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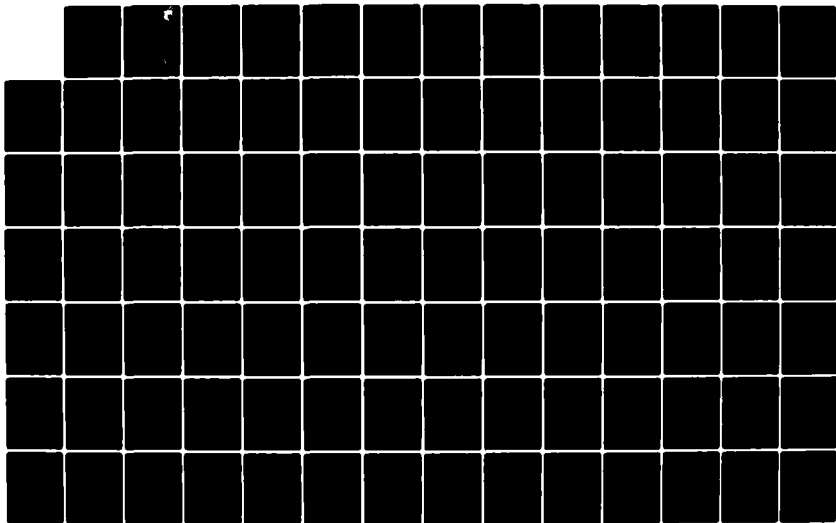
UNSTEADY TRANSONIC PRESSURE MEASUREMENTS ON A SEMI-SPAN
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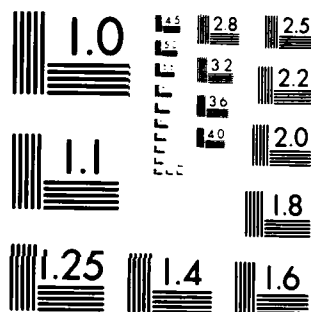
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Part II

UNSTEADY TRANSONIC PRESSURE MEASUREMENTS ON A
SEMI-SPAN WIND TUNNEL MODEL OF A TRANSPORT-
TYPE SUPERCRITICAL WING (LANN MODEL)

PART II: PRESSURE DISTRIBUTIONS (PLOTTED) AND
PLOTS OF THE VIBRATION MODES



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March 1983
Final Report for Period April 1980 - April 1982

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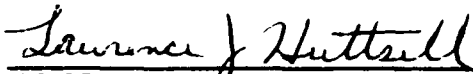
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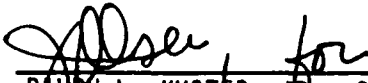


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Part I of the report presents the general description, the aerodynamic coefficients (printed and plotted vs. incidence, reduced frequency and Mach number and the vibration modes.

Part II presents the plotted pressure distributions and vibration modes.

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FOREWORD

AFOSR Grant 80-0136, "Transonic Wind Tunnel Measurements on a Supercritical Wing" was initiated by the Structures and Dynamics Division (FIB) of the Air Force Wright Aeronautical Laboratories (AFWAL). The objective of this effort was to obtain experimental data on a supercritical wing to guide improvements in transonic unsteady aerodynamics.

This effort was a part of a cooperative program involving Lockheed-Georgia, Air Force, NASA, and NLR. This cooperative effort has become known as the LANN program.

The principal investigators at NLR were J. J. Horsten, R. G. den Boer, and R. J. Zwaan. The AFWAL project engineer was L. J. Huttshell and the work unit was 24010236.

Part I of this report presents the general description, the aerodynamic coefficients (printed and plotted vs incidence, reduced frequency, and Mach number) and the vibration modes. Part II presents the plotted pressure distributions and vibration modes. The pressure distributions in tabulated form can be obtained from AFWAL/FIBRC upon request.

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LIST OF SYMBOLS

Note: Coefficients derived from the zeroth harmonic component of unsteady pressure signals, are indicated simply as "steady" coefficients instead of "mean" coefficients. For a pure sinusoidal signal, there is principally no difference between steady and mean coefficients.

a	modulus of pressure tube transfer function, $a = \text{mod}(p_u/p_i)$ (see section 3.1 and figure 6 in part I)
AR	aspect ratio, $AR = 7.92$
AC	aerodynamic center
c	local chord, m
c_{AC}	mean aerodynamic chord, $c_{AC} = 0.268$ m
c_r	root chord, m
c_t	tip chord, m
C_m	steady sectional pitching moment coefficient (see App. A)
C_{mi}	unsteady sectional pitching moment coefficient, $C_{mi} = C_m' + i C_m''$ (see App. A)
C_{mq}	quasi-steady sectional pitching moment coefficient (see App. A)
C_M	steady wing pitching moment coefficient (see App. A)
C_{Mi}	unsteady wing pitching moment coefficient (see App. A)
C_{Mq}	quasi-steady wing pitching moment coefficient (see App. A)
C_{pi}	unsteady pressure coefficient, $C_{pi} = C_p' + i C_p''$ (see App. A)
C_{pi_T}	value of C_{pi} measured with in situ transducer, $C_{pi_T} = p_{i_T}/q_{\infty} \alpha_i = C_{p_T}' + i C_{p_T}''$
C_{pm}	steady pressure coefficient (see App. A)
C_{pq}	quasi-steady pressure coefficient (see App. A)
C_z	steady sectional normal force coefficient (see App. A)
C_{zi}	unsteady sectional normal force coefficient, $C_{zi} = C_z' + i C_z''$ (see App. A)
C_{zq}	quasi-steady sectional normal force coefficient (see App. A)
C_Z	steady wing normal force coefficient (see App. A)
C_{Zi}	unsteady wing normal force coefficient, $C_{Zi} = C_Z' + i C_Z''$ (see App. A)
C_{Zq}	quasi-steady wing normal force coefficient (see App. A)

DZ	ratio of acceleration pick-up signal and LVDT displacement signal, $DZ = DZ' + i DZ''$
DZ_1	amplitude of LVDT displacement, mm
f, FREQ	frequency, Hz
harm, HARM	harmonic component (harm = 0: mean, harm = 1: 1st harmonic, harm = 2: 2nd harmonic)
i	$\sqrt{-1}$
k, REDFR.	reduced frequency, $k = \pi f c_{AC}/V$
M, Mach, MACH	free stream Mach number
M	steady sectional pitching moment about quarter-chord, Nm/m (see App. A)
Mi	unsteady sectional pitching moment about quarter-chord, Nm/m/rad (see App. A)
$M_{i_{wing}}$	unsteady wing pitching moment about aerodynamic center, Nm/rad (see App. A)
M-LOC	local Mach number
M_1	quasi-steady sectional pitching moment about quarter-chord, Nm/m/rad (see App. A)
$M_{q_{wing}}$	quasi-steady wing pitching moment about aerodynamic center, Nm/rad (see App. A)
M_{wing}	steady wing pitching moment about aerodynamic center, Nm (see App. A)
N_m	number of acceleration pick-ups, $N_m = 12$
N_p	number of pressure tubes at each section, $N_p = 40$
N_s	number of sections, $N_s = 6$
N_T	number of transducers, $N_T = 12$
p	pressure at model surface, $p = p_m + p_i$, Pa
p, P-SETTL.	stagnation pressure, Pa
p_i	nth harmonic component of unsteady pressure at model surface, $p_i = p_i \exp[i(\omega t)]$, Pa (see Fig. 6 in part I)
p_{iT}	value of p_i measured with in-situ transducer
p_m	mean pressure, Pa
p_q	amplitude of quasi-steady pressure oscillation, $p_q = [p_m(\alpha_m + \Delta\alpha) - p_m(\alpha_m - \Delta\alpha)]/2$, Pa
p_u	nth harmonic component of unsteady pressure at the end of a pressure tube, $p_u = p_u \exp[i(\omega t + \phi)]$, Pa (see Fig. 6 in part I)
q_∞ , Q	free-stream dynamic pressure, Pa

Re, RE	Reynolds number, $Re = Vc_{AC}/\nu$
s	semi-span, $s = 1.000$ m
S	wing surface, $S = 0.2526$ m ²
t	airfoil thickness, m
t	time, s
T	model temperature, deg cent.
T-SETTL.	stagnation temperature, deg cent.
V	free-stream velocity, m/s
WRP	Wing Reference Plane (see Fig. 1) (X-y plane)
x	$x = X - X_{\text{leading}}$
x_{tr}	x-coordinate of boundary layer transition strip
X	coordinate in free-stream direction, m (see Fig. 1)
X_r	X-coordinate of rotation axis, m (see Fig. 1)
y	spanwise coordinate, m (see Fig. 1)
z	coordinate normal to the X-y plane, m
Z	steady sectional normal force, N/m (see App. A)
Zi	unsteady sectional normal force, N/m/rad (see App. A)
Zi_{wing}	unsteady wing normal force, N/rad (see App. A)
Zq	quasi-steady sectional normal force, N/m/rad (see App. A)
Zq_{wing}	quasi-steady wing normal force, N/rad (see App. A)
Z_{wing}	steady wing normal force, N (see App. A)
α , alpha, ALFA	wing incidence at LVDT position, $\alpha = \alpha_m + \alpha_i$, deg
α_i	unsteady wing incidence at LVDT position, $\alpha_i = \alpha_i \exp(i\omega t) = \Delta\alpha \exp(i\omega t)$, deg
α_m	steady wing incidence at LVDT position, deg
$\Delta\alpha$, Dalphi, DALFA	amplitude of unsteady wing incidence at LVDT position $\Delta\alpha = \alpha_i $, deg
φ	phase of tube transfer function, $\varphi = \arg(p_u/p_i)$
η	relative spanwise coordinate, $\eta = y/s$
$\Lambda_{0.25}$	sweep angle of quarter chord line, deg
ν	kinematic viscosity (m ² /s)
ω	angular velocity, $\omega = 2\pi f$, rad/s
θ	local wing incidence, deg (see Fig. 1)
θ	wing twist, $\theta = \theta_t - \theta_r$, deg (see Fig. 1)

+ upper $z < 0$ (see Fig. 1)
- lower $z > 0$ (see Fig. 1)
 ∞ free-stream

TABLE 1
Steady test program for LANN model (run numbers)

$\alpha \backslash M$	0.62	0.72	0.77	0.82	0.87	0.95
-0.4	16	27	46	67	88	97
0.35	17			68		
0.60*)	15/19	28	47	69	89	98
0.85	18			70		
1.60	20	29	48	71	90	99
2.00	183			218		
2.35	235	238	240	132		155
2.50				219		
2.60*)	234	109	121	222/133		154
2.75				220	242	245
2.85	236	237	241	134		156
2.90				231		230
3.00*)	184			221	168	246
3.25				223	244	247
3.50				224		
3.60	104/232	110	122	135		157
4.00				225	169	248
4.50				226		
4.75			201	205		
5.00*)	185	193	202	206		228
5.25			203	207		
5.50				227		
6.00	186	194	204	208		229

*) Steady incidences for which unsteady measurements were performed as well

TABLE 2

Unsteady test program for LANN model (run numbers)

f		12	24	36	48	60	72
$\Delta\alpha$		1.0	0.25	0.25	0.25	0.25	.025
α	M						
0.6	0.62	36	129/22	23	24	25	26
	0.72		30		31	32	33
	0.77	117	118	119	120	65	66
	0.82	83	73	77	85	86	87
	0.87	91	92	93	94	95	96
	0.95		100		101	102	103
2.6	0.62		105		106	107	108
	0.72	111	112	113	114	115	116
	0.77	123	124	125	126		128
	0.82	139	143	150	151	152	153
3.0	0.72		165				
	0.77		166				
	0.82		167				
	0.87		170		171	172	173
	0.95	250	175	179	180	181	182
5.0	0.62	187	188	189	190	191	192
	0.72	195	196	197	198	199	200
	0.82	211	212	214	215	216	217

TABLE 3
 Test program for amplitude variation and higher harmonics
 for LANN model (run numbers)

M	α	f	$\Delta\alpha$	0.125	0.25	0.5	1.0
			harm				
0.62	0.6	12	1	34	21	35	36
		24	1	37	22/39/129	42	
		24	2		40/130	43	
		24	3		41/131	44	
		36	1	45	23		
0.82	0.6	12	1		72	82	83
		24	1	78	73	79	
		24	2		74	80	
		24	3		75	81	
		36	1	76	77		
0.82	2.6	12	1	136	137	138	139
		24	1	140	143	146	
		24	2	141	144	147	
		24	3	142	145	148	
		36	1	149	150		
0.95	2.6	12	1		161	162	163
0.95	3.0	24	1		175	178	
		24	2		176		
		24	3		177		
0.82	5.0	12	1		209	210	211
		24	1		212	213	

TABLE 4
Miscellaneous runs for LANN-model

run number	α	M	f	$\Delta\alpha$	harm
38	0.6	0.62	24.0	0.50	1
84	0.6	0.82	18.0	0.50	1
127	2.6	0.77	50.0	0.25	1
164	3.0	0.95	12.0	0.50	1
174	3.0	0.95	12.0	0.50	1
158	0.6	0.95	30.1	0.05	1
159	0.6	0.95	30.1	0.05	2
160	0.6	0.95	30.1	0.05	3
253	4.0	0.00	12.0	0.25	1
254	4.0	0.00	24.0	0.25	1
255	4.0	0.00	36.0	0.25	1
256	4.0	0.00	48.0	0.25	1
257	4.0	0.00	60.0	0.25	1
258	4.0	0.00	72.0	0.25	1

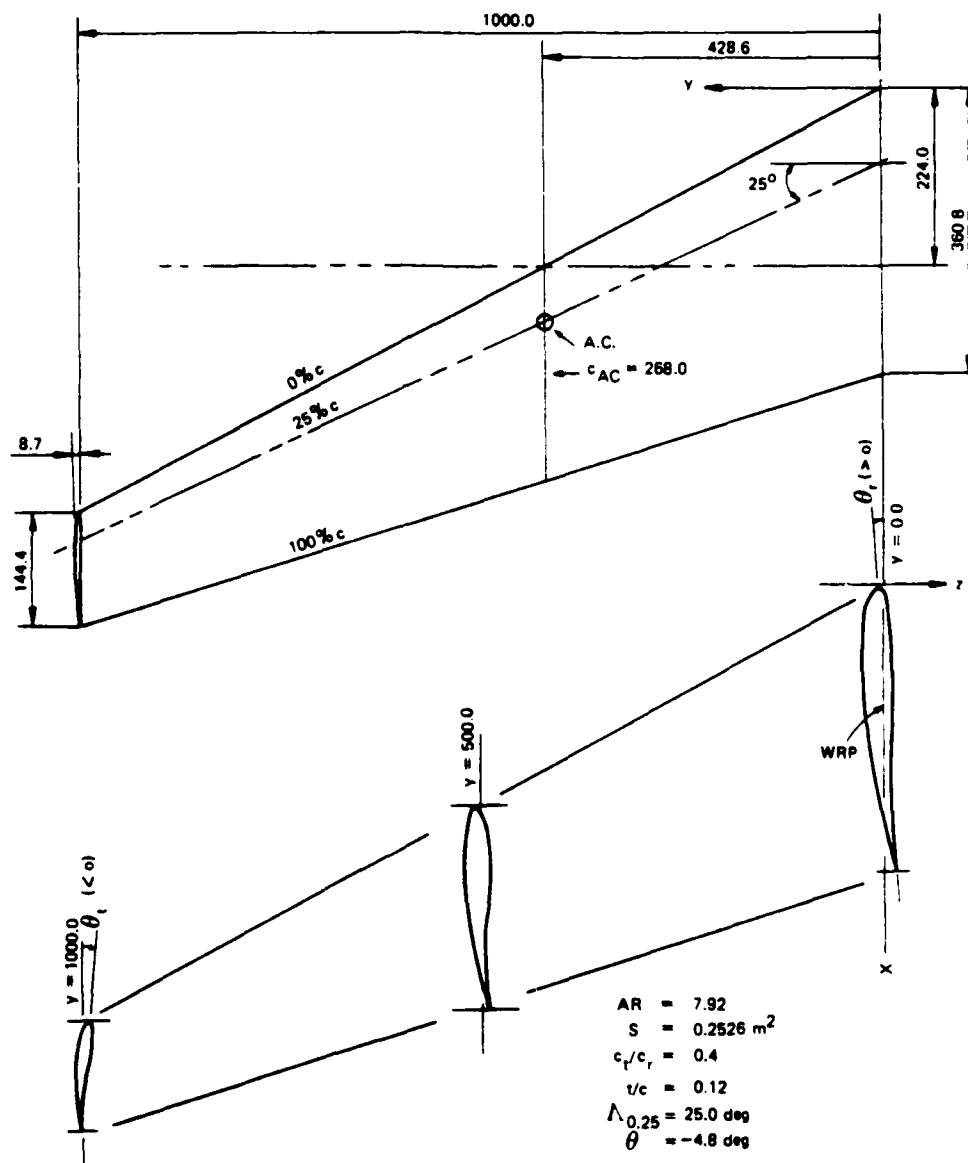
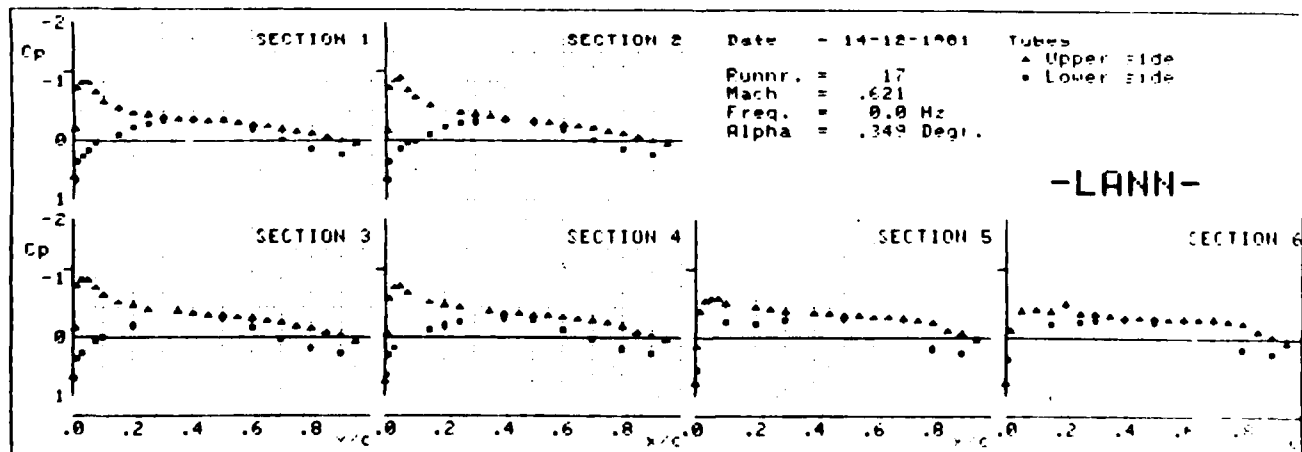
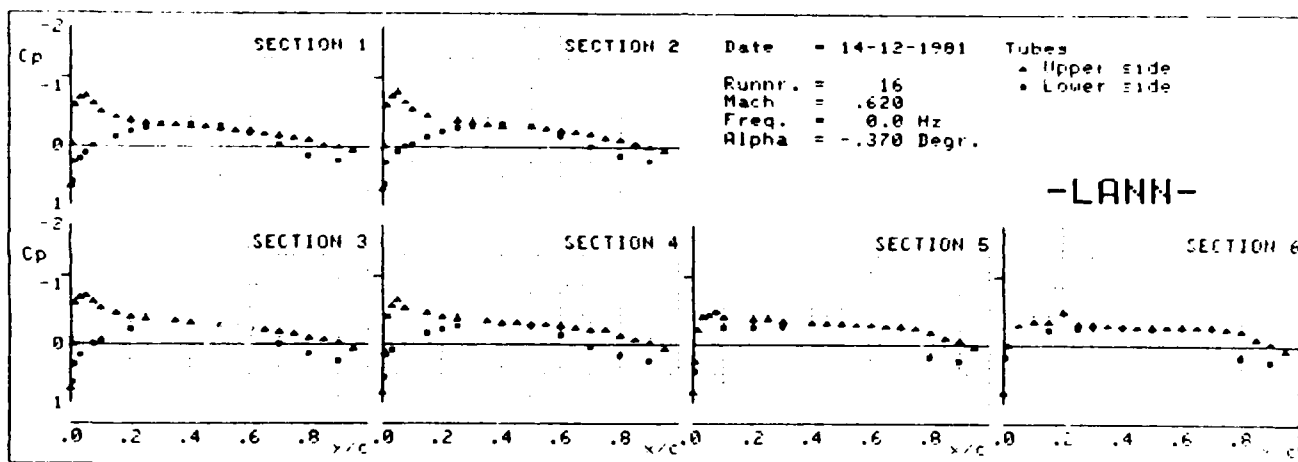
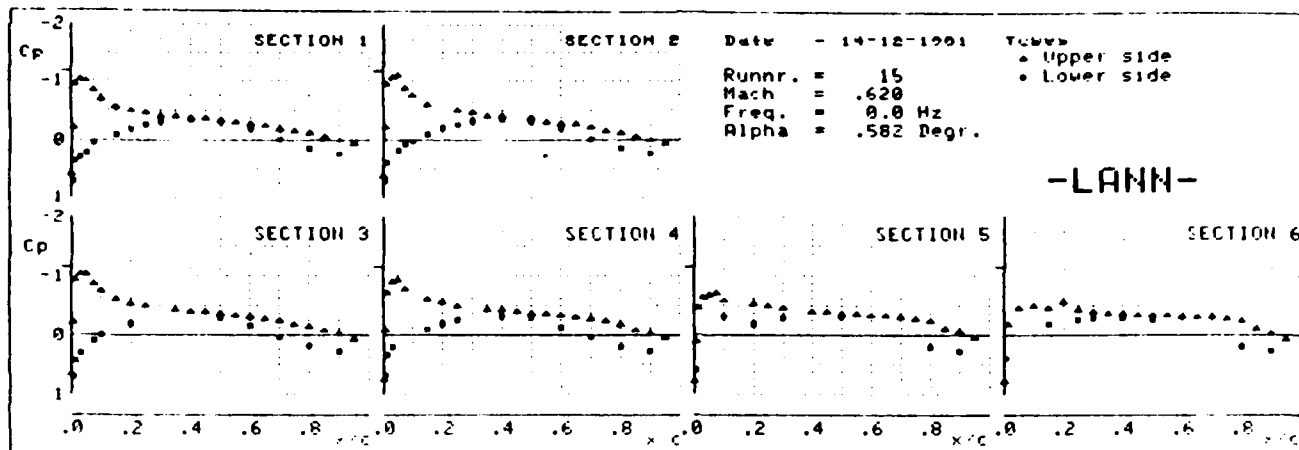
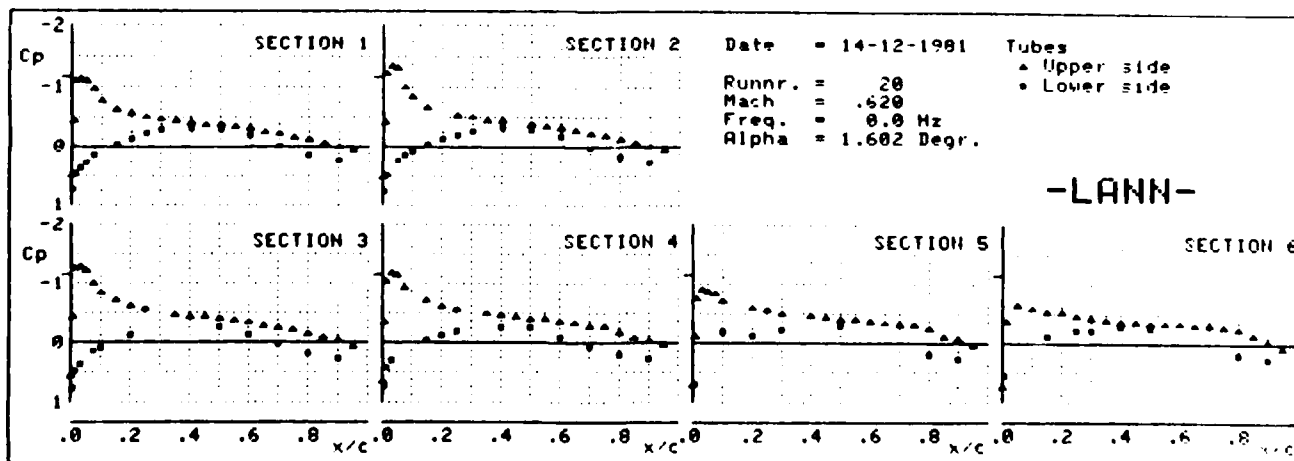
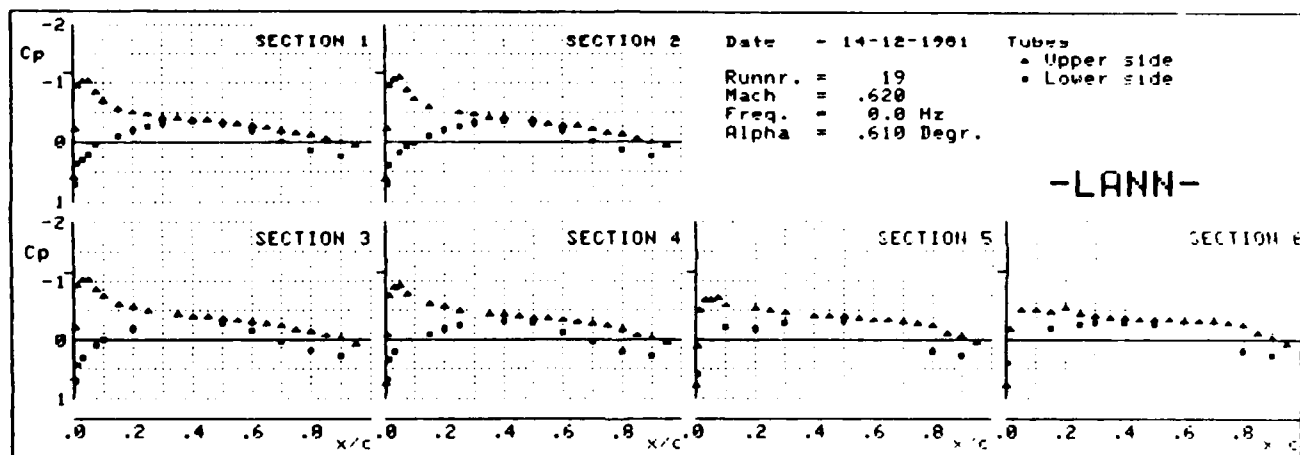
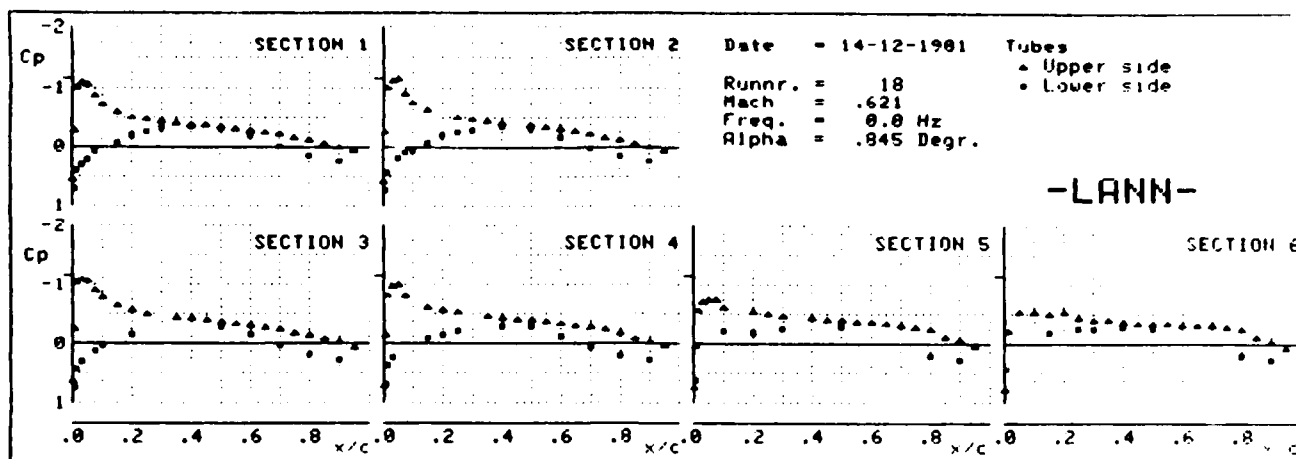
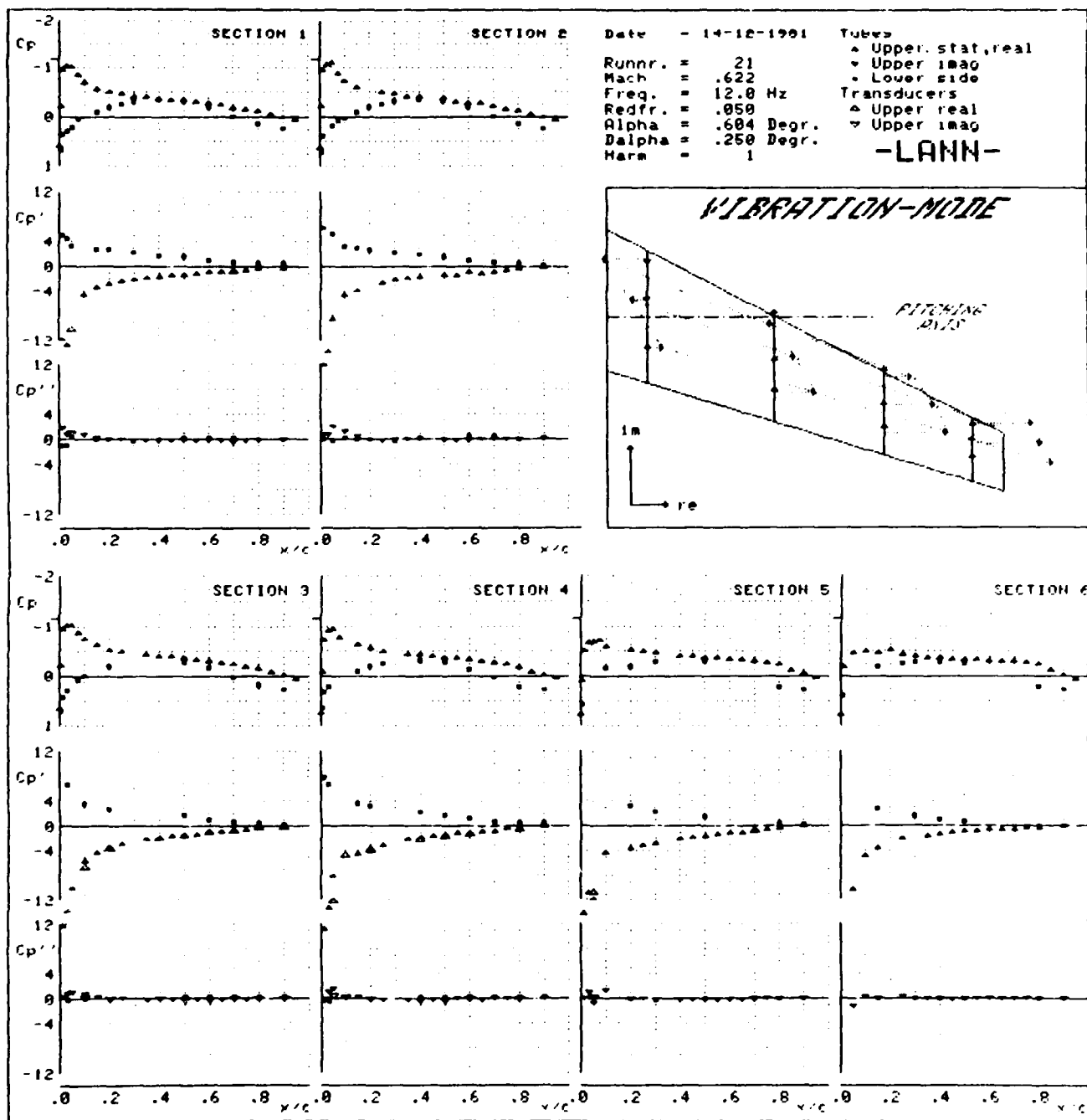
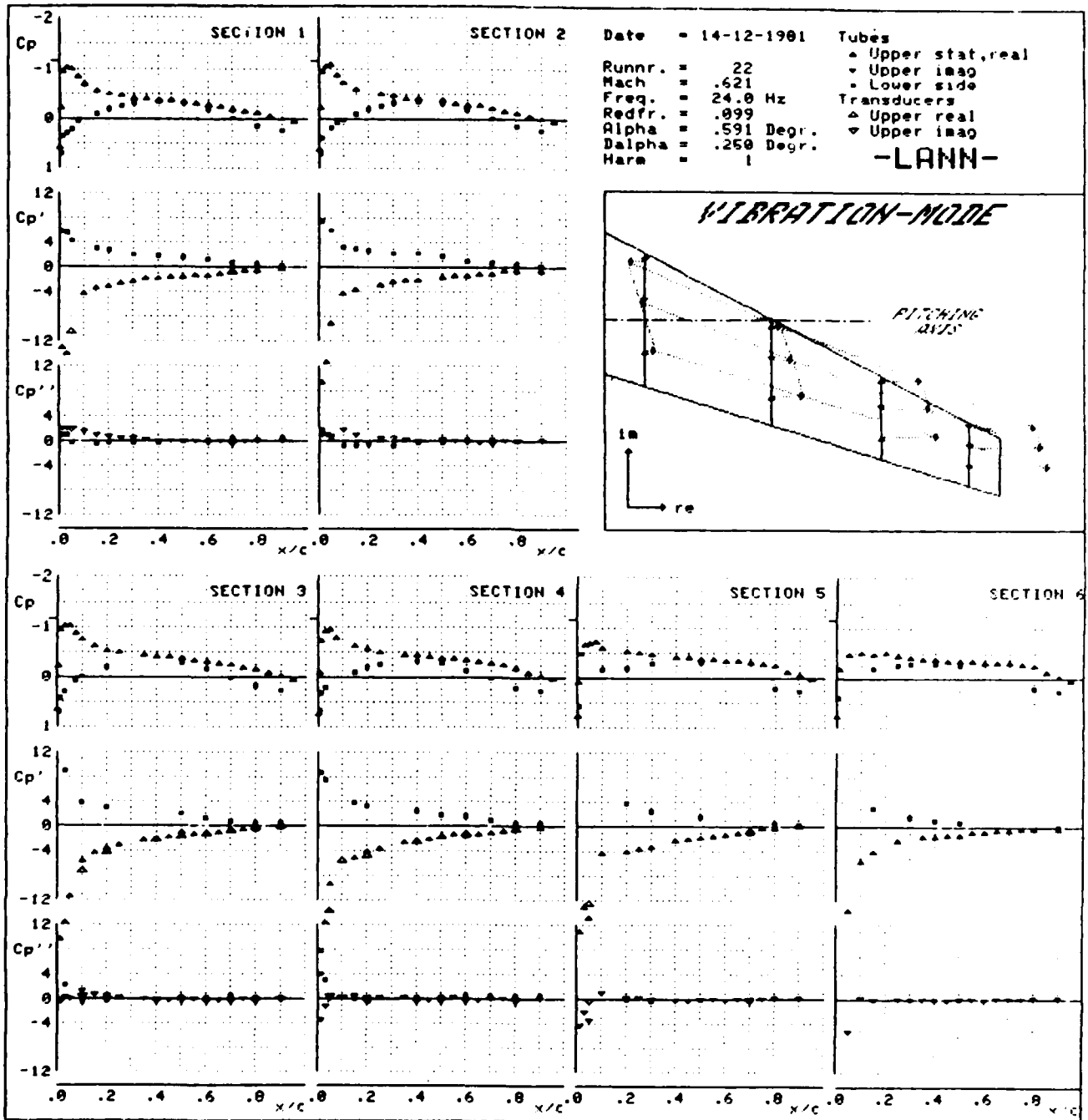


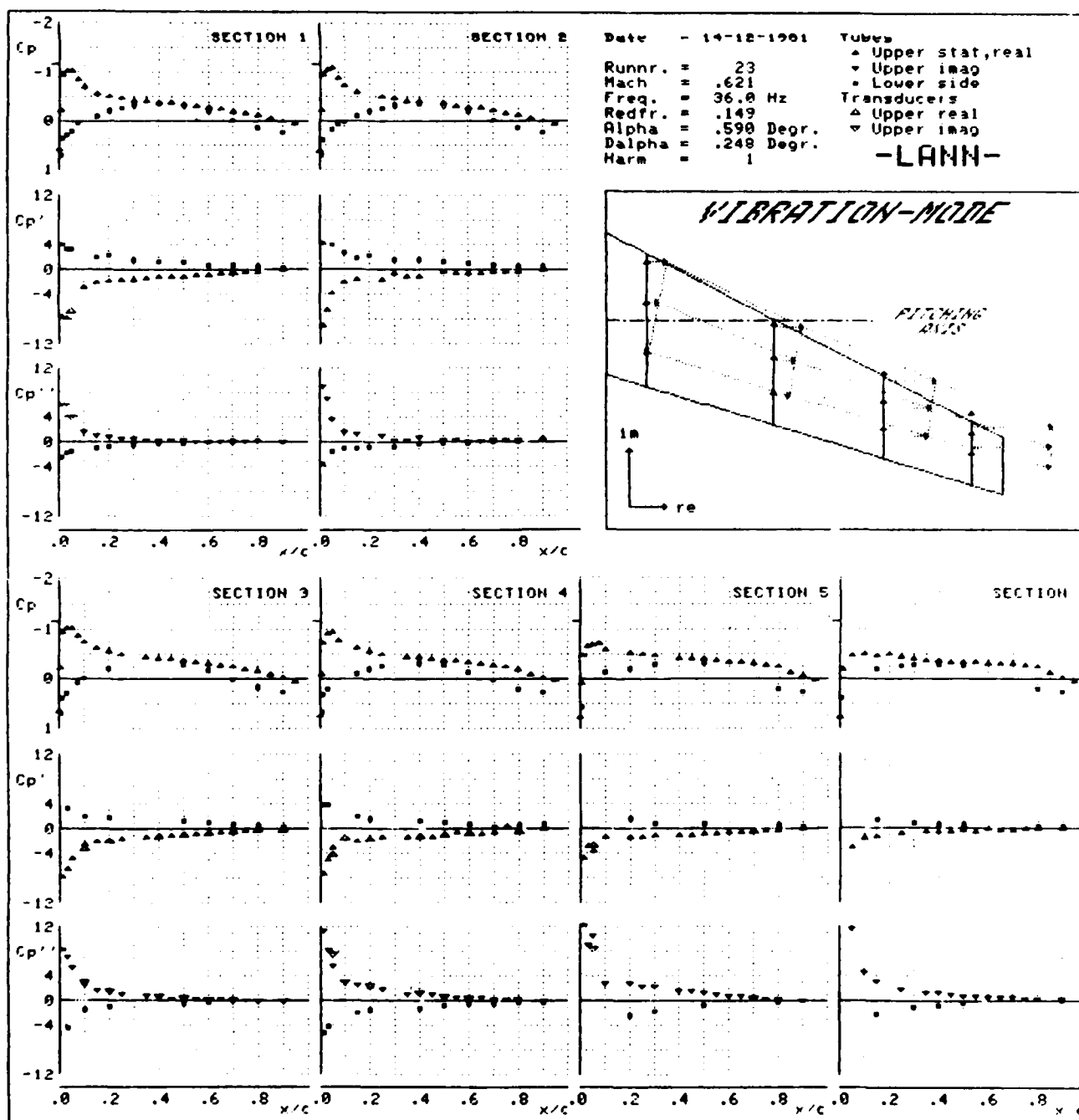
Fig. 1 Wing planform (dimensions in mm)

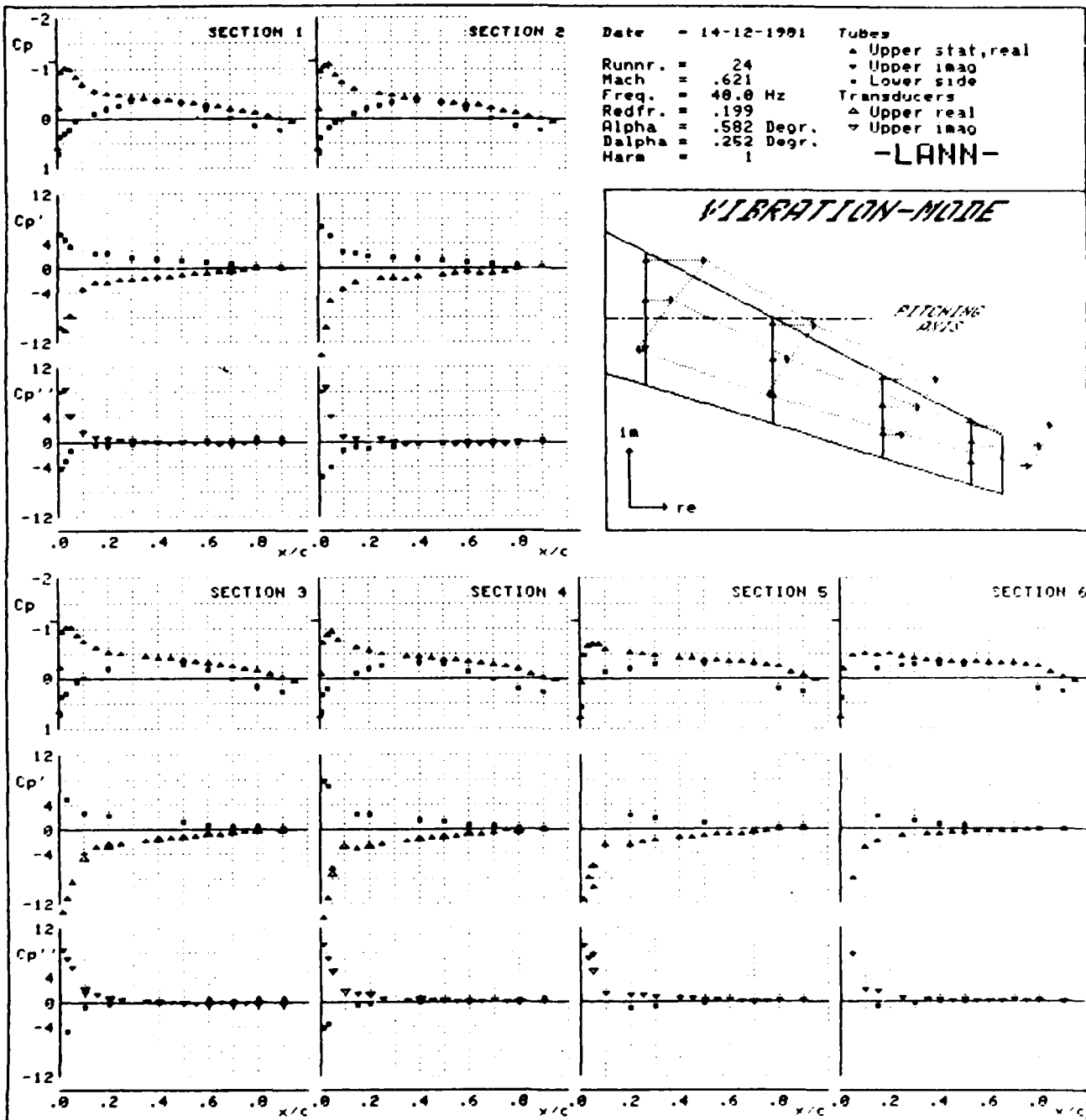


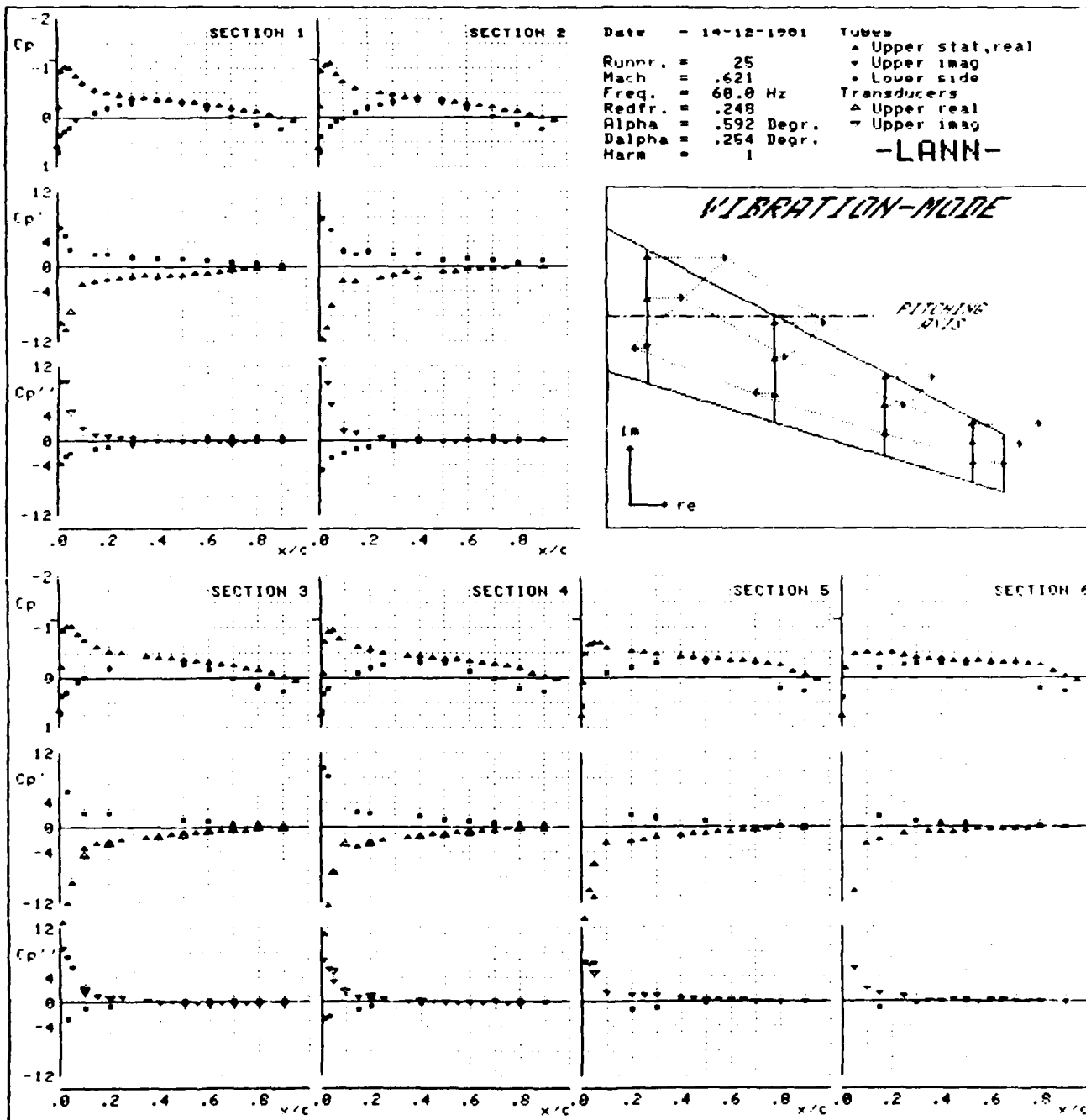


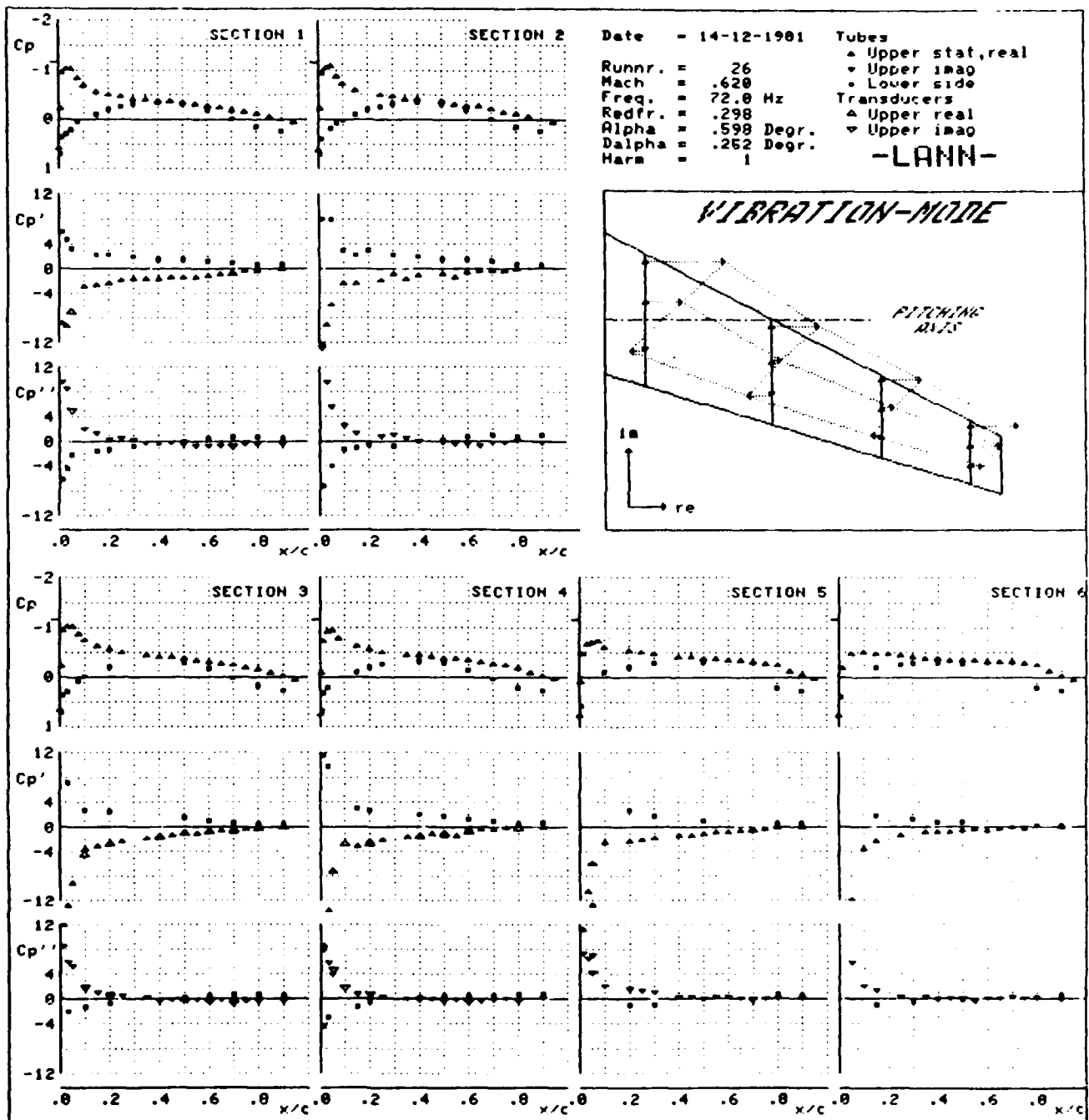


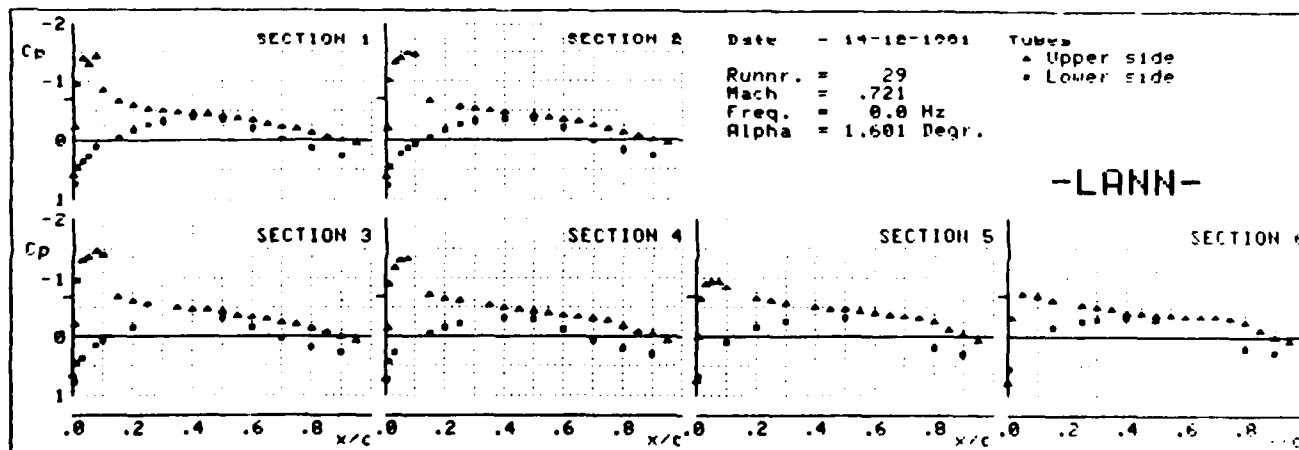
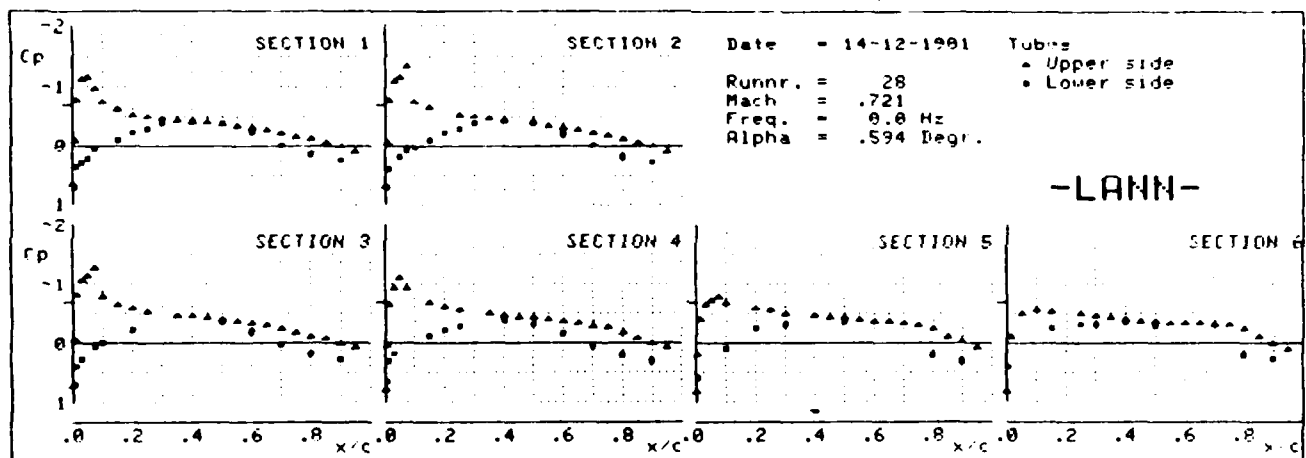
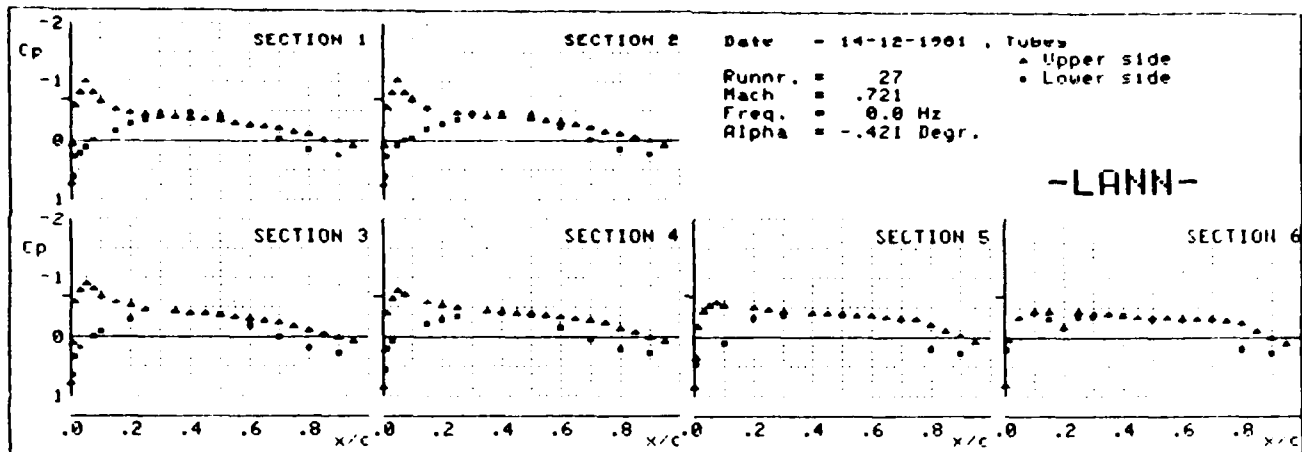


