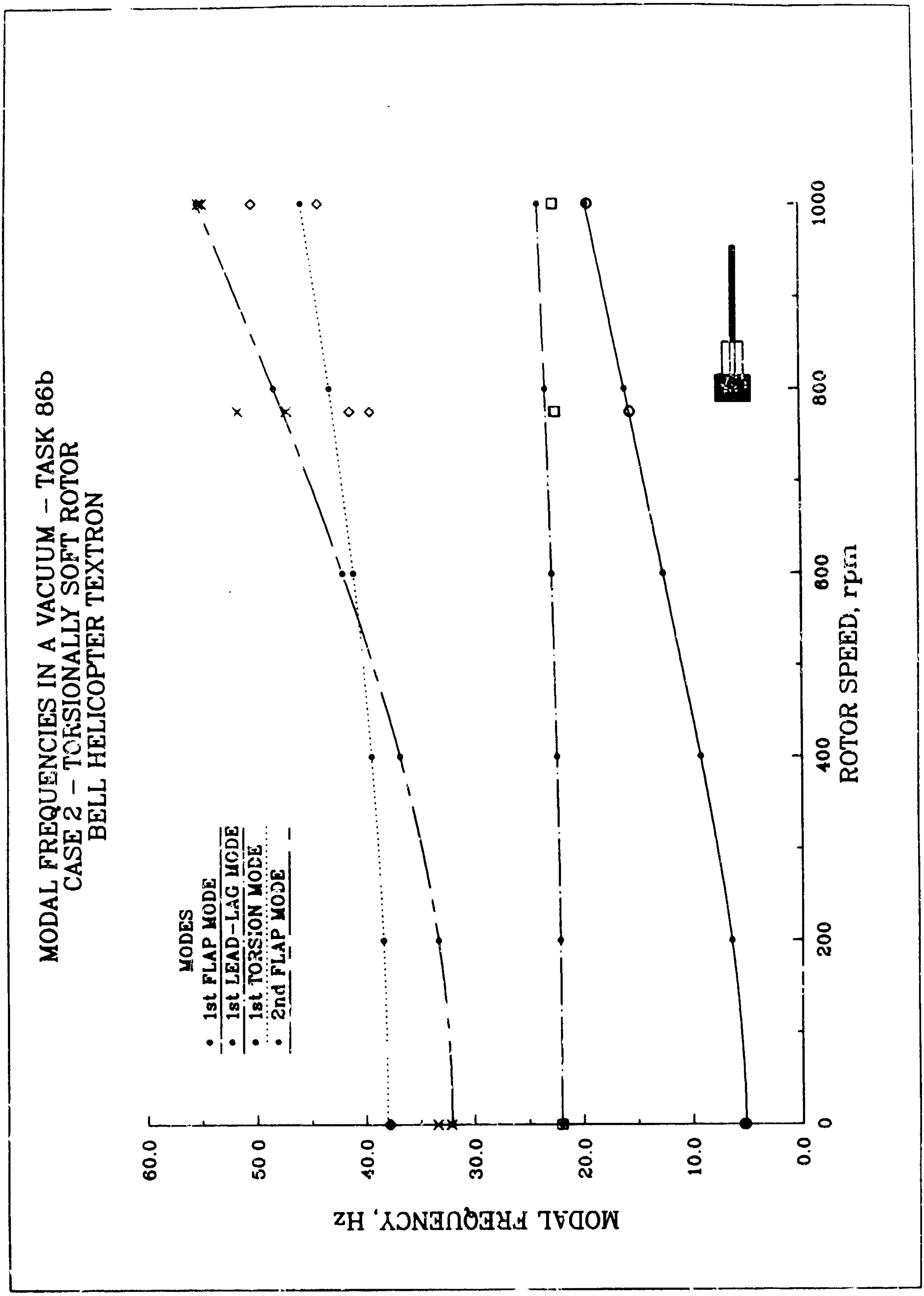

BLADE TIP DEFLECTION – TASK 86g
LINEAR AERODYNAMIC COEFFICIENTS
CASE 6 – TORSIONALLY SOFT ROTOR
PITCH ANGLE = 12 deg
FLAP DEFLECTION, in
LEAD–LAG DEFLECTION, in
CALCULATIONS
+ = UNDEFORMED
○ = BELL
□ = BOEING HELICOPTER
● = MCDONNELL DOUGLAS
■ = SIKORSKY
× = AEROFLIGHTDYNAMICS (PFLT)

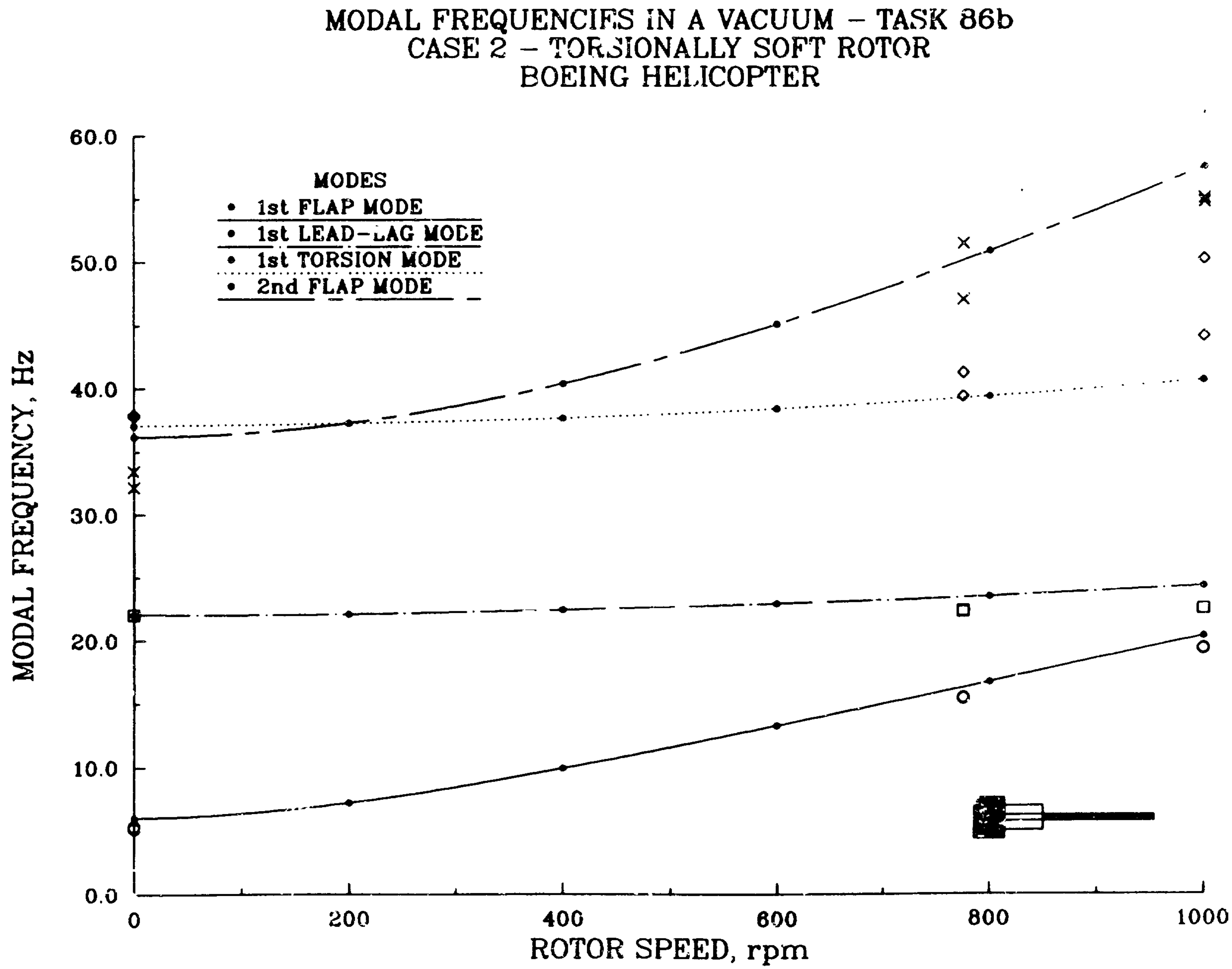

1st FLAP MODE FREQUENCY IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
AEROFLIGHTDYNAMICS (GRASP)
30.0
25.0
20.0
15.0
10.0
5.0
0
200
400
600
1000


1st LEAD-LAG MODE FREQ JENCY IN A VACUUM - TASK 86b
CASE 2 - TORSIONALLY SOFT ROTOR
26.0
24.0
22.0
20.0
18.0
16.0
MODAL FREQUENCY, Hz
0
200
400
600
800
1000
ROTOR SPEED, rpm
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
AEROFLIG. TDYNAMICS (GRASP)

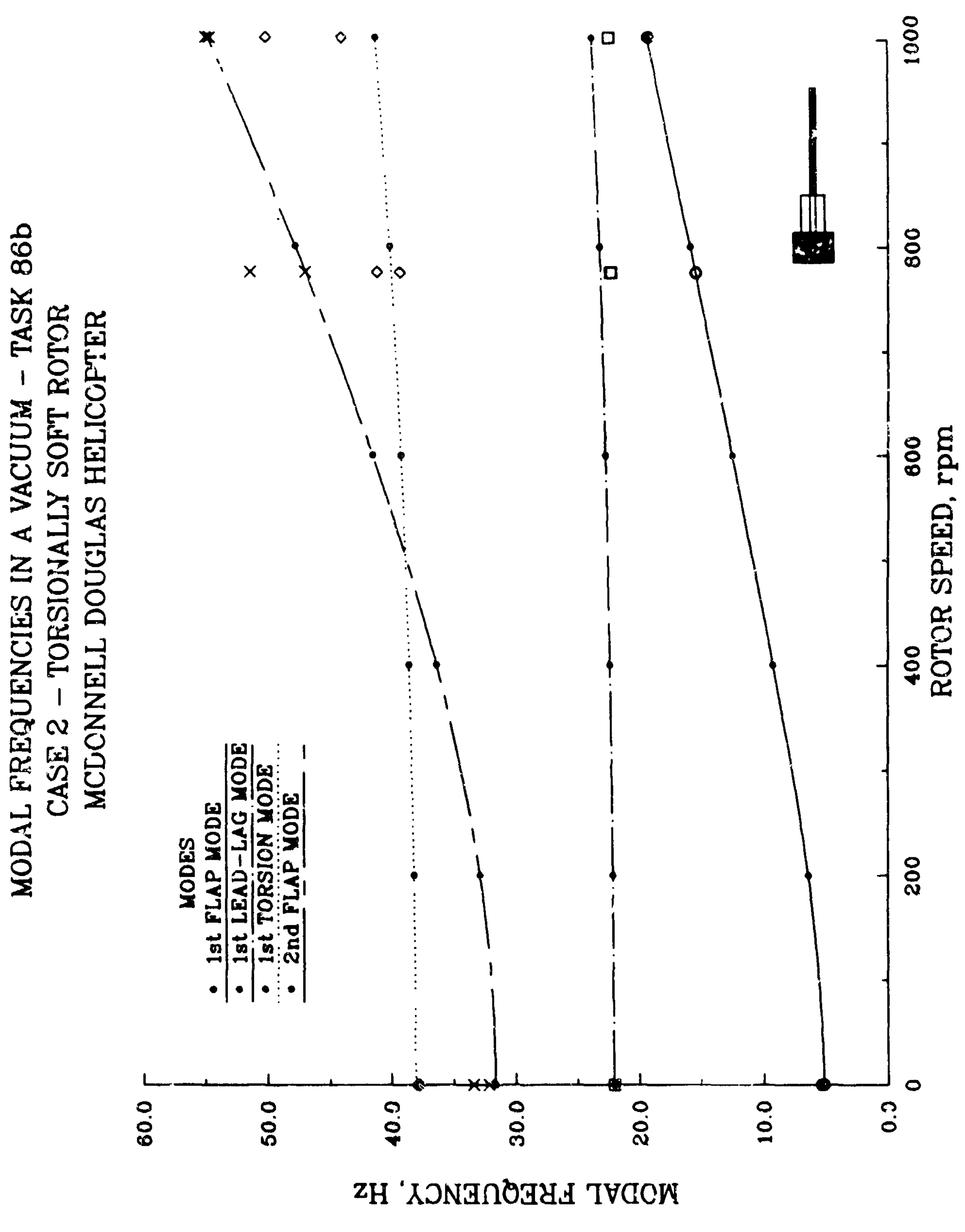

1st TORSION MODE FREQUENCY IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
MODAL FREQUENCY, Hz
55.0
50.0
45.0
40.0
35.0
30.0
25.0
0
200
400
600
800
1000
ROTOR SPEED, rpm
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
AEROFLIGHTDYNAMICS (GRASP)


2nd FLAP MODE FREQUENCY IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
AEROFLIGHTDYNAMICS (GRASP)
MODAL FREQUENCY, Hz
60.0
50.0
45.0
40.0
35.0
30.0
ROTOR SPEED, rpm
0
400
600
800
1000

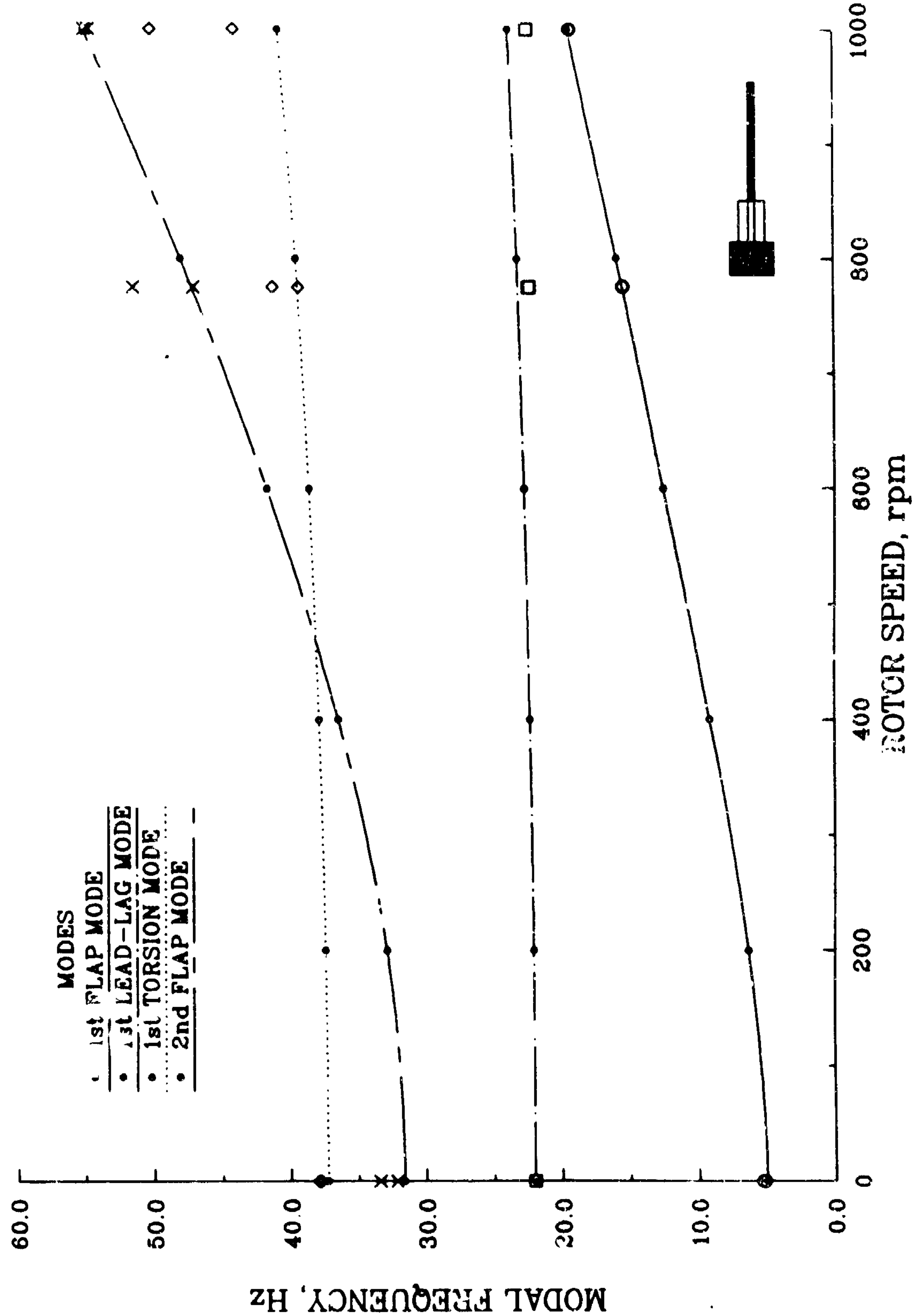

MODAL FREQUENCIES IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
0.0
10.0
20.0
30.0
40.0
50.0
60.0
ROTOR SPEED, rpm
0
200
400
600
800
1000



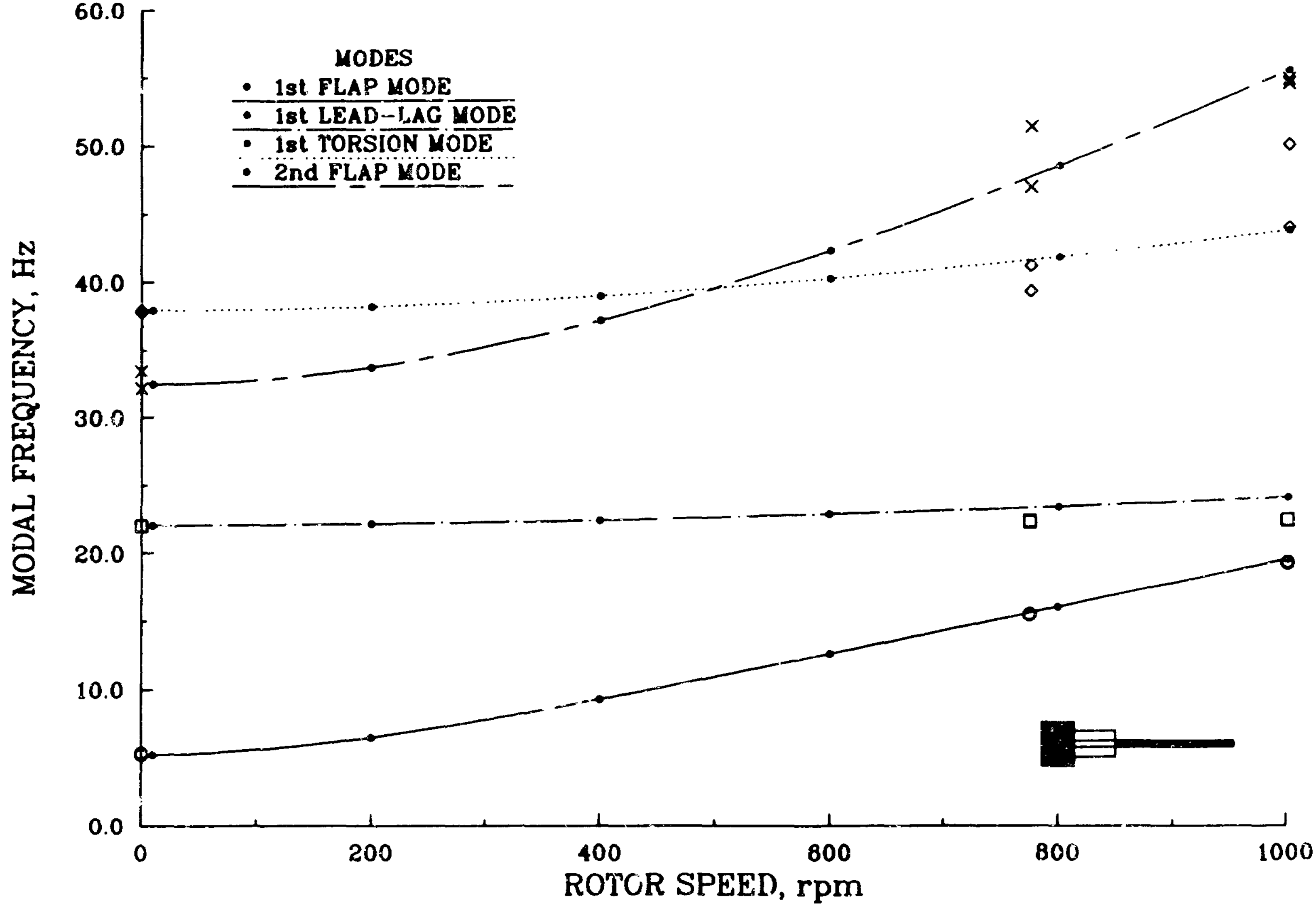
MODAL FREQUENCIES IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
BOEING HELICOPTER
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000


MODAL FREQUENCIES IN A VACUUM - TASK 86b
CASE 2 - TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
ROTOR SPEED, rpm

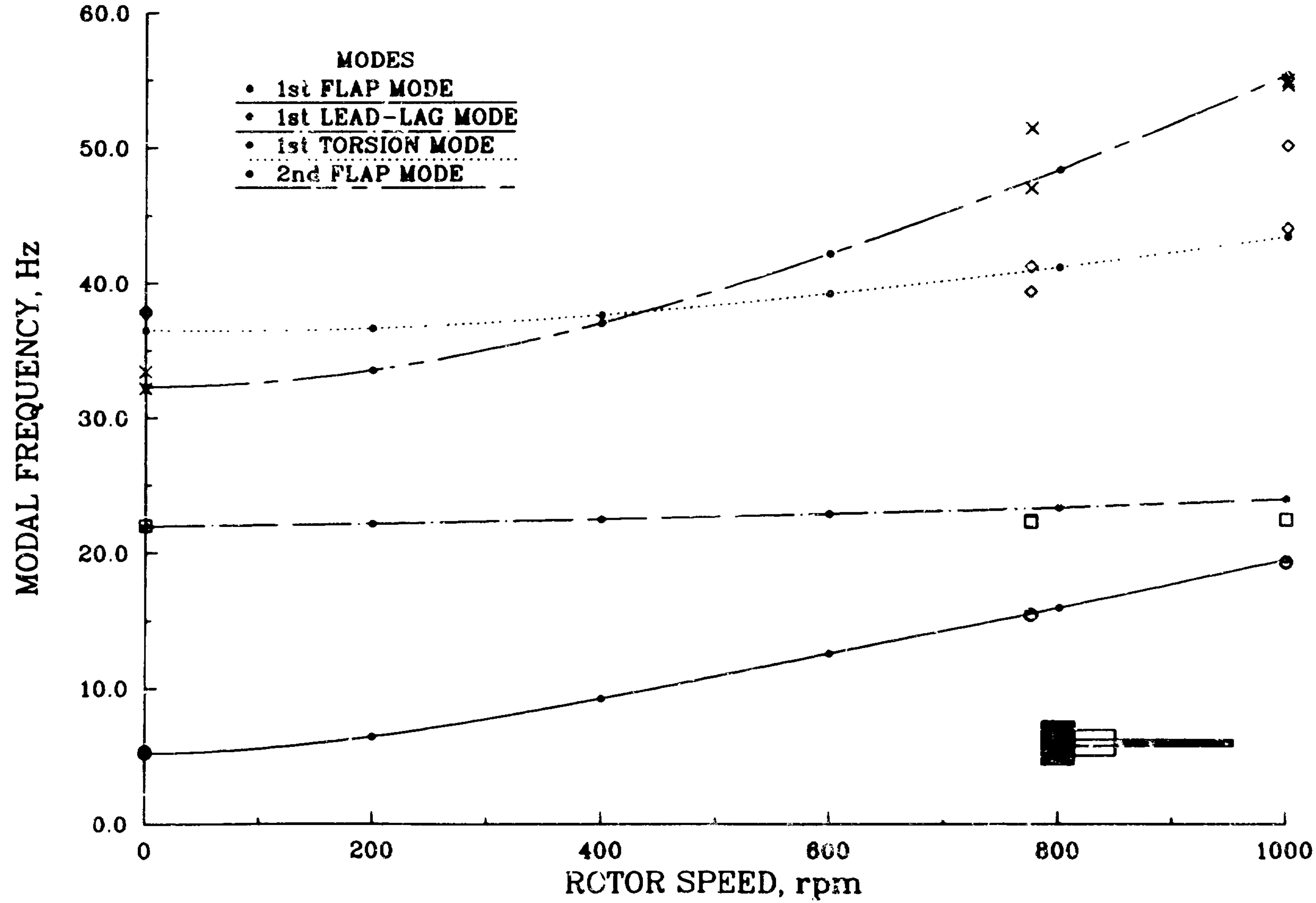
MODAL FREQUENCIES IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT



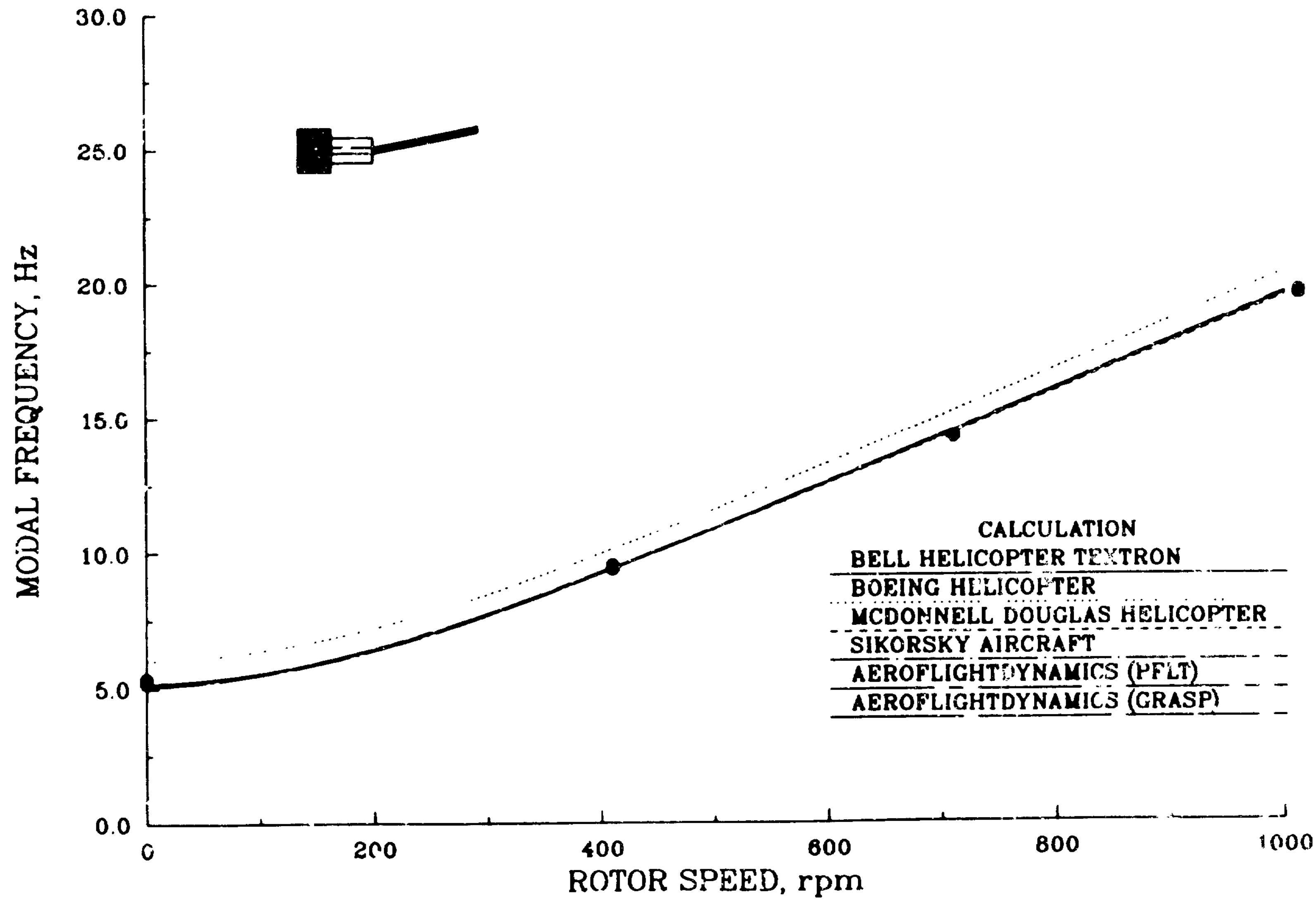
MODAL FREQUENCIES IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
AEROFLIGHTDYNAMICS (PFLT)



