TITLE: NACA 0012 Oscillatory and Transient Pitching

3E3. NACA 0012 OSCILLATORY AND TRANSIENT PITCHING

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INTRODUCTION

These results are extracted from tabulations of wing pressures resulting from the 3rd series of pitching tests about 0.25c axis made in the ARA 2-dimensional tunnel, using the pitching and heaving rig, Ref 1.

The main purpose of these tests was to examine the conditions of dynamic stall and recovery at scaled time rates similar to those of a typical helicopter application. Dynamic similarity was maintained also in Reynolds number; the approximately quarter scale blade section was therefore run, for all the cases reported here, at a tunnel stagnation pressure of 4 bar to match low altitude flight of the helicopter. Consequently, no artificial boundary layer transition trips were applied to the test wing.

The output of dynamic pressure transducers was sampled at fixed intervals, the instantaneous pressures and reference conditions having a matched and filtered response within 3 dB up to 460 Hz.

The results represent one specific cycle, and are not averaged over a number of cycles. The data bank at ARA contains at least 4 cycles of each dynamic condition. Ramp motions have only a single transient.

Up to 6 increments of mean incidence and amplitude, singly or in combination, could be run: the present programme called for 3 increments (called programme steps or PSTEP) of mean incidence α_m.

The time-dependent results are presented without harmonic or spectral analysis. Note that the harmonic content of the pitching motion is relatively high, due to the intrusion of other modes of the drive system:

AGARD Case	f (Hz)	Harmonic content and phase angle relative to the fundamental			
		First	Second	Third	Fourth
1, 2, 3	50.32	2.44%, -10°	2.45%, -30°	0.5%, -51°	0.38%, 0°
5	62.5	0.22%, -13°	2.60%, -44°	0.37%, -61°	0.07%, -76°

The instantaneous Mach number varies in sympathy with the drag of the wing: the flow momentum loss changes the effective area of the choked throat that controls the flow down-stream of the model, thus making speed dependent on drag. Mach number is thus given for each data point in the results.

The heave mode (no results presented here) allowed the wing to be placed up to 63.5 mm (2.5 in) above and below the tunnel centre line. Some pitching tests are reported in Ref 2 to show possible effects on dynamic readings of wall proximity: there has been no analysis of unsteady tunnel interference, but corrections appropriate to steady interference have been applied to some of the measured quantities.

Notes on the data

The ordinates of the NACA 0012 airfoil are given in Table 1. The chordwise and spanwise locations of the 30 pressure holes and their channel numbers are given in Table 2, and the arrangement of the data is explained in Table 3.

Ten data sets are presented in tables 4 to 13 which provide experimental comparison with AGARD CT Cases. For the priority CT Case 1 the tabulated data are presented as 32 sets of pressure coefficients at equal time intervals during a cycle of oscillation, extracted from 64 sets in the original data. For the other CT Cases of oscillatory pitch the number is reduced to 8 sets. The ramp motion and quasi-steady data have 16 points, chosen to give approximately equal incidence increments, again taken from more closely spaced original data. Tables 4 to 7 include a pitch damping factor which is irrelevant for the present purpose and its value is also shown in each of the oscillatory plots. Note also that the ramp incidence rate is an approximate or nominal value: the incidence rate $d\alpha/dt$ is not constant, and when calculated from different ranges of incidences, will give different values. Approximate representations of the motions in Ref 6 are recommended for comparative calculations at given α. No measurements were made for strictly steady conditions, but instantaneous pressures were measured for very slow oscillations of incidence. The results of three of these quasi-steady tests are given in Tables 11 to 13.