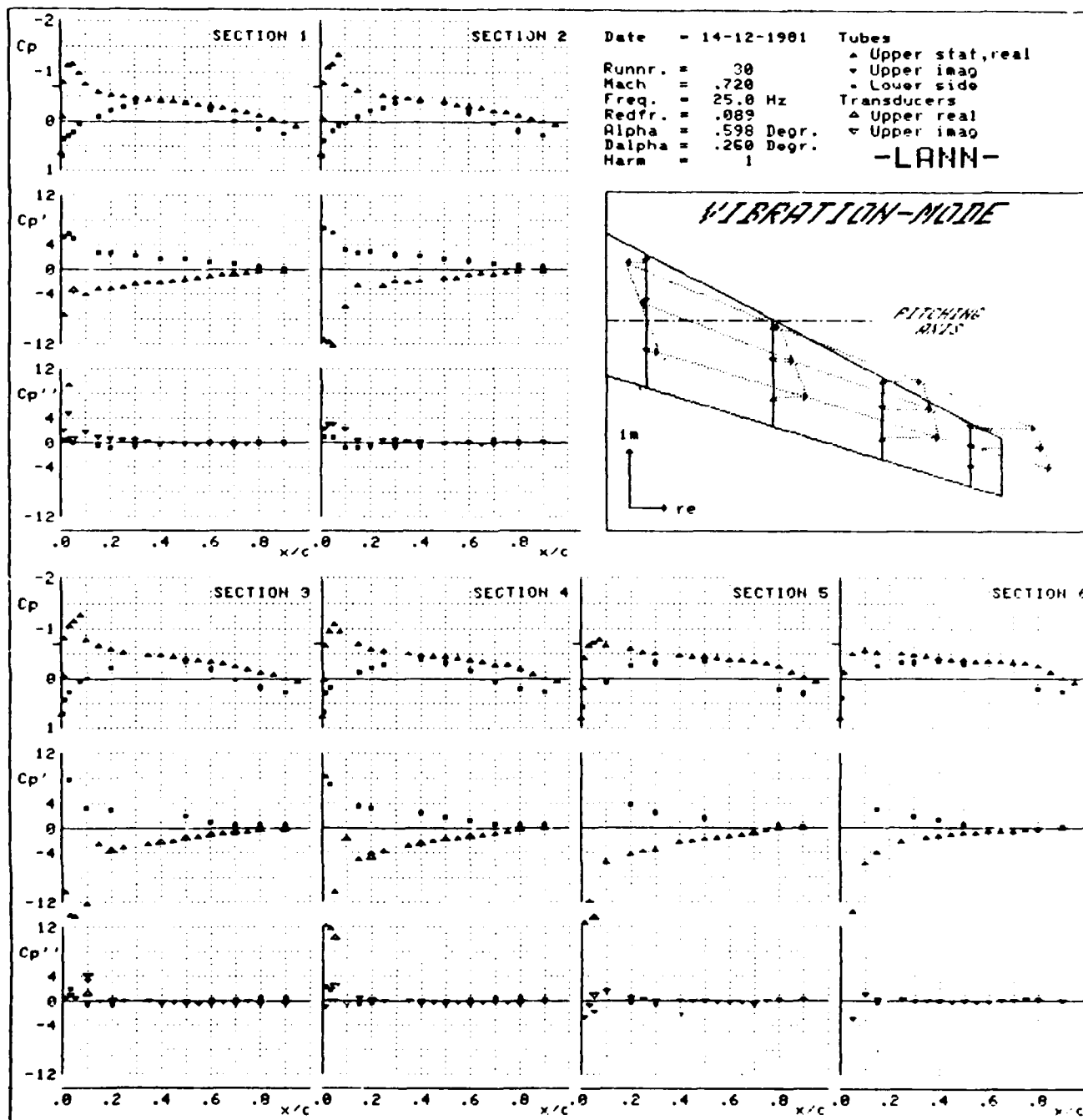


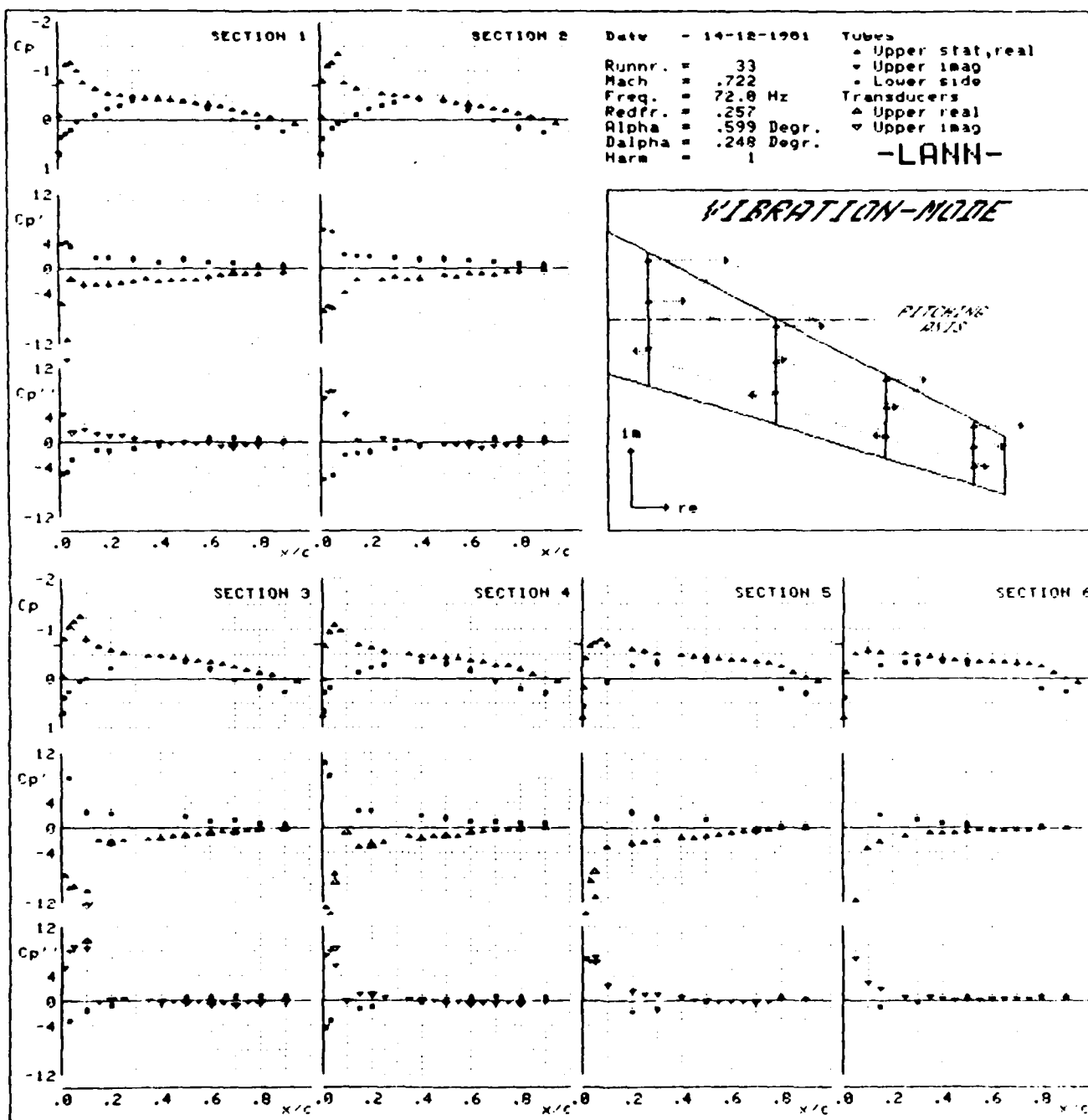


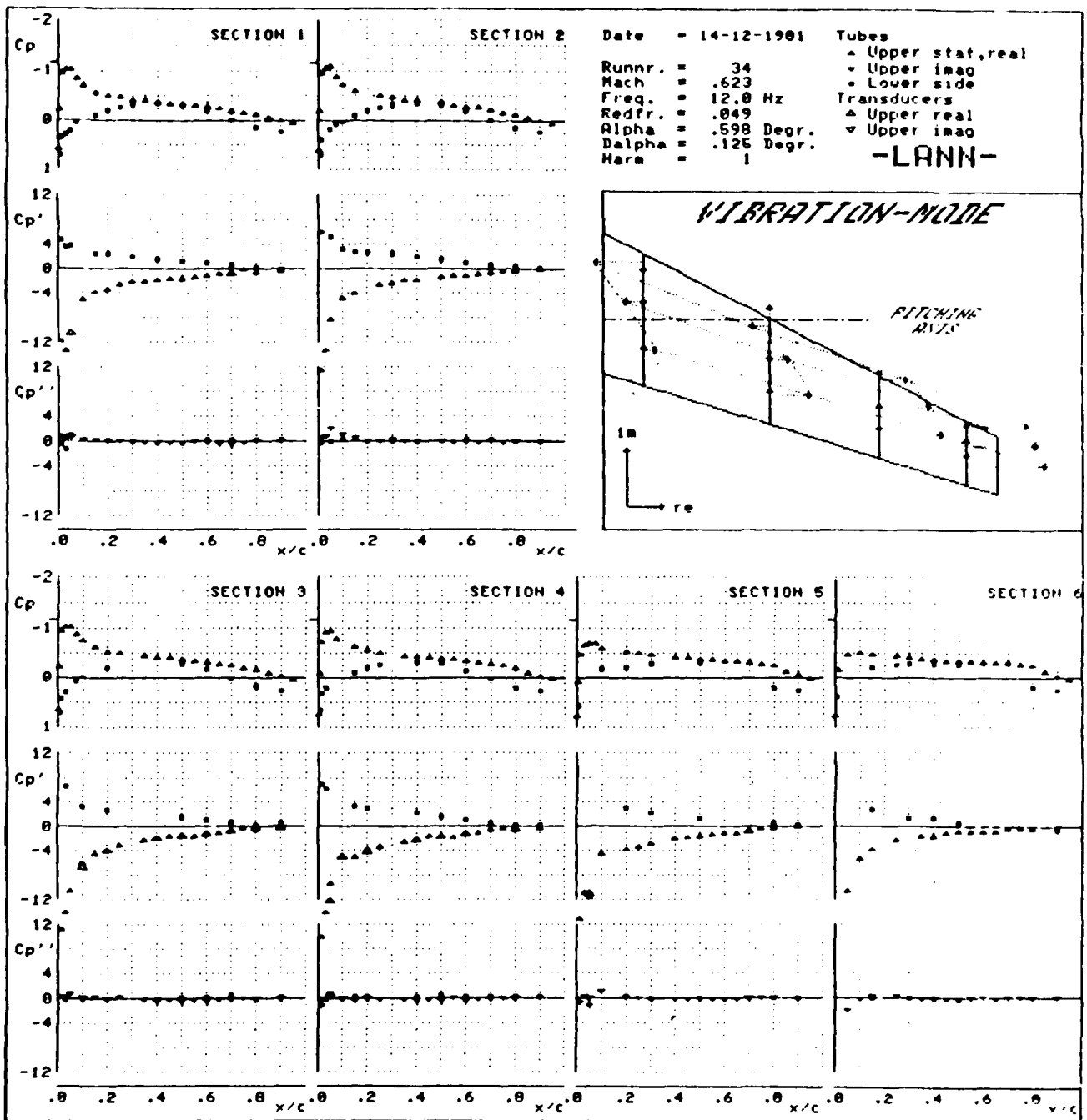


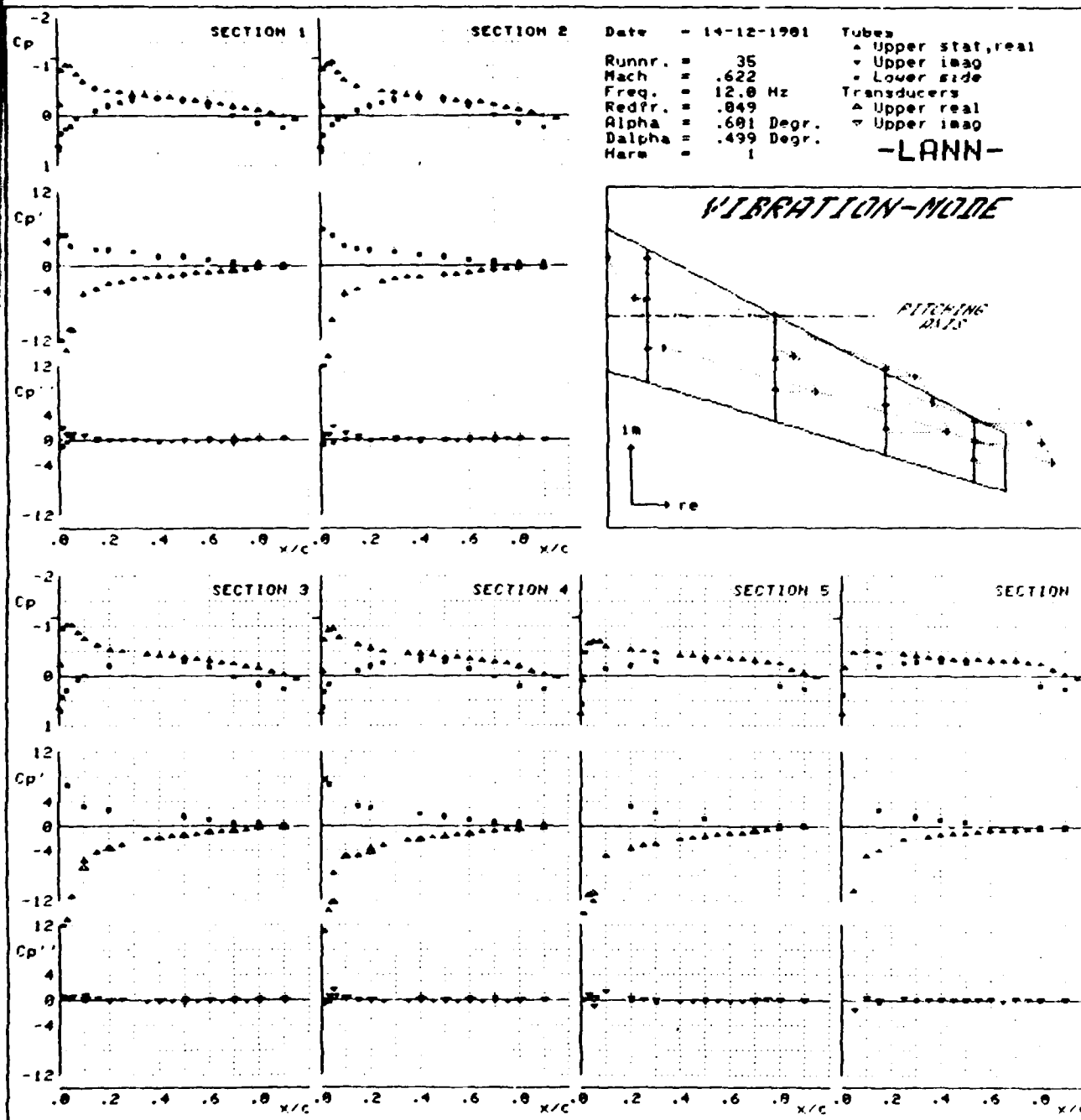


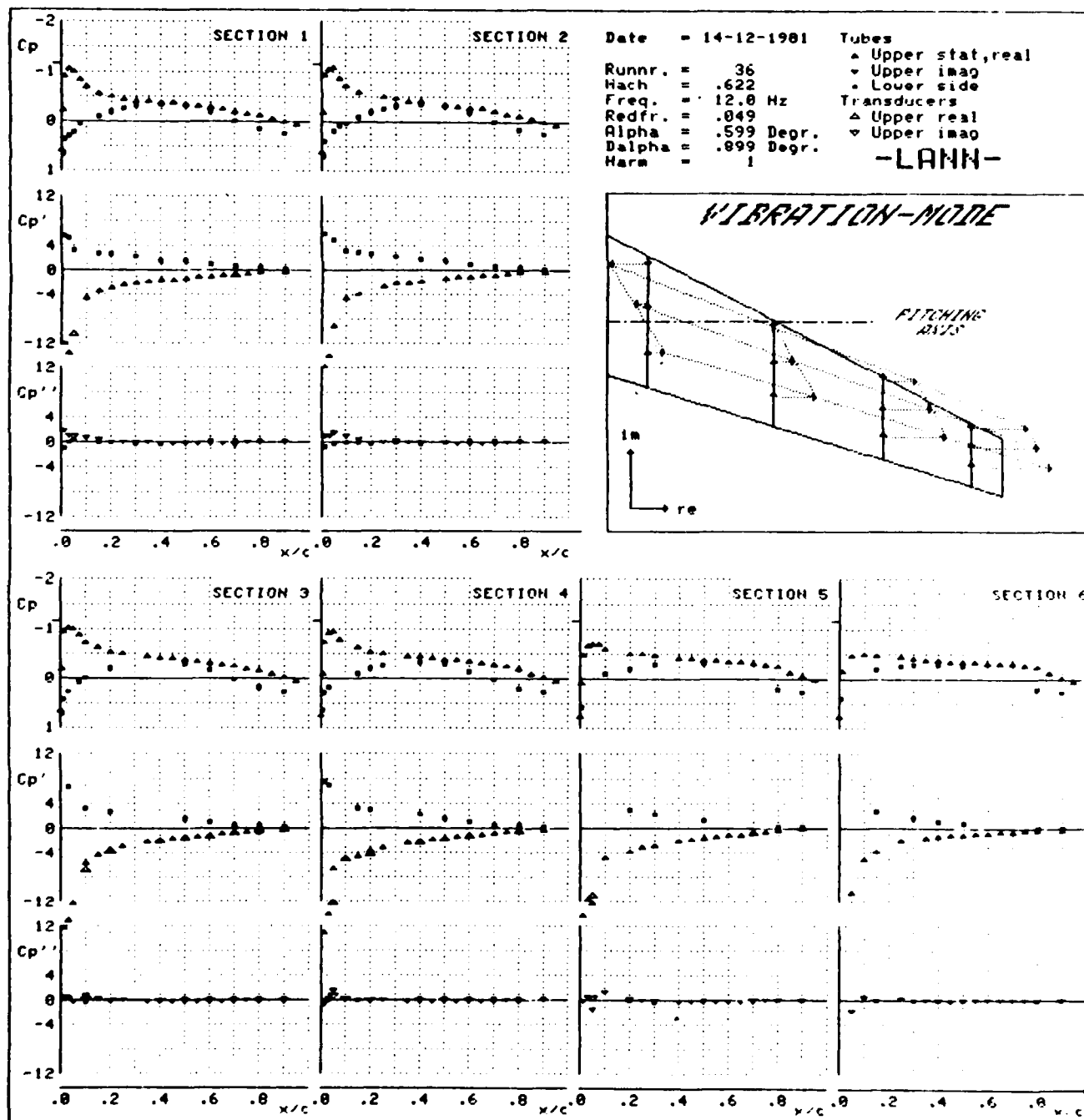


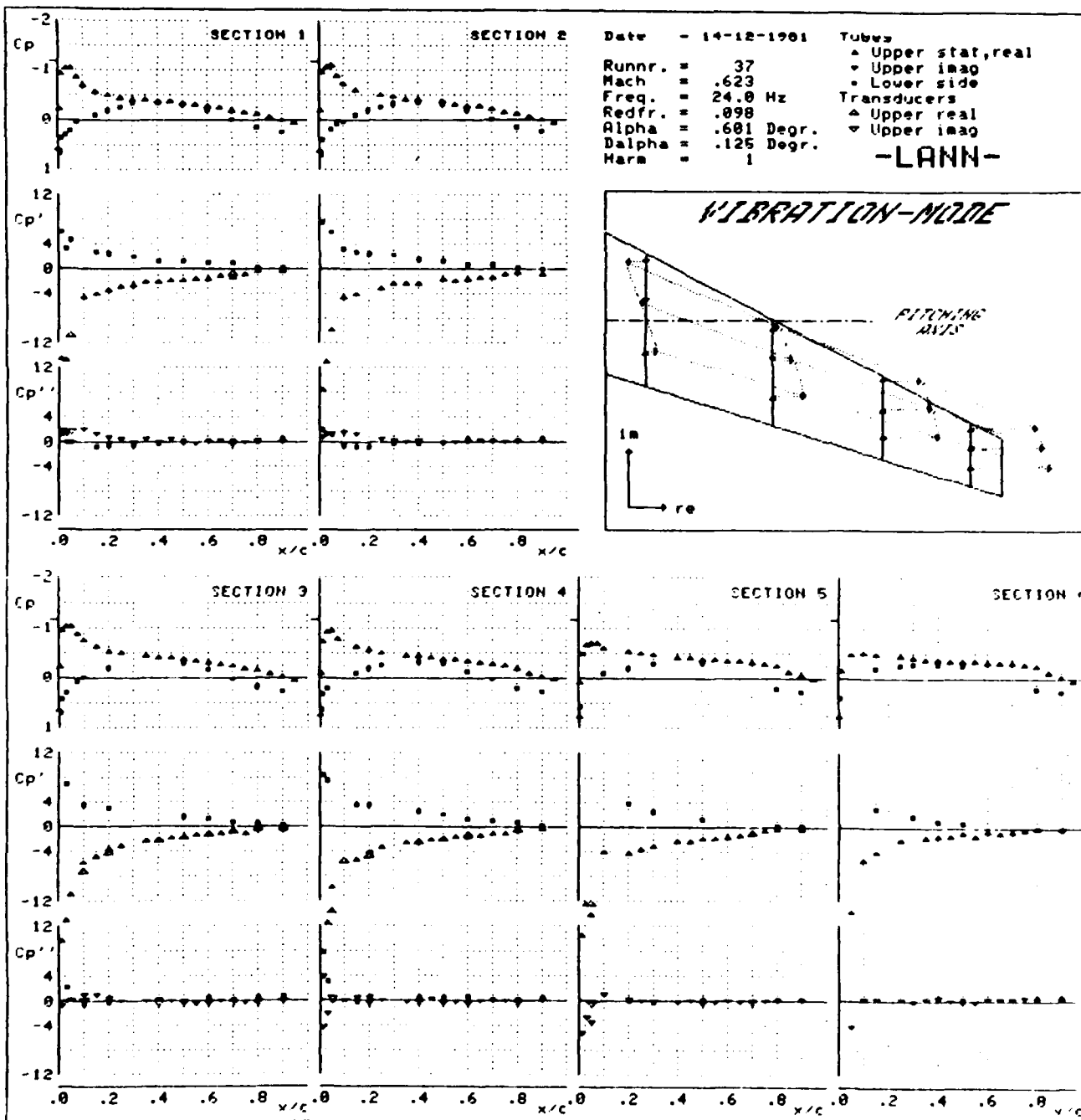


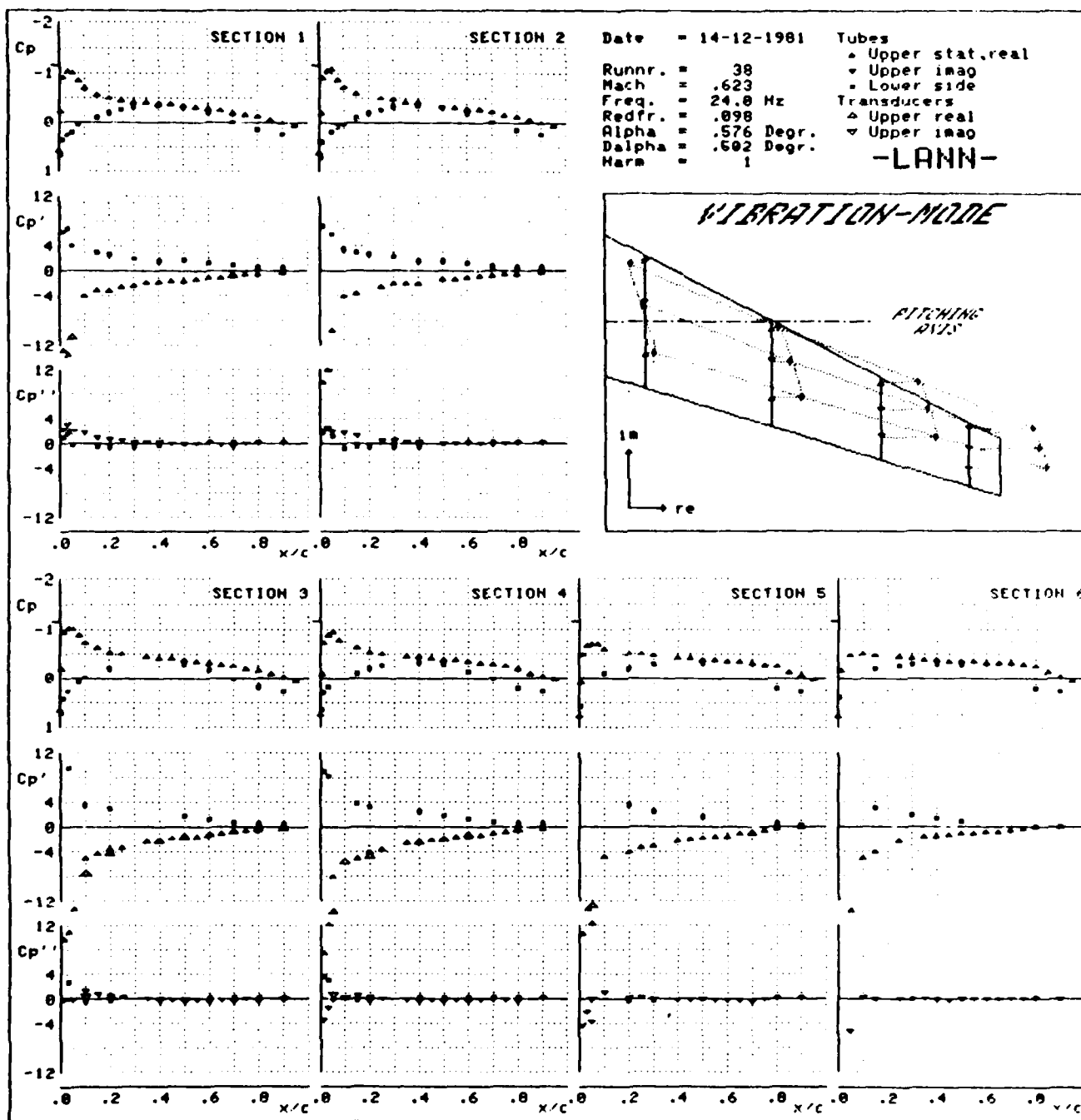


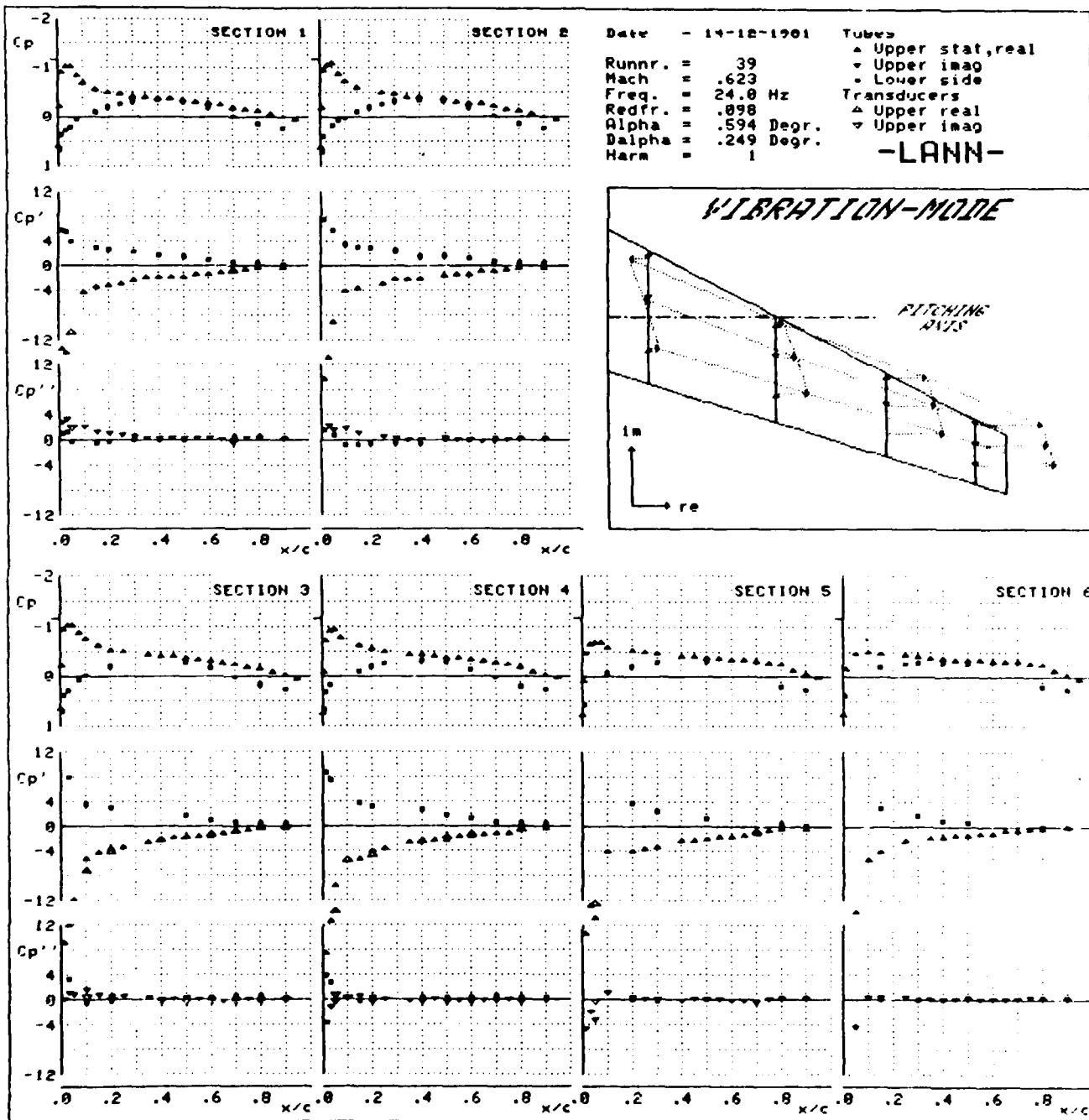


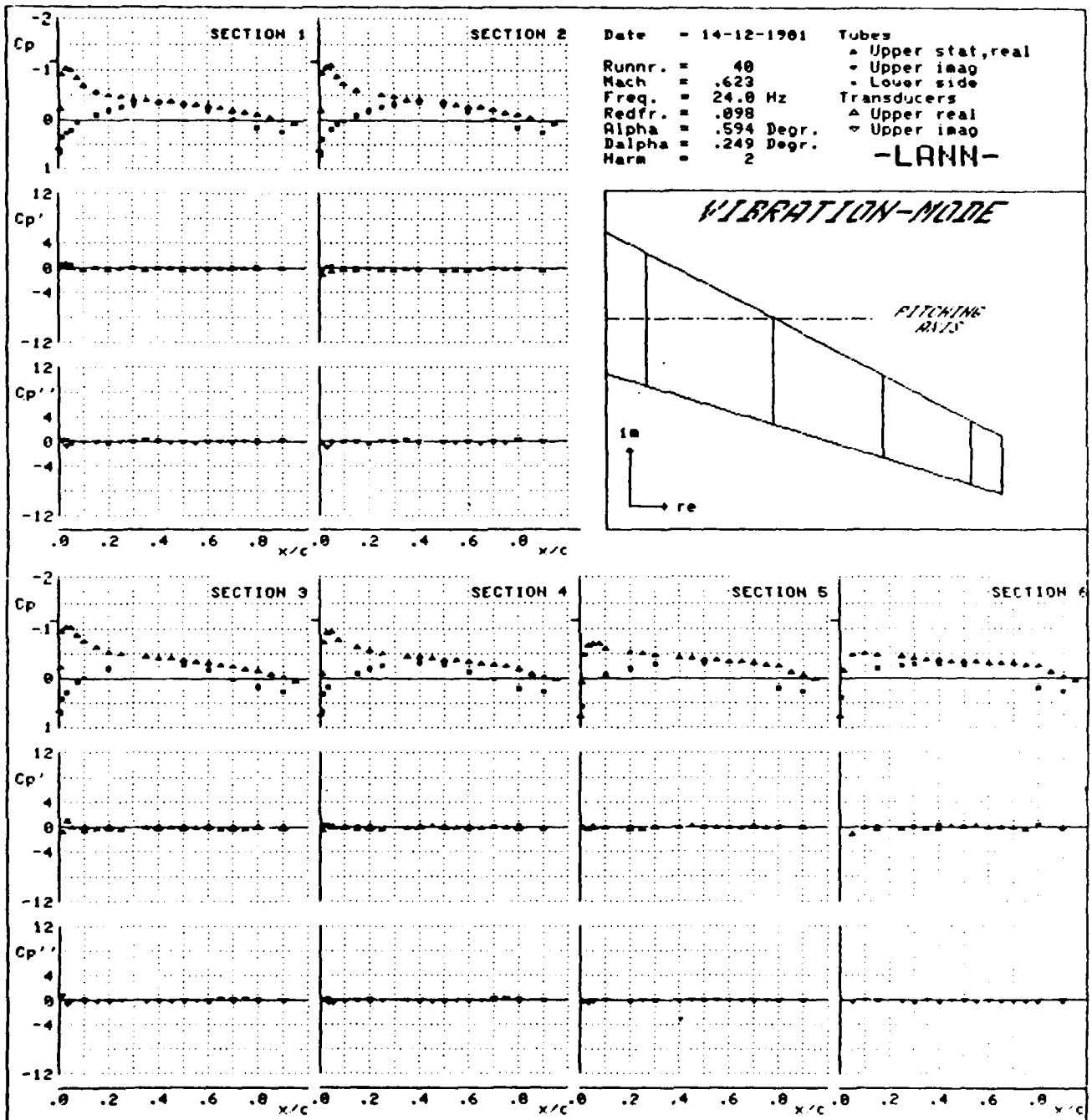


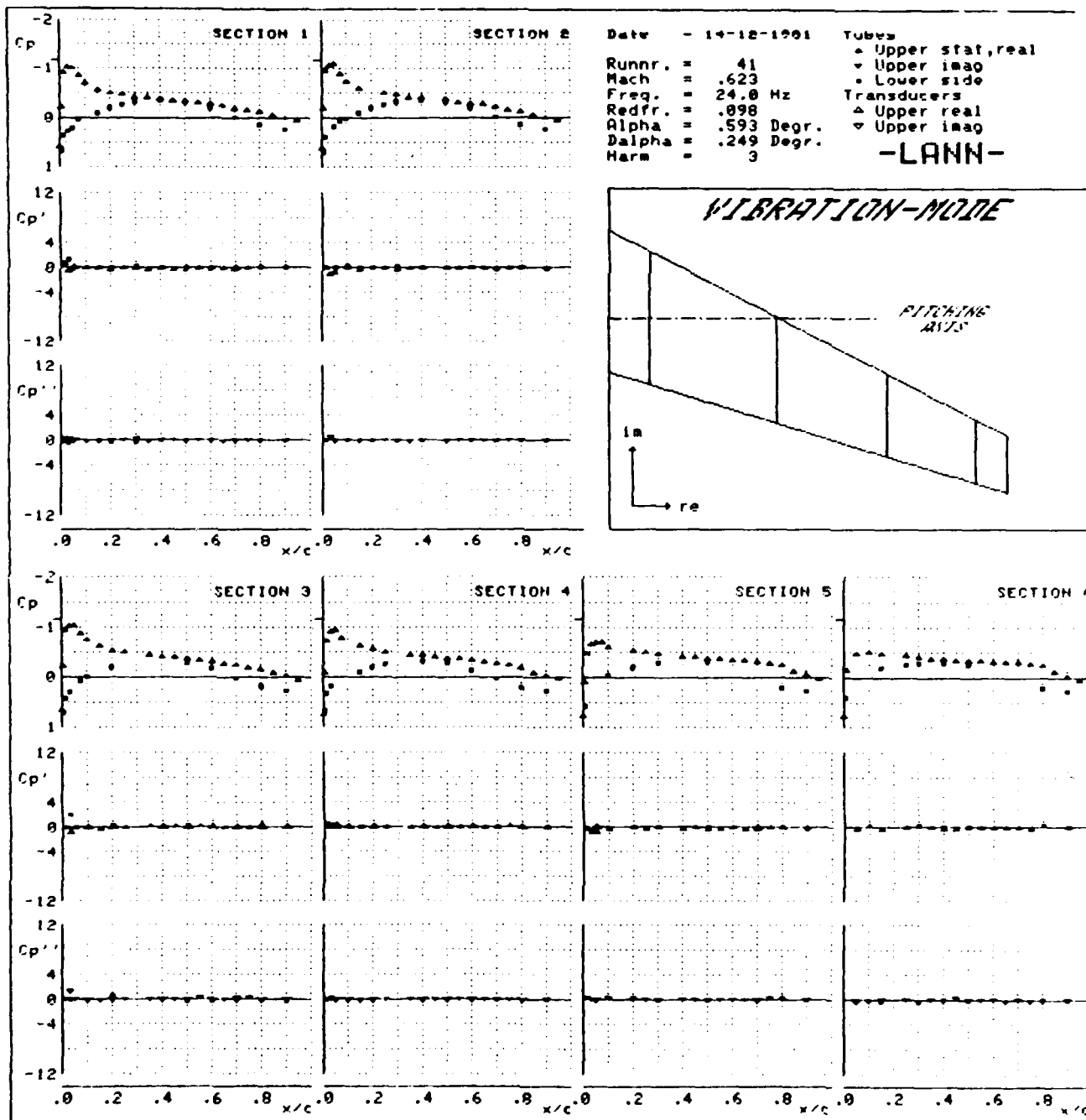


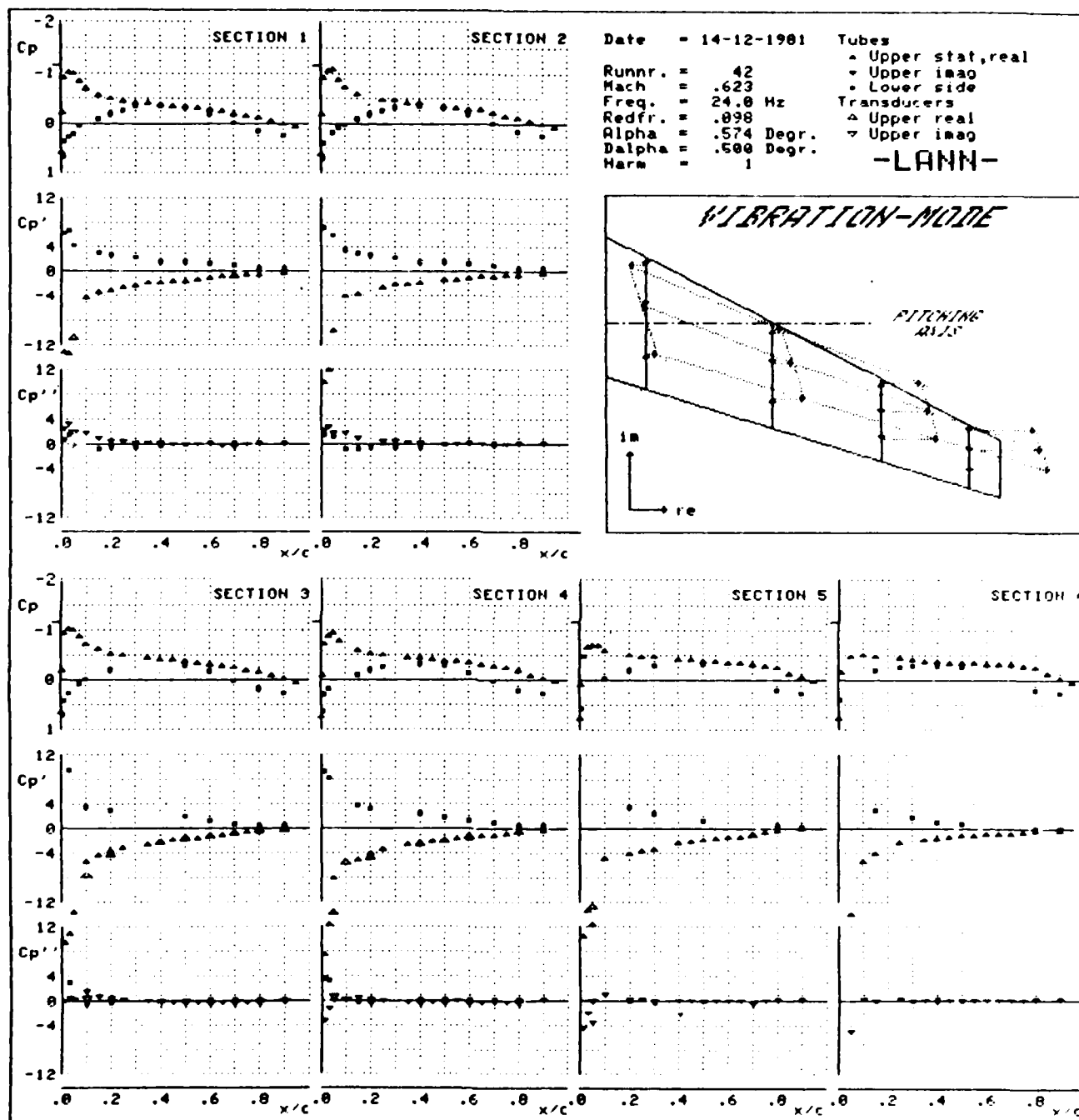


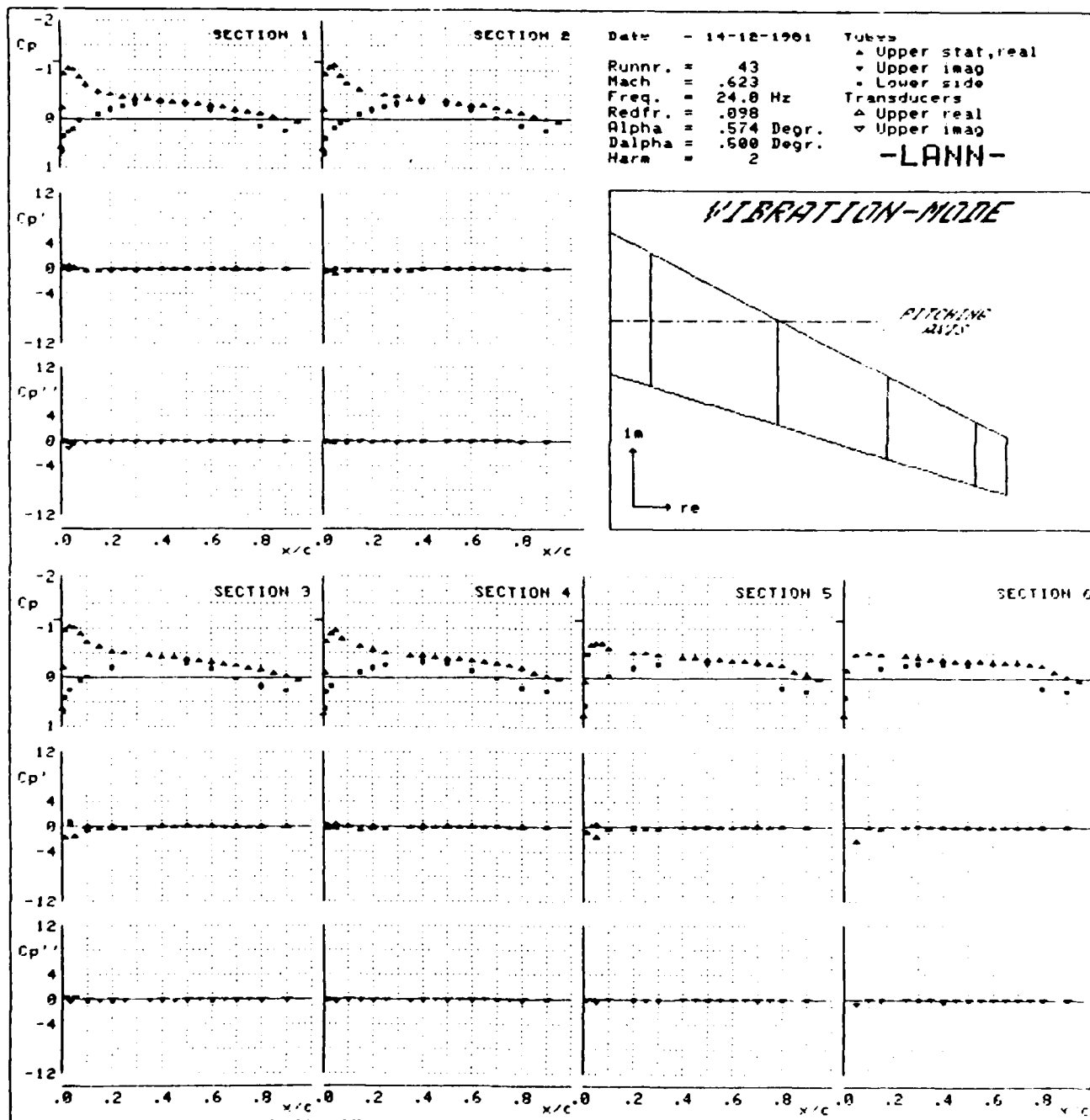


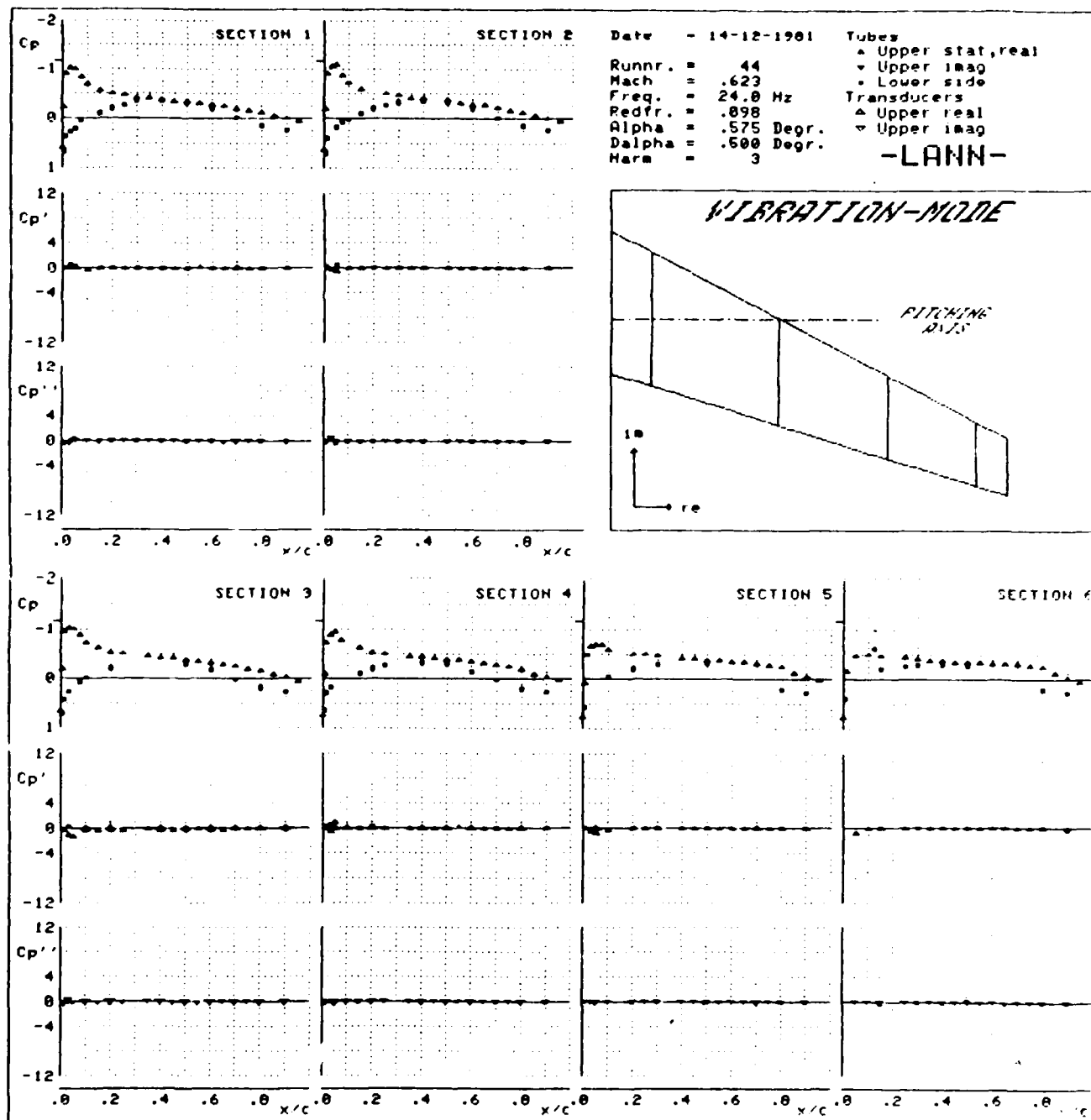


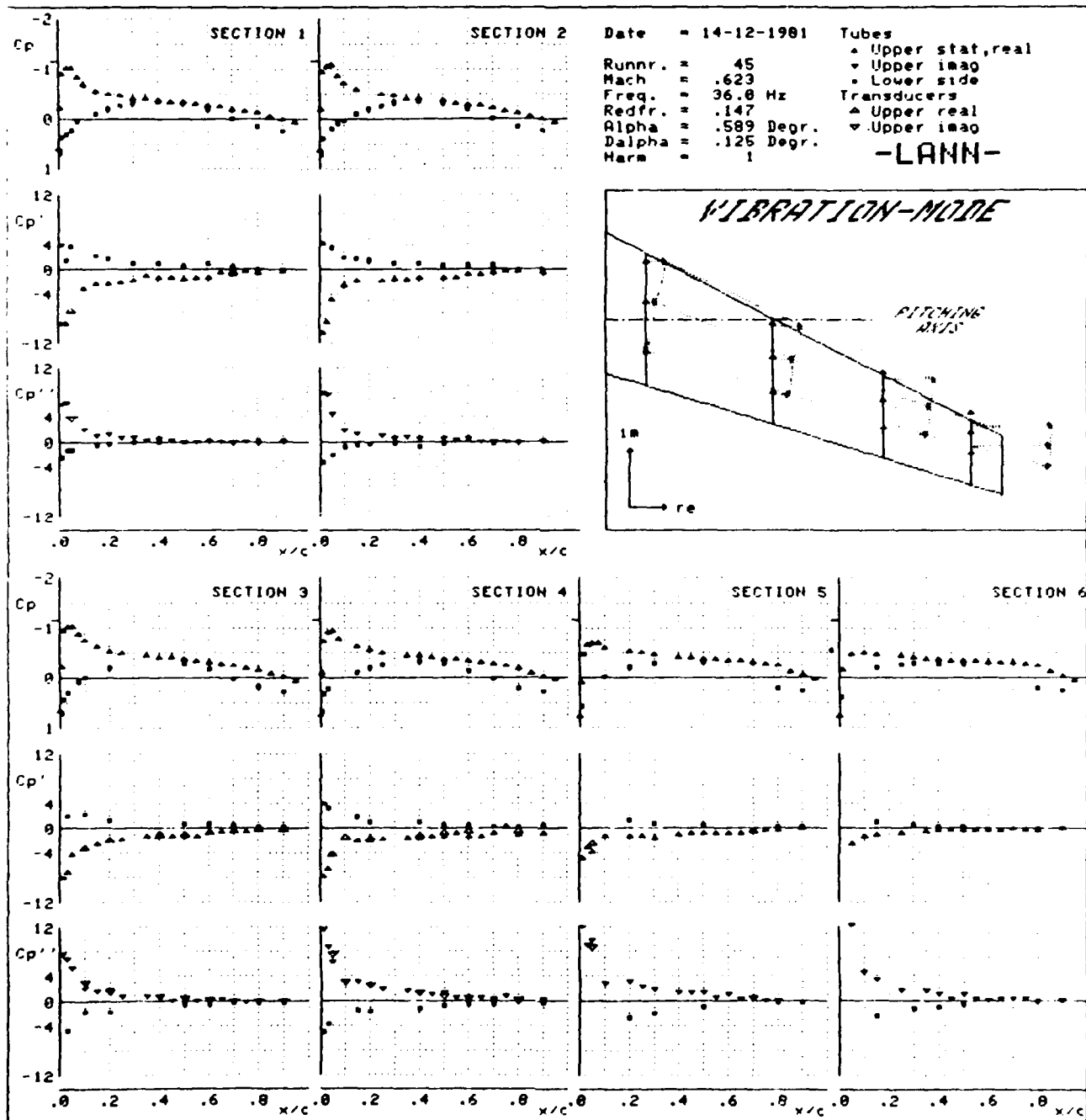


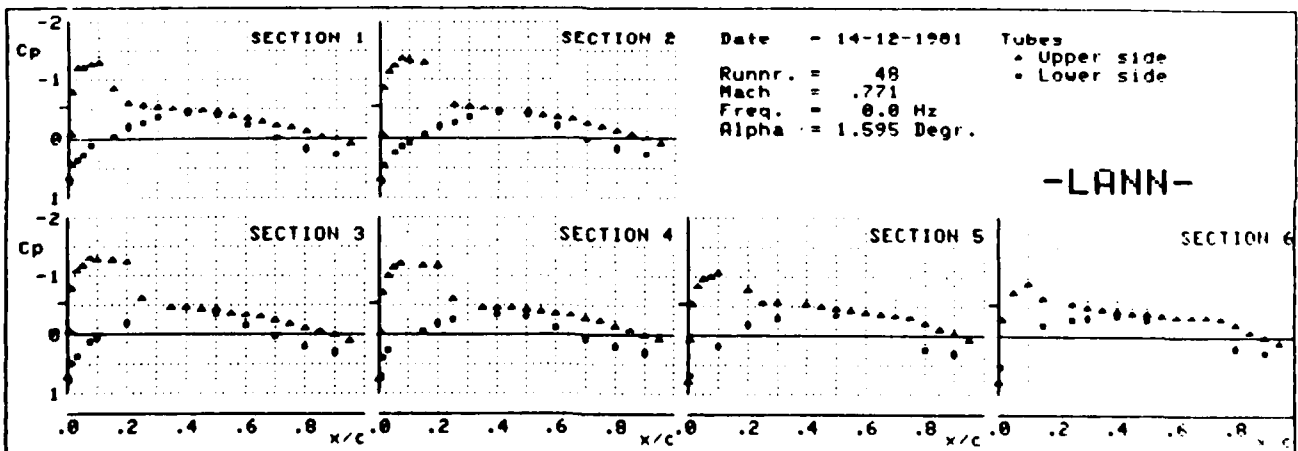
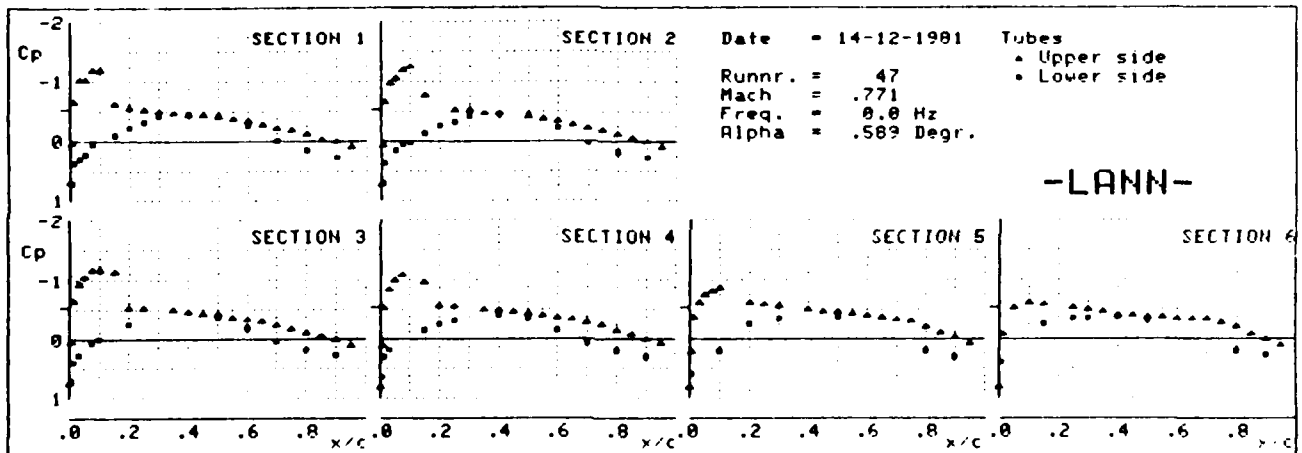
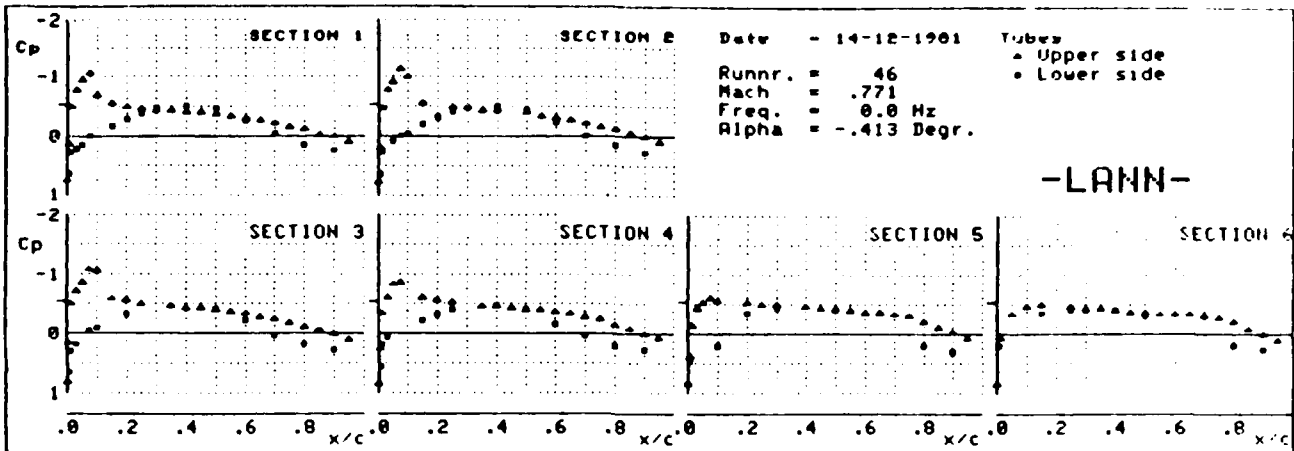


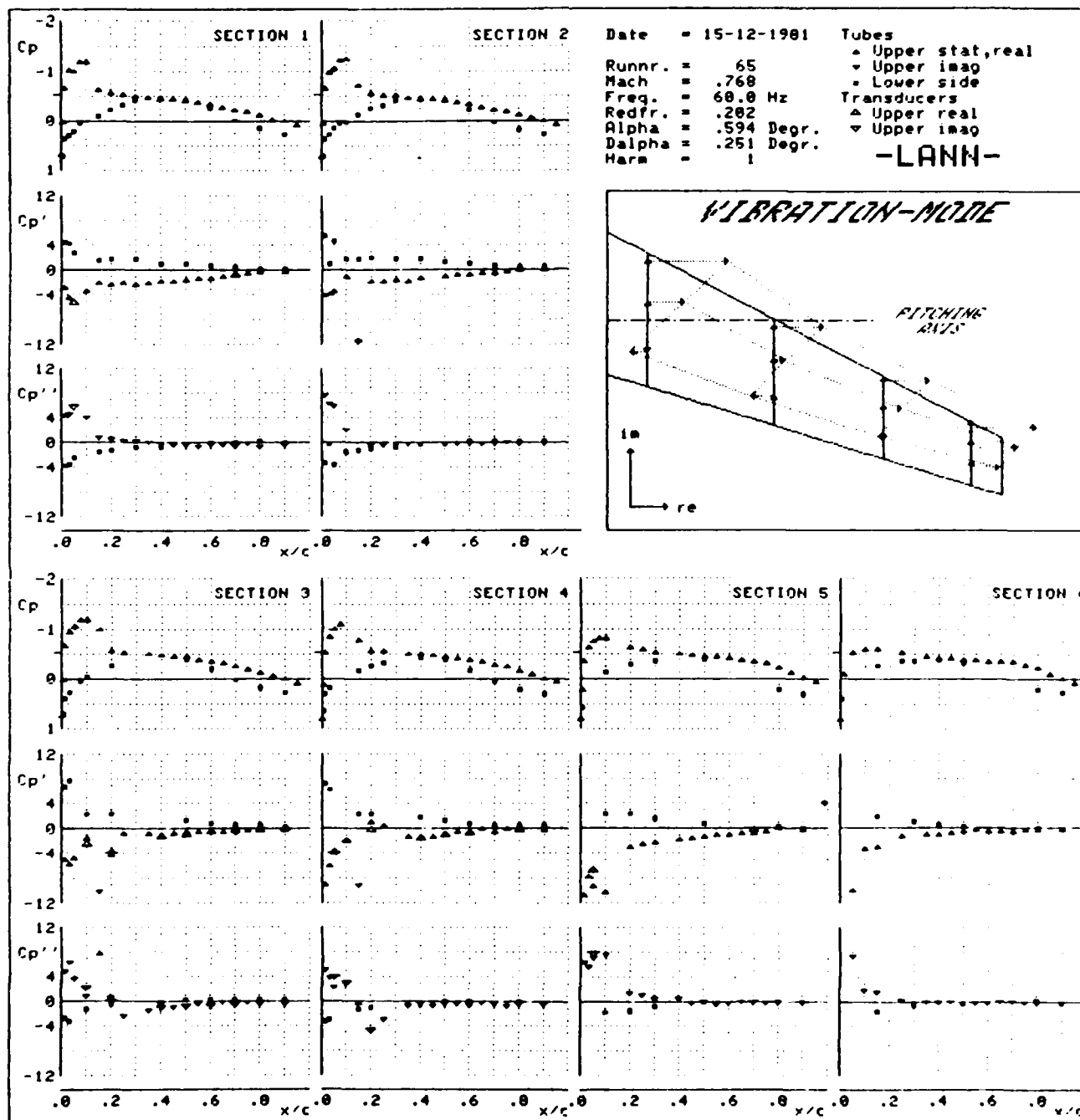


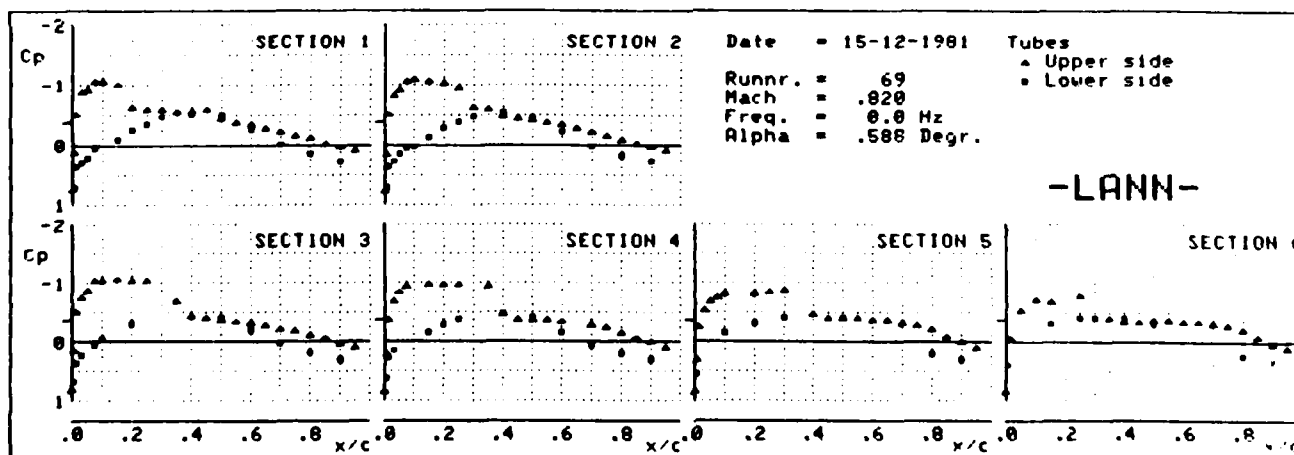
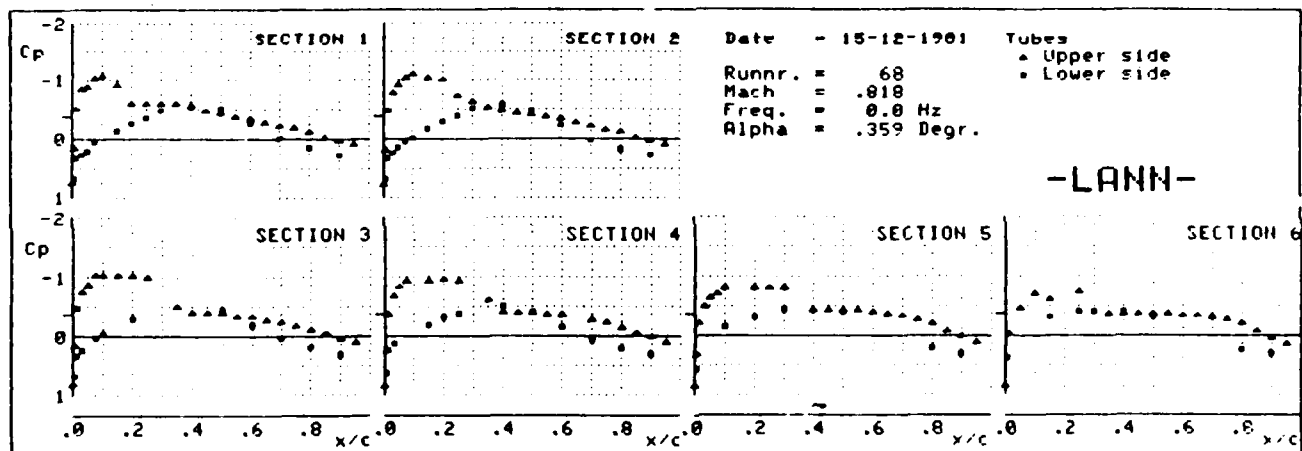
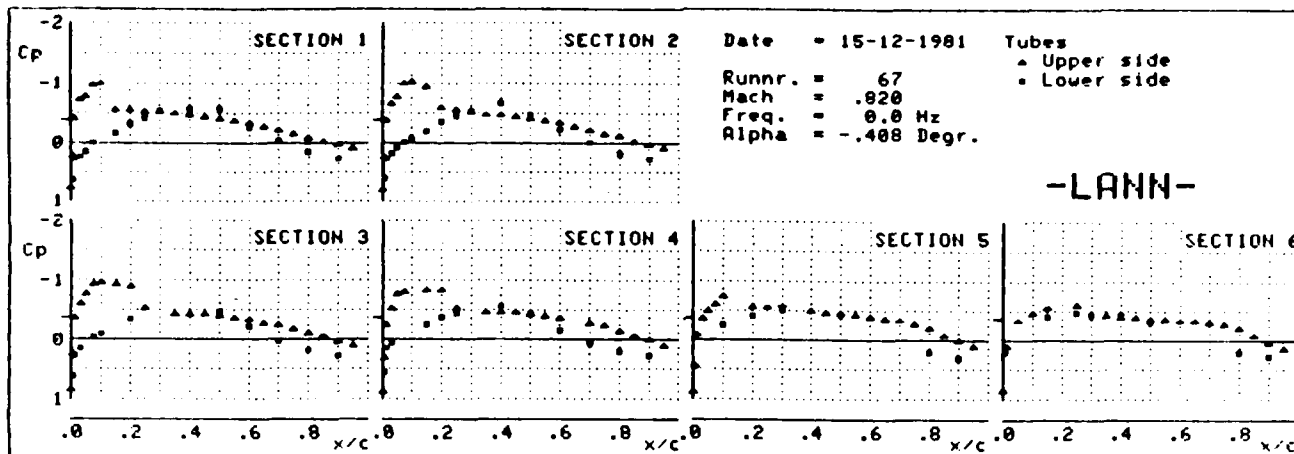


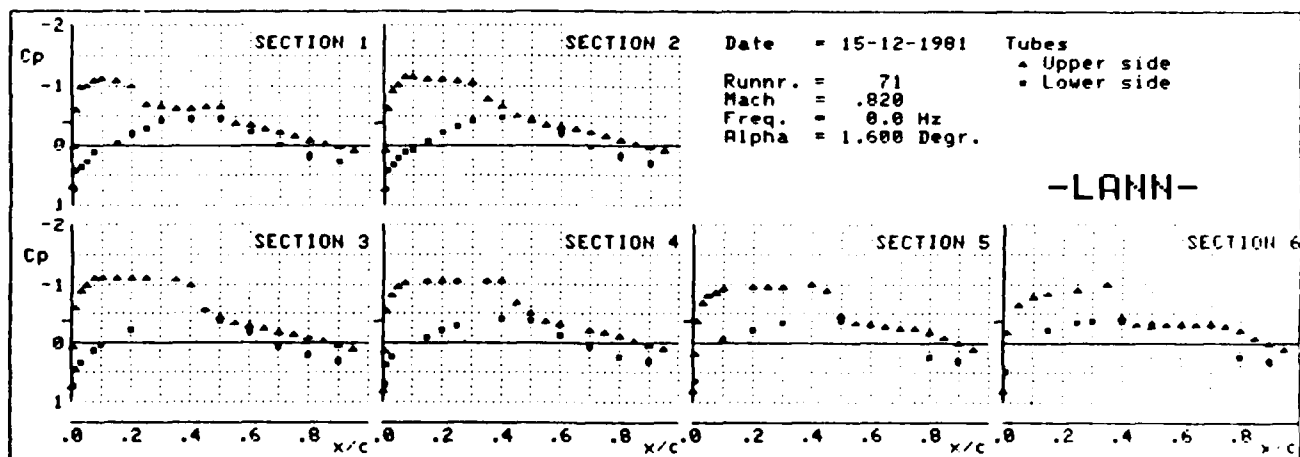
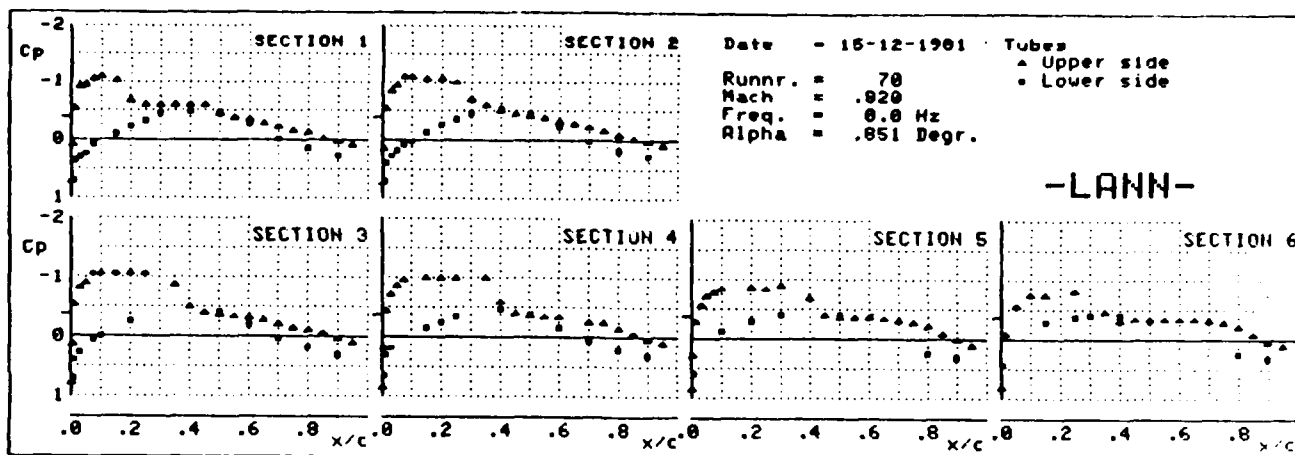