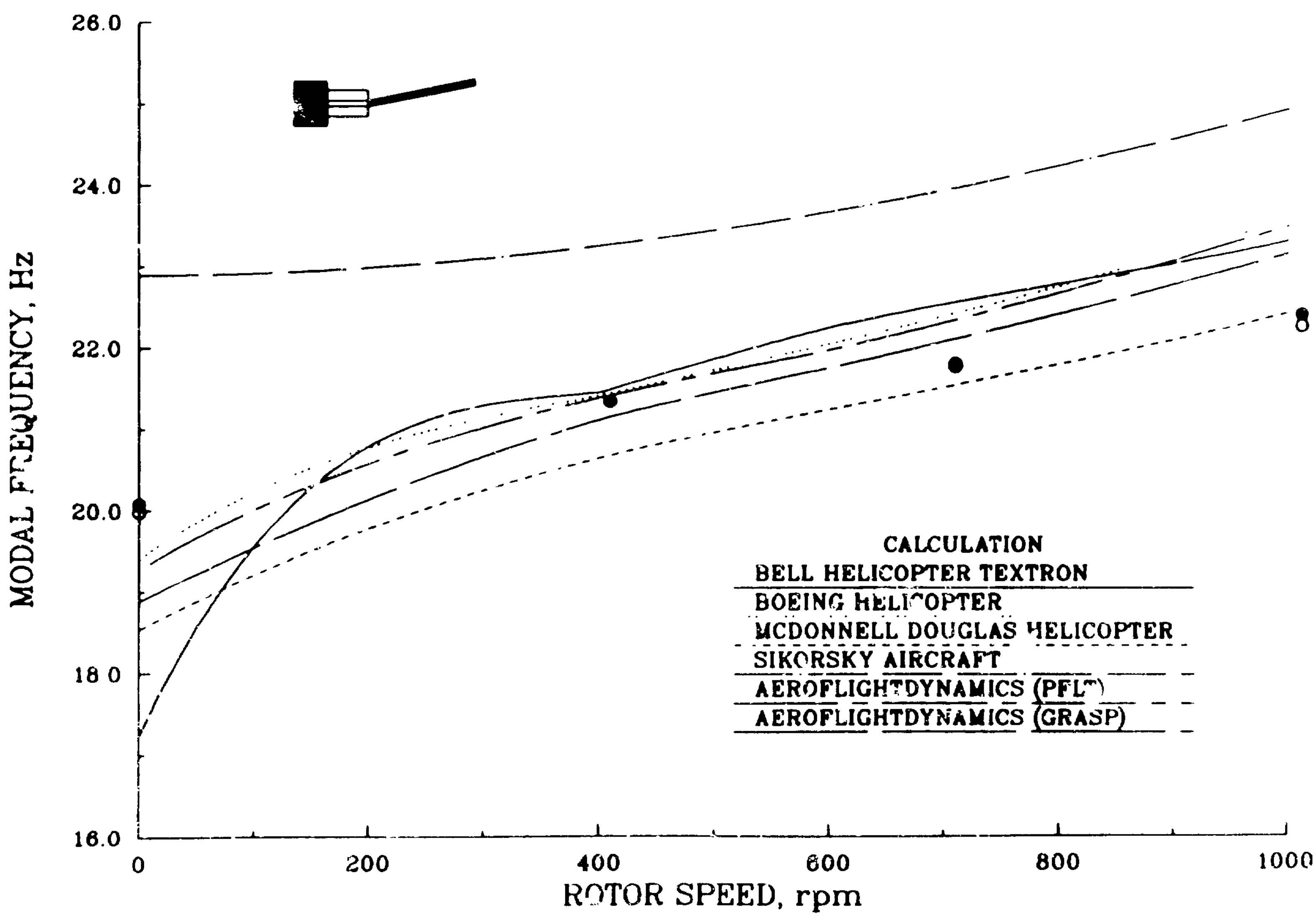
MODAL FREQUENCIES IN A VACUUM – TASK 86b
CASE 2 – TORSIONALLY SOFT ROTOR
AEROFLIGHTDYNAMICS (GRASP)

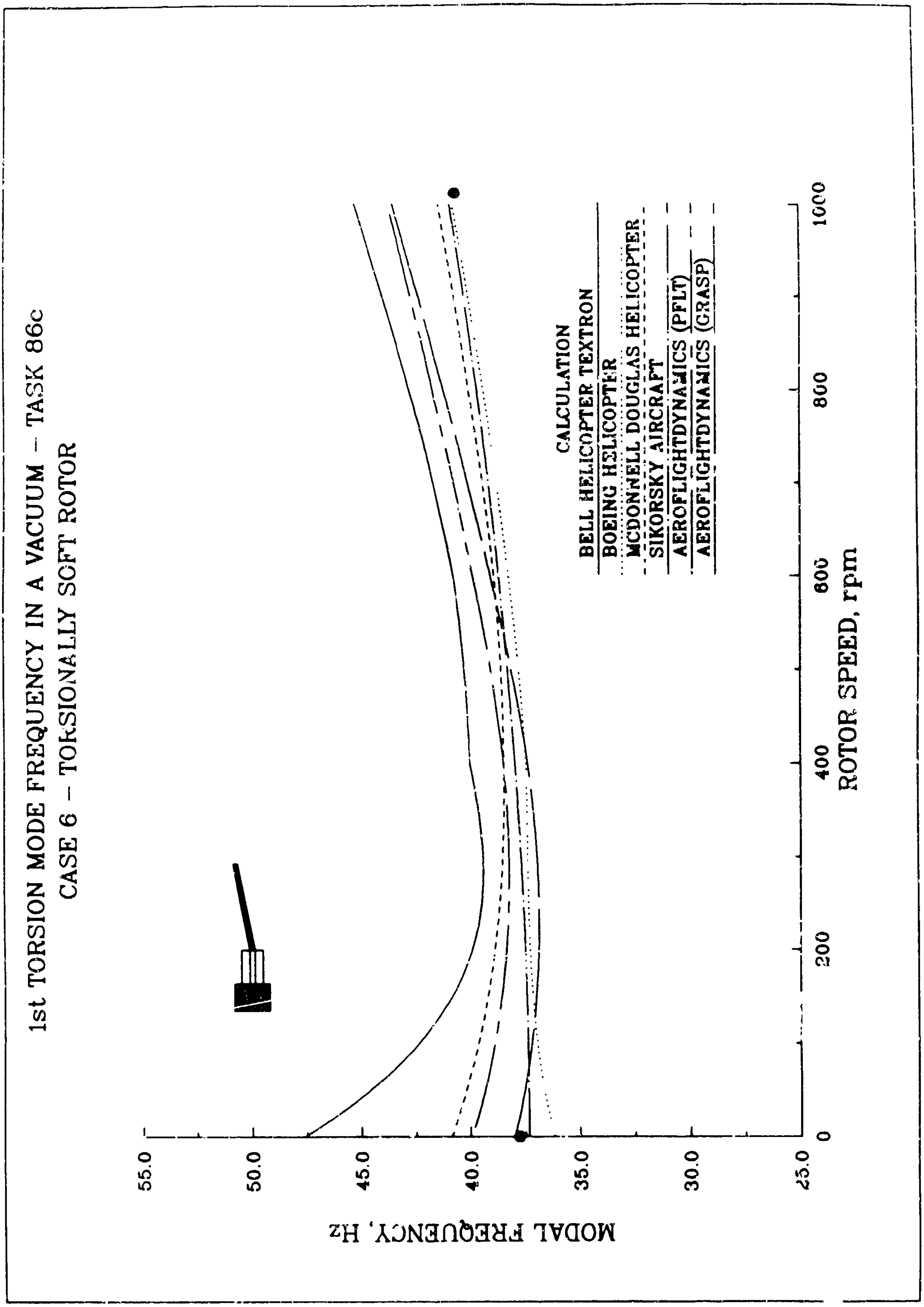


1st FLAP MODE FREQUENCY IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR

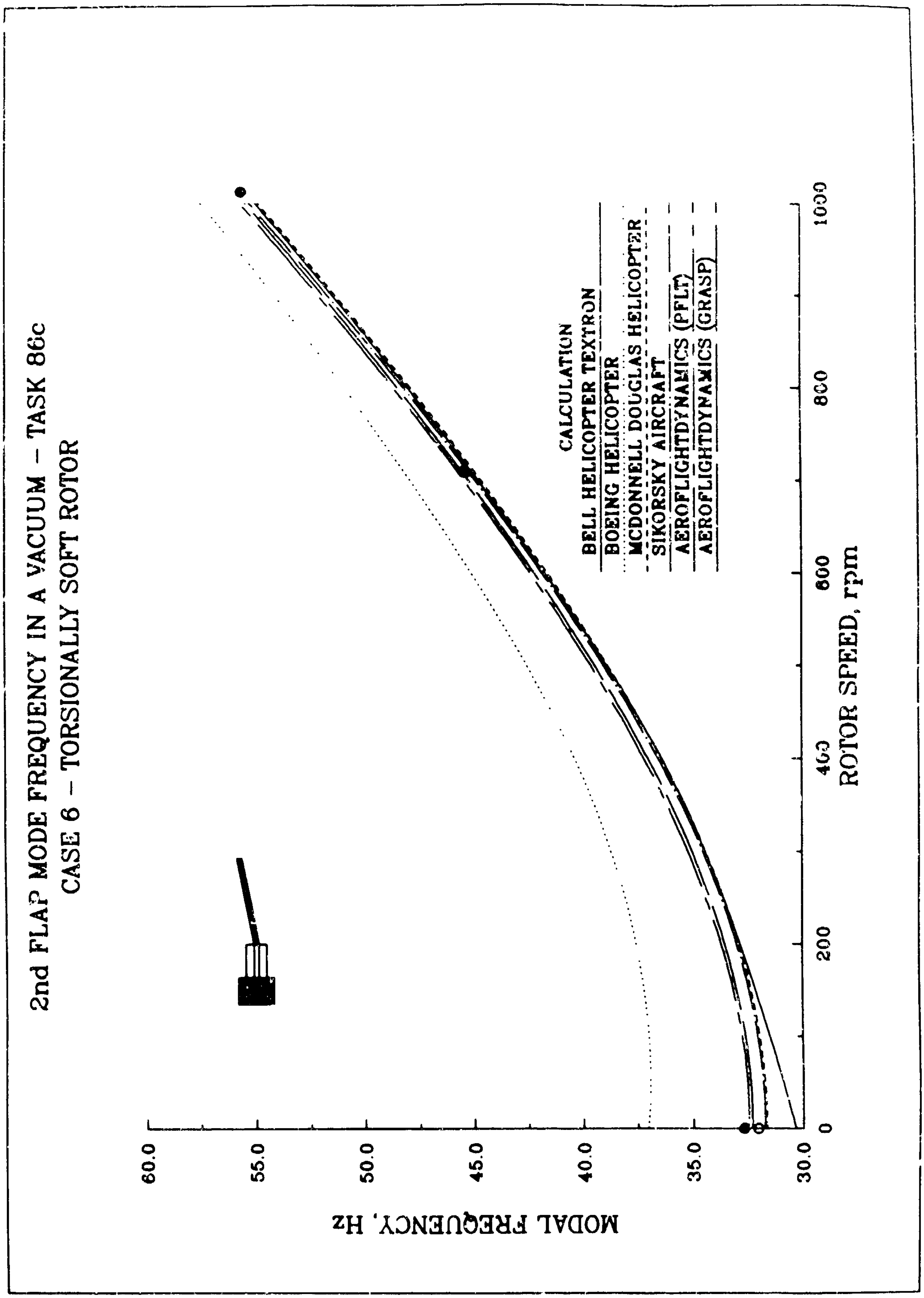


1st LEAD -LAG MODE FREQUENCY IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR

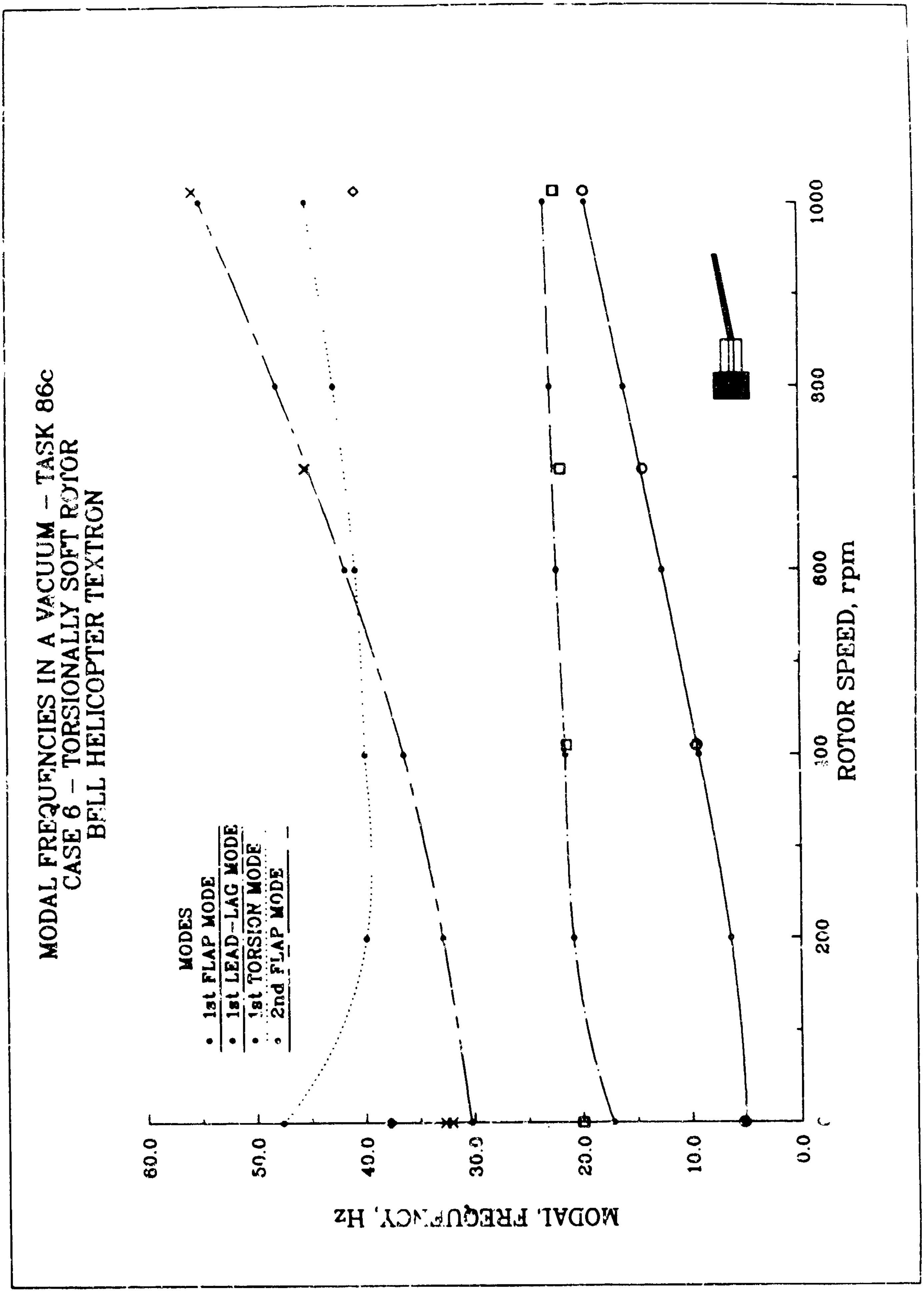




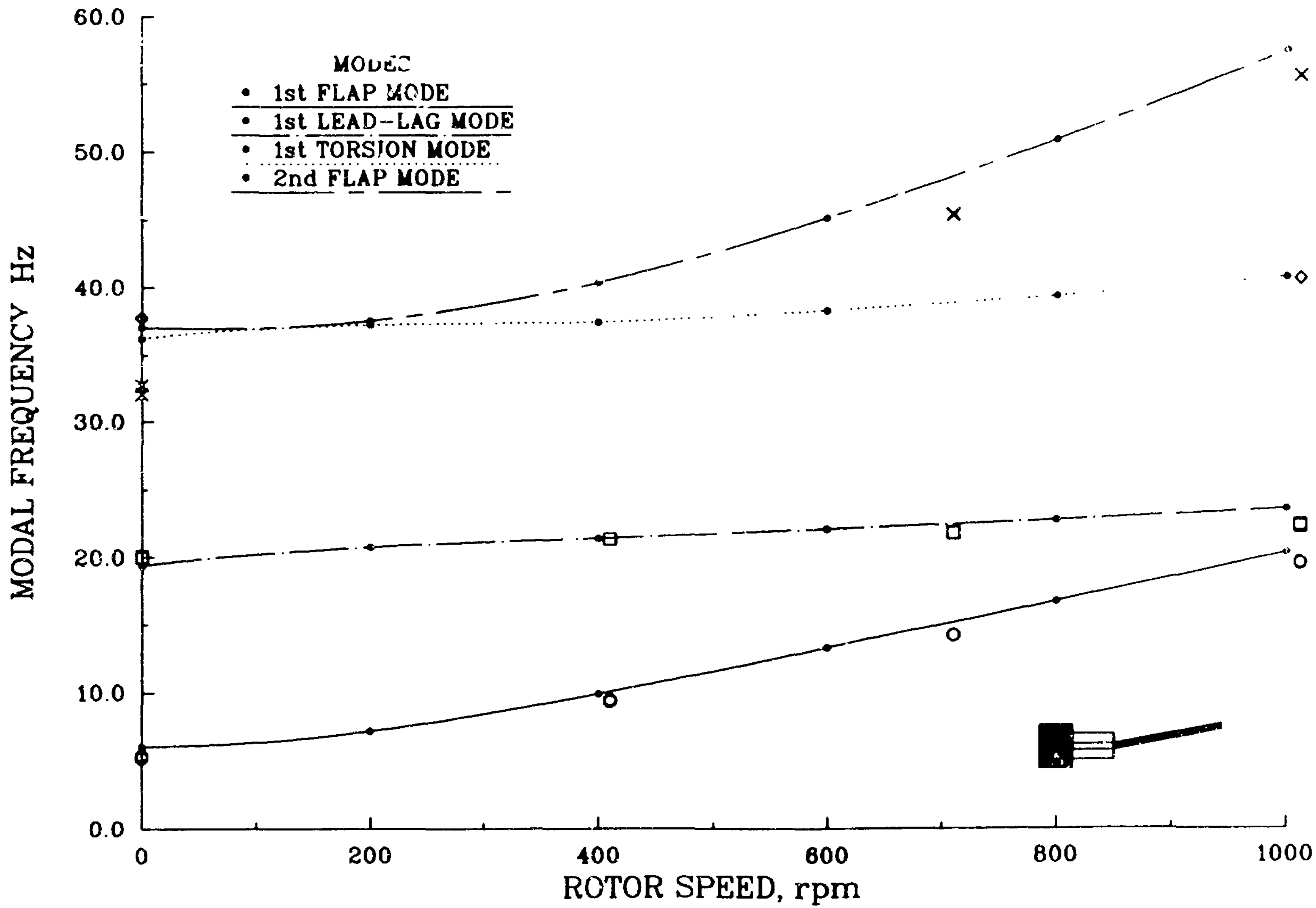
1st TORSION MODE FREQUENCY IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
AEROFLIGHTDYNAMICS (GRASP)
MODAL FREQUENCY, Hz
55.0
50.0
45.0
40.0
35.0
30.0
25.0
0
200
400
600
800
1000
ROTOR SPEED, rpm

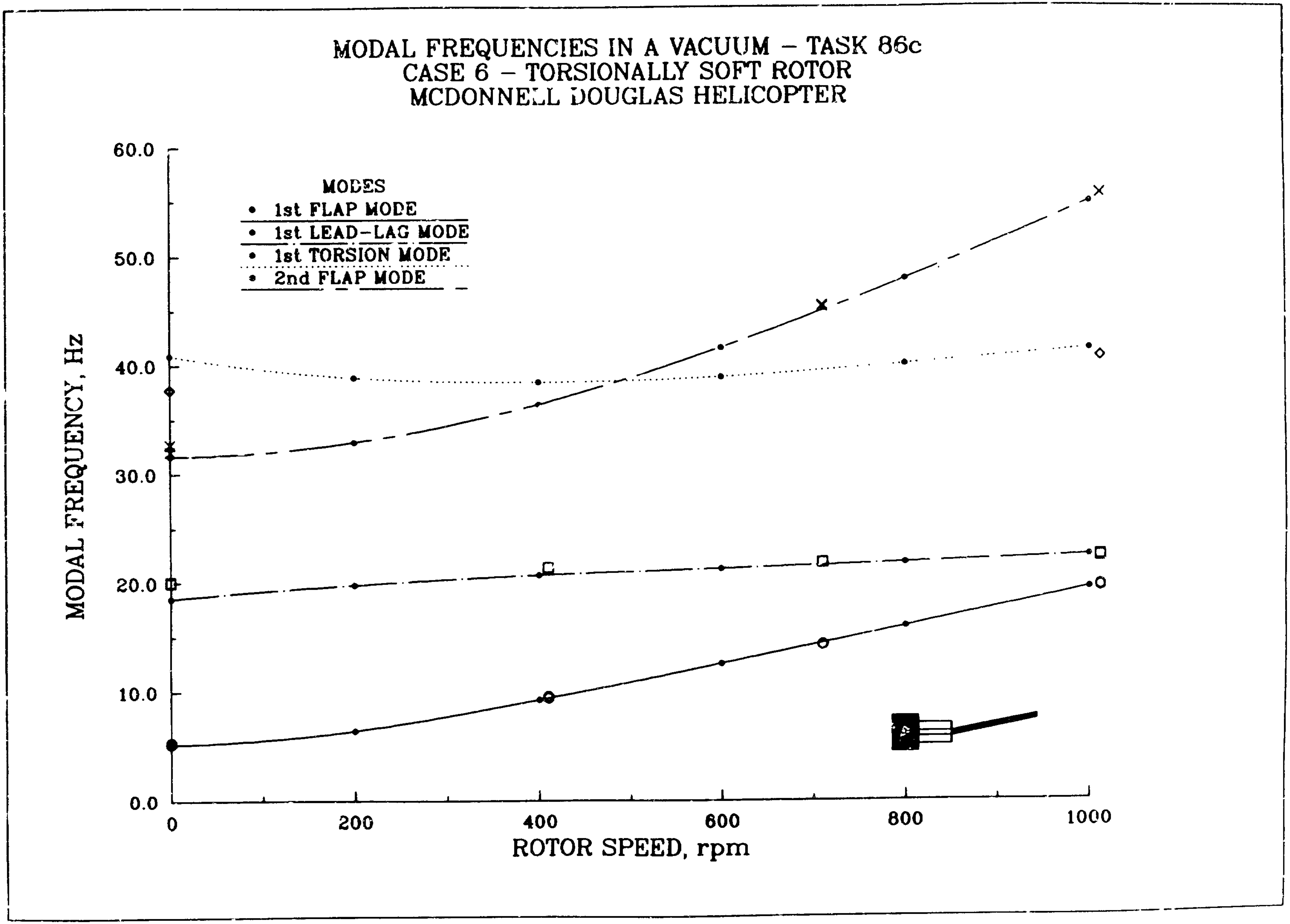


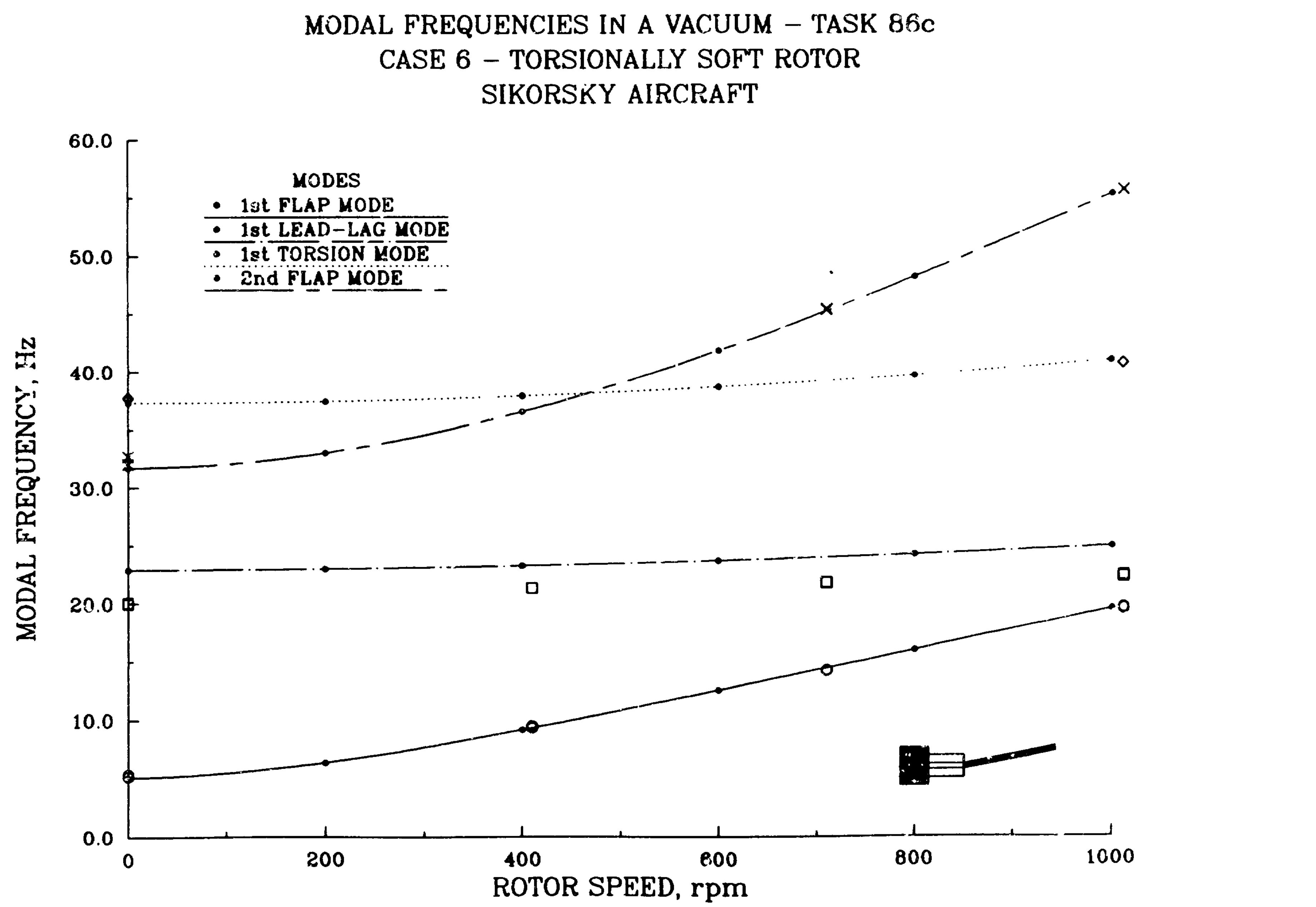
2nd FLAP MODE FREQUENCY IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
MODAL FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
0
200
400
600
800
1000
ROTOR SPEED, rpm
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
AEROFLIGHTDYNAMICS (PFLT)
AEROFLIGHTDYNAMICS (GRASP)

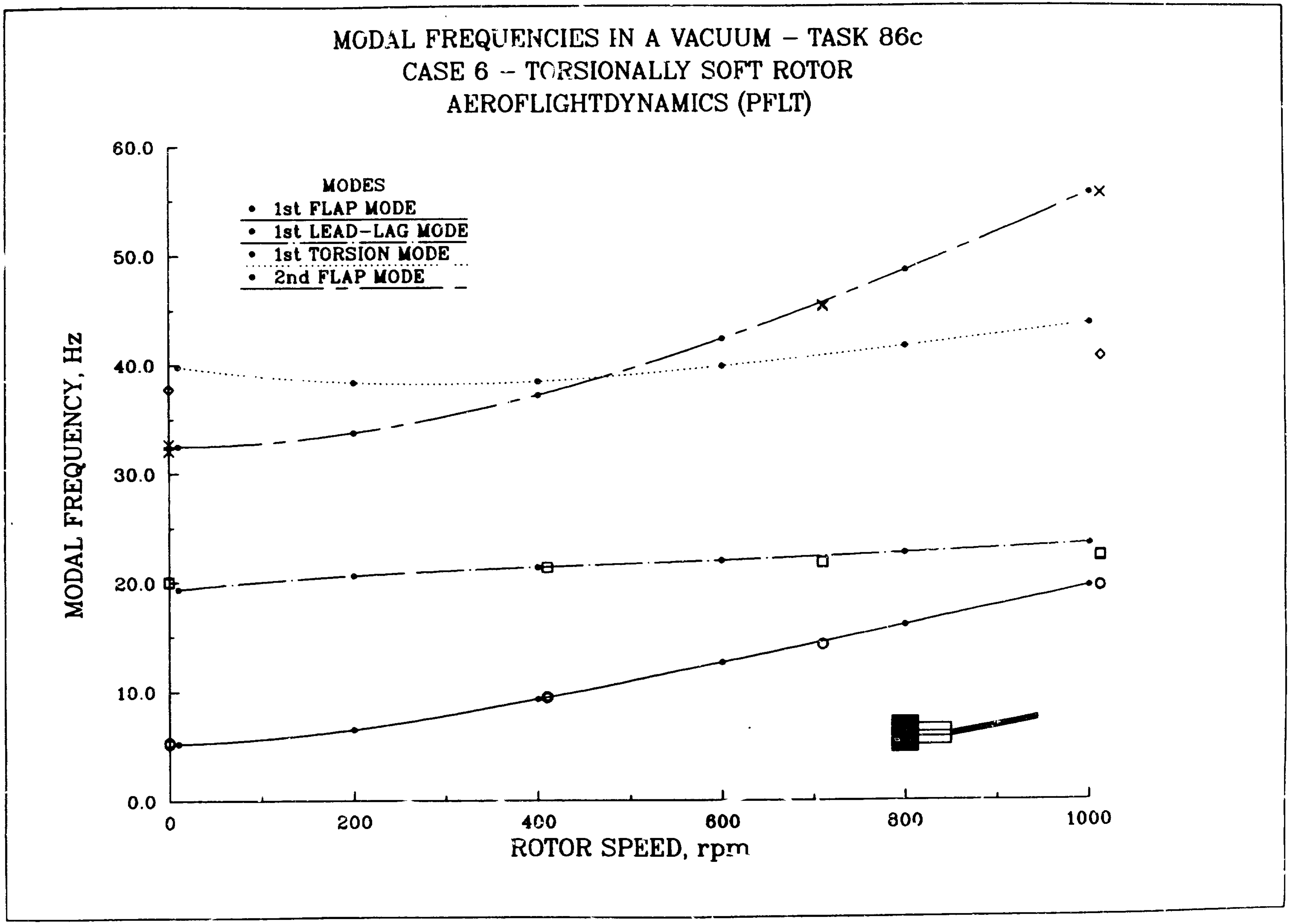

MODAL FREQUENCIES IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
BELL HELICOPTER TEXTRON
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
0.0
10.0
20.0
30.0
40.0
50.0
60.0
0
200
400
600
800
1000