Oscillatory pitch about 0.25c:

Related	Run No.	Experimental conditions							
AGARD CT case	and P step	M	α_m (deg)	α_0 (deg)	f (Hz)	k	Re x 10^{-6}	Sets	Data table
1	87-1	0.600	2.89	2.41	50.32	0.0808	4.8	32	4
2	89-1	0.600	3.16	4.59	50.32	0.0811	4.8	8	5
3	87-3	0.600	4.86	2.44	50.32	0.0810	4.8	8	6
5	128-1	0.755	0.016	2.51	62.5	0.0814	5.5	8	7

Ramp motion about 0.25c:

Related	Run No.	Experimental conditions					
AGARD CT case		M	α range (deg)	Re x 10^{-6}	Approx $d\alpha/dt$ (deg/s)	Sets	Data table
6	218	0.30	-0.03 to 15.54	2.7	1280	16	8
7	227	0.57	-0.01 to 14.80	4.6	425	16	9
8	230	0.56	-0.01 to 14.97	4.5	1380	16	10

Quasi-steady:

Run No.	M	α range in table (deg)	Re x 10^{-6}	Sets	Data table
6	0.30	-0.12 to 15.55	2.6	16	11
11	0.58	-0.13 to 11.56	4.6	16	12
151	0.75	-3.27 to 3.35	5.5	16	13

Figs 2 to 4 show typical results extracted from Ref 2 for oscillatory pitching at M = 0.6 and 0.75, showing the effect of reduced frequency parameter on normal force, pitching moment and a damping factor DF. The related AGARD CT cases 1, 2, 3 and 5 are included in these figures. Figs 2 and 3 are for respective amplitudes $\alpha_0 = 2.5^o$ and 5.0^o.

Fig 5 shows curves of C_N against α from the quasi-steady data and for the two ramp rates at M = 0.57 to illustrate the lag in the growth of C_N and the delayed stall under dynamic conditions.

LIST OF SYMBOLS AND DEFINITIONS

b	airfoil span and tunnel width
c	chord
C_N	normal force coefficient
C_m	pitching moment coefficient (about 0.25c)
f	frequency (Hz)
h	tunnel height
k	reduced frequency, $\omega c/2V$
M	Mach number
q	dynamic pressure
R, R_e	Reynolds number
t	time (seconds)
V	velocity

x,y,z	airfoil coordinates
α	incidence
α_m	mean incidence
α_0	pitch amplitude
δ^*	displacement thickness of boundary layer
ω	frequency (rad/sec)

For each chosen case, experimental dat are presented as sets of instantaneous values of the quantities C_p C_N C_m α and M for particular times t (in seconds) in tables 4 to 13.

Uncorrected coefficients C'_N and C'_m are evaluated by a curve fitting procedure from the integrals

$$C'_N = \int_0^1 (C_{pL} - C_{pU})\, d(x/c)$$

$$C'_m = \int_0^1 (C_{pL} - C_{pU})\,(0.25 - (x/c))\, d(x/c)$$

where $C_p = (p - p_\infty) / q$ is uncorrected and the suffices L and U denote lower and upper surfaces respectively.

Oscillatory motion is defined by

$$\alpha = \alpha_m + \alpha_0 \sin(\omega t + \varepsilon)$$

where ε is a phase angle dependent on the time datum.

The quantities α α_m α_0 C_N and C_m (but not C_p) have each been corrected for tunnel constraint effects. The corrections, as derived for steady conditions in refs 3, 4 and 5, are applied to each instantaneous condition as if it were steady.

PRESENTATION OF DATA

The data were presented in tables 4 to 13 of the original AGARD R702 report. In this document the first part of table 4 is supplied as a sample and the remaining tables are supplied in an ASCII data file SET3.DAT. A FORTRAN program (SET3.FOR) is provided which demonstrates the extraction of the data. The program includes a sample main segment which reproduces the data of a table via a call to subroutine SET3SEL, with output either online or to a formatted file. This subroutine may be employed in a user's code to extract the data for a single table or to serve as a model for other data extraction codes.