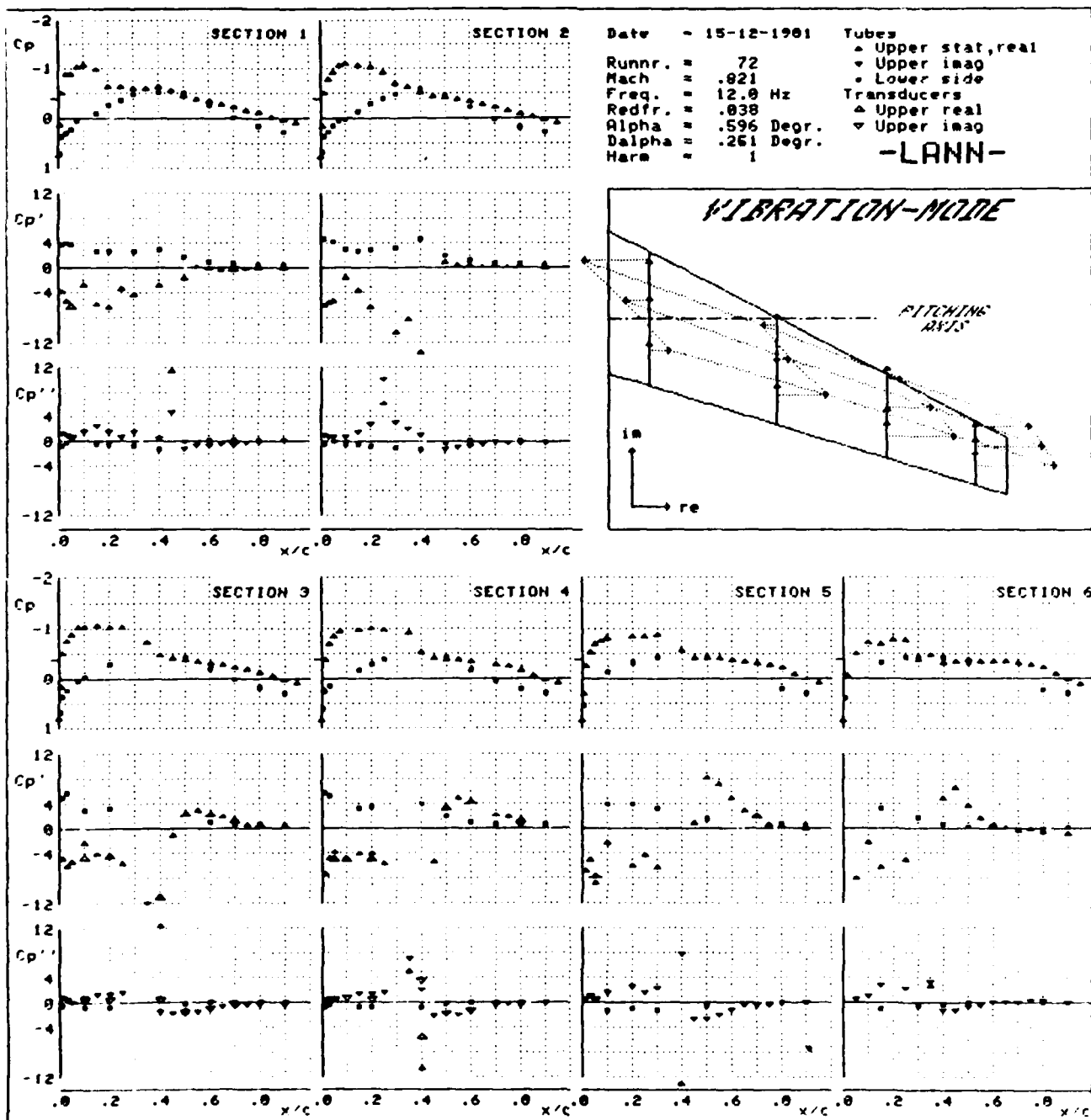


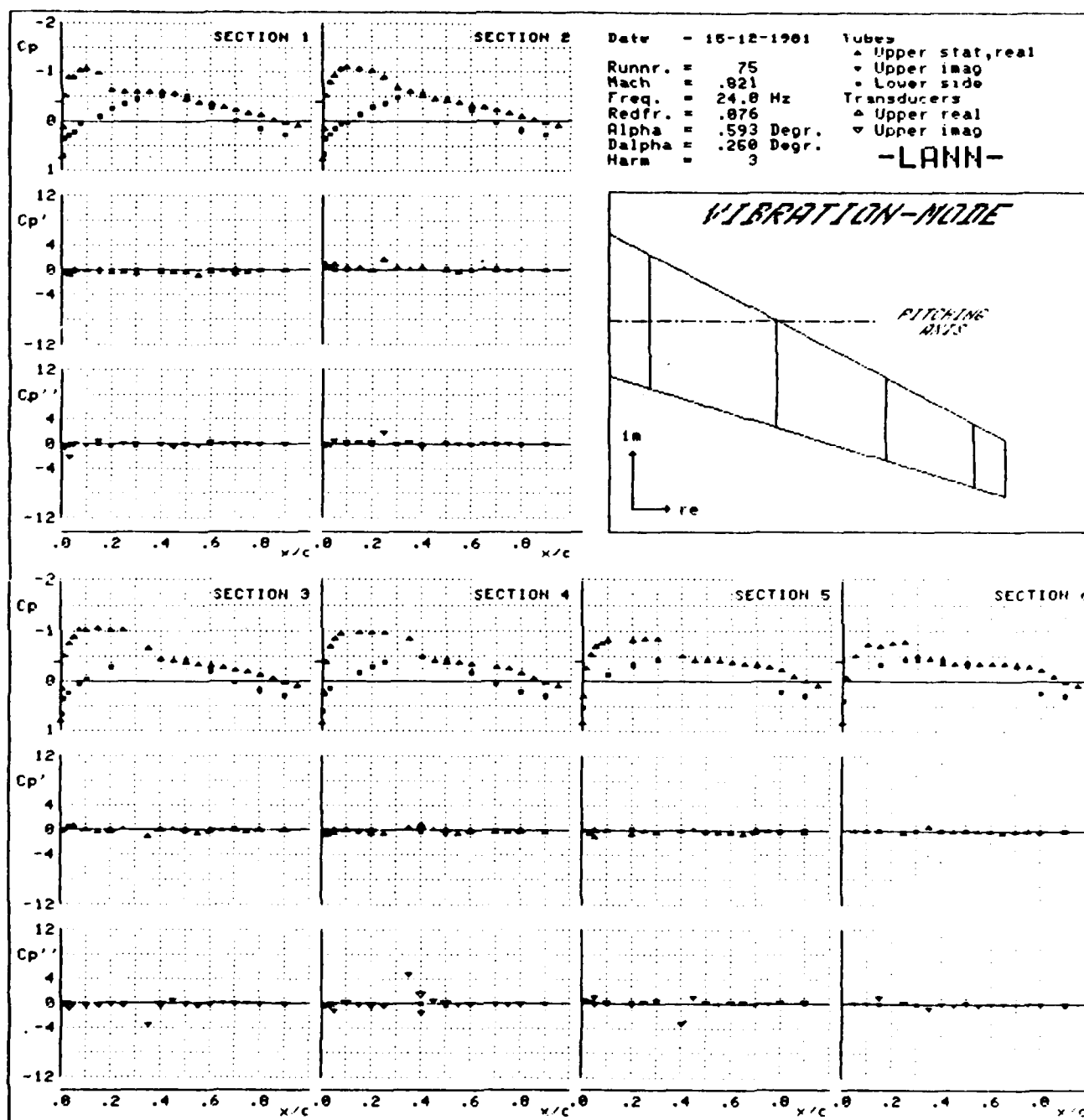


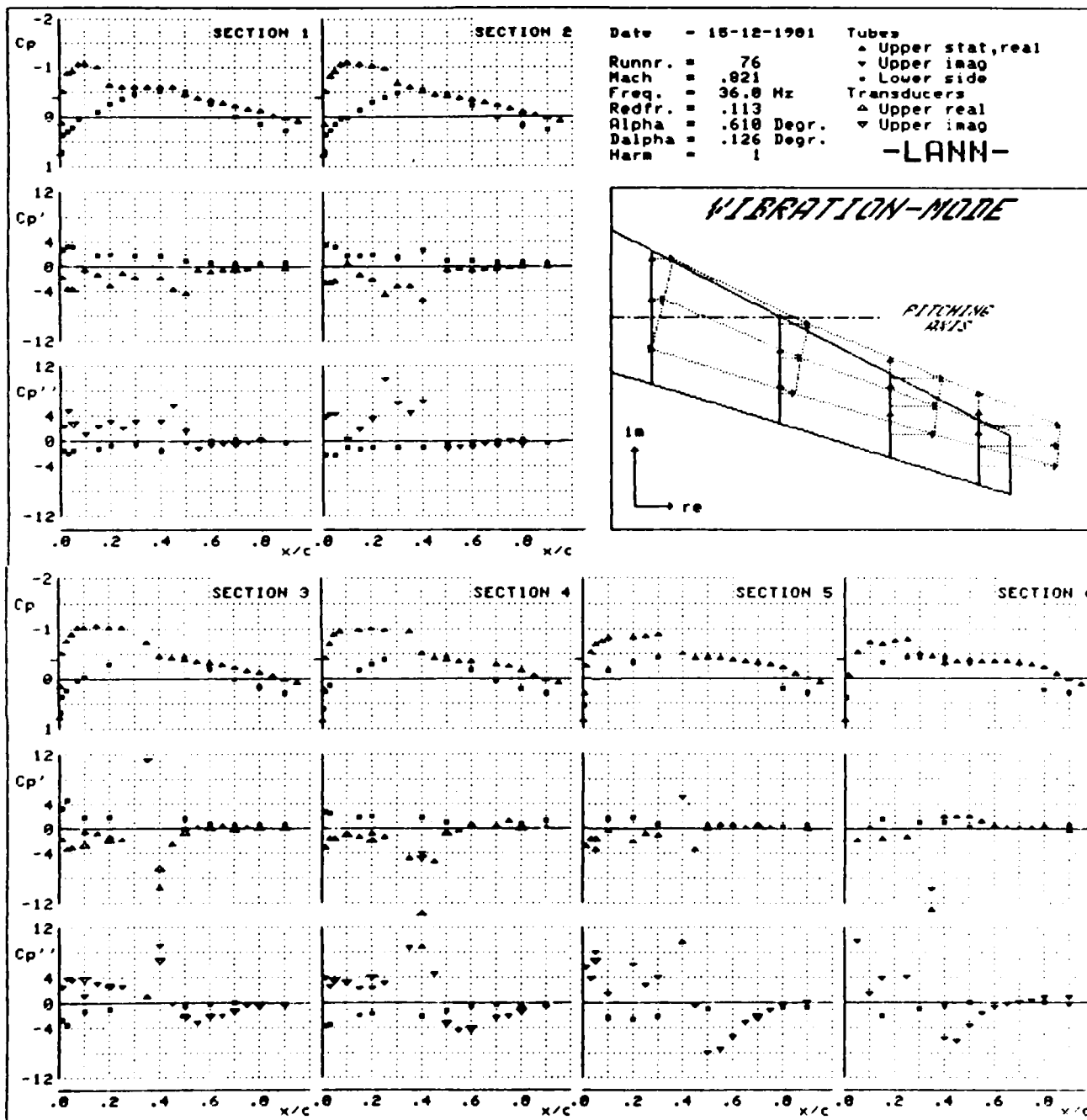


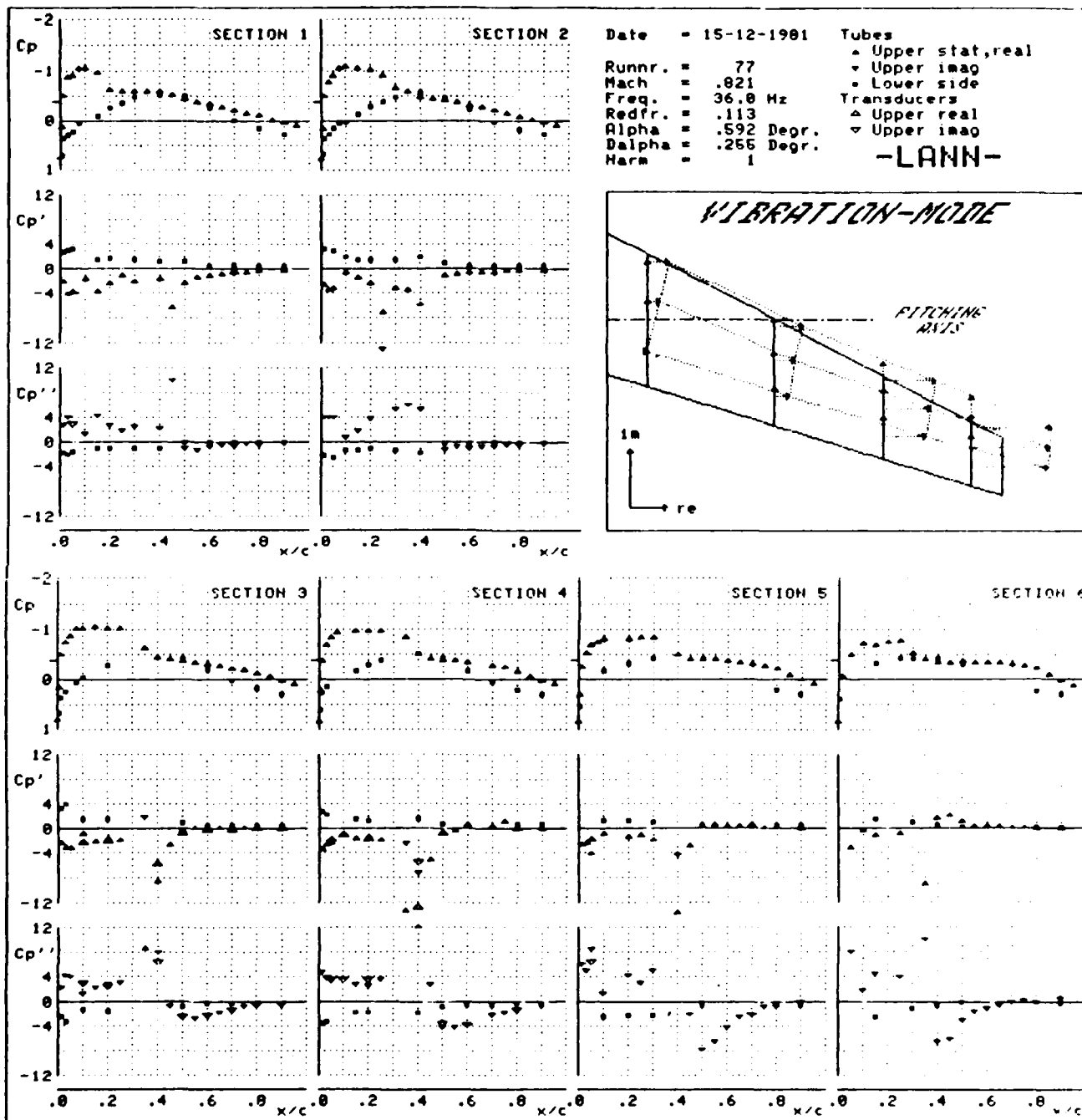


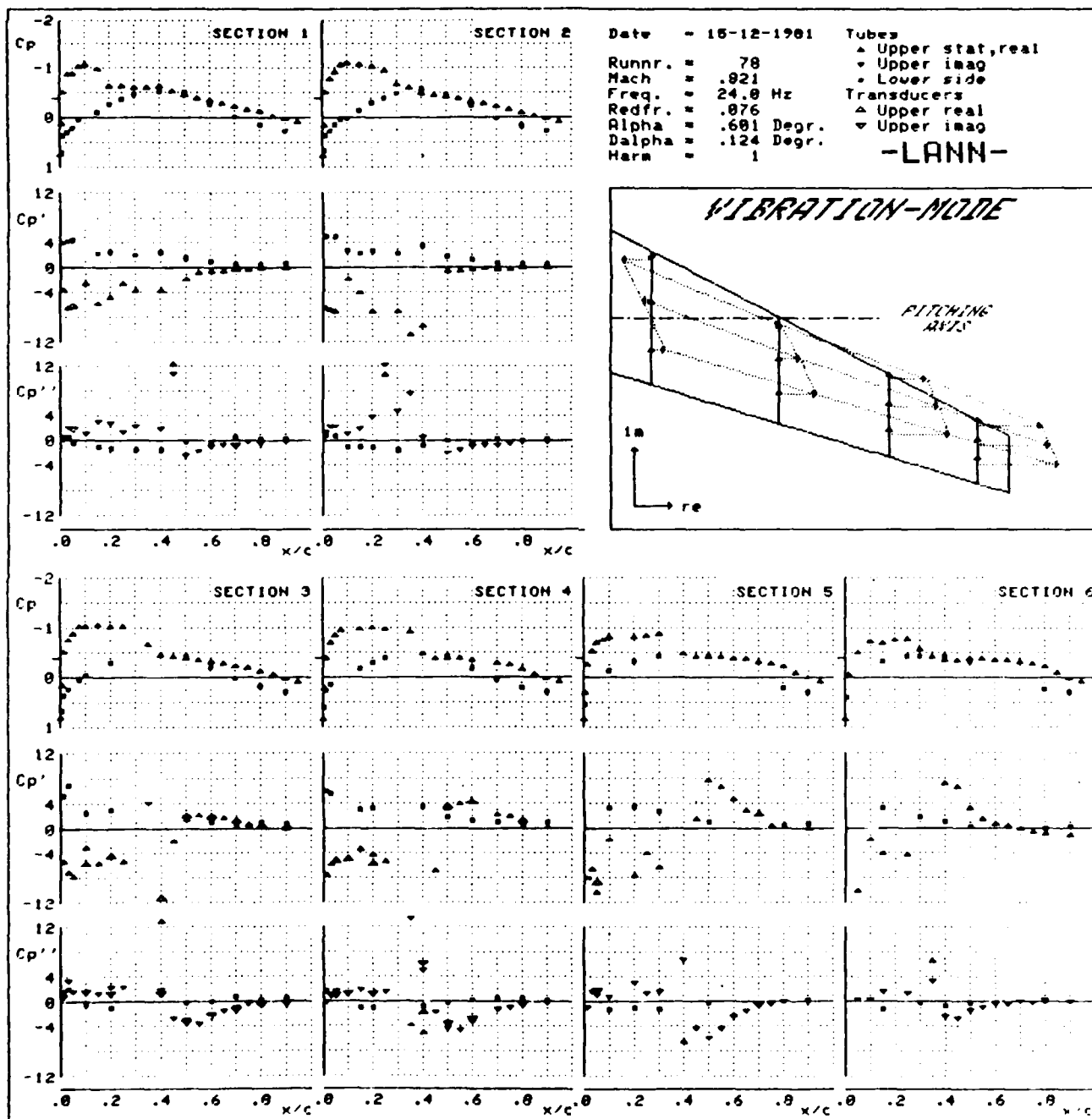


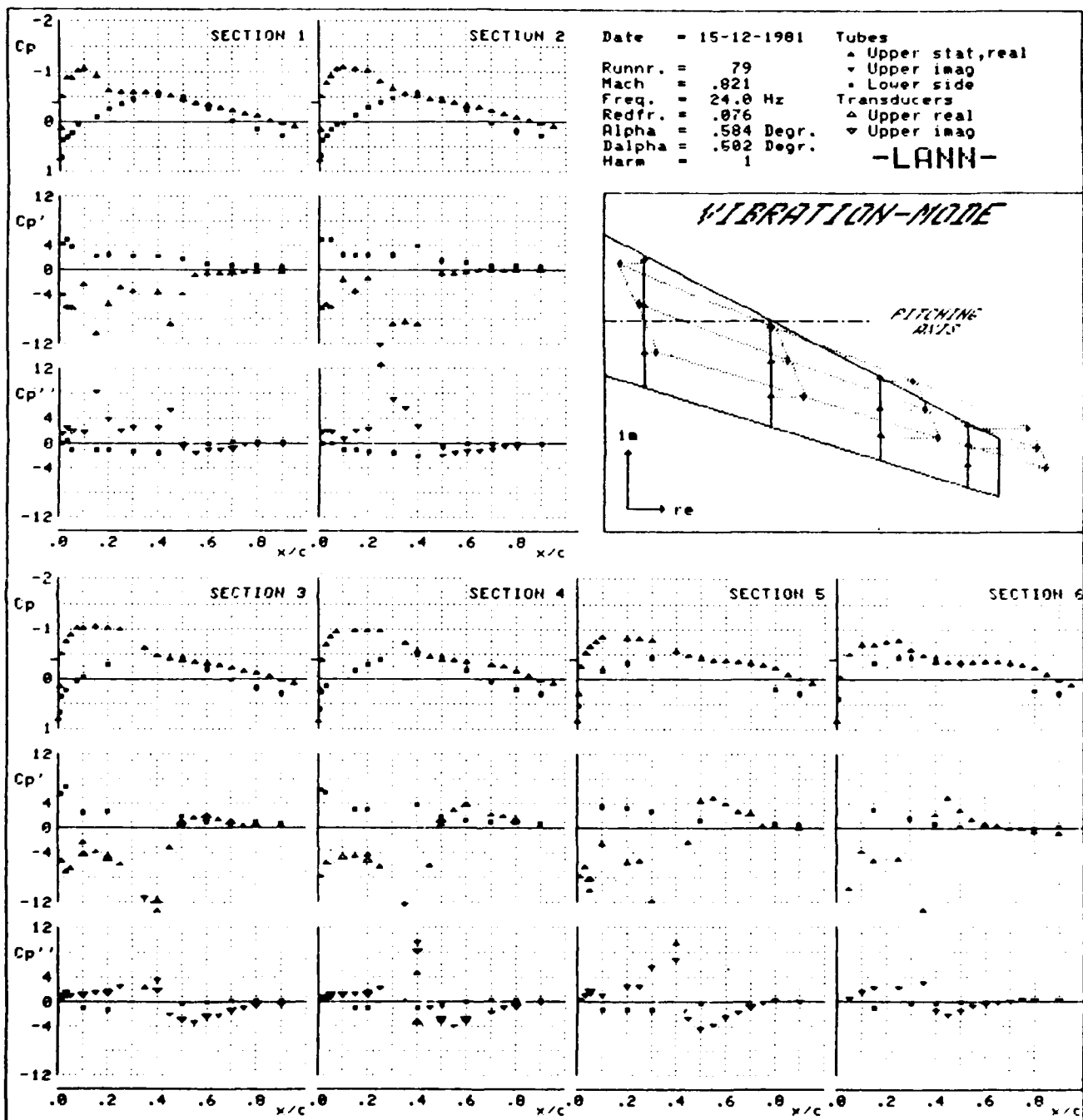


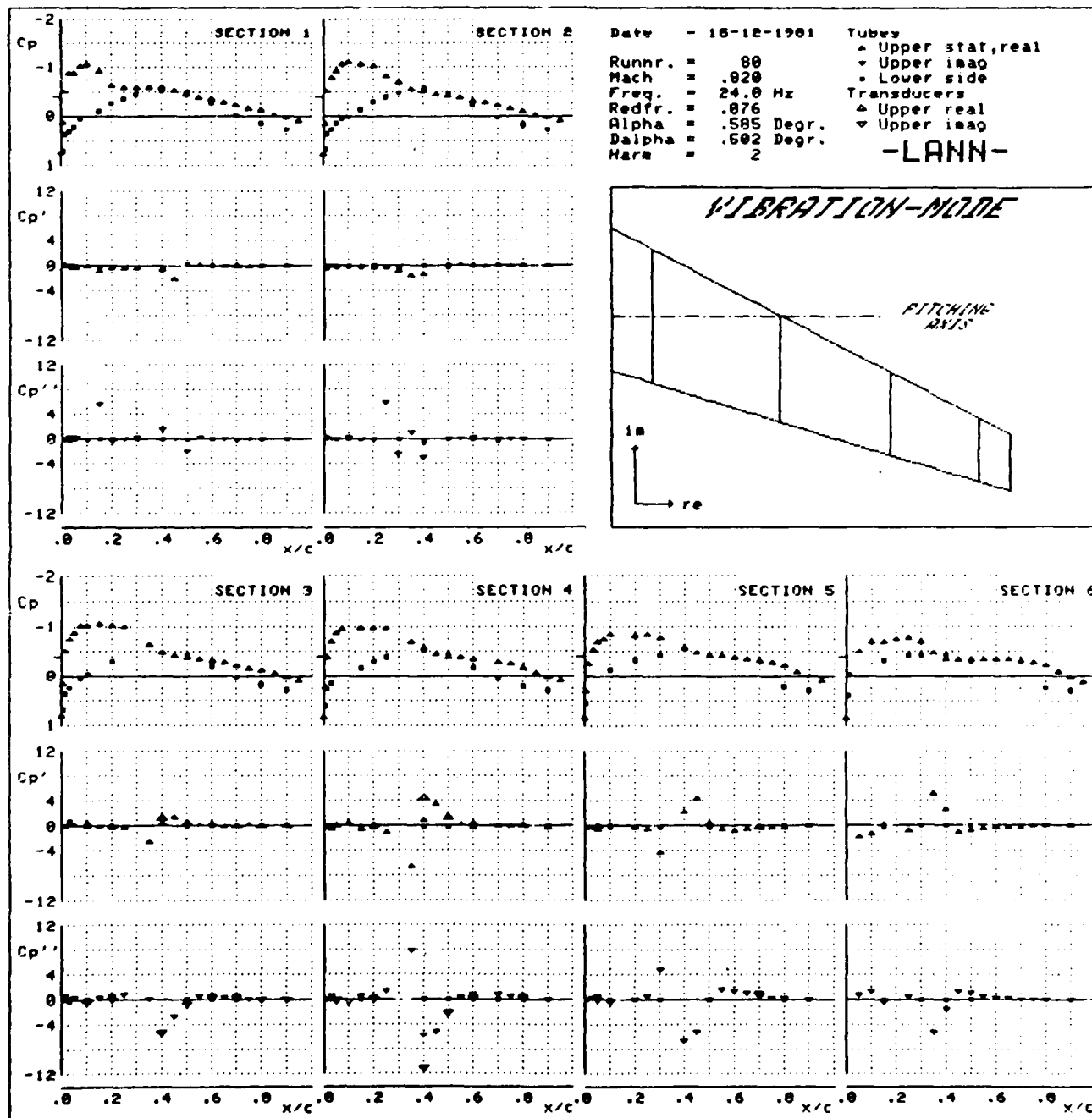


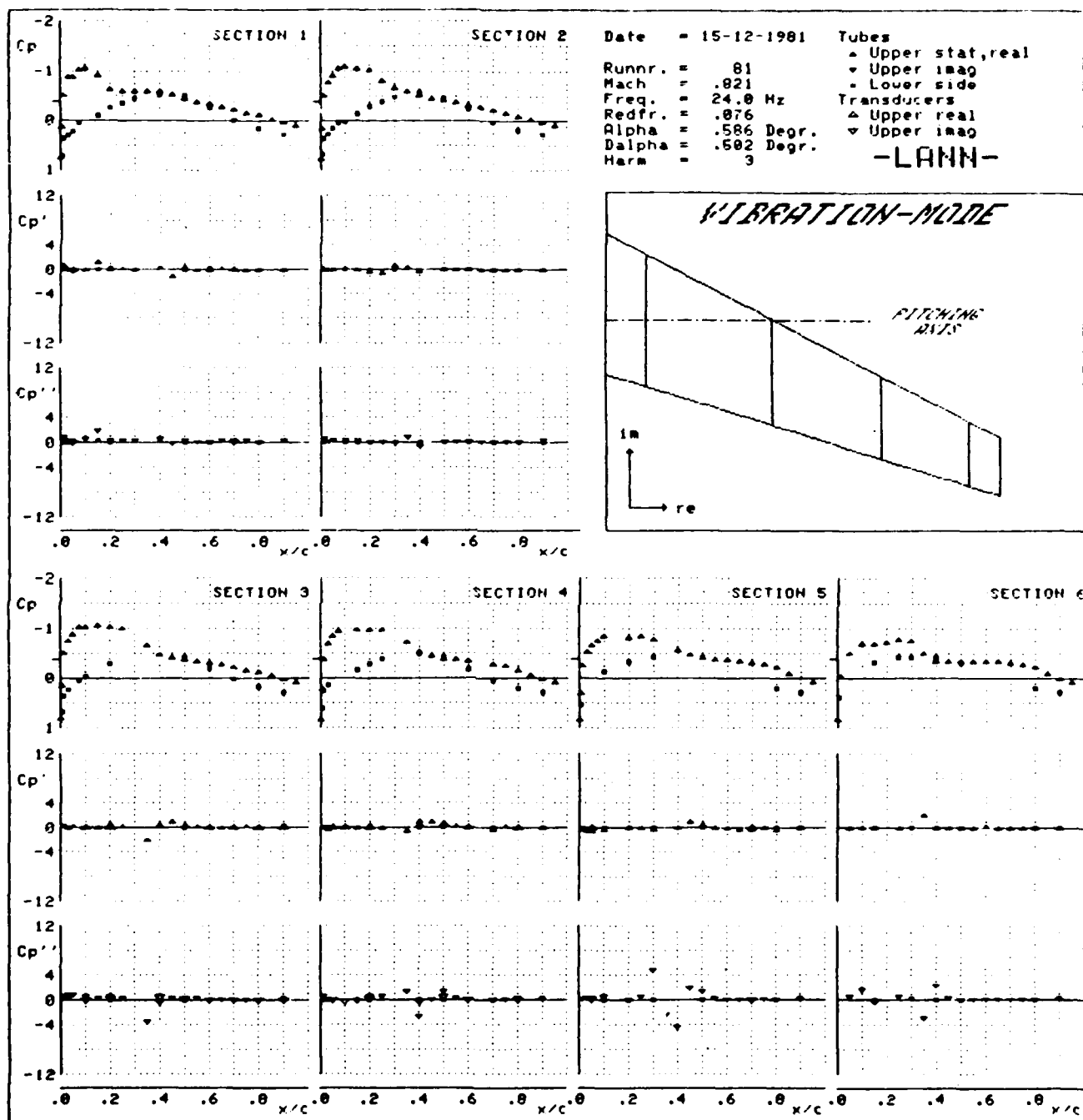


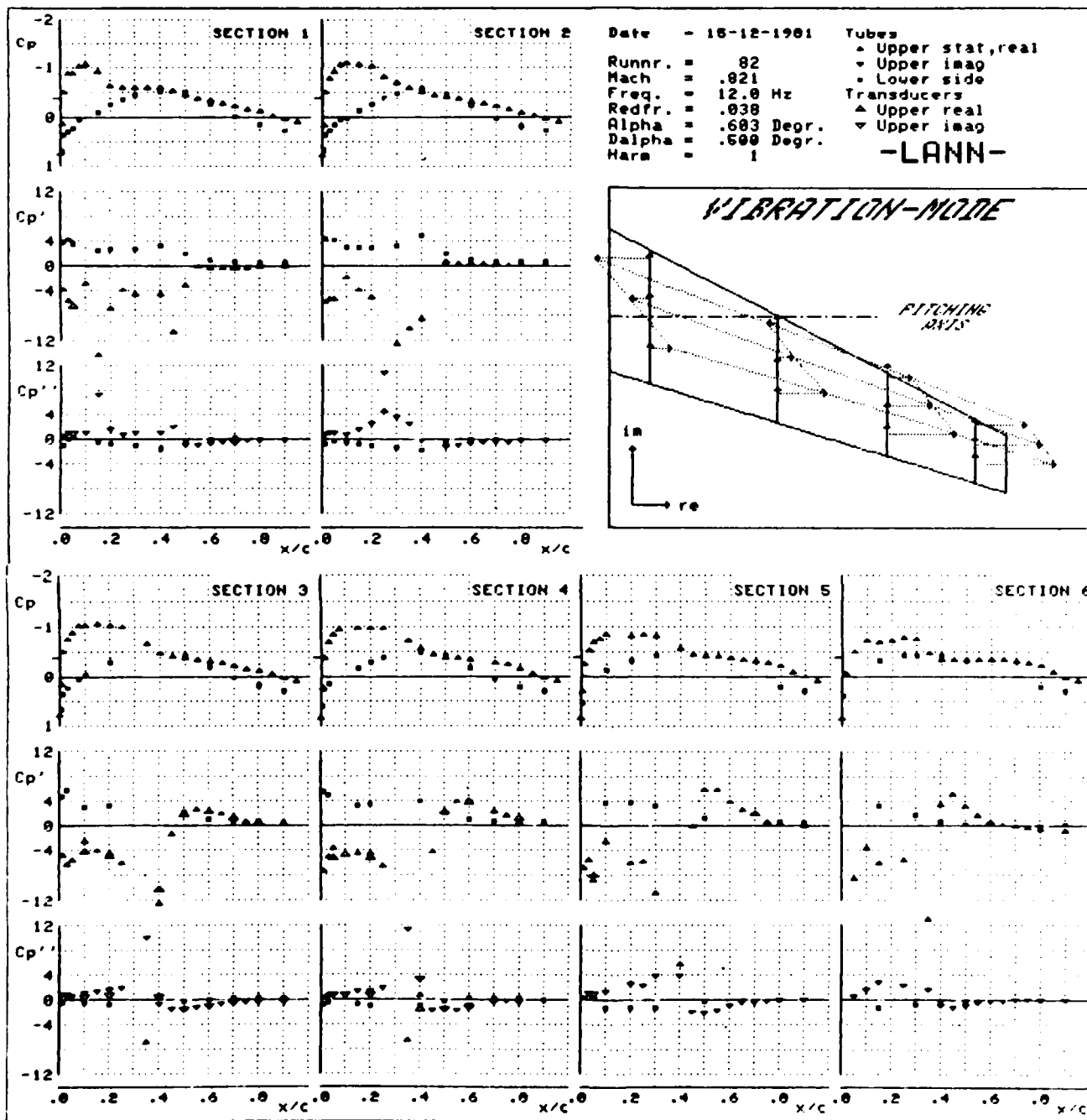


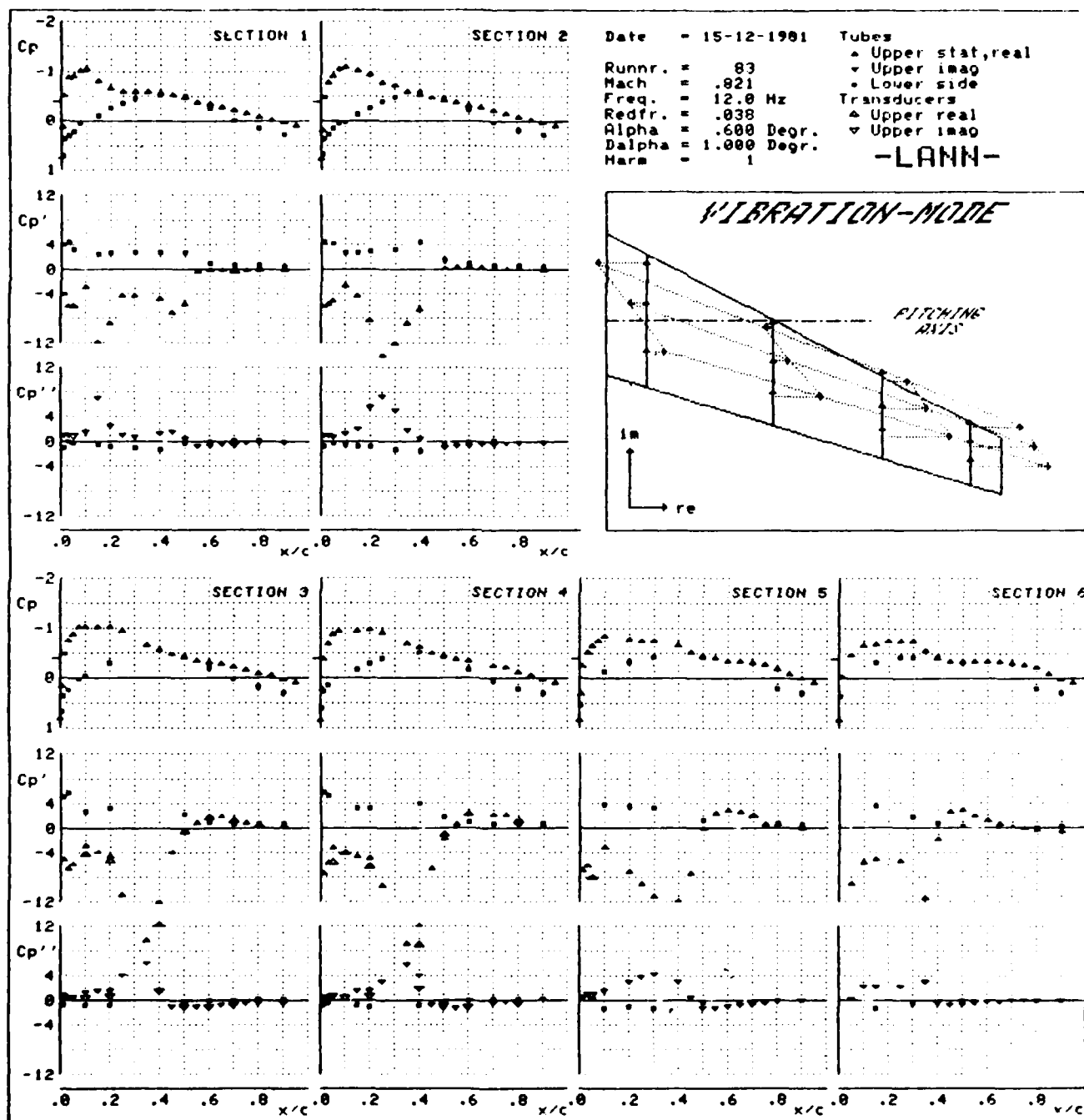


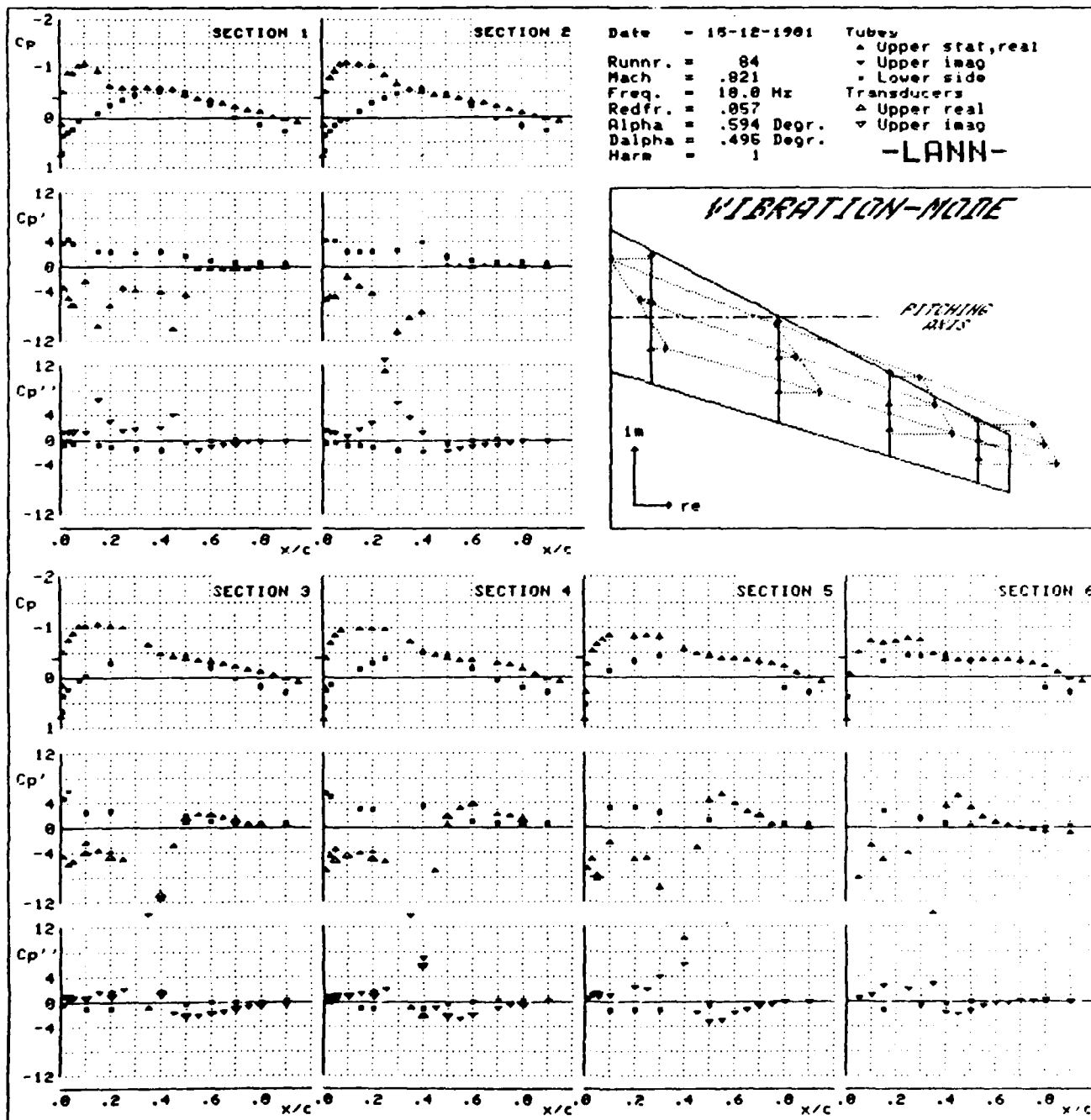


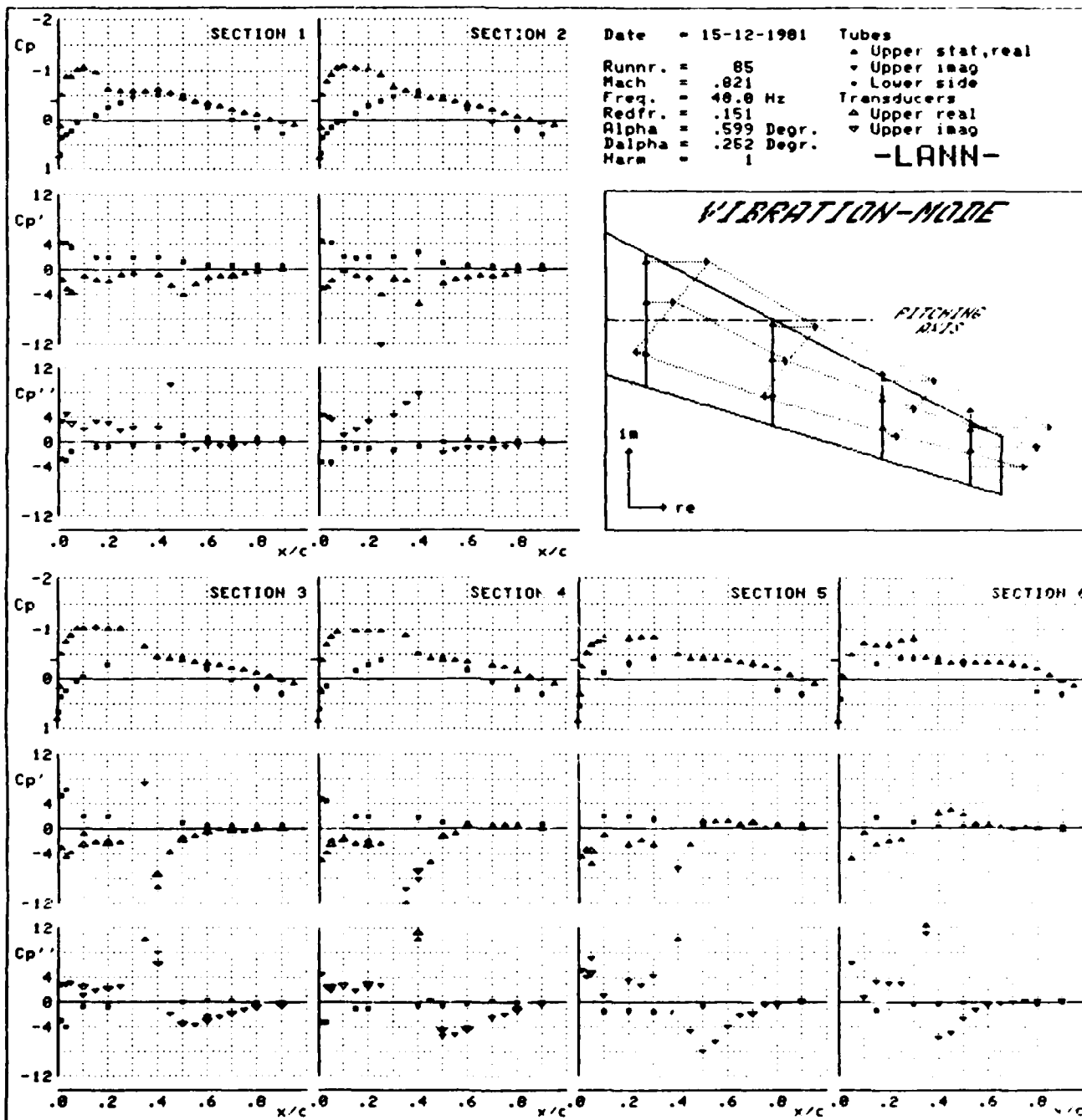


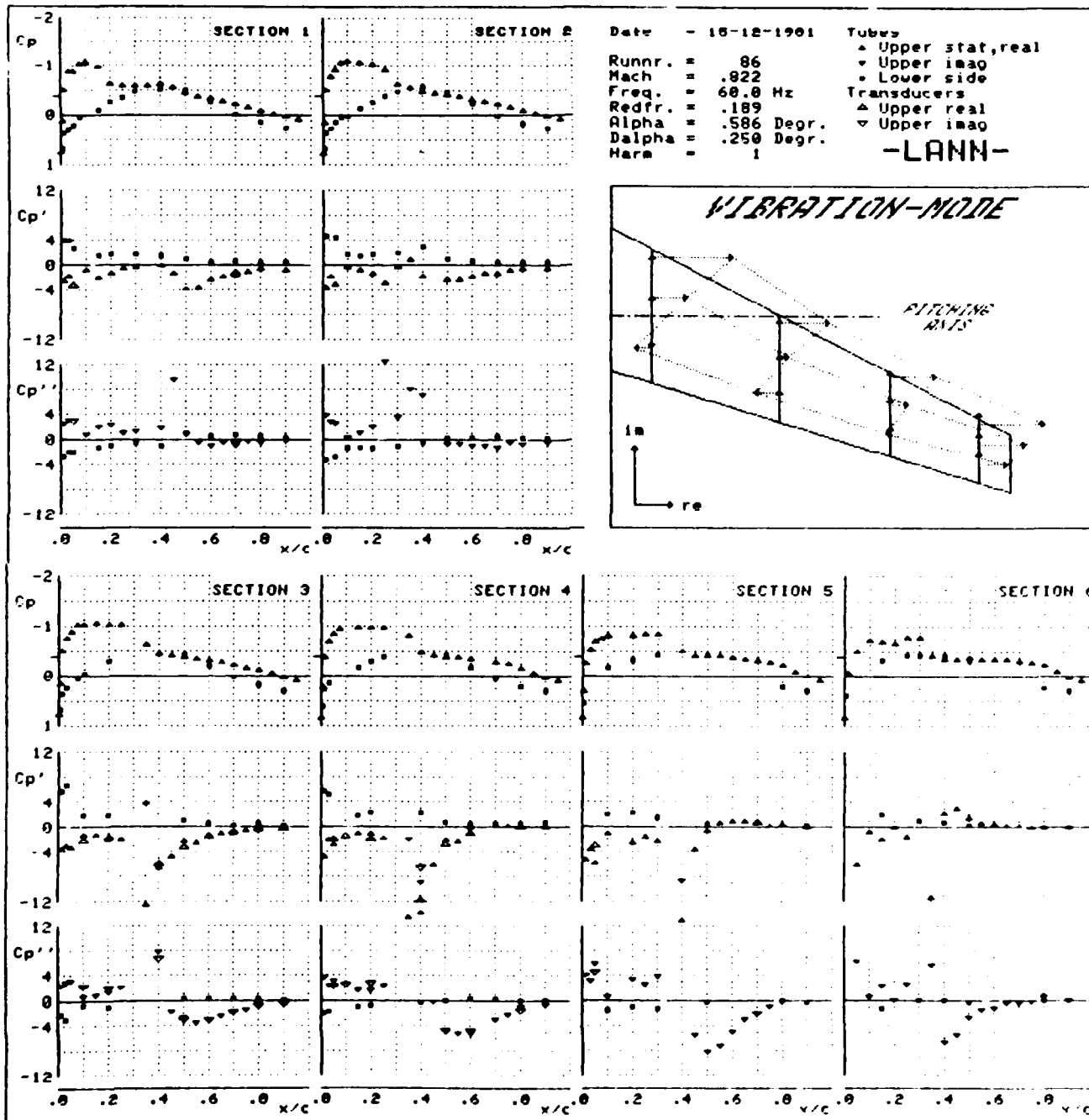


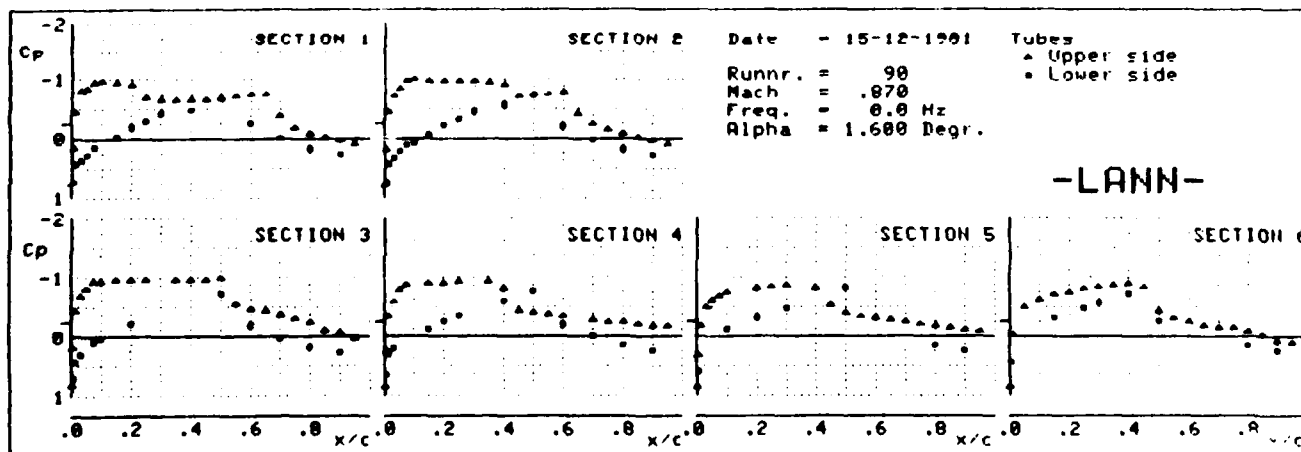
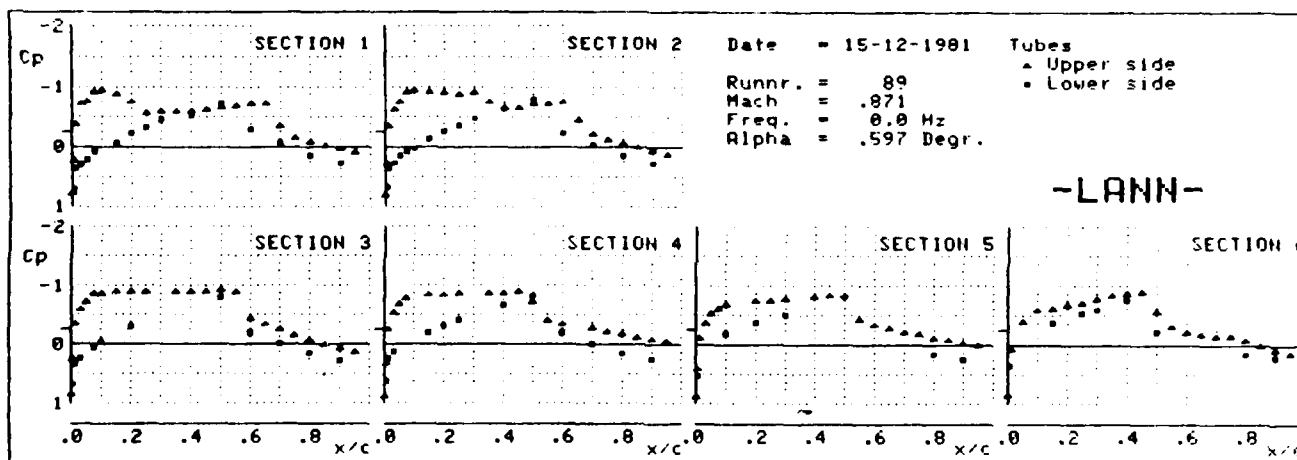
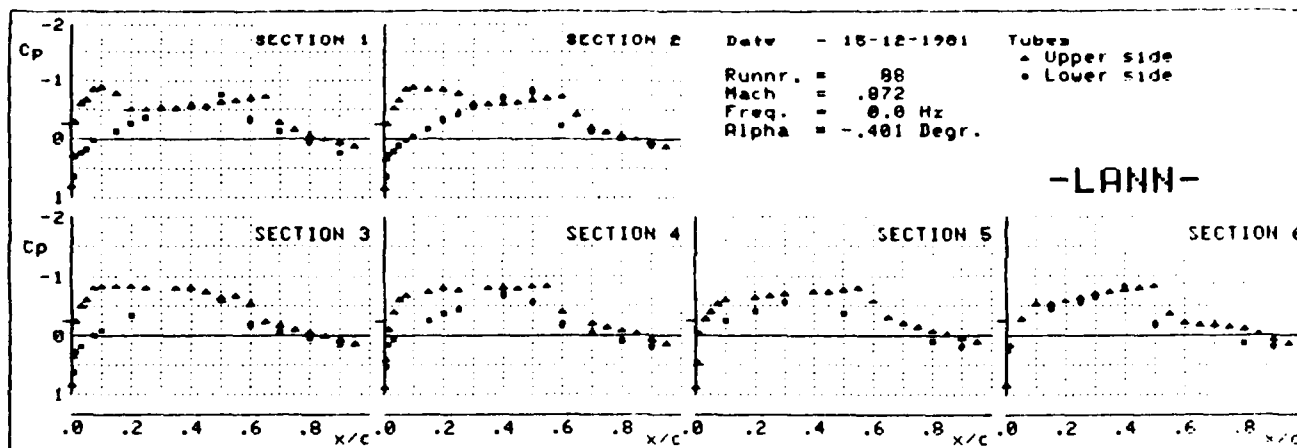


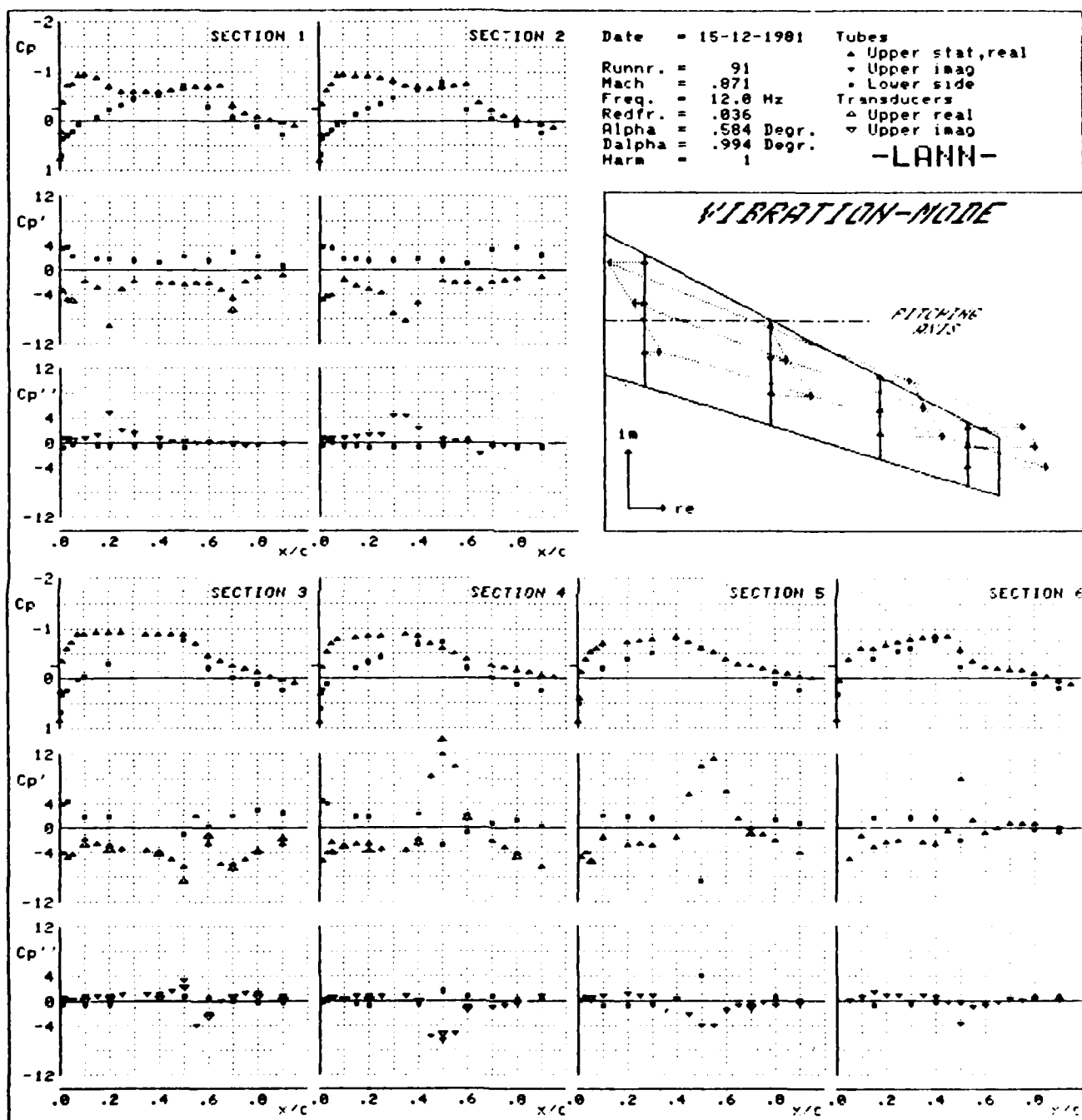


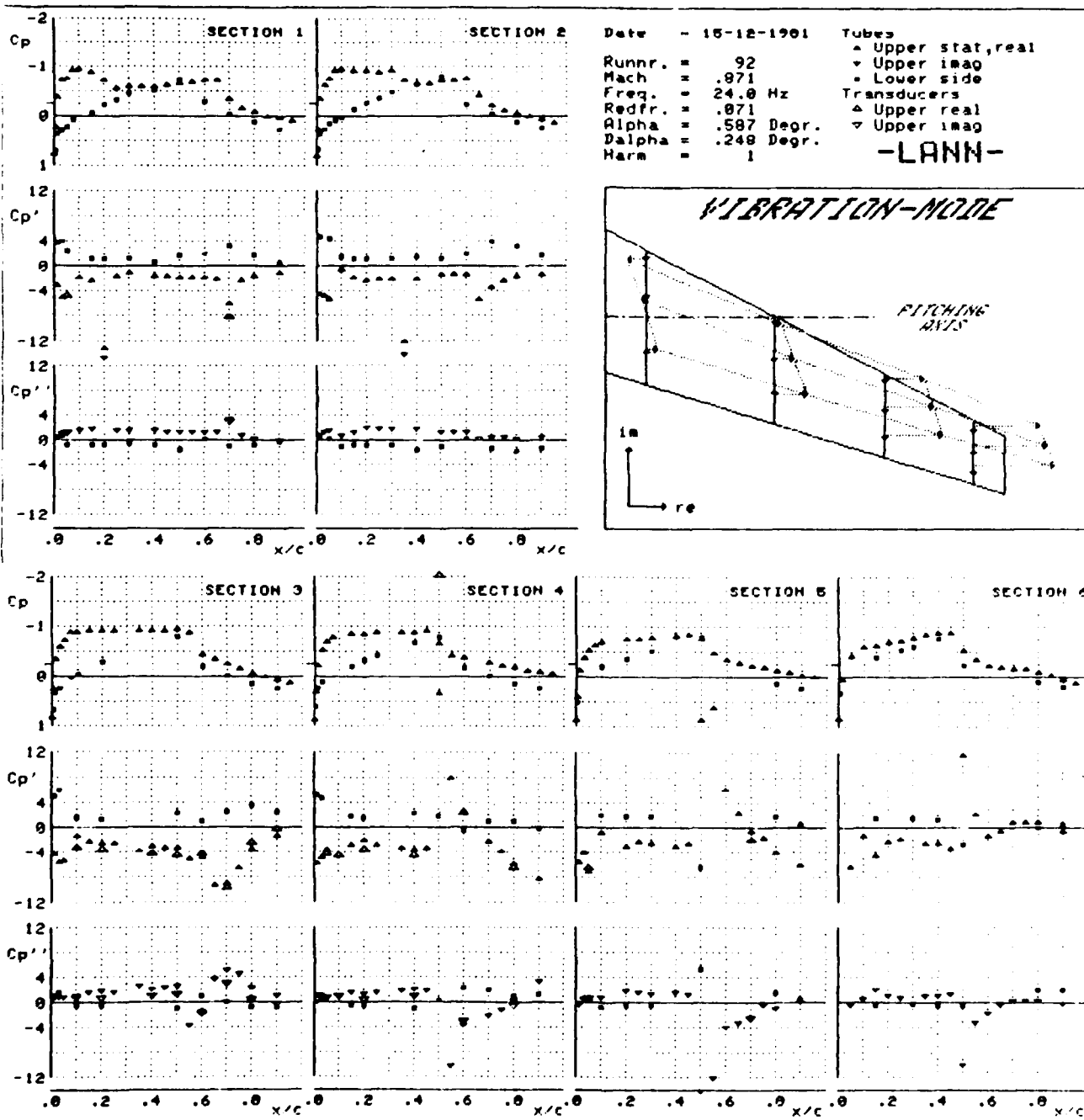


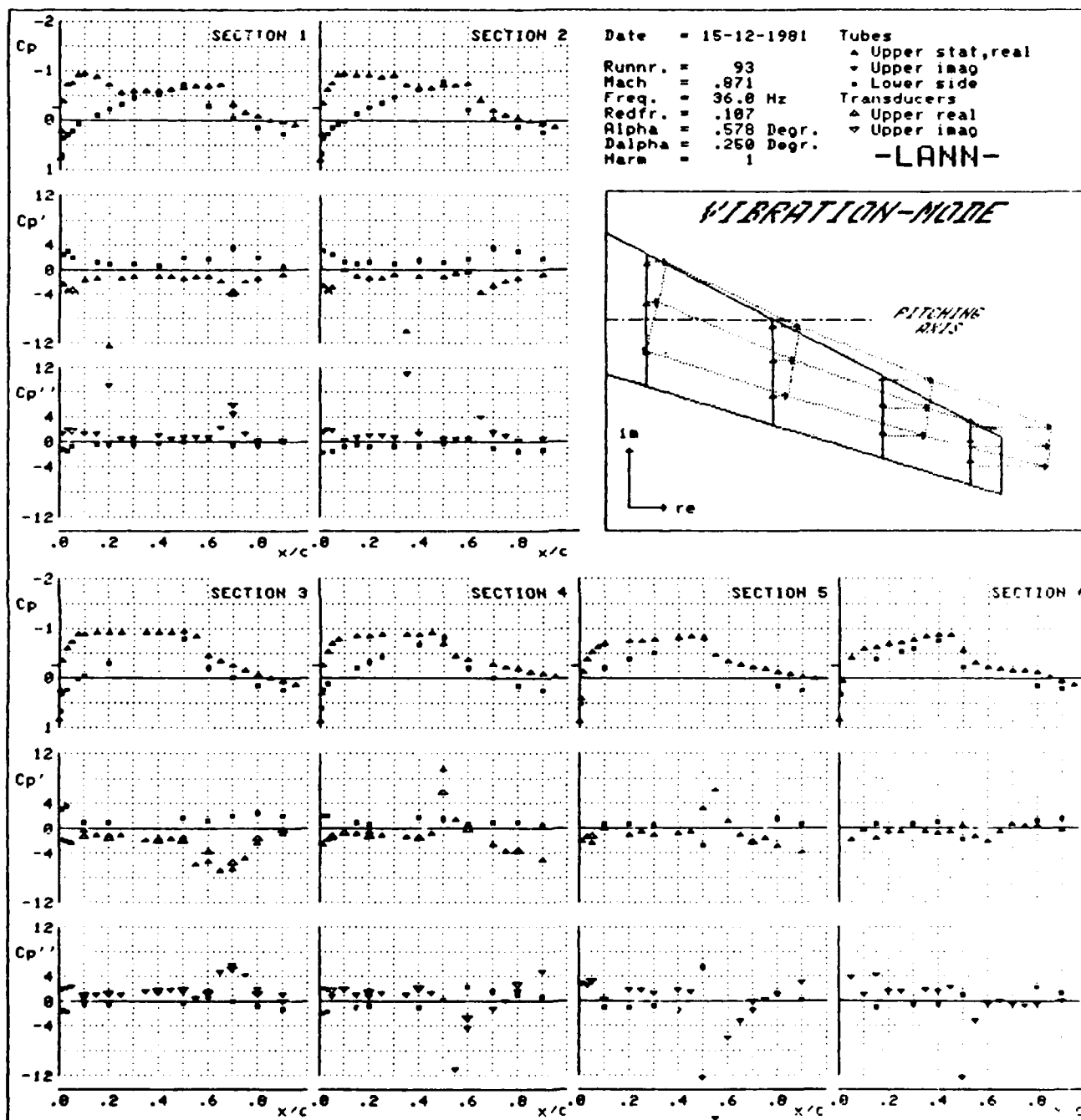


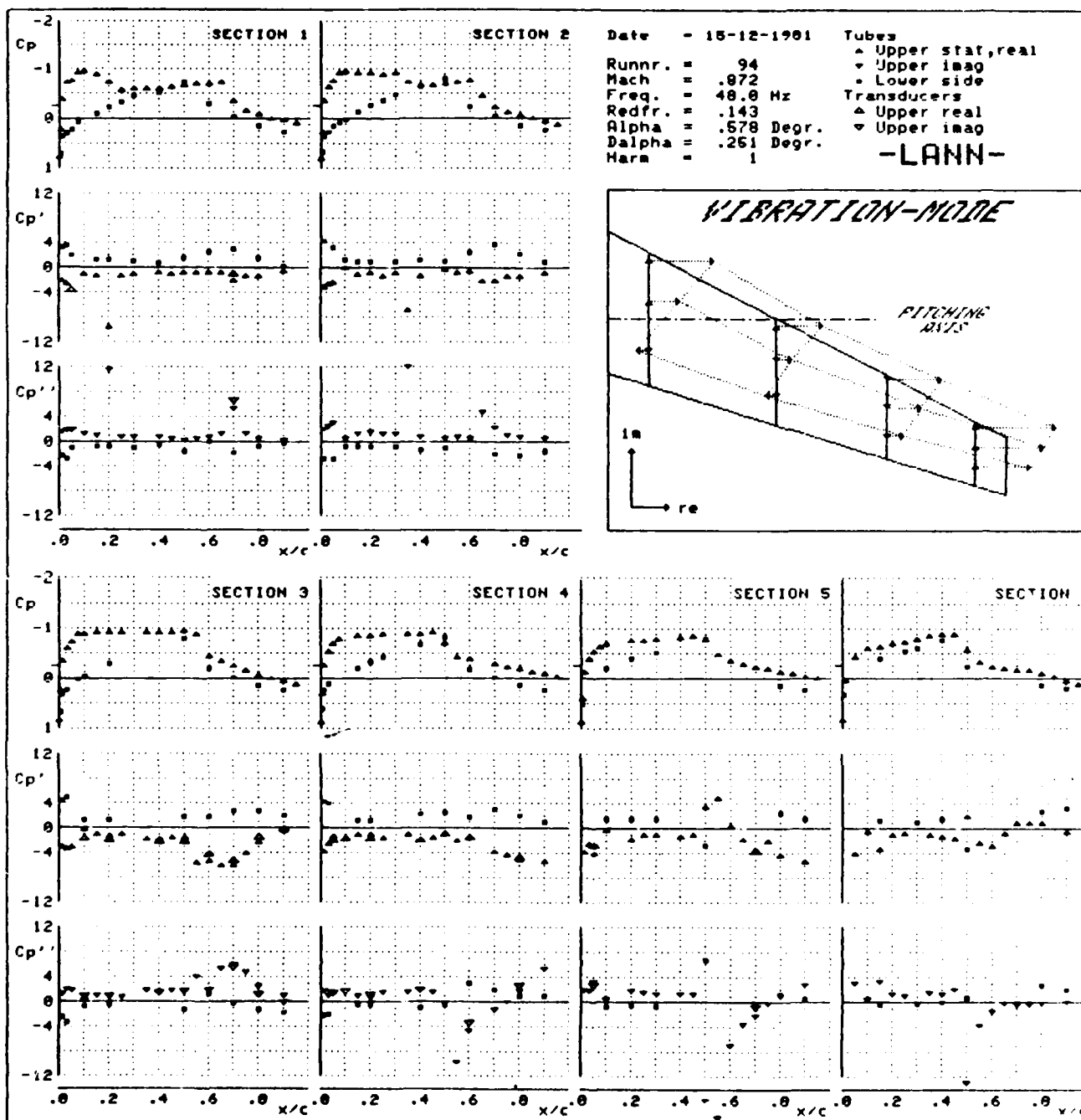


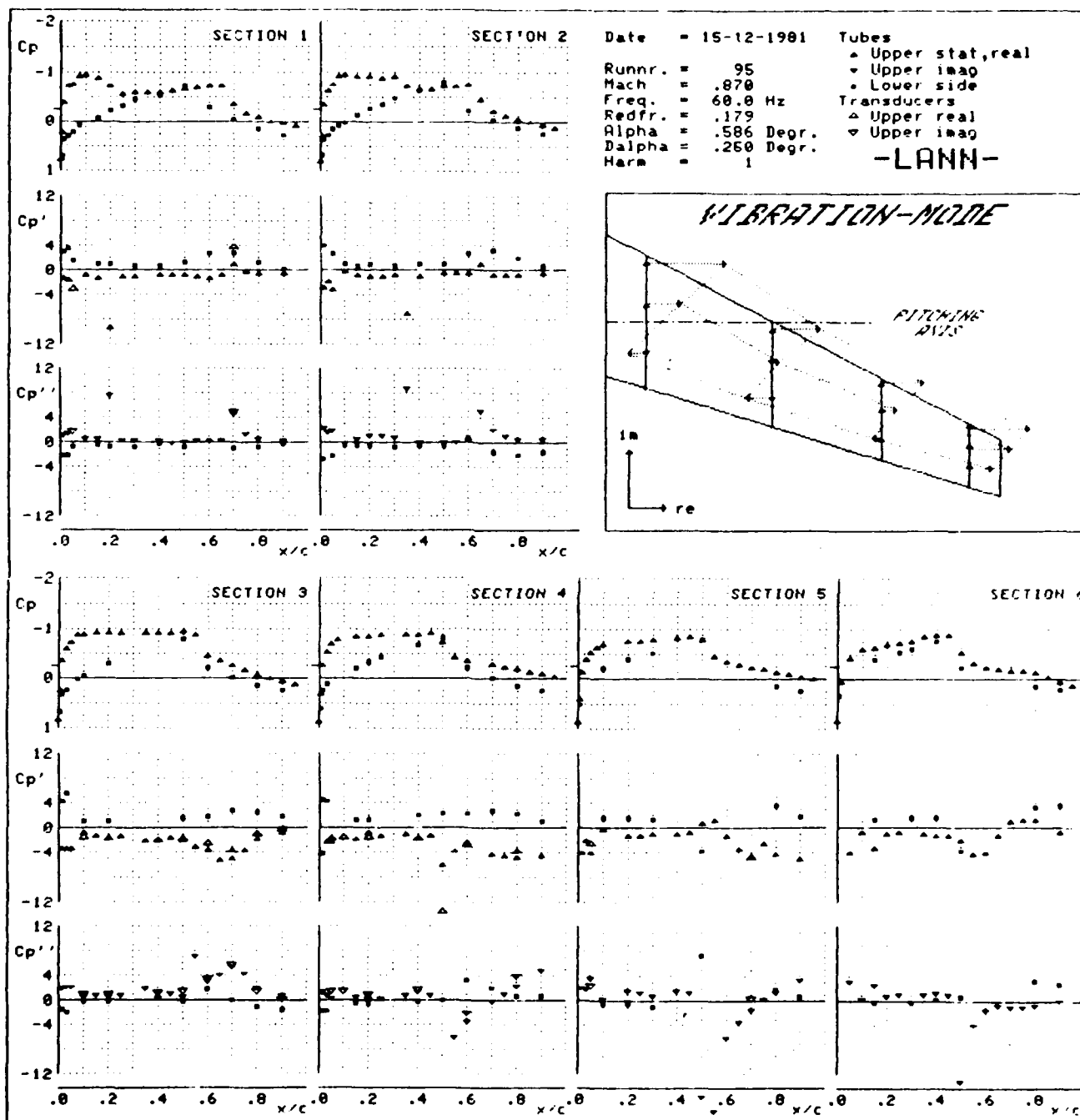


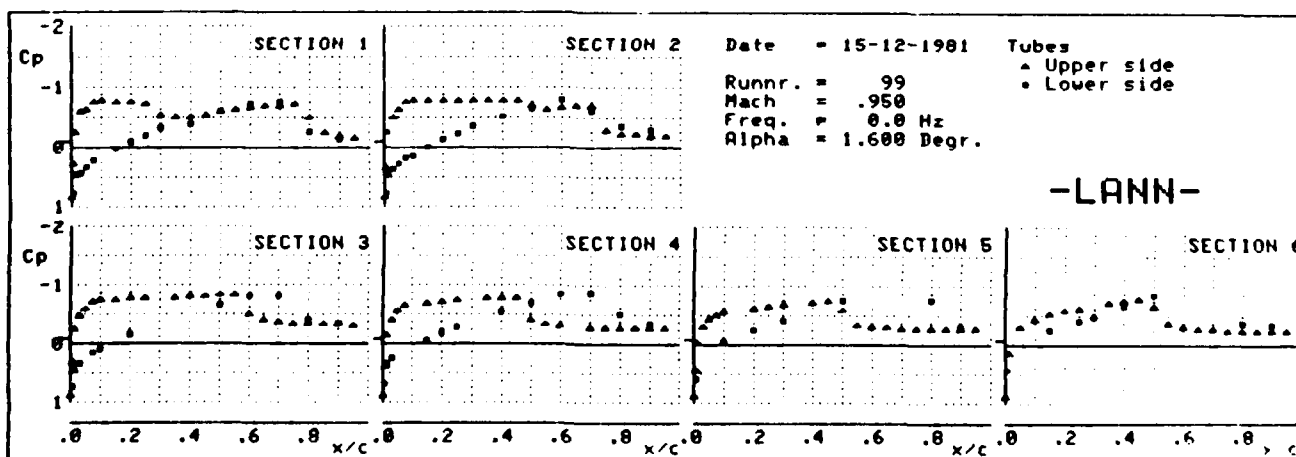
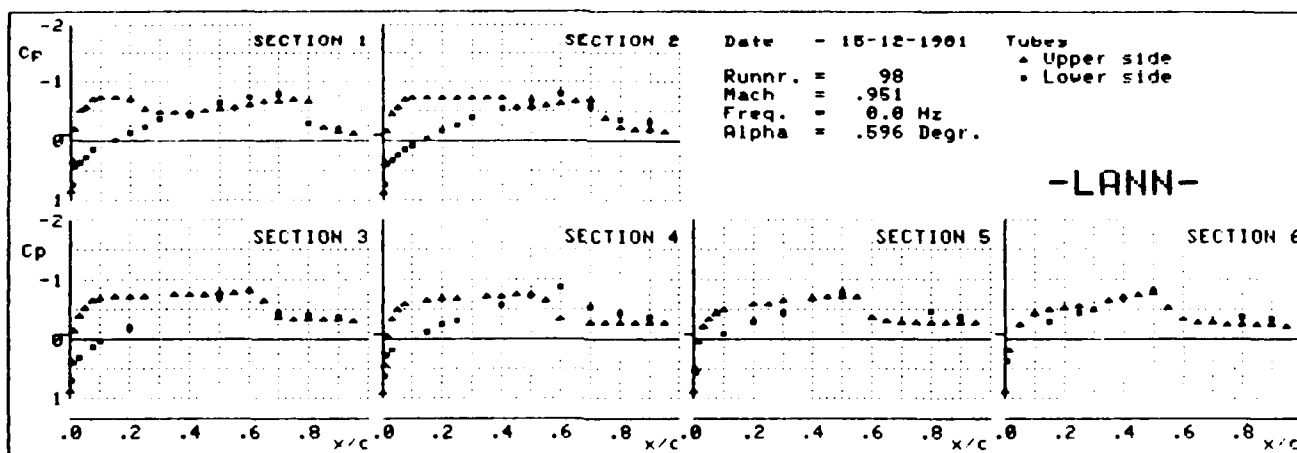
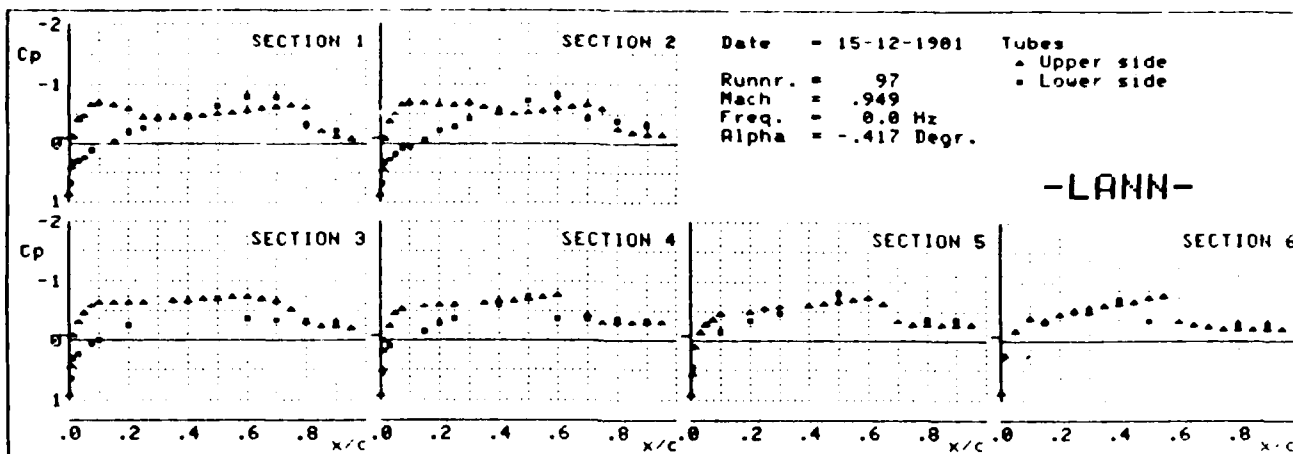