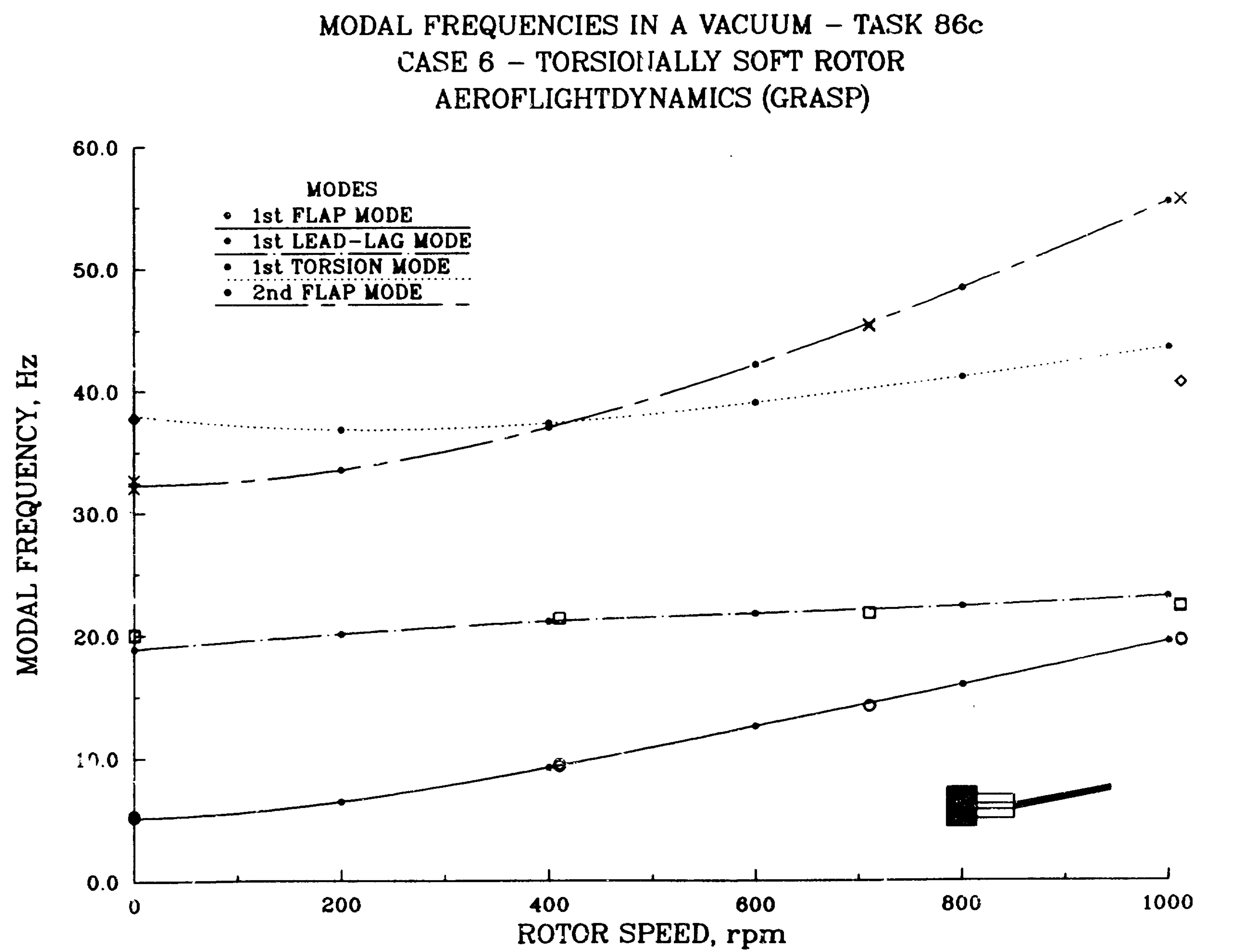
MODAL FREQUENCIES IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
BOEING HELICOPTER

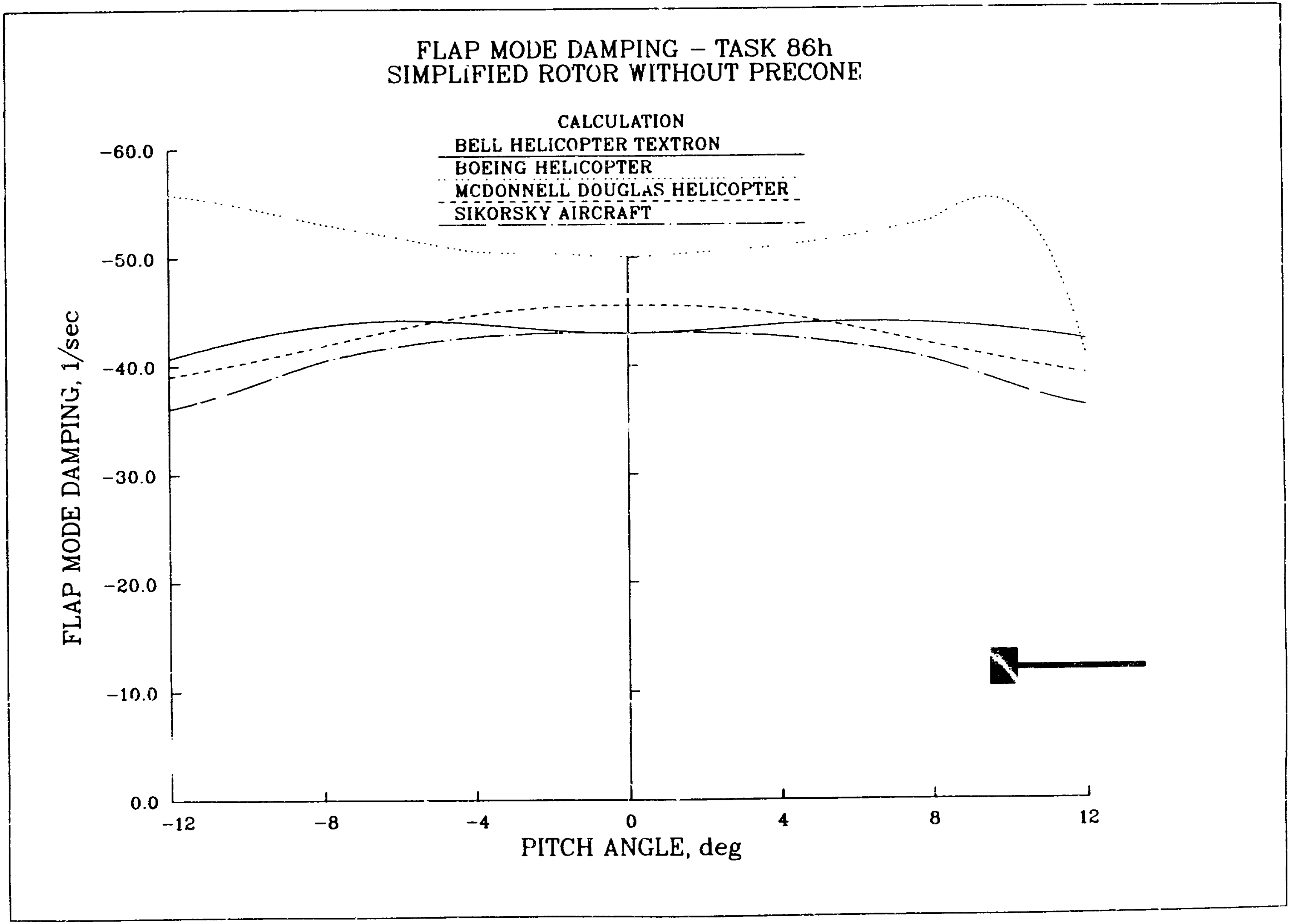


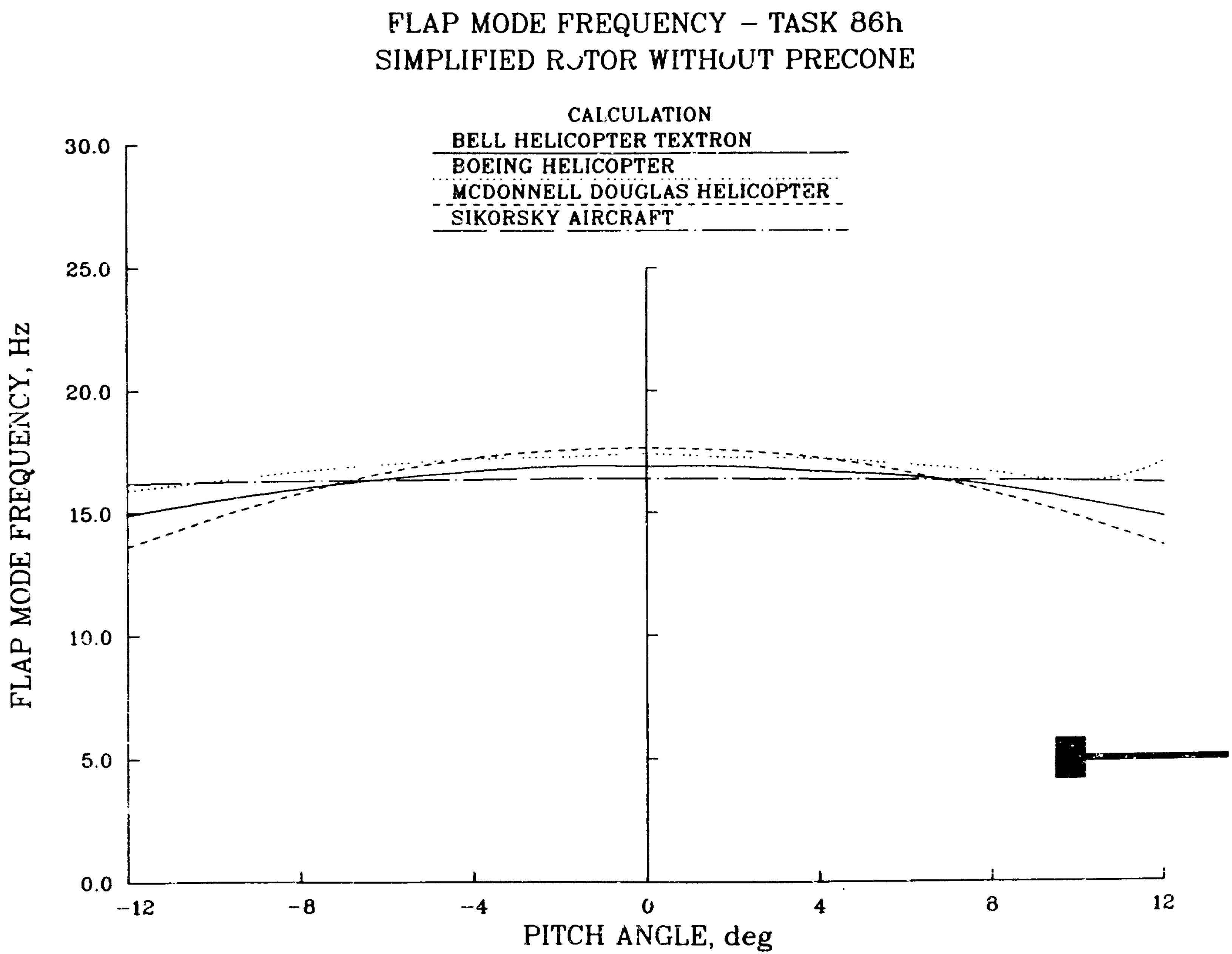

MODAL FREQUENCIES IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
MCDONNELL DOUGLAS HELICOPTER
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
ROTOR SPEED, rpm

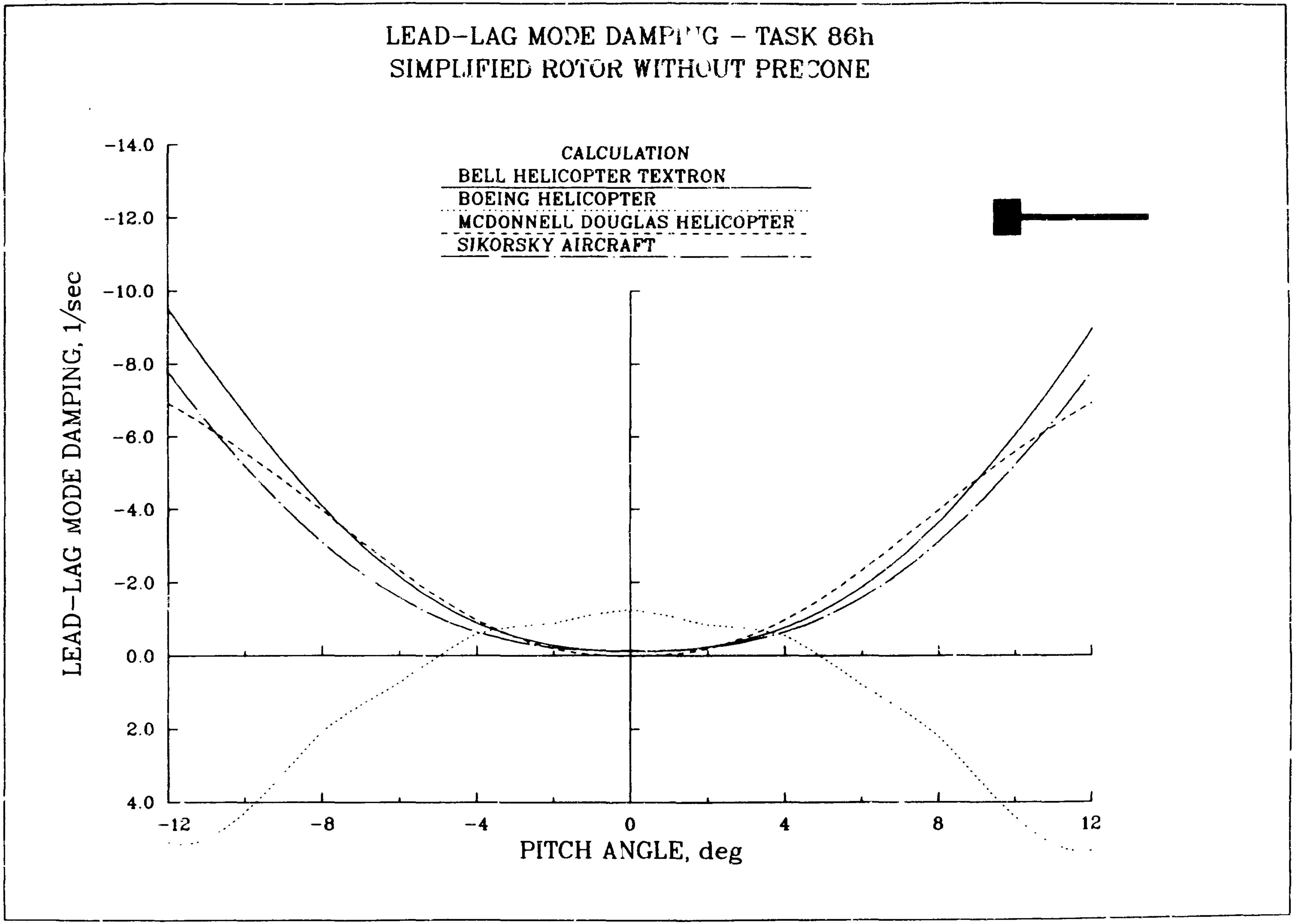

MODAL FREQUENCIES IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
SIKORSKY AIRCRAFT
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
ROTOR SPEED, rpm


MODAL FREQUENCIES IN A VACUUM – TASK 86c
CASE 6 -- TORSIONALLY SOFT ROTOR
AEROFLIGHTDYNAMICS (PFLT)
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
0.0
10.0
20.0
30.0
40.0
50.0
60.0
0
200
400
600
800
1000
ROTOR SPEED, rpm


MODAL FREQUENCIES IN A VACUUM – TASK 86c
CASE 6 – TORSIONALLY SOFT ROTOR
AEROFLIGHTDYNAMICS (GRASP)
MODES
1st FLAP MODE
1st LEAD-LAG MODE
1st TORSION MODE
2nd FLAP MODE
MODAL FREQUENCY, Hz
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
ROTOR SPEED, rpm

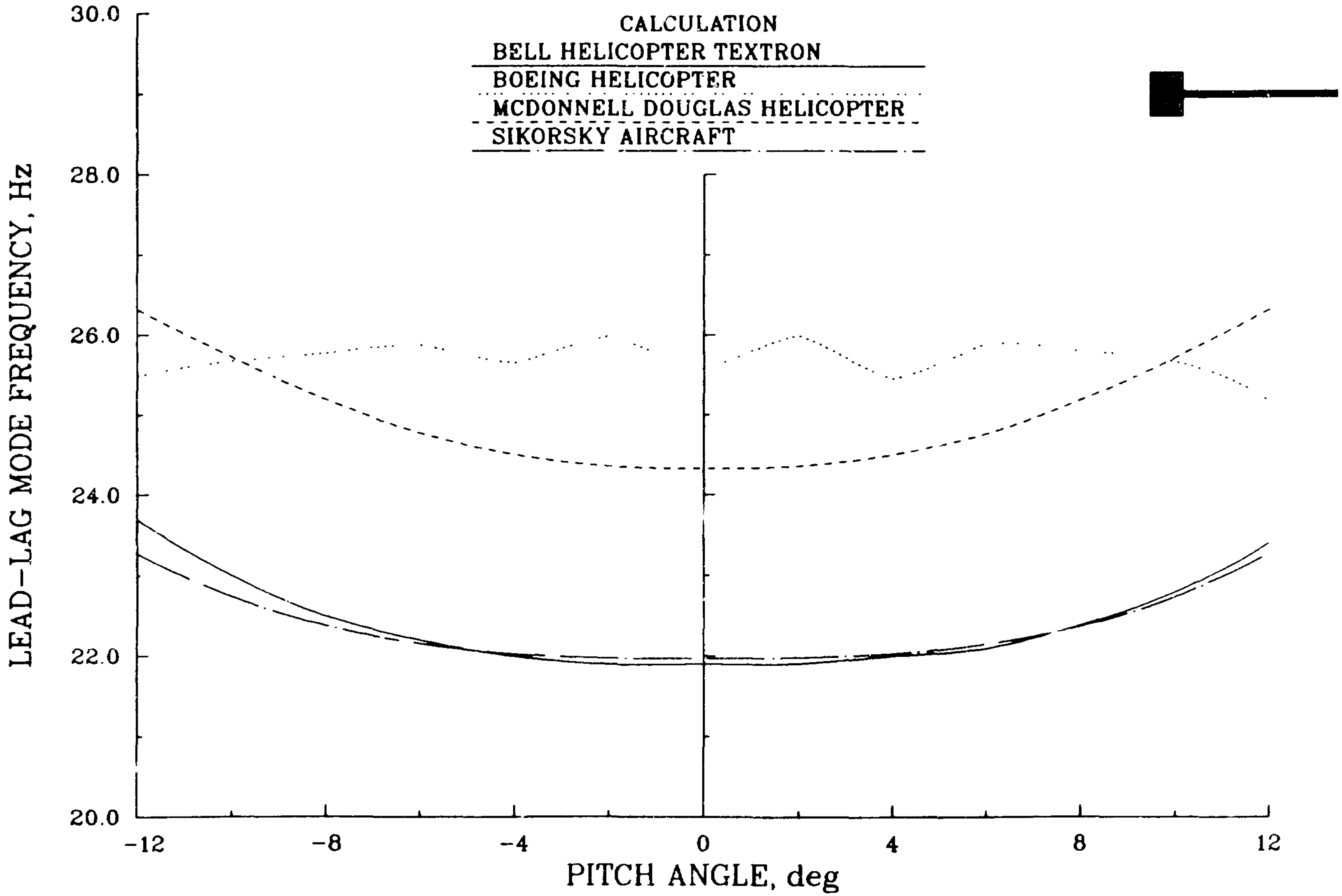

FLAP MODE DAMPING – TASK 86h
SIMPLIFIED ROTOR WITHOUT PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
FLAP MODE DAMPING, 1/sec
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg


FLAP MODE FREQUENCY – TASK 86h
SIMPLIFIED ROTOR WITHOUT PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

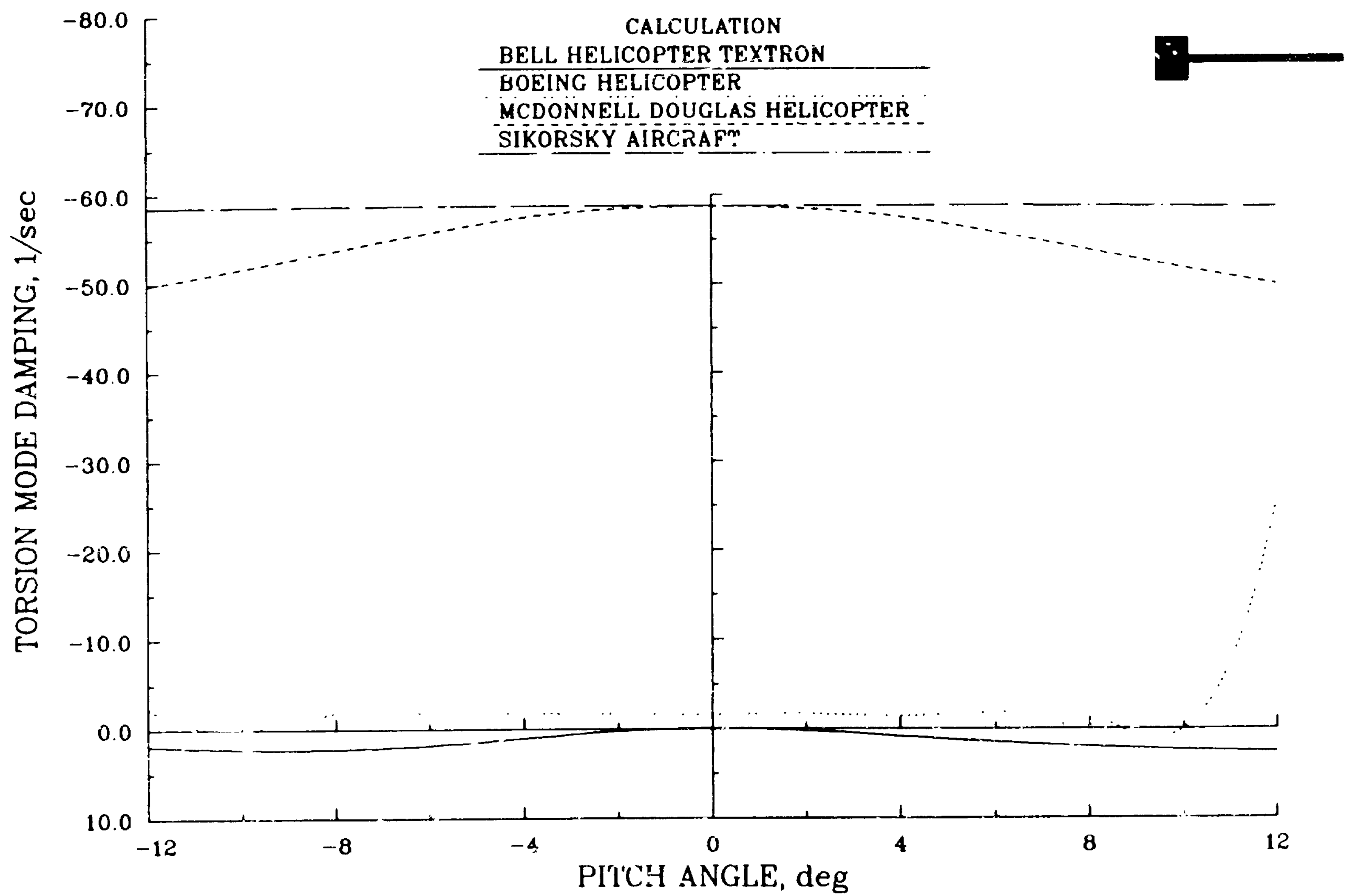


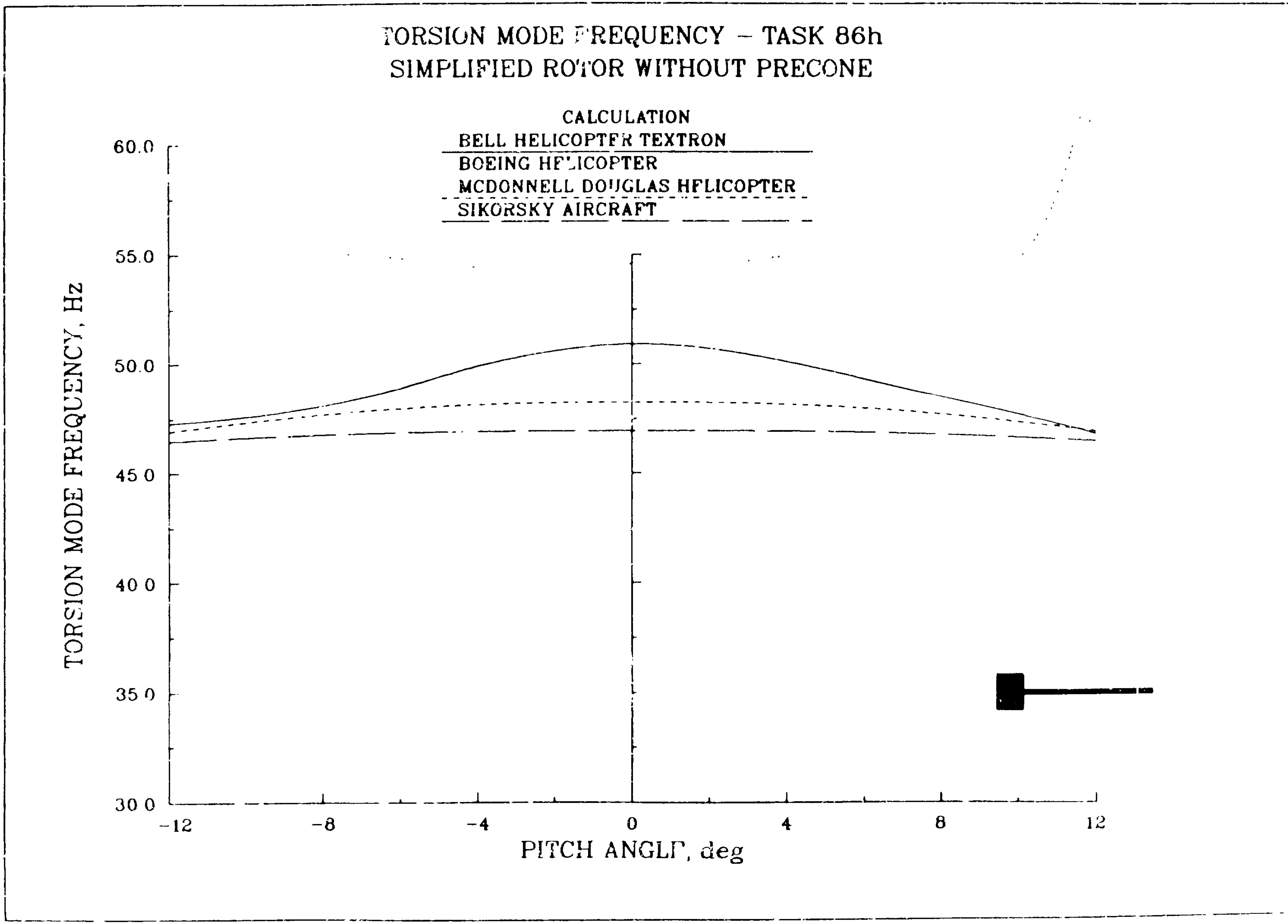
LEAD–LAG MODE DAMPING – TASK 86h
SIMPLIFIED ROTOR WITHOUT PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
LEAD–LAG MODE DAMPING, 1/sec
-14.0
-12.0
-10.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