SET3SEL subroutine

A description of the subroutine call and arguments follows:

```
      SUBROUTINE SET3SEL(NCH,ITAB,MAXP,MAXT,RMACH
     1,VMACH,TIM,ALPHA,CN,CM,Q,CPST,NUMP,STN,NTIM)
C
C-- This routine reads and selects tables from the data file SET3.DAT
C   which contains the data of tables 4 to 13 of R702 data set 3 (ARA).
C-- Arguments are as defined below (all except NCH,ITAB, MAXP,MAXT must be
c   variables):
C   Input values
C         NCH     channel number to be used for reading the input file
C         ITAB    Specifies the required table number.
C         MAXP    The declared dimension in the calling routine of the
C                 array STN and leading dimension of CPST (must be >=30)
C         MAXT    The declared dimension in the calling routine of the
C                 time variation arrays VMACH...
C   Returned values:
C         RMACH   The nominal Mach number for this run
C   Time variable arrays of instantaneous values:
C         VMACH   Mach number
C         TIM     Time (sec)
C         ALPHA   Incidence (deg)
C         CN      Normal force coefficient
```

```
C        CM      Pitching moment coefficient (about 0.25c)
C        Q       dynamic pressure
C   Time and location array:
C        CPST    Instantaneous pressure coefficient [CPST(i,j,k) is the
C                value of CP at transducer i,and time value j and
C                surface k (1=upper, 2=lower)]
C
C        NUMP    The number of chordwise locations, 2-element integer array
C                with NUMP(1) the number of upper surface points
C                and NUMP(2) the number of lower surface points
C        STN     2-dimensional array of locations of transducers (X/C)
C                STN(i,j) is the i-th transducer on the upper (j=1) or
C                lower (j=2) surface
C        NTIM    The number of times at which data is given
C
      REAL CPST(MAXP,MAXT,2),VMACH(MAXT),TIM(MAXT),ALPHA(MAXT)
      REAL CN(MAXT),CM(MAXT),Q(MAXT),STN(MAXP,2)
      INTEGER NUMP(2)
```

FORMULARY

1 General Description of model

1.1	Designation	NACA 0012
1.2	Type	Symmetrical 12% thick
1.3	Derivation	
1.4	Additional remarks	Ordinates given in table 1
1.5	References	6, 7

2 Model Geometry

2.1	Planform	Two-dimensional airfoil
2.2	Aspect ratio	NA
2.3	Leading edge sweep	NA
2.4	Trailing edge sweep	NA
2.5	Taper ratio	NA
2.6	Twist	None
2.7	Wing centreline chord	0.1016 m
2.8	Span of model	0.2032 m
2.9	Area of planform	0.0206 m^2
2.10	Location of reference sections and definition of profiles	NA
2.11	Lofting procedure between reference sections	NA
2.12	Form of wing-body junction	NA
2.13	Form of wing tip	NA
2.14	Control surface details	NA
2.15	Additional remarks	Accuracy of profile see fig.1. Trailing edge thickness 0.383mm, approximately 0.127mm too thick
2.16	References	None

3 Wind Tunnel

3.1	Designation	ARA 2-dimensional tunnel
3.2	Type of tunnel	Intermittent blow down
3.3	Test section dimensions	h = 0.4572, b = 0.2032, length = 1.251 m
3.4	Type of roof and floor	Slotted, 3.2% open area ratio
3.5	Type of side walls	Solid
3.6	Ventilation geometry	Roof and floor each have 6 slots and 2 half slots at corners. Plenum chambers 133 mm deep connected by large ducts. Top and bottom walls diverge.
3.7	Thickness of side wall boundary layer	$2\,\delta^* / b = 0.015$
3.8	Thickness of boundary layers at roof and floor	Not known
3.9	Method of measuring Mach number	Static hole in side wall 5 chords ahead of model
3.10	Flow angularity	NA
3.11	Uniformity of Mach number over test section	Centre line distribution within ± 0.038 mm in region of model
3.12	Sources and levels of noise or turbulence in empty tunnel	No serious disturbances
3.13	Tunnel resonances	No evidence
3.14	Additional remarks	None
3.15	References on tunnel	Ref.8

4 Model motion

4.1	General description	Pitching about 0.25c, oscillation or ramp.
4.2	Natural frequencies and normal modes of model and support system	Lowest frequency is bending at 600 Hz

5 Test Conditions

5.1	Model chord/tunnel width	0.222
5.2	Model chord/tunnel height	0.5
5.3	Blockage	-
5.4	Position of model in tunnel	-
5.5	Range of Mach numbers	0.3 to 0.87
5.6	Range of tunnel total pressure	1.5 to 4 bar
5.7	Range of tunnel total temperature	Temperature 280°K approx, uncontrolled
5.8	Range of model steady or mean incidence	$\pm 11^{\circ}$
5.9	Definition of model incidence	On chordline: datum matched on chordwise pressure distributions
5.10	Position of transition, if free	Not knwon
5.11	Position and type of trip, if transition fixed	No trips in presented data because model Re transition fixed consistent with full-scale helicopter blade
5.12	Flow instabilities during tests	No simple answer, refer to ARA
5.13	Changes to mean shape of model due to steady aerodynamic load	No significant distortion
5.14	Additional remarks	None
5.15	References describing tests	1, 2