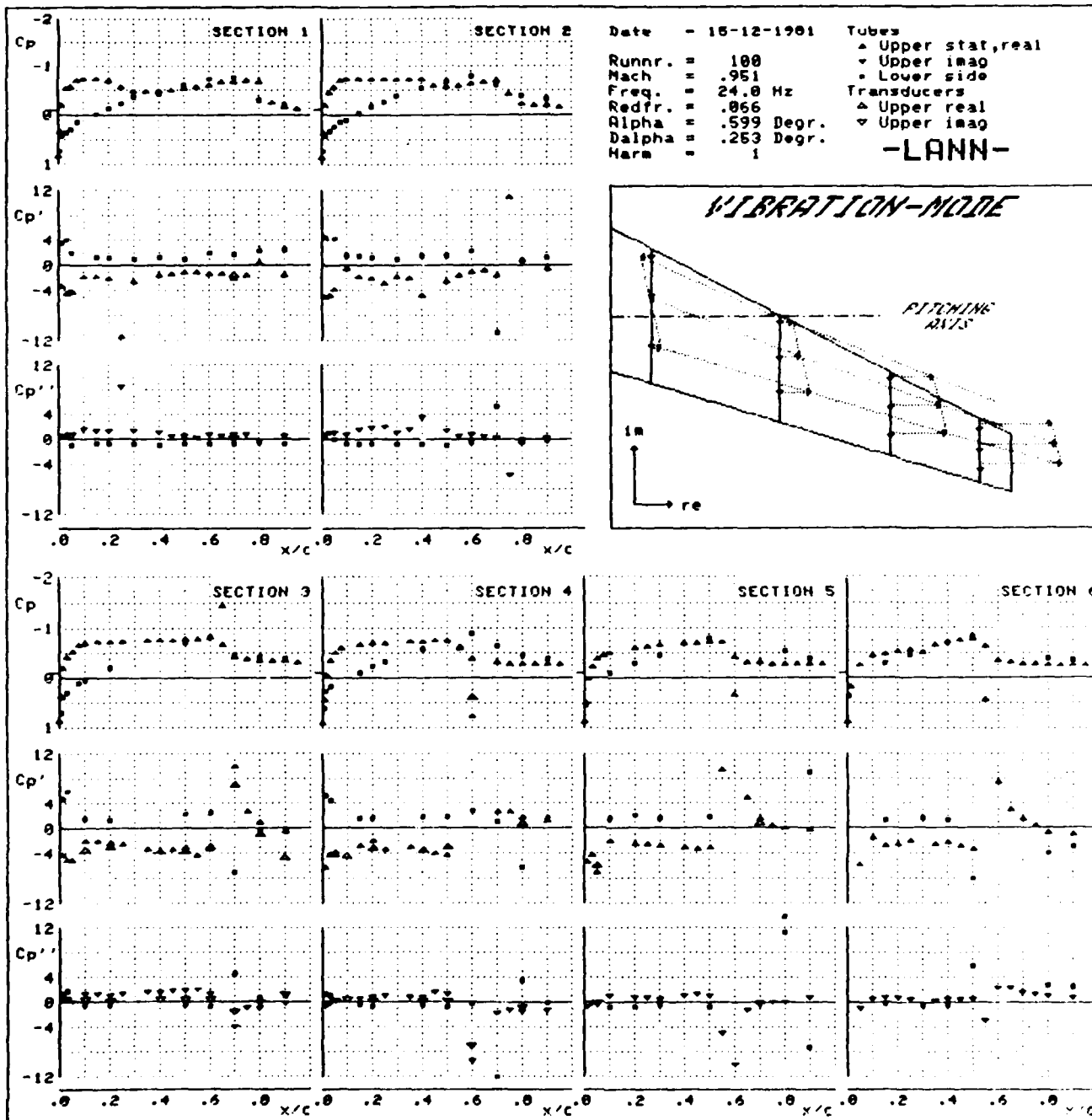


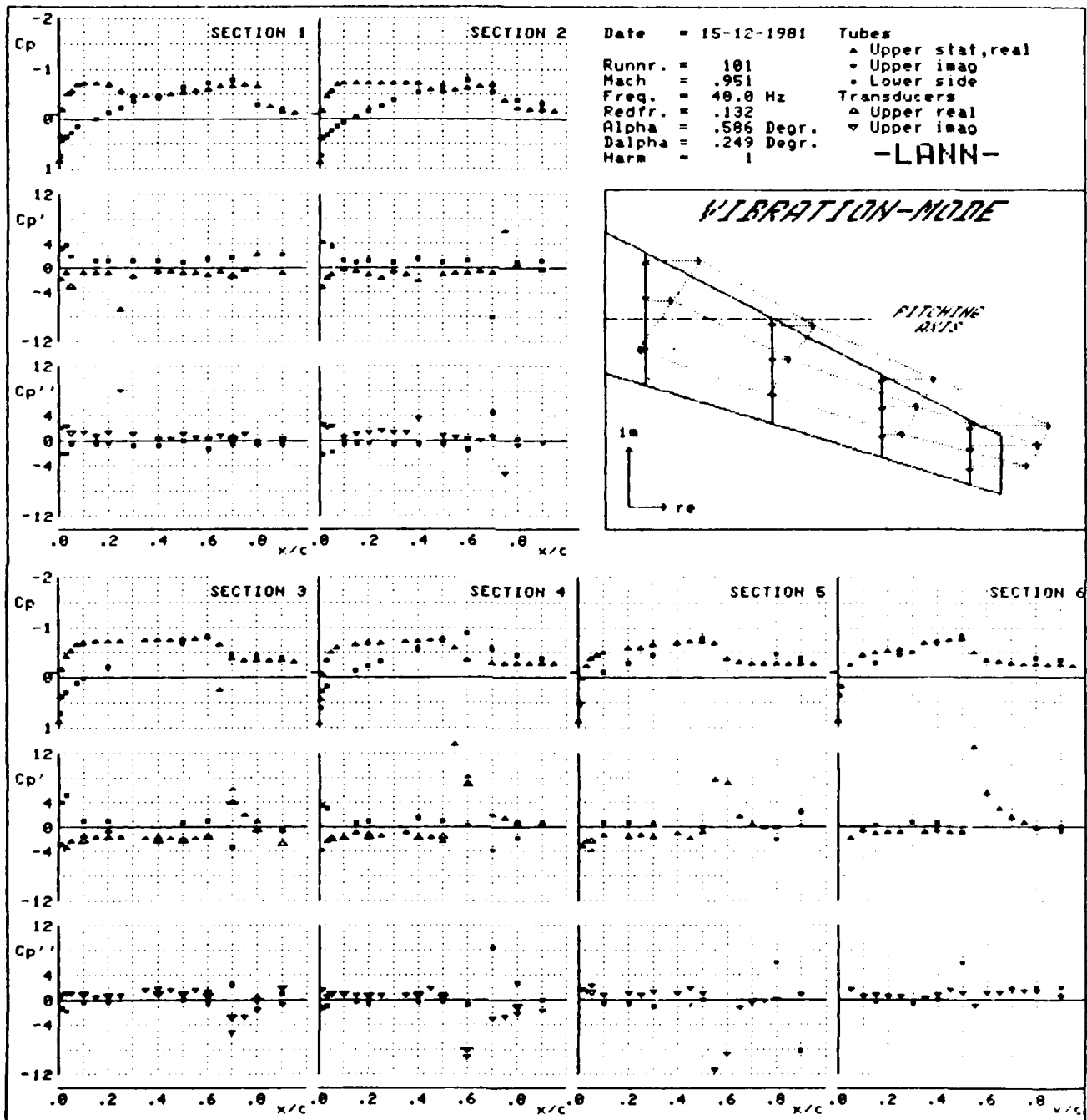


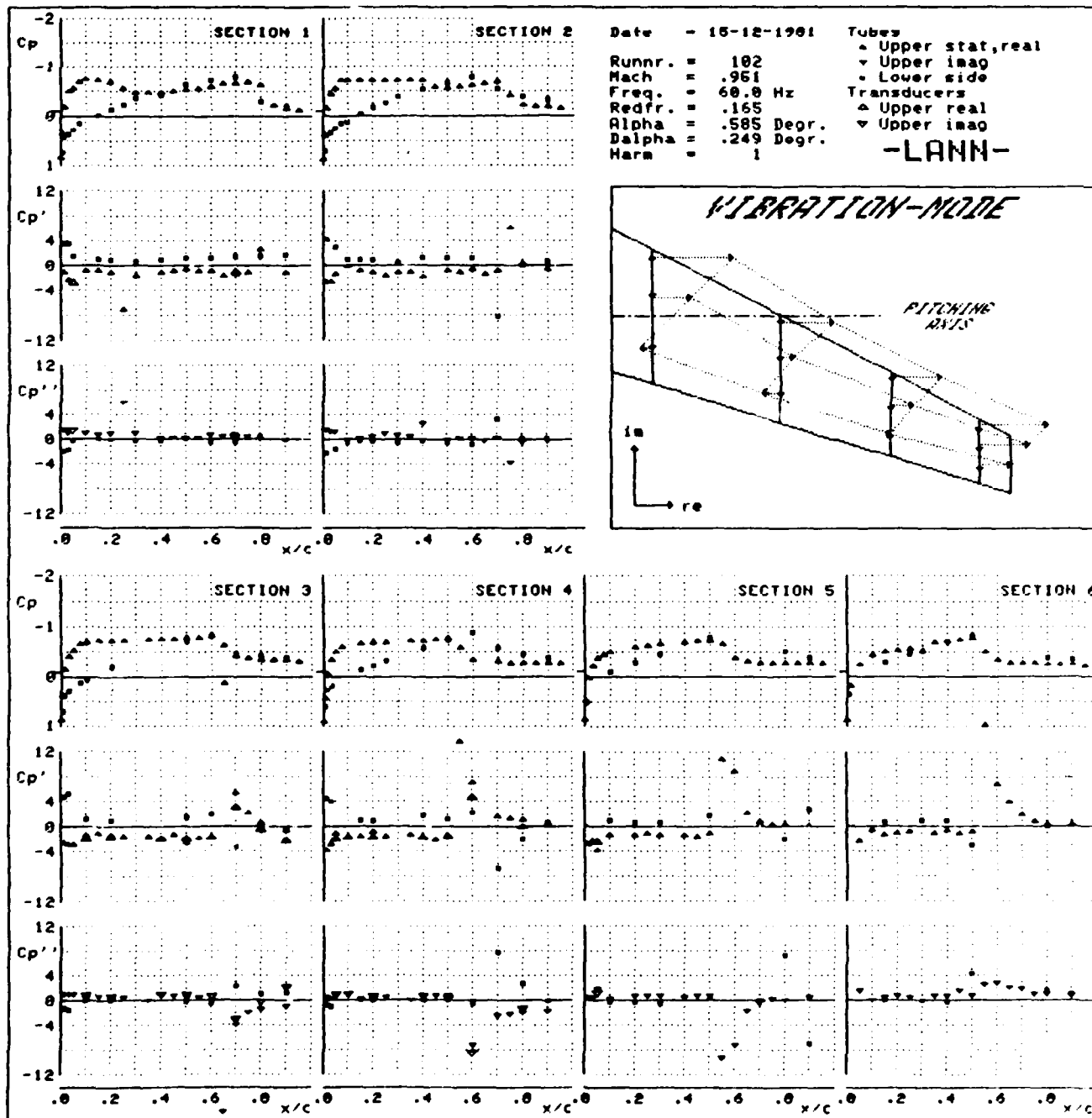


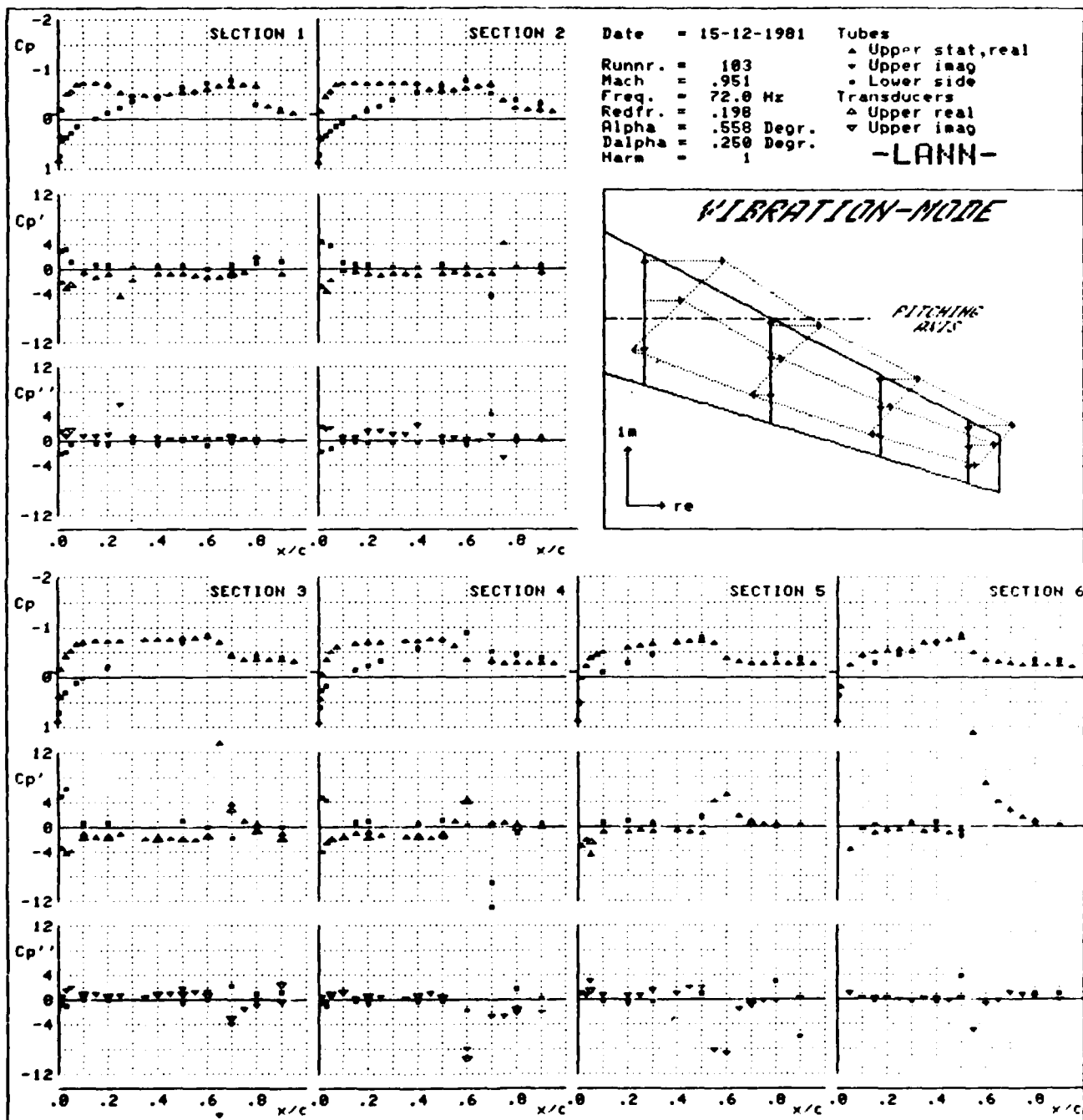


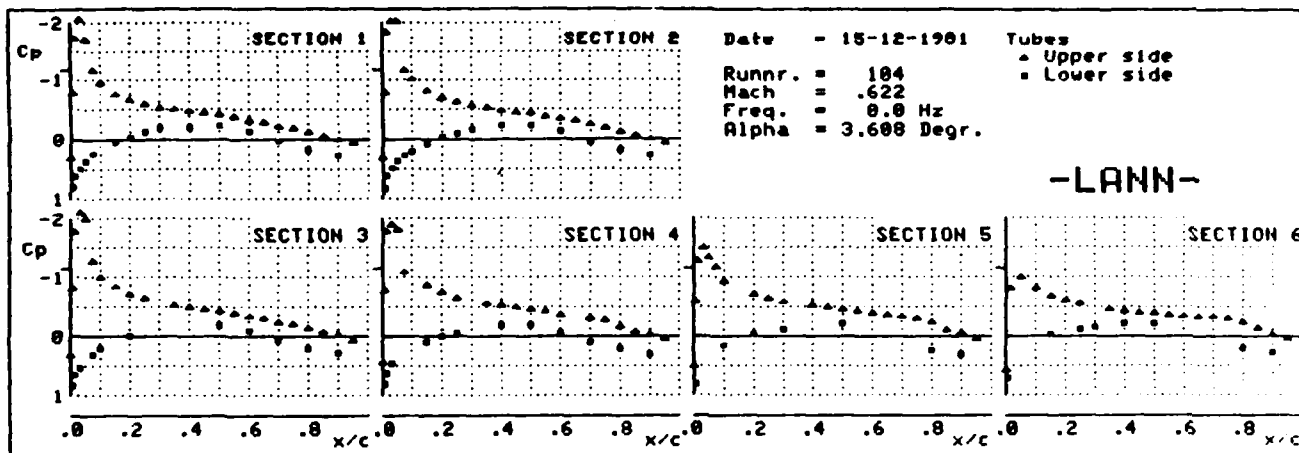


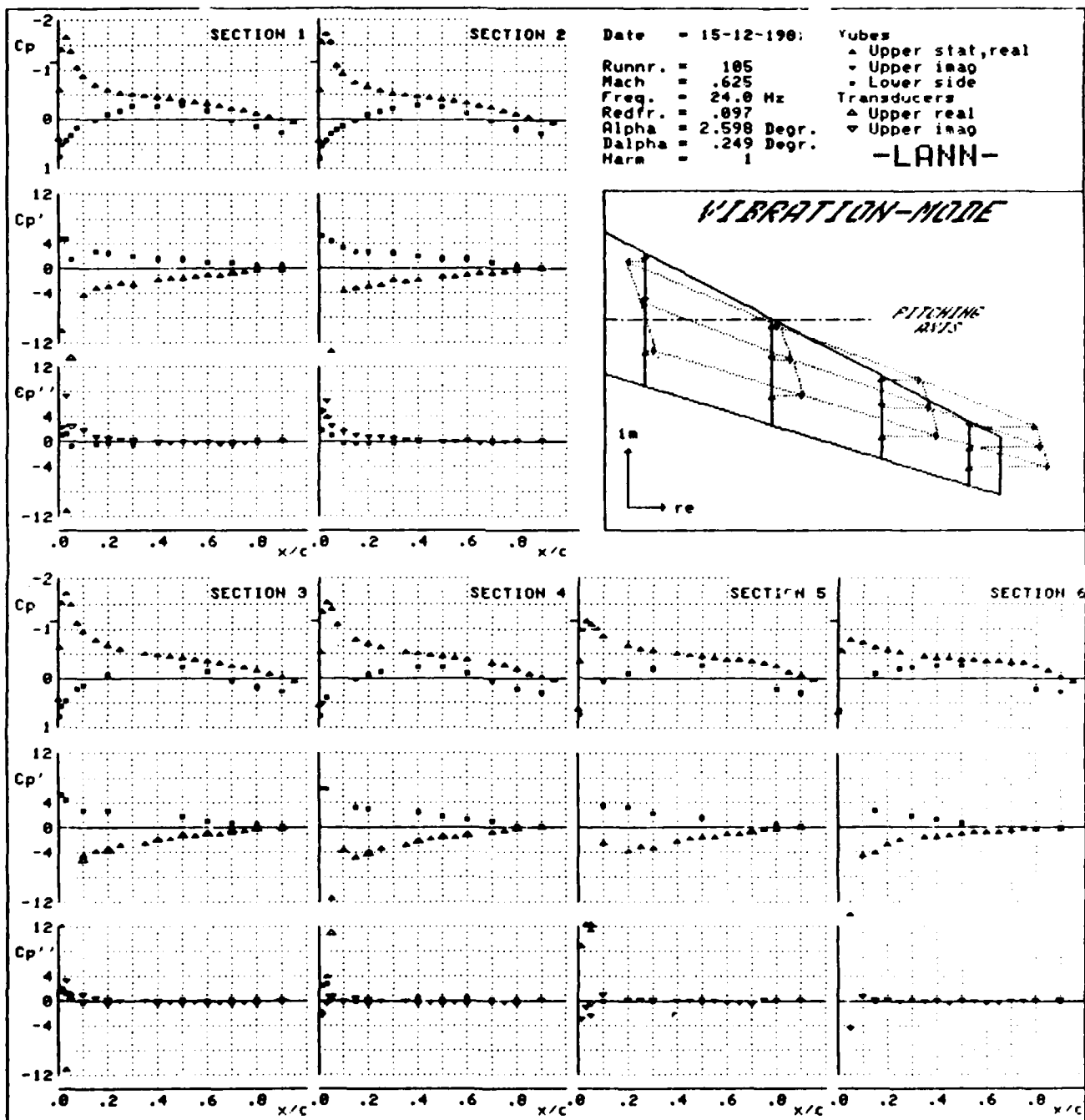


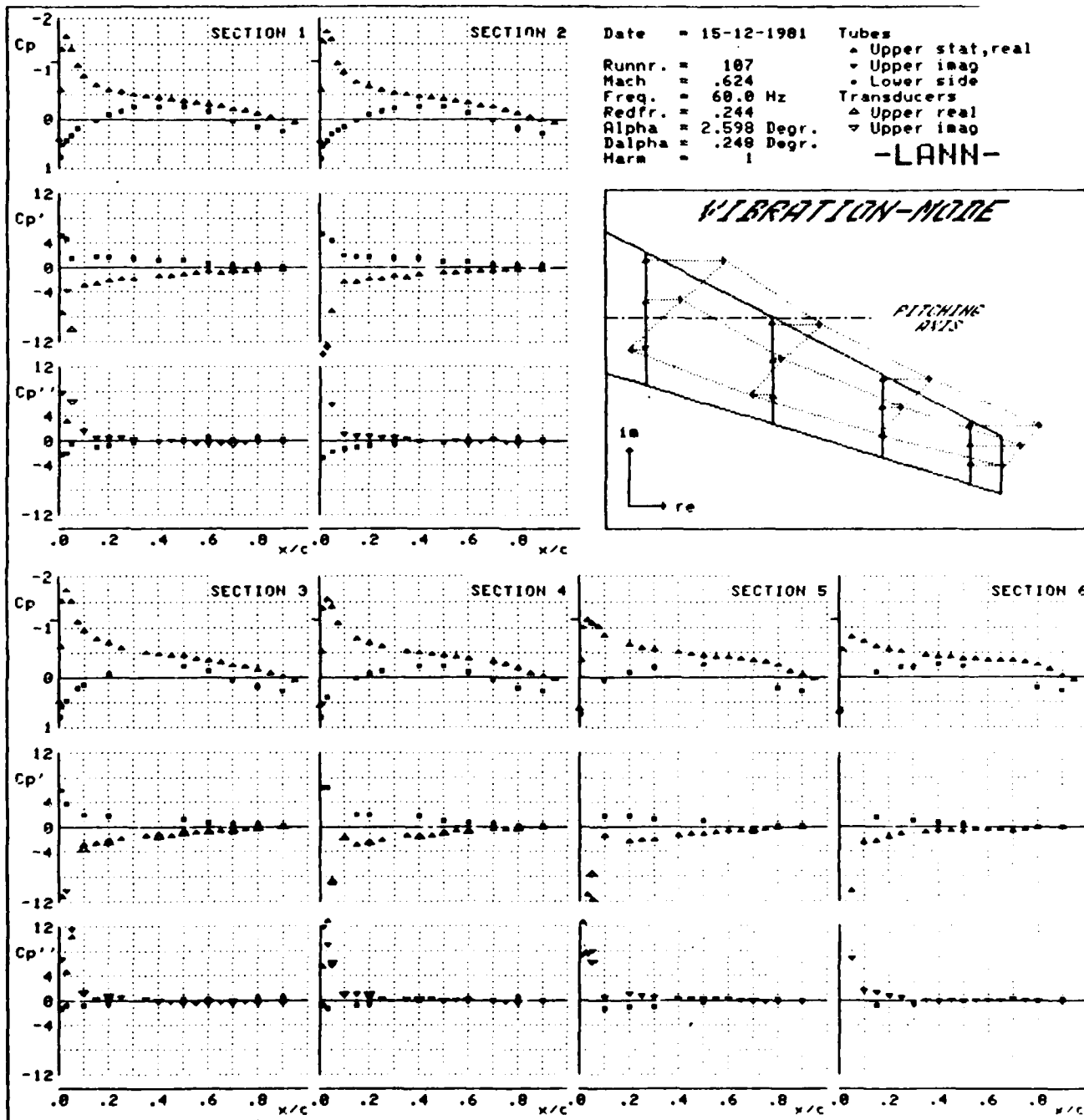


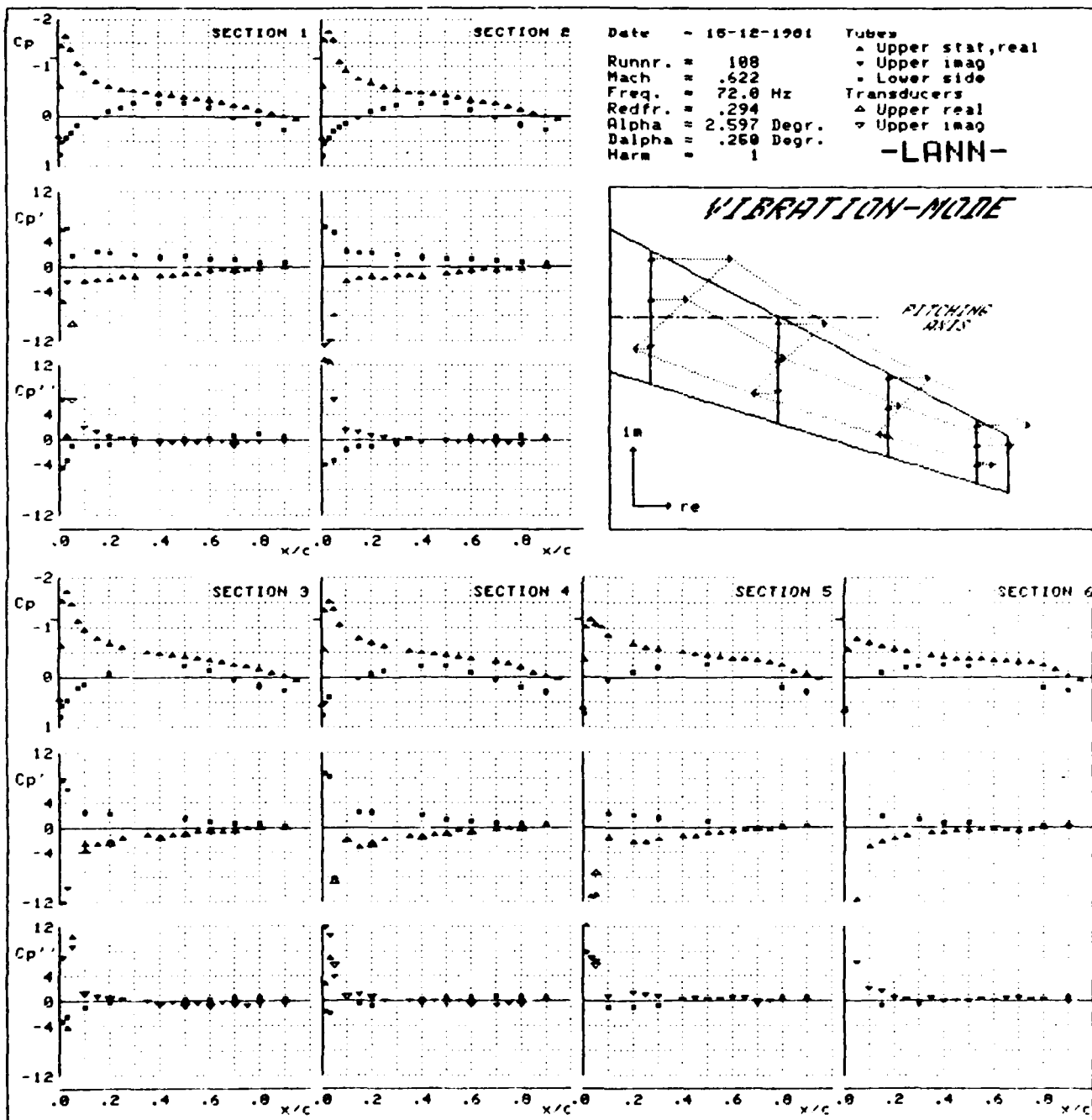


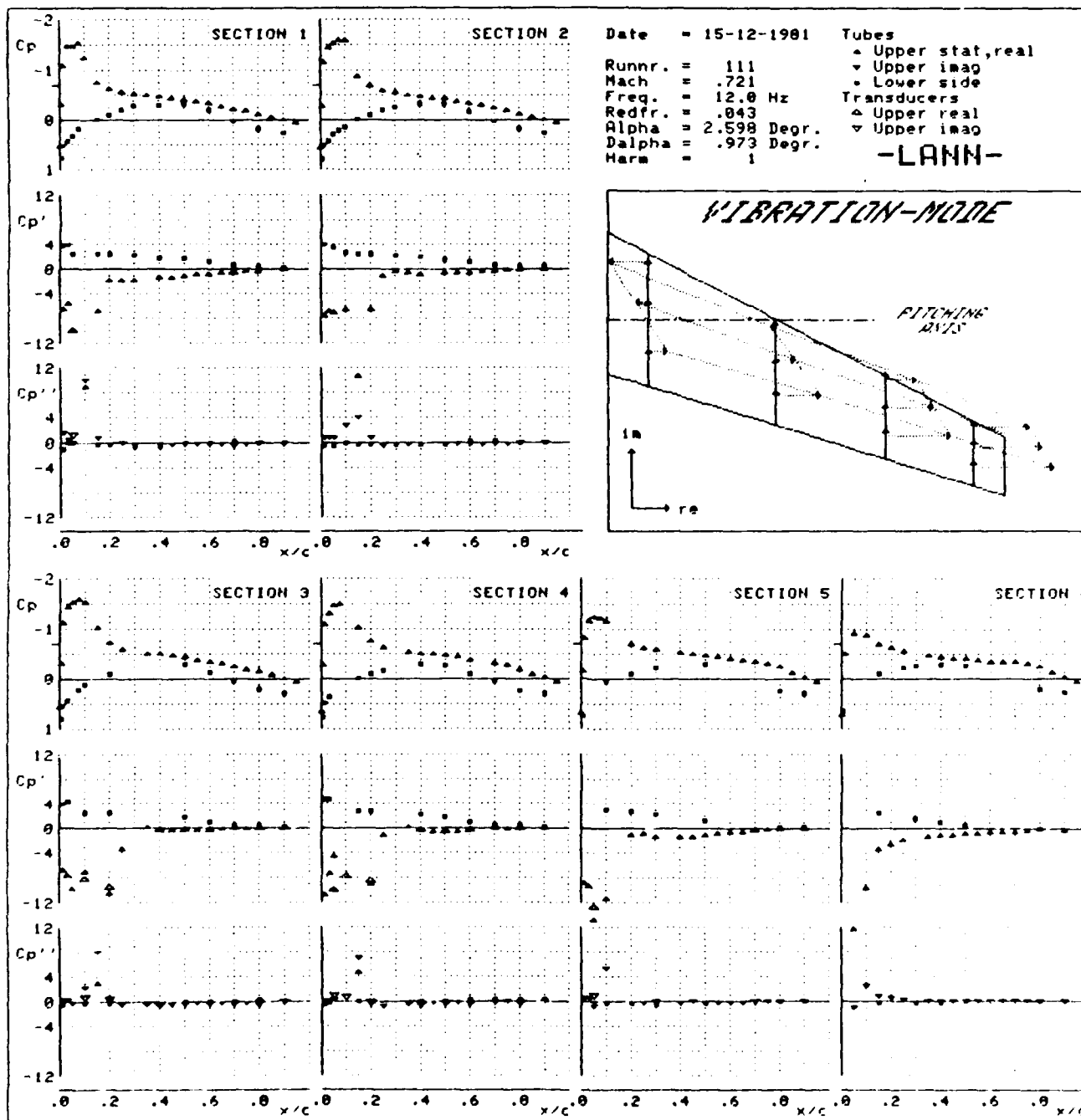


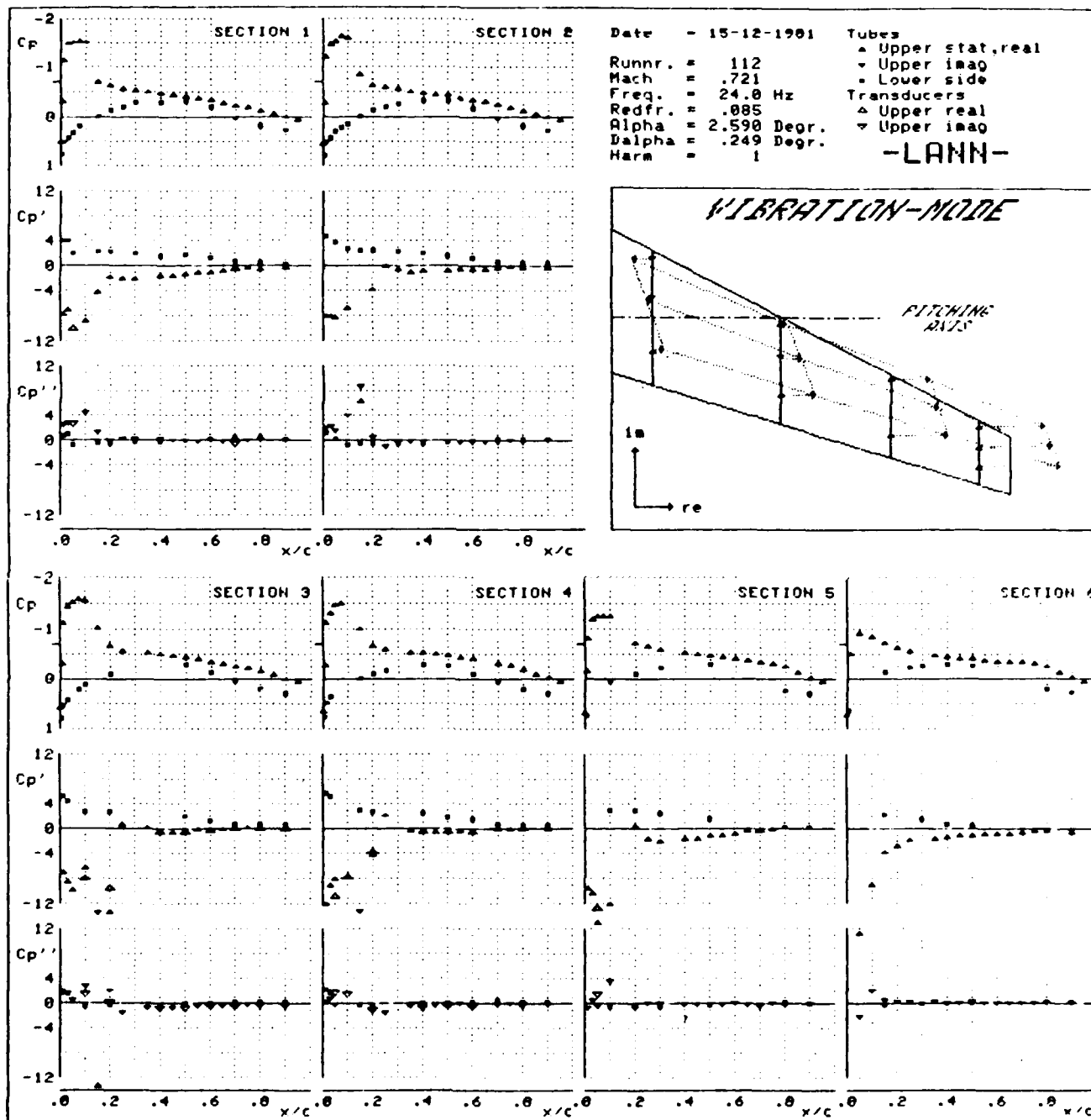


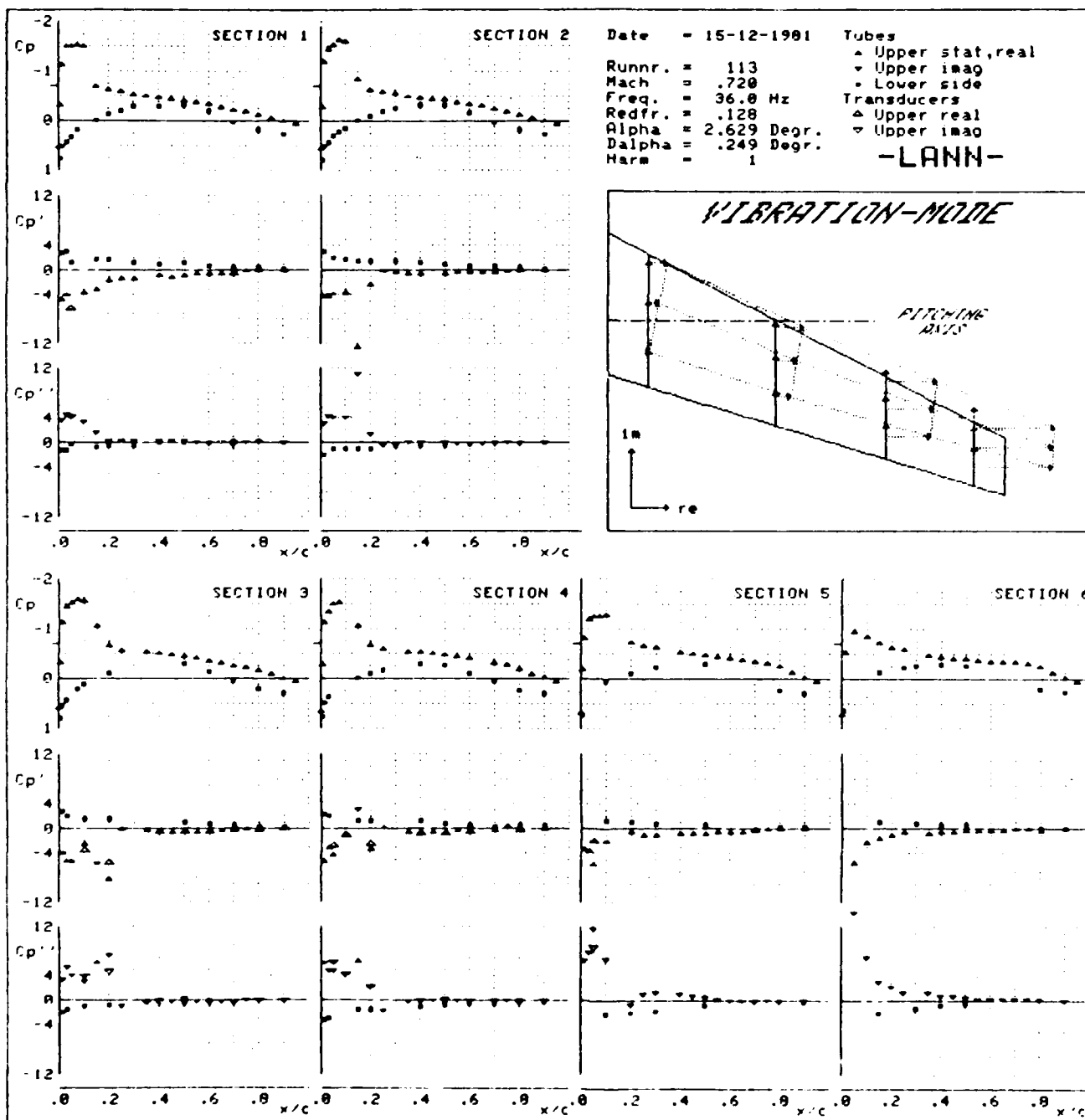


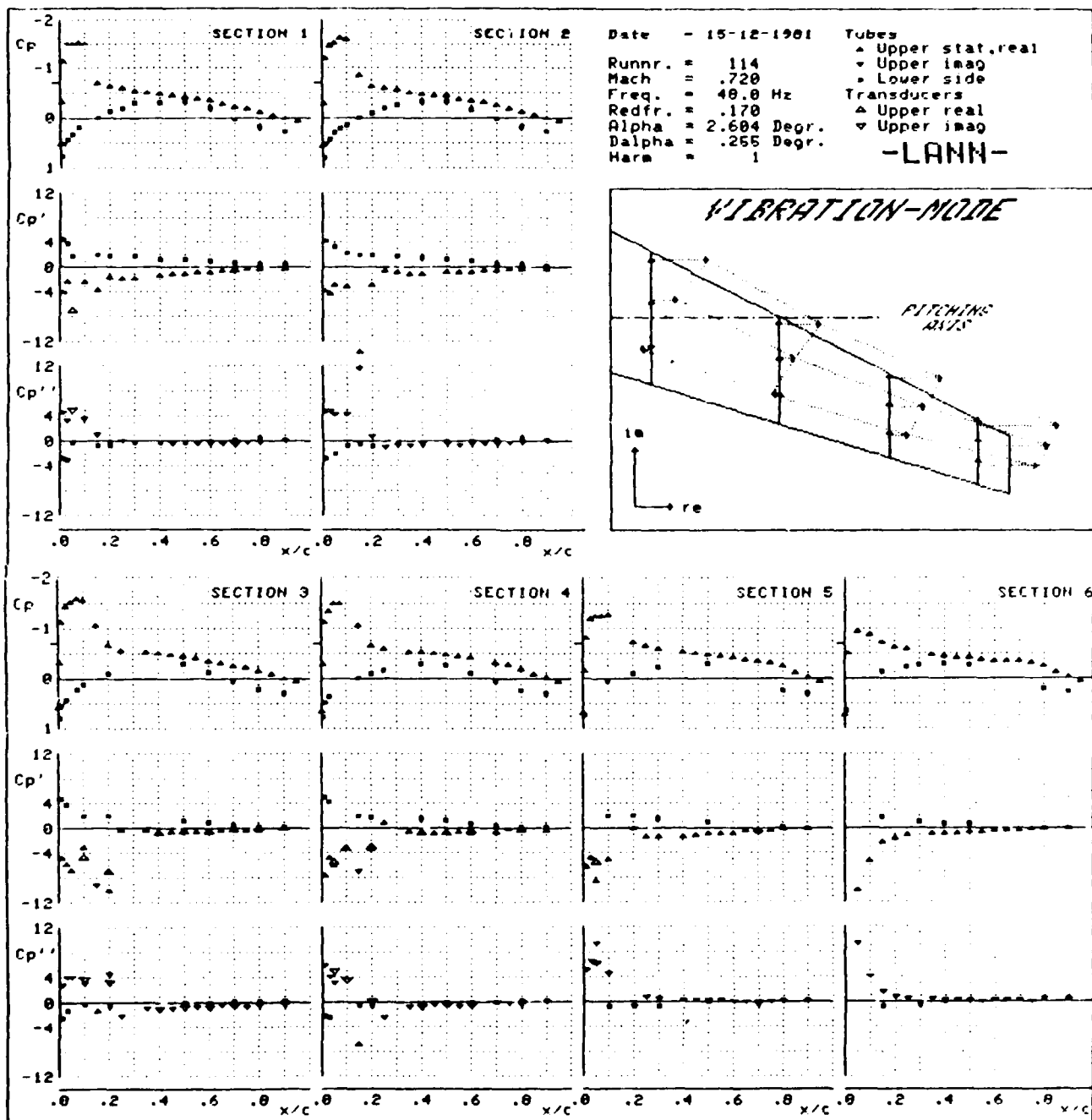


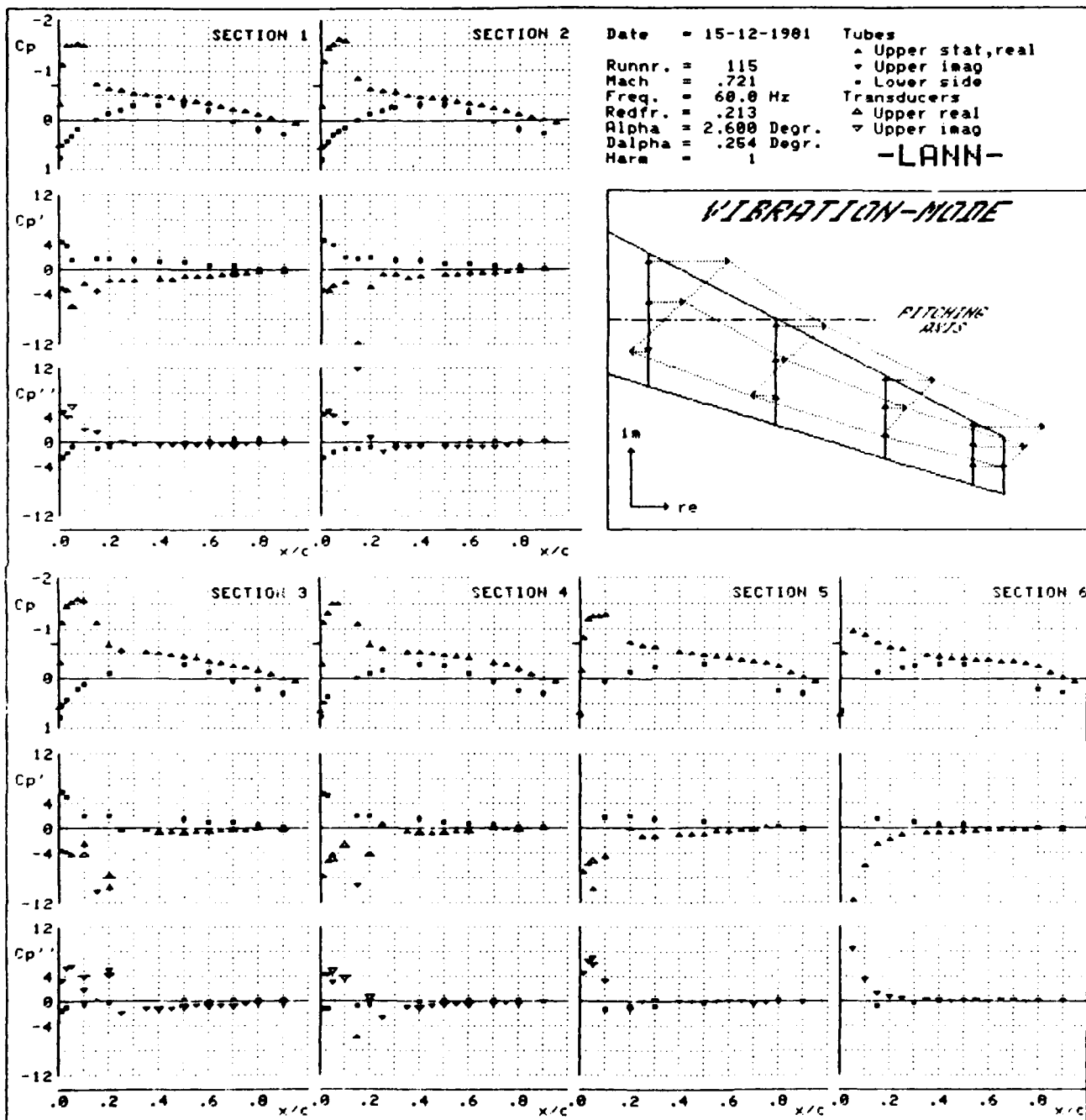


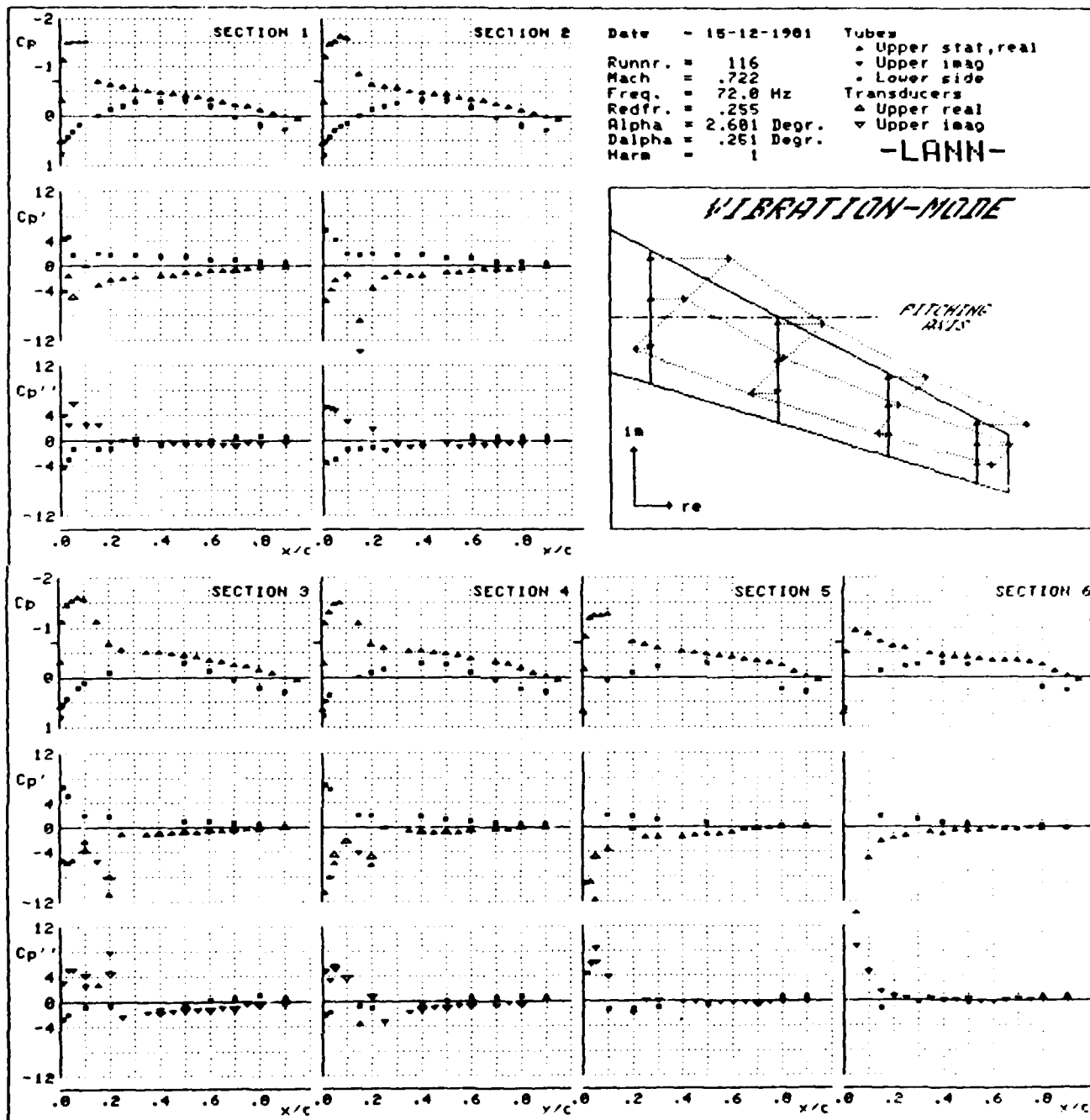


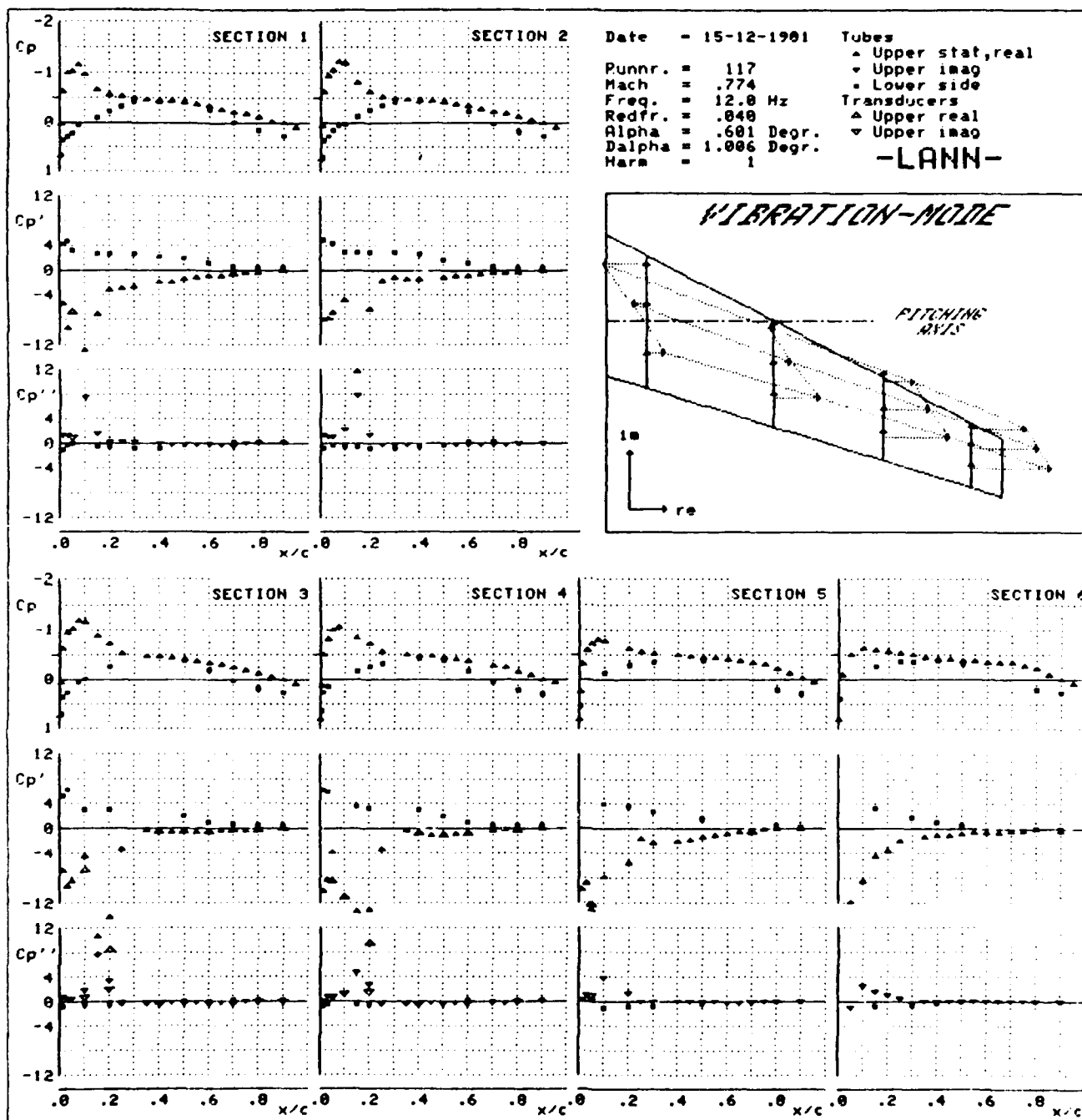


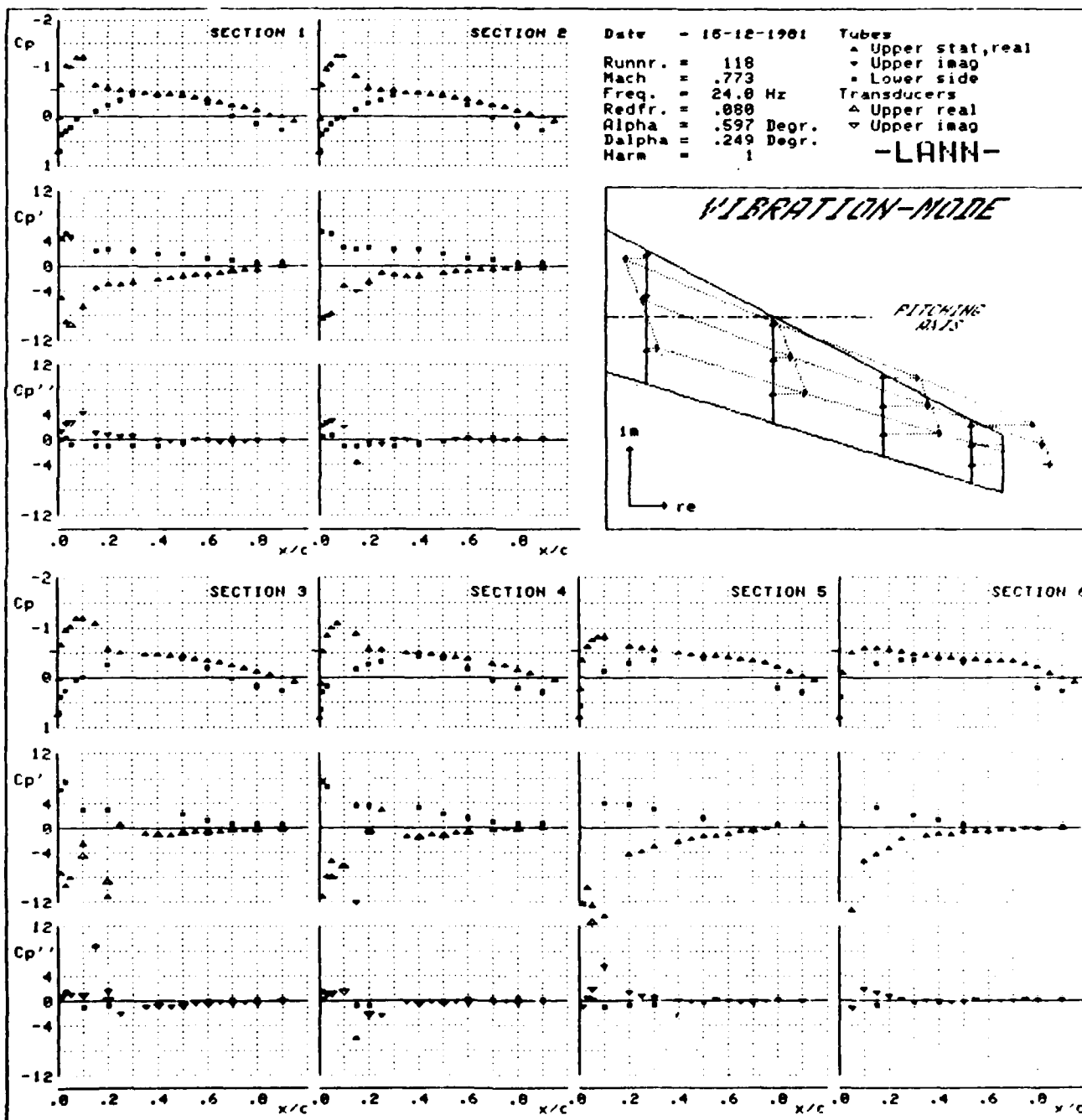


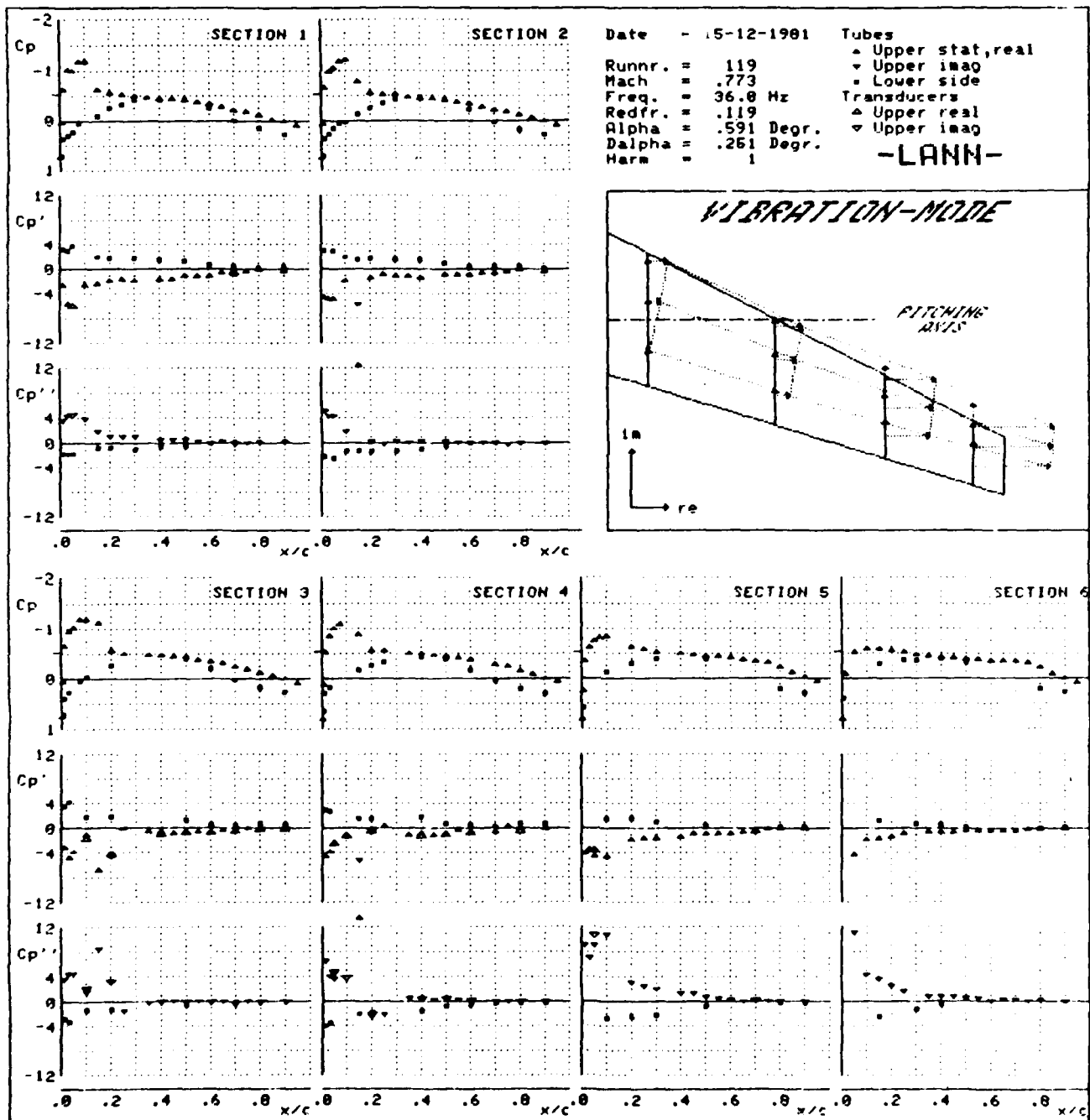


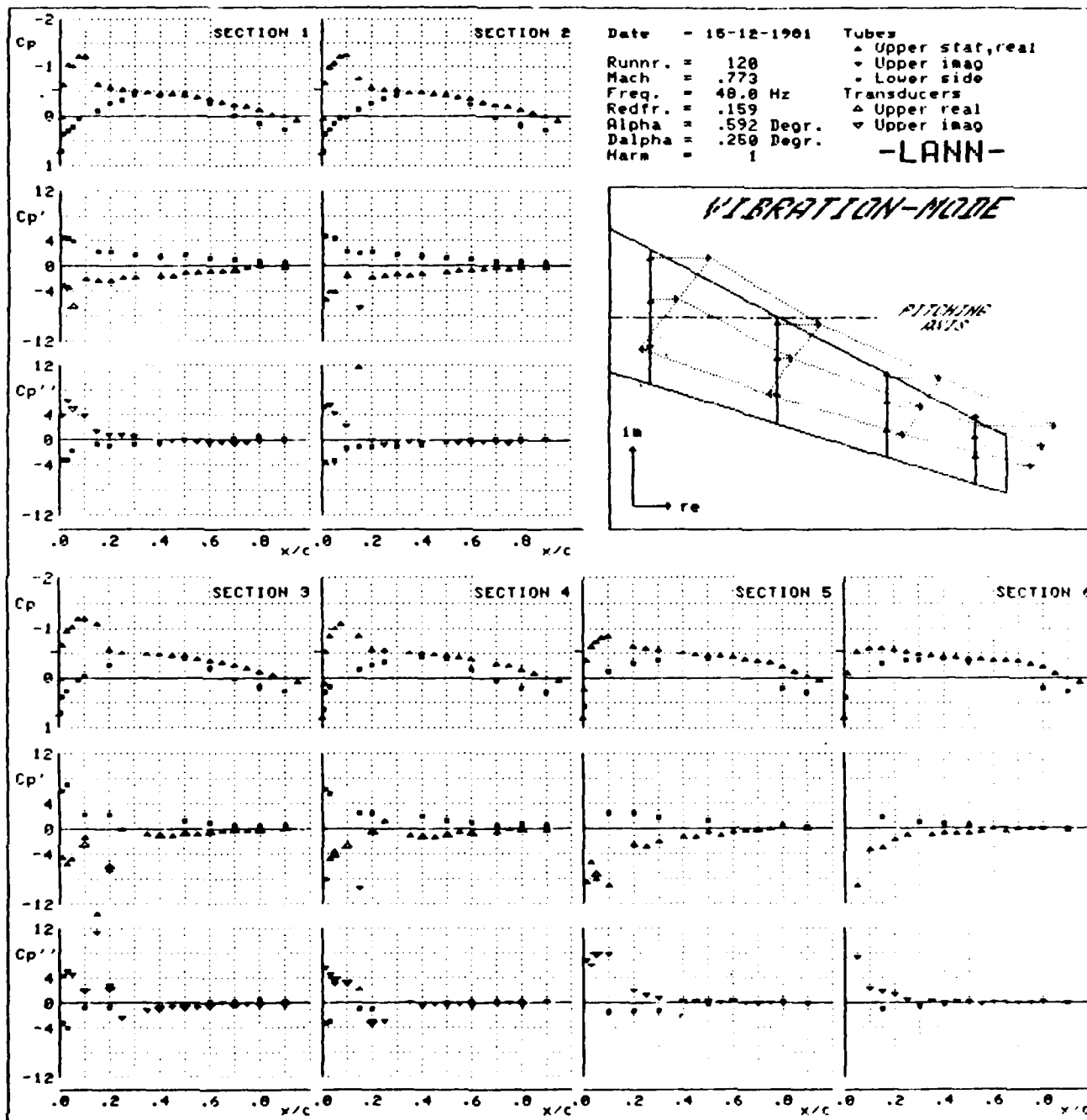


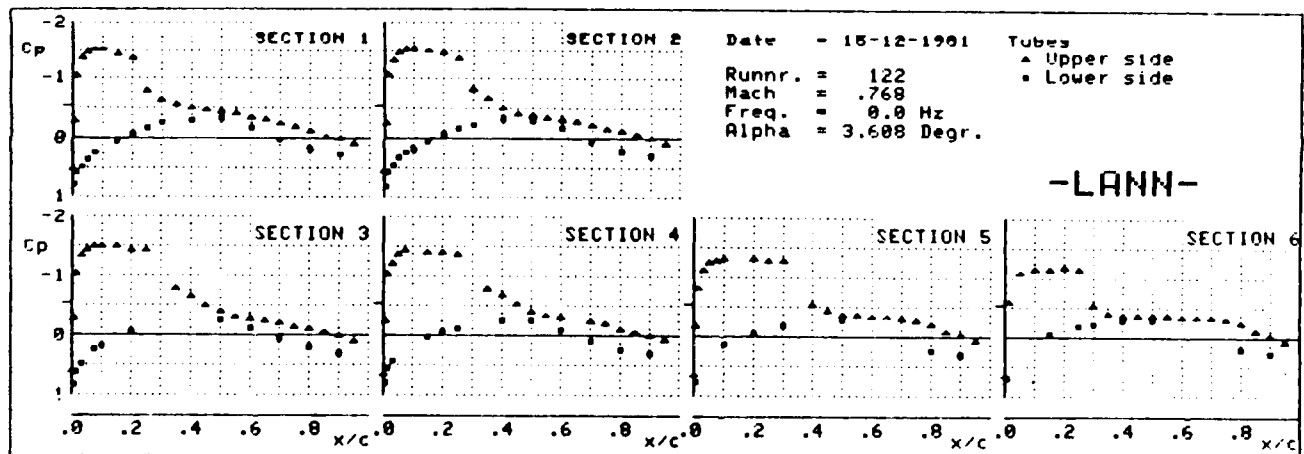
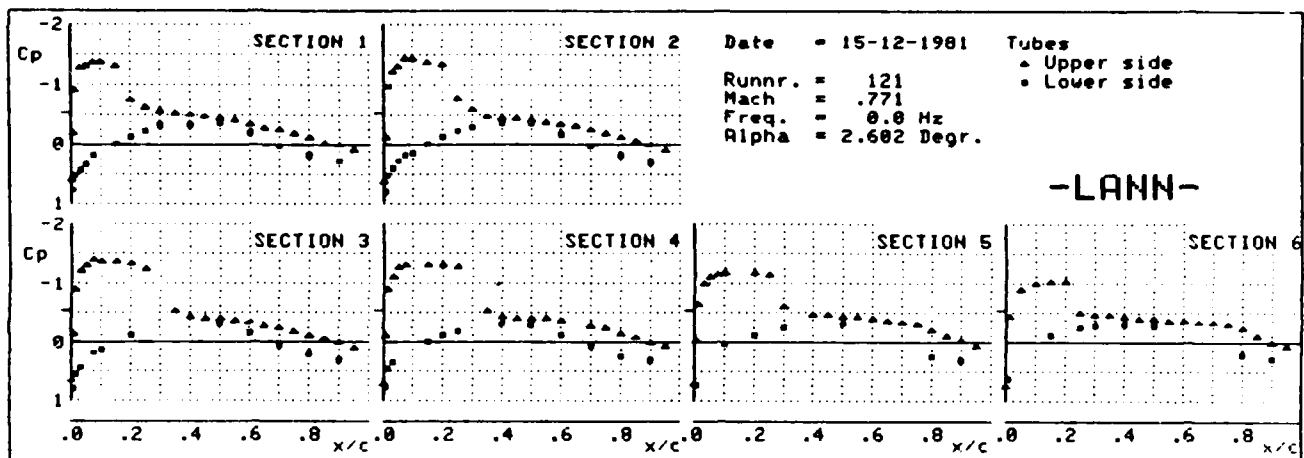


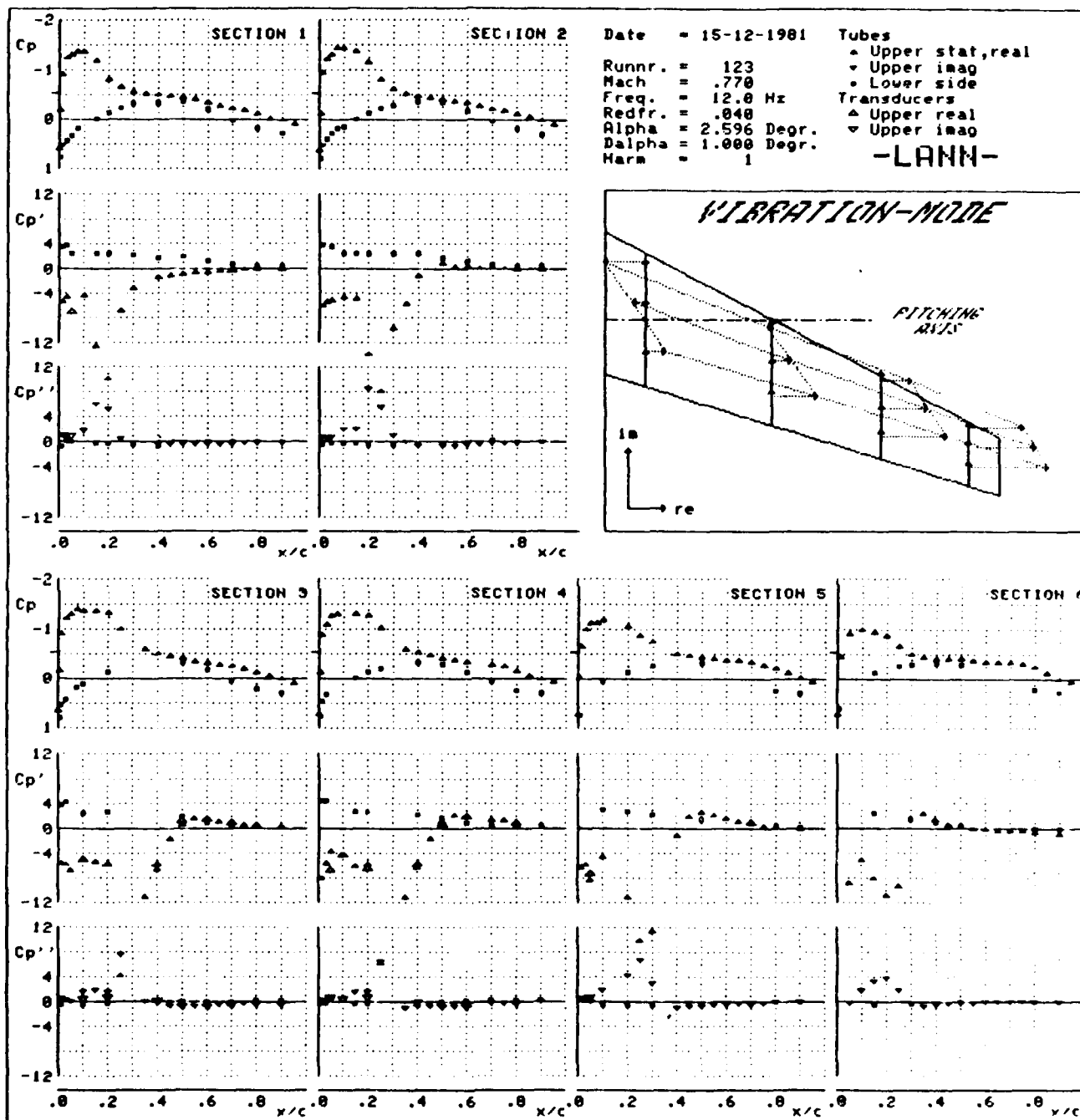


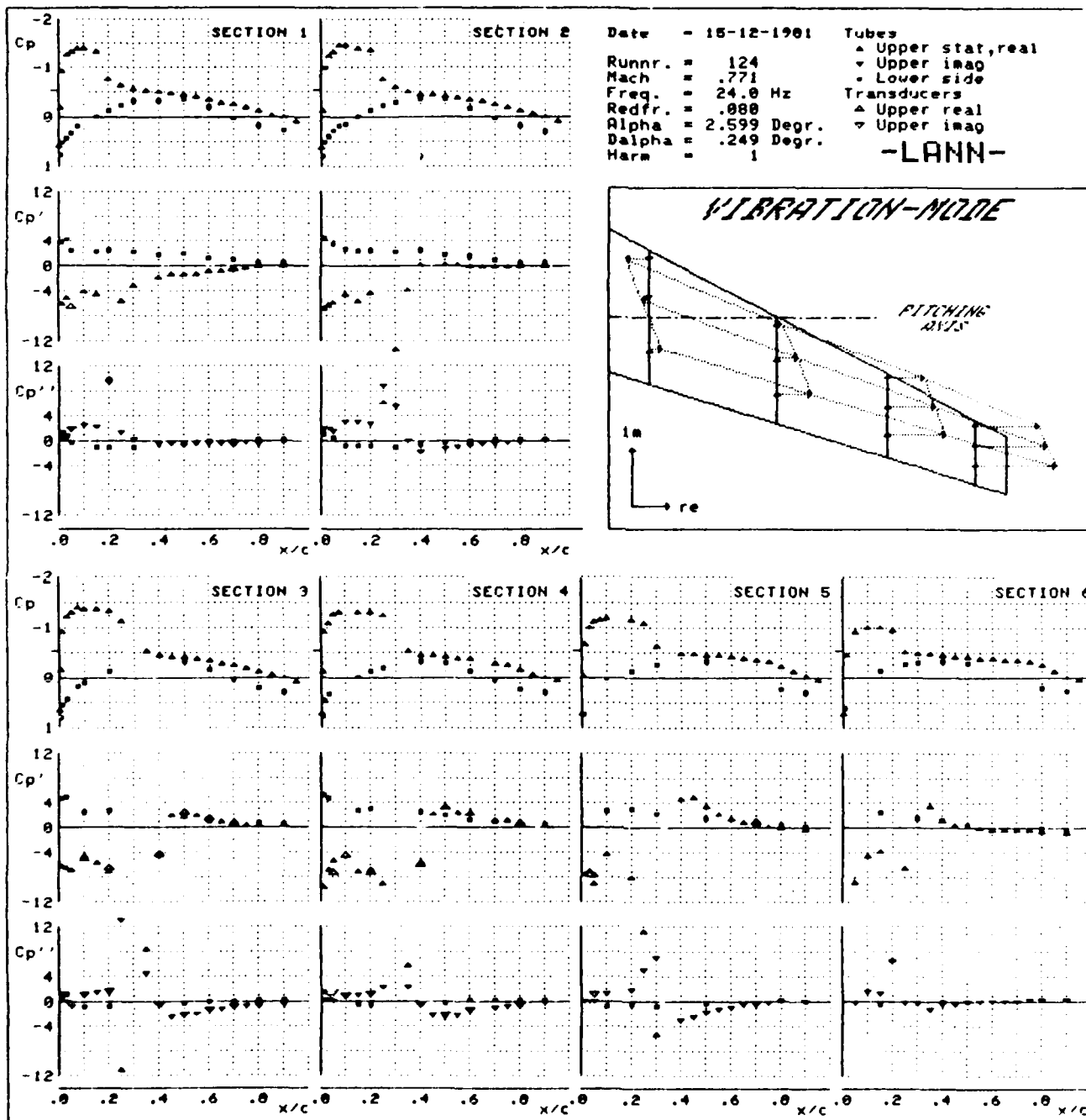


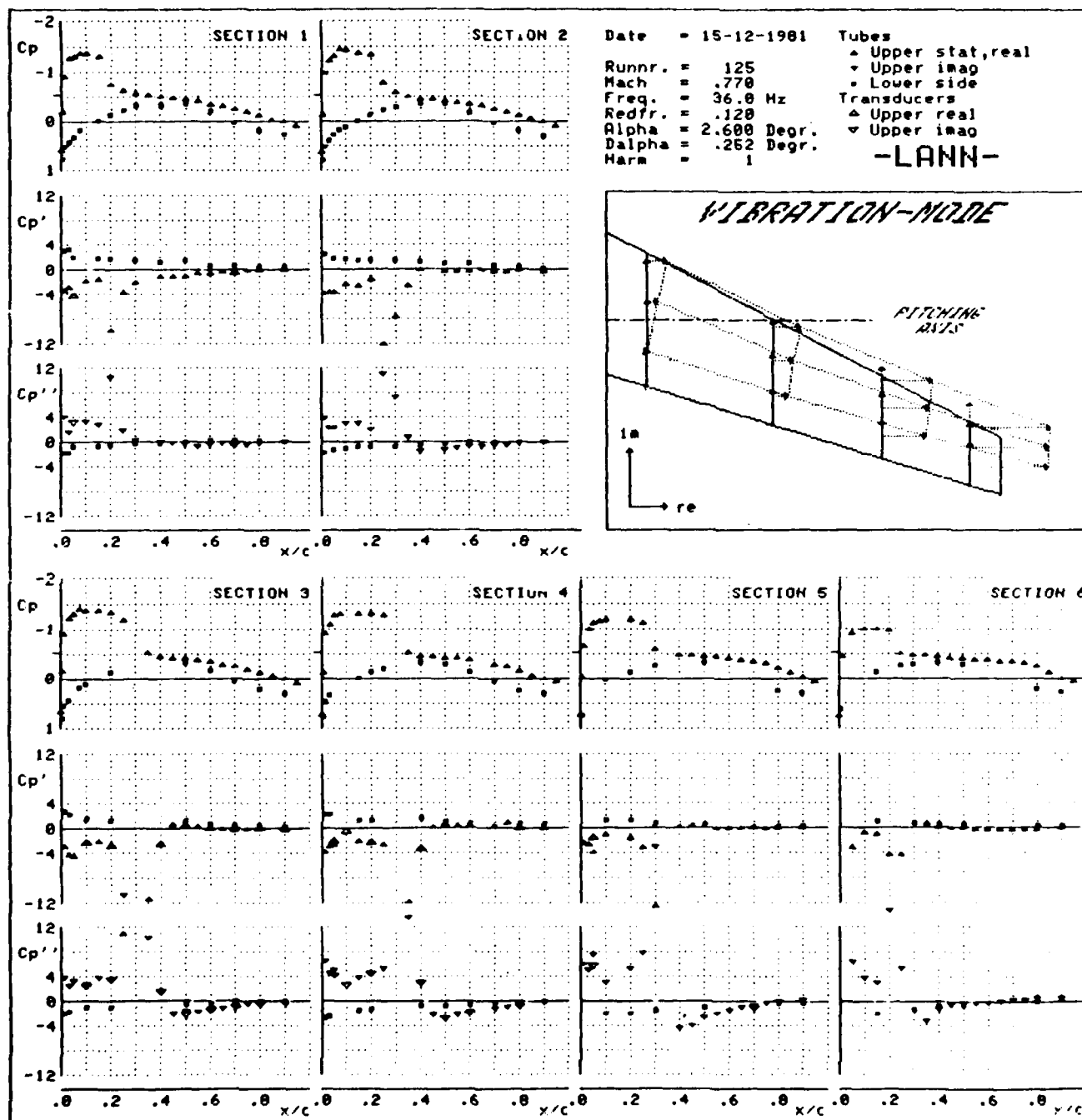


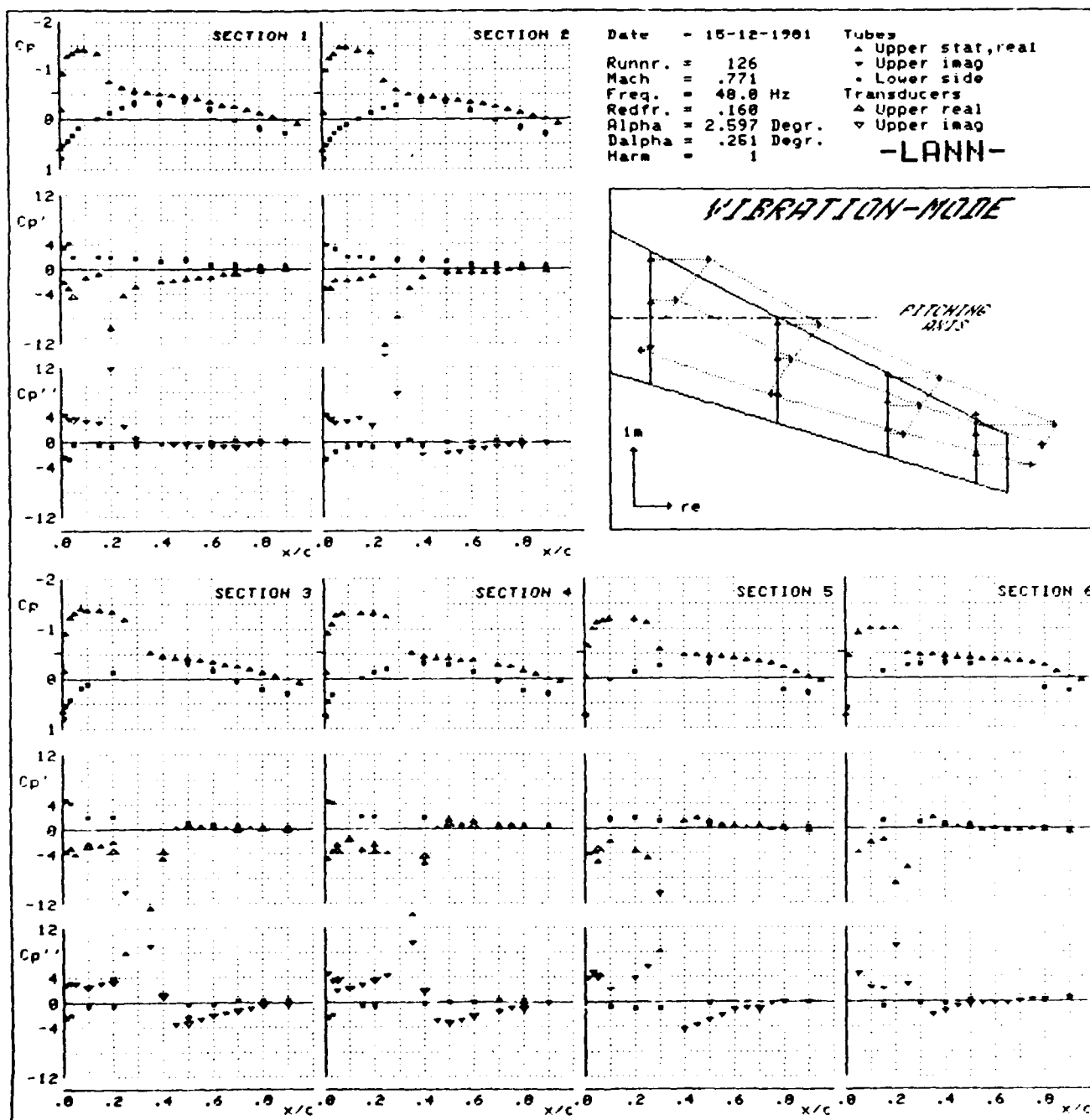


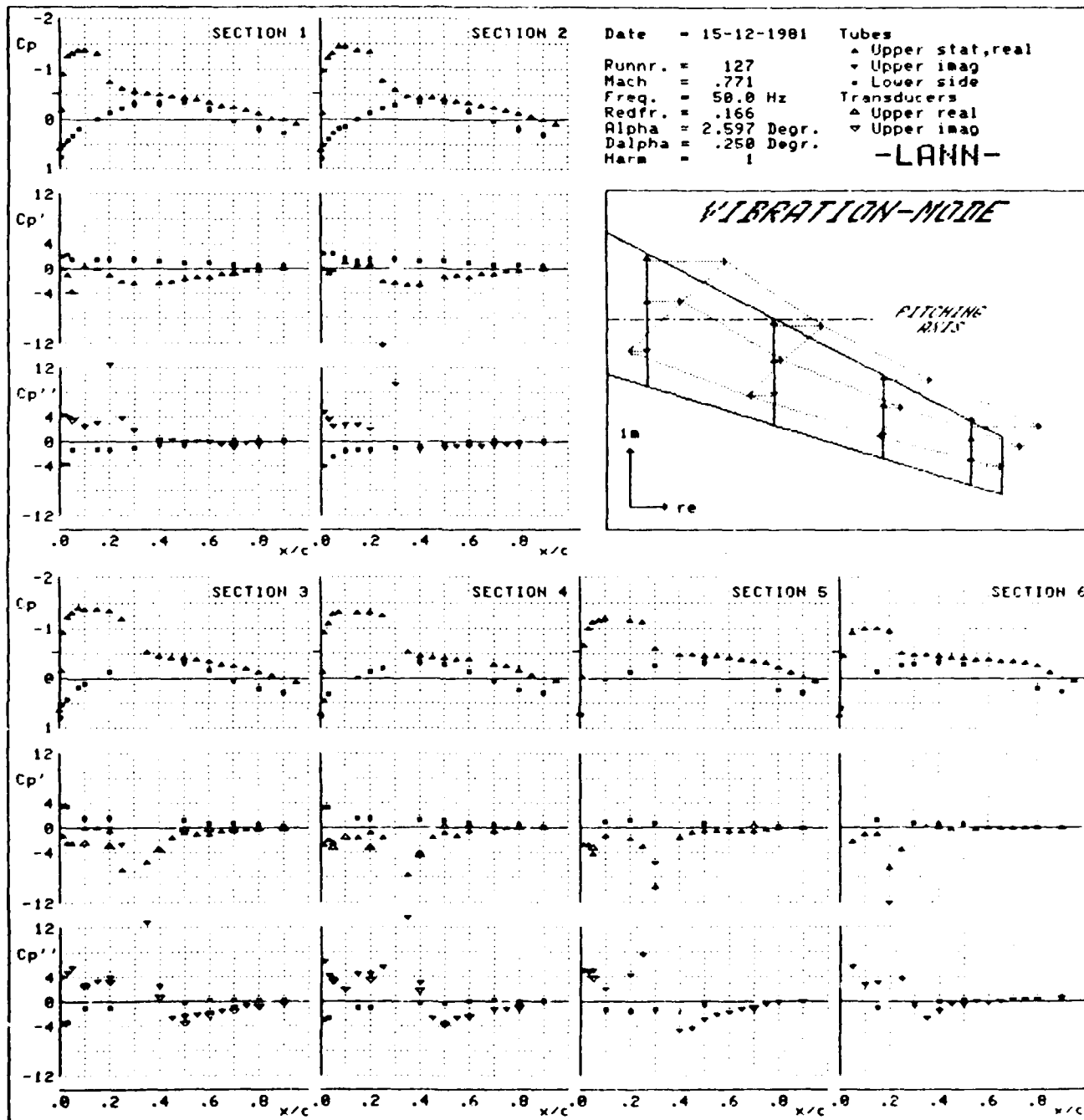












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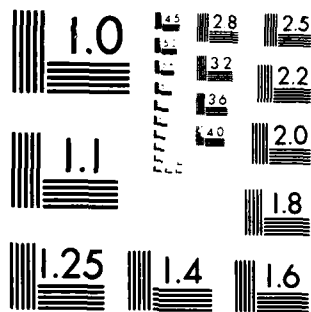
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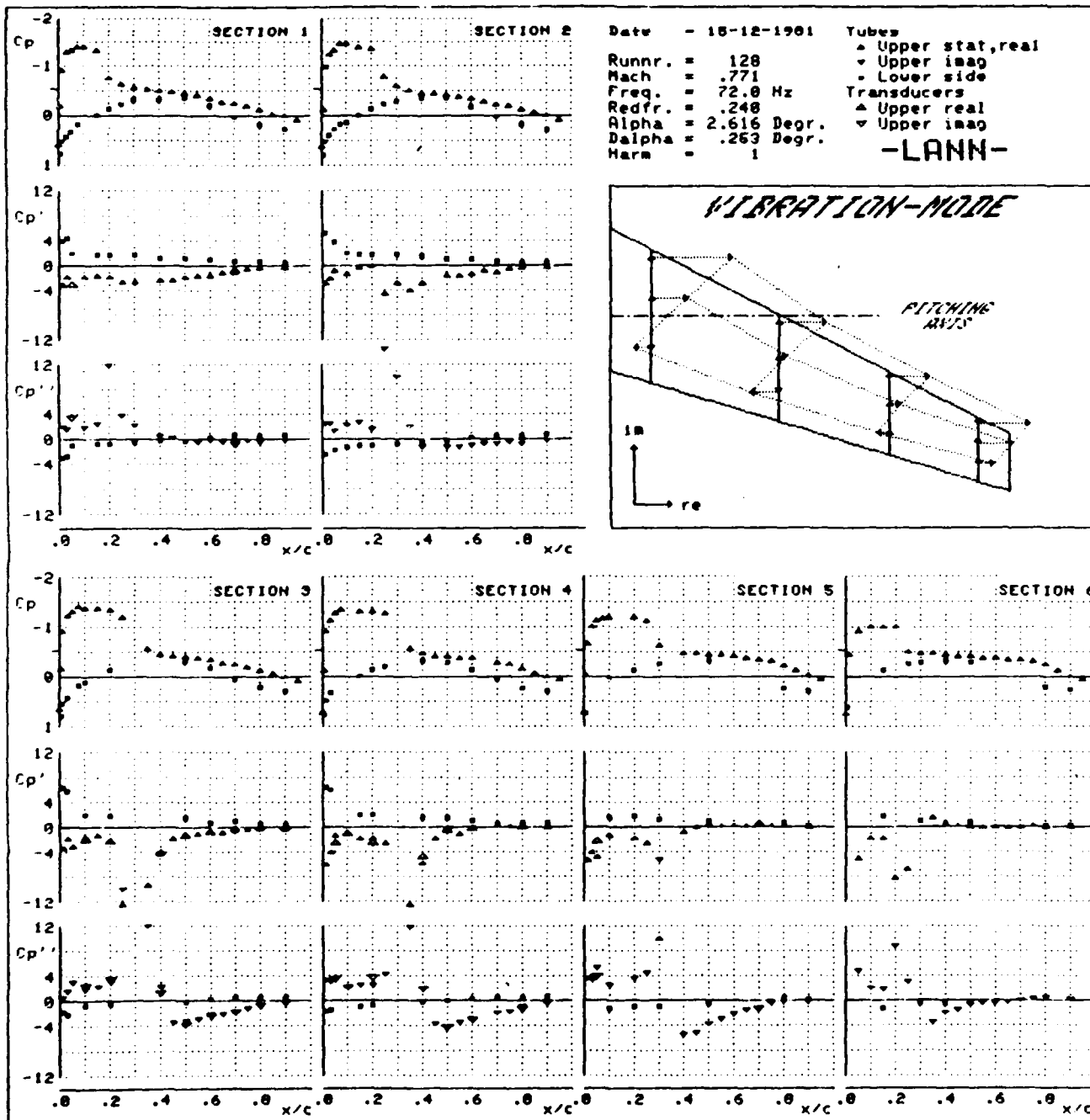
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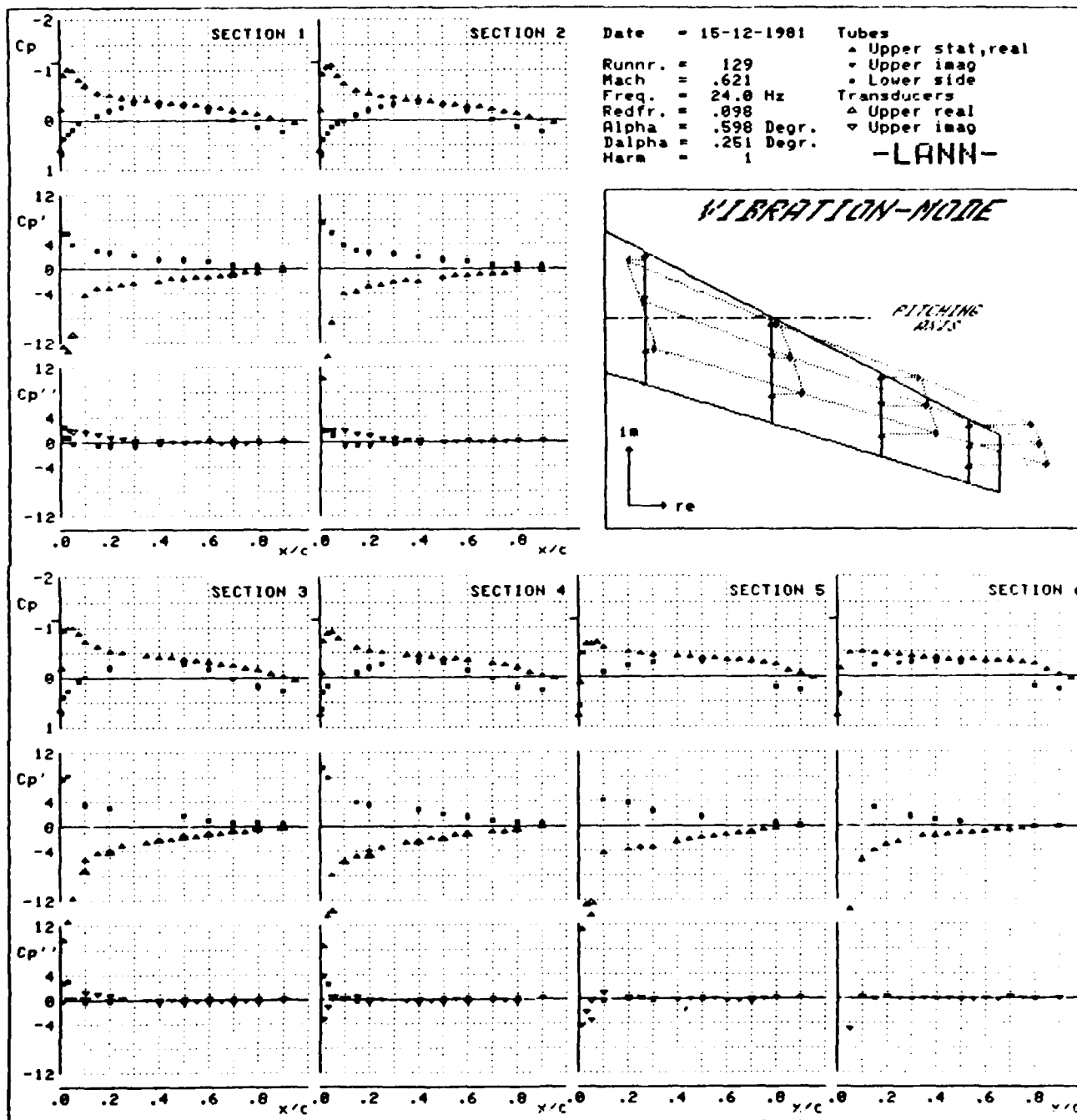
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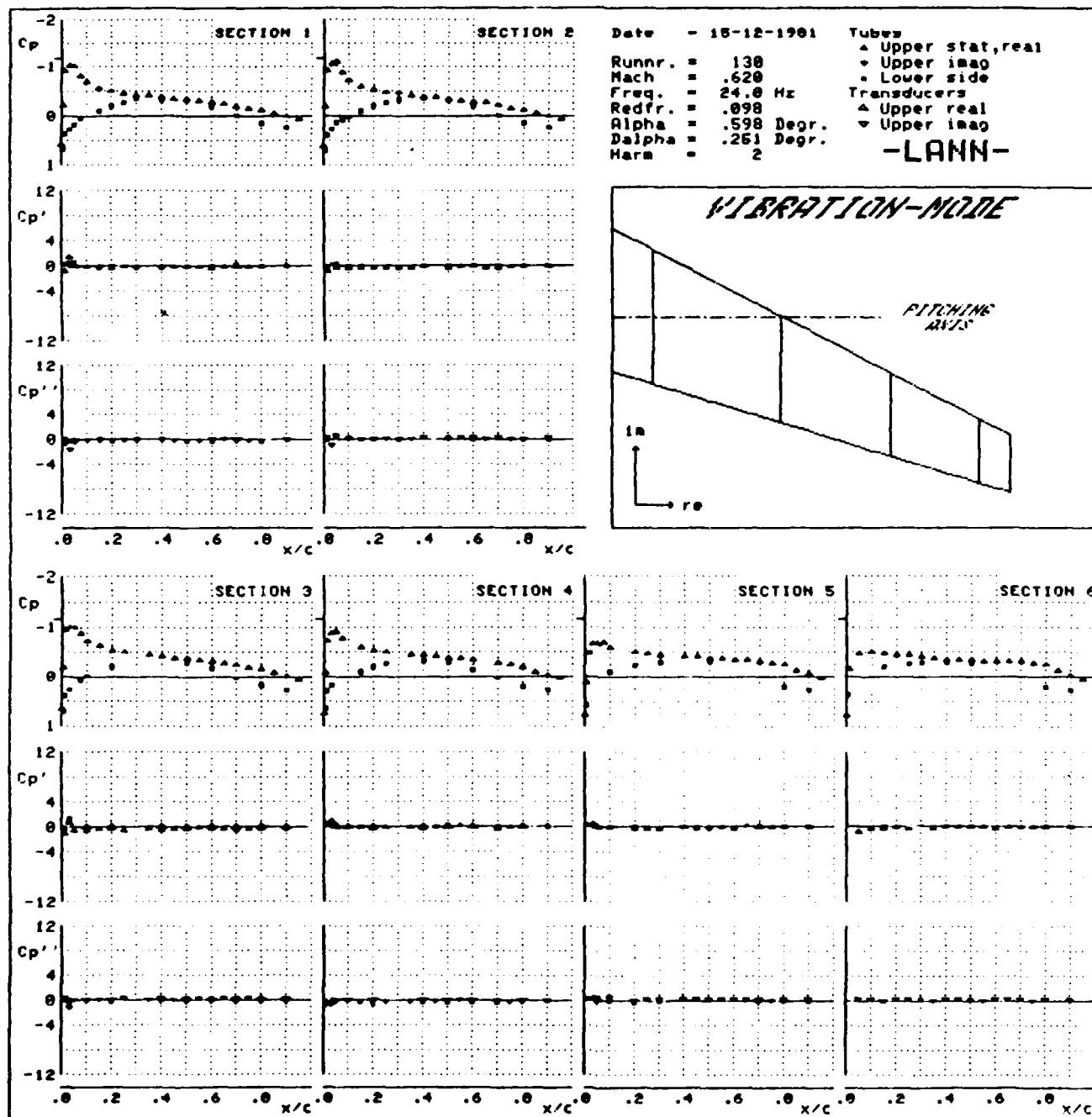
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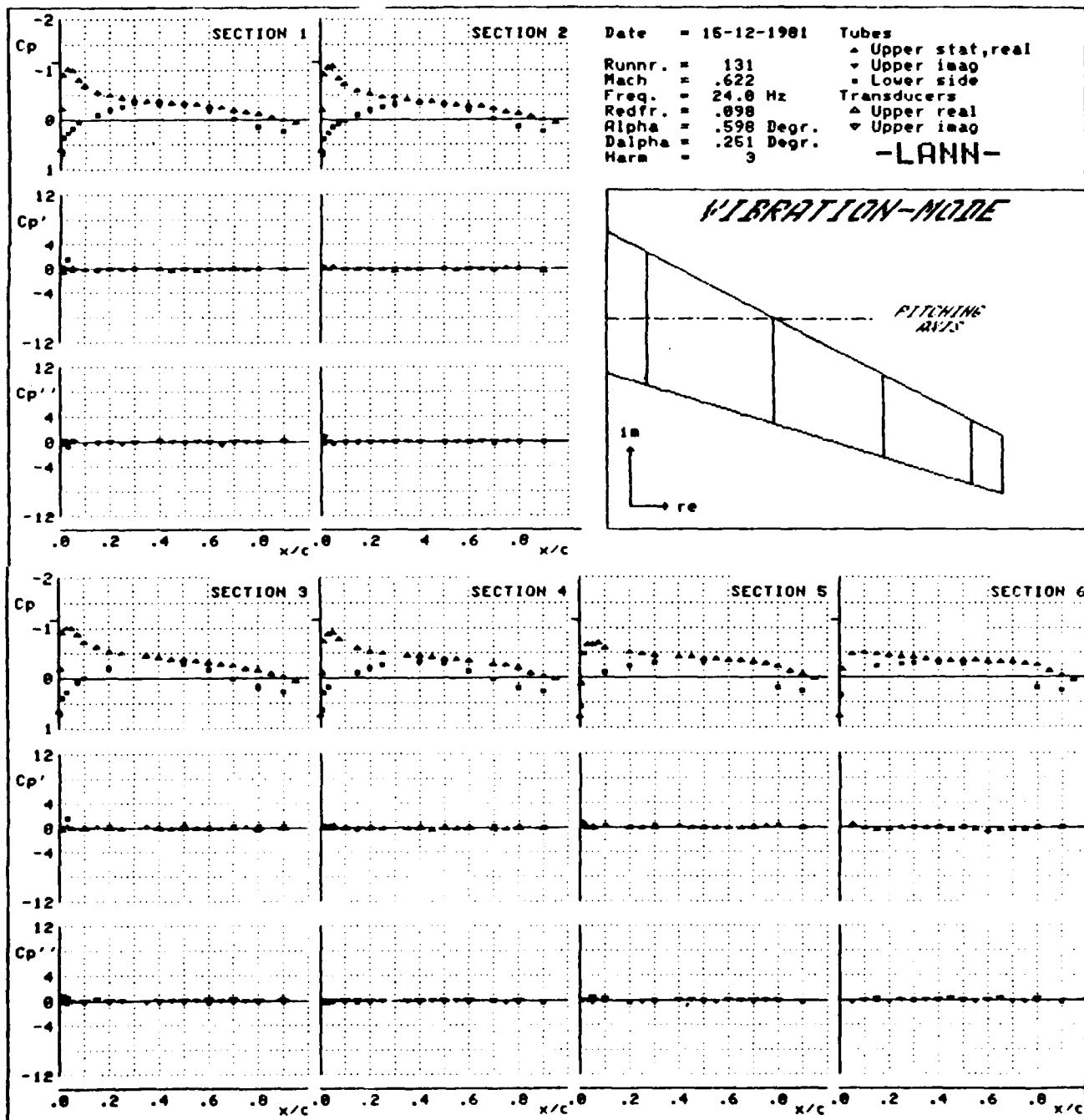


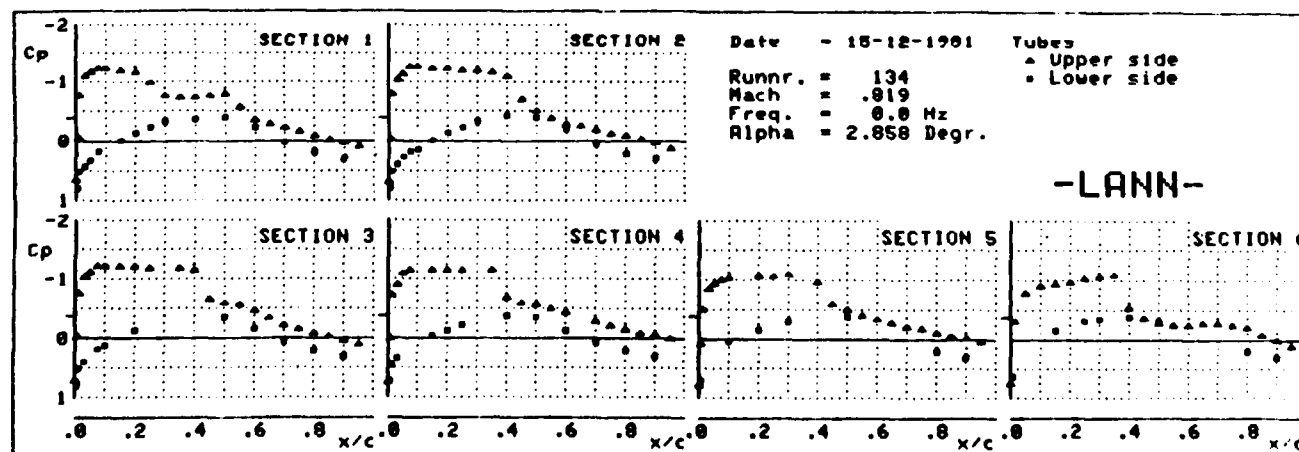
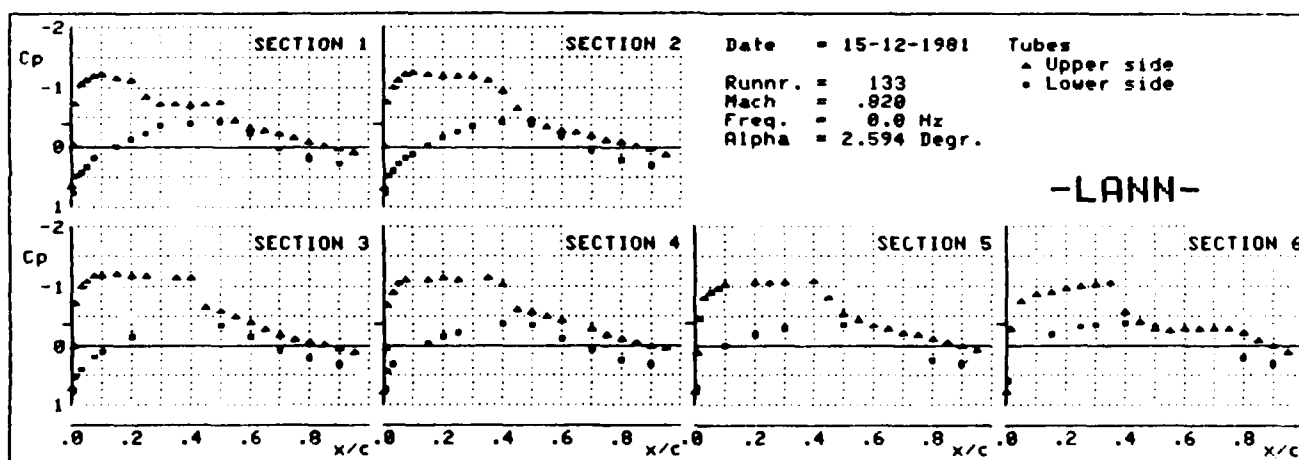
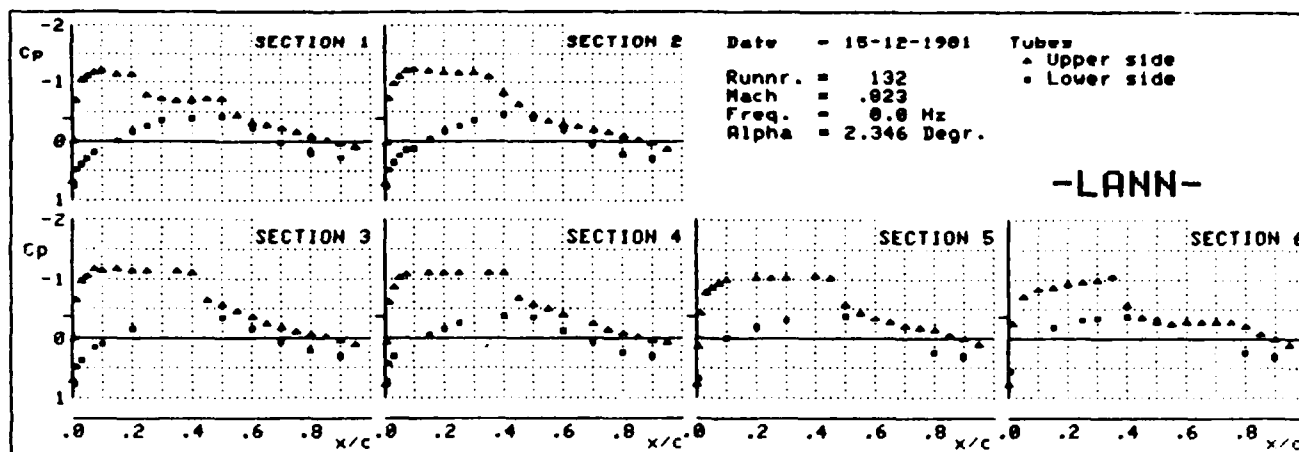
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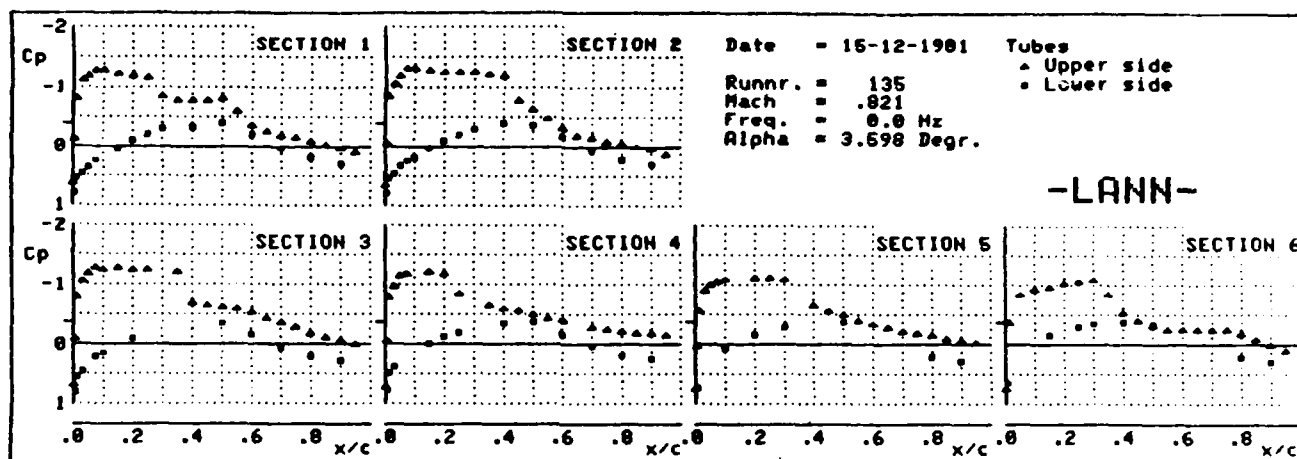