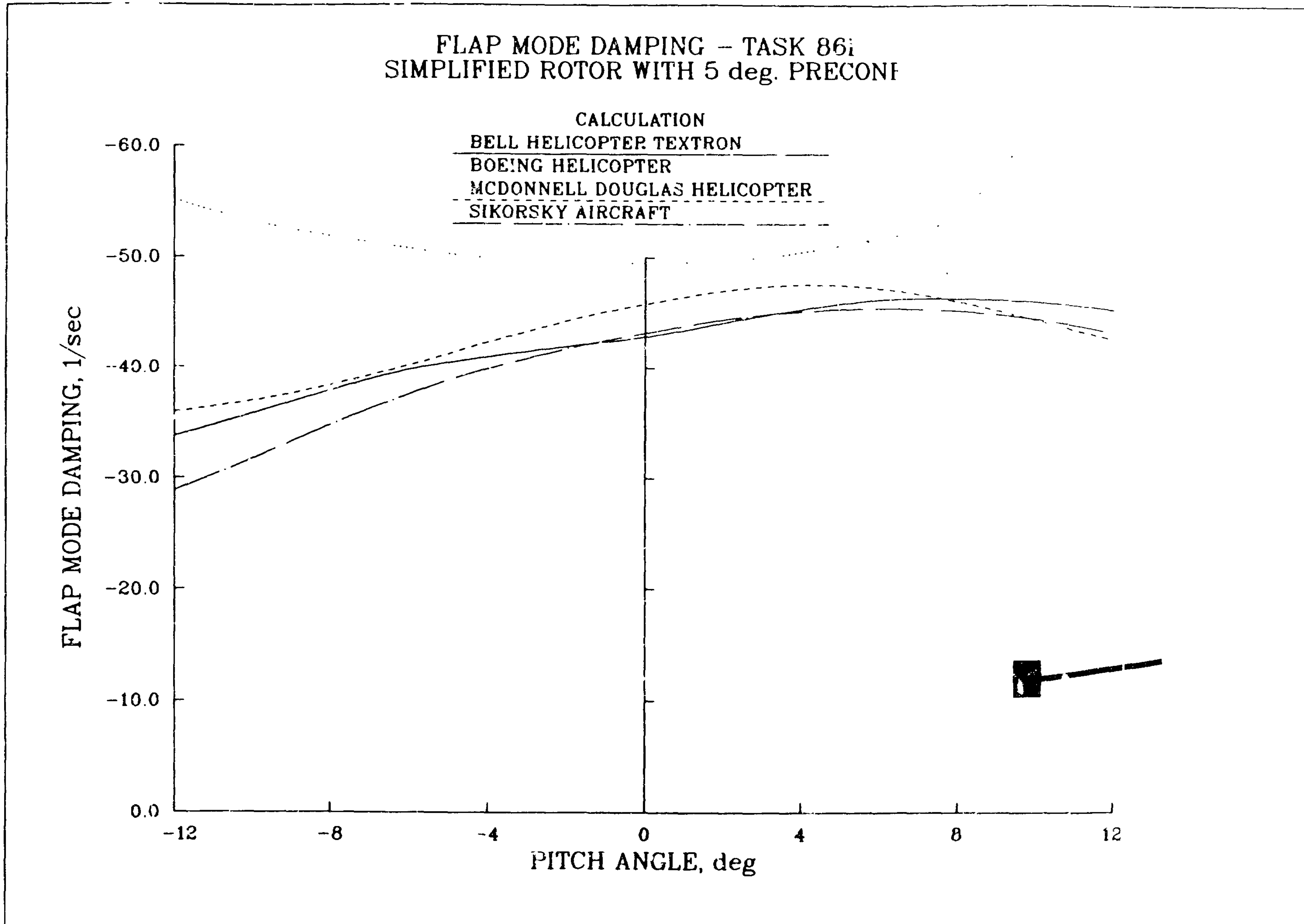
LEAD–LAG MODE FREQUENCY – TASK 86h
SIMPLIFIED ROTOR WITHOUT PRECONE



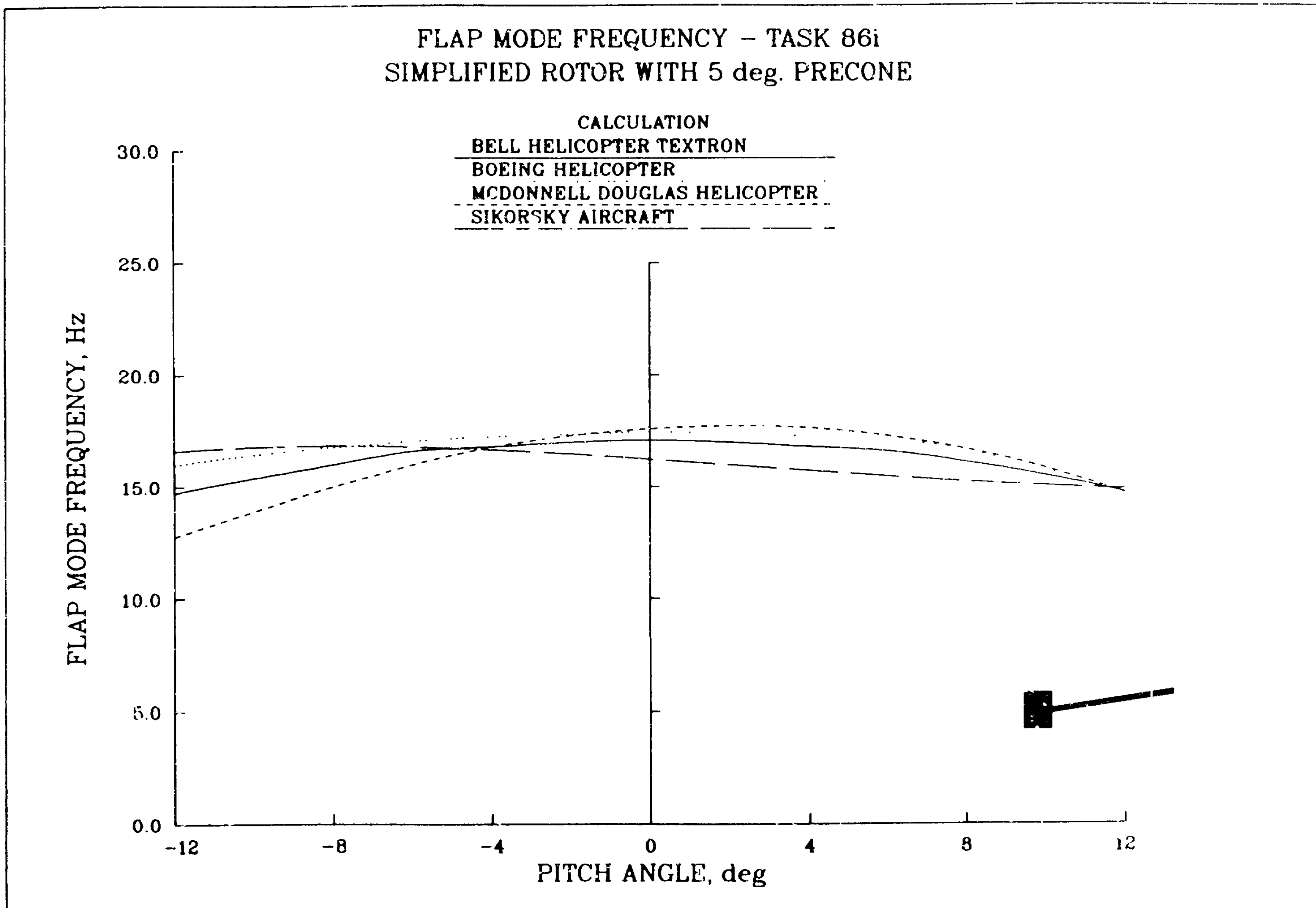
TORSION MODE DAMPING – TASK 86h
SIMPLIFIED ROTOR WITHOUT PRECONE

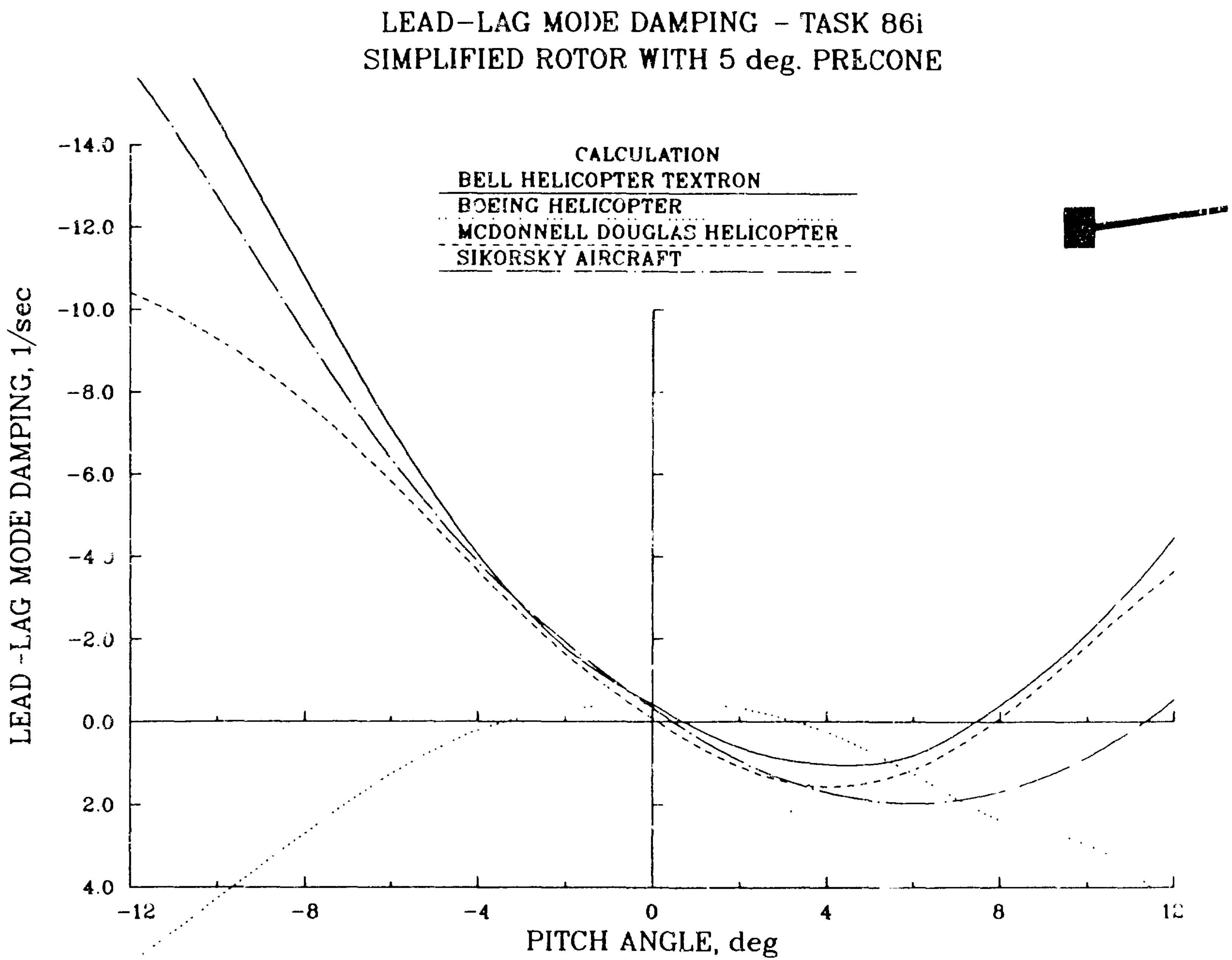



TORSION MODE FREQUENCY – TASK 86h
SIMPLIFIED ROTOR WITHOUT PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

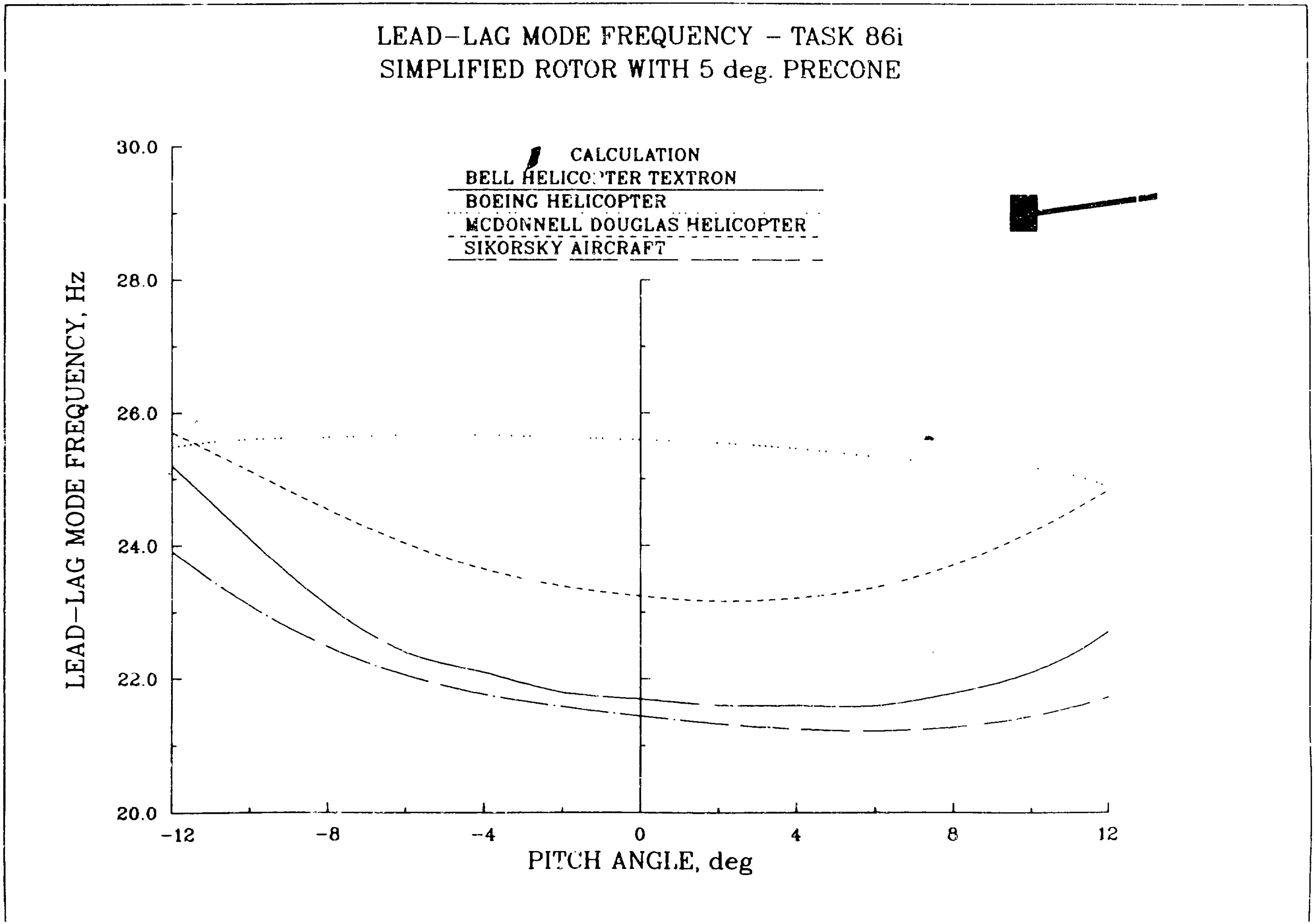


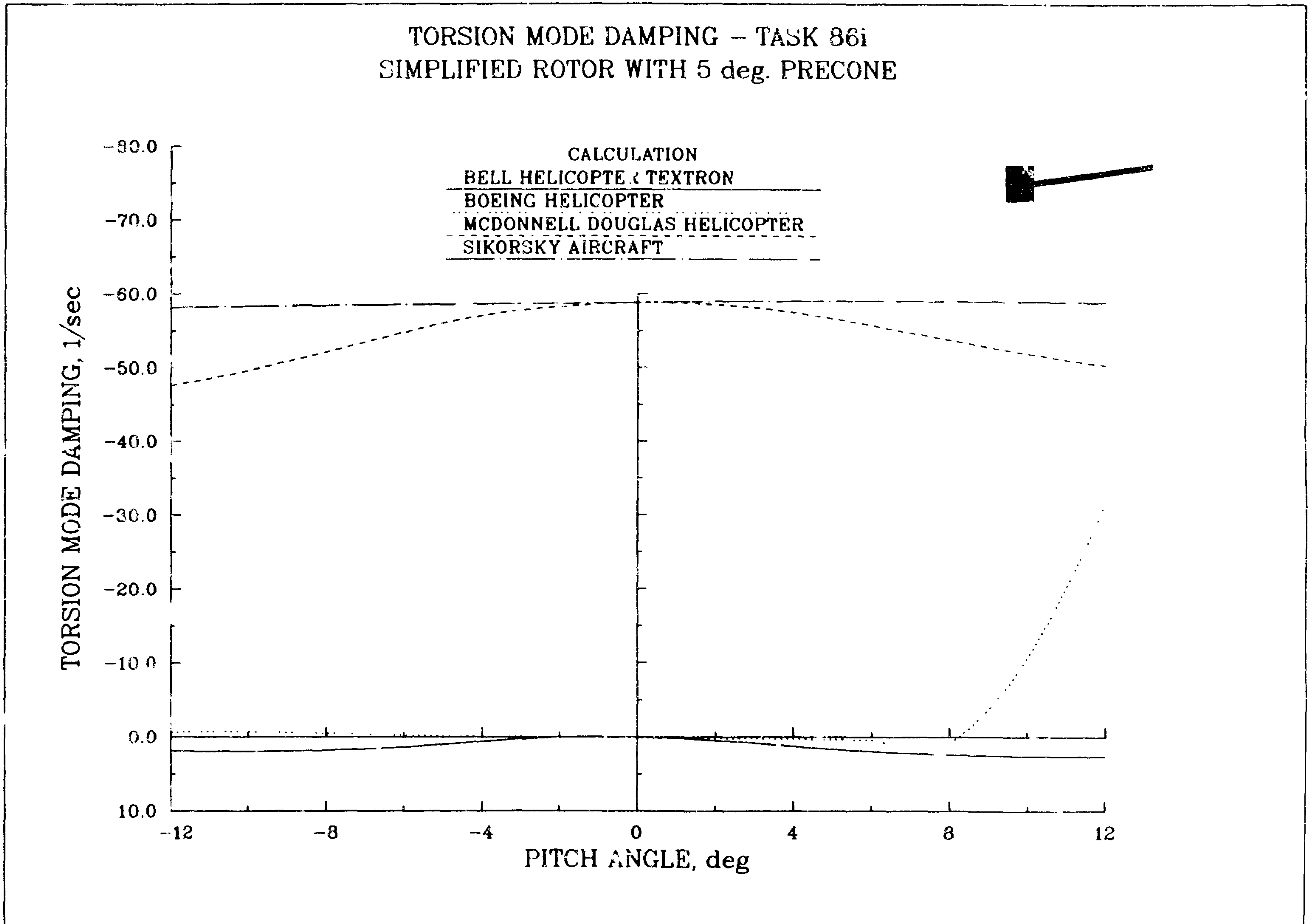
FLAP MODE DAMPING – TASK 86i
SIMPLIFIED ROTOR WITH 5 deg. PRECONI
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
FLAP MODE DAMPING, 1/sec
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

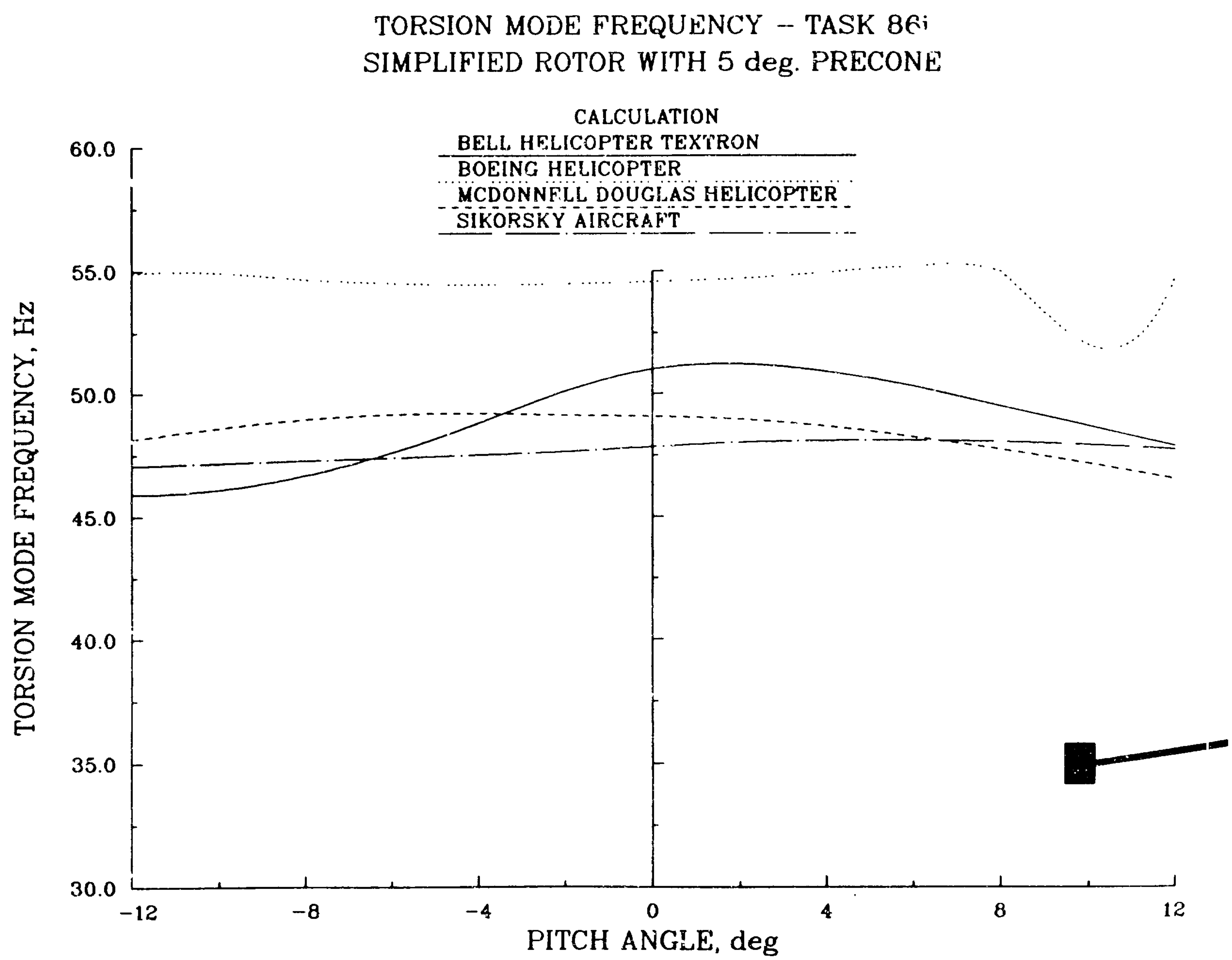

FLAP MODE FREQUENCY – TASK 86i
SIMPLIFIED ROTOR WITH 5 deg. PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
FLAP MODE FREQUENCY, Hz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg

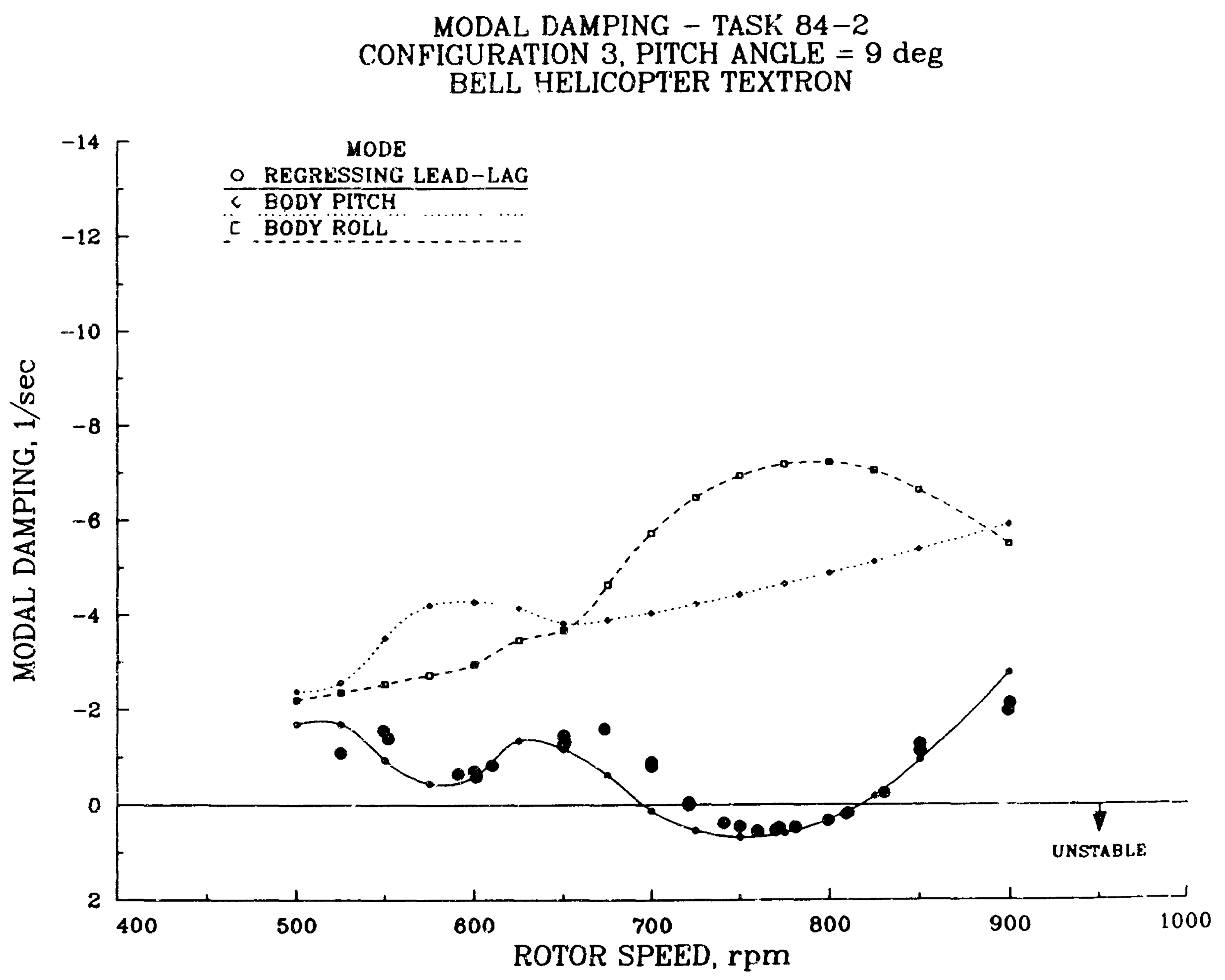


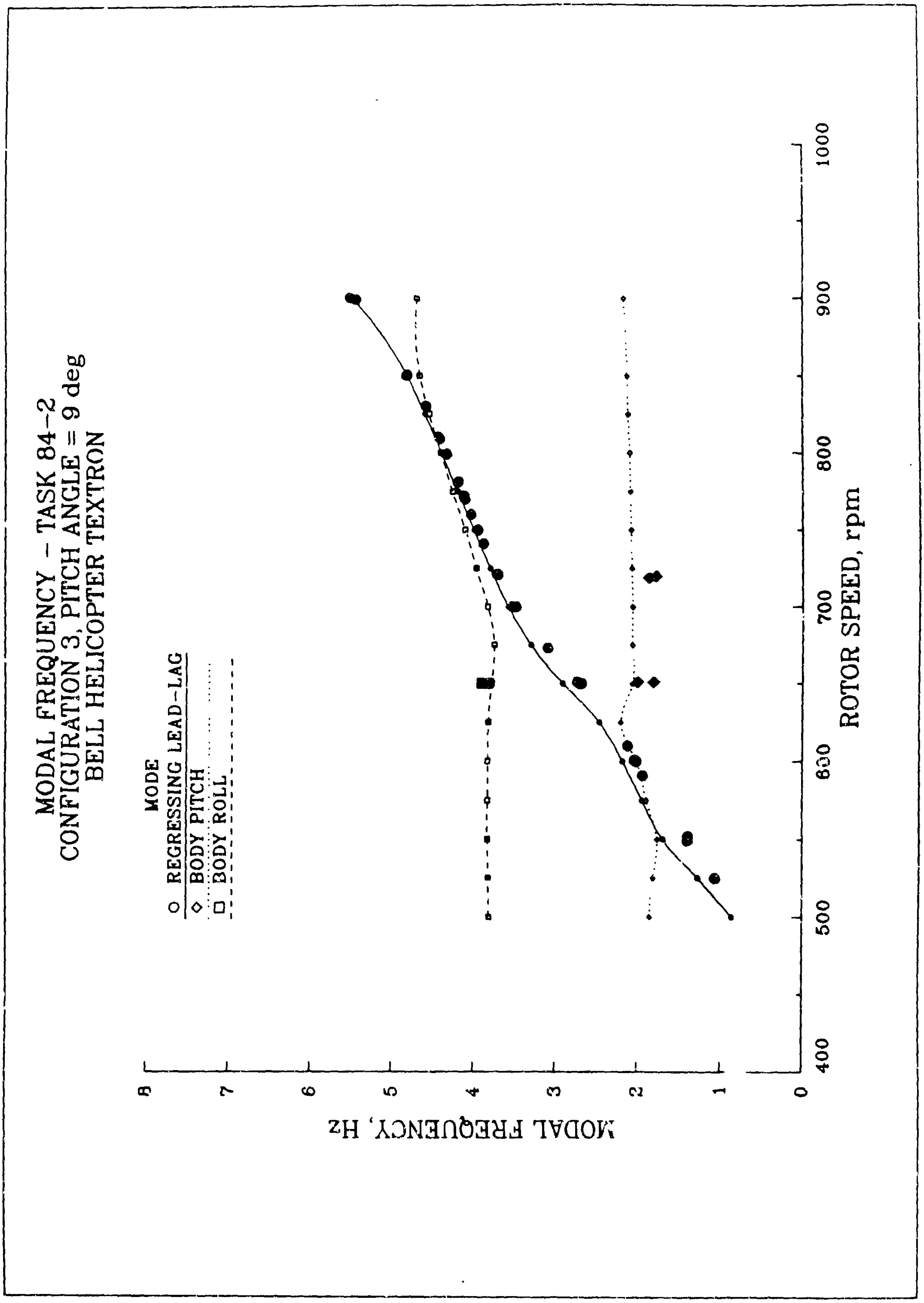
LEAD–LAG MODE DAMPING – TASK 86i
SIMPLIFIED ROTOR WITH 5 deg. PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
LEAD-LAG MODE DAMPING, 1/sec
-14.0
-12.0
-10.0
-8.0
-6.0
-2.0
0.0
2.0
4.0
-12
-8
-4
0
4
8
PITCH ANGLE, deg