6 Measurements and Observations

6.1	Steady pressures for the mean conditions	N
6.2	Steady pressures for small changes from the mean conditions	N
6.3	Quasi-steady pressures	Y
6.4	Unsteady pressures	Y
6.5	Steady section forces for the mean conditions by integration of pressures	N
6.6	Steady section forces for small changes from the mean conditions by integration	N
6.7	Quasi-steady section forces by integration	Y
6.8	Unsteady section forces by integration	Y
6.9	Measurement of actual motion at points of model	N
6.10	Observation or measurement of boundary layer properties	N
6.11	Visualisation of surface flow	N
6.12	Visualisation of shock wave movements	N
6.13	Aditional remarks	None

7 Instrumentation

7.1	Steady pressure	Pressures for quasi-steady conditions measured with same system used for unsteady pressures
	7.1.1 Position of orifices spanwise and chordwise	See 7.2
	7.1.2 Type of measuring system	See 7.2
7.2	Unsteady pressure	
	7.2.1 Position of orifices spanwise and chordwise	See table 2
	7.2.2 Diameter of orifices	0.25mm
	7.2.3 Type of measuring system	30 transducers in model (see ref. 1)
	7.2.4 Type of transducers	Kulite XCQL absolute
	7.2.5 Principle and accuracy of calibration	Calibrated under steady conditions against calibration Texas Quartz Pressure Test Set. Accuracy: $\pm$2.7 mb
7.3	Model motion	
	7.3.1 Method of measuring motion reference coordinate	Shaft encoder
	7.3.2 Method of determining spatial mode of motion	NA
	7.3.3 Accuracy of measured motion	Resolution $\pm$0.1 deg
7.4	Processing of unsteady measurements	
	7.4.1 Method of acquiring and processing measurements	Signals sampled at known time intervals, same points in cycle
	7.4.2 Type of analysis	Instantaneous pressures reduced to non-dimensional coefficients
	7.4.3 Unsteady pressure quantities obtained and accuracies achieved	Approximately $\pm$0.01 in C_p
	7.4.4 Method of integration to obtain forces	Standard curve fitting procedure
7.5	Additional remarks	Tabulated C_N and C_m are corrected for wall constraint
7.6	References on techniques	1, 9, 10

8 Data presentation

8.1	Test cases for which data could be made available	None. The test cases covered in the original test were listed in tables in AGARD R702. However, since the publication of the original report, this data has become unavailable from ARA.
8.2	Test cases for which data are included in this document	See Introduction
8.3	Steady pressures	No
8.4	Quasi-steady or steady perturbation pressures	Tables 11, 12, 13
8.5	Unsteady pressures	Tables 4 to 10
8.6	Steady forces or moments	No
8.7	Quasi-steady or unsteady perturbation forces	Tables 11, 12, 13
8.8	Unsteady forces and moments	Tables 4 to 10
8.9	Other forms in which data could be made available	None
8.10	Reference giving other representations of data	1

9 Comments on data

9.1	Accuracy	
	9.1.1 Mach number	± 0.0015
	9.1.2 Steady incidence	Instantaneous incidence to $\pm 0.1^{\circ}$
	9.1.3 Reduced frequency	Within about 1%
	9.1.4 Steady pressure coefficients	NA
	9.1.5 Steady pressure derivatives	NA
	9.1.6 Unsteady pressure coefficients	Instantaneous Cp to ± 0.01 (see ref 10)
9.2	Sensitivity to small changes of parameter	Not recorded
9.3	Non-linearities	Not recorded
9.4	Influence of tunnel total pressure	Not recorded
9.5	Effects on data of uncertainty, or variation, in mode of model motion	Not recorded
9.6	Wall interference corrections	Values of α, α_m, α_0, , C_N and C_m have been corrected on the basis of steady calibrations (see para 12). No corrections appear to be necessary for M
9.7	Other relevant tests on same model	None
9.8	Relevant tests on other models of nominally the same shapes	Ref.11 gives steady measurements on another model of NACA 0012 in same tunnel
9.9	Any remarks relevant to comparison between experiment and theory	None
9.10	Additional remarks	None
9.11	References on discussion of data	2