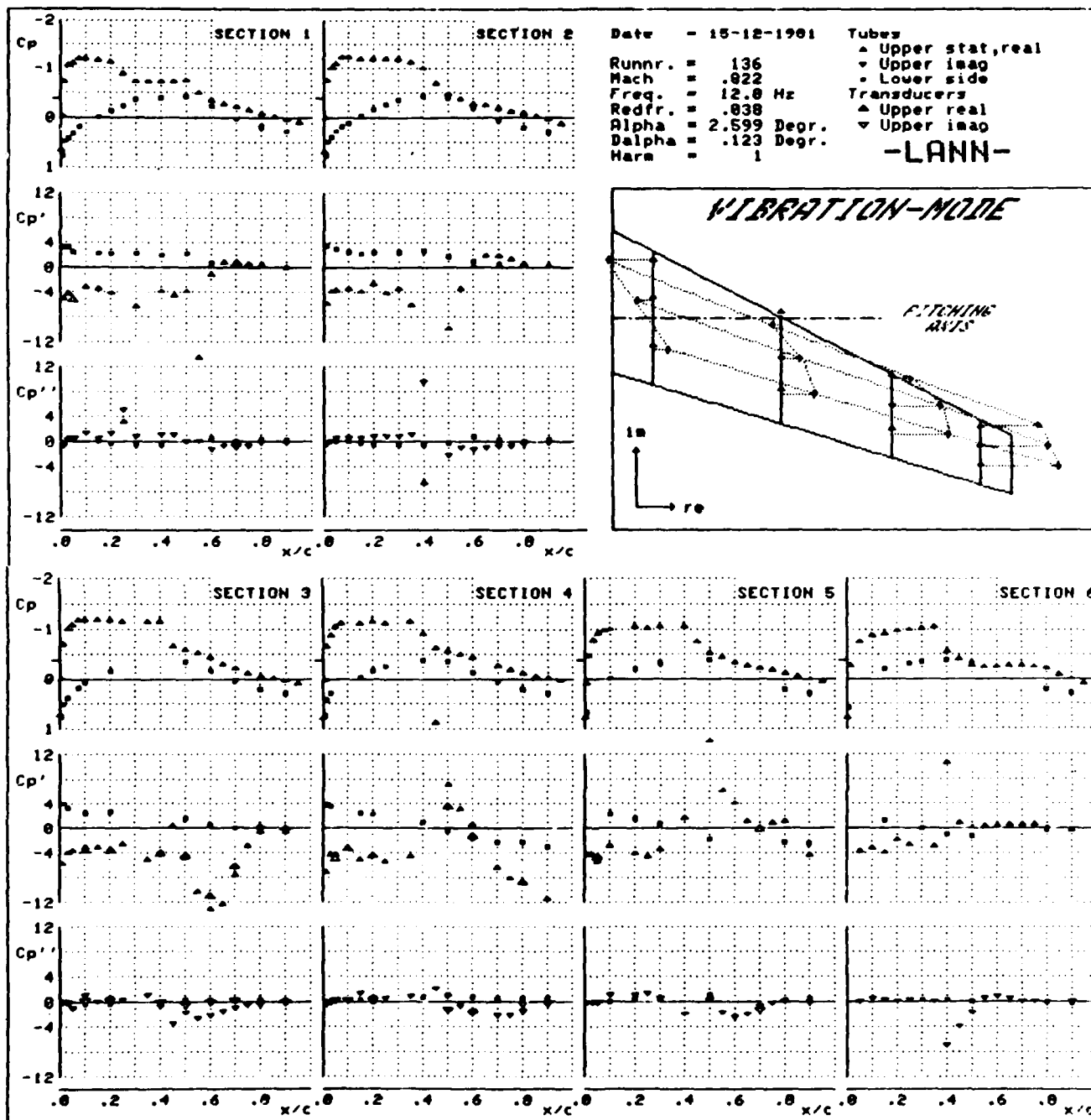


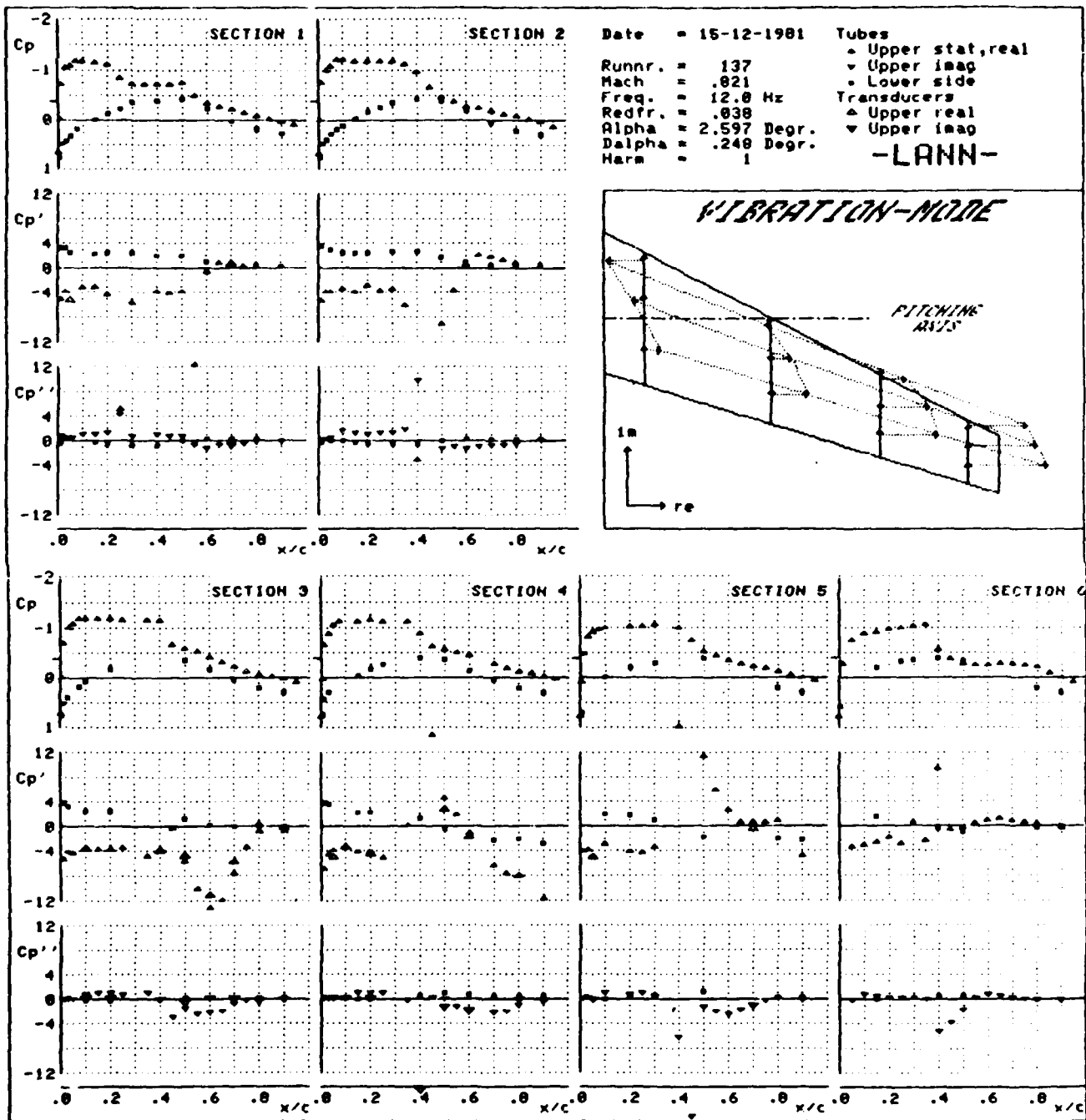


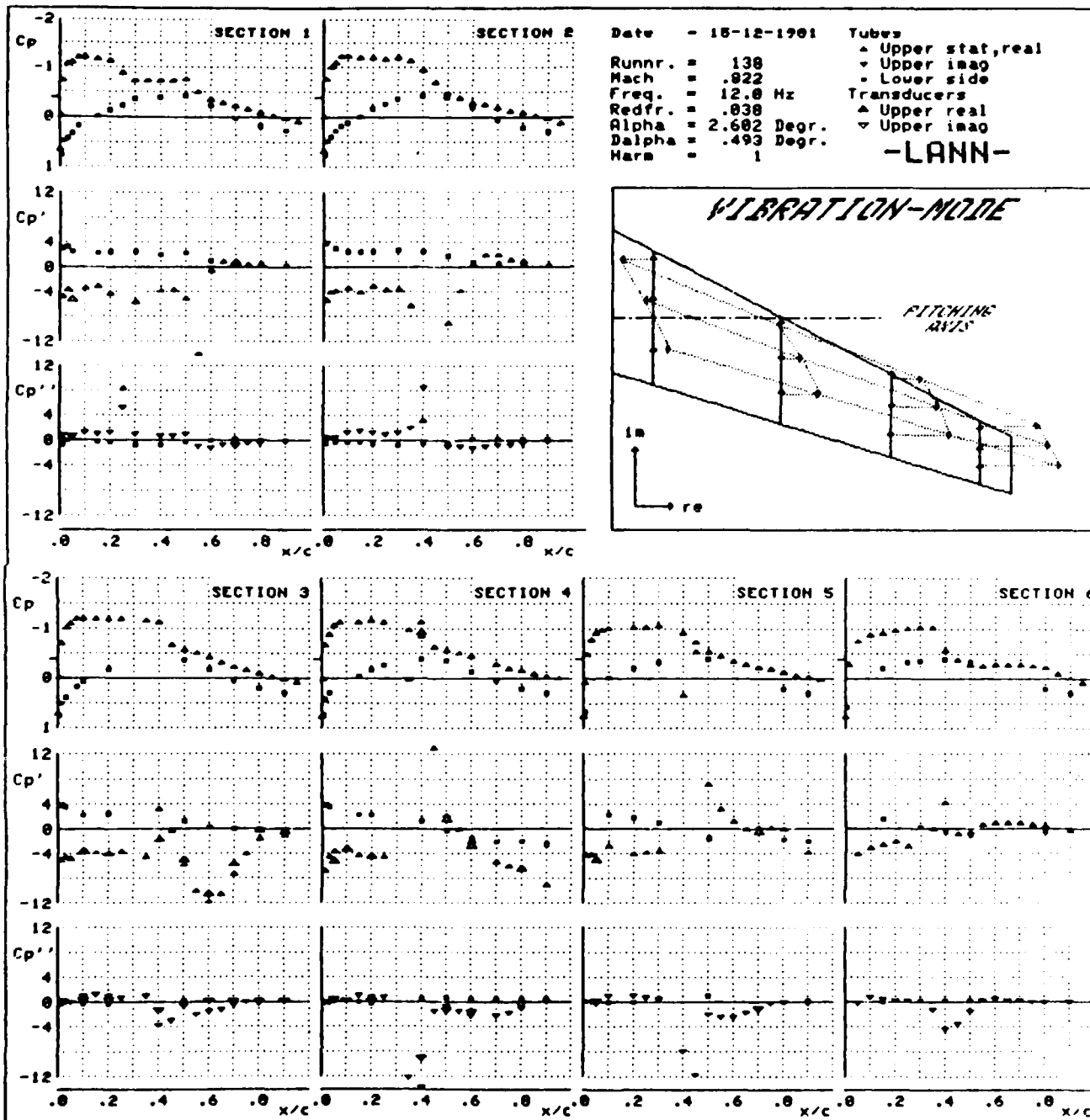


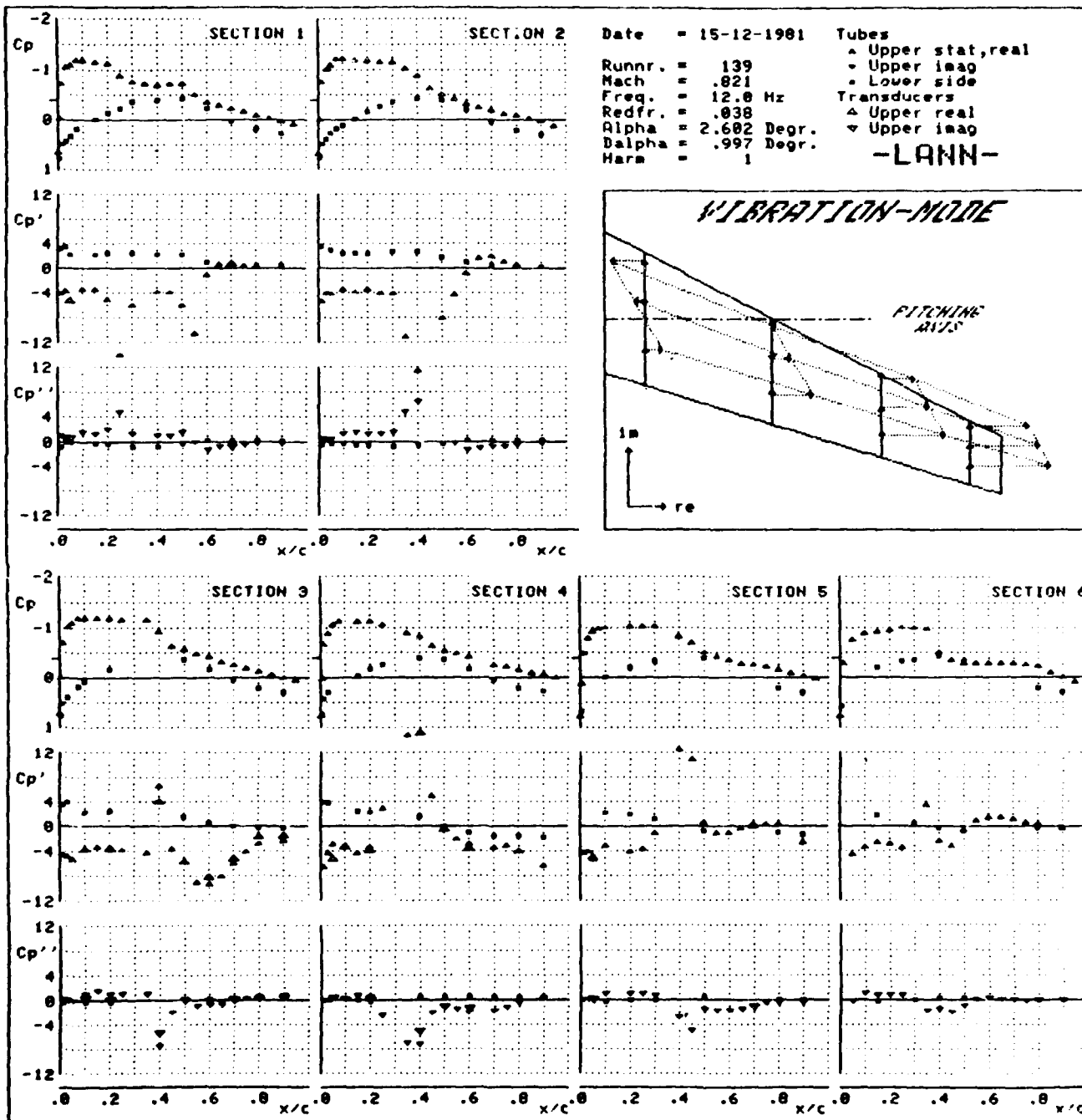


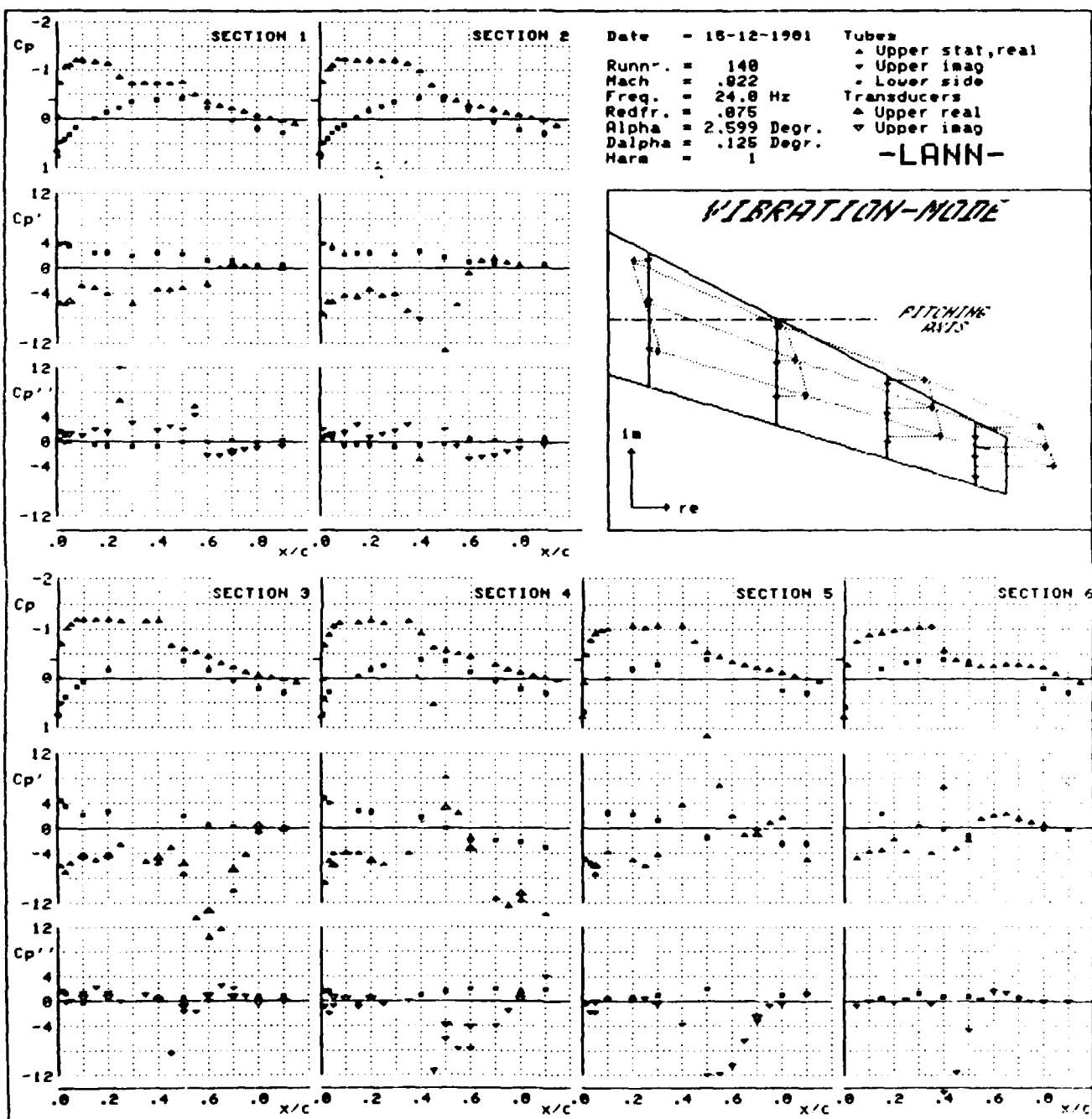


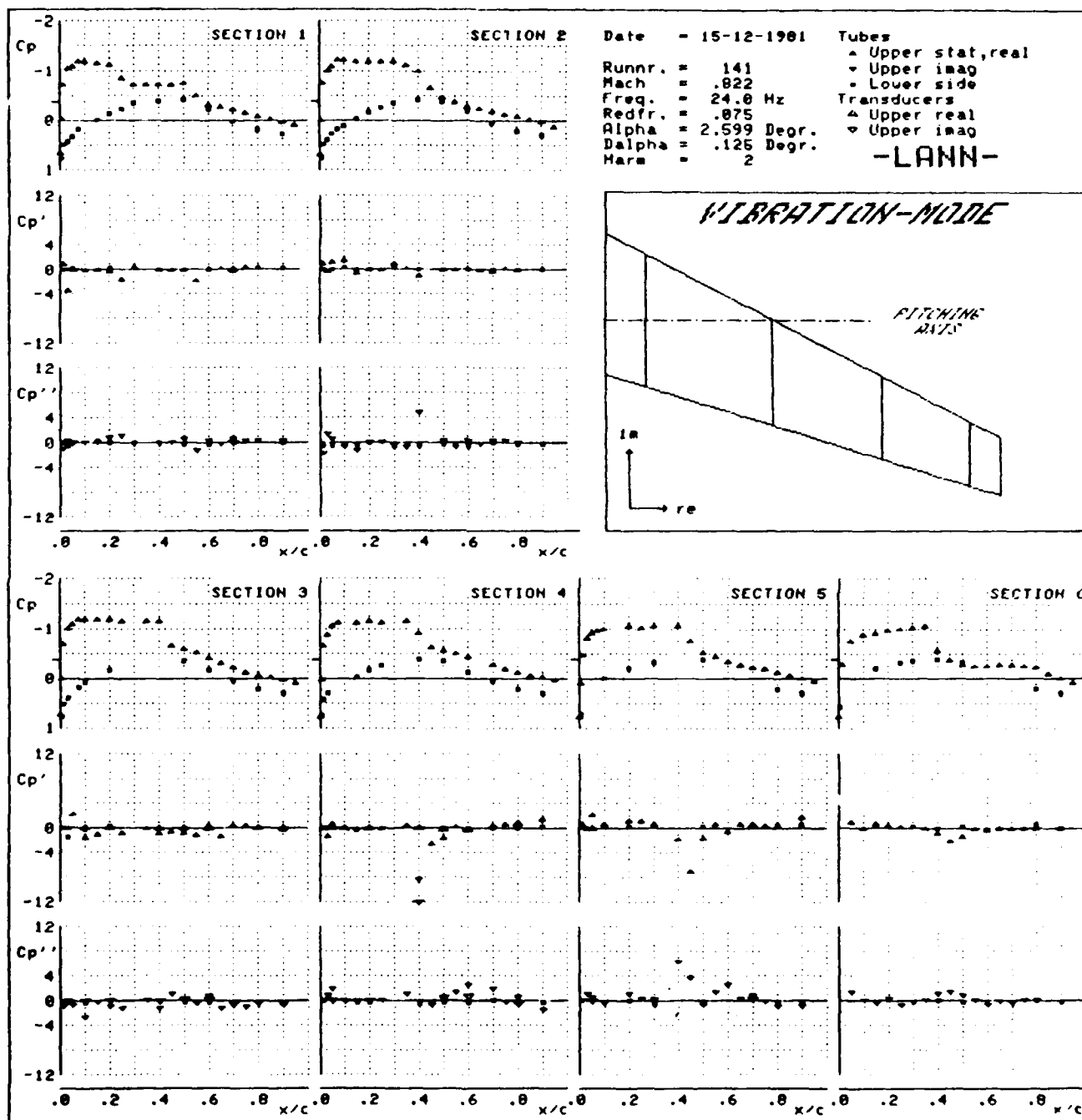


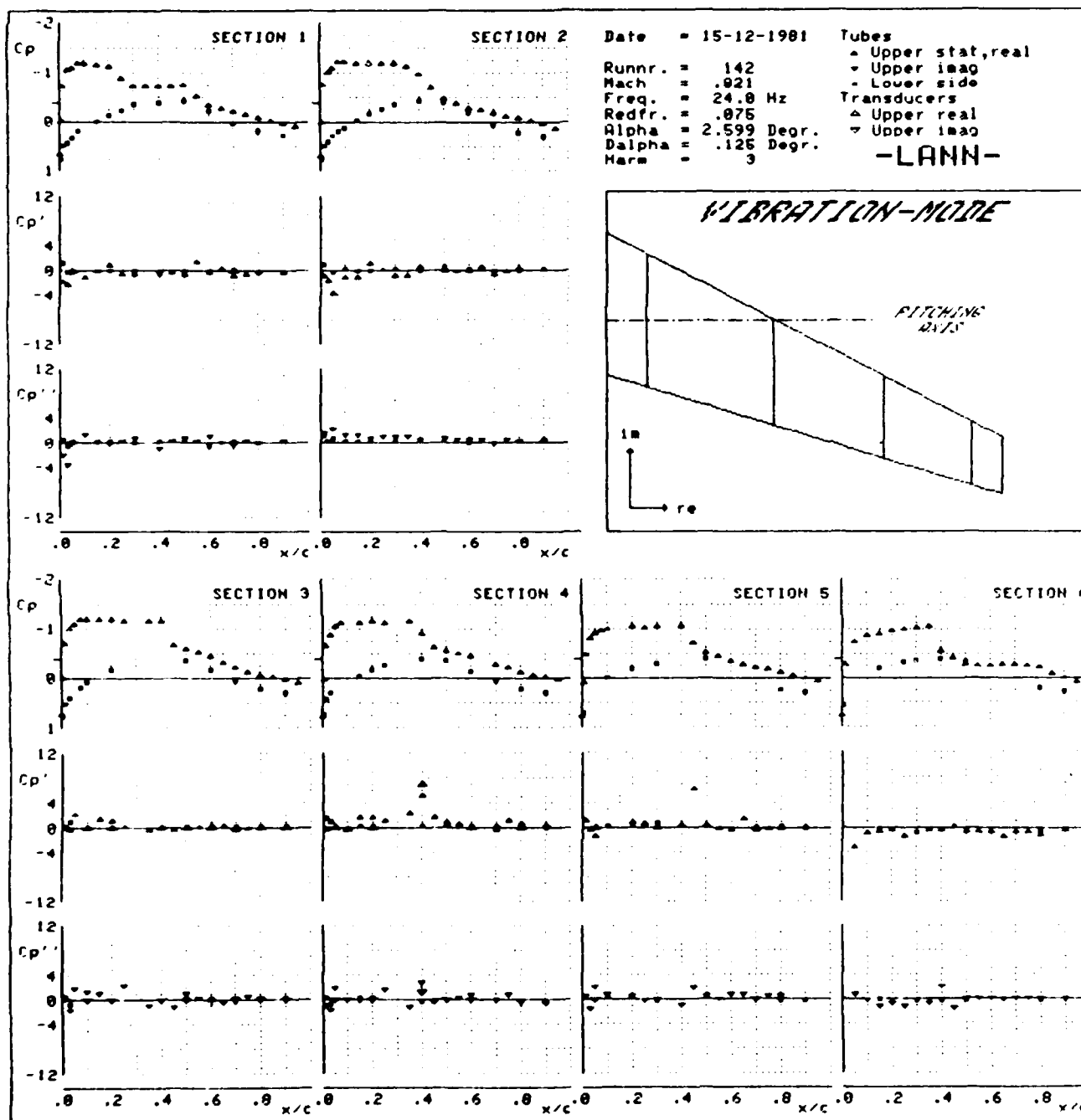


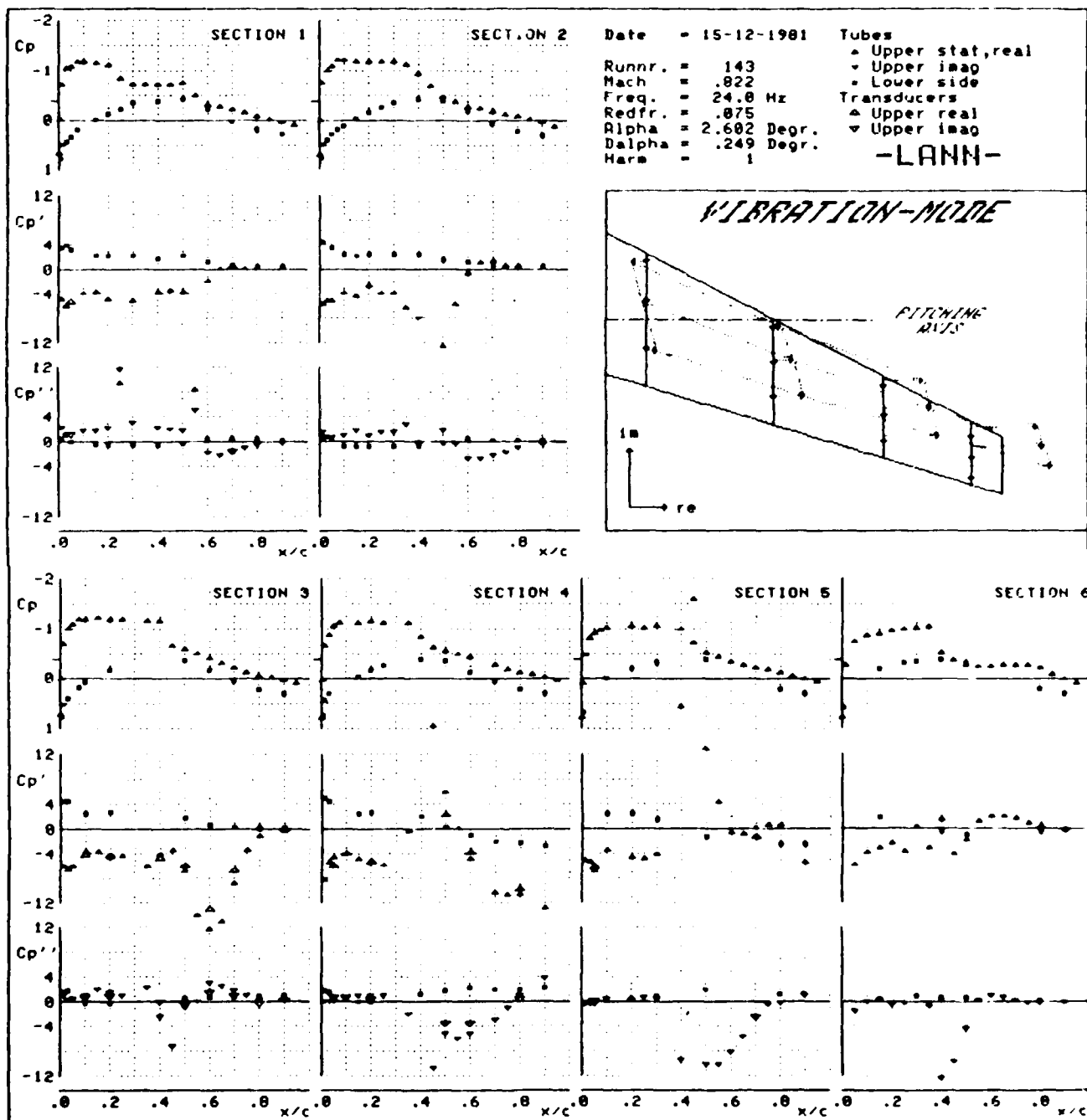


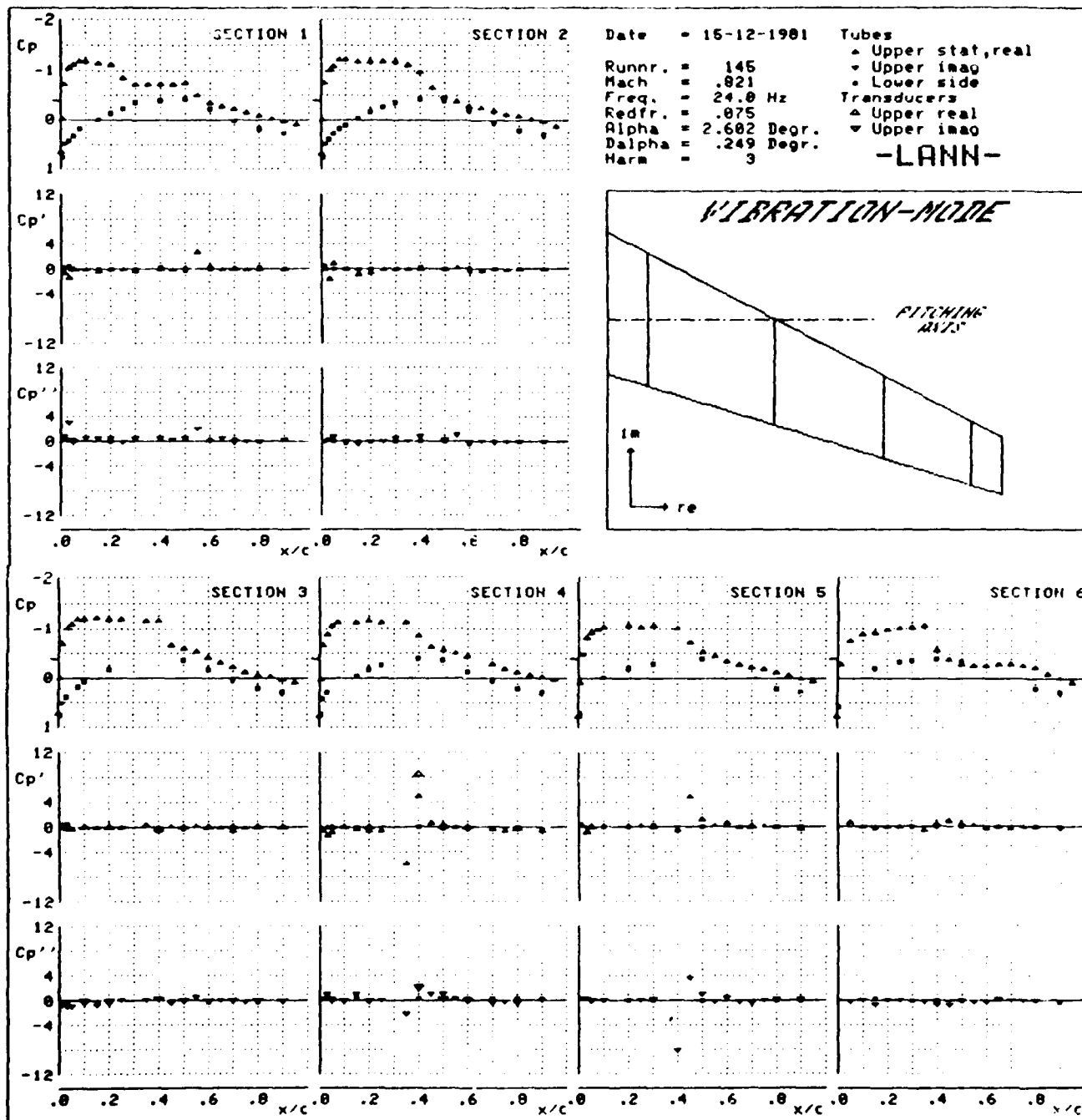


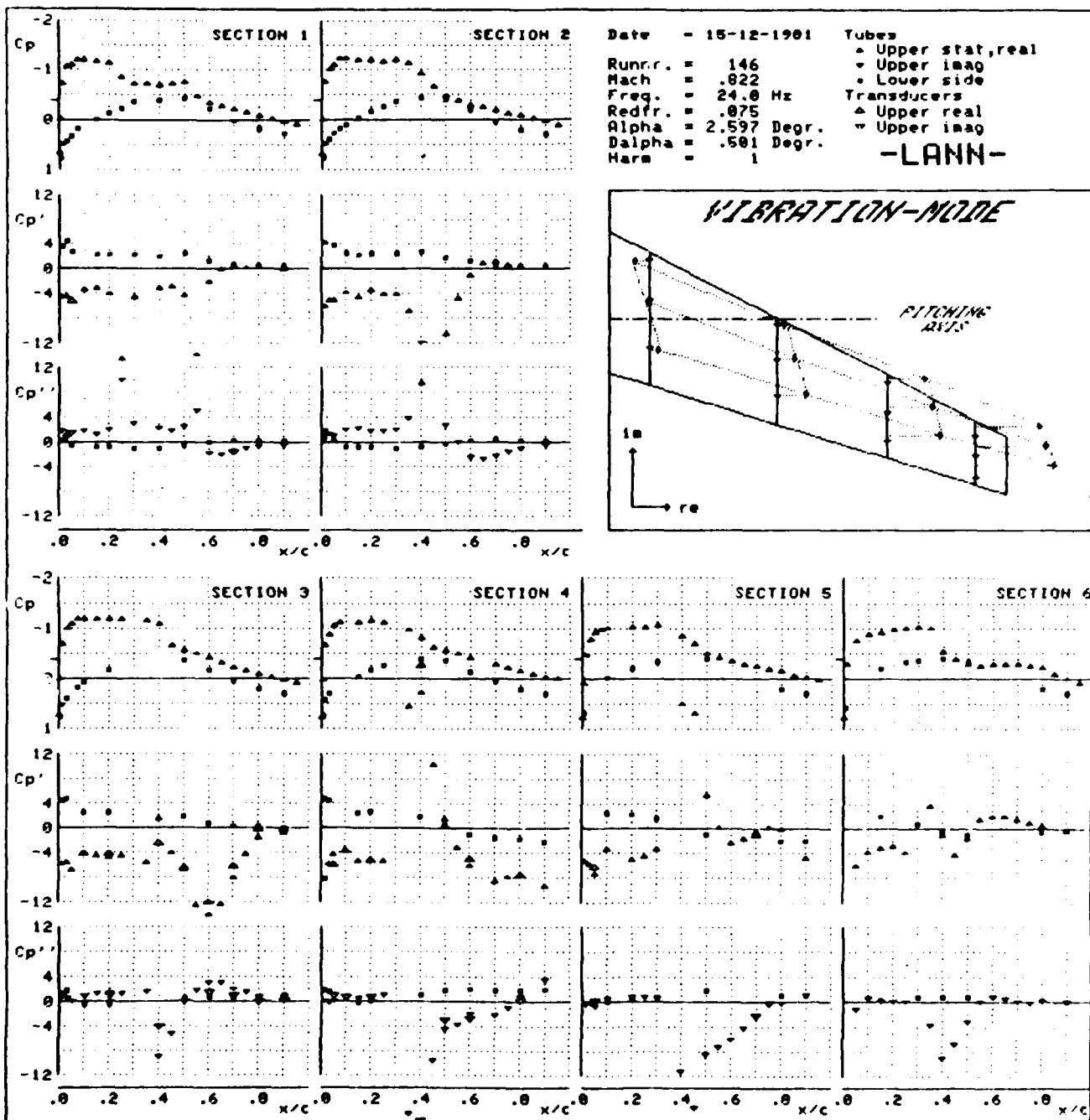


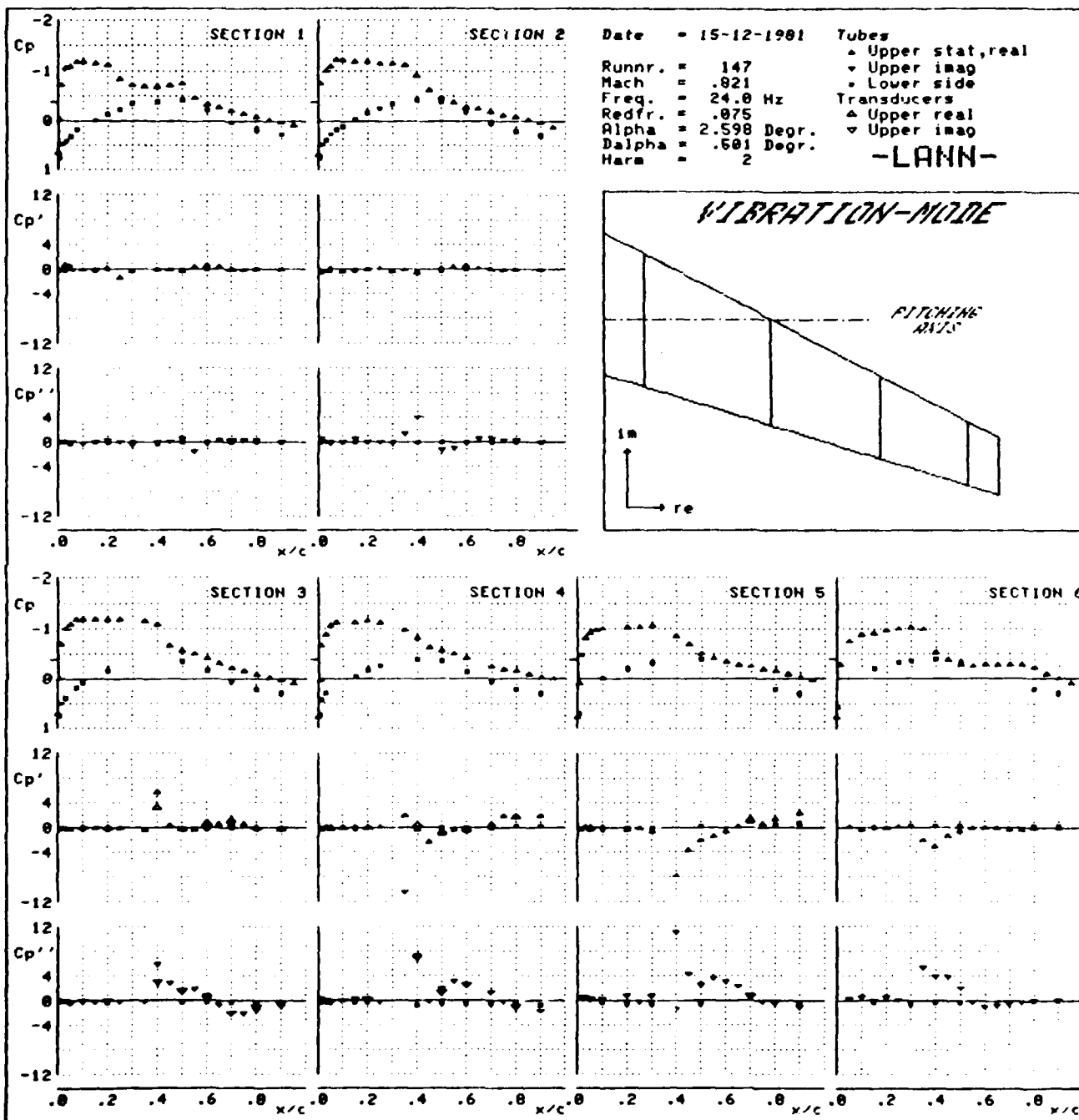


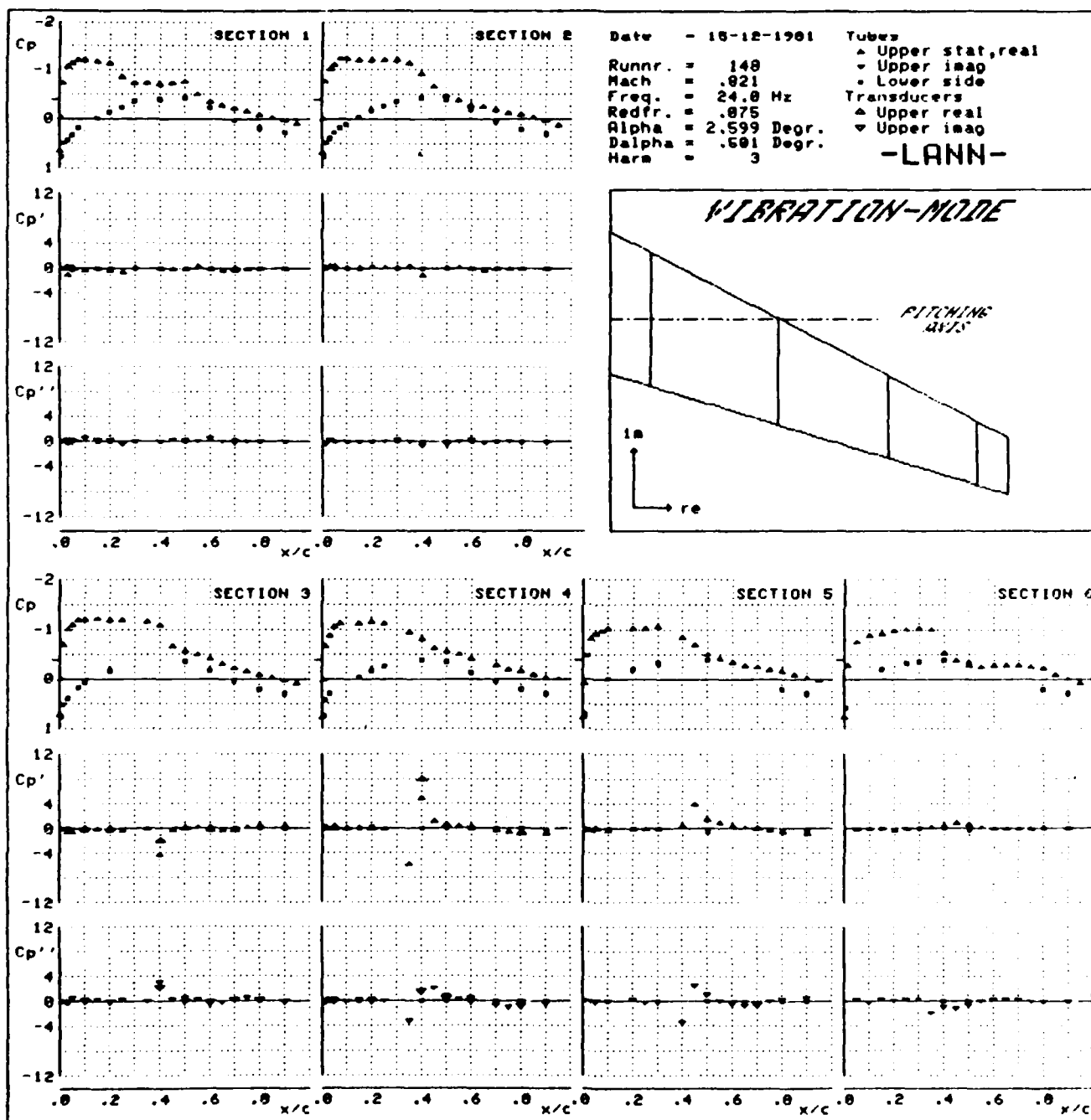


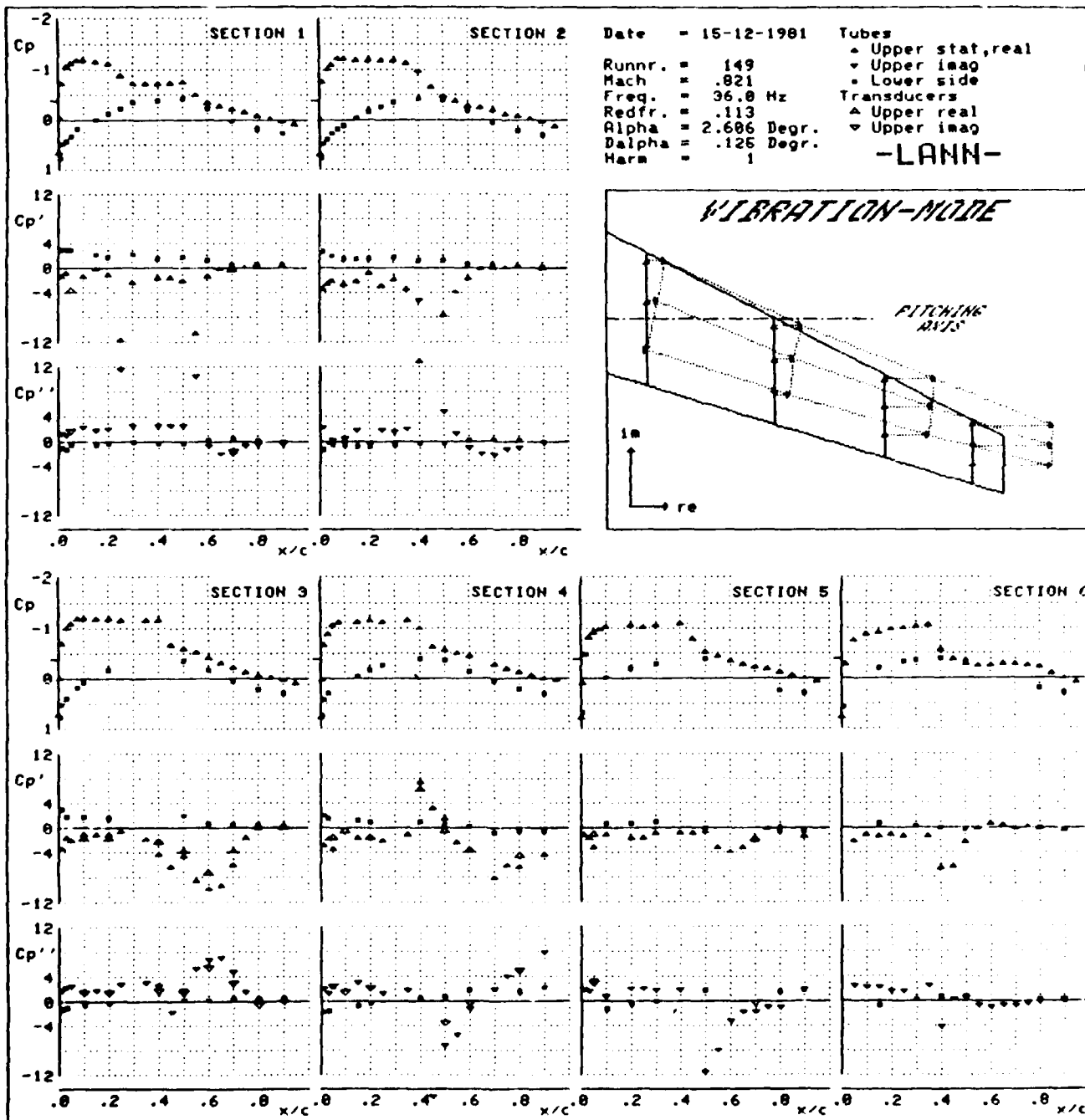


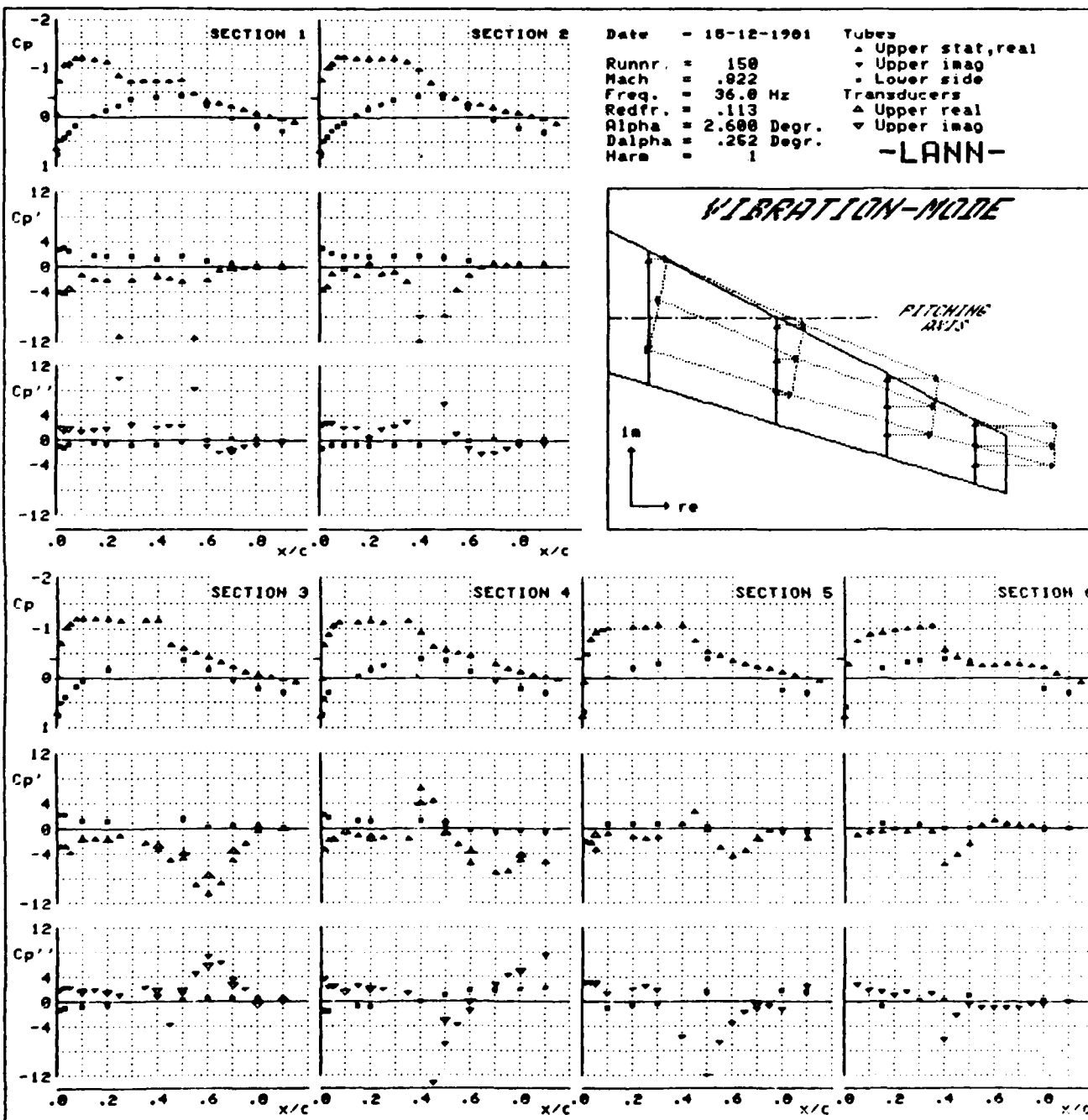


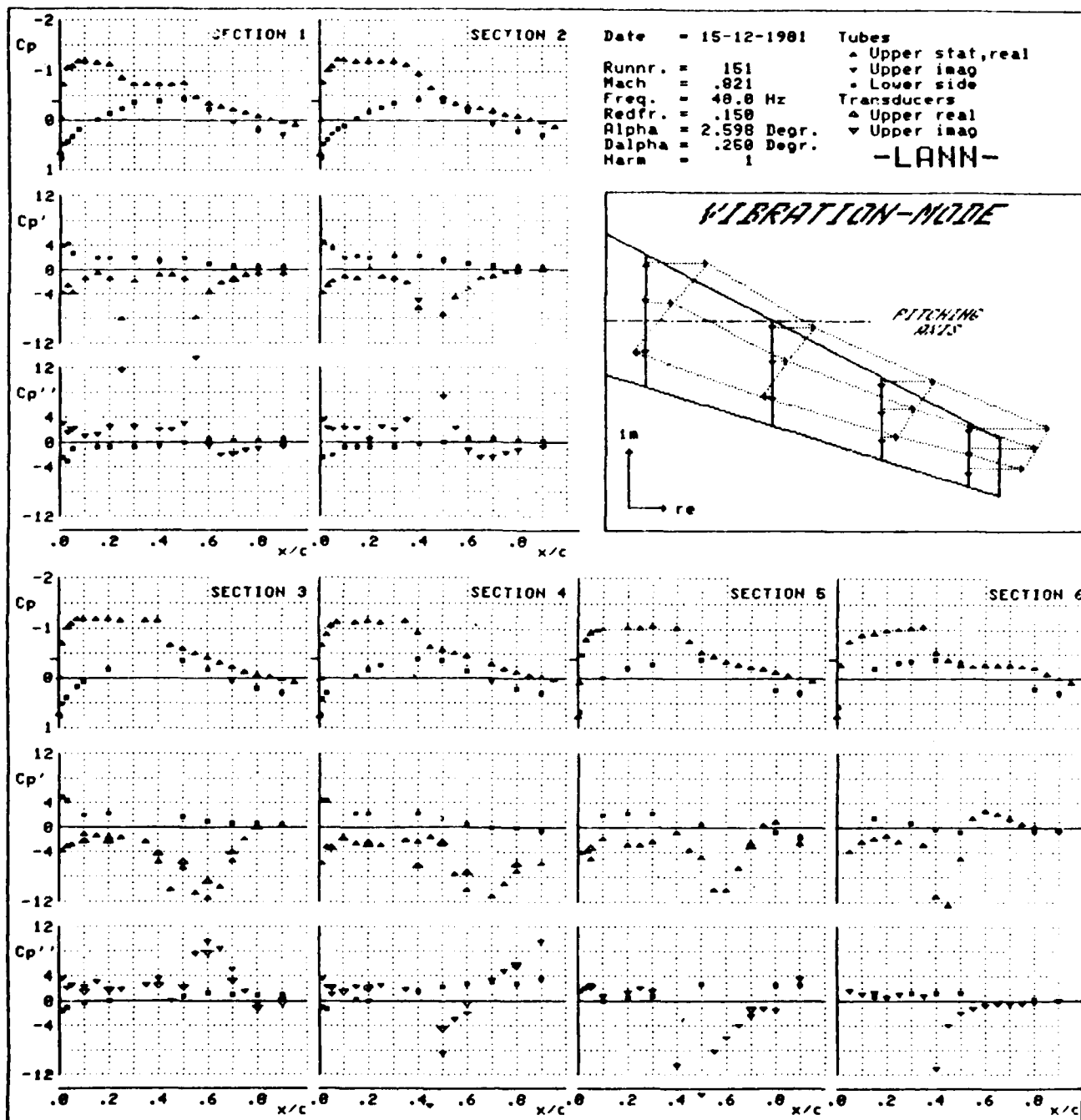


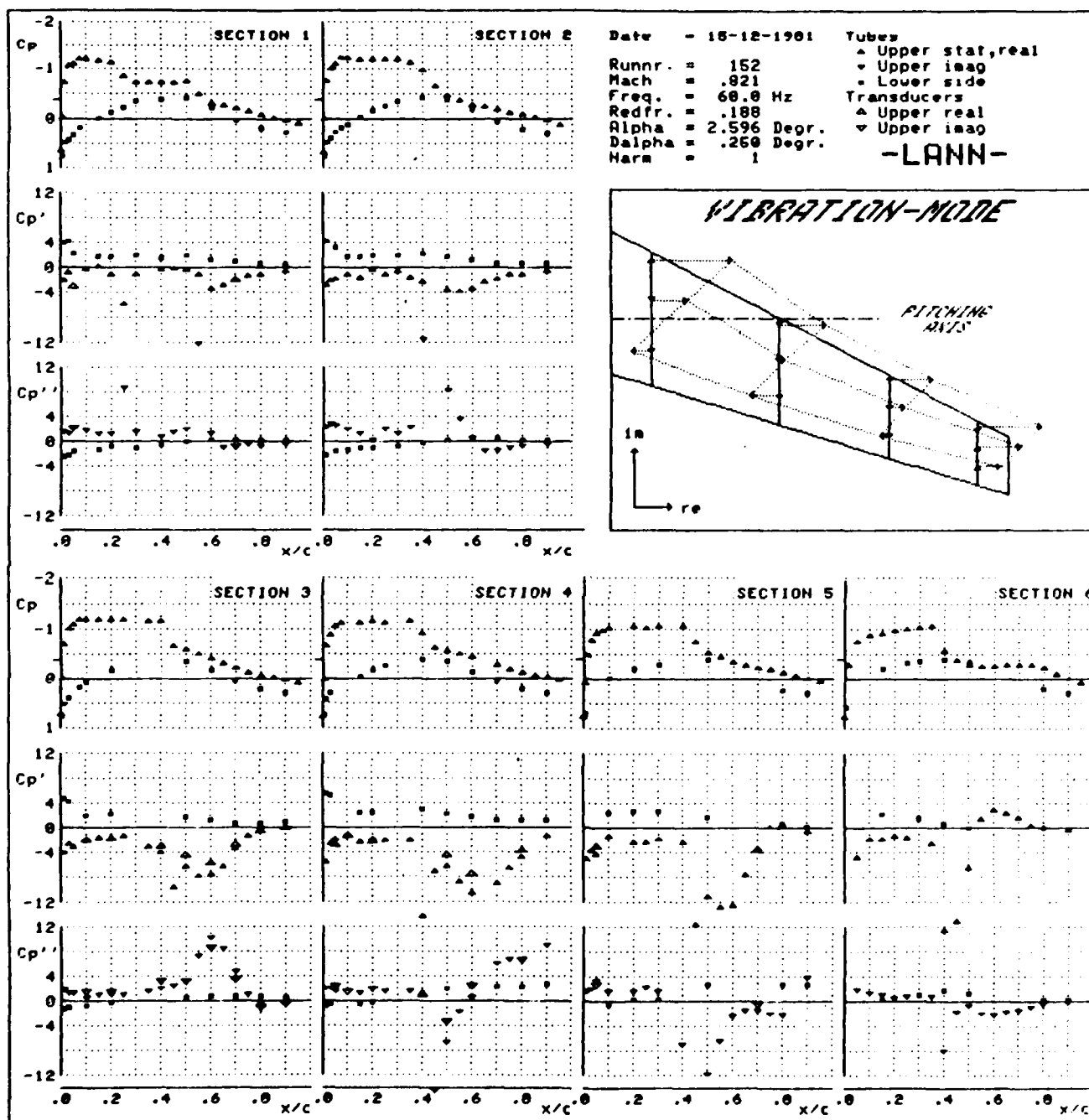


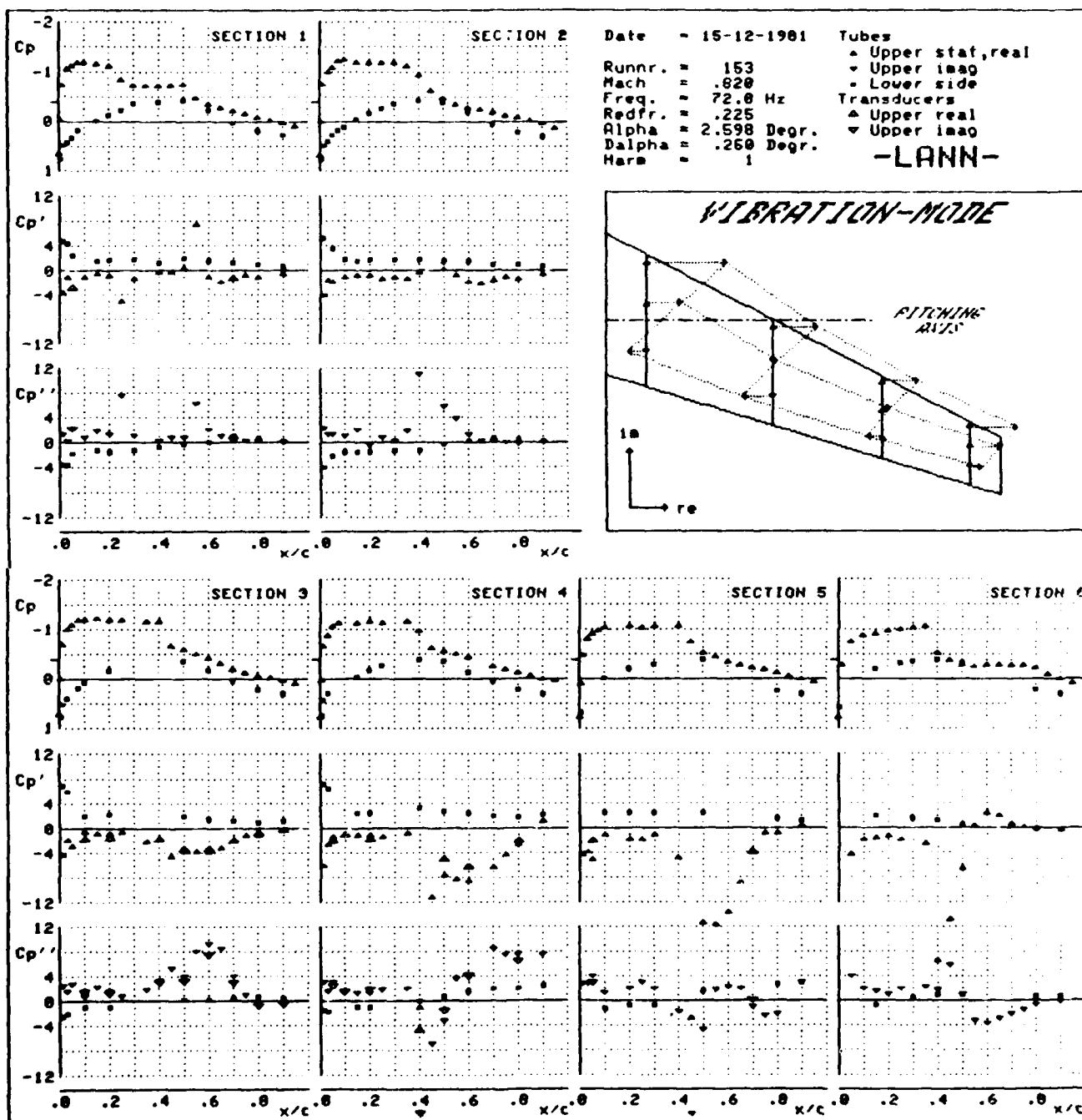


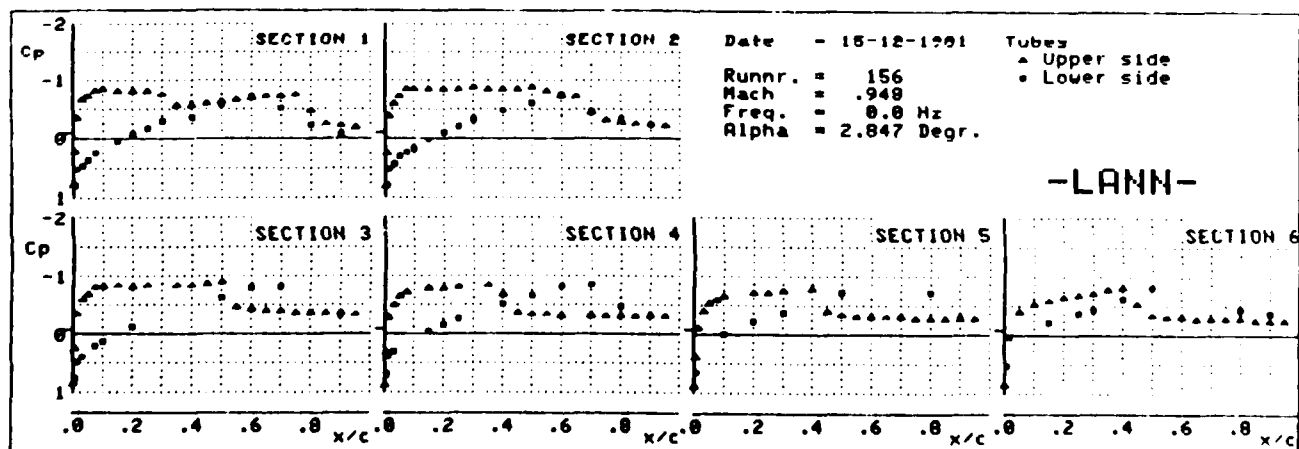
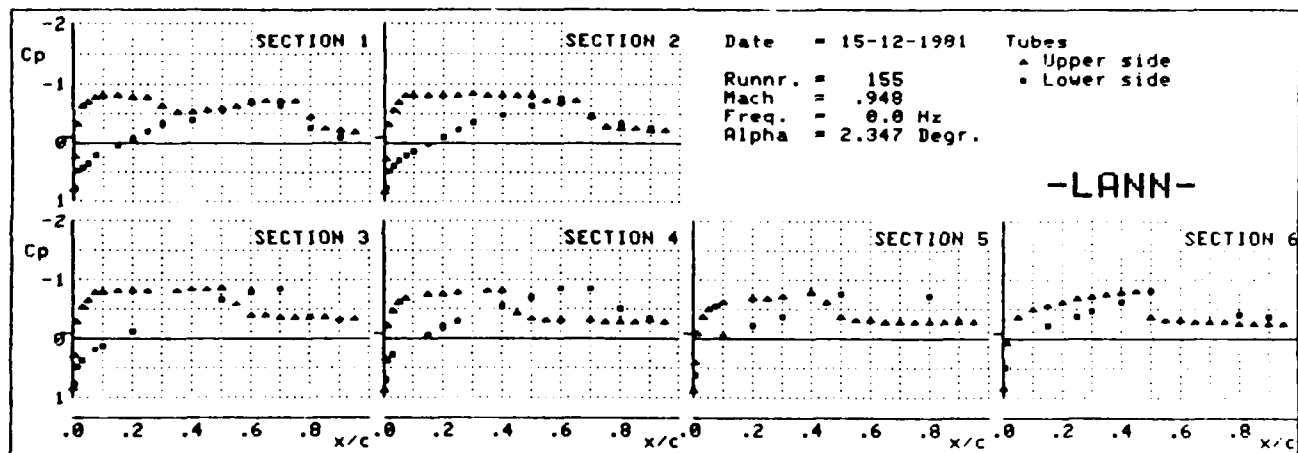
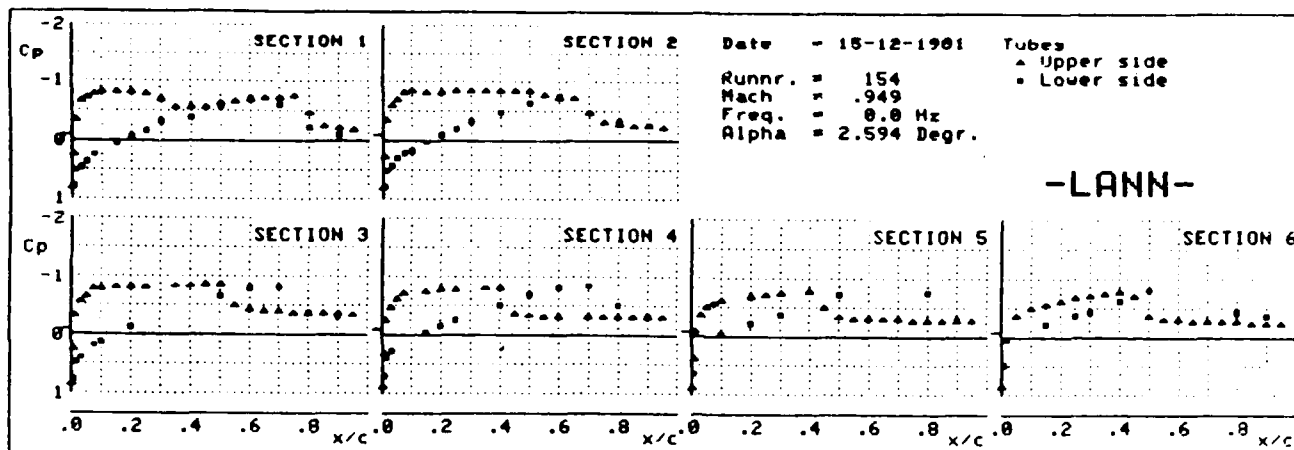