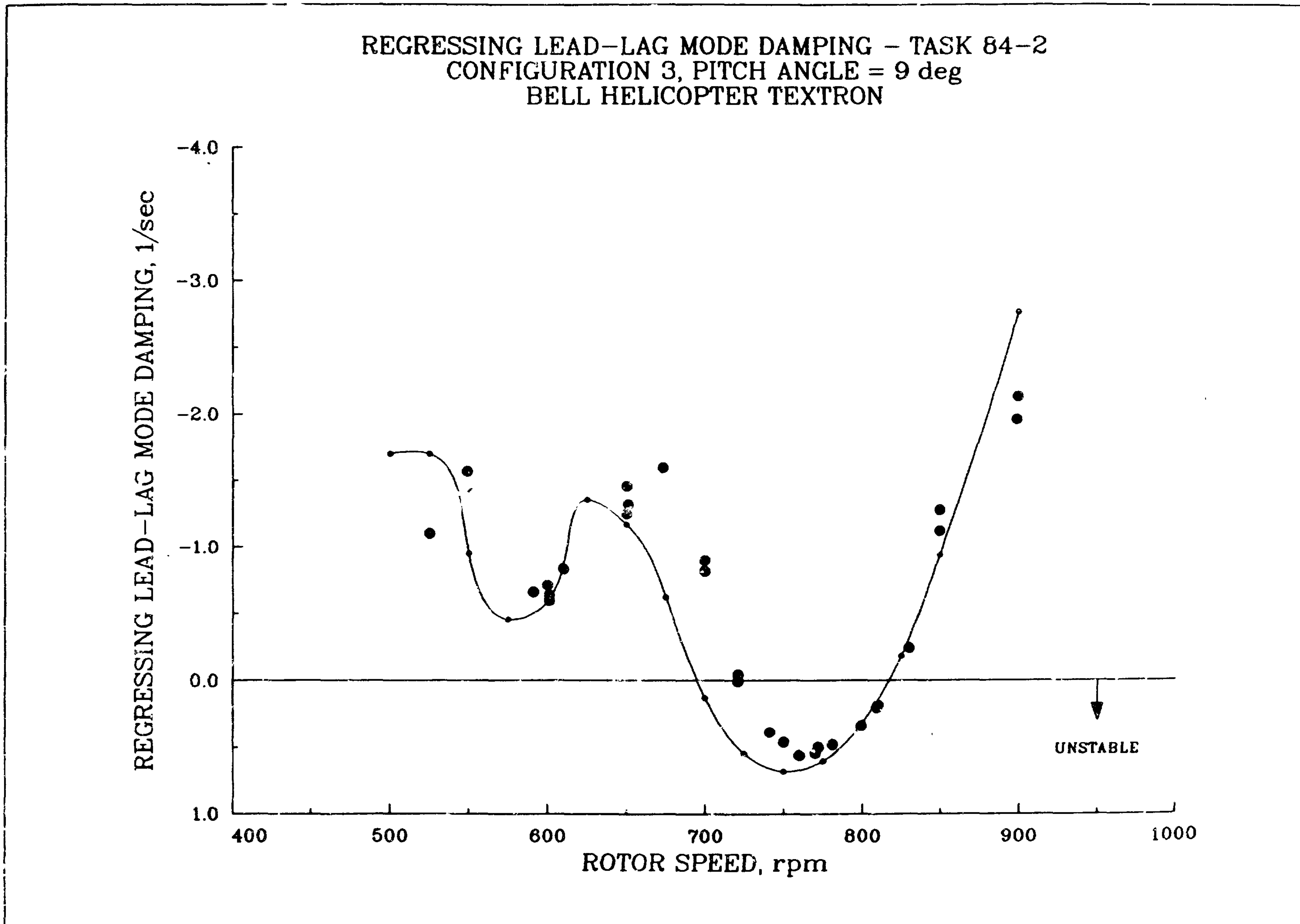

LEAD–LAG MODE FREQUENCY – TASK 86i
SIMPLIFIED ROTOR WITH 5 deg. PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
LEAD–LAG MODE FREQUENCY, Hz
30.0
28.0
26.0
24.0
22.0
20.0
–12
–8
–4
0
4
8
12
PITCH ANGLE, deg

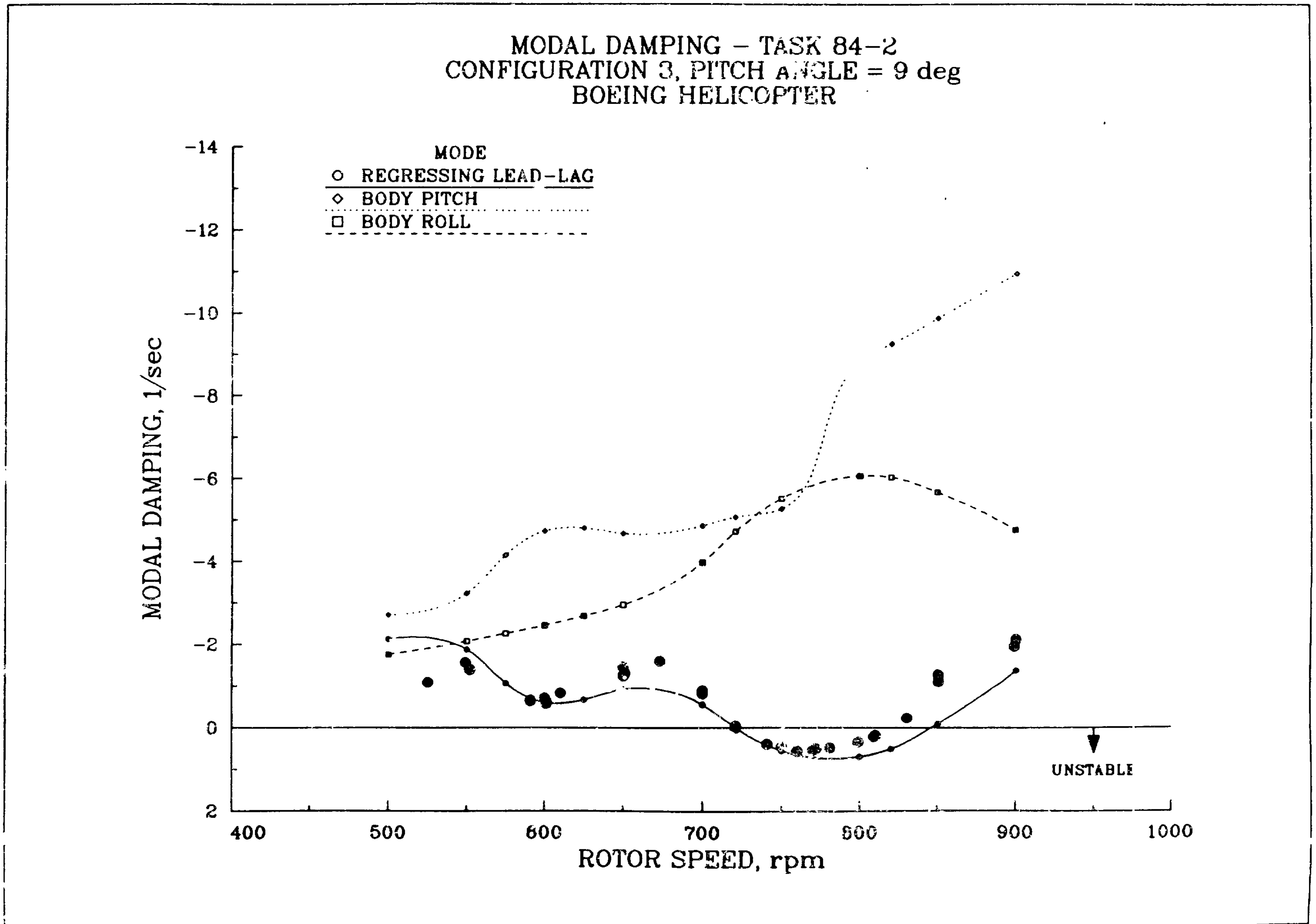

TORSION MODE DAMPING – TASK 86i
SIMPLIFIED ROTOR WITH 5 deg. PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
TORSION MODE DAMPING, 1/sec
-80.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
-12
-8
-4
0
4
8
12
PITCH ANGLE, deg

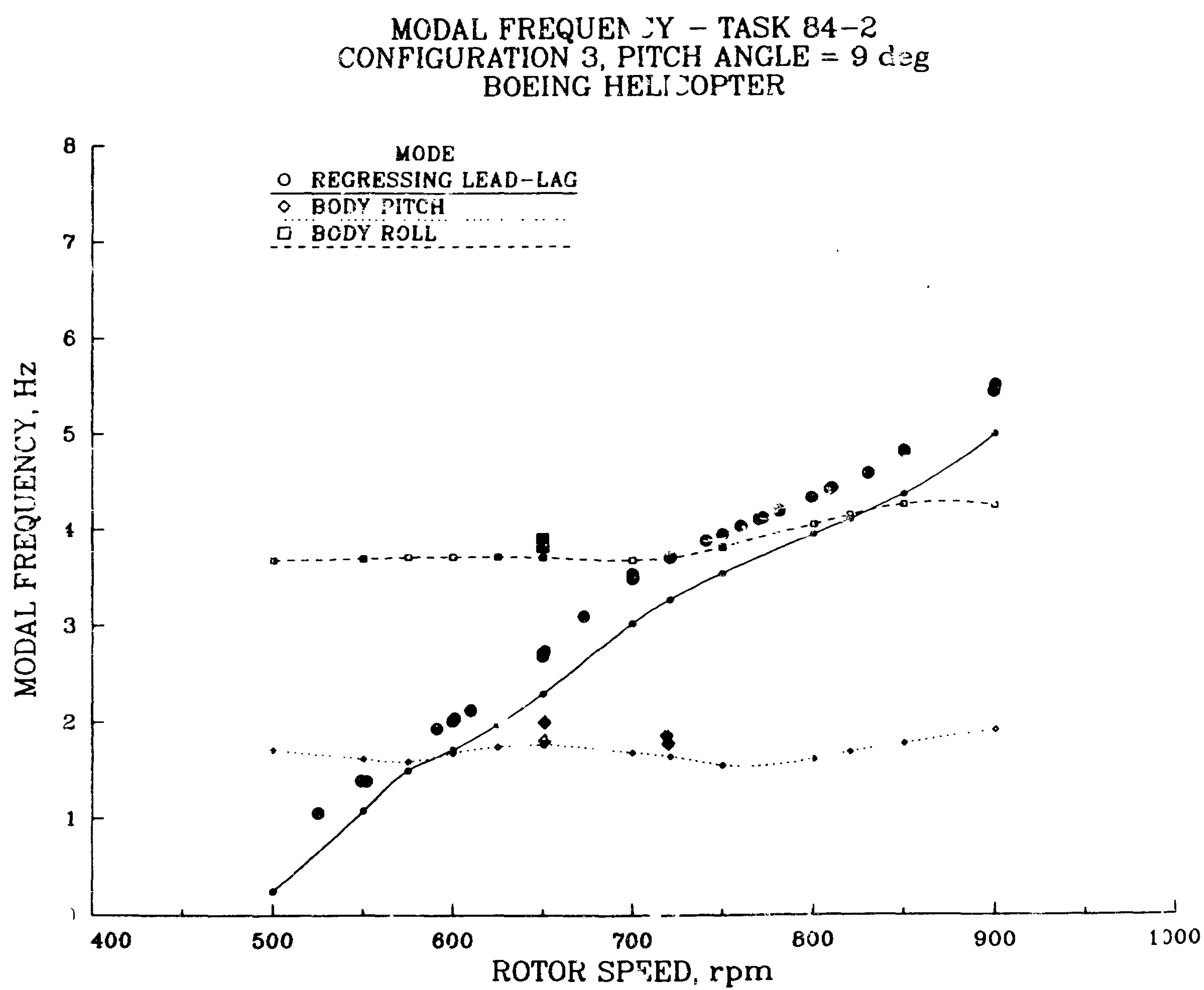

TORSION MODE FREQUENCY – TASK 86i
SIMPLIFIED ROTOR WITH 5 deg. PRECONE
CALCULATION
BELL HELICOPTER TEXTRON
BOEING HELICOPTER
MCDONNELL DOUGLAS HELICOPTER
SIKORSKY AIRCRAFT
TORSION MODE FREQUENCY, Hz
60.0
55.0
50.0
45.0
40.0
35.0
30.0
−12
−8
−4
0
4
8
12
PITCH ANGLE, deg


MODAL DAMPING – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
BELL HELICOPTER TEXTRON
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
-2
0
2
UNSTABLE
400
500
600
700
800
900
1000
ROTOR SPEED, rpm

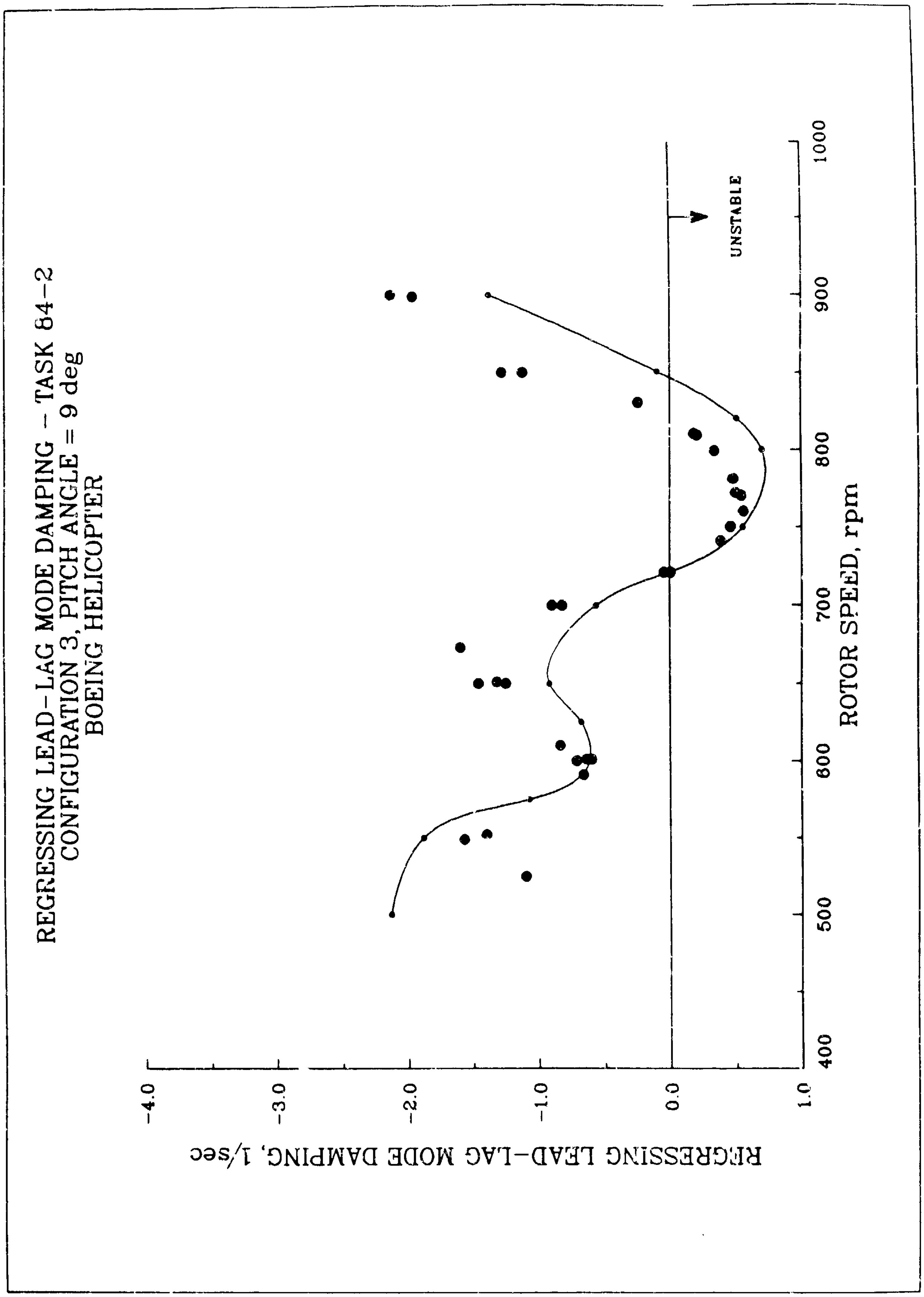

MODAL FREQUENCY – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
BELL HELICOPTER TEXTRON
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
MODAL FREQUENCY, Hz
0
1
2
3
4
5
6
7
8
ROTOR SPEED, rpm
400
500
600
700
800
900
1000


REGRESSING LEAD−LAG MODE DAMPING − TASK 84−2
CONFIGURATION 3, PITCH ANGLE = 9 deg
BELL HELICOPTER TEXTRON
REGRESSING LEAD−LAG MODE DAMPING, 1/sec
−4.0
−3.0
−2.0
−1.0
0.0
1.0
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
UNSTABLE

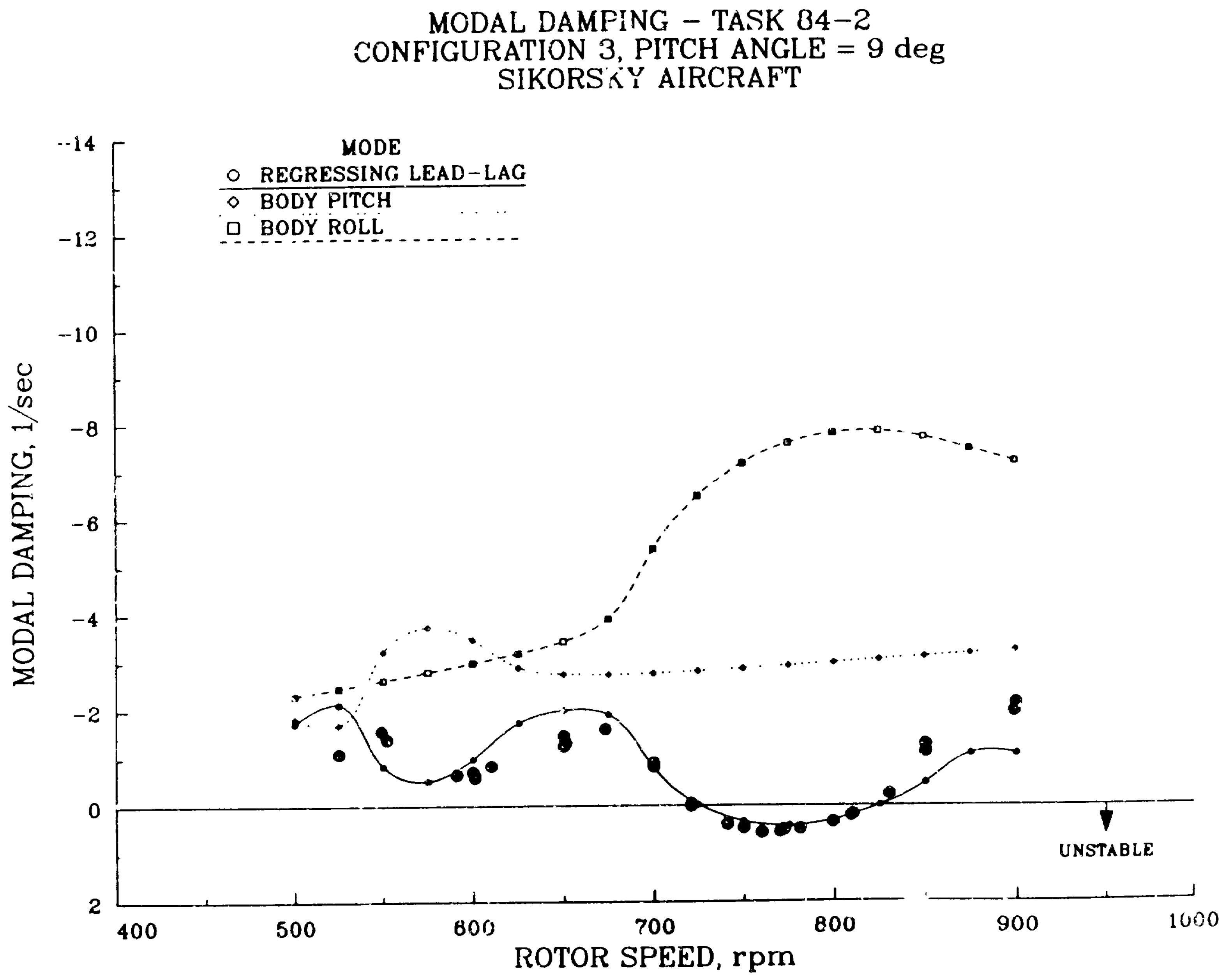

MODAL DAMPING – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
BOEING HELICOPTER
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
-2
0
2
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
UNSTABLE

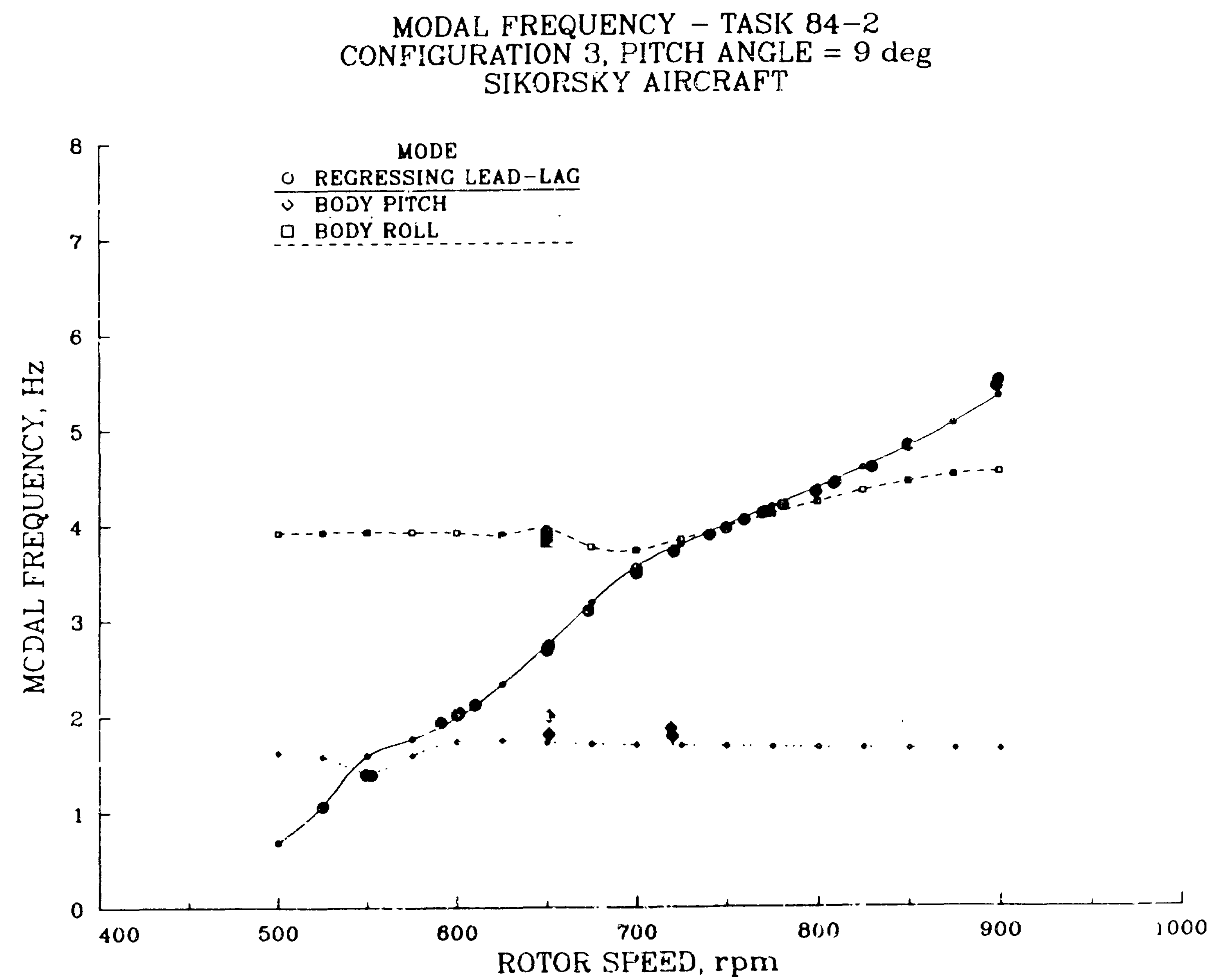


MODAL FREQUENCY – TASK 84-2
CONFIGURATION 3, PITCH ANGLE = 9 deg
BOEING HELICOPTER
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm

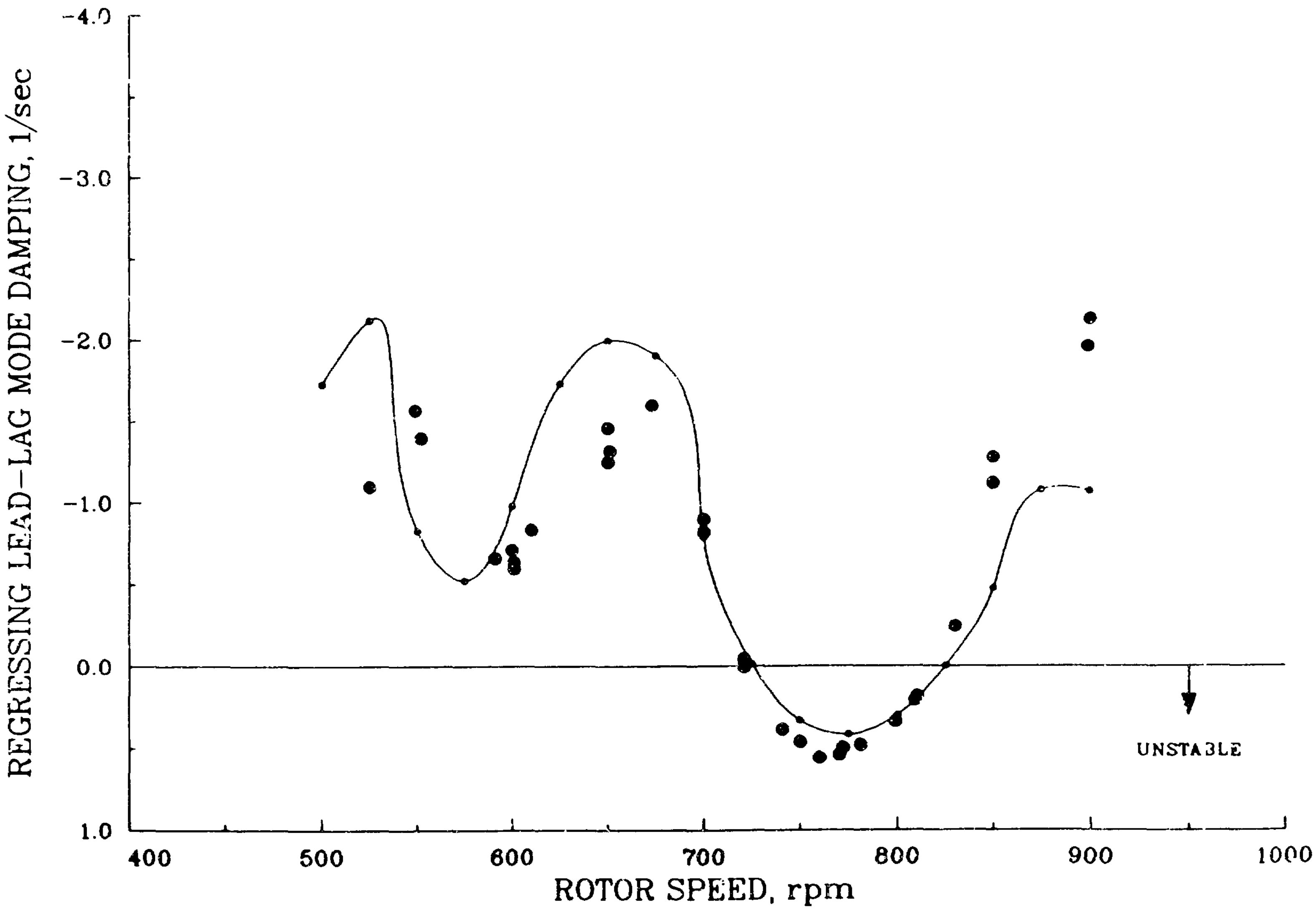


REGRESSING LEAD–LAG MODE DAMPING – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
BOEING HELICOPTER
UNSTABLE
ROTOR SPEED, rpm
400
500
600
700
800
900
1000
REGRESSING LEAD–LAG MODE DAMPING, 1/sec
-4.0
-3.0
-2.0
-1.0
0.0
1.0