10 Personal contact for further information

Aircraft Research Association Ltd, Manton Lane, Bedford MK41 7PF, England

11 List of references

1 R H Landon. A description of the ARA 2-dimensional pitch and heave rig and some results from the NACA 0012 wing. ARA Memo 199, September 1977

2 Mrs M.E. Wood. Results of oscillatory pitch and ramp tests on the NACA 0012 blade section. ARA Memo 220, December 1979

3 A Harris. Calibration of ARA's 2-dimensional facility using 2.8% open area liners. April 1971, unpublished Memorandum

4 A Harris, A B Haines. Evidence on wall interference effects in the ARA 2-dimensional tunnel. ARA Memo 147, 1972

5 A B Haines. An evaluation of wall interference effects in ARA's 2-dimensional tunnel. Item 5, Tech Comm, June 1973

6 Ed. S R Bland. AGARD two-dimensional aeroelastic configurations. AGARD-AR-156, 1979

7 I H Abbott, A E Von Doenhoff. Theory of wing sections: including a summary of airfoil data. McGraw-Hill, New York 1949

8 B L F Hammond. Some notes on model testing in the ARA 2-dimensional facility. ARA Memo 170, 1975

9 R H Landon, Mrs M E Wood. Some sources of error with Kulite pressure transducers in the ARA pitch/heave rig. ARA Memo 204, 1978

10 R H Landon, Mrs M E Wood. The pitch/heave rig data selection and reduction program, and Corrigendum. ARA Memo 182, 1976

11 Mrs J Sawyer. Results of tests on aerofoil M.102/9 (NACA 0012(in the ARA 2-dimensional tunnel. ARA Model Test Note M.102/9, 1978

Table 1 NACA 0012 Section Ordinates

x/c	z/c
0	0
0.0050	±0.01221
0.0125	±0.01894
0.0250	±0.02615
0.0500	±0.03555
0.0750	±0.04200
0.1000	±0.04683
0.1500	±0.05345
0.2000	±0.05738
0.2500	±0.05941
0.3000	±0.06002
0.3500	±0.05949
0.4000	±0.05803
0.4500	±0.05581
0.5000	±0.05294
0.5500	±0.04952
0.6000	±0.04563
0.6500	±0.04132
0.7000	±0.03664
0.7500	±0.03160
0.8000	±0.02623
0.8500	±0.02053
0.9000	±0.01448
0.9500	±0.00807
1.0000	±0.00126

Table 2 NACA 0012 Wing Pressure Locations And Channel Number Identities

Upper surface			Lower surface		
Channel No.	x/c	y/b	Channel No.	x/c	y/b
1	1.0 TE	0.52	21	0 LE	0.44
2	0.9	0.51	22	0.01	0.46
3	0.8	0.48	23	0.02	0.48
4	0.7	0.49	24	0.04	0.48
5	0.6	0.5	25	0.10	0.48
6	0.5	0.5	26	0.22	0.5
7	0.4	0.5	27	0.34	0.5
8	0.3	0.5	28	0.46	0.5
9	0.2	0.51	29	0.57	0.5
10	0.15	0.48	30	0.68	0.5
11	0.125	0.48	31	0.79	0.54
12	0.1	0.49	32	0.90	0.55
13	0.075	0.5			
14	0.05	0.51			
15	0.03	0.52			
16	0.02	0.53			
17	0.01	0.55			
18	0.005	0.56			

Table 3 Layout of Results in Tables 4 to 13.
Note the layout differs from that in AGARD R702.