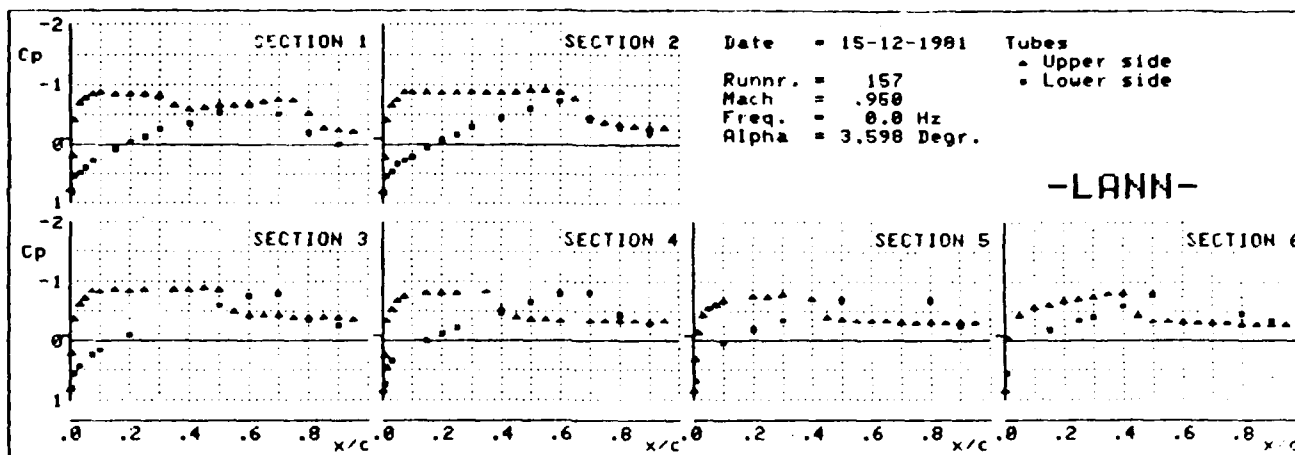


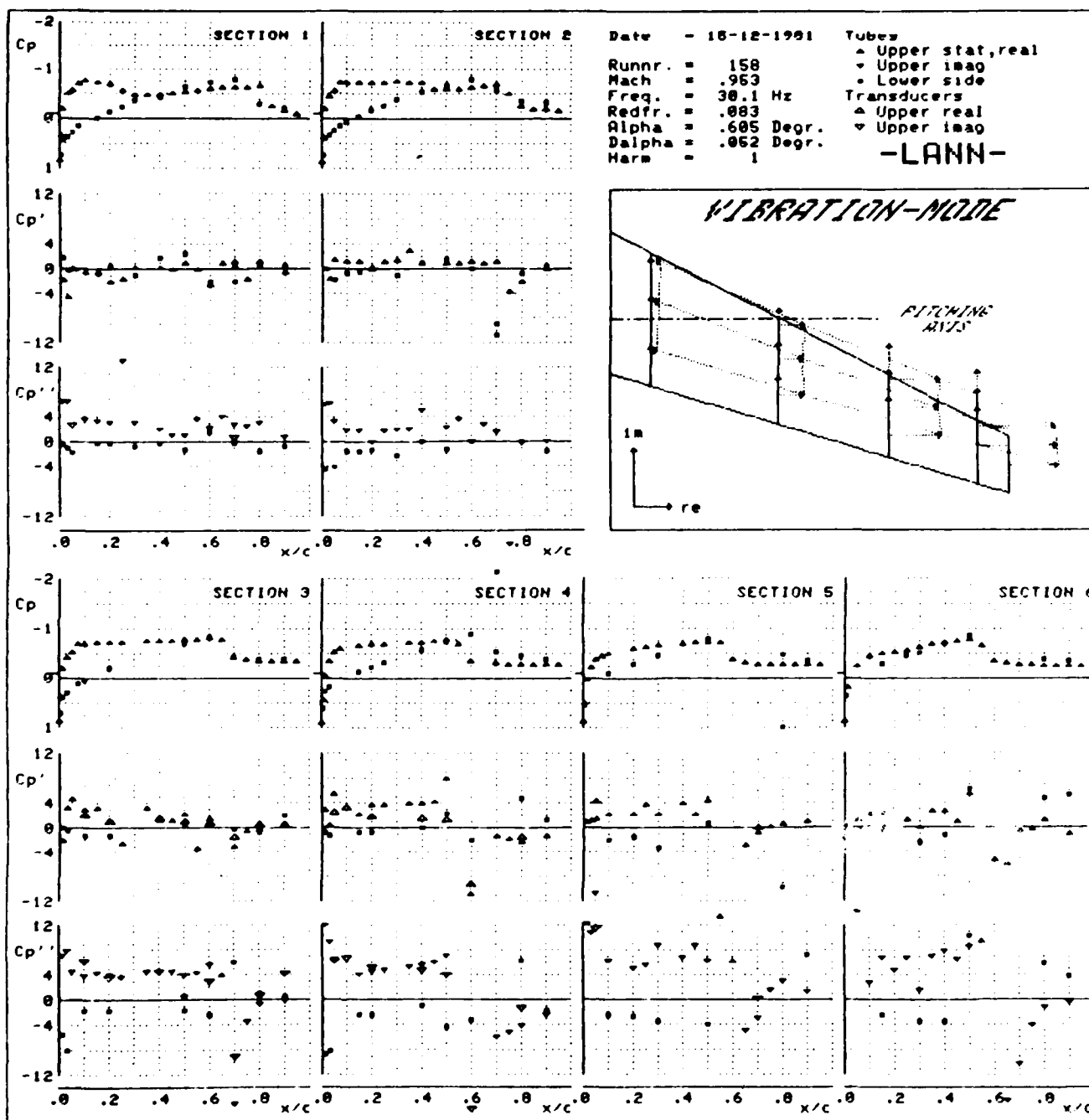


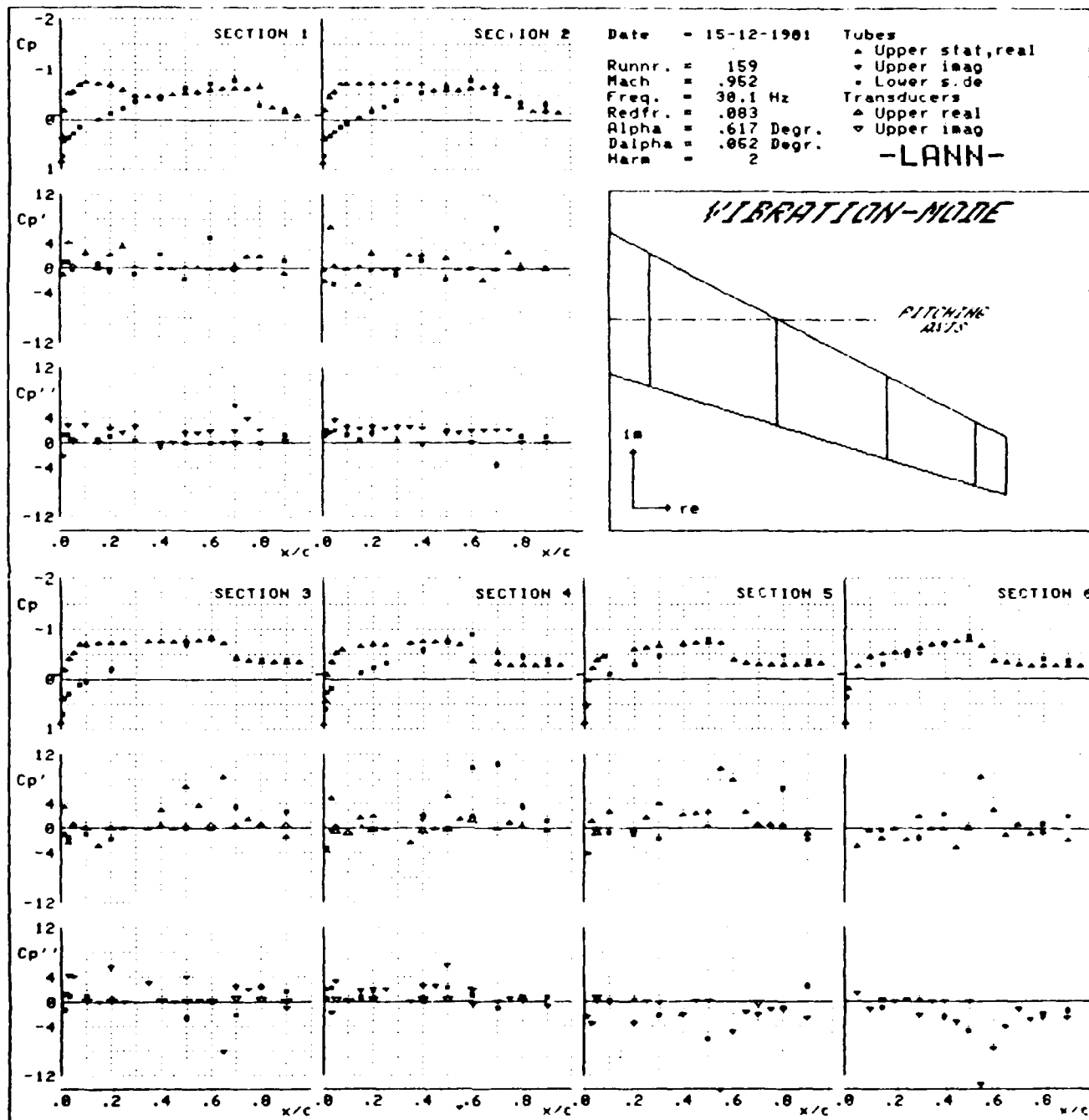


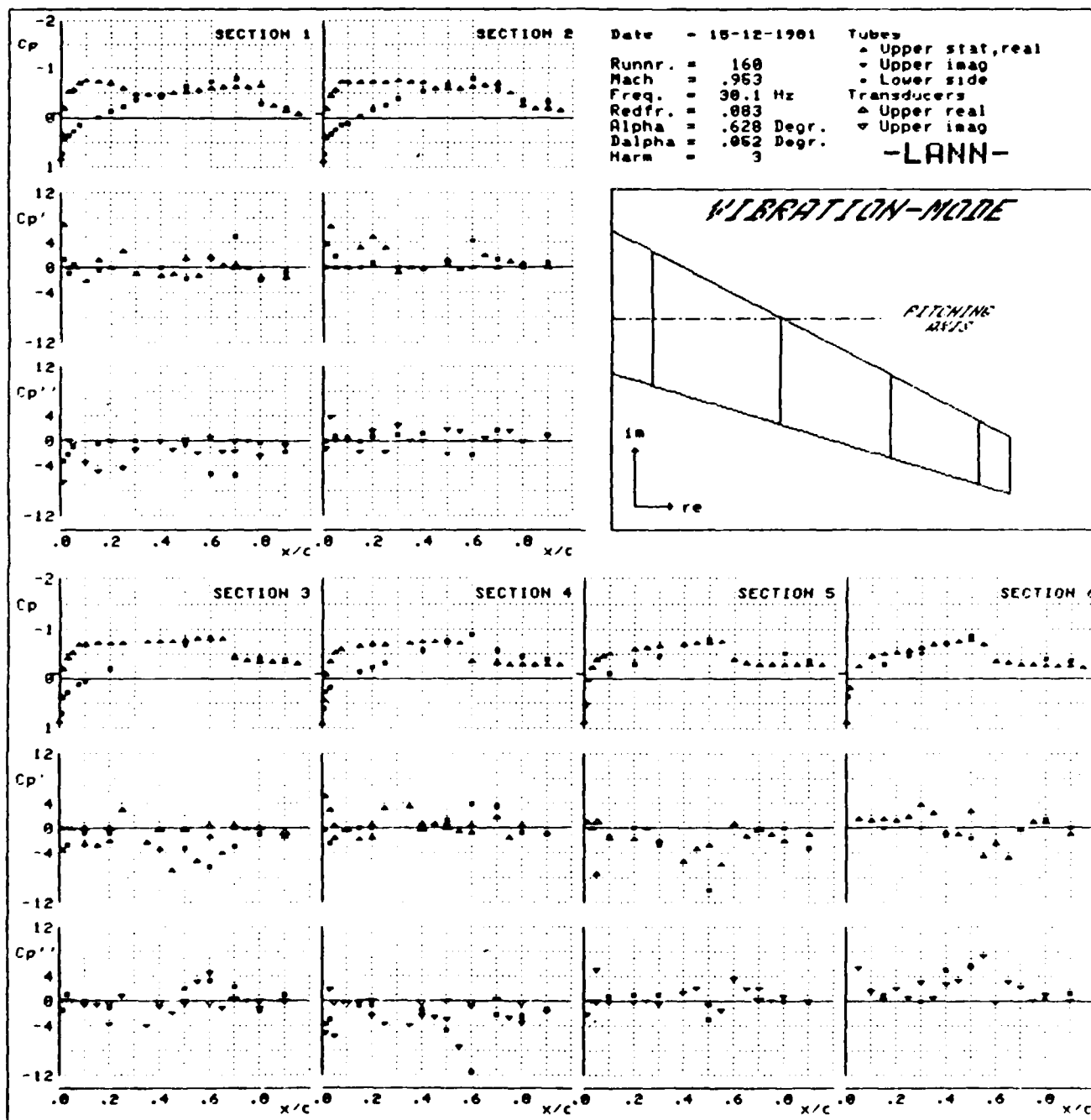


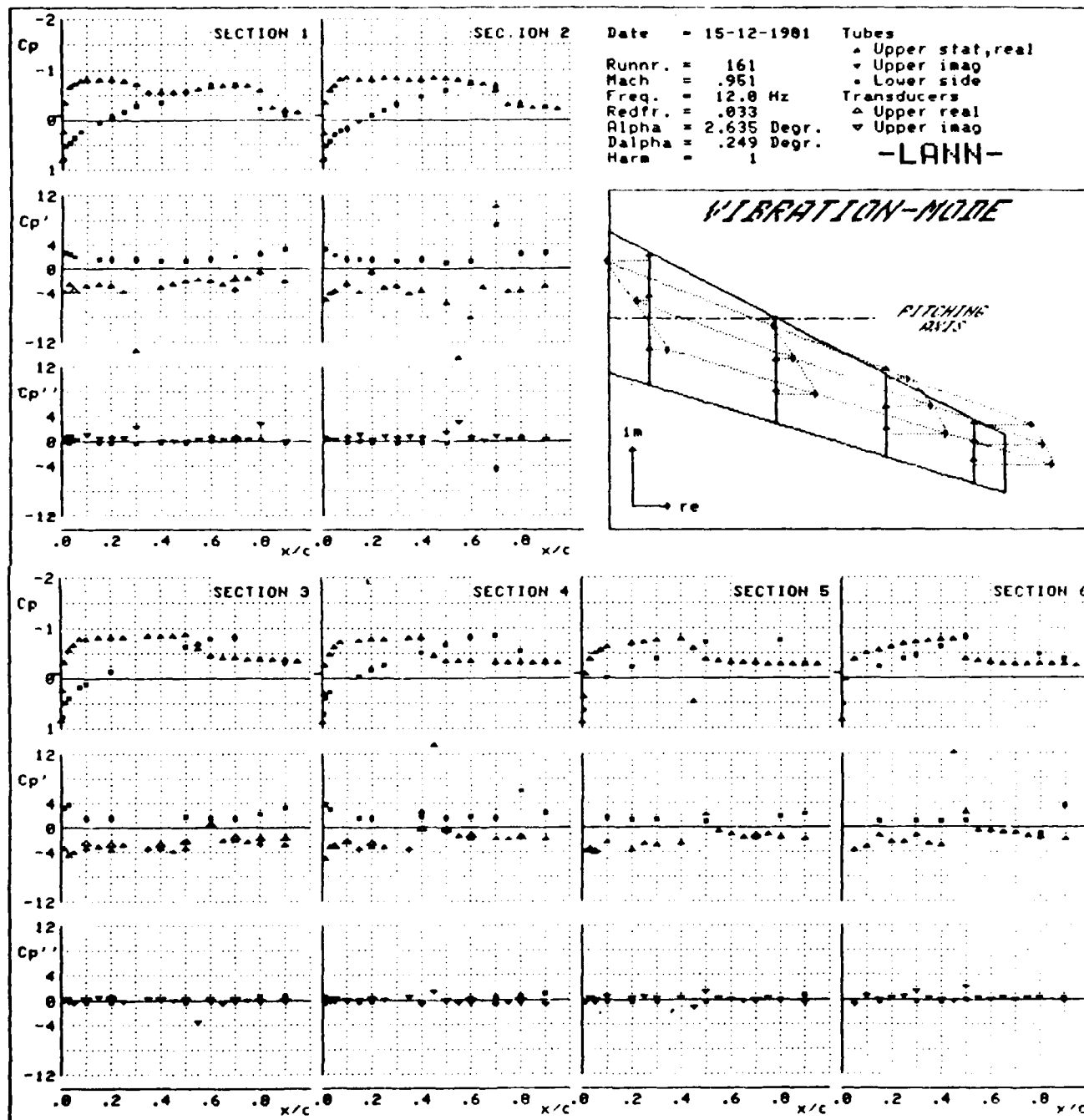


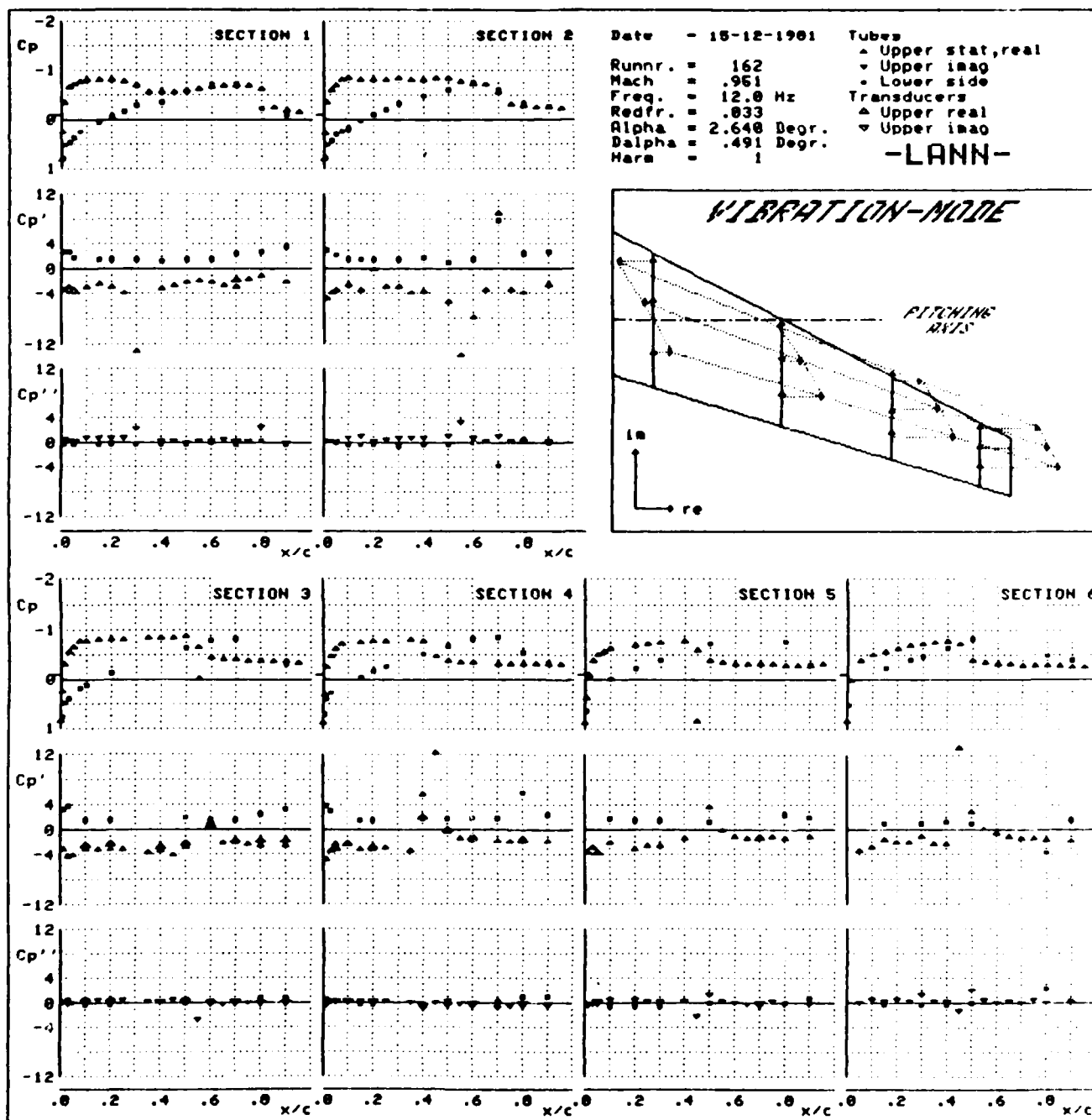


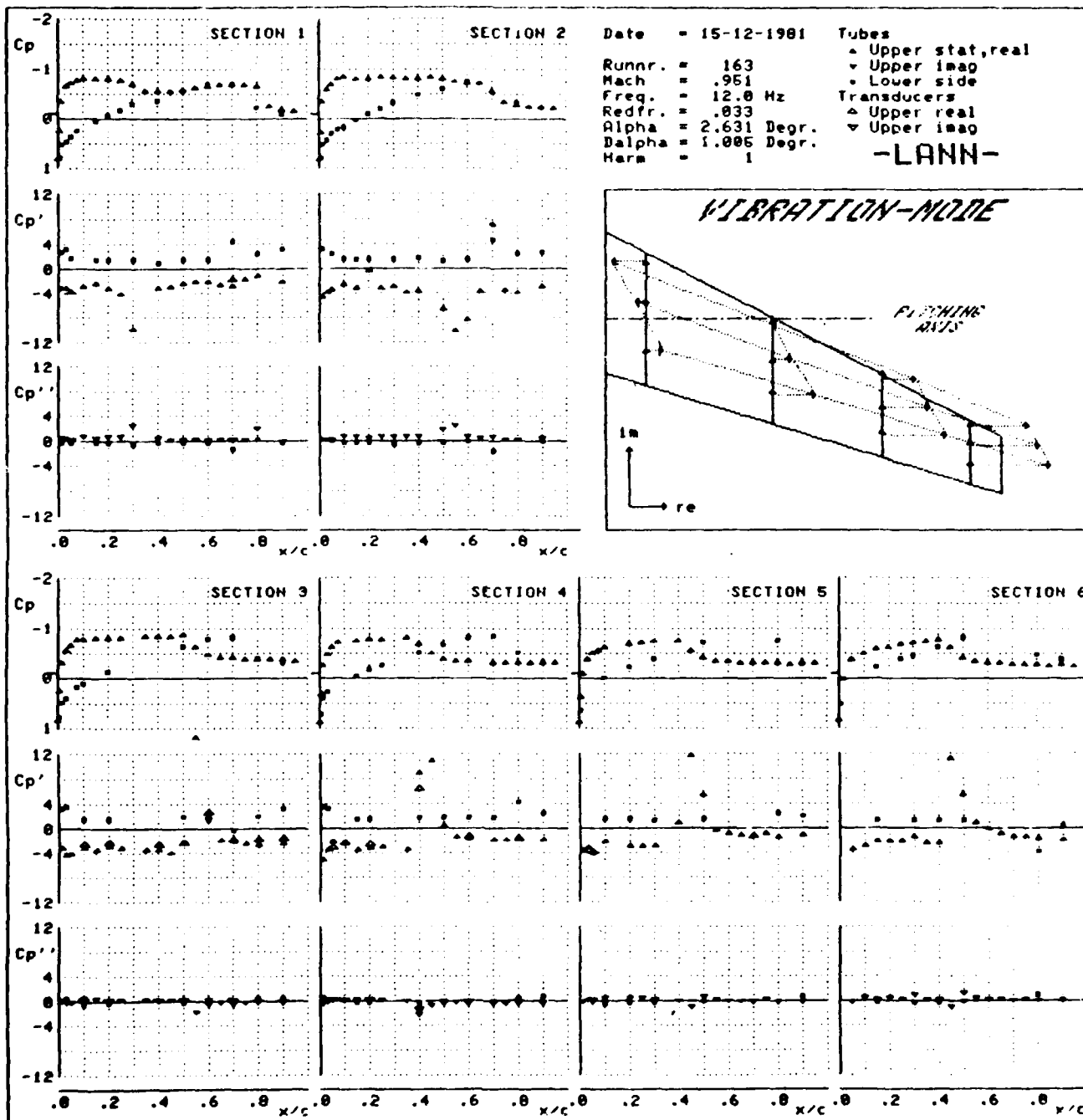


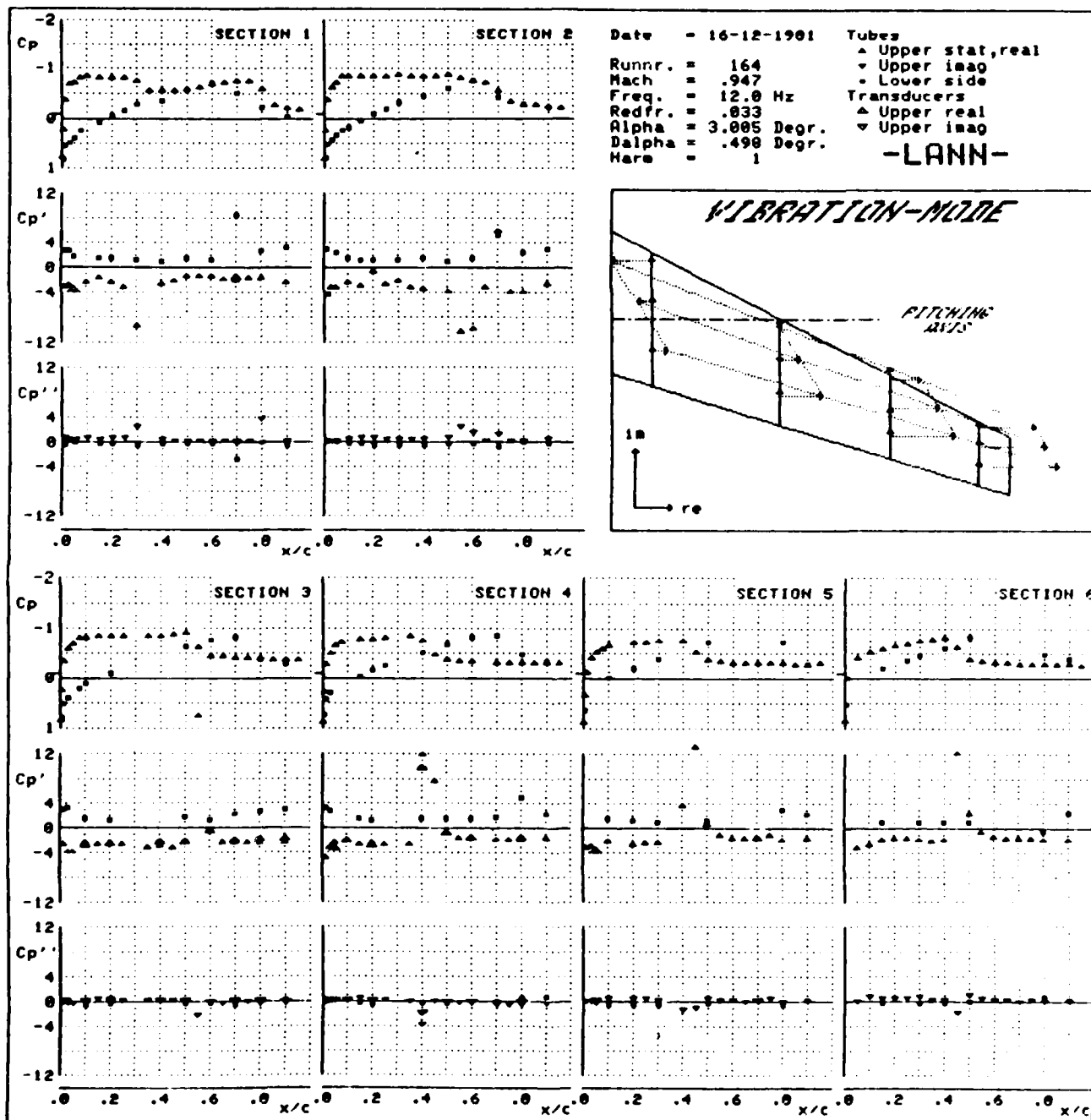


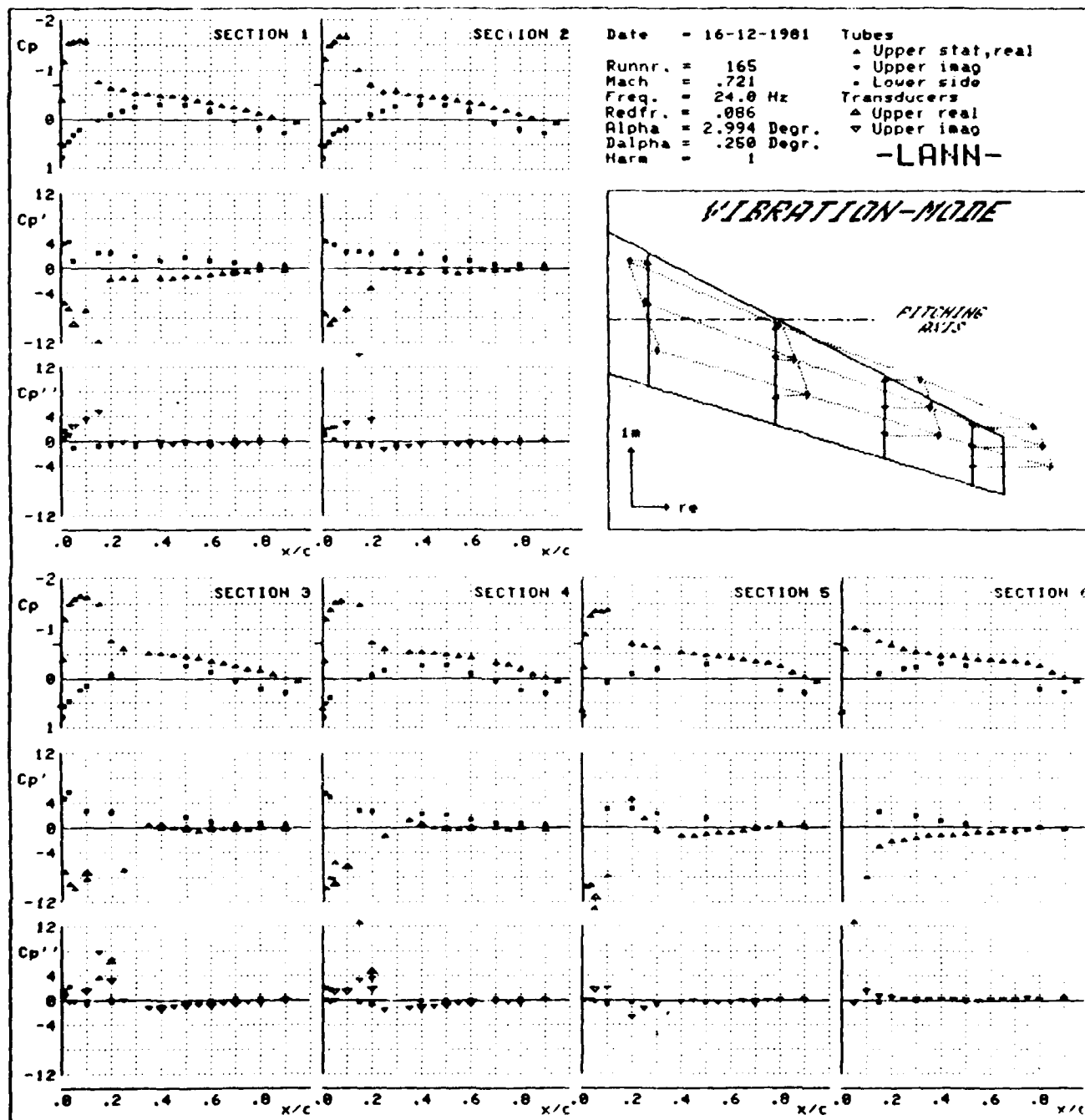


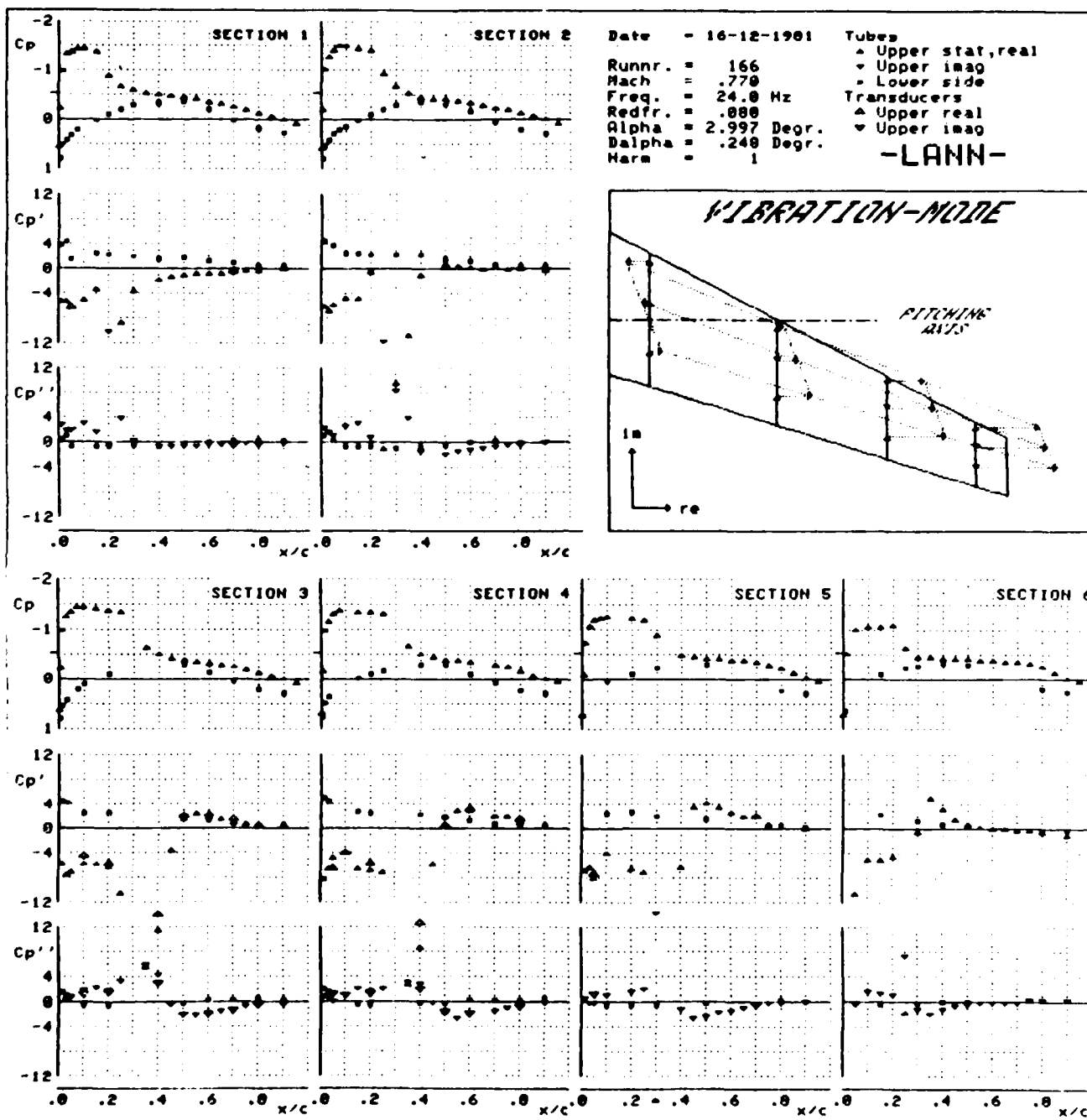


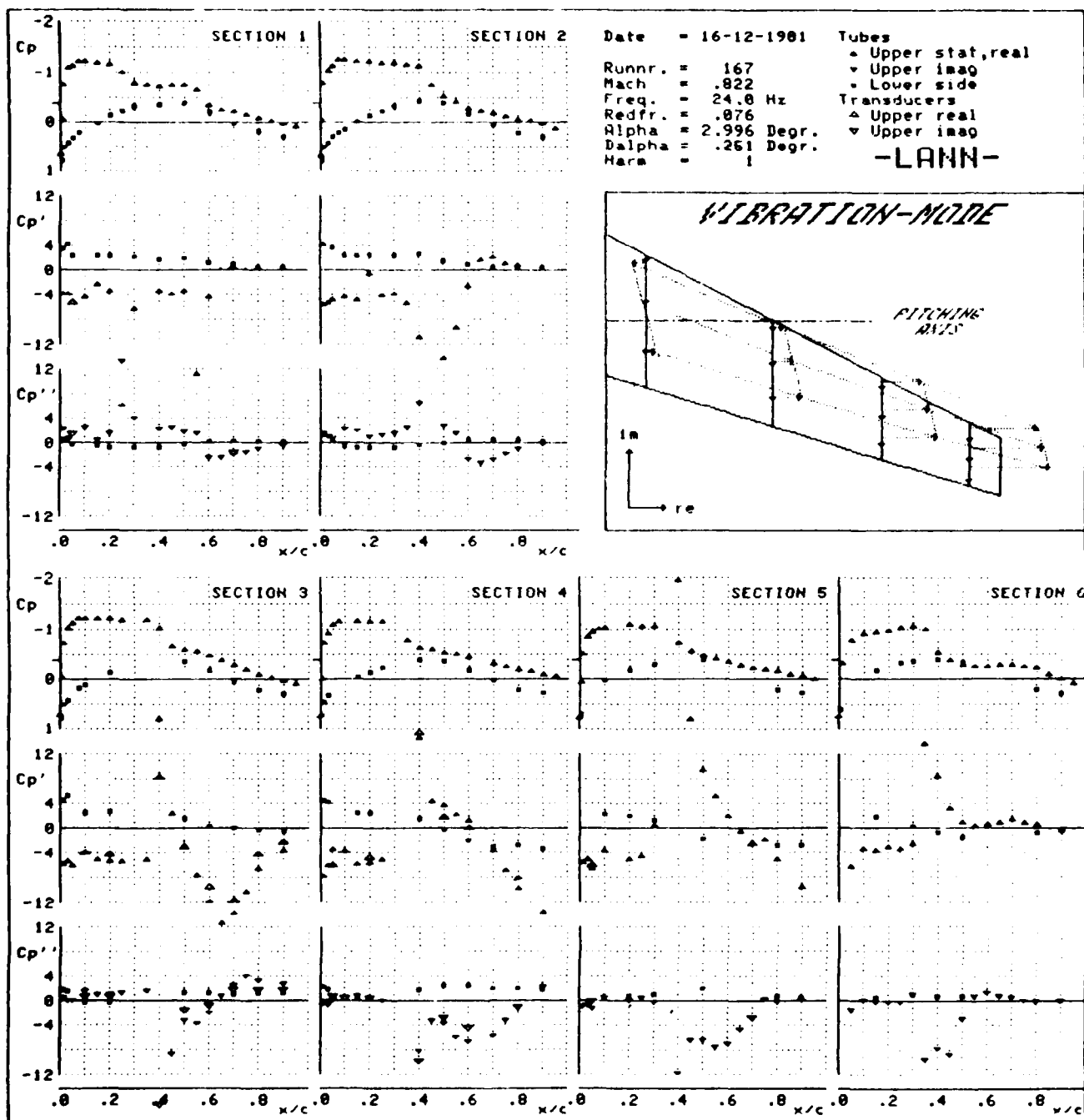


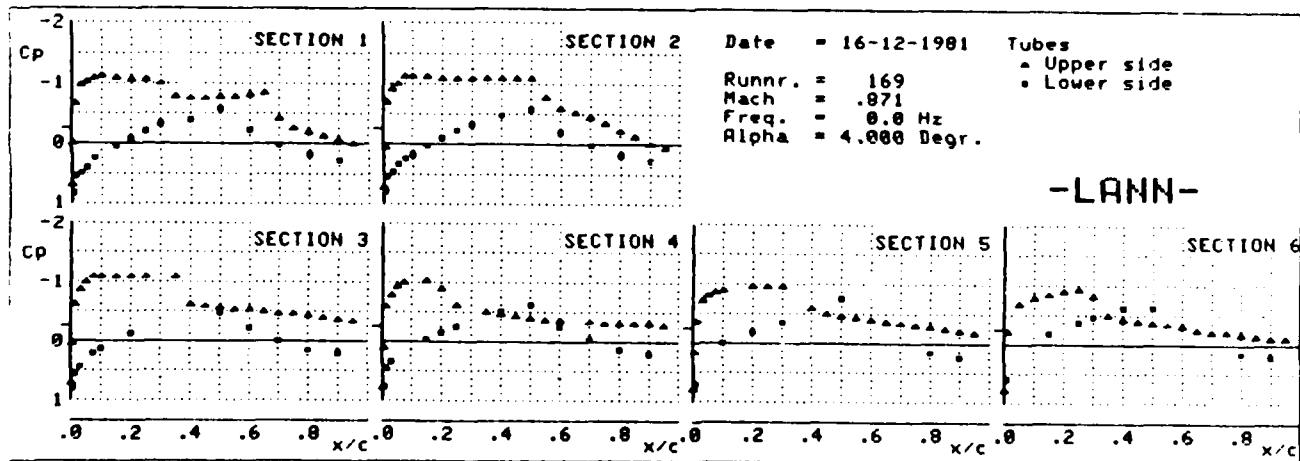
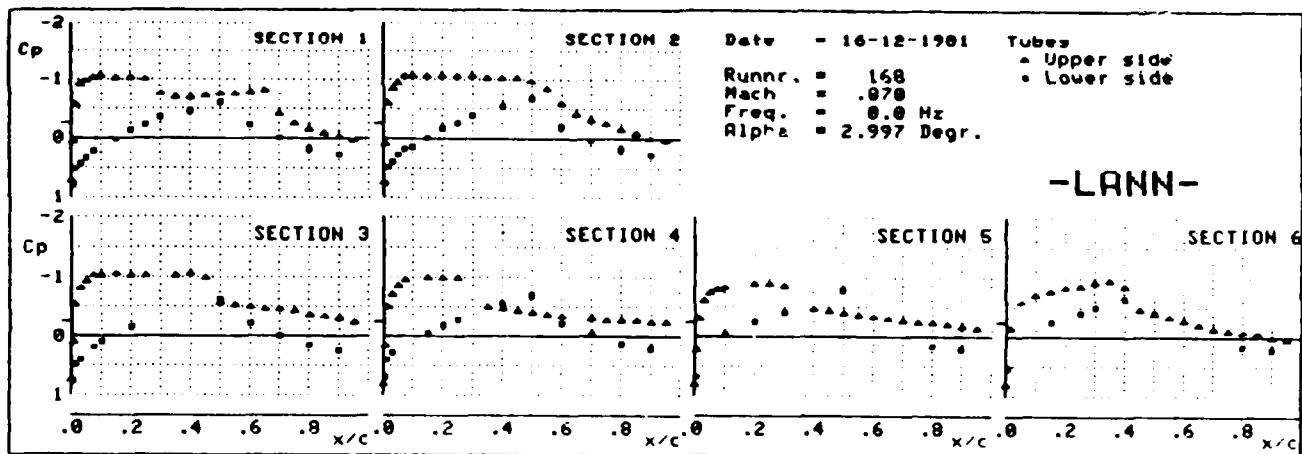