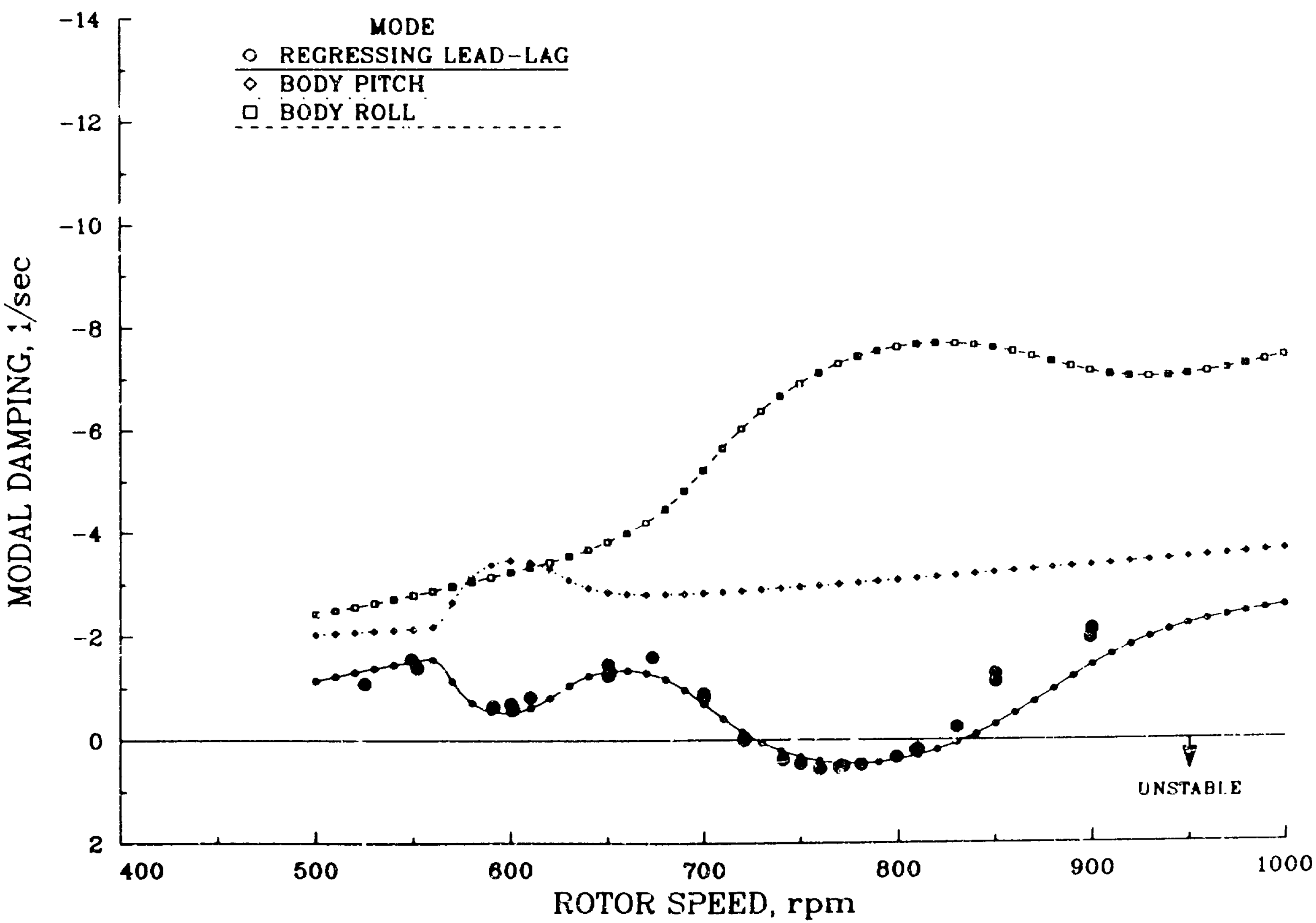

MODAL DAMPING – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
SIKORSKY AIRCRAFT
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
-2
0
2
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
UNSTABLE

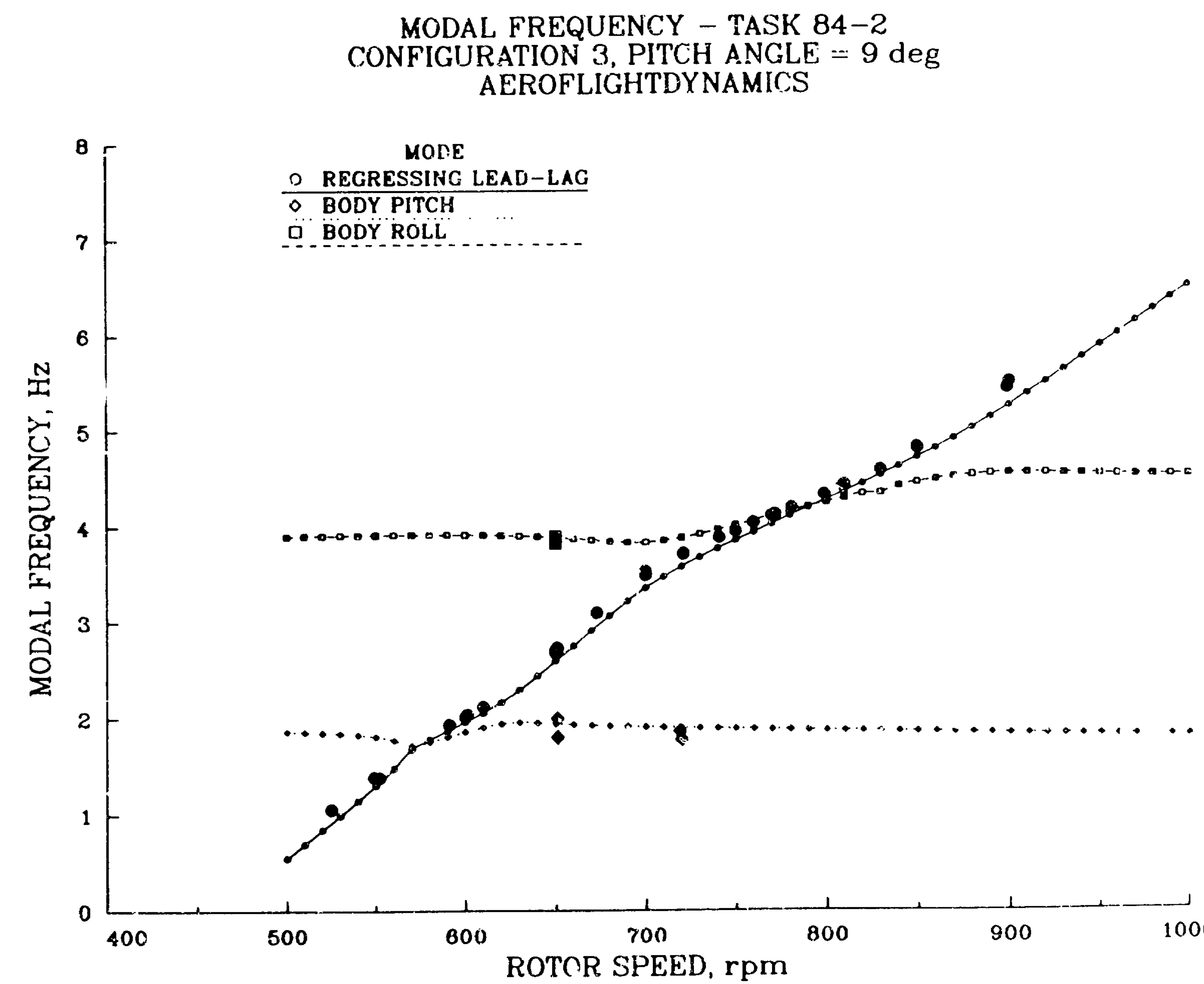

MODAL FREQUENCY – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
SIKORSKY AIRCRAFT
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
MODAL FREQUENCY, Hz
0
1
2
3
4
5
6
7
8
400
500
600
700
800
900
1000
ROTOR SPEED, rpm

REGRESSING LEAD–LAG MODE DAMPING – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
SIKORSKY AIRCRAFT

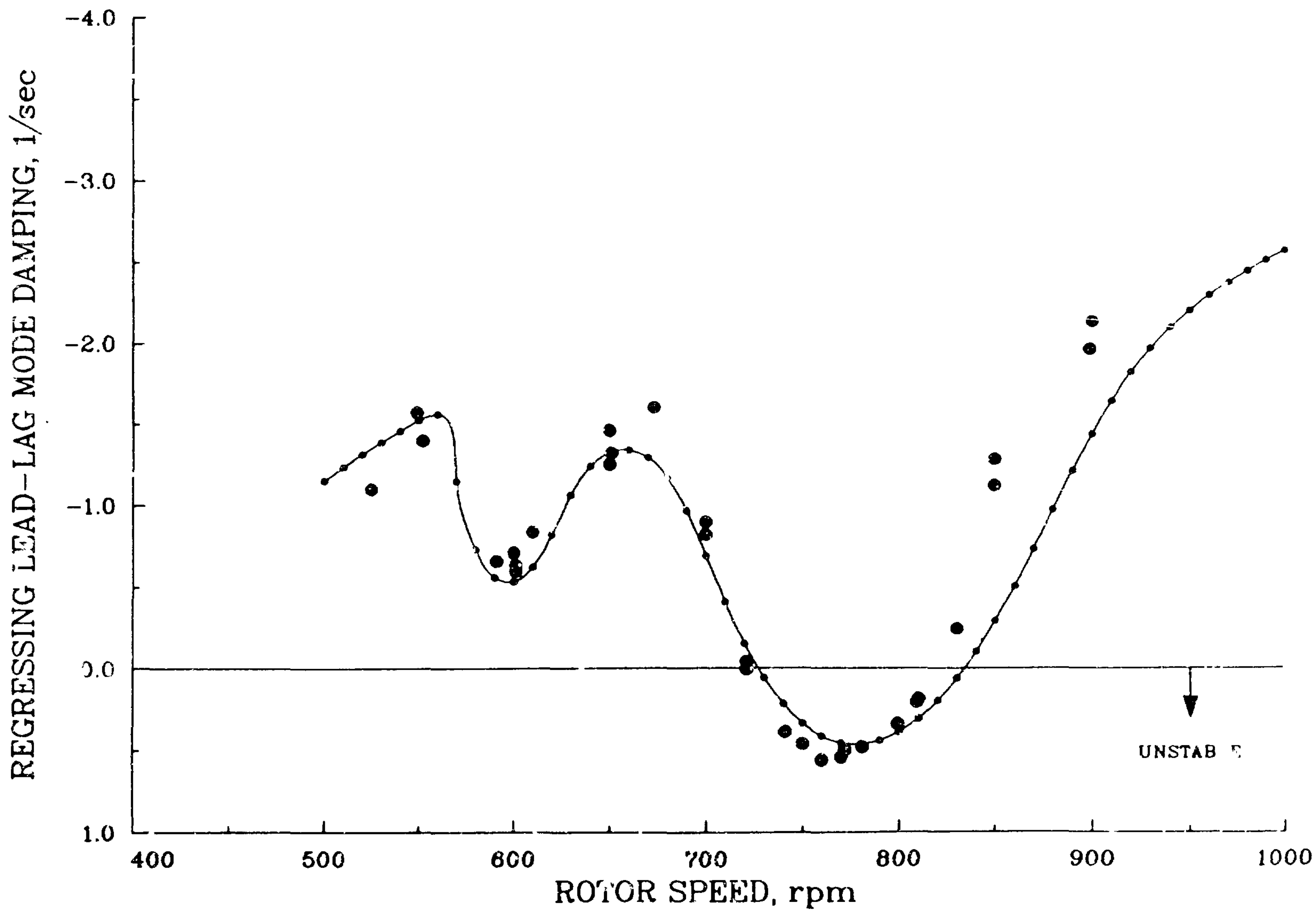


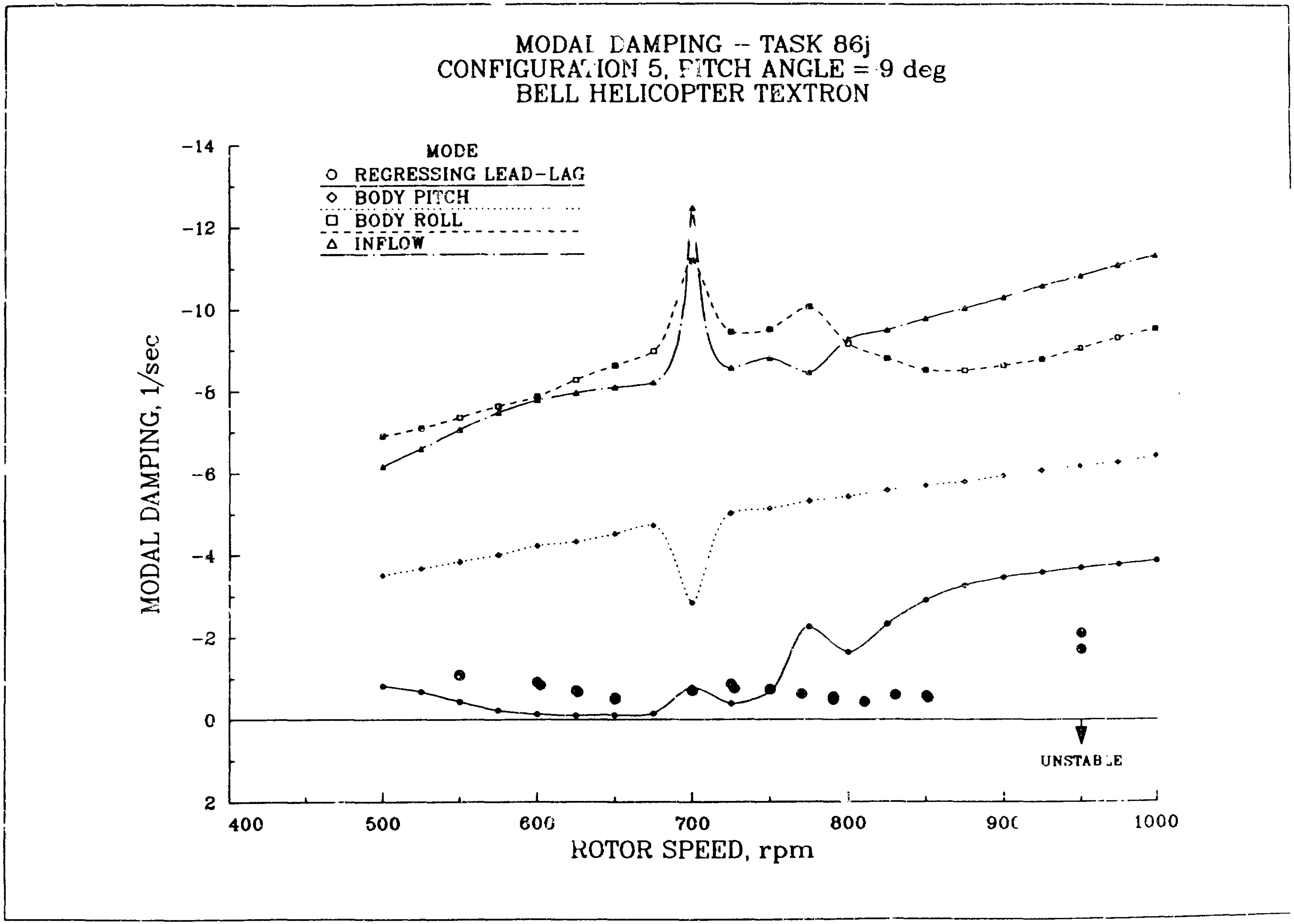
MODAL DAMPING – TASK 84-2
CONFIGURATION 3, PITCH ANGLE = 9 deg
AEROFLIGHTDYNAMICS

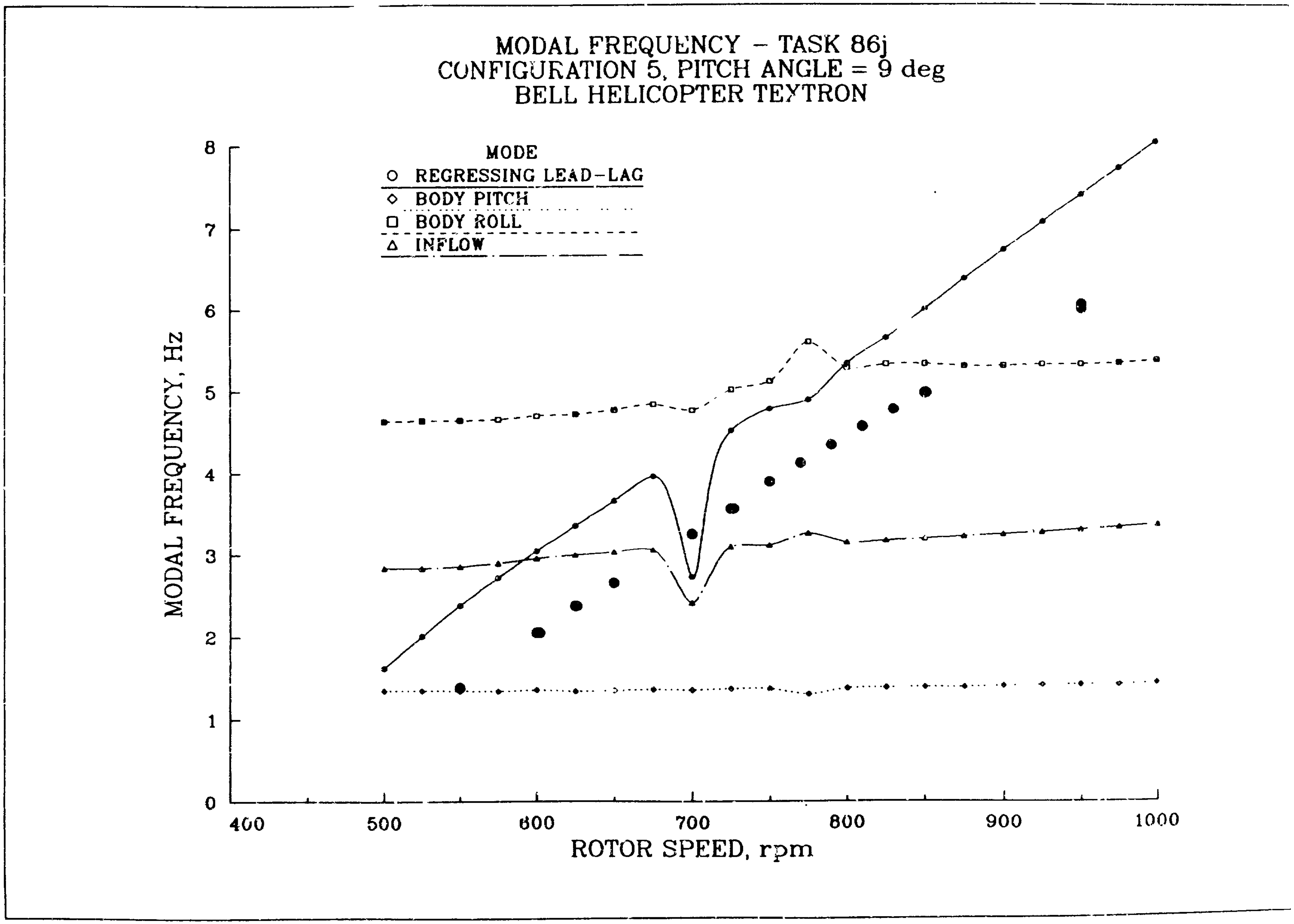


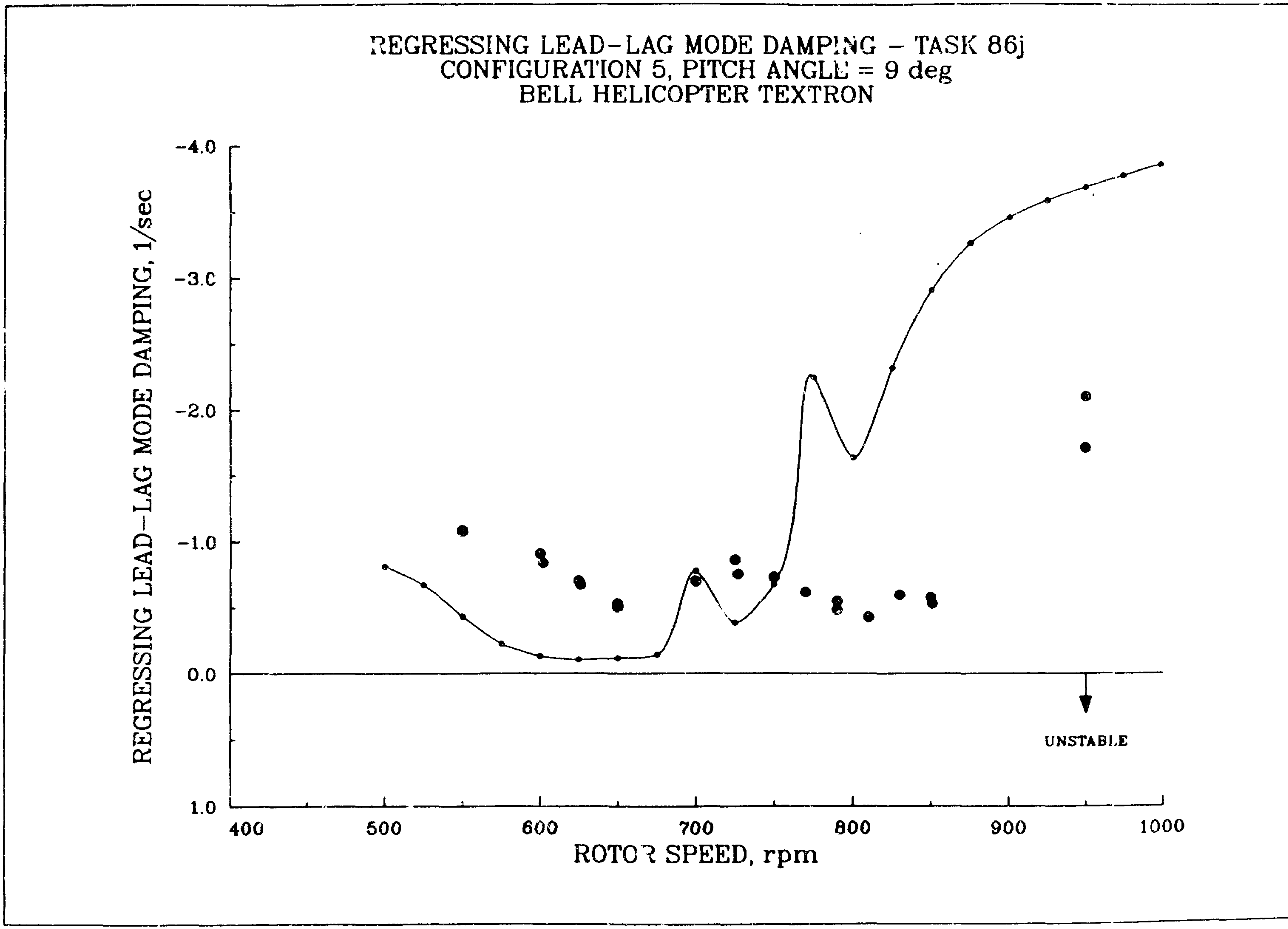

MODAL FREQUENCY – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
AEROFLIGHTDYNAMICS
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
0
1
2
3
4
5
6
7
8
400
500
600
700
800
900
1000