t(sec)	M	α (deg)	C_N	C_m	q (lb/ft^2)				
C_{p+1}	C_{p+2}	C_{p+3}	C_{p+4}	C_{p+5}	C_{p+6}	C_{p+7}	C_{p+8}	C_{p+9}	C_{p+10}
C_{p+11}	C_{p+12}	C_{p+13}	C_{p+14}	C_{p+15}	C_{p+16}	C_{p+17}	C_{p+18}	C_{p-1}	C_{p-2}
C_{p-3}	C_{p-4}	C_{p-5}	C_{p-6}	C_{p-7}	C_{p-8}	C_{p-9}	C_{p-10}	C_{p-11}	C_{p-12}

where, in the arrangement above, C_{p+n} is the instantaneous value of C_p for channel n on the upper surface and C_{p-n} is the instantaneous value of C_p for channel n on the lower surface. Chordwise locations can be identified from the following key:

Upper									
1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.10	0.15
Upper								Lower	
0.125	0.10	0.075	0.05	0.03	0.02	0.01	0.005	0	0.01
Lower									
0.02	0.04	0.10	0.22	0.34	0.46	0.57	0.68	0.79	0.90

Table 4 AGARD Case 1 - oscillatory pitch. Sample showing first part of data

M=0.600 NT=31 Re=$8*10^6$ $\omega c/2V$=0.0808 α_m=2.89 α_0=2.41 Damping=0.06708

0.00000	0.6020	2.97	0.3719	0.0014	1706.3				
0.1647	-0.0007	-0.1408	-0.2437	-0.3383	-0.4547	-0.5912	-0.7231	-0.8666	-0.9290
-1.0117	-1.0640	-1.1383	-1.1316	-1.1096	-0.9442	-0.7231	-0.5408	0.9766	0.6306
0.3993	0.1580	-0.1897	-0.2488	-0.2454	-0.1948	-0.1560	-0.1070	-0.0530	0.0263
0.00062	0.6020	3.42	0.4267	0.0022	1706.3				
0.1562	-0.0024	-0.1493	-0.2539	-0.3501	-0.4716	-0.5965	-0.7535	-0.9172	-0.9965
-1.0894	-1.1484	-1.2615	-1.2683	-1.2582	-1.0928	-0.8683	-0.6860	0.9191	0.7031
0.4752	0.2254	-0.1358	-0.2151	-0.2134	-0.1746	-0.1391	-0.0986	-0.0497	0.0263
0.00124	0.6020	3.84	0.4777	0.0043	1708.7				
0.1645	0.0044	-0.1439	-0.2518	-0.3512	-0.4760	-0.6057	-0.7760	-0.9597	-1.0507
-1.1519	-1.2277	-1.3979	-1.4097	-1.4148	-1.2328	-1.0103	-0.8316	0.8674	0.7747
0.5455	0.2977	-0.0731	-0.1759	-0.1810	-0.1473	-0.1203	-0.0815	-0.0343	0.0348
0.00187	0.6000	4.23	0.5285	0.0070	1696.6				
0.1657	0.0078	-0.1416	-0.2519	-0.3571	-0.4879	-0.6304	-0.8070	-1.0107	-1.1024
-1.2161	-1.3044	-1.5827	-1.5929	-1.5963	-1.3689	-1.1516	-0.9699	0.8158	0.8277
0.6036	0.3558	-0.0312	-0.1348	-0.1568	-0.1314	-0.1059	-0.0720	-0.0261	0.0367
0.00249	0.6020	4.56	0.5731	0.0083	1708.7				
0.1594	0.0044	-0.1473	-0.2586	-0.3681	-0.4996	-0.6445	-0.8299	-1.0406	-1.1434
-1.2446	-1.4333	-1.7570	-1.7772	-1.7182	-1.4772	-1.2581	-1.0878	0.7460	0.8572
0.6449	0.4005	0.0094	-0.0968	-0.1389	-0.1187	-0.0984	-0.0647	-0.0260	0.0398
0.00311	0.6050	4.83	0.6049	0.0124	1723.1				
0.1632	0.0094	-0.1394	-0.2530	-0.3616	-0.4954	-0.6441	-0.8296	-1.0419	-1.1271