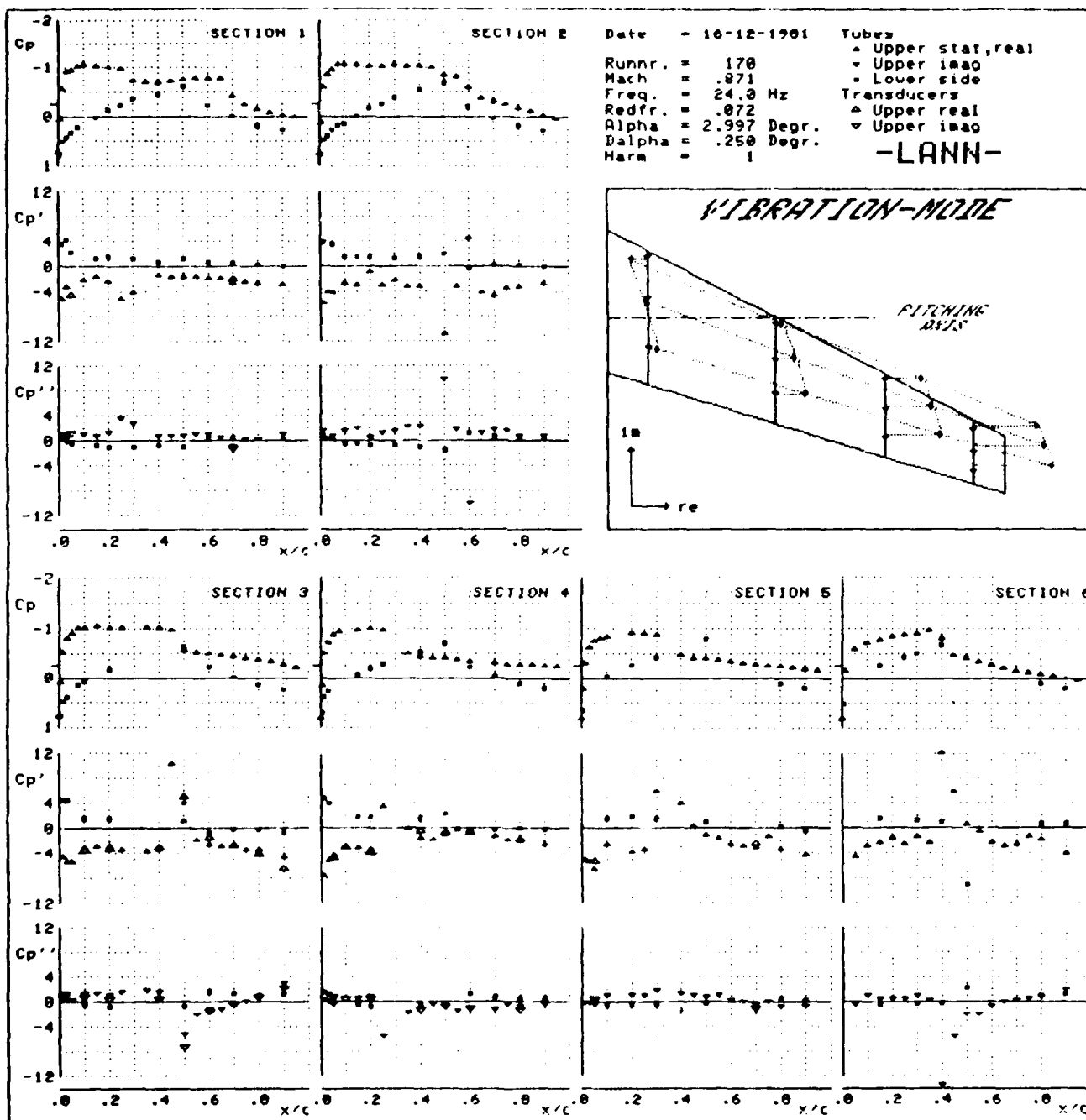


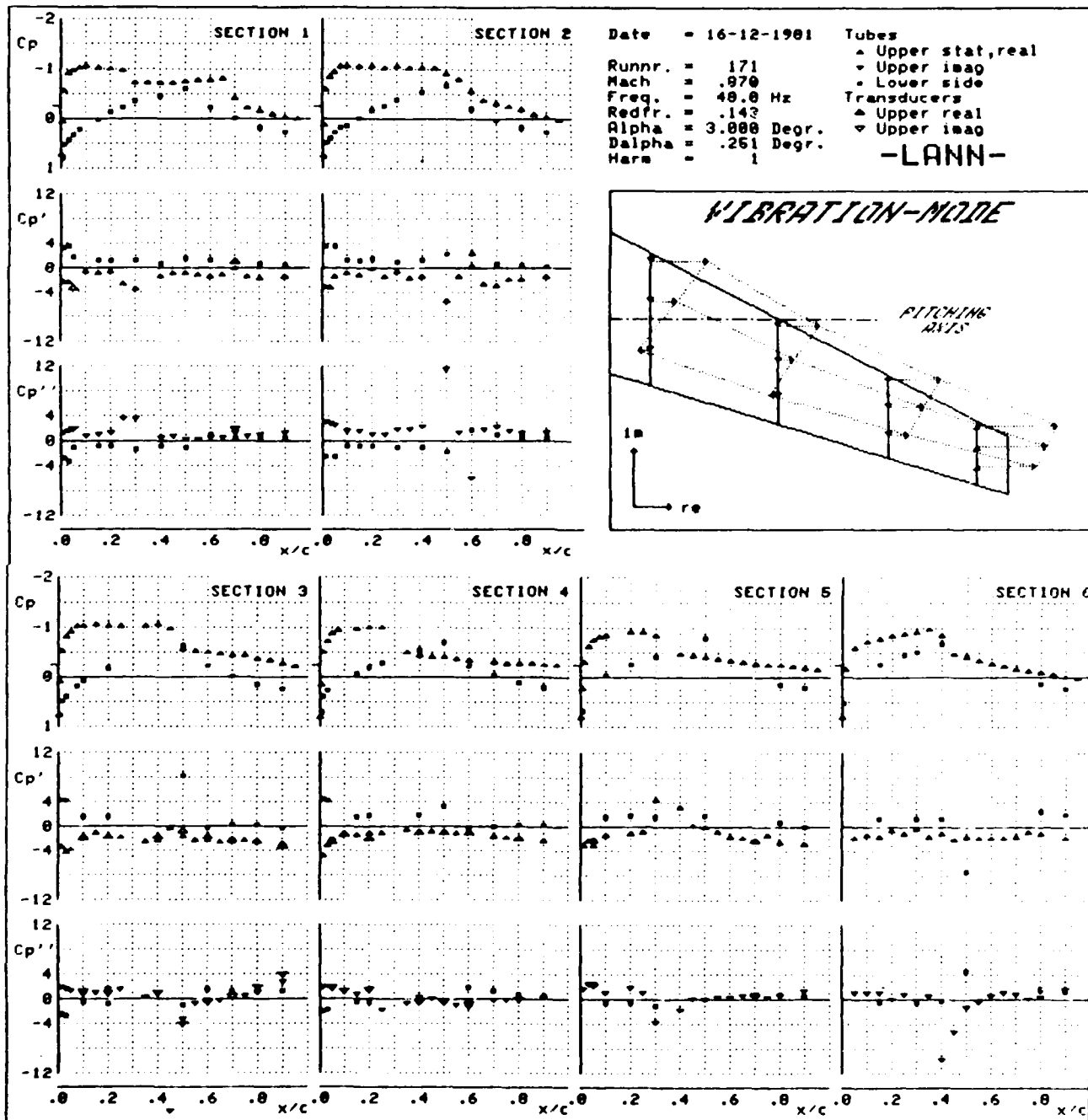


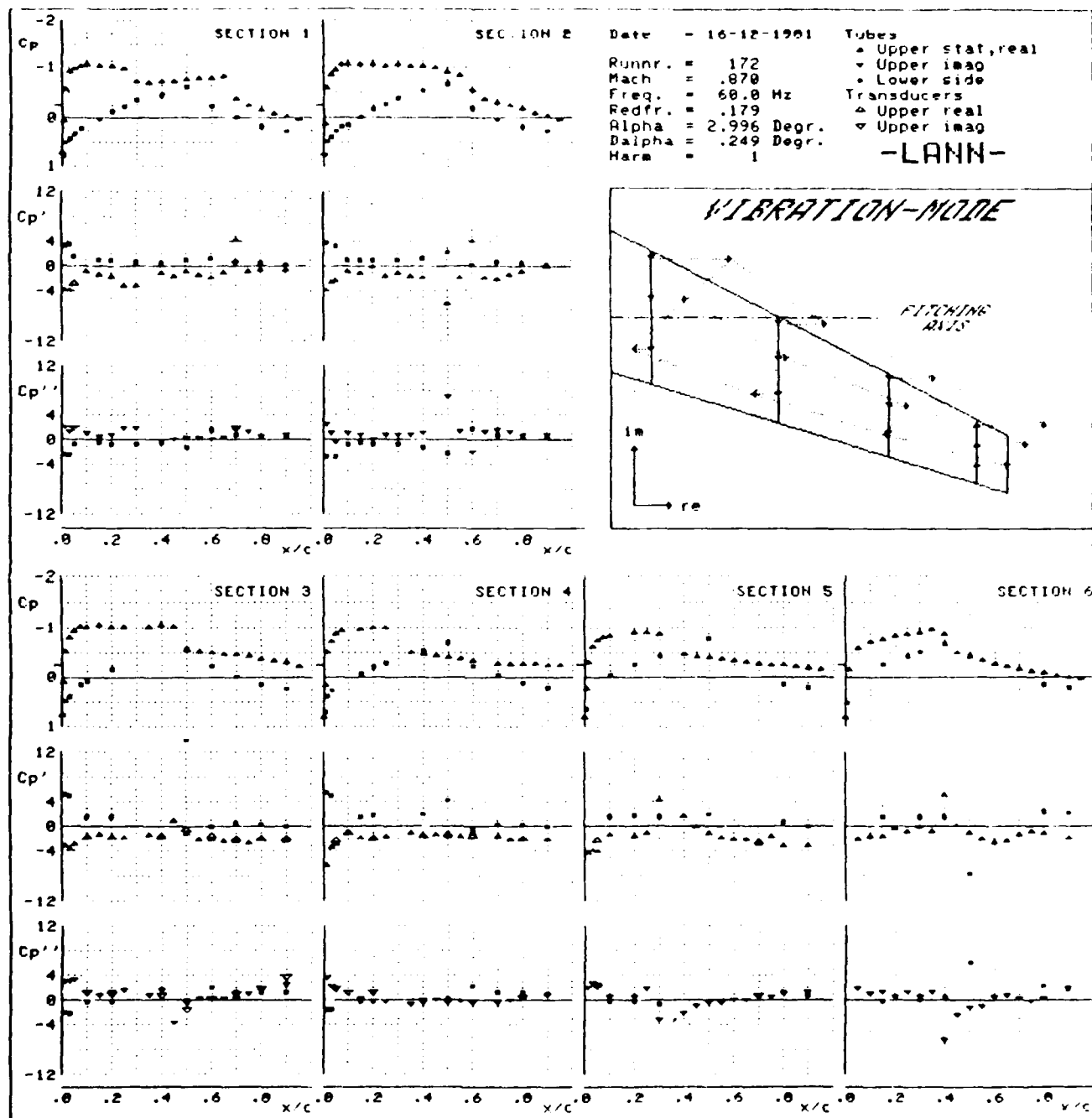


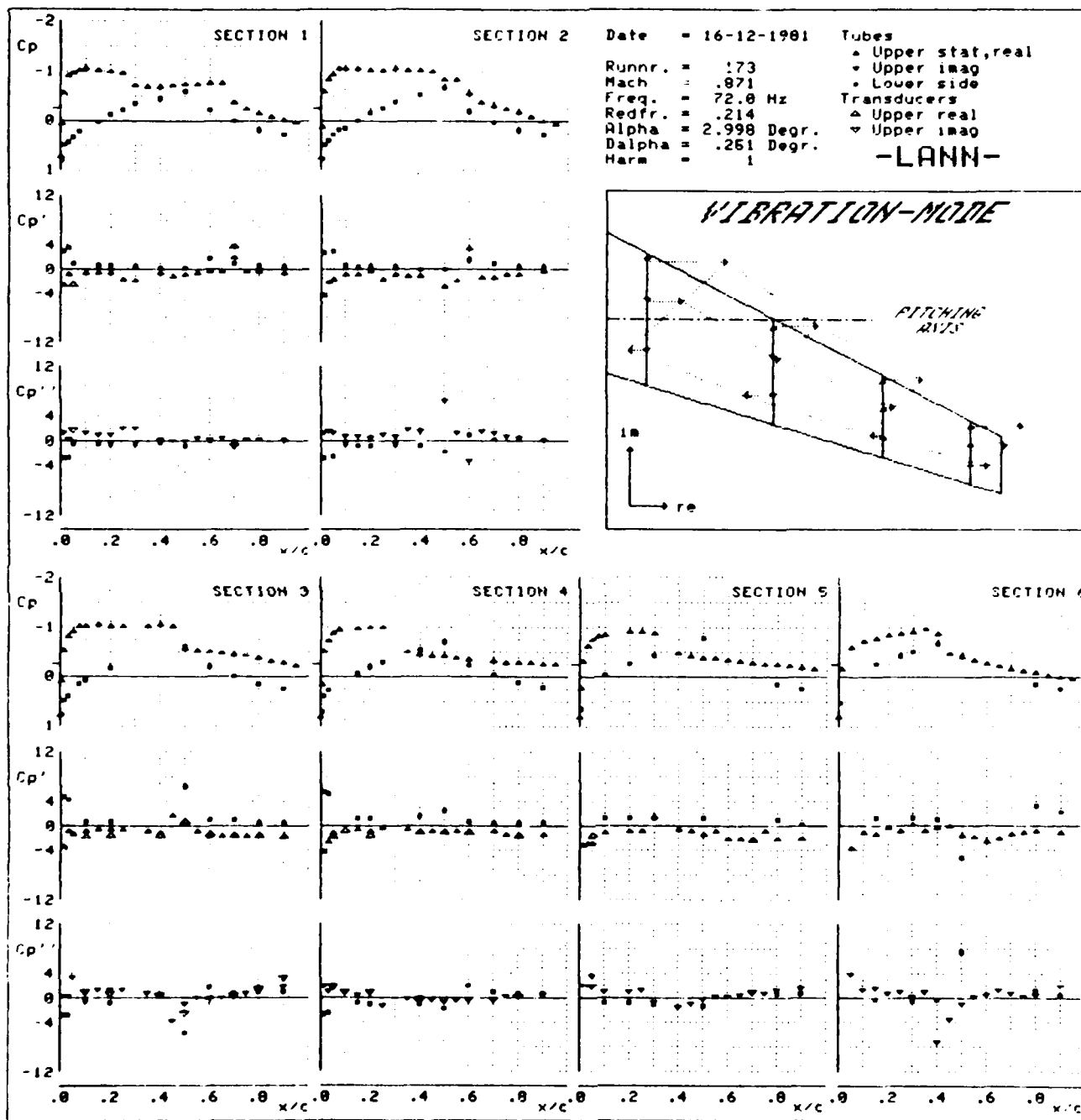


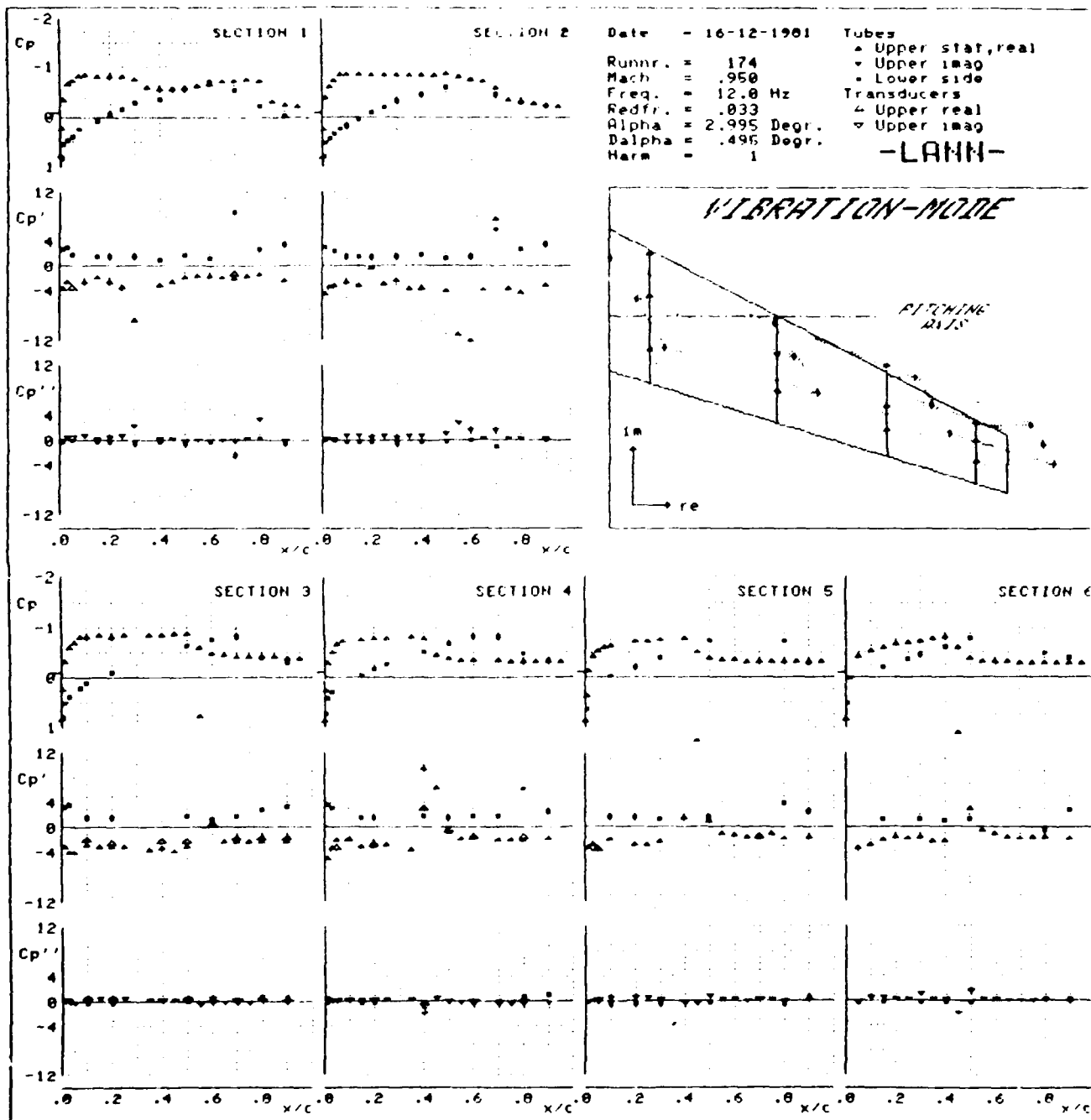


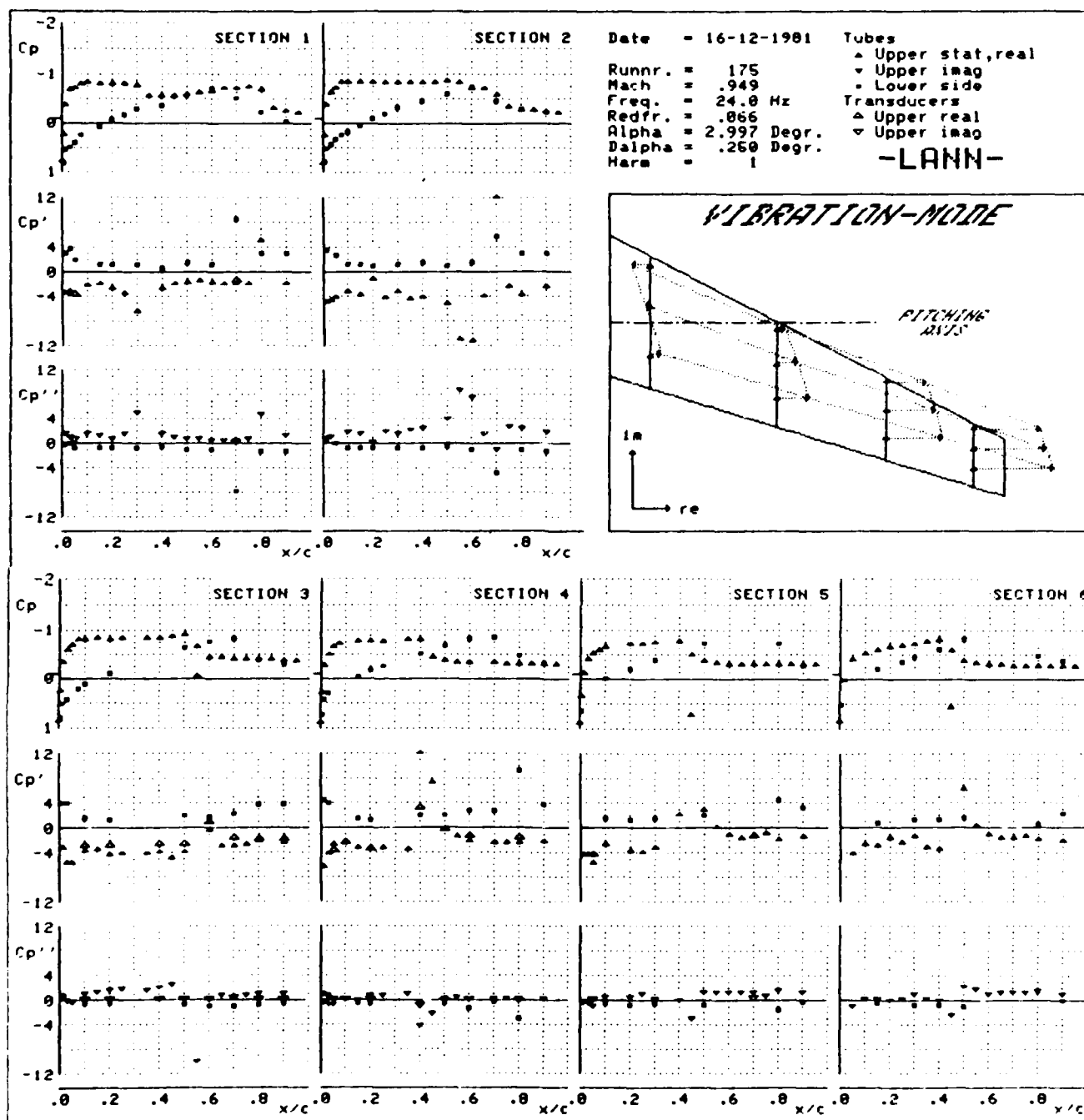


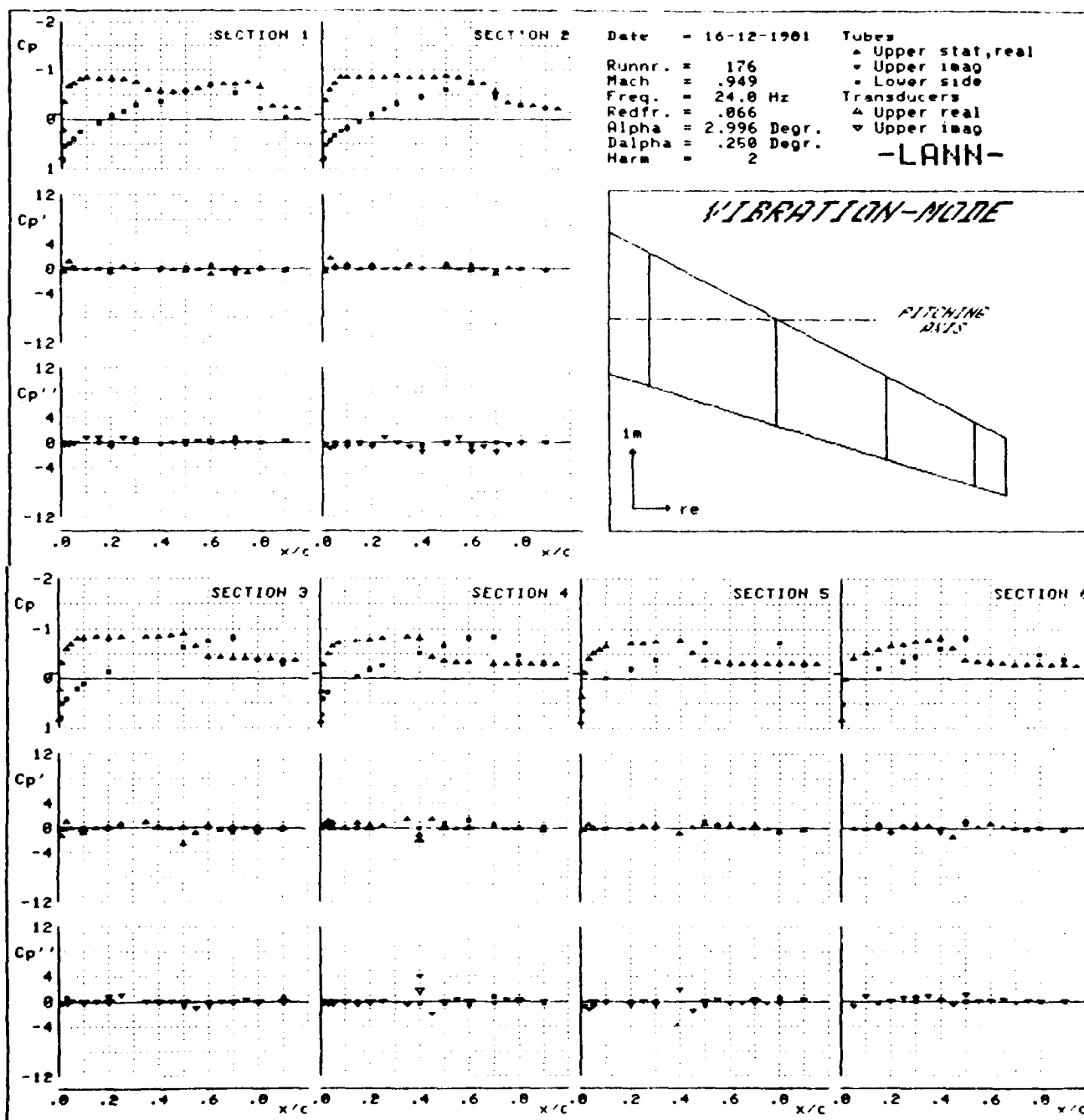


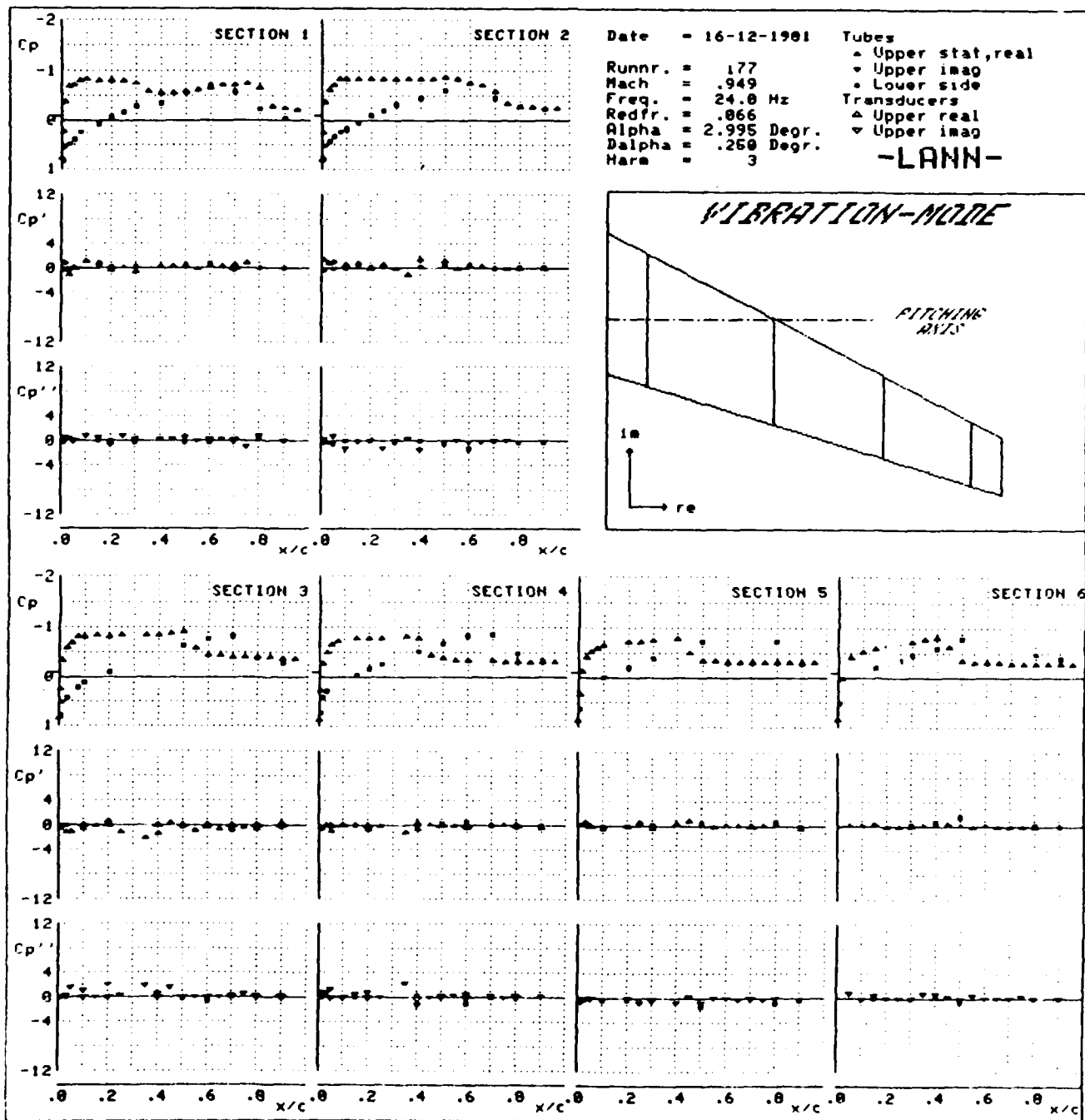


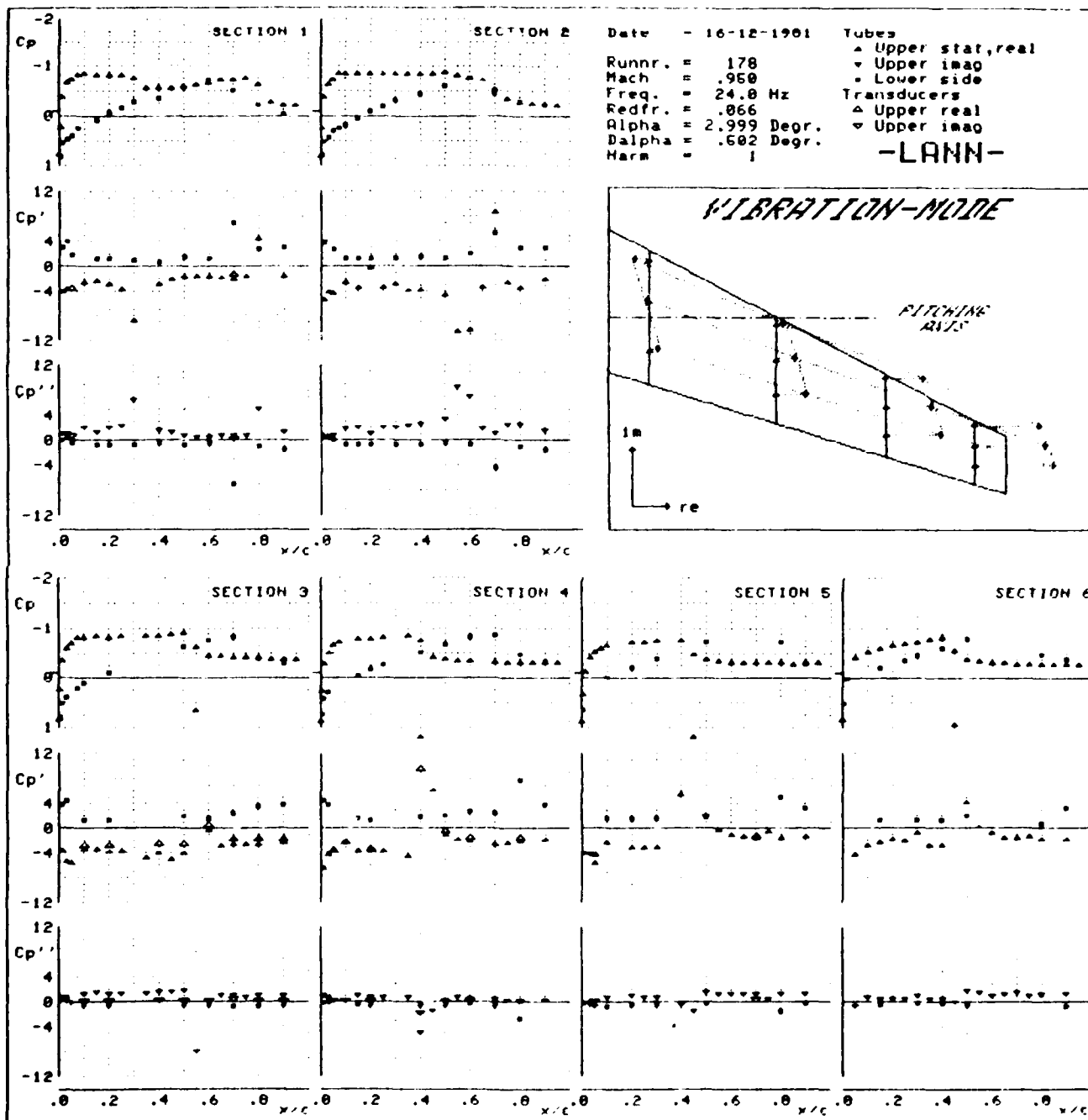


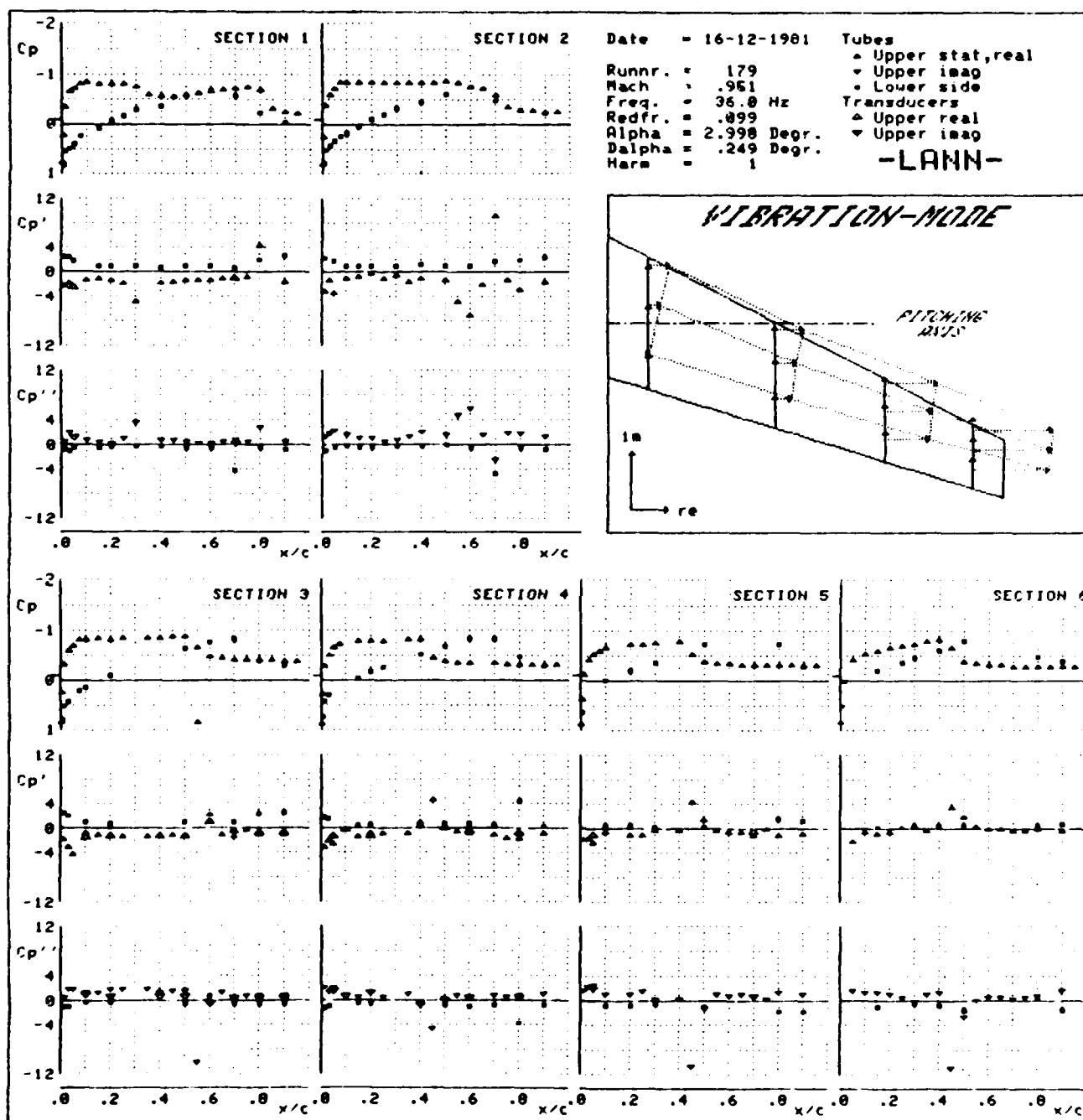


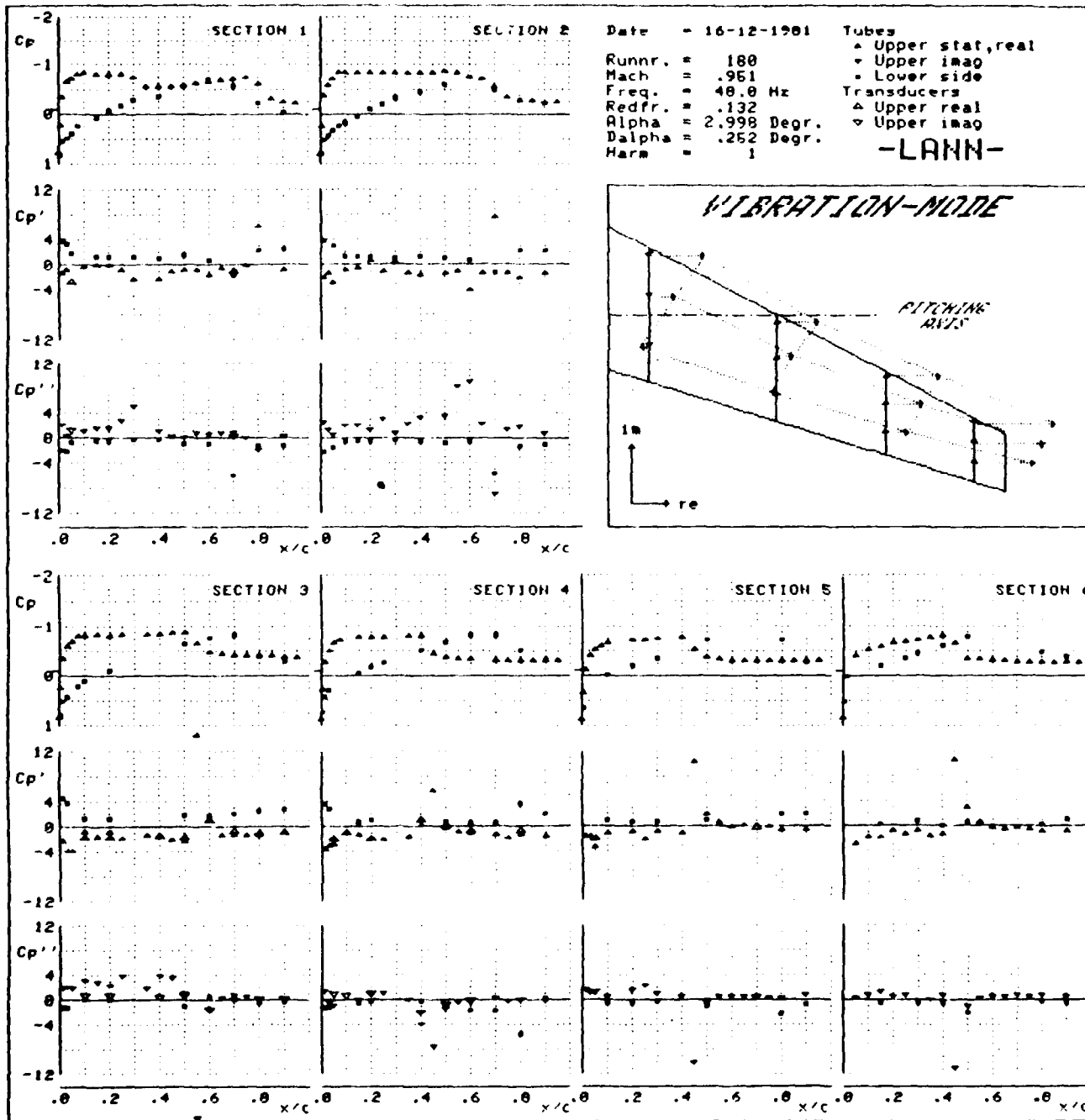


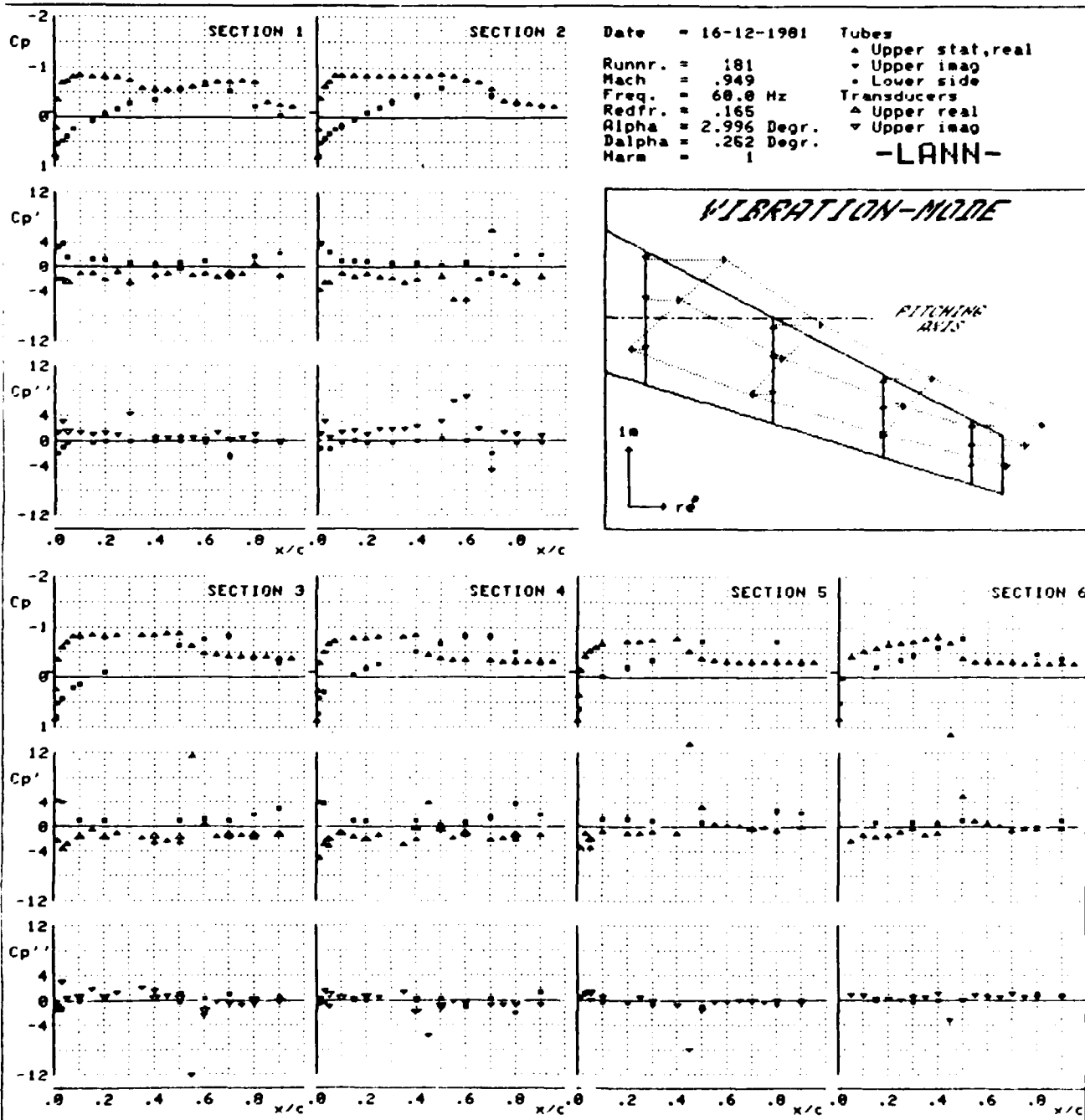


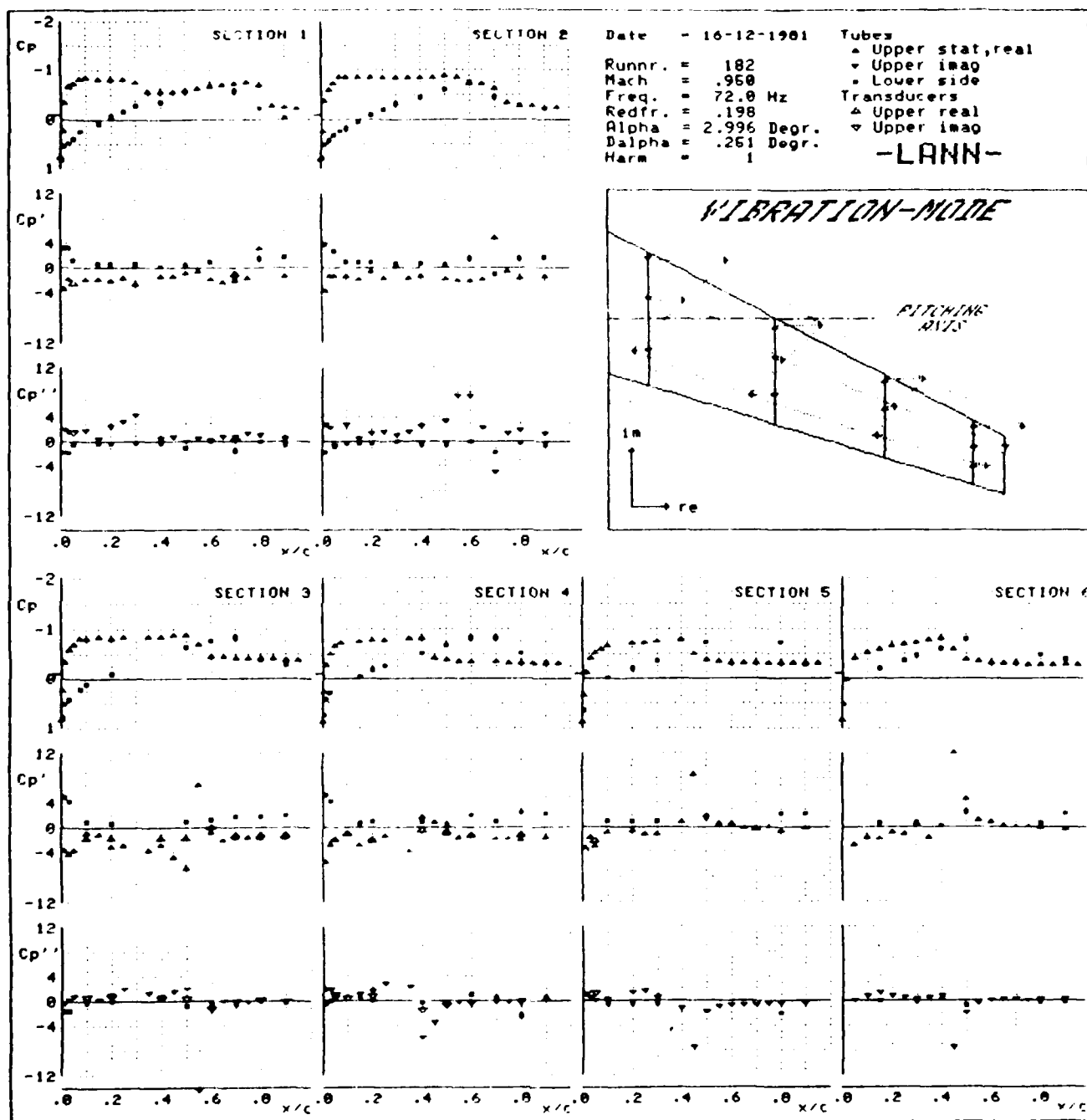


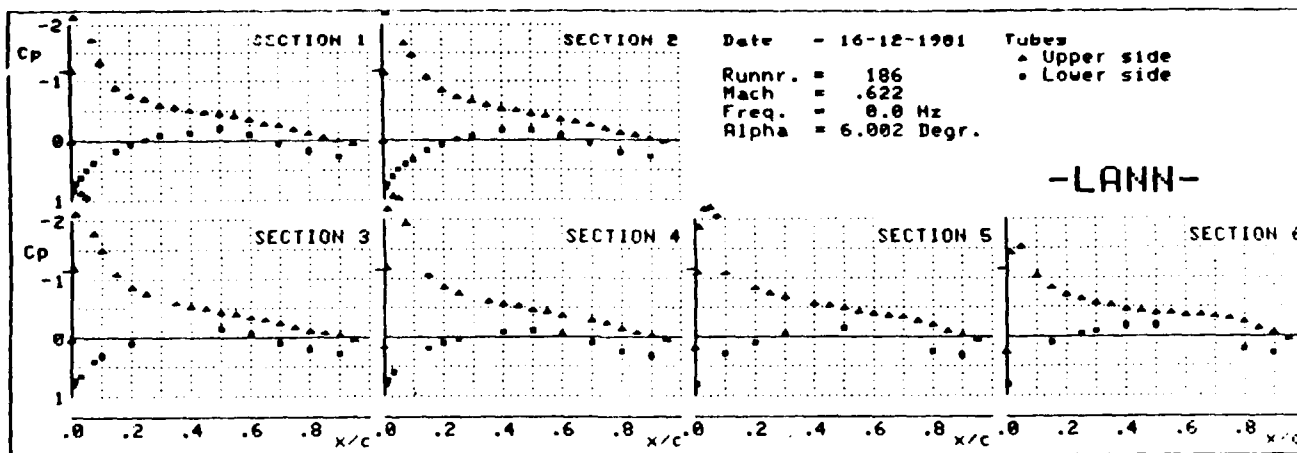


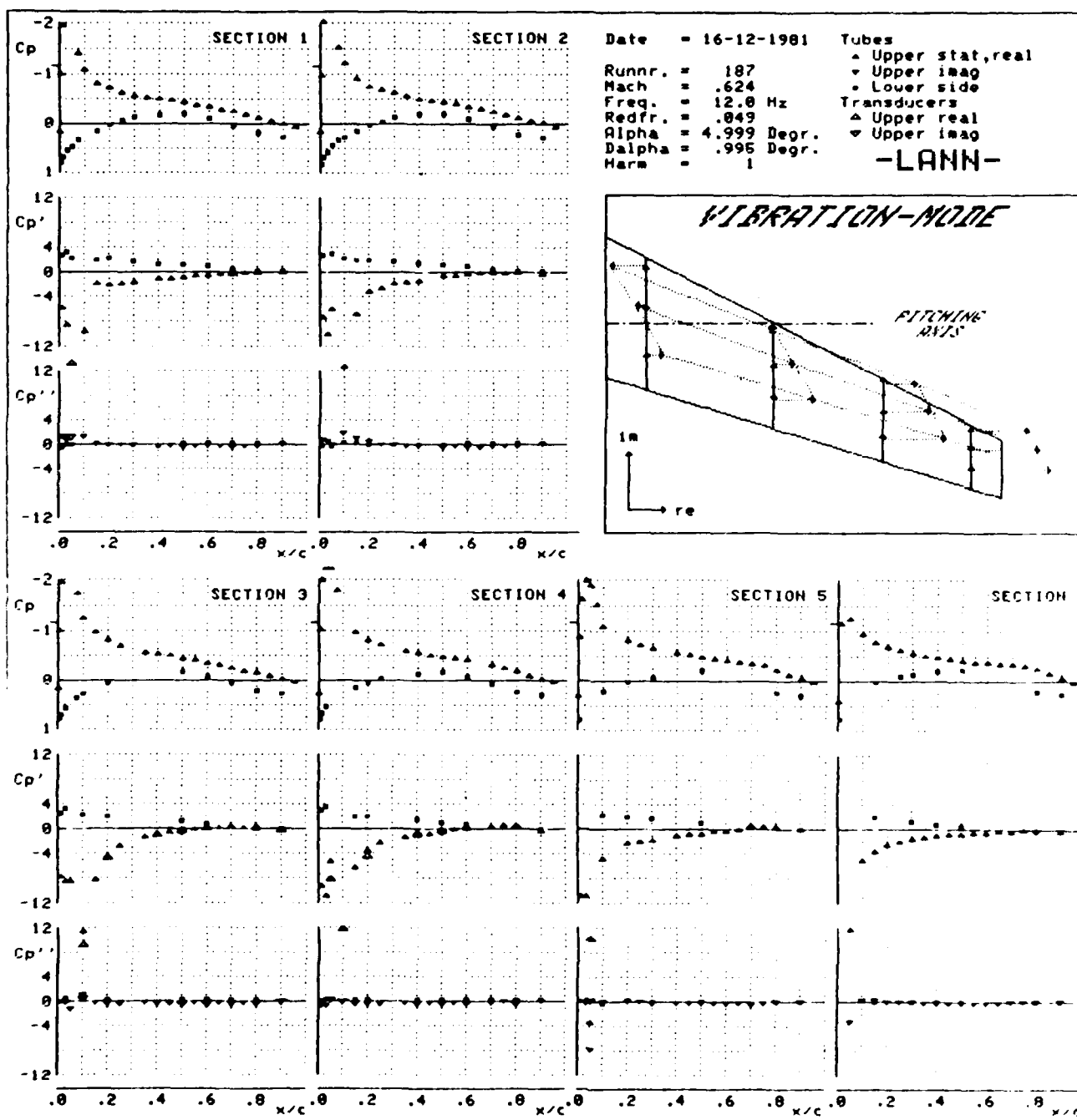


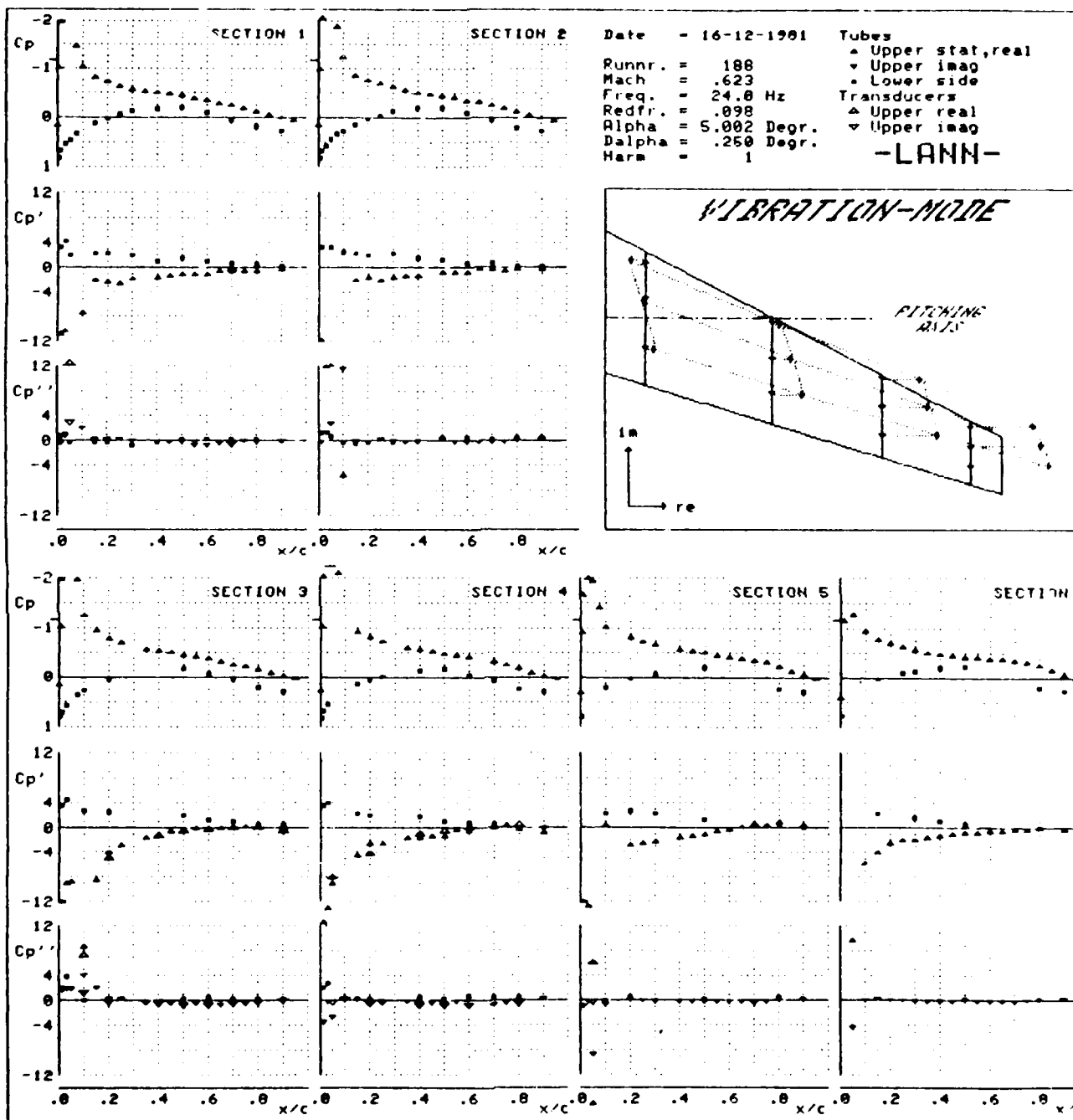


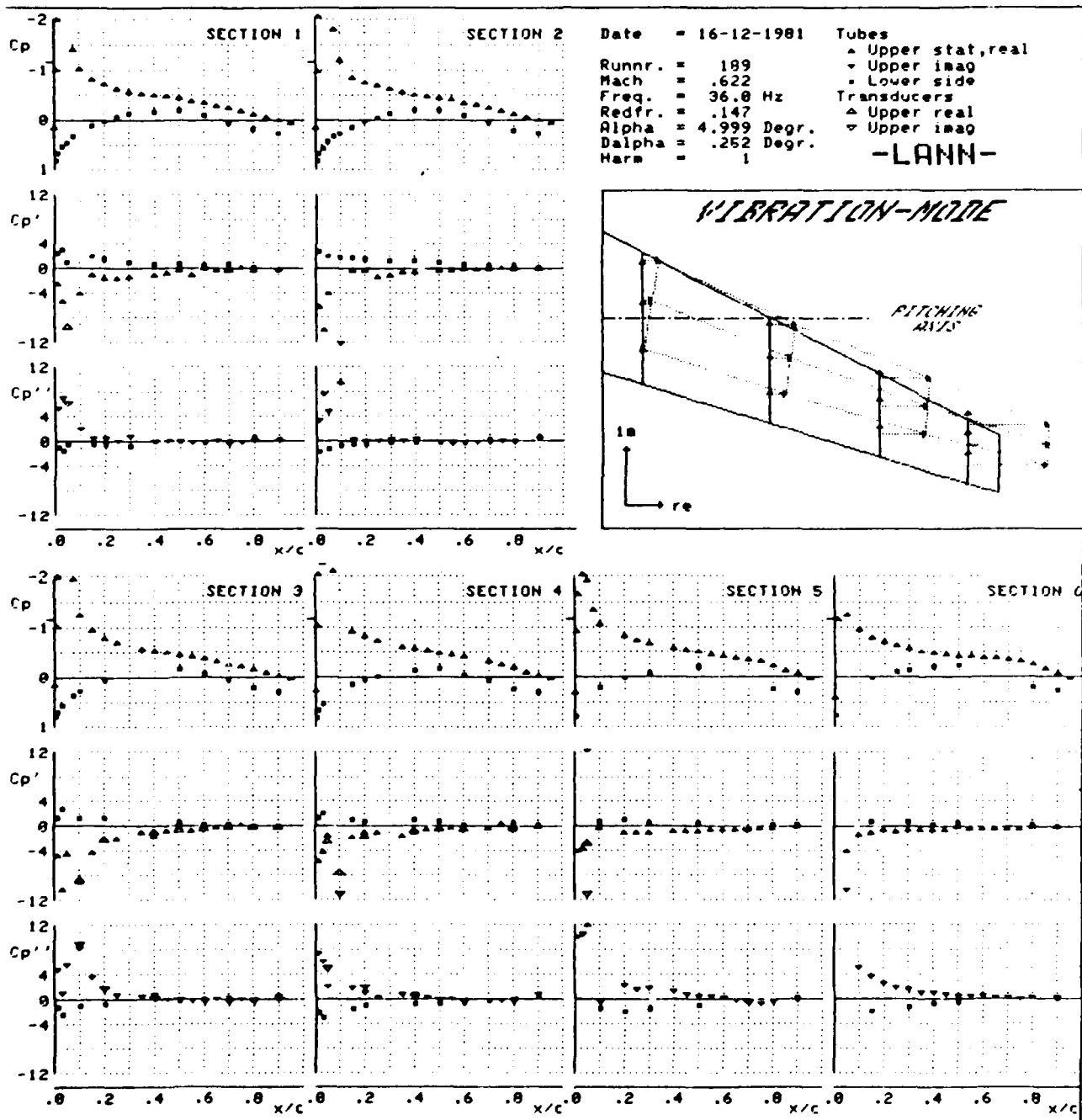


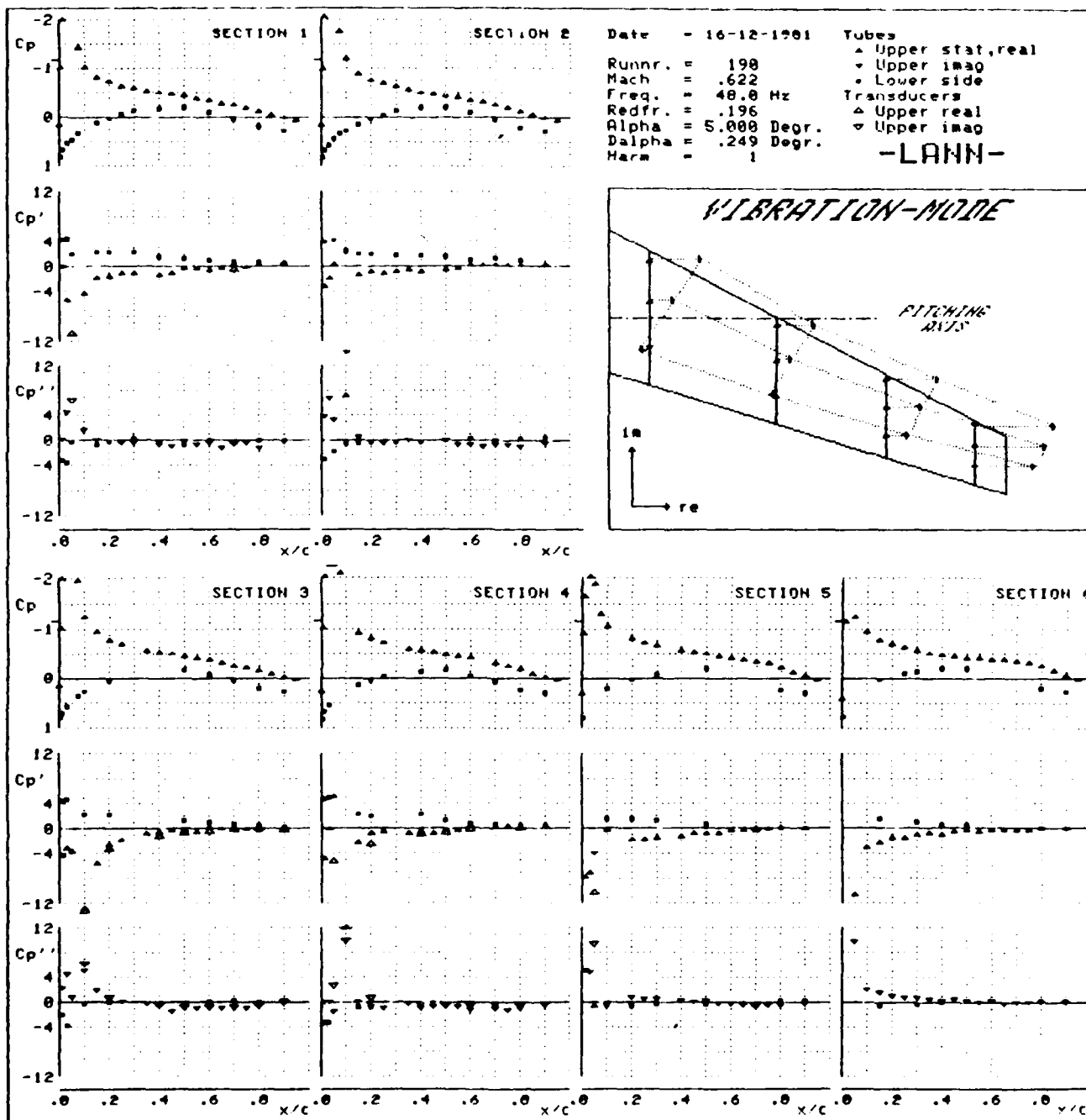


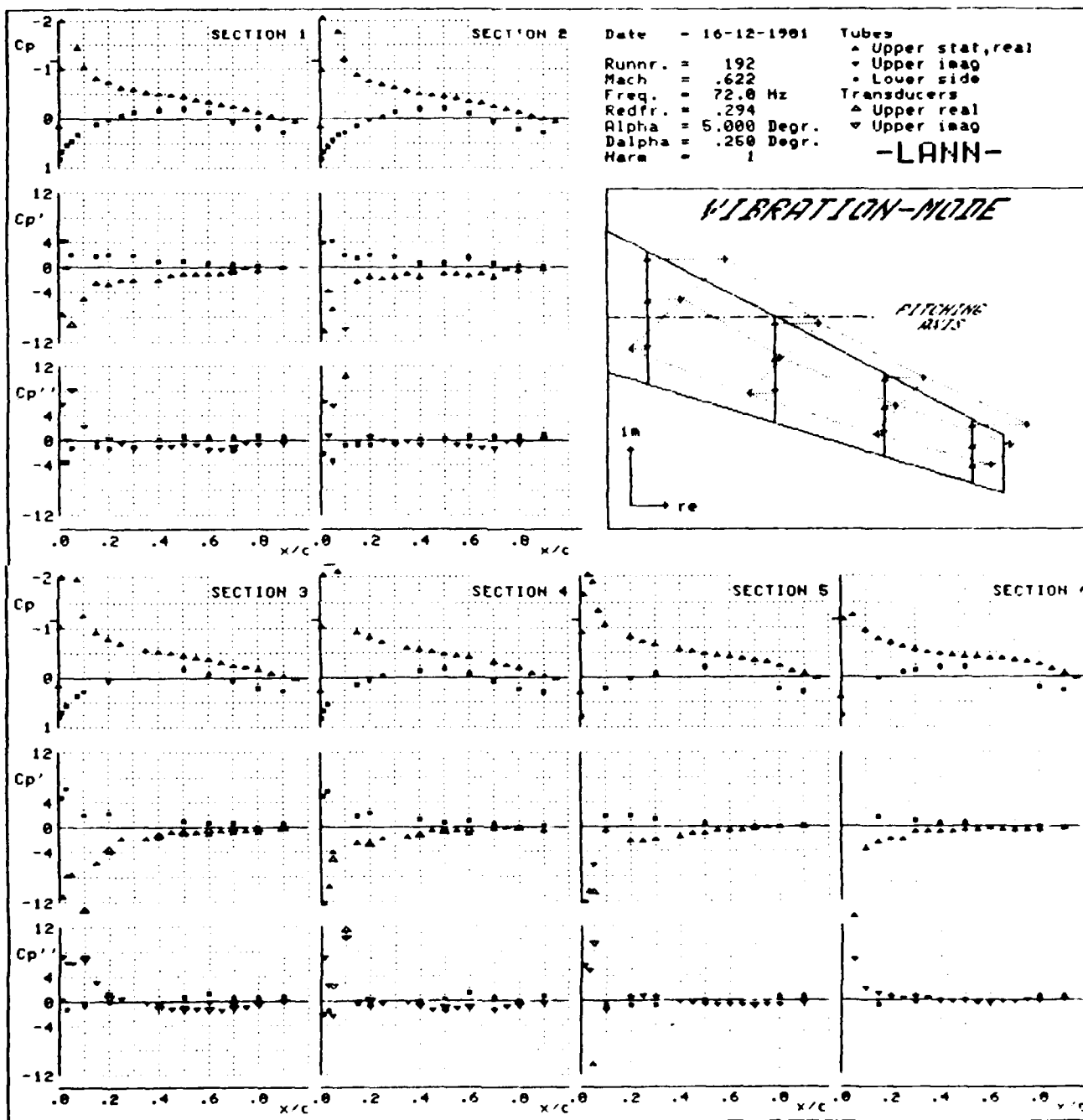


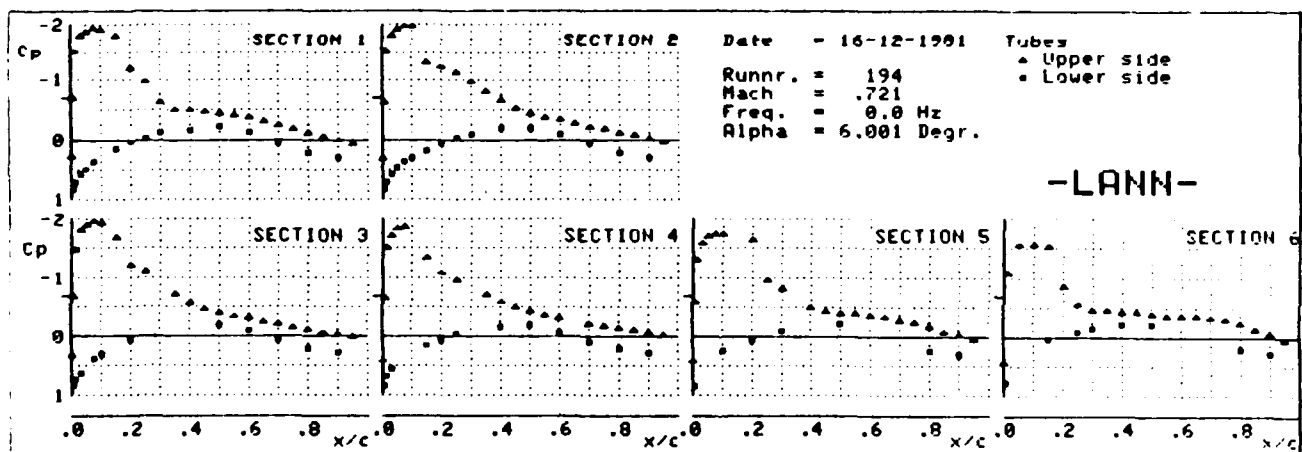
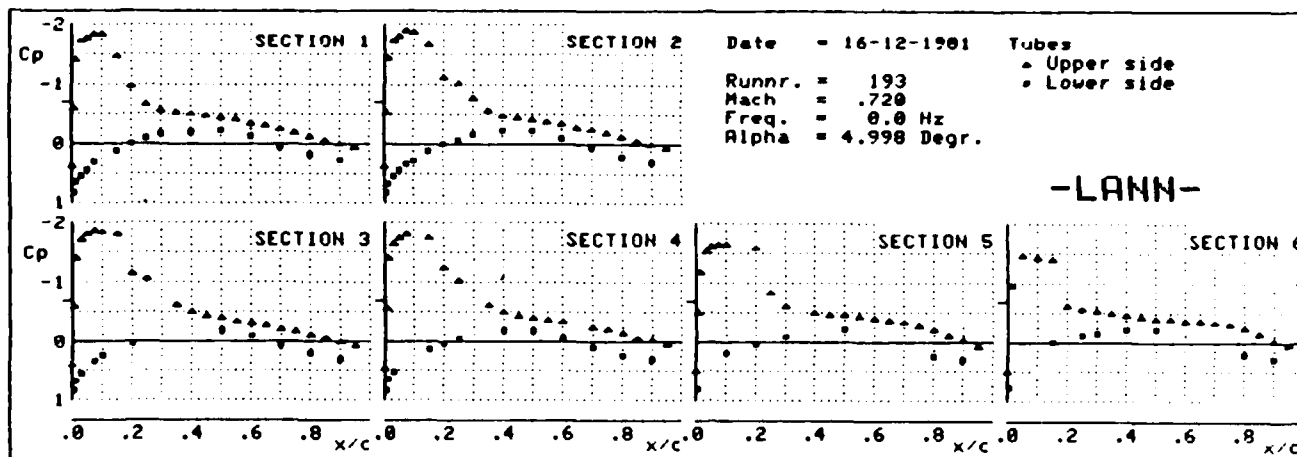


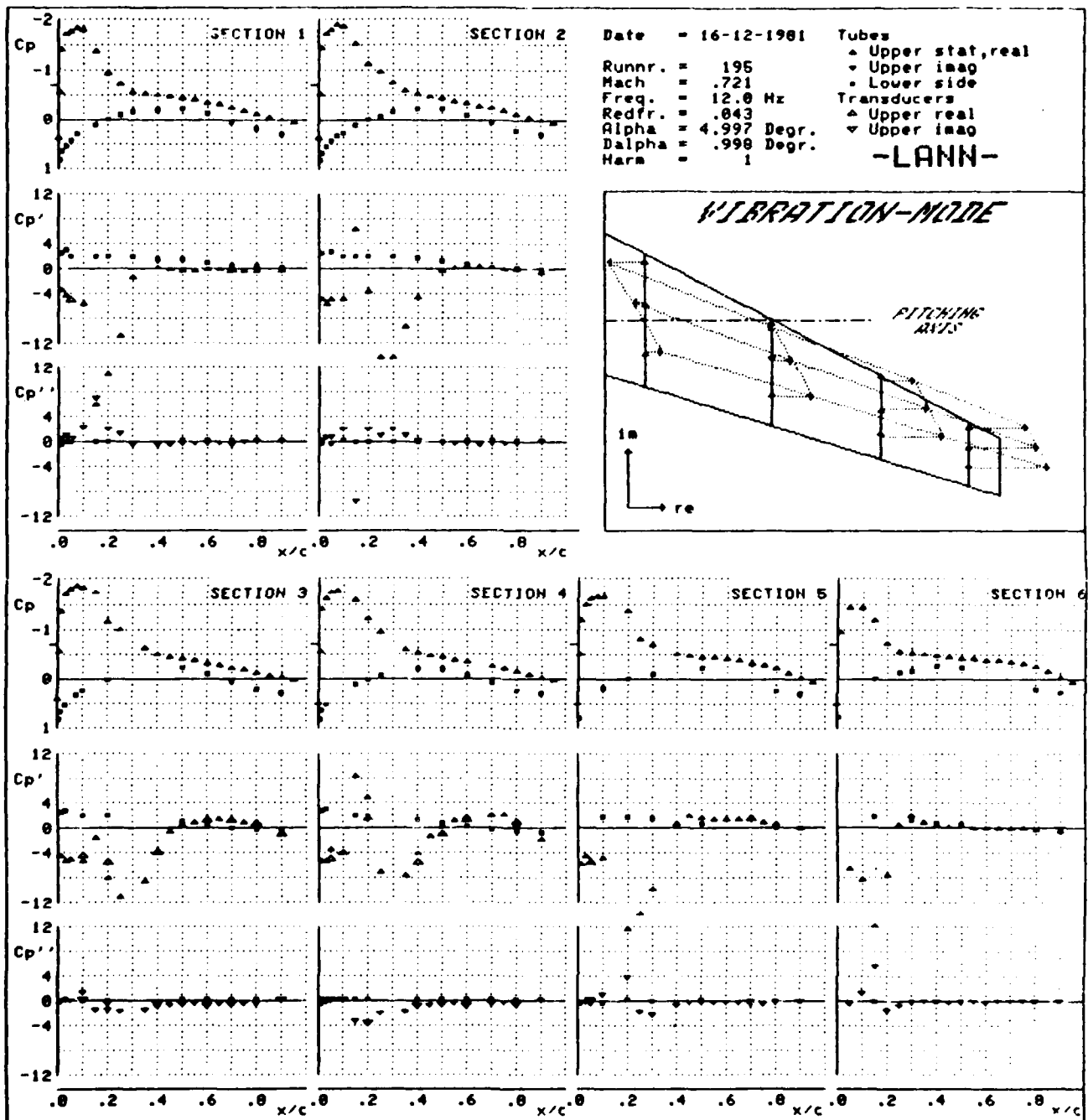


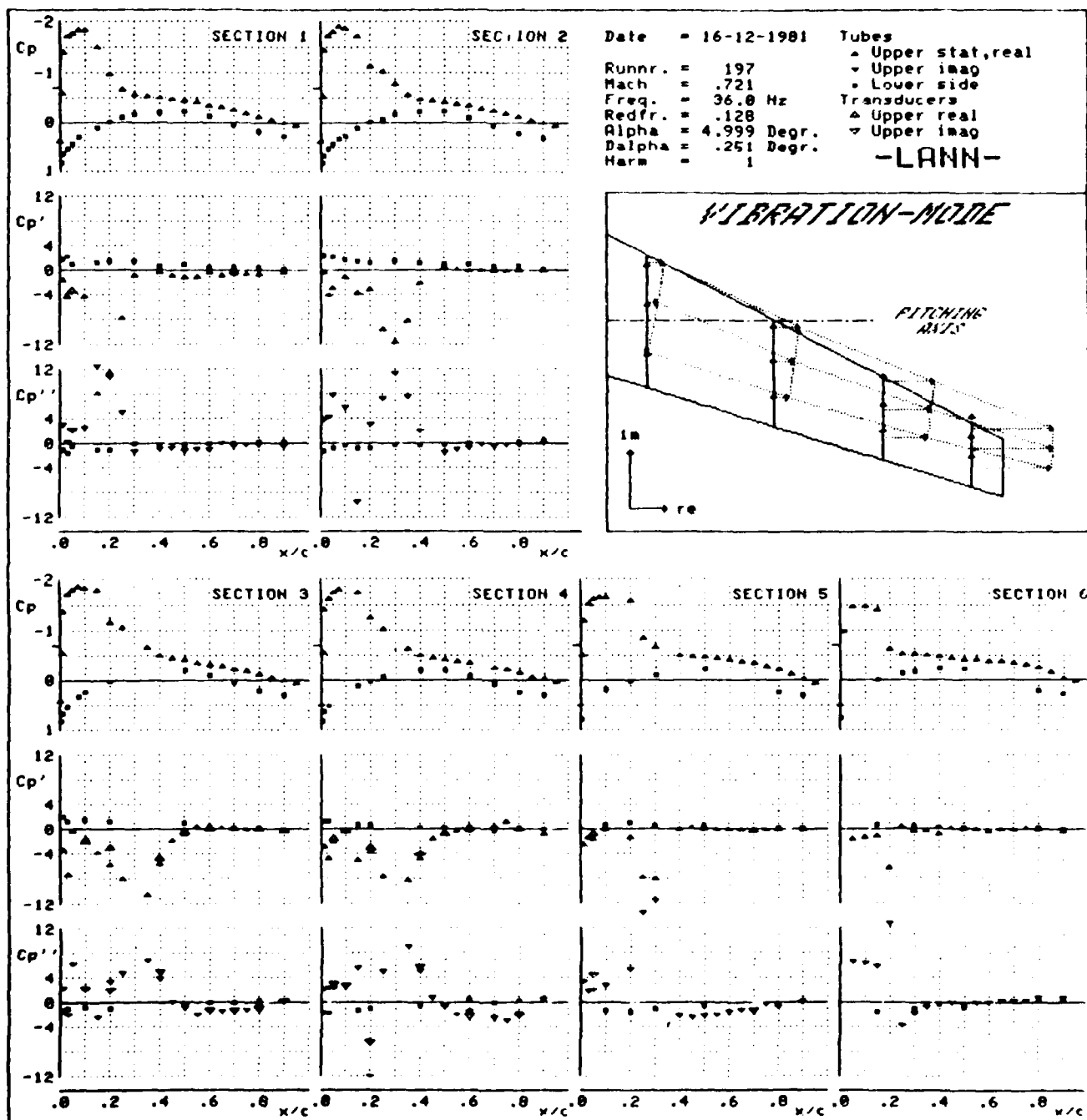


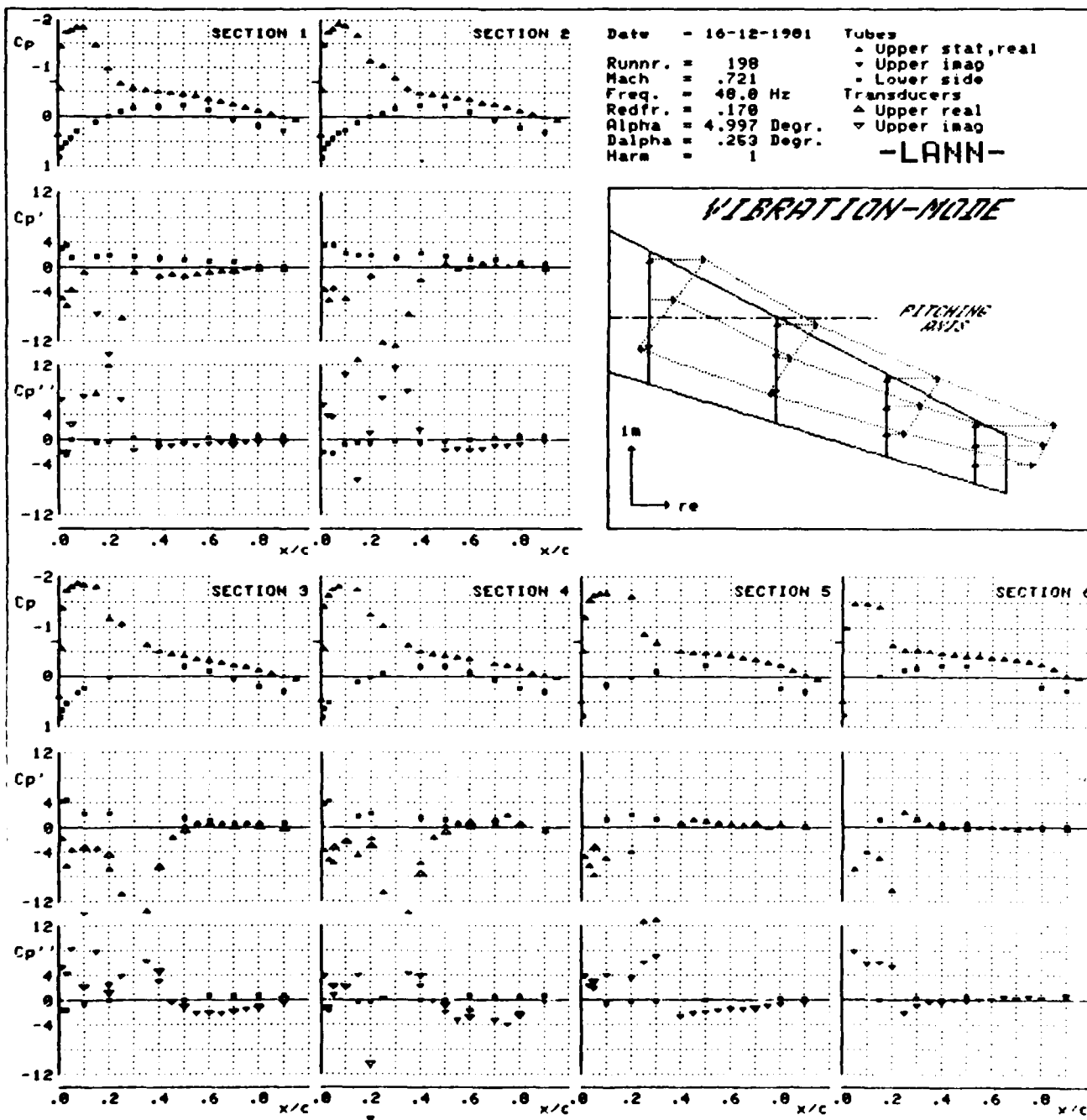


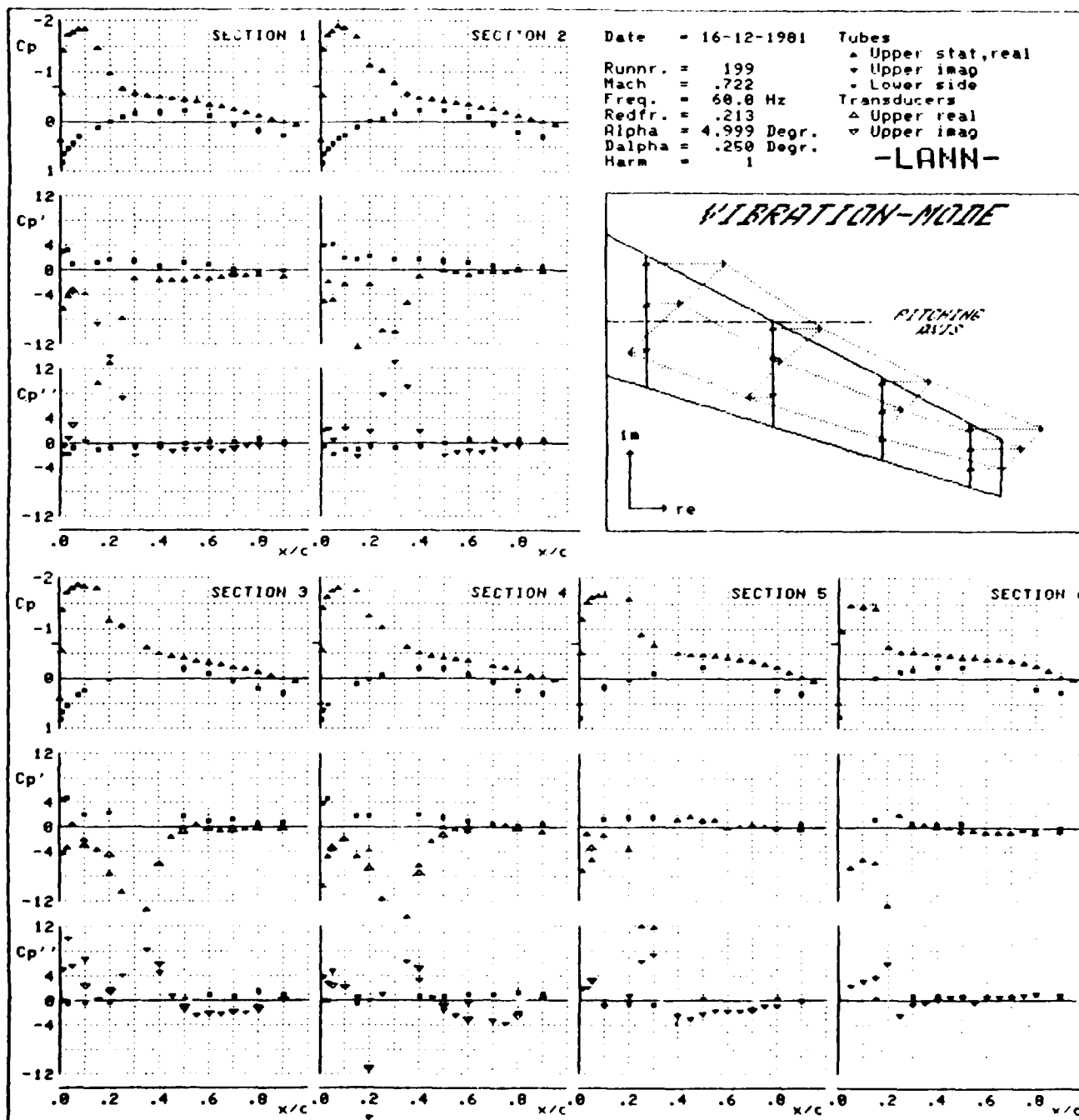


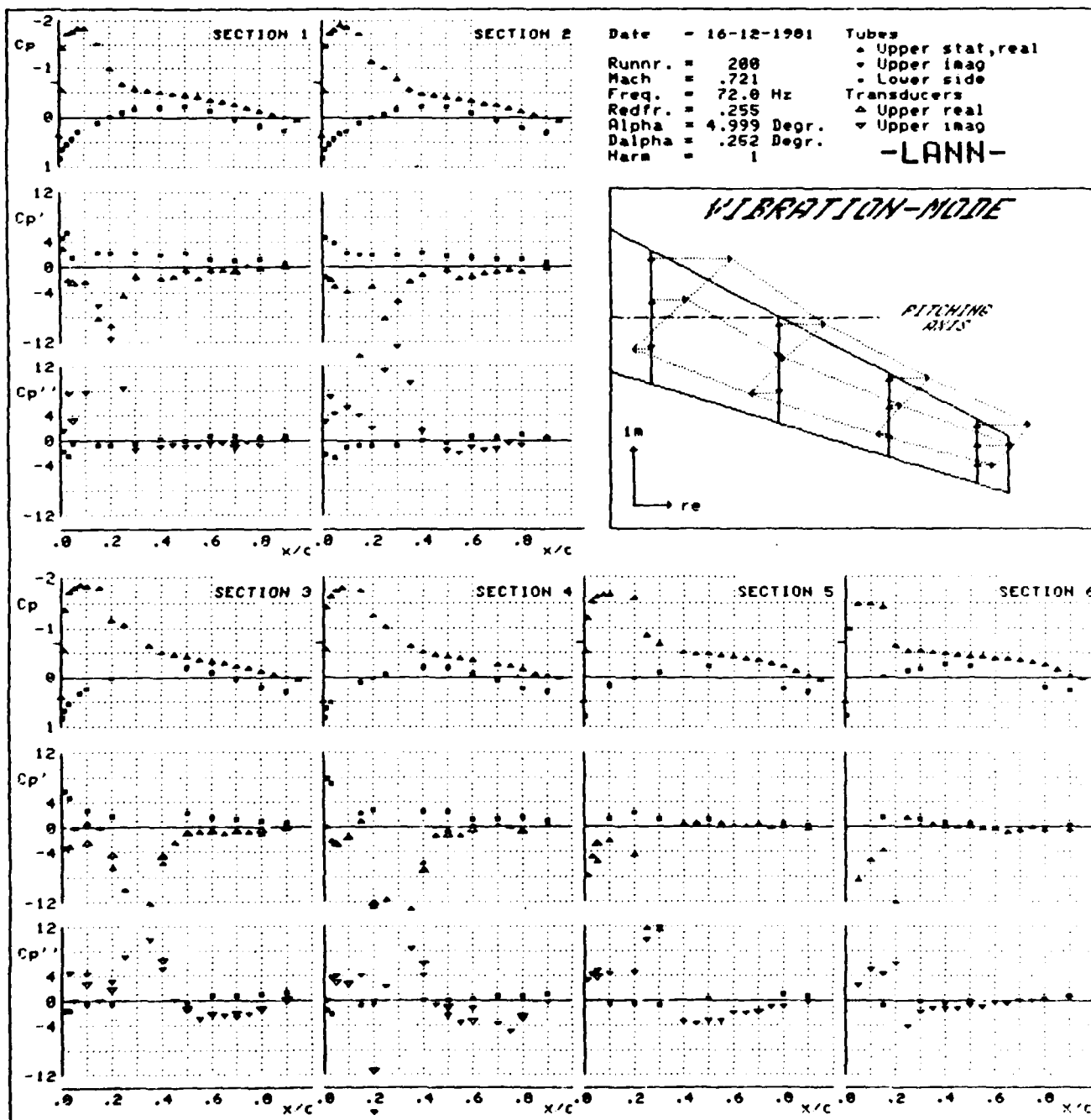


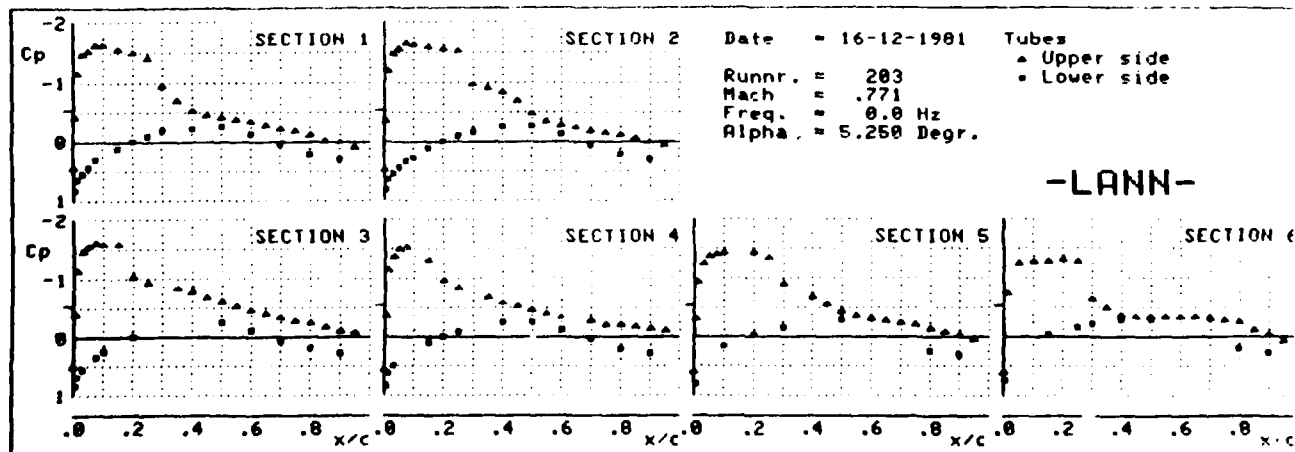
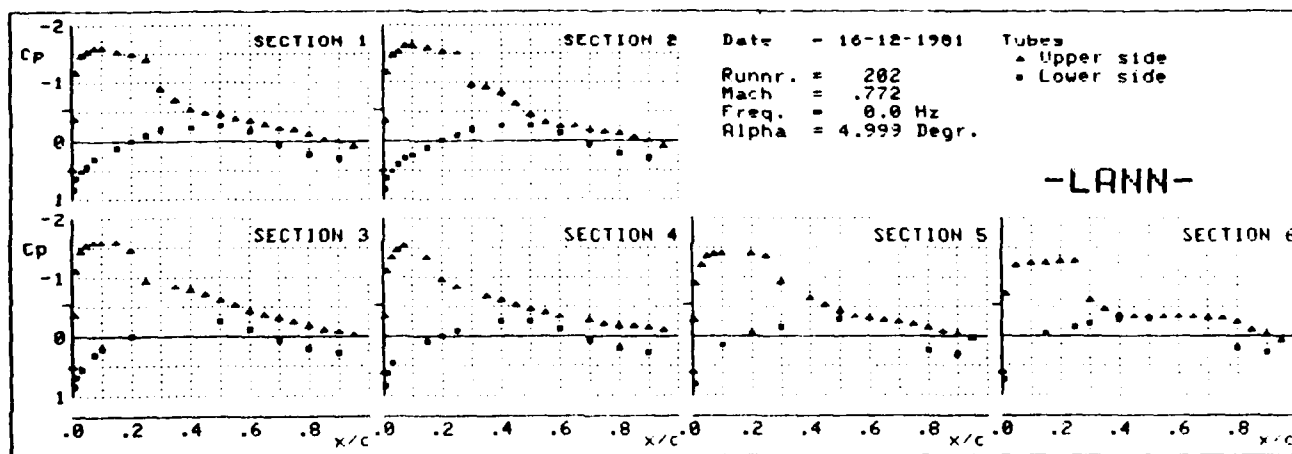
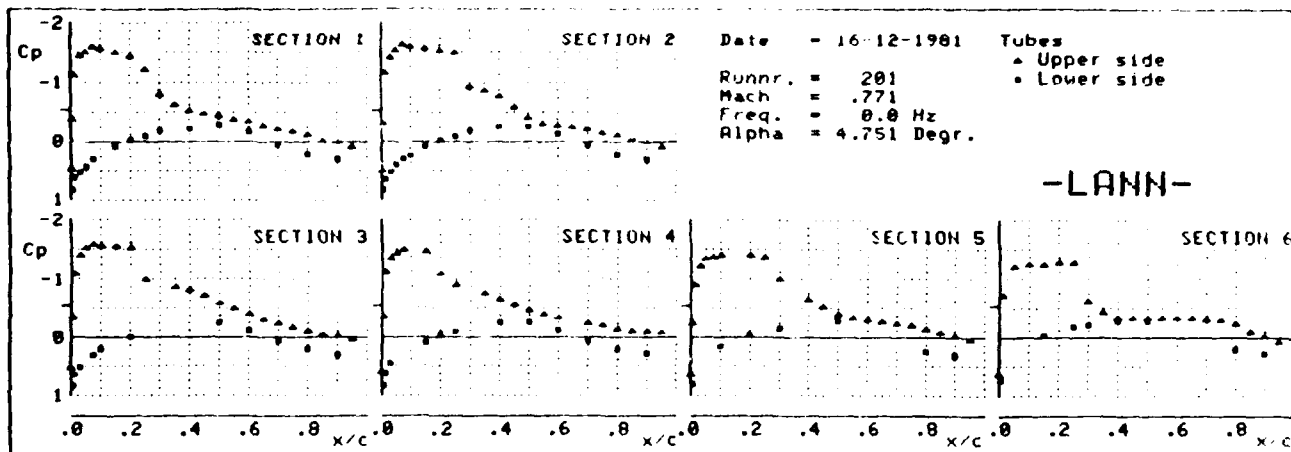


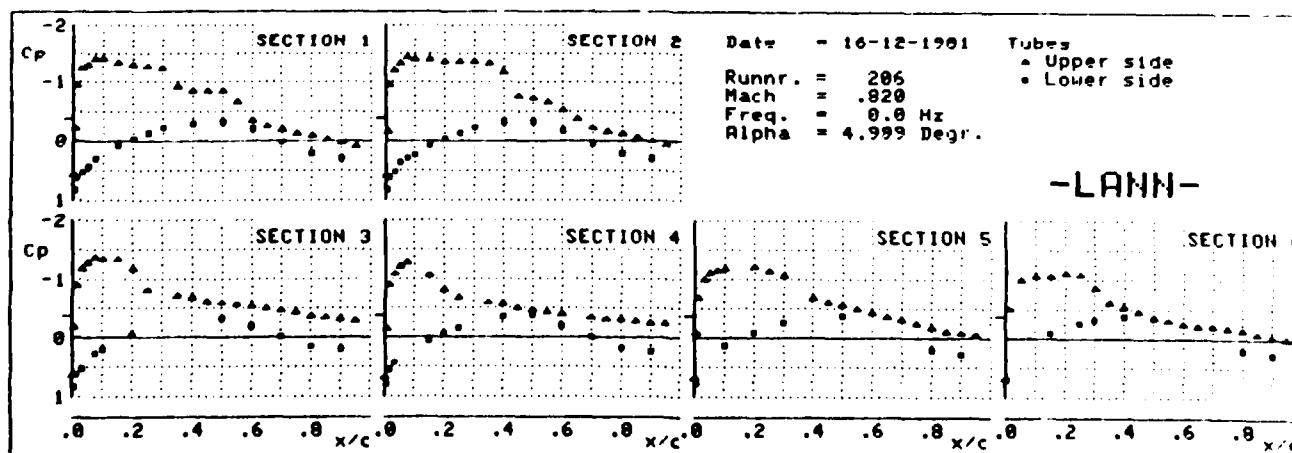
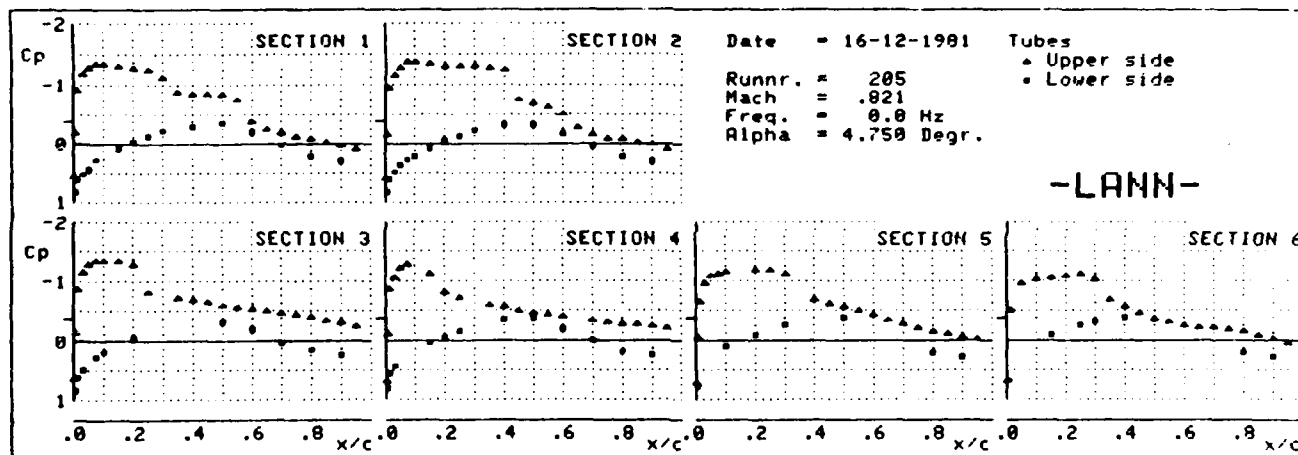
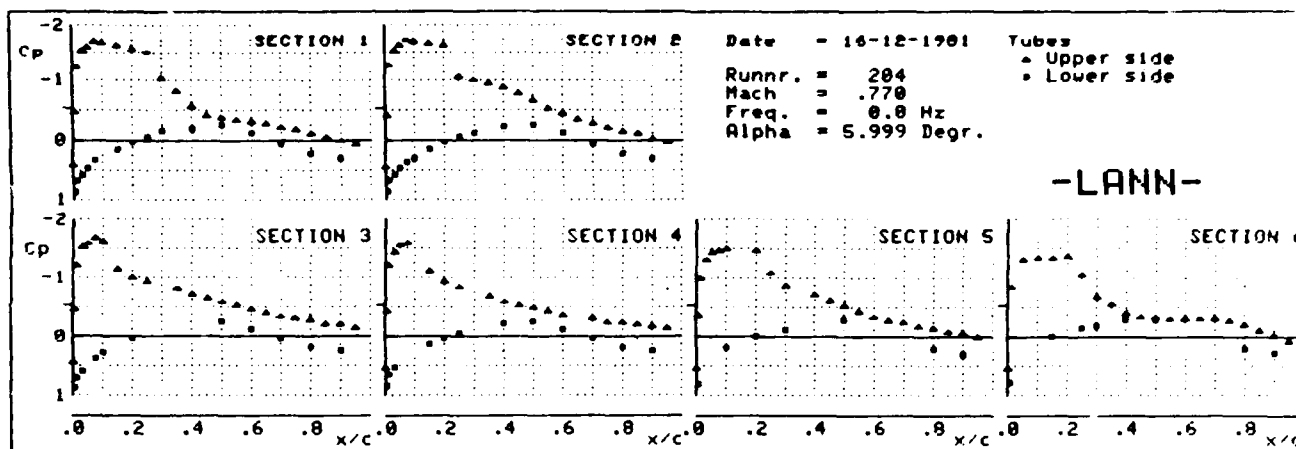


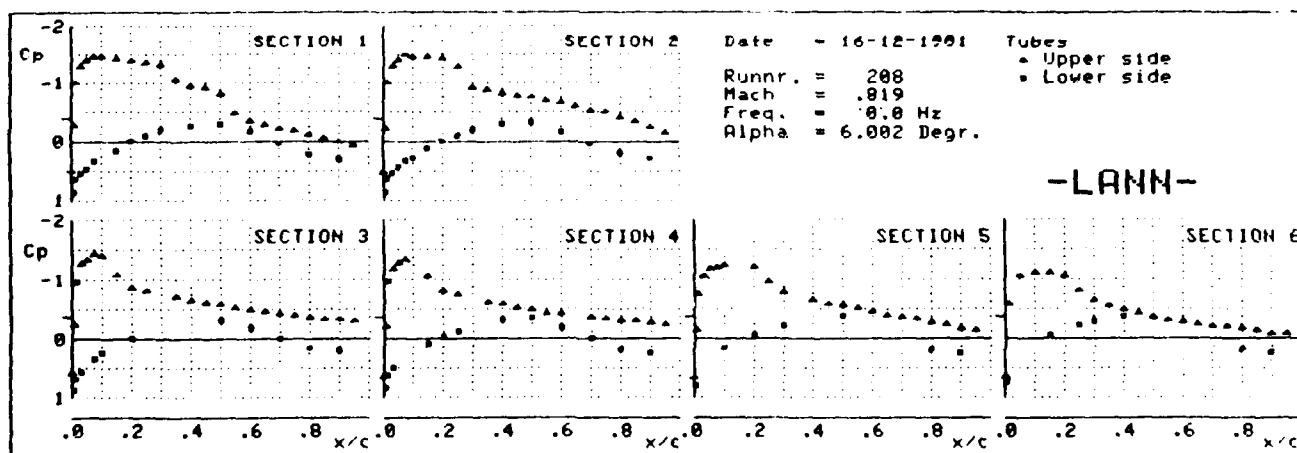
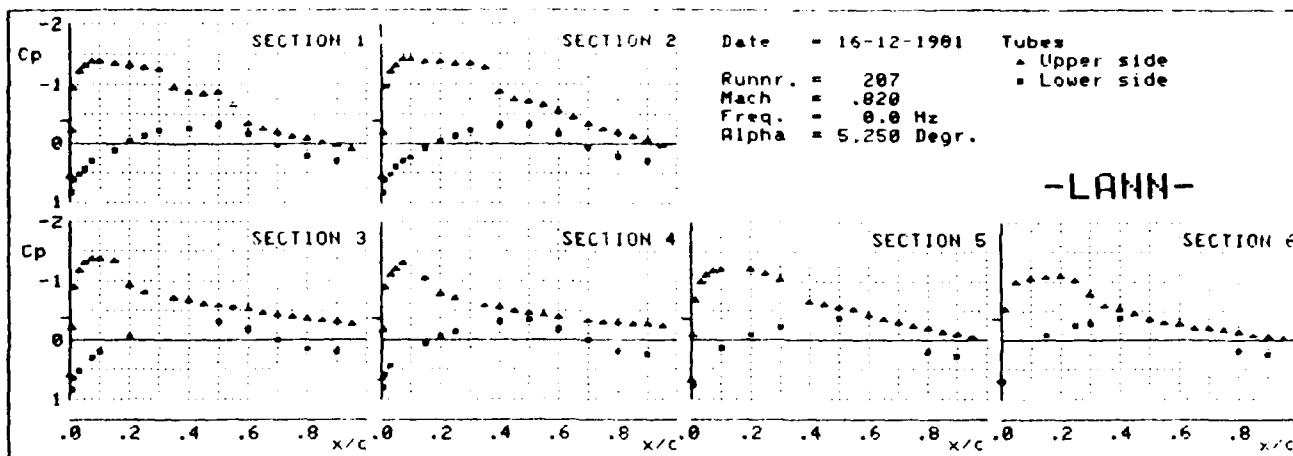