REGRESSING LEAD–LAG MODE DAMPING – TASK 84–2
CONFIGURATION 3, PITCH ANGLE = 9 deg
AEROFLIGHTDYNAMICS

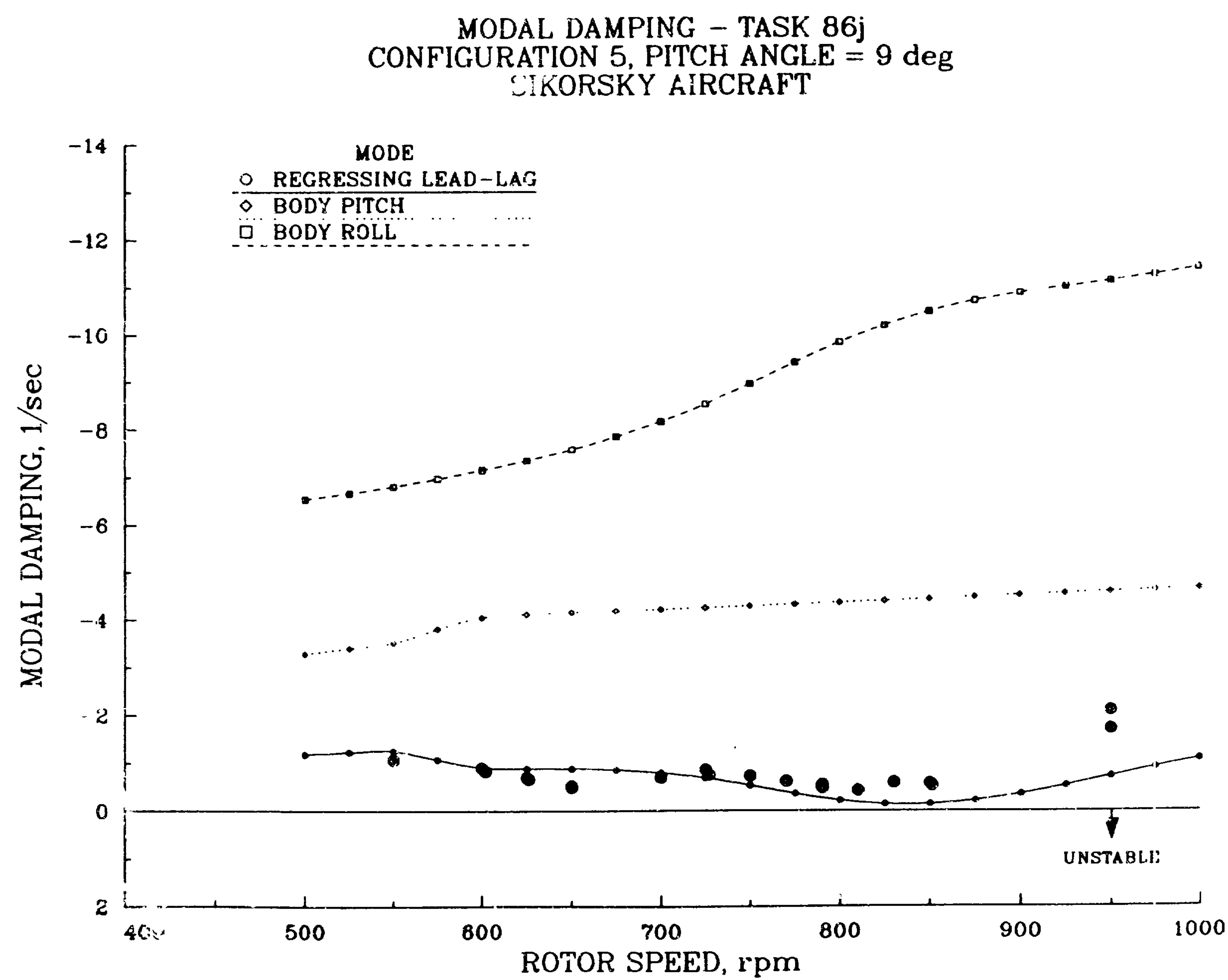


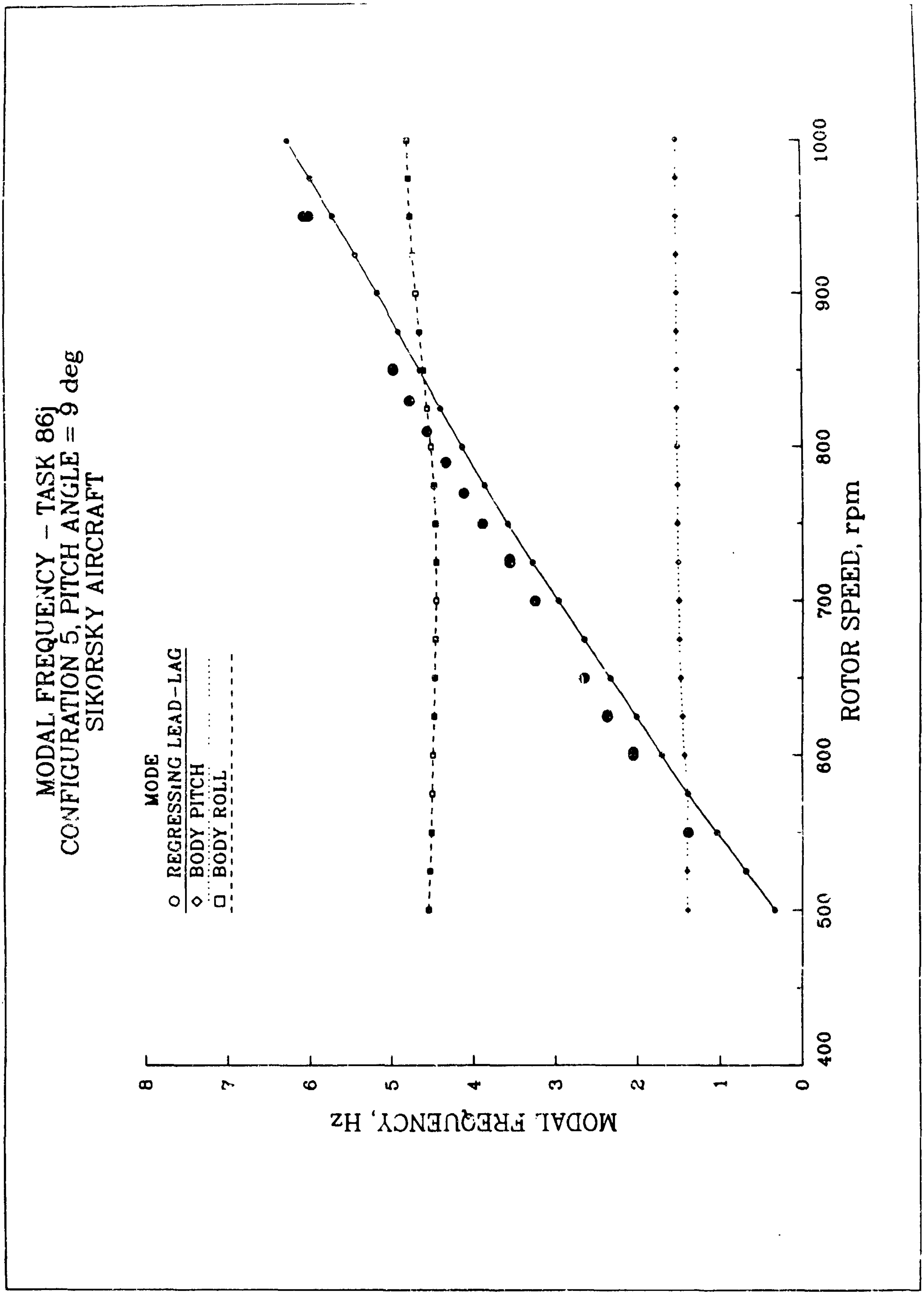

MODAL DAMPING -- TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
BELL HELICOPTER TEXTRON
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
INFLOW
MODAL DAMPING, 1/sec
ROTOR SPEED, rpm
UNSTABLE
-14
-12
-10
-8
-6
-4
-2
0
2
400
500
600
700
800
900
1000


MODAL FREQUENCY – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
BELL HELICOPTER TEXTRON
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
INFLOW
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
0
1
2
3
4
5
6
7
8
400
500
600
700
800
900
1000

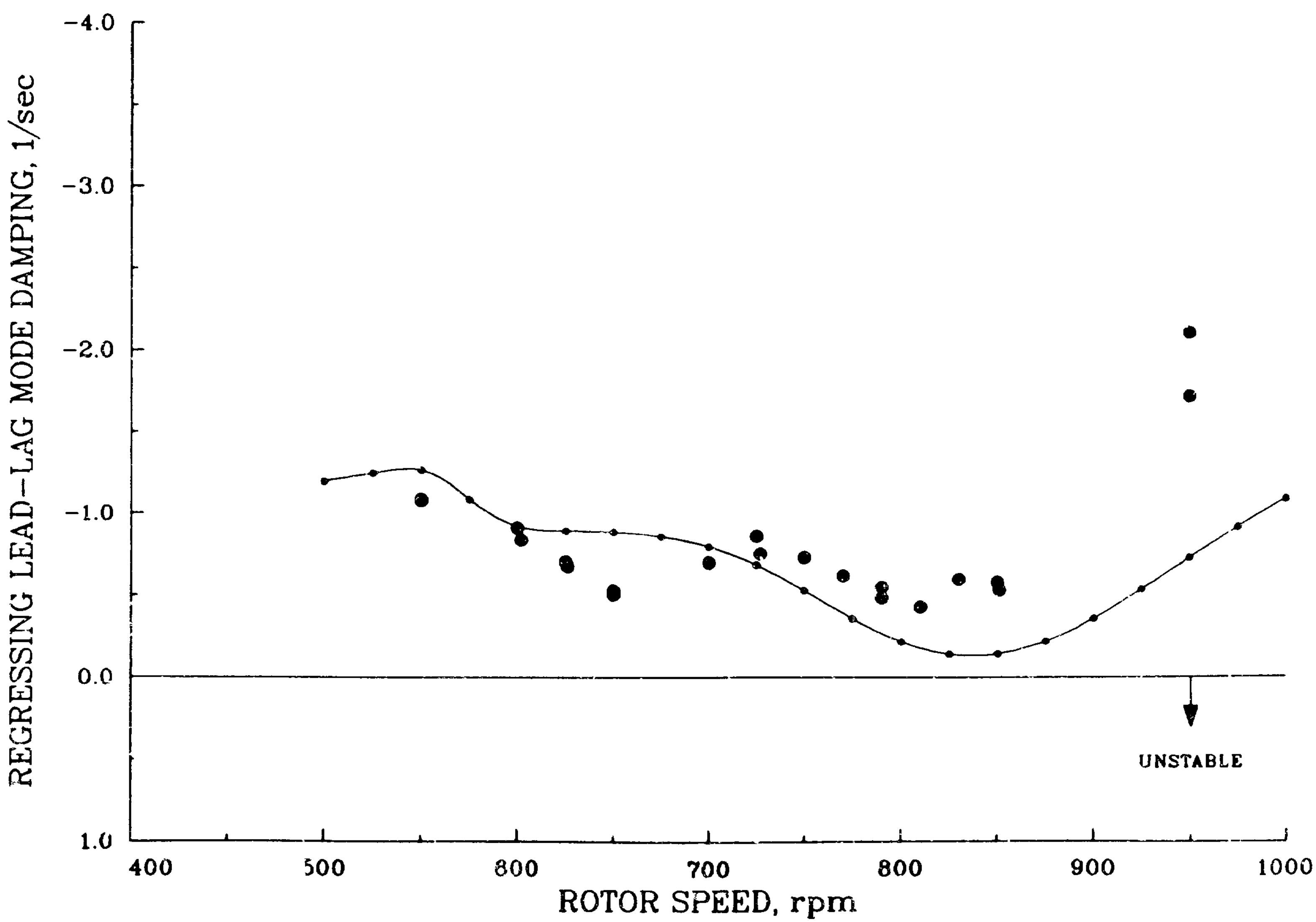


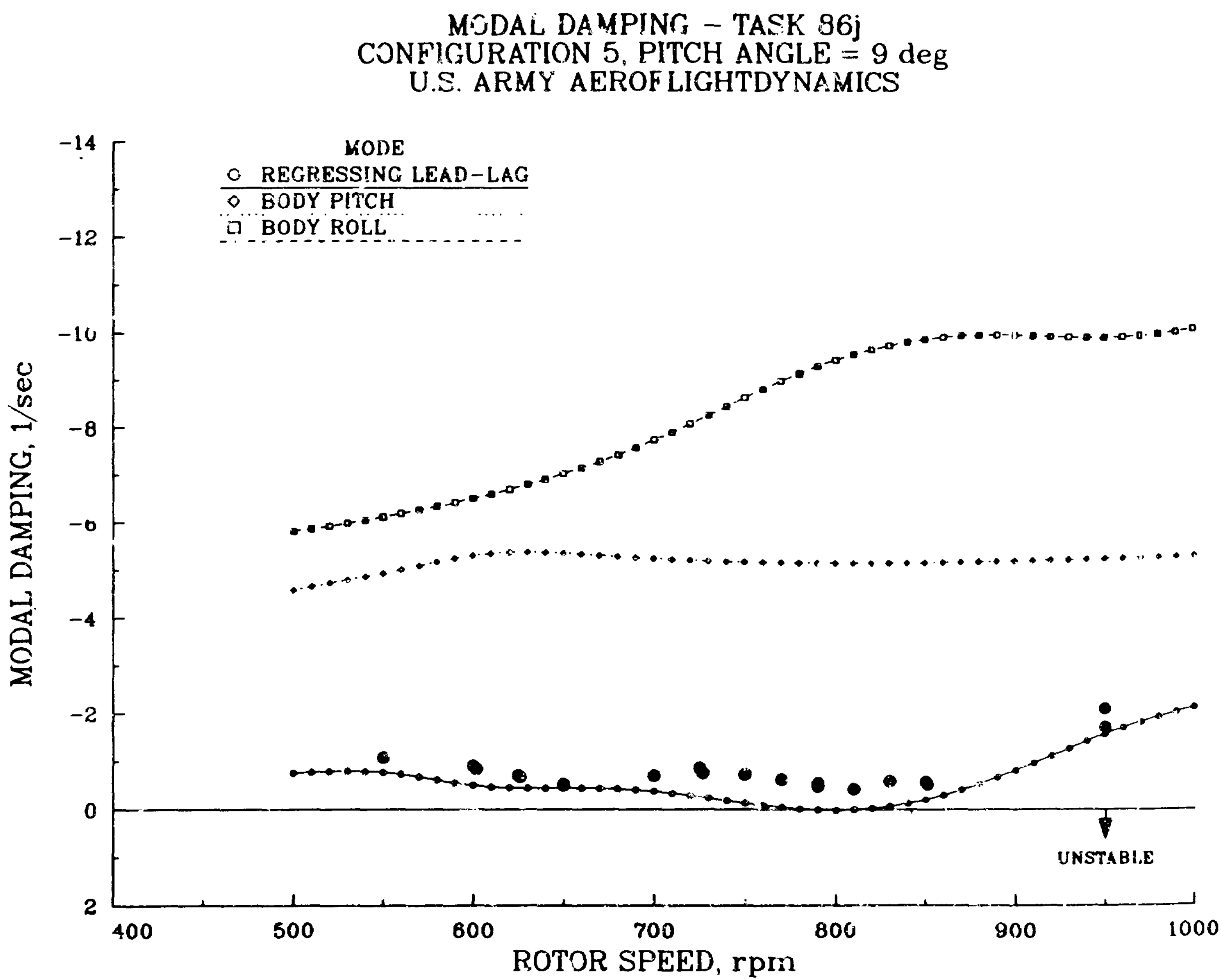
REGRESSING LEAD–LAG MODE DAMPING – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
BELL HELICOPTER TEXTRON
REGRESSING LEAD–LAG MODE DAMPING, 1/sec
-4.0
-3.0
-2.0
-1.0
0.0
1.0
UNSTABLE
400
500
600
700
800
900
1000
ROTOR SPEED, rpm


MODAL DAMPING – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
SIKORSKY AIRCRAFT
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
-2
0
2
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
UNSTABLE

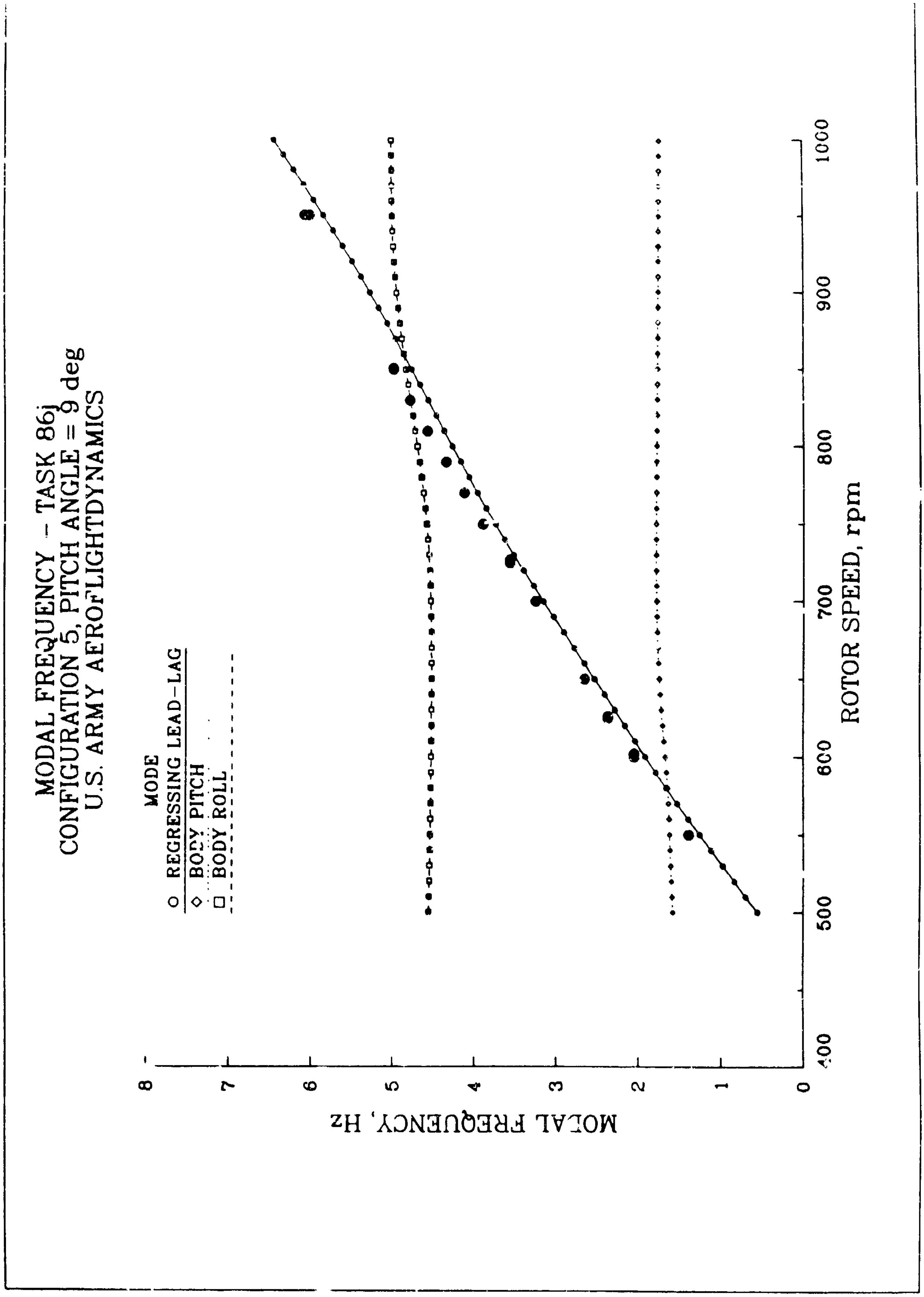

MODAL FREQUENCY – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
SIKORSKY AIRCRAFT
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
0
1
2
3
4
5
6
7
8
400
500
600
700
800
900
1000

REGRESSING LEAD–LAG MODE DAMPING – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
SIKORSKY AIRCRAFT

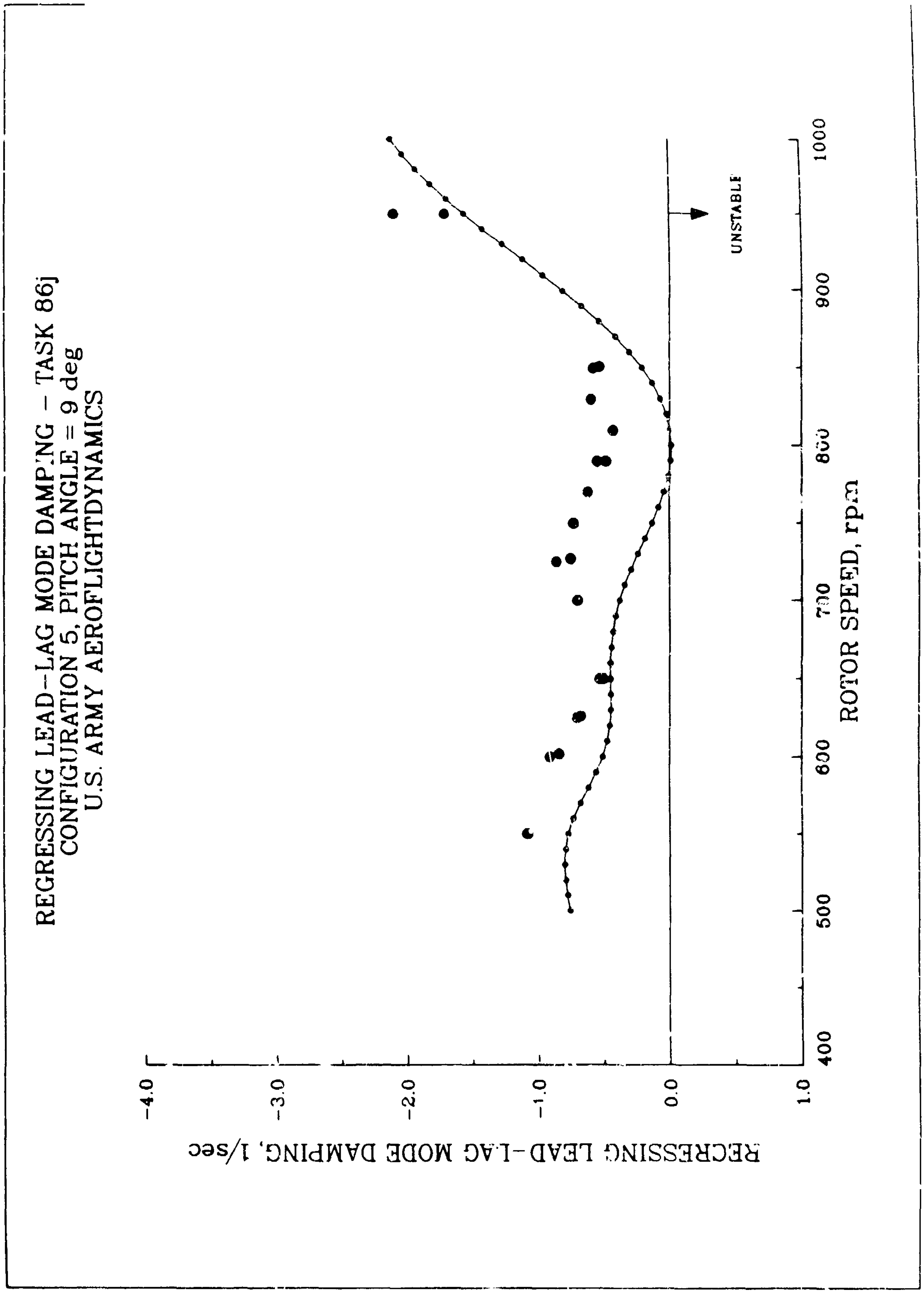


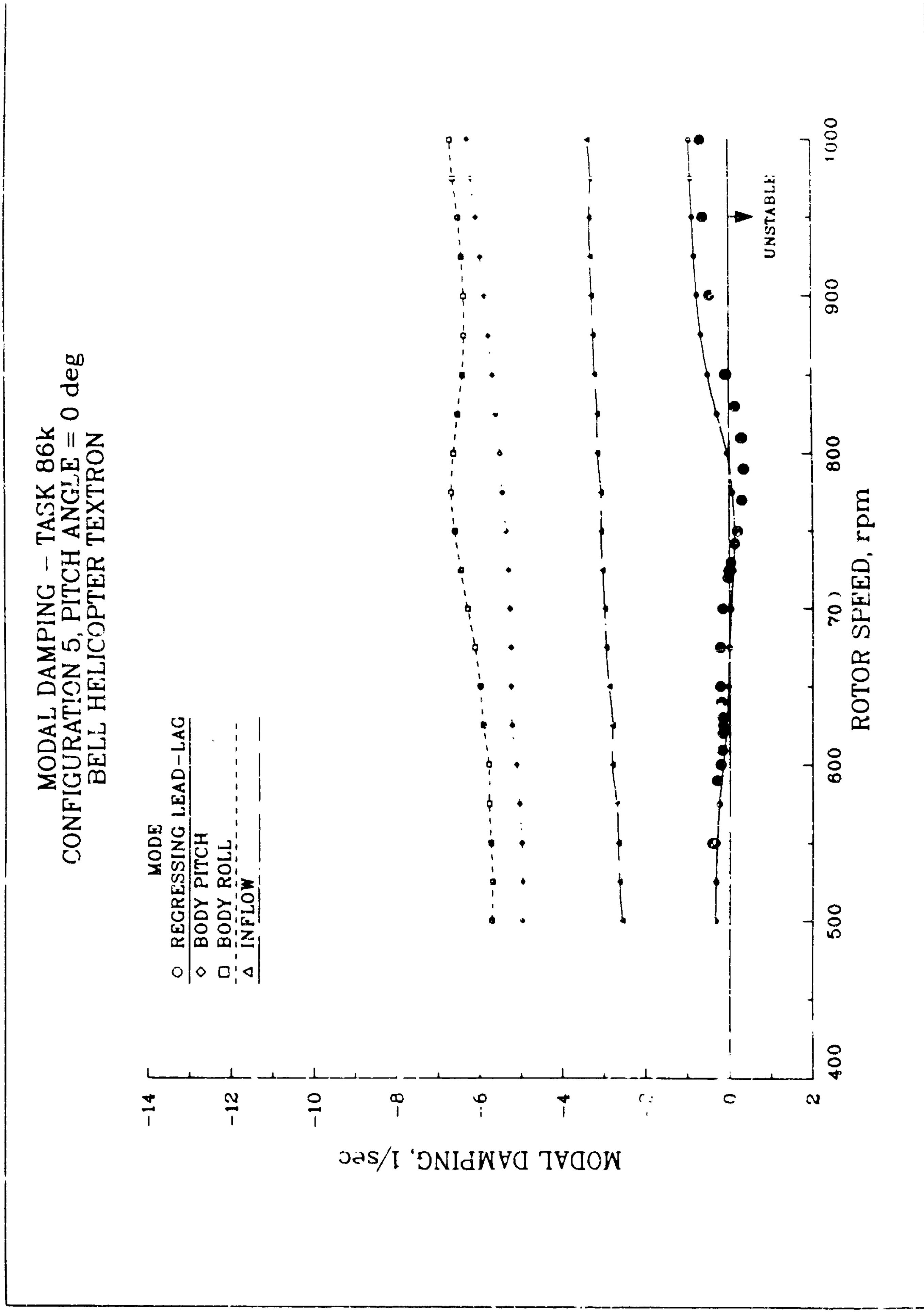


MODAL DAMPING – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
U.S. ARMY AEROFLIGHTDYNAMICS
MODE
○ REGRESSING LEAD-LAG
◇ BODY PITCH
□ BODY ROLL
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
-2
0
2
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
UNSTABLE

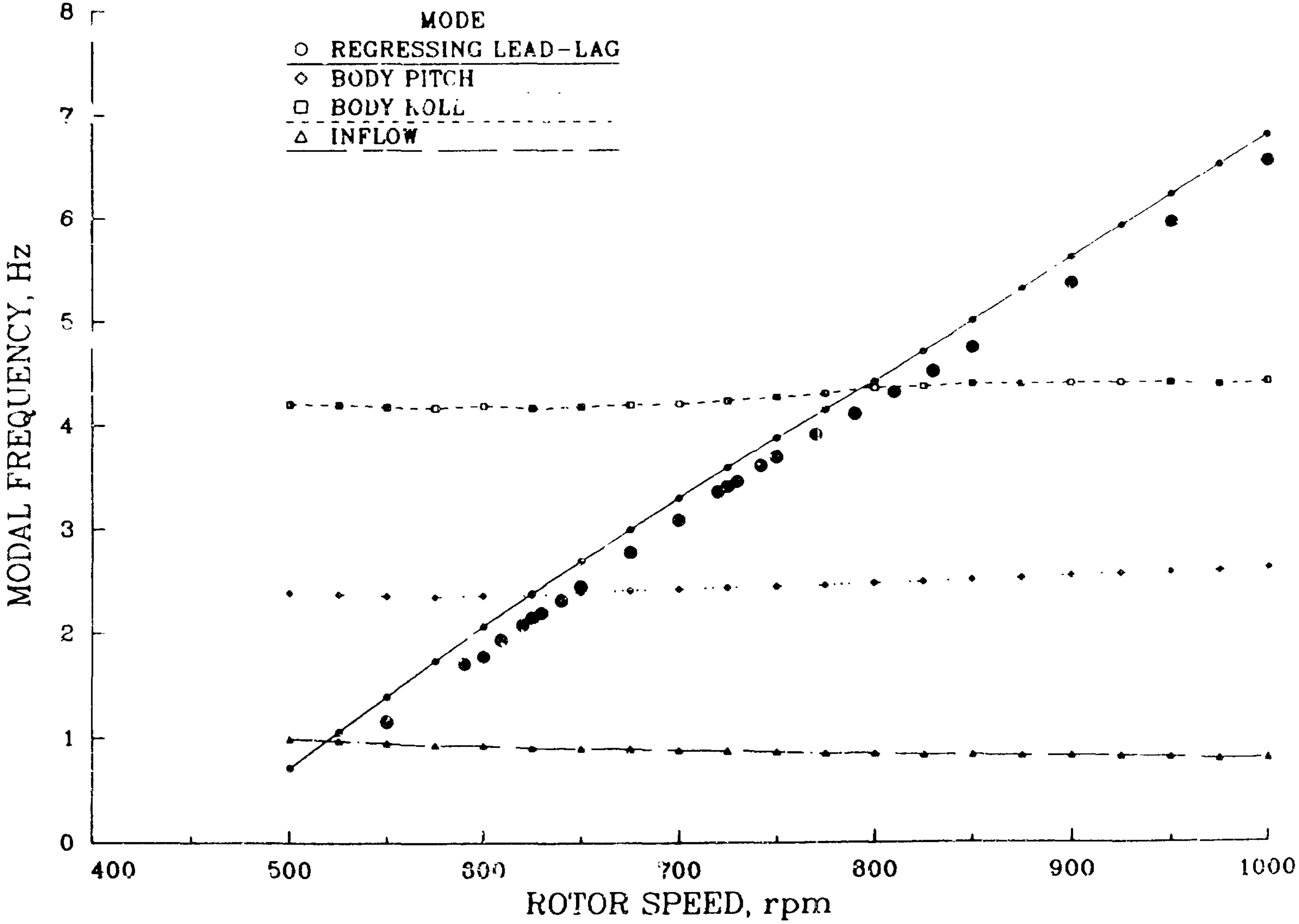


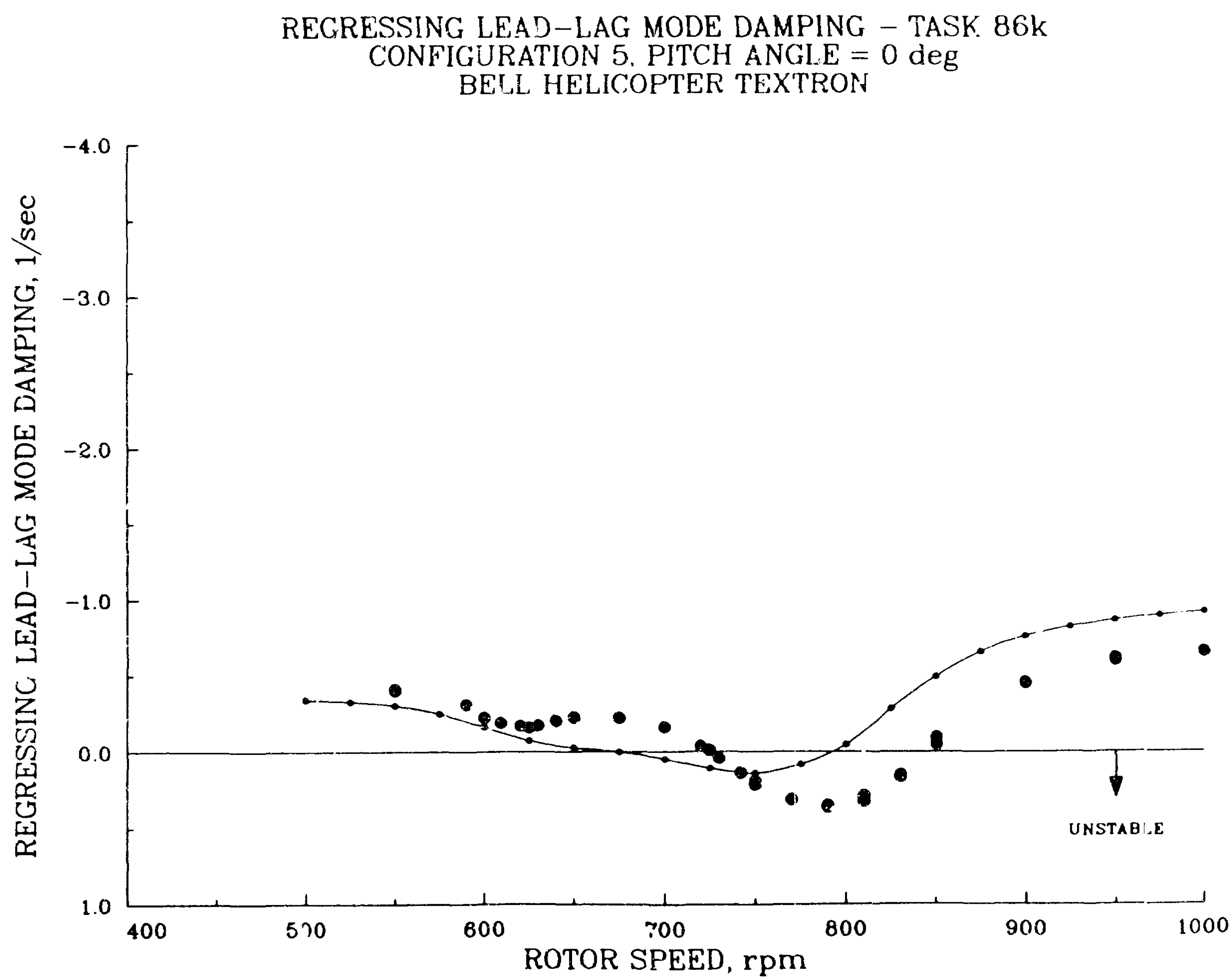
MODAL FREQUENCY – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
U.S. ARMY AEROFLIGHTDYNAMICS
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
0
1
2
3
4
5
6
7
8
400
500
600
700
800
900
1000

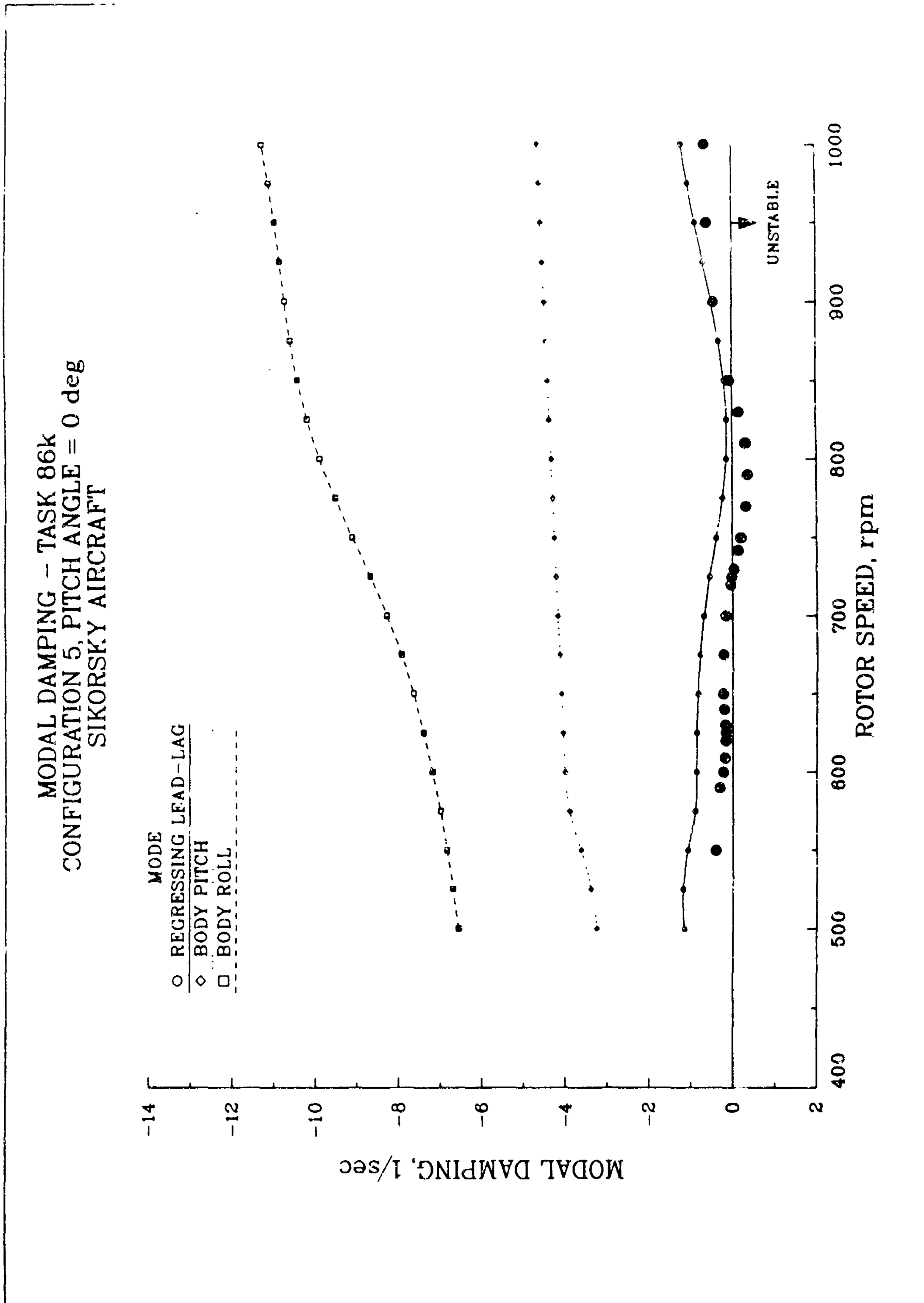

REGRESSING LEAD–LAG MODE DAMPING – TASK 86j
CONFIGURATION 5, PITCH ANGLE = 9 deg
U.S. ARMY AEROFLIGHTDYNAMICS
UNSTABLE
ROTOR SPEED, rpm
REGRESSING LEAD–LAG MODE DAMPING, 1/sec
-4.0
-3.0
-2.0
-1.0
0.0
1.0
400
500
600
700
800
900
1000


MODAL DAMPING – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
BELL HELICOPTER TEXTRON
MODE
REGRESSING LEAD-LAG
BODY PITCH
BODY ROLL
INFLOW
UNSTABLE
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
0
2
ROTOR SPEED, rpm
400
500
600
800
900
1000

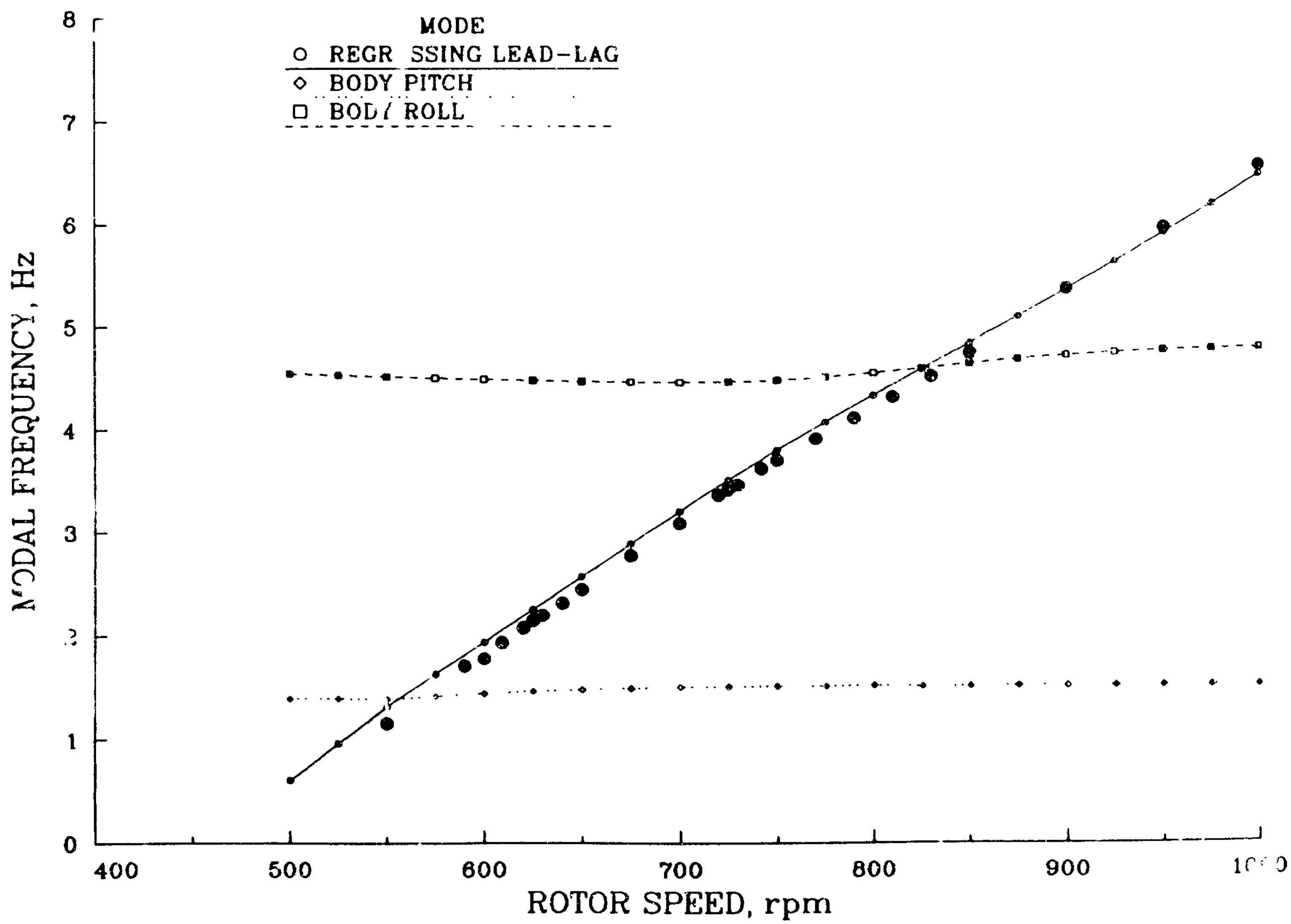
MODAL FREQUENCY – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
BELL HELICOPTER TEXTRON

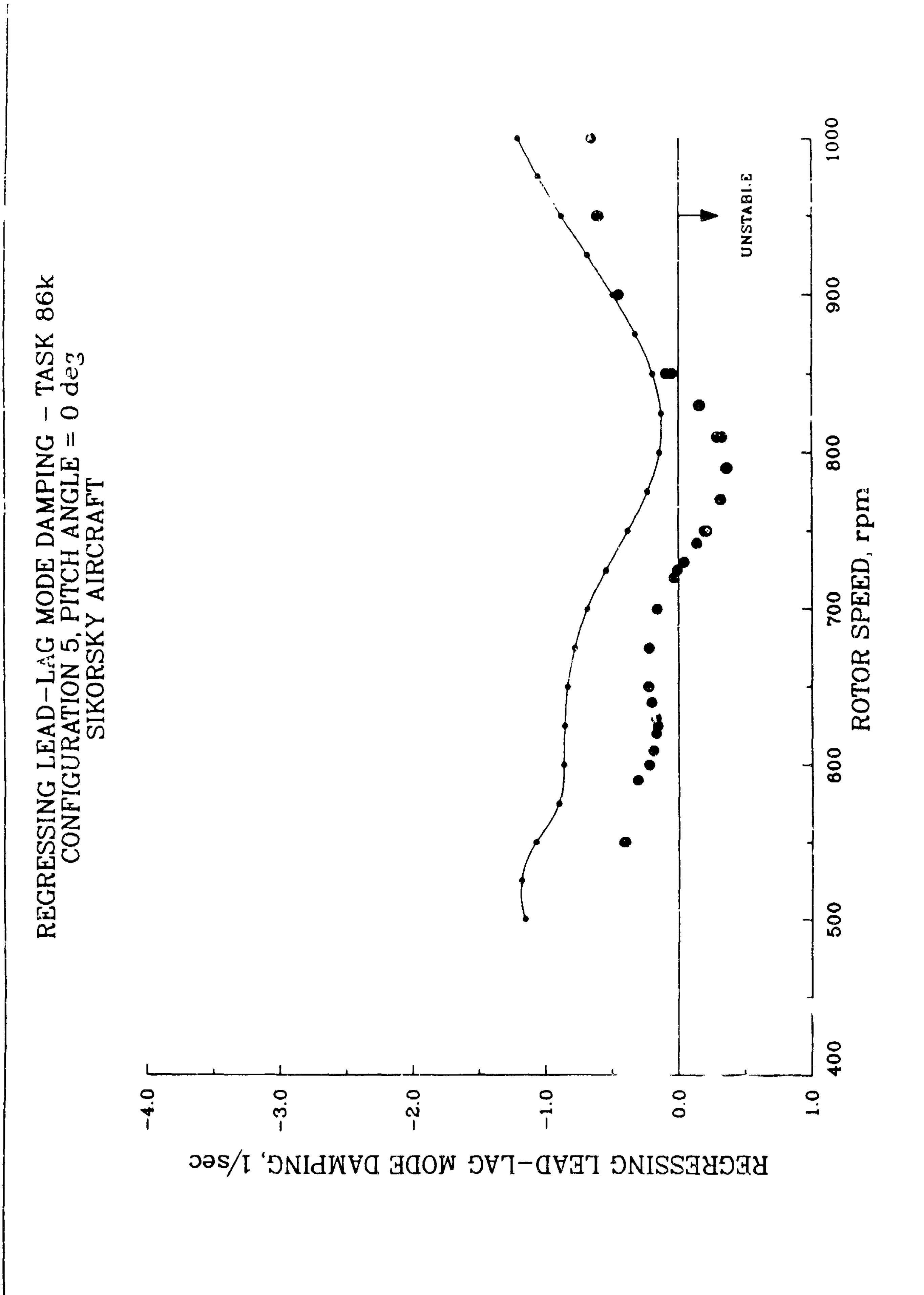


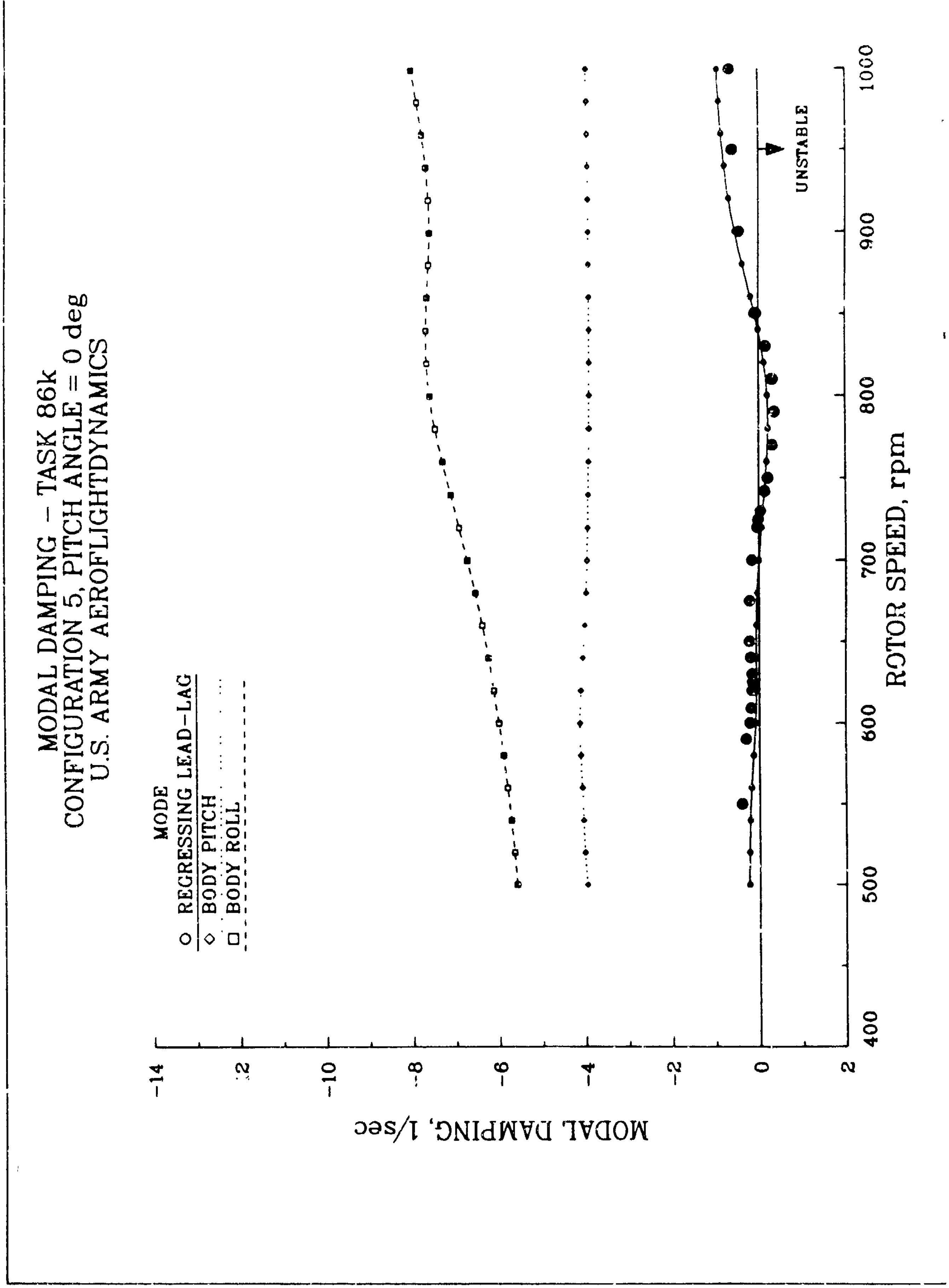

REGRESSING LEAD–LAG MODE DAMPING – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
BELL HELICOPTER TEXTRON
REGRESSING LEAD–LAG MODE DAMPING, 1/sec
-4.0
-3.0
-2.0
-1.0
0.0
1.0
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
UNSTABLE

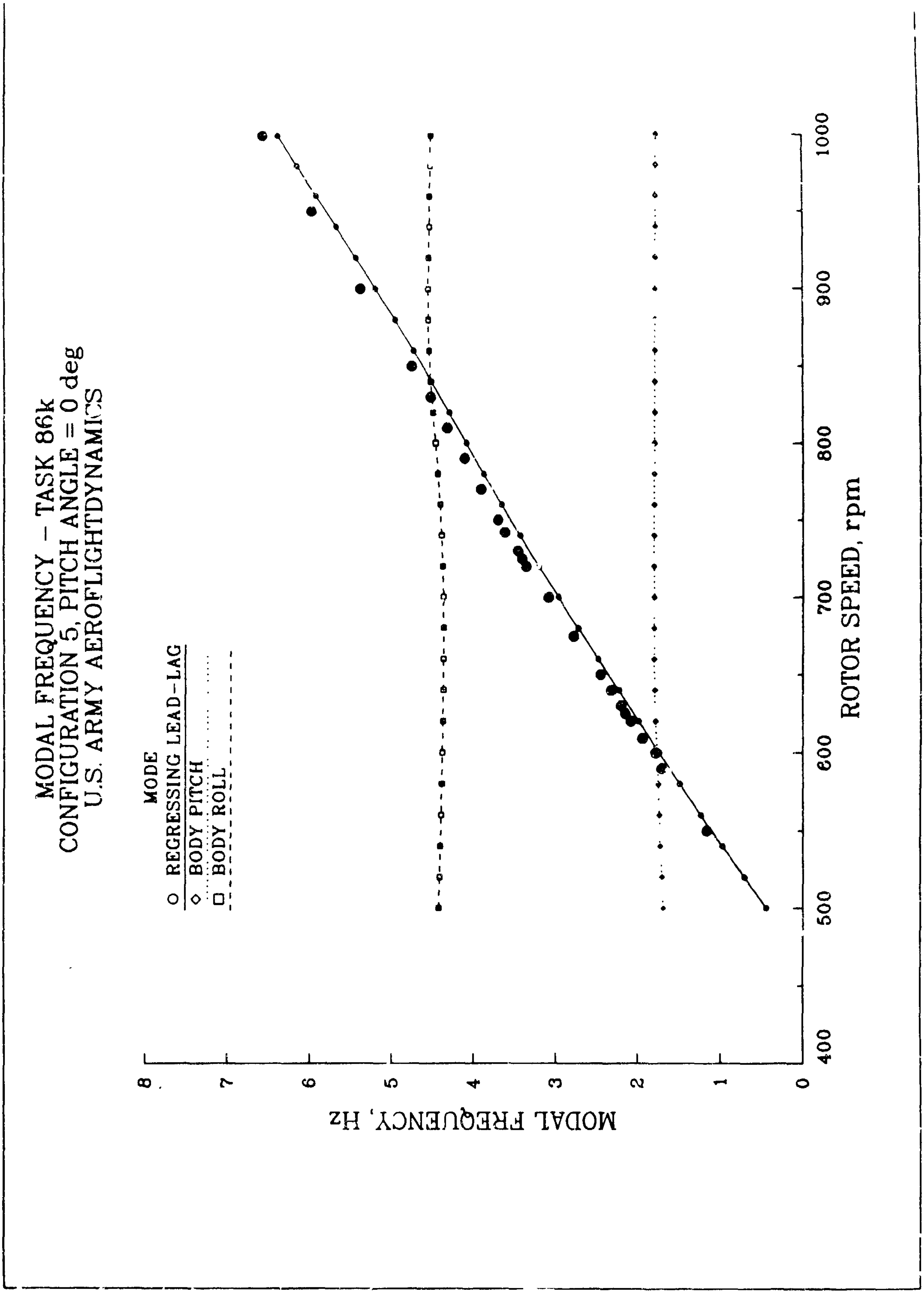

MODAL DAMPING – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
SIKORSKY AIRCRAFT
MODE
○ REGRESSING LEAD-LAG
◇ BODY PITCH
□ BODY ROLL
UNSTABLE
MODAL DAMPING, 1/sec
-14
-12
-10
-8
-6
-4
-2
0
2
ROTOR SPEED, rpm
400
500
600
700
800
900
1000

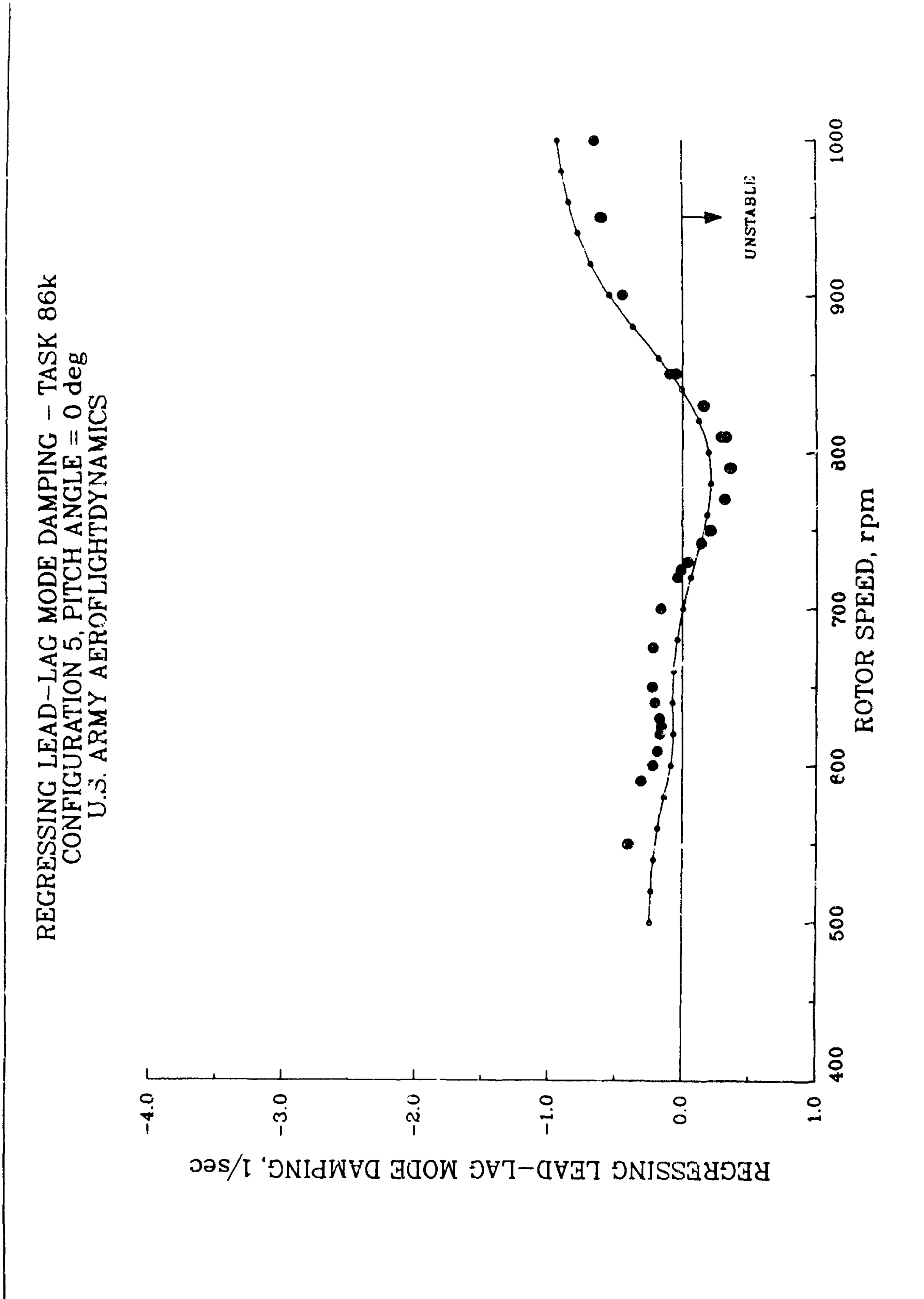
MODAL FREQUENCY — TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
SIKORSKY AIRCRAFT




REGRESSING LEAD–LAG MODE DAMPING – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
SIKORSKY AIRCRAFT
UNSTABLE
REGRESSING LEAD–LAG MODE DAMPING, 1/sec
-4.0
-3.0
-2.0
-1.0
0.0
1.0
400
500
600
700
800
900
1000
ROTOR SPEED, rpm


MODAL DAMPING – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
U.S. ARMY AEROFLIGHTDYNAMICS
MODE
REGRESSING LEAD–LAG
BODY PITCH
BODY ROLL
UNSTABLE
MODAL DAMPING, 1/sec
ROTOR SPEED, rpm
-14
-10
-8
-6
-4
-2
0
2
400
500
600
700
800
900
1000


MODAL FREQUENCY – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
U.S. ARMY AEROFLIGHTDYNAMICS
MODE
○ REGRESSING LEAD-LAG
◇ BODY PITCH
□ BODY ROLL
MODAL FREQUENCY, Hz
ROTOR SPEED, rpm
0
1
2
3
4
5
6
7
8
400
500
600
700
800
900
1000


REGRESSING LEAD–LAG MODE DAMPING – TASK 86k
CONFIGURATION 5, PITCH ANGLE = 0 deg
U.S. ARMY AEROFLIGHTDYNAMICS
UNSTABLE
400
500
600
700
800
900
1000
ROTOR SPEED, rpm
-4.0
-3.0
-2.0
-1.0
0.0
1.0
REGRESSING LEAD–LAG MODE DAMPING, 1/sec

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15. Supplementary Notes

Point of Contact: William G. Bousman, Ames Research Center, MS 215-1
Moffett Field, CA 94035-1000
(415) 604-3748 or FTS 464-3748

16. Abstract

Helicopter rotor aeroelastic and aeromechanical stability predictions for four data sets were made using industry and government stability analyses and compared with data at a workshop held at Ames Research Center, August 2-3, 1988. The present report contains the workshop comparisons.

17. Key Words (Suggested by Author(s)) Aeromechanic stability; Aeroelastic stability; Rotorcraft dynamics	18. Distribution Statement Unclassified-Unlimited Subject Category – 01

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