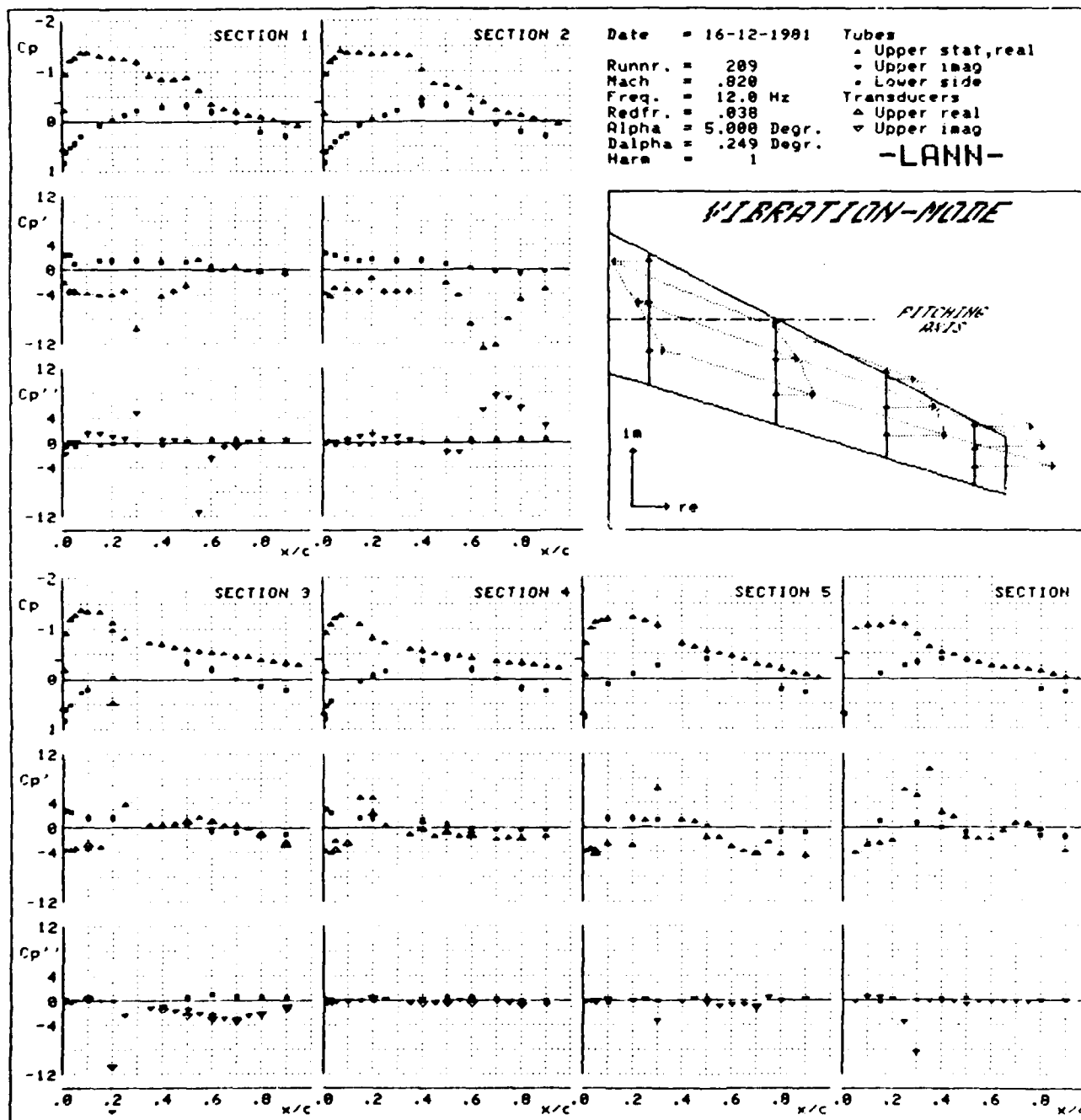


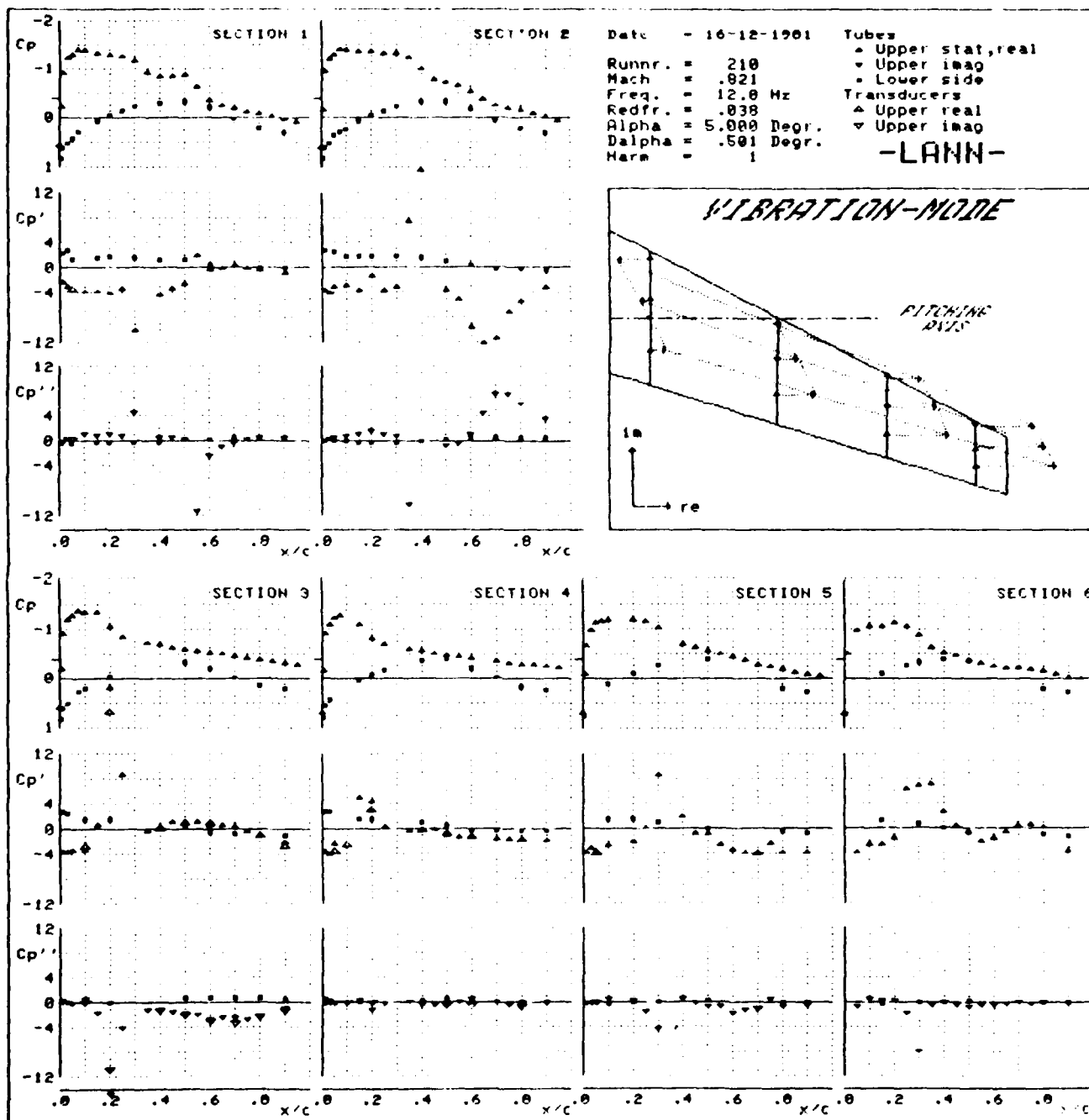


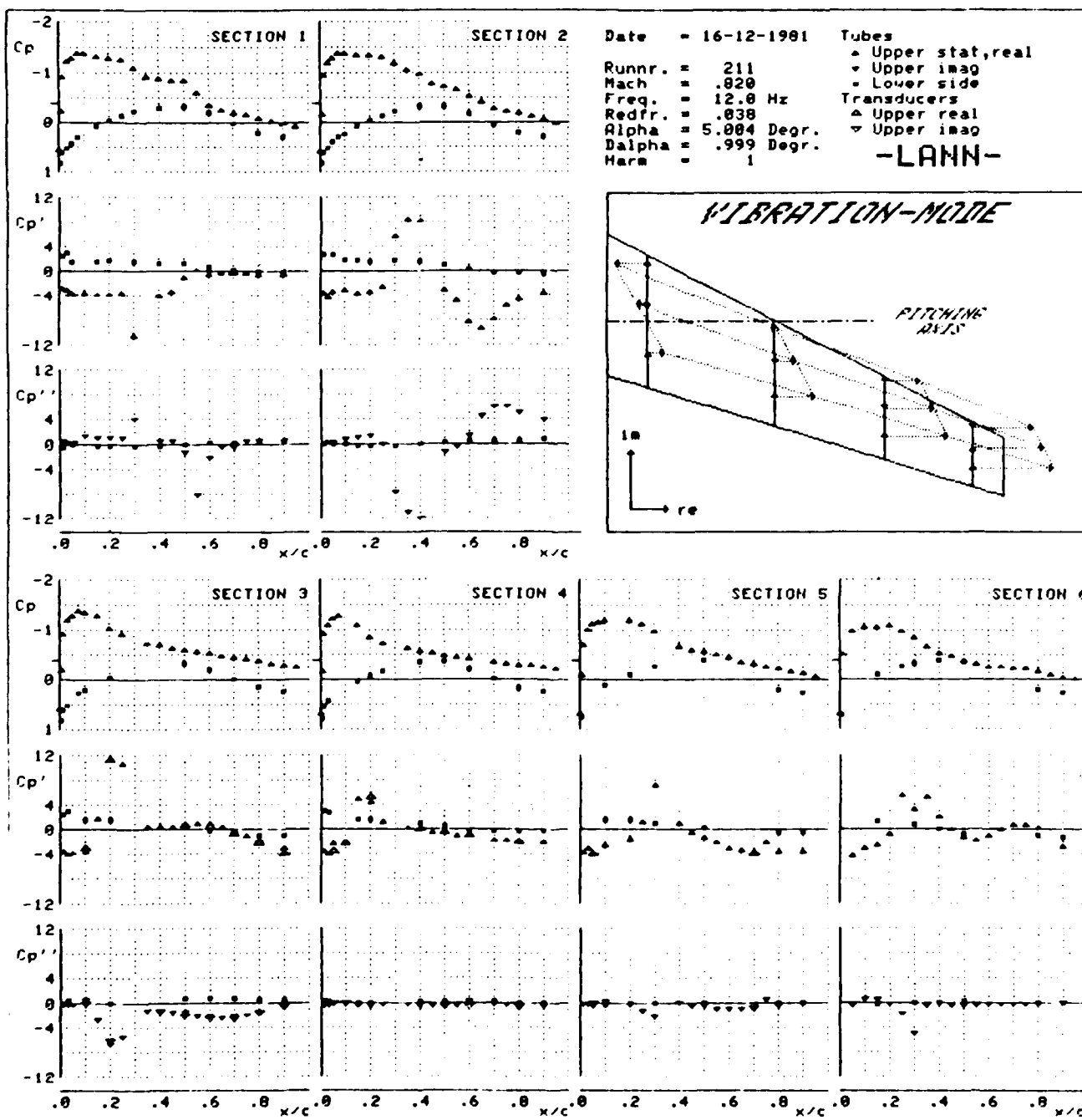


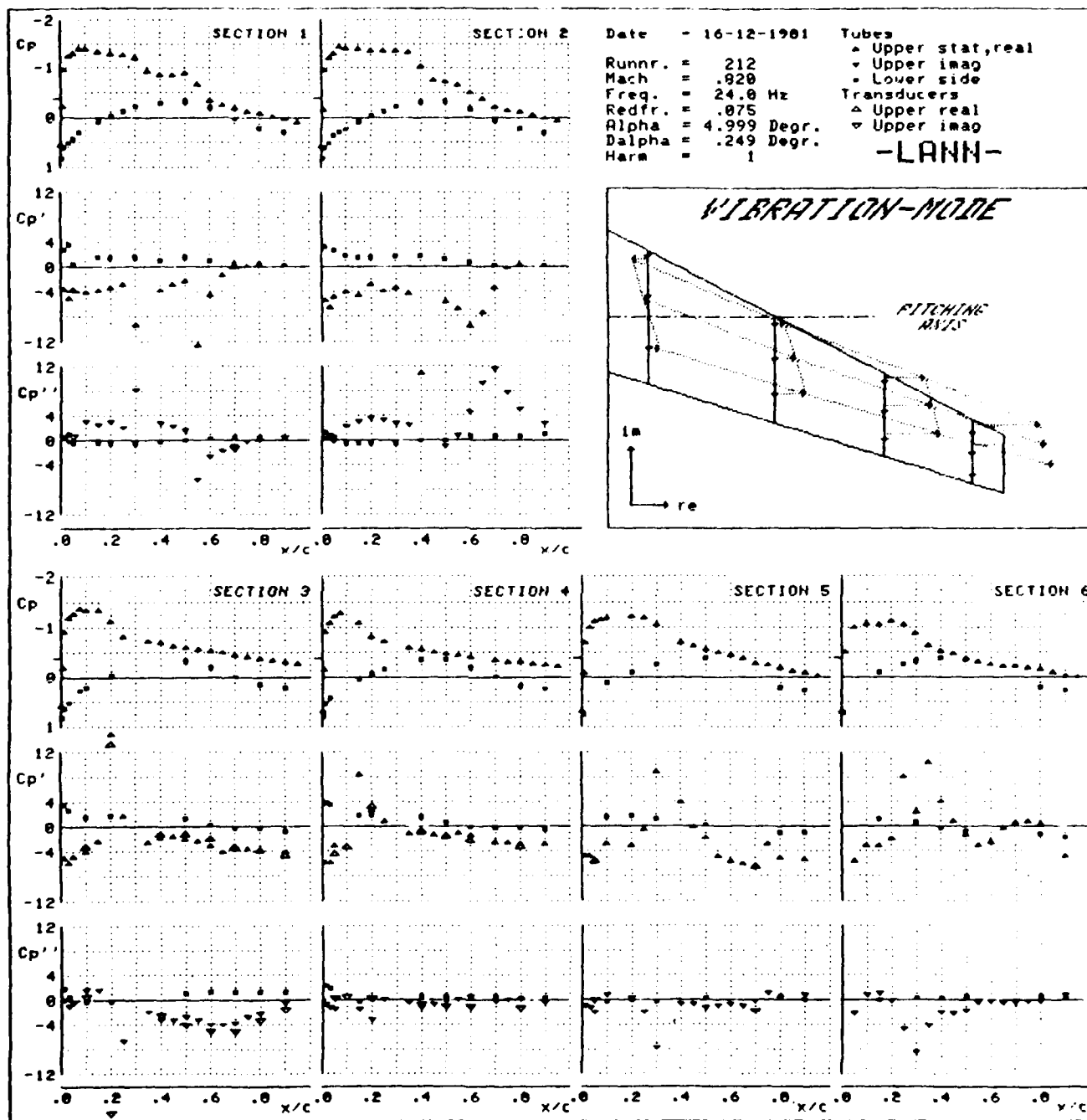


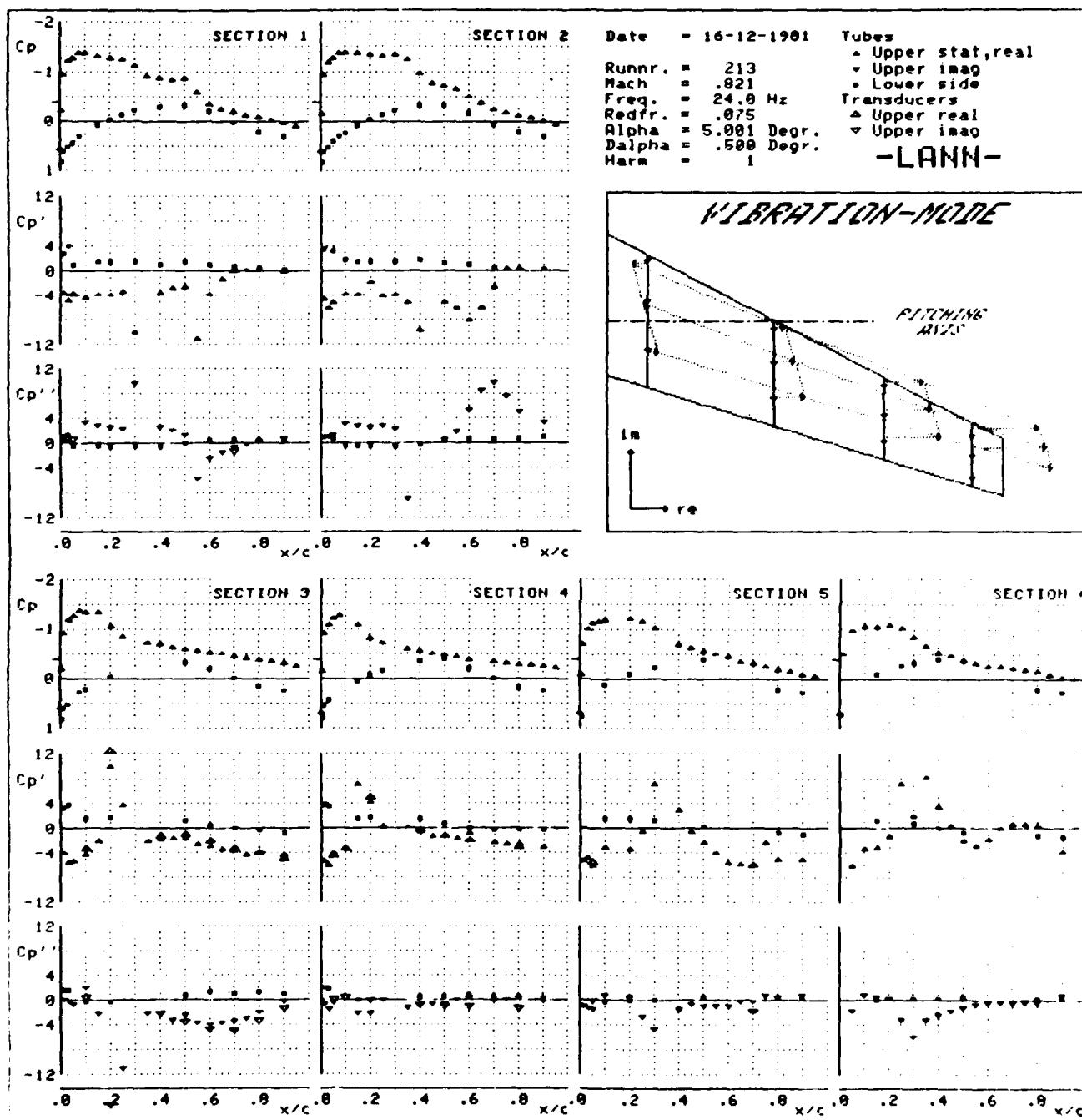


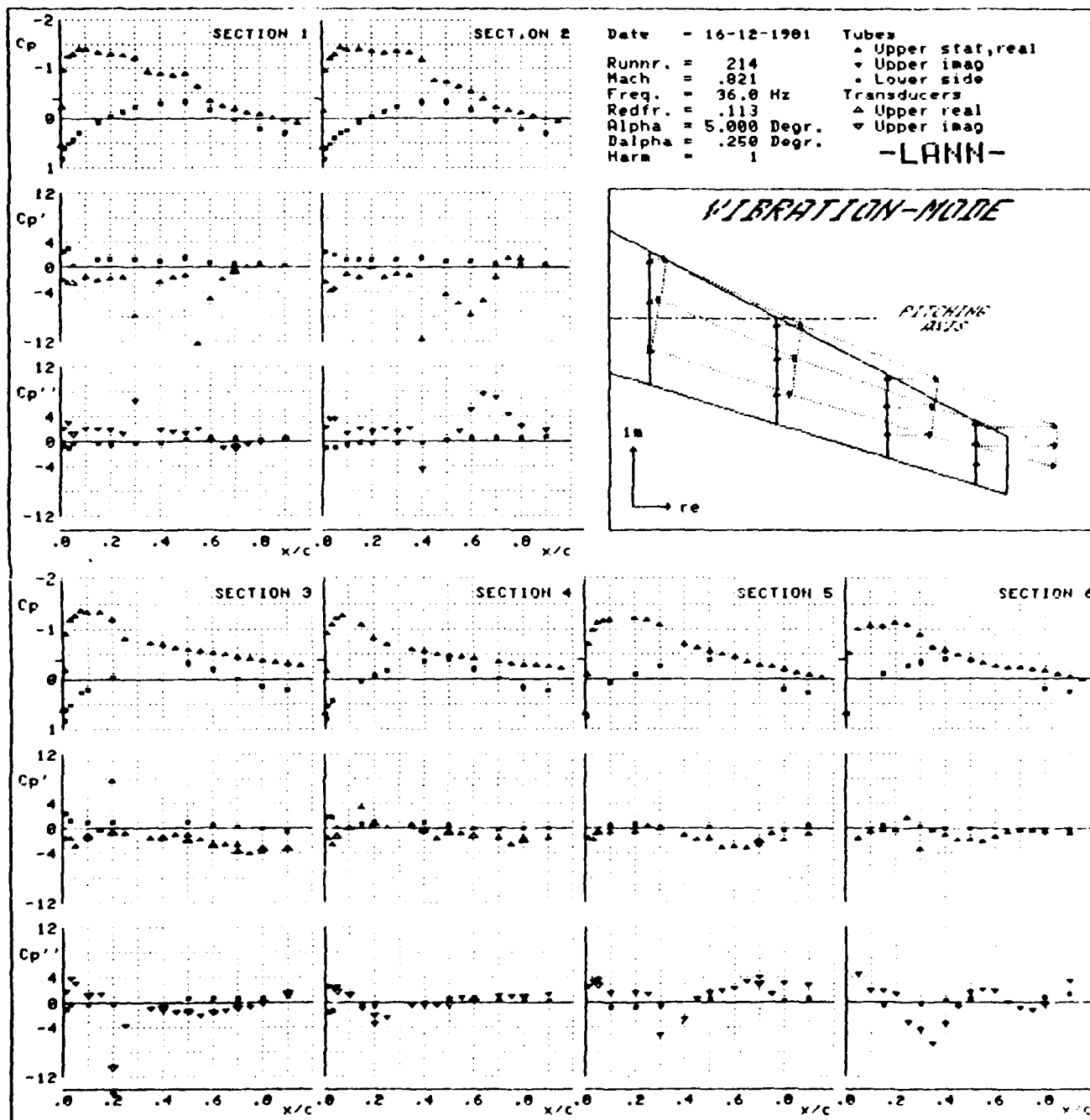


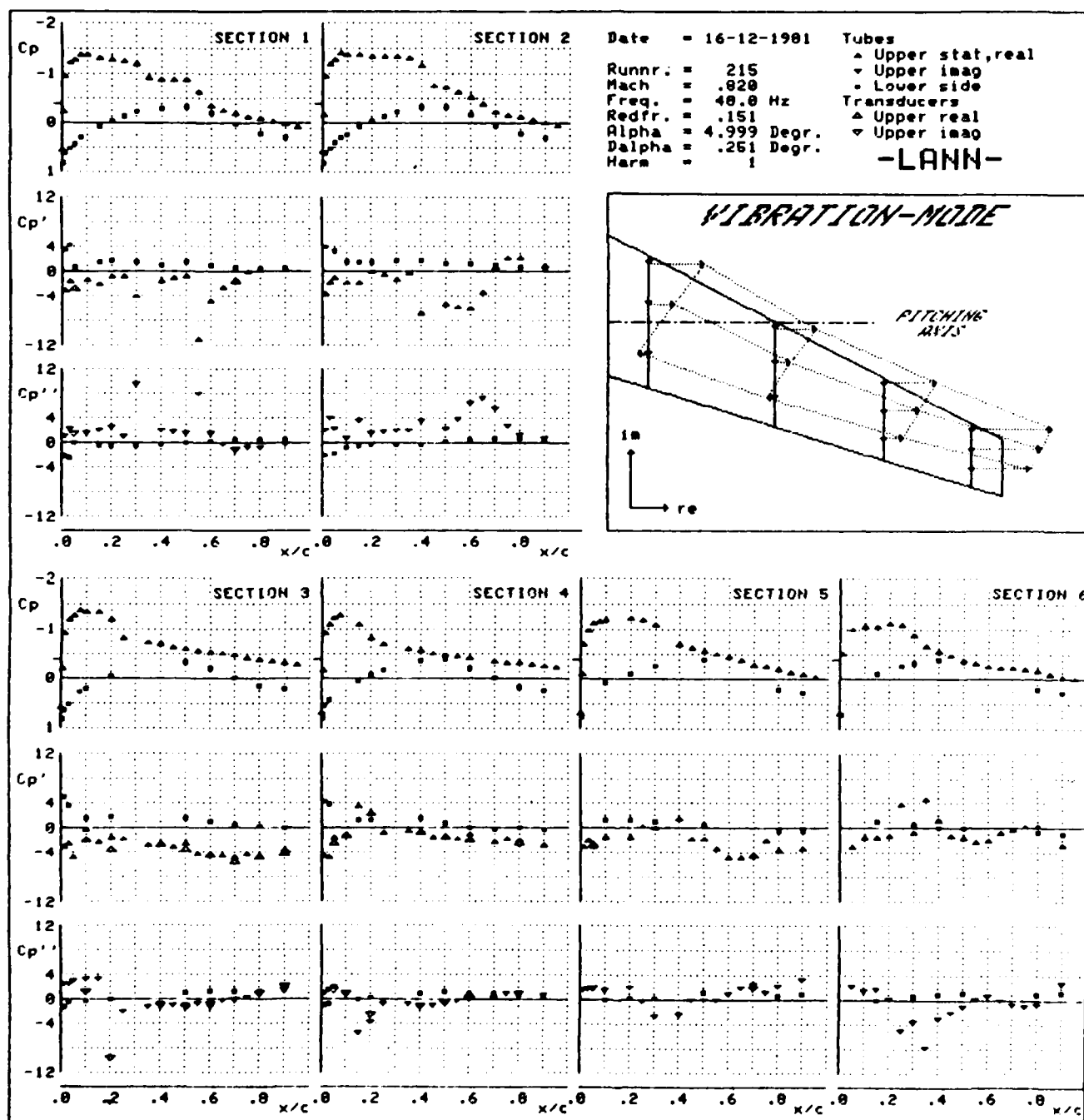


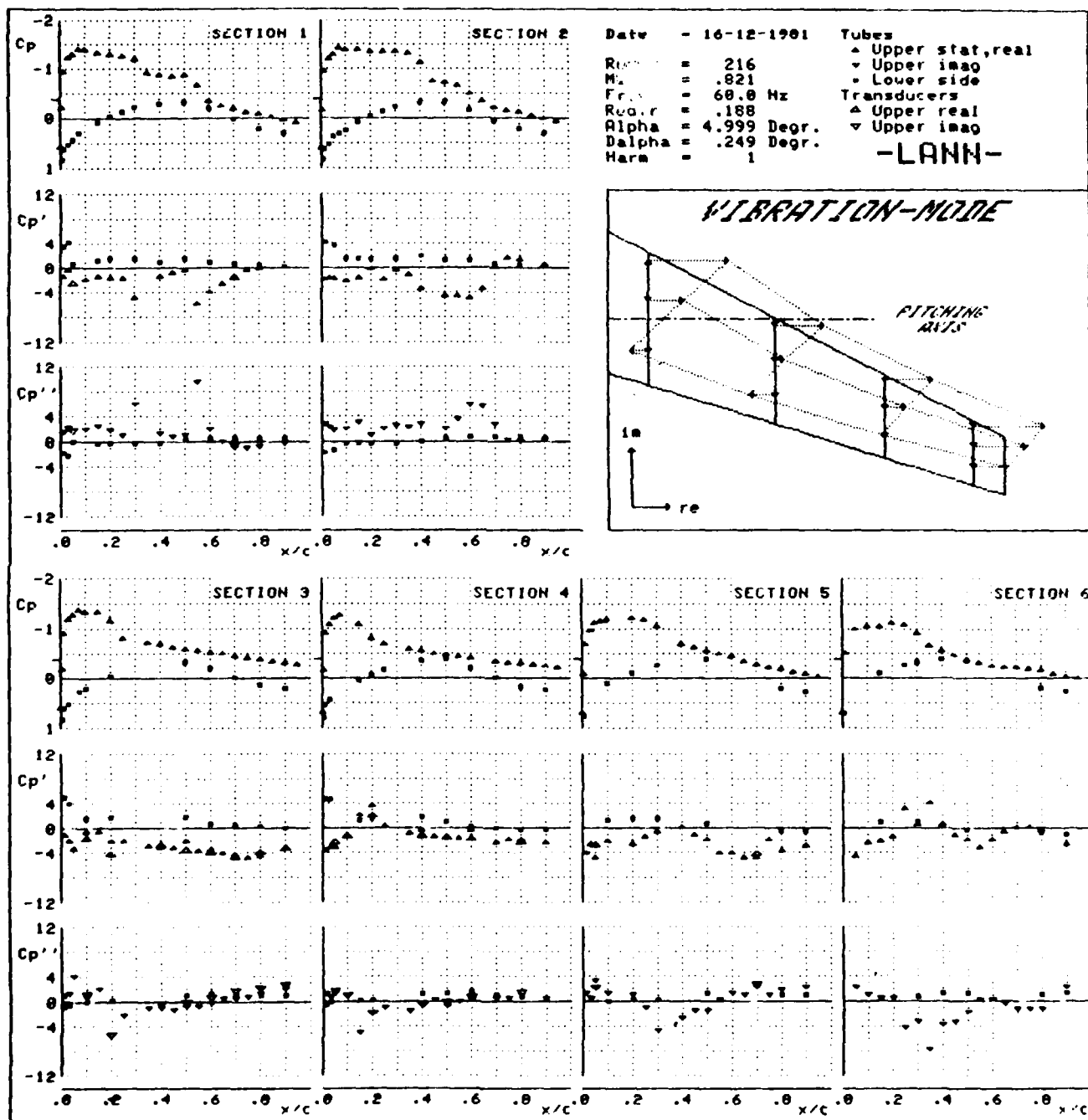


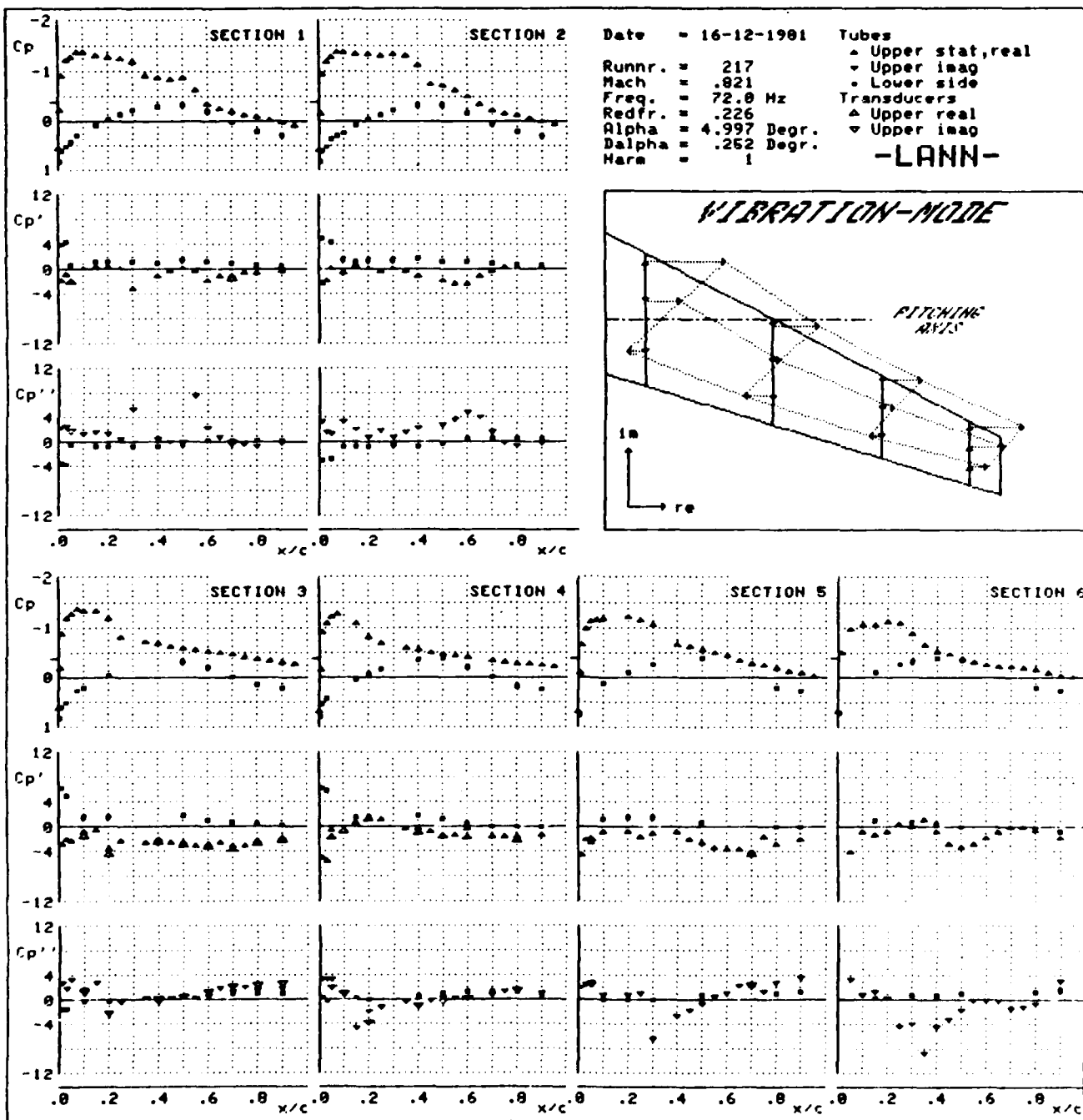


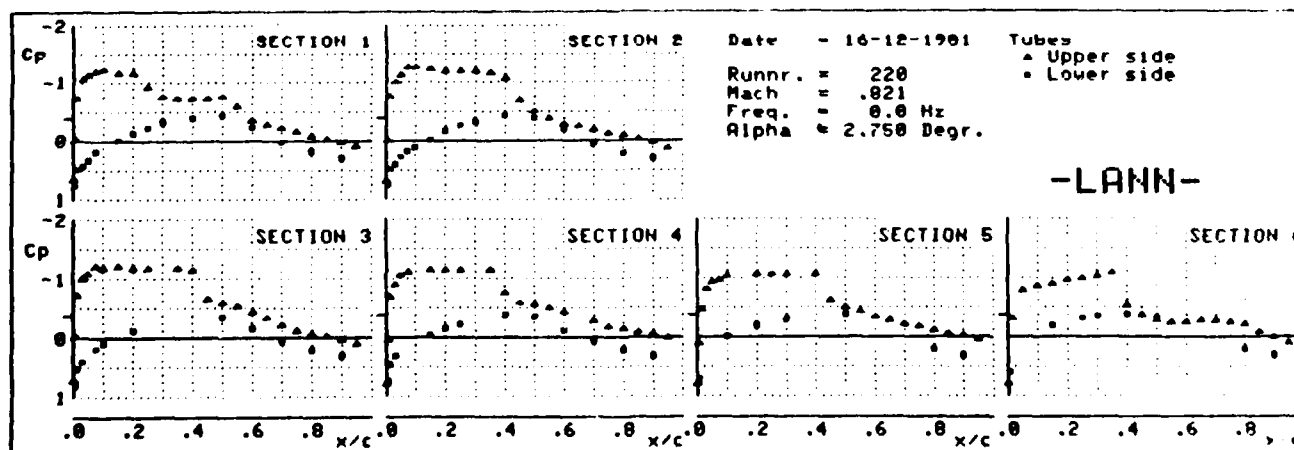
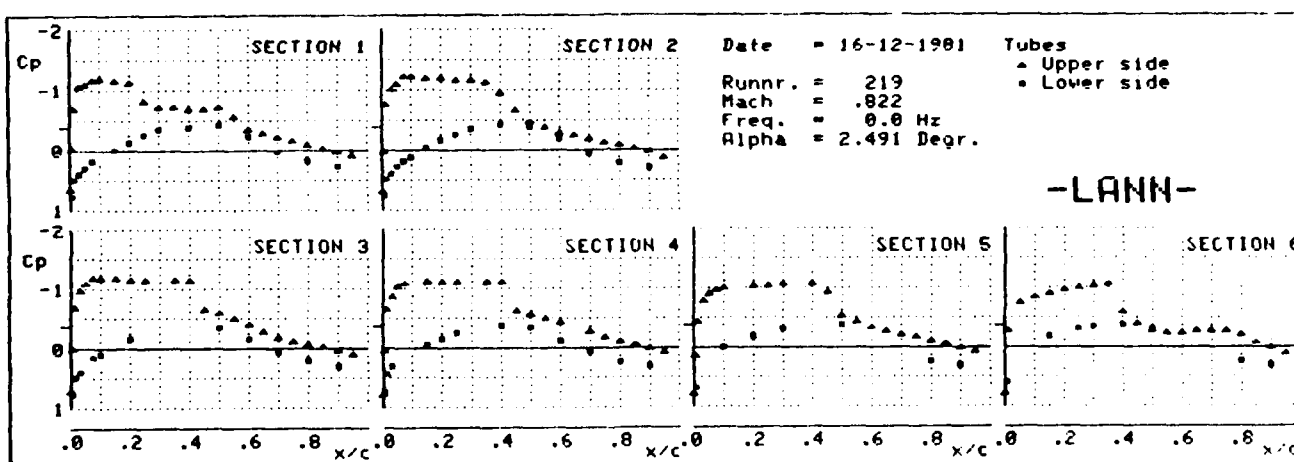
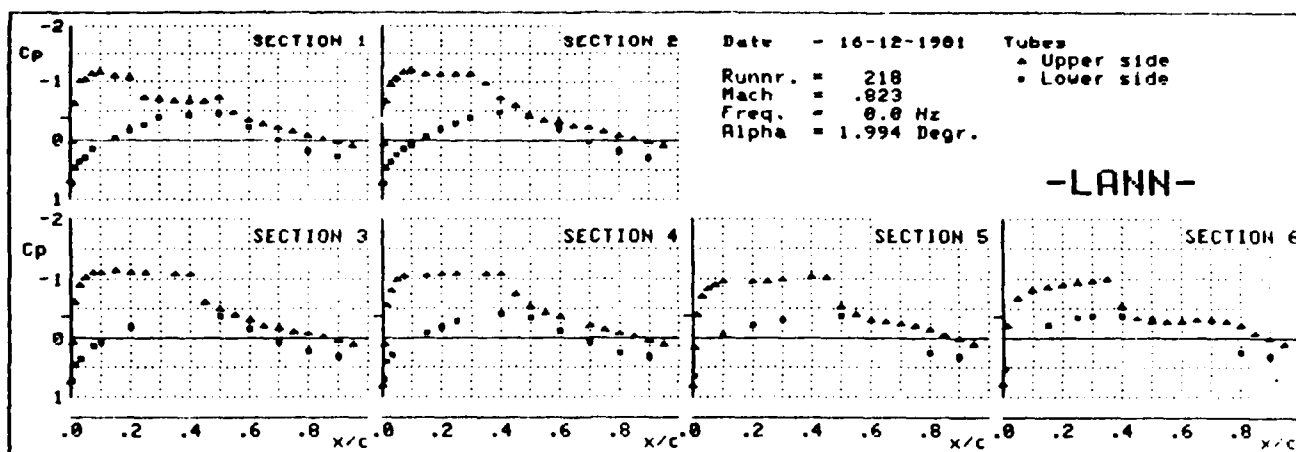


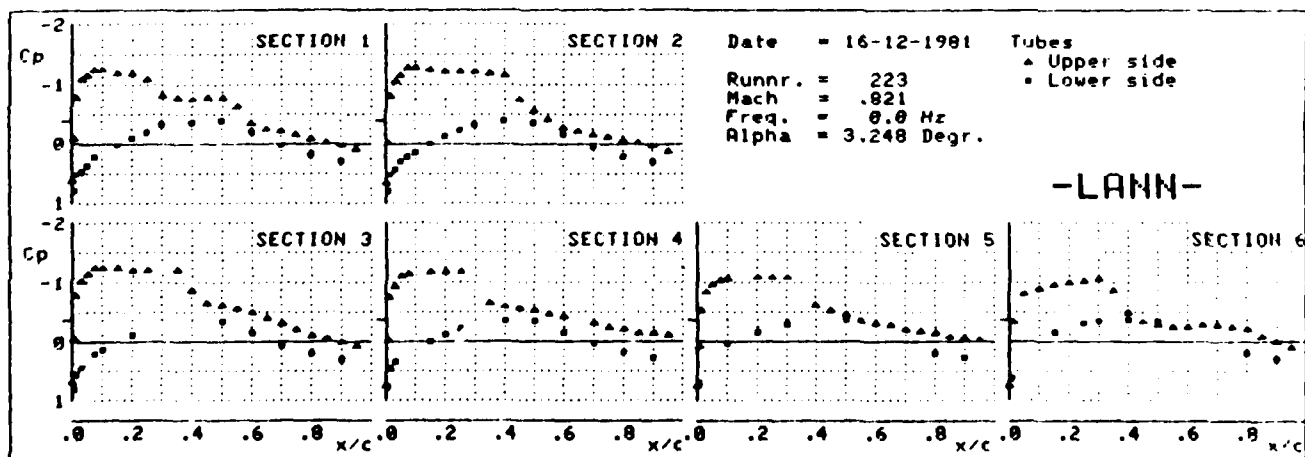
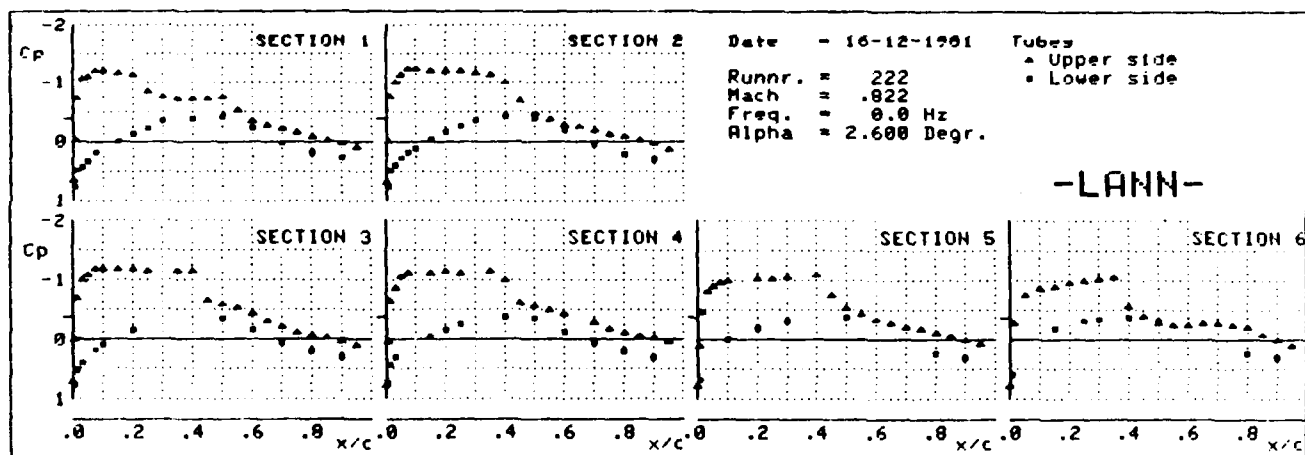
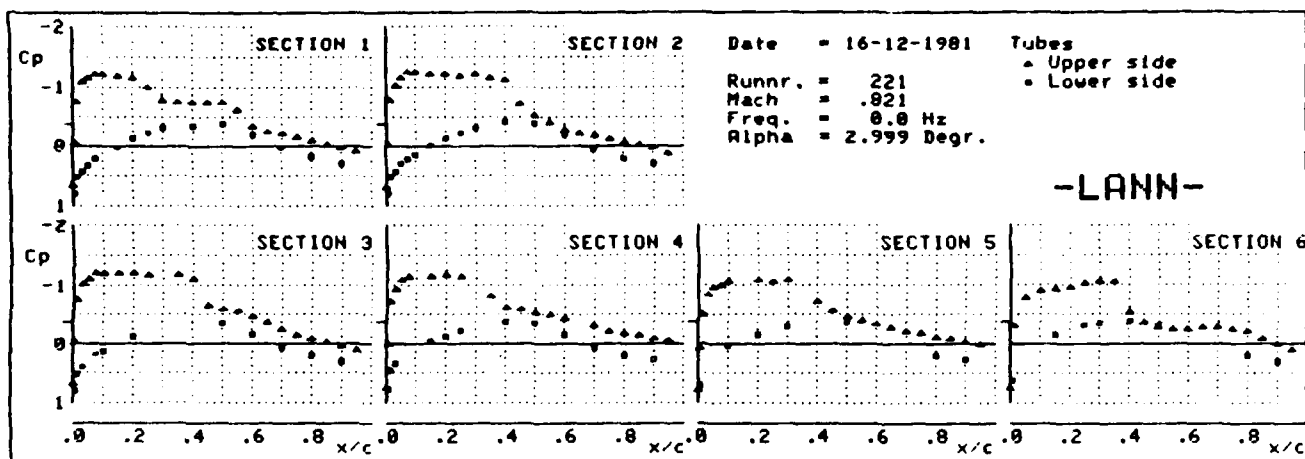


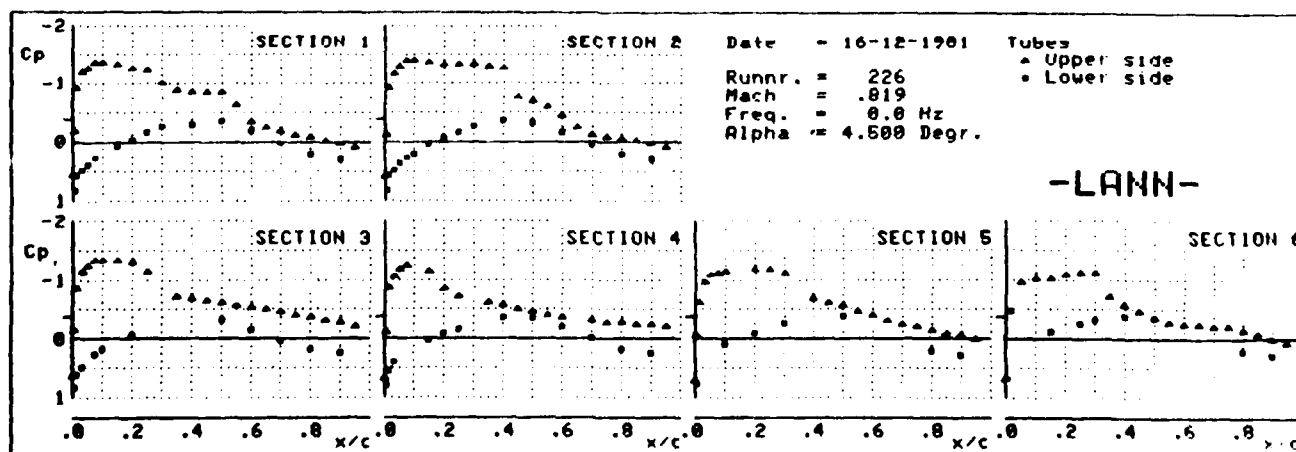
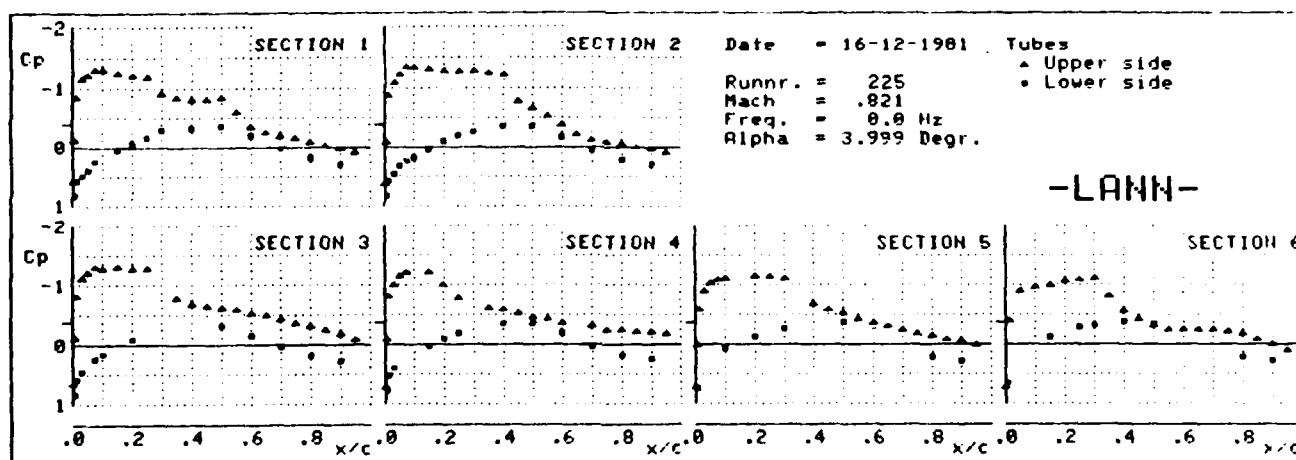
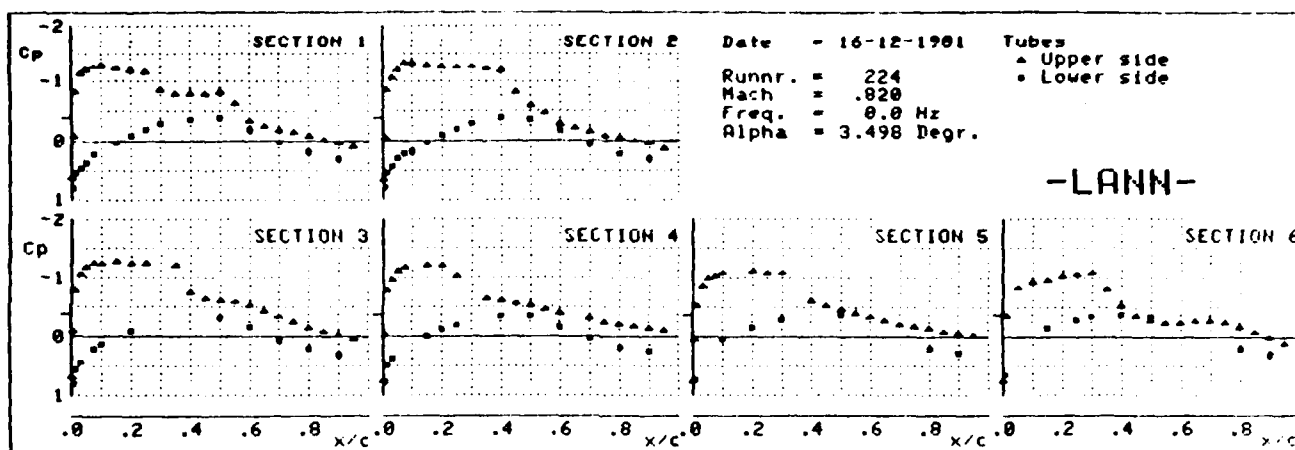


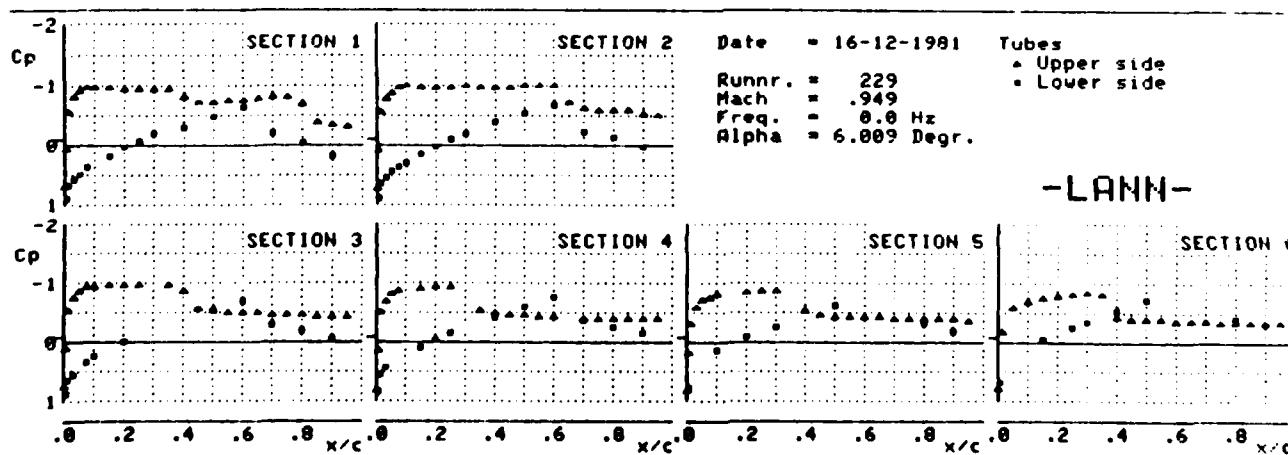
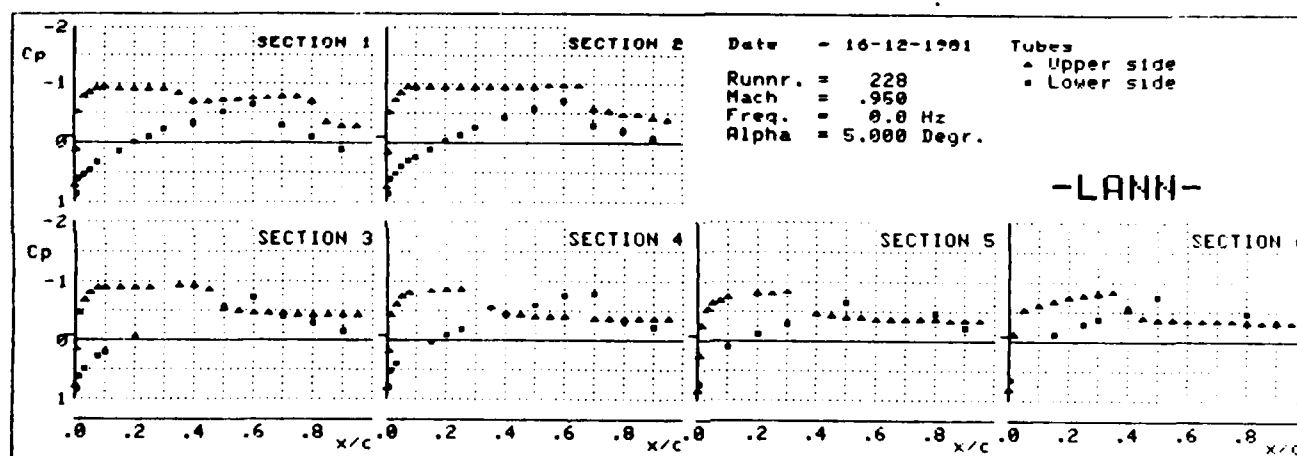
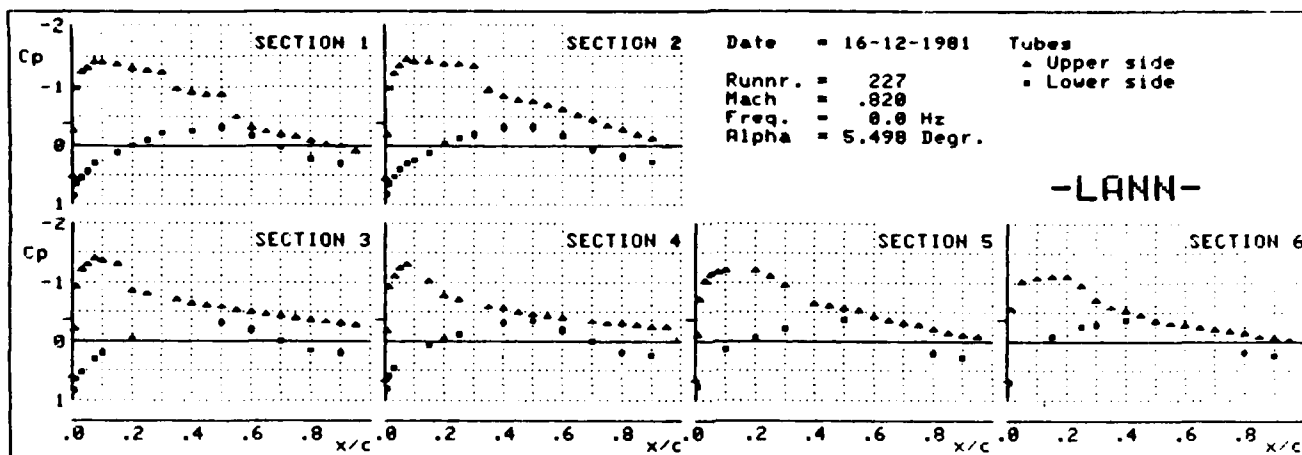


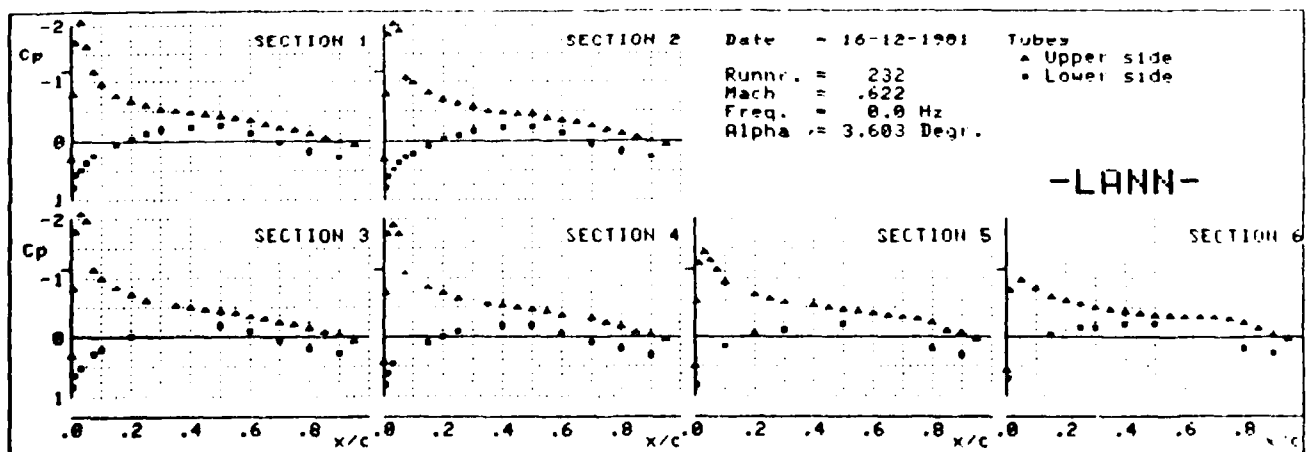
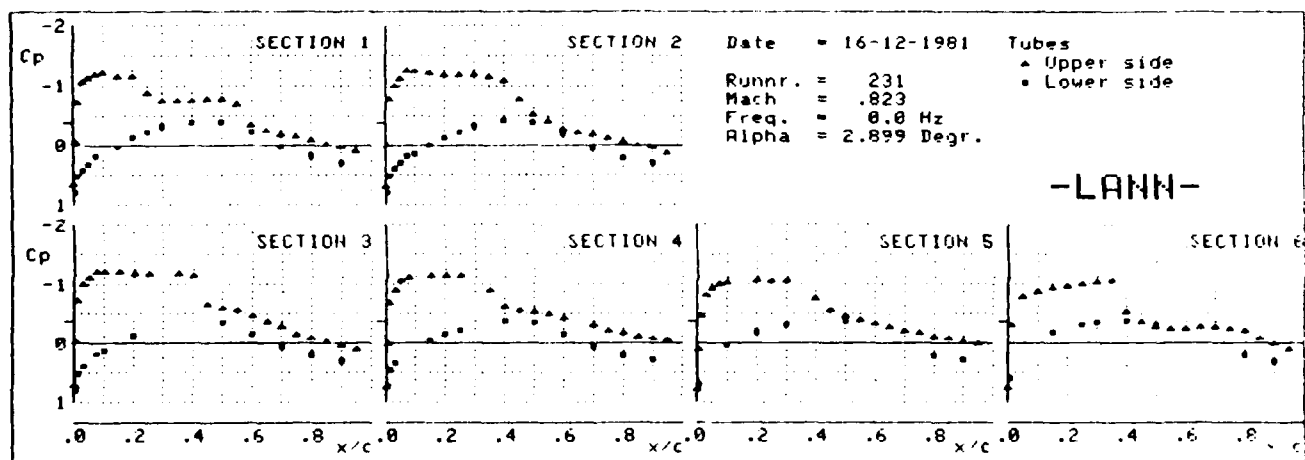
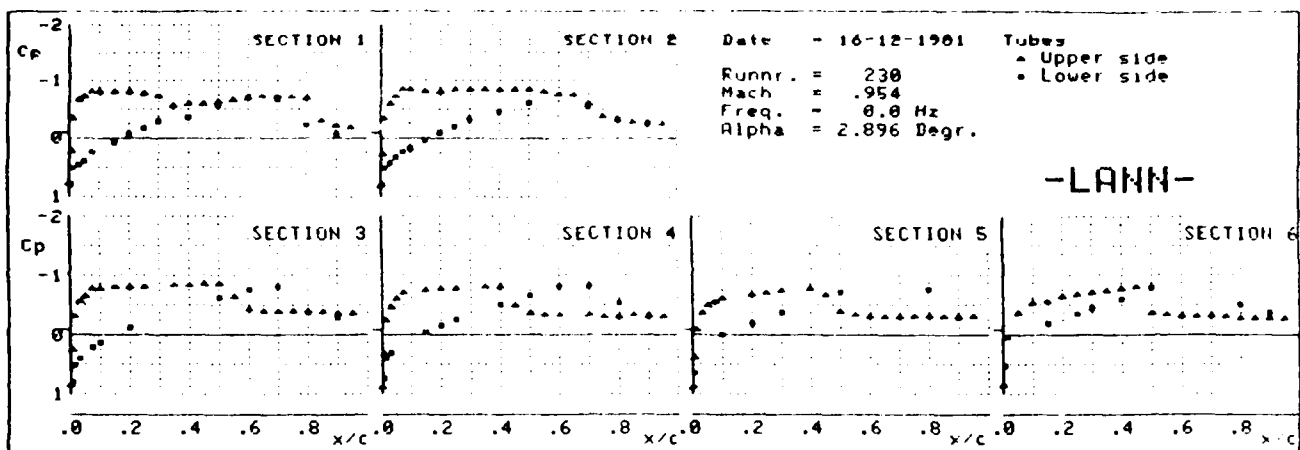


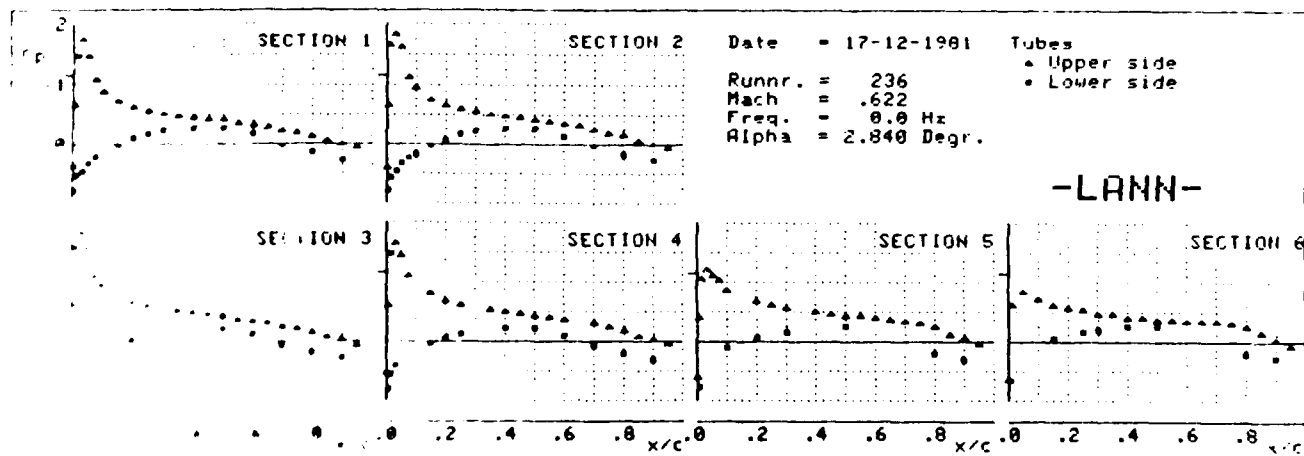
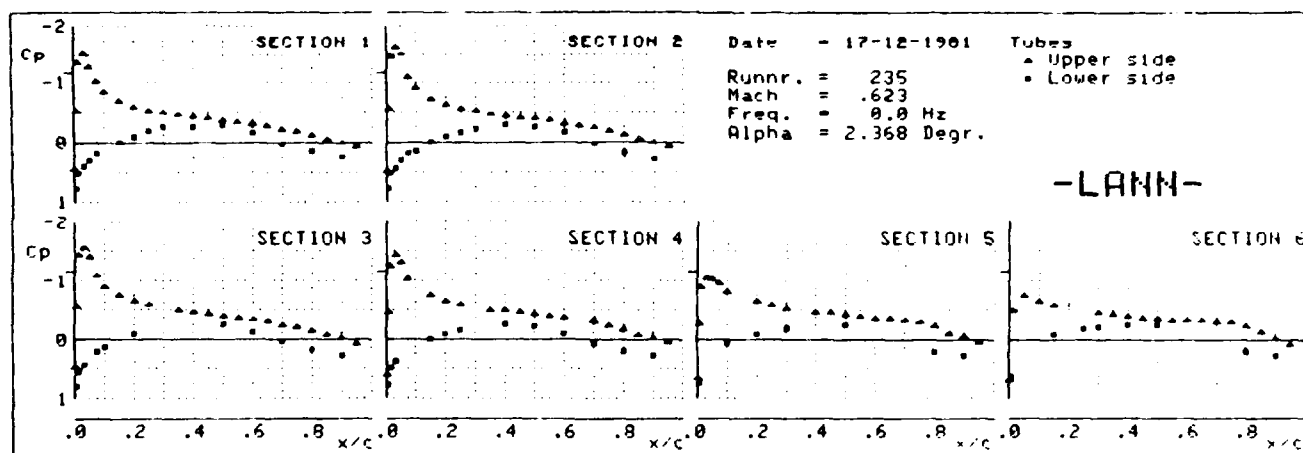
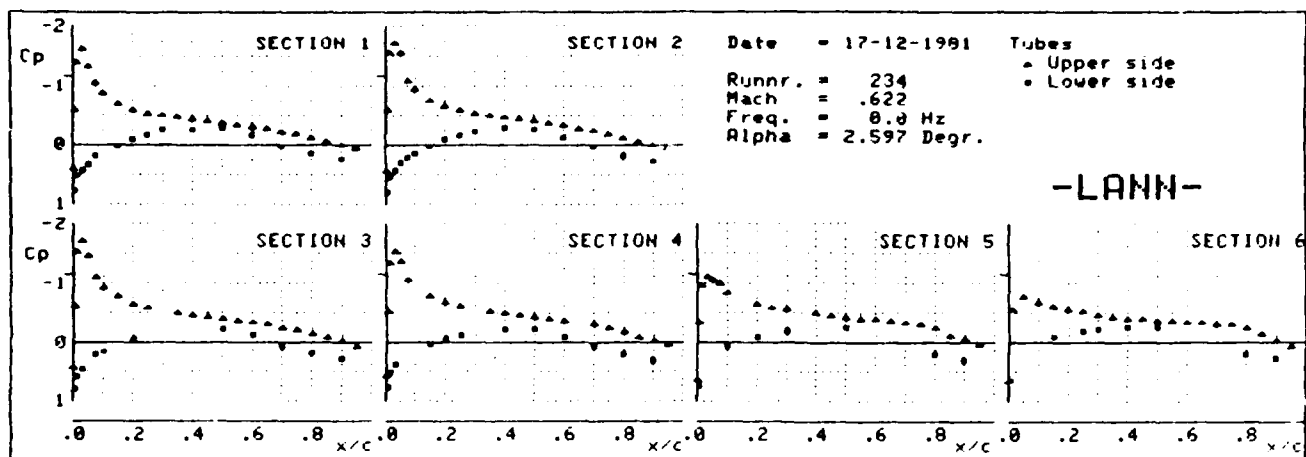


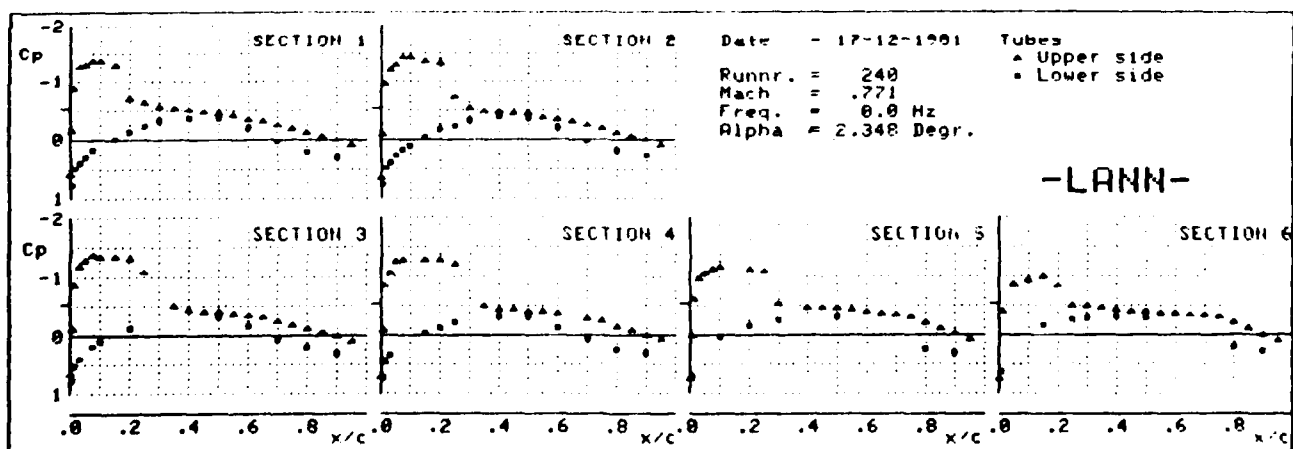
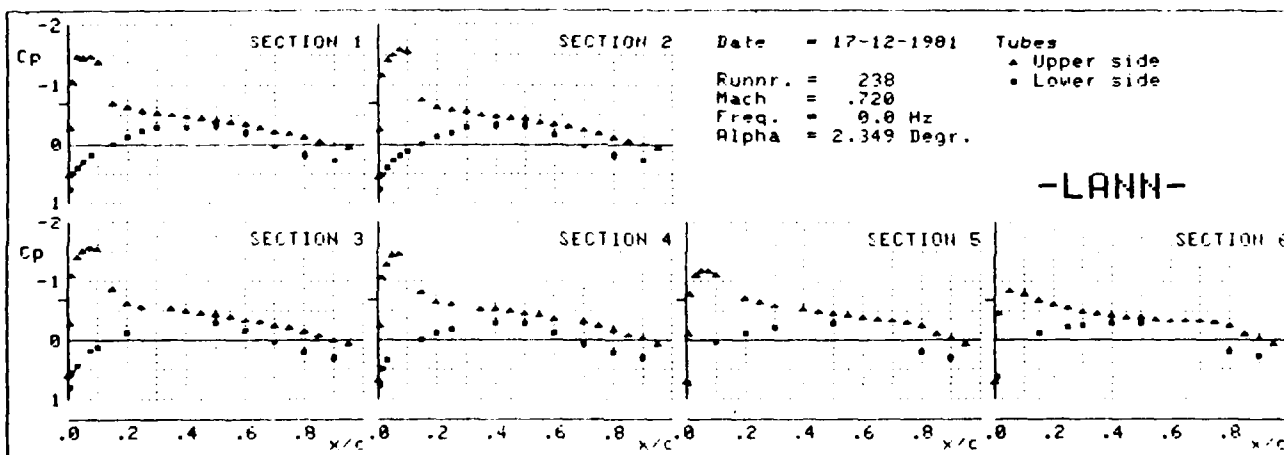
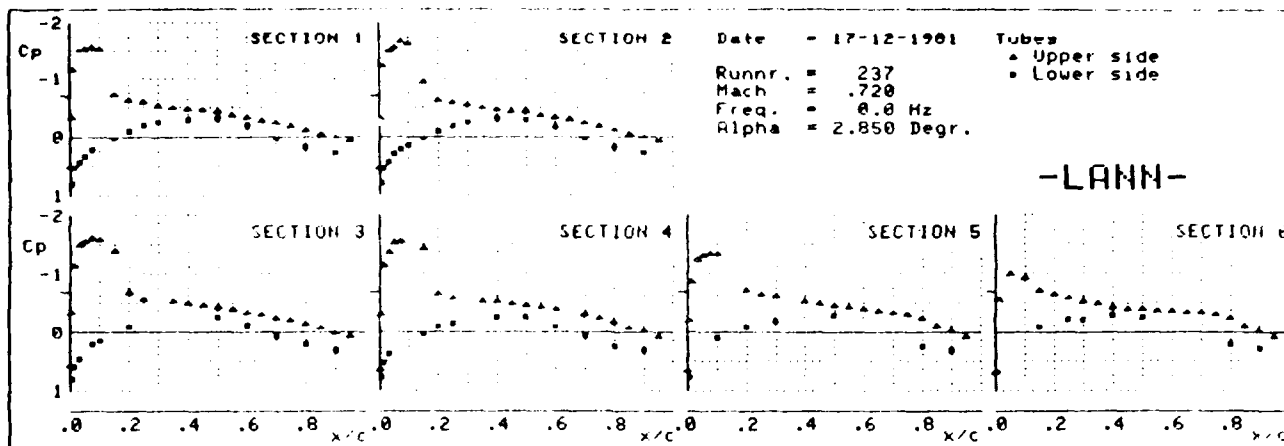


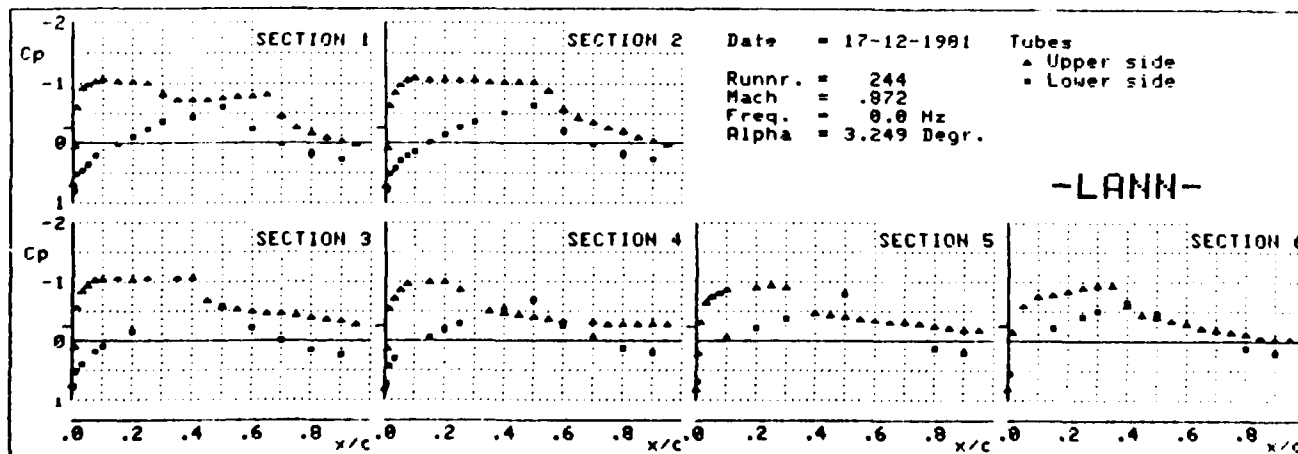
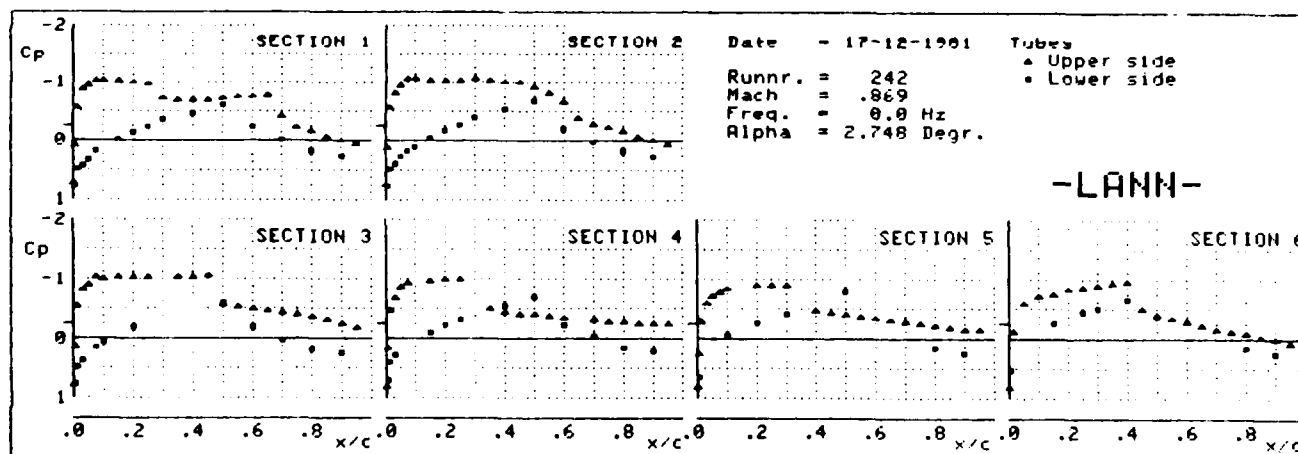
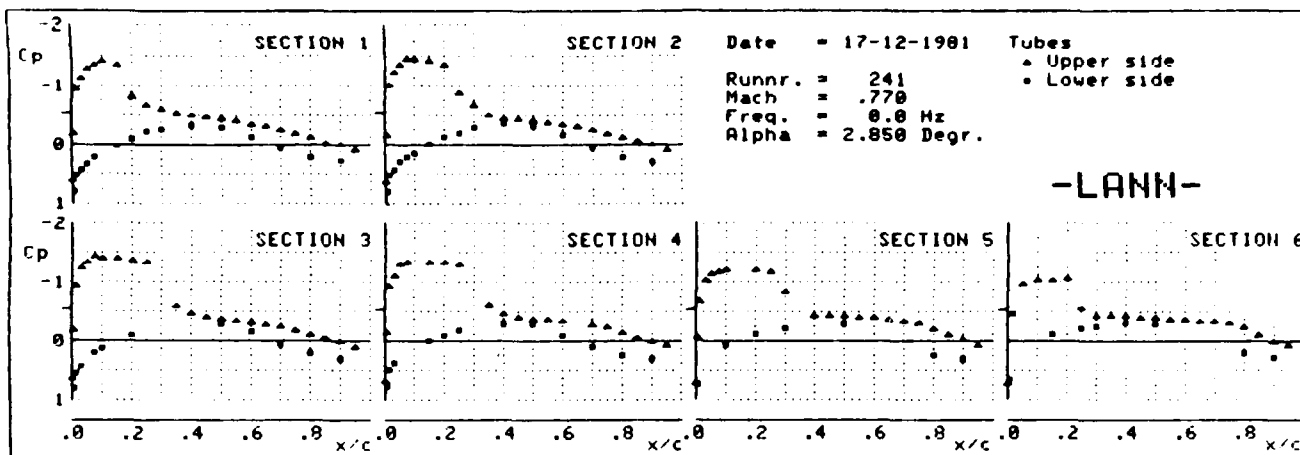


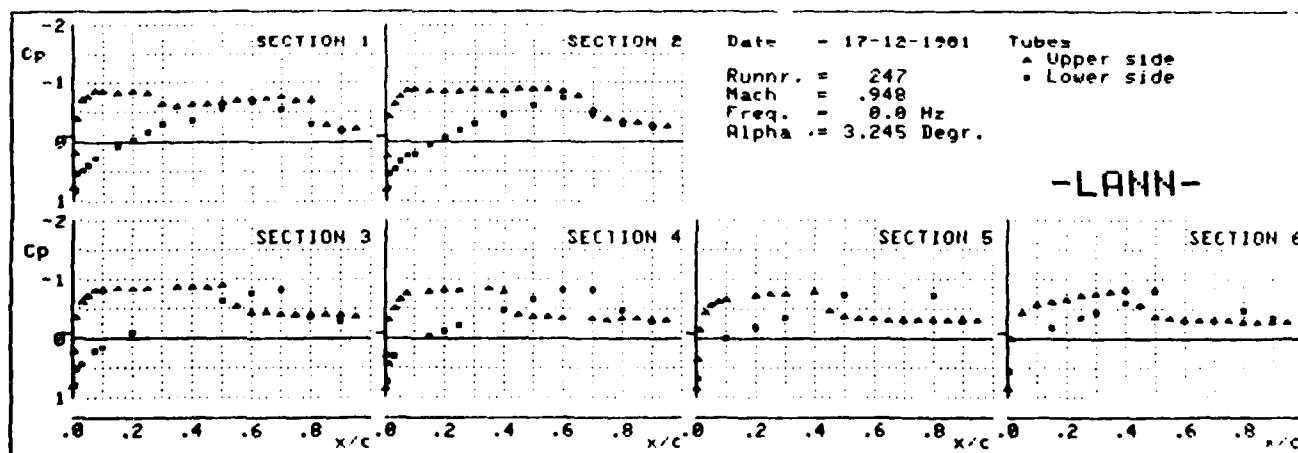
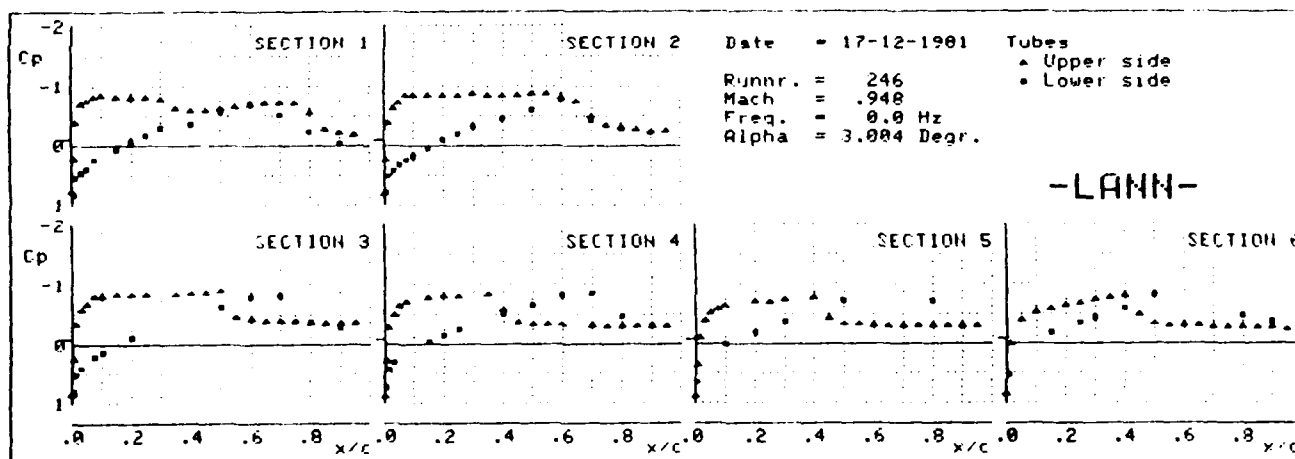
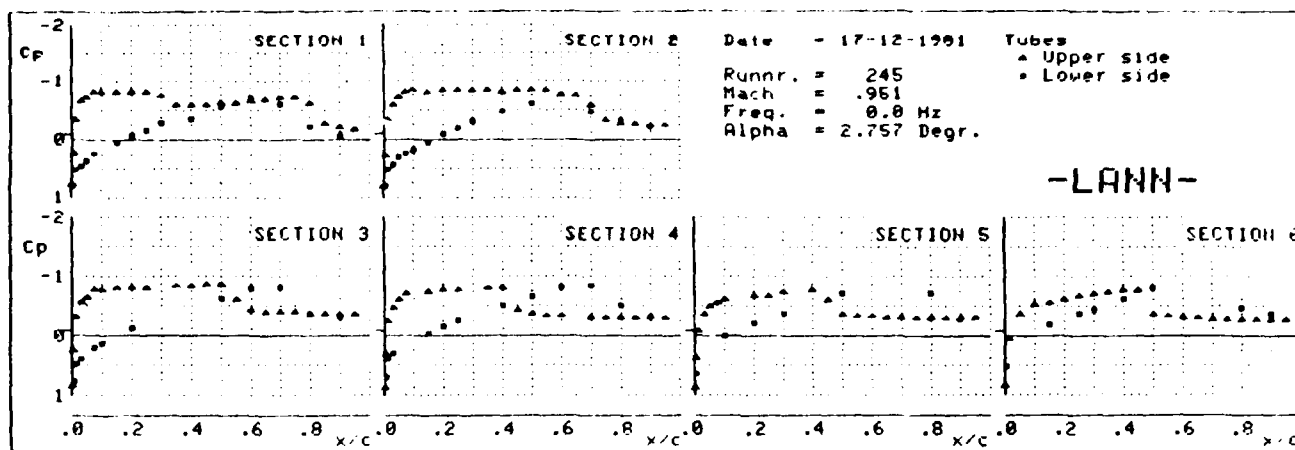


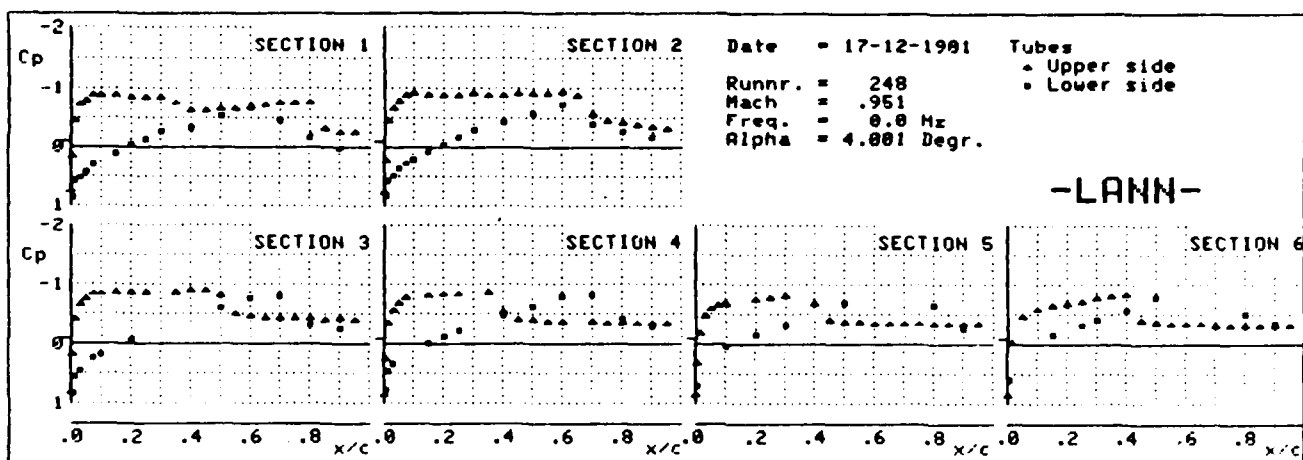


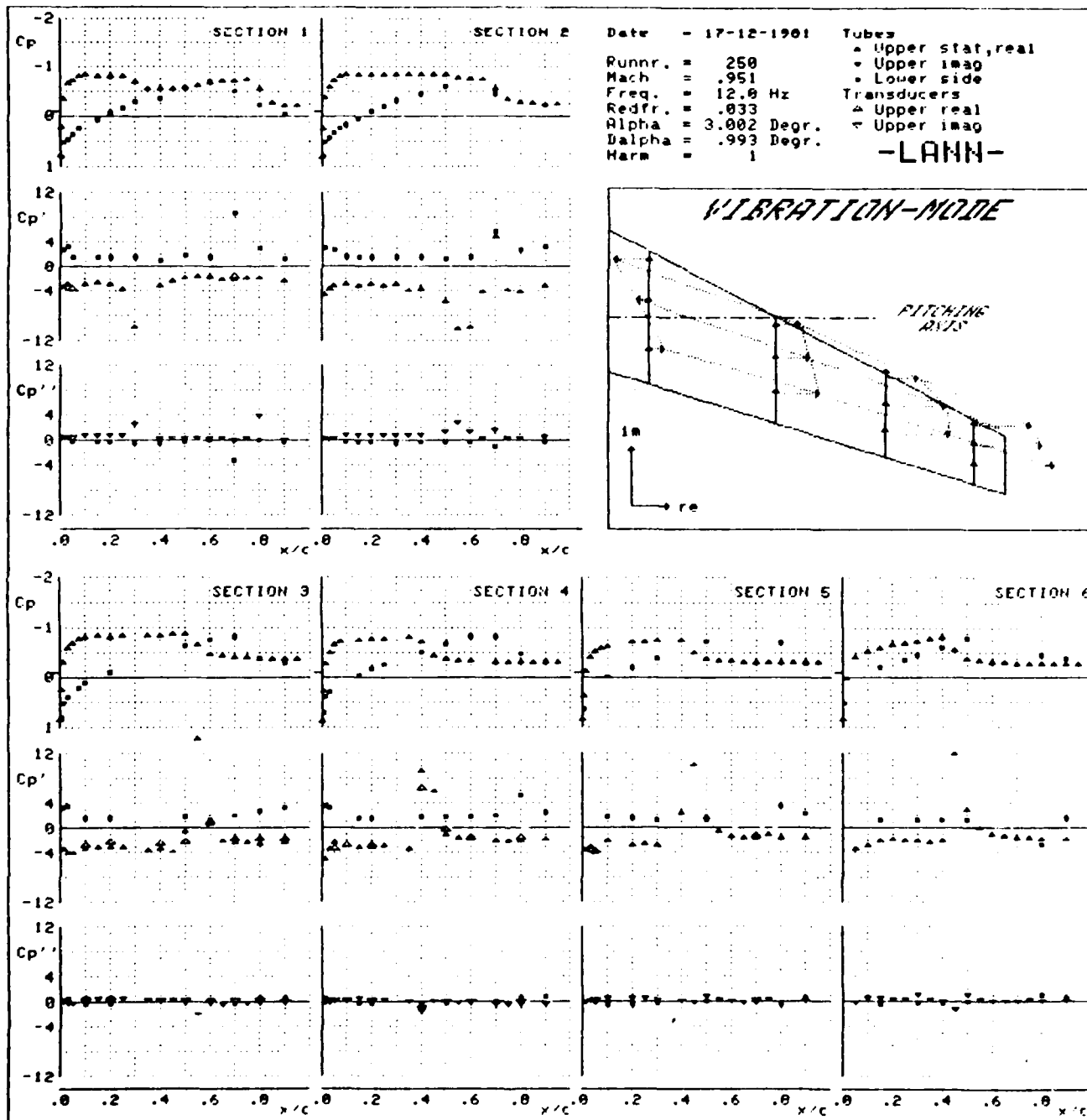








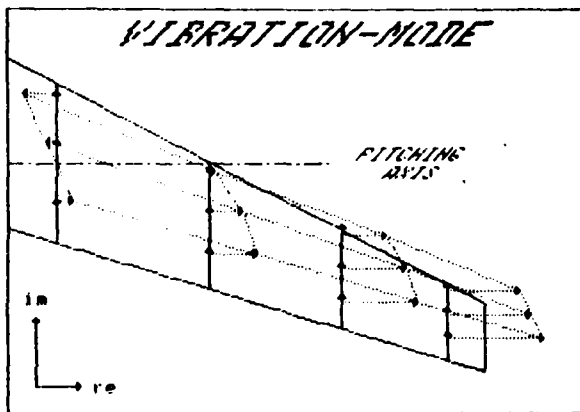




Date = 17-12-1981 Tubes
 Runnr. = 253
 Mach = .021
 Freq. = 12.0 Hz
 Redfr. = 1.340
 Alpha = 3.995 Degr.
 Dalpha = 1.000 Degr.
 Harm = 1

Transducers
 ▲ Upper stat,real
 ▼ Upper imao
 • Lower side
 ▲ Upper real
 ▼ Upper imao

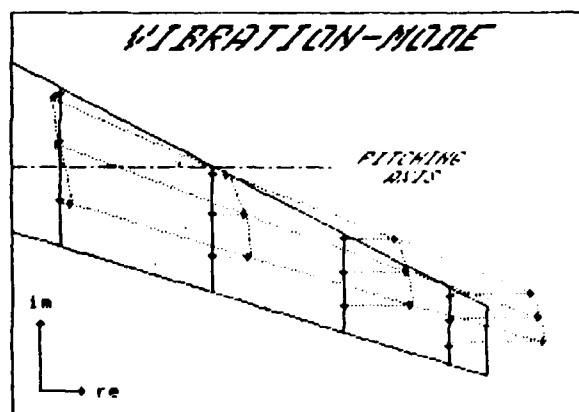
-LANN-



Date = 17-12-1981 Tubes
 Runnr. = 254
 Mach = .021
 Freq. = 24.0 Hz
 Redfr. = 2.681
 Alpha = 4.005 Degr.
 Dalpha = .250 Degr.
 Harm = 1

Transducers
 ▲ Upper stat,real
 ▼ Upper imao
 • Lower side
 ▲ Upper real
 ▼ Upper imao

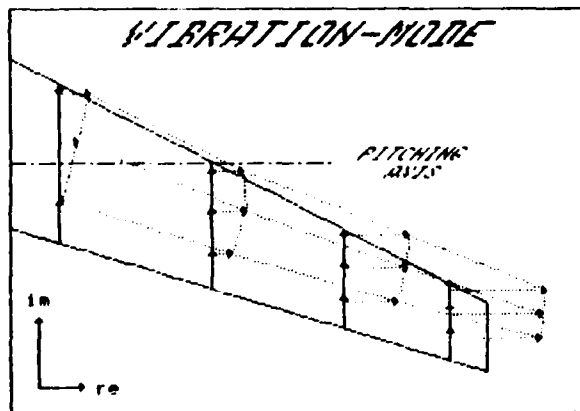
-LANN-



Date = 17-12-1981 Tubes
 Runnr. = 255
 Mach = .030
 Freq. = 36.0 Hz
 Redfr. = 2.843
 Alpha = 3.993 Degr.
 Dalpha = .252 Degr.
 Harm = 1

Transducers
 ▲ Upper stat,real
 ▼ Upper imao
 • Lower side
 ▲ Upper real
 ▼ Upper imao

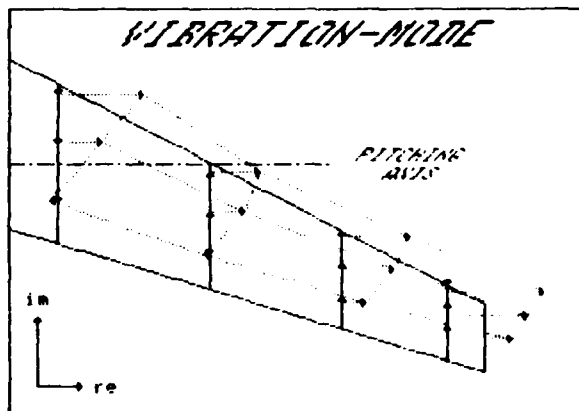
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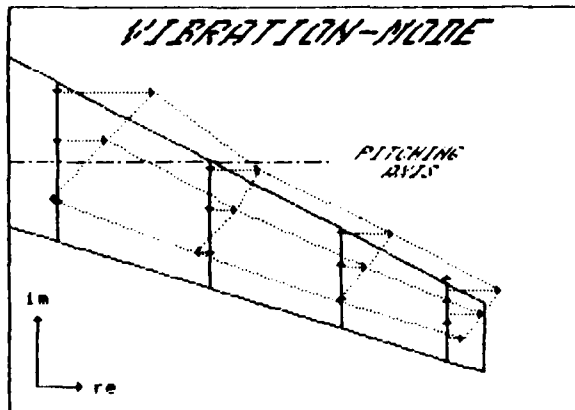
Date = 17-12-1981 Tubes
 Runnr. = 256
 Mach = 0.000
 Freq. = 48.0 Hz
 Redfr. = \$\$\$\$
 Alpha = 3.990 Degr.
 Dalpha = .250 Degr.
 Harm = 1

Transducers
 ▲ Upper stat,real
 ▼ Upper imao
 • Lower side
 ▲ Upper real
 ▼ Upper imao

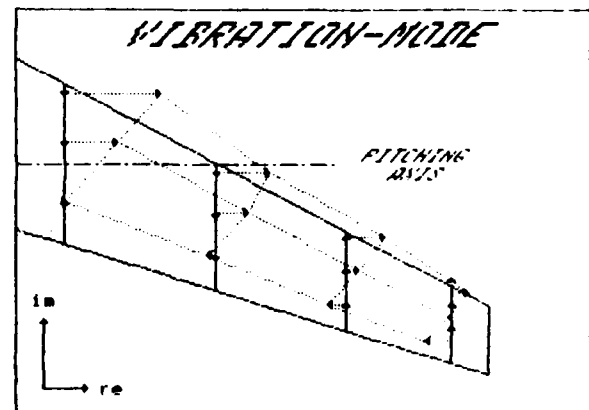
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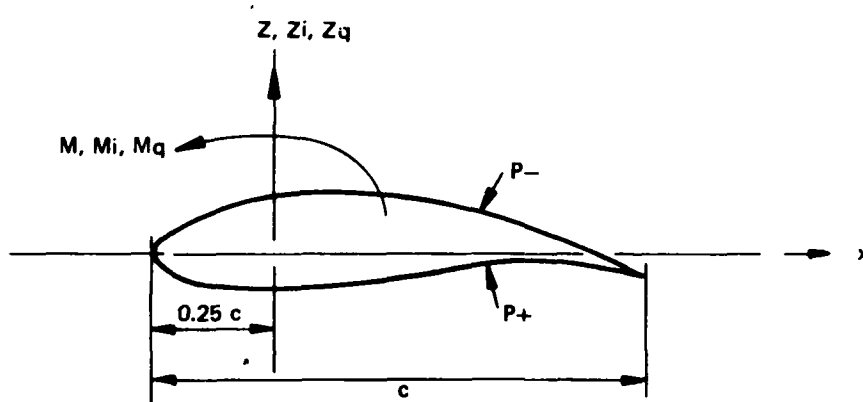
Date = 17-12-1981 Tubes
 Runnr. = 257 ▲ Upper stat,real
 Mach = .021 ▼ Upper imao
 Freq. = 68.0 Hz • Lower side
 Redfr. = 6.782 Transducers
 Alpha = 3.983 Degr. ▲ Upper real
 Dalpha = .251 Degr. ▼ Upper imao
 Harm = 1
 -LANN-



Date = 17-12-1981 Tubes
 Runnr. = 258 ▲ Upper stat,real
 Mach = 0.000 ▼ Upper imao
 Freq. = 72.0 Hz • Lower side
 Redfr. = 3888 Transducers
 Alpha = 3.972 Degr. ▲ Upper real
 Dalpha = .246 Degr. ▼ Upper imao
 Harm = 1
 -LANN-



APPENDIX A
Definitions and sign conventions



Note: Coefficients derived from the zeroth harmonic component of unsteady pressure signals, are indicated simply as "steady" coefficients instead of "mean" coefficients. For a pure sinusoidal signal, there is principally no difference between steady and mean coefficients.

Steady

Steady pressure coefficient:

$$C_{pm} = \frac{P_m - P_\infty}{q_\infty}$$

Steady sectional normal force:

$$Z = C_z q_\infty c ; C_z = - \int_0^1 (C_{pm+} - C_{pm-}) d\left(\frac{x}{c}\right)$$

Steady sectional pitching moment about quarter-chord

$$M = C_m q_\infty c^2 ; C_m = - \int_0^1 (C_{pm+} - C_{pm-}) \left(\frac{x}{c} - 0.25\right) d\left(\frac{x}{c}\right)$$

Steady wing normal force:

$$Z_{\text{wing}} = C_Z \cdot q_\infty \cdot S ; C_Z = - \frac{1}{S} \int_0^s \int_0^1 (C_{pm+} - C_{pm-}) d\left(\frac{x}{c}\right) \cdot c \cdot dy$$

Steady wing pitching moment about aerodynamic centre:

$$M_{\text{wing}} = C_M \cdot q_\infty \cdot c_{AC} \cdot S ; C_M = - \frac{1}{S c_{AC}} \int_0^s \int_0^1 (C_{pm+} - C_{pm-}) \left(\frac{x-x_{AC}}{c}\right) d\left(\frac{x}{c}\right) c^2 \cdot dy$$

Unsteady

Unsteady pressure coefficient:

$$C_{pi} = C'_p + i \cdot C''_p = \frac{P_i}{q_\infty \cdot \alpha_i}$$

Unsteady sectional normal force:

$$Z_i = 2\pi \cdot q_\infty \cdot \frac{c}{2} \cdot C_{zi} \cdot \Delta\alpha \cdot e^{i\omega t}$$

$$C_{zi} = C'_z + i \cdot C''_z = - \frac{1}{\pi} \int_0^1 (C_{pi+} - C_{pi-}) d\left(\frac{x}{c}\right)$$

Unsteady sectional pitching moment about quarter-chord:

$$M_i = 2\pi \cdot q_\infty \cdot \left(\frac{c}{2}\right)^2 \cdot C_{mi} \cdot \Delta\alpha \cdot e^{i\omega t} ;$$

$$C_{mi} = C'_m + i \cdot C''_m = - \frac{2}{\pi} \int_0^1 (C_{pi+} - C_{pi-}) \left(\frac{x}{c} - 0.25\right) d\left(\frac{x}{c}\right)$$

Unsteady wing normal force:

$$Z_{i\text{wing}} = 2\pi \cdot q_\infty \cdot \frac{S}{2} \cdot C_{zi} \cdot \Delta\alpha \cdot e^{i\omega t} ;$$

$$C_{zi} = C'_Z + i \cdot C''_Z = - \frac{1}{\pi S} \int_0^s \int_0^1 (C_{pi+} - C_{pi-}) d\left(\frac{x}{c}\right) \cdot c \cdot dy$$

Unsteady wing pitching moment about aerodynamic centre:

$$M_{i\text{wing}} = 2\pi \cdot q_\infty \cdot \left(\frac{c_{AC}}{2}\right) \cdot \frac{S}{2} \cdot C_{mi} \cdot \Delta\alpha \cdot e^{i\omega t} ;$$

$$C_{mi} = C'_M + i \cdot C''_M = - \frac{2}{\pi S c_{AC}} \int_0^s \int_0^1 (C_{pi+} - C_{pi-}) \left(\frac{x-x_{AC}}{c}\right) d\left(\frac{x}{c}\right) \cdot c^2 \cdot dy$$

Quasi-steady

Quasi-steady pressure coefficient:

$$C_{pq} = \frac{P_q}{q_\infty \Delta \alpha}$$

Quasi-steady sectional normal force:

$$Z_q = 2\pi \cdot q_\infty \cdot \frac{c}{2} C_{zq} \Delta \alpha ;$$

$$C_{zq} = \frac{1}{\pi} \cdot \frac{C_z(\alpha_m + \Delta \alpha) - C_z(\alpha_m - \Delta \alpha)}{2\Delta \alpha}$$

Quasi-steady sectional pitching moment about quarter-chord:

$$M_q = 2\pi \cdot q_\infty \cdot \left(\frac{c}{2}\right)^2 \cdot C_{mq} \Delta \alpha ;$$

$$C_{mq} = \frac{2}{\pi} \cdot \frac{C_m(\alpha_m + \Delta \alpha) - C_m(\alpha_m - \Delta \alpha)}{2\Delta \alpha}$$

Quasi-steady wing normal force:

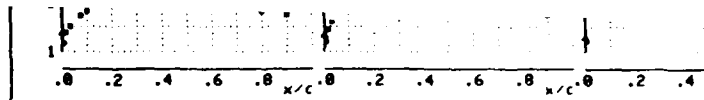
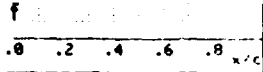
$$Z_{q_{wing}} = 2\pi \cdot q_\infty \cdot \frac{S}{2} \cdot C_{Zq} \Delta \alpha ;$$

$$C_{Zq} = \frac{1}{\pi} \cdot \frac{C_Z(\alpha_m + \Delta \alpha) - C_Z(\alpha_m - \Delta \alpha)}{2\Delta \alpha}$$

Quasi-steady wing pitching moment about aerodynamic centre:

$$M_{q_{wing}} = 2\pi \cdot q_\infty \cdot \left(\frac{c_{AC}}{2}\right) \cdot \frac{S}{2} \cdot C_{Mq} \Delta \alpha ;$$

$$C_{Mq} = \frac{2}{\pi} \cdot \frac{C_M(\alpha_m + \Delta \alpha) - C_M(\alpha_m - \Delta \alpha)}{2\Delta \alpha}$$



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