-1.2191	-1.6887	-1.9077	-1.9043	-1.8024	-1.5817	-1.3528	-1.1940	0.6830	0.8936
0.6880	0.4540	0.0529	-0.0641	-0.1143	-0.0976	-0.0825	-0.0553	-0.0173	0.0378
0.00373	0.5960	4.98	0.6485	0.0149	1677.4				
0.1537	-0.0008	-0.1571	-0.2721	-0.3871	-0.5211	-0.6807	-0.8730	-1.0791	-1.1237
-1.4293	-1.9393	-2.0835	-2.0577	-1.9461	-1.7401	-1.4929	-1.3194	0.6413	0.9229
0.7186	0.4782	0.0627	-0.0661	-0.1193	-0.1038	-0.0953	-0.0643	-0.0283	0.0301
0.00435	0.5970	5.11	0.6717	0.0189	1684.6				
0.1479	0.0043	-0.1495	-0.2675	-0.3803	-0.5205	-0.6778	-0.8710	-1.0556	-1.1018
-1.8471	-2.0318	-2.1514	-2.1138	-1.9976	-1.8078	-1.5616	-1.3719	0.6010	0.9395
0.7343	0.5001	0.0830	-0.0521	-0.1085	-0.0948	-0.0880	-0.0640	-0.0264	0.0300
0.00497	0.6030	5.09	0.6725	0.0208	1711.1				
0.1559	0.0111	-0.1387	-0.2548	-0.3659	-0.5005	-0.6520	-0.8389	-0.9887	-1.0863
-2.0255	-2.0675	-2.1551	-2.1130	-2.0002	-1.8218	-1.5761	-1.3707	0.5750	0.9402
0.7433	0.5127	0.1003	-0.0326	-0.0949	-0.0781	-0.0781	-0.0545	-0.0158	0.0364
0.00559	0.6010	5.00	0.6756	0.0236	1701.5				
0.1533	0.0094	-0.1429	-0.2580	-0.3697	-0.5119	-0.6643	-0.8504	-0.9926	-1.1213
-2.0945	-2.1233	-2.1994	-2.1571	-2.0471	-1.8643	-1.6223	-1.3971	0.5646	0.9369
0.7440	0.5087	0.0940	-0.0414	-0.1057	-0.1006	-0.0888	-0.0685	-0.0261	0.0297
0.00621	0.5970	4.82	0.6694	0.0254	1679.7				
0.1553	0.0061	-0.1430	-0.2545	-0.3642	-0.5065	-0.6591	-0.8443	-0.9918	-1.0792
-2.1234	-2.1594	-2.2365	-2.1902	-2.0839	-1.8936	-1.6484	-1.4015	0.5737	0.9389
0.7400	0.5034	0.0833	-0.0522	-0.1207	-0.1122	-0.0967	-0.0710	-0.0333	0.0301
0.00683	0.6000	4.54	0.6422	0.0262	1699.1				
0.1552	0.0077	-0.1381	-0.2482	-0.3567	-0.4940	-0.6432	-0.8313	-0.9906	-0.9923
-1.9992	-2.1144	-2.1924	-2.1551	-2.0534	-1.8619	-1.6110	-1.3296	0.6027	0.9128
0.7145	0.4755	0.0653	-0.0686	-0.1313	-0.1177	-0.1025	-0.0770	-0.0364	0.0247
0.00745	0.6010	4.17	0.6039	0.0238	1706.4				
0.1494	0.0009	-0.1426	-0.2523	-0.3603	-0.4936	-0.6354	-0.8244	-1.0101	-1.0320
-1.4118	-2.0548	-2.1358	-2.1172	-2.0295	-1.8134	-1.5637	-1.2784	0.6237	0.8785
0.6743	0.4363	0.0313	-0.0936	-0.1510	-0.1392	-0.1189	-0.0903	-0.0447	0.0194
0.00807	0.5980	3.80	0.5738	0.0238	1687.0				
0.1597	0.0112	-0.1373	-0.2449	-0.3524	-0.4873	-0.6256	-0.8168	-1.0216	-1.1070
-1.0848	-1.9657	-2.0698	-2.0784	-2.0067	-1.7472	-1.4945	-1.2077	0.6889	0.8665
0.6582	0.4124	0.0095	-0.1151	-0.1698	-0.1527	-0.1271	-0.0947	-0.0486	0.0231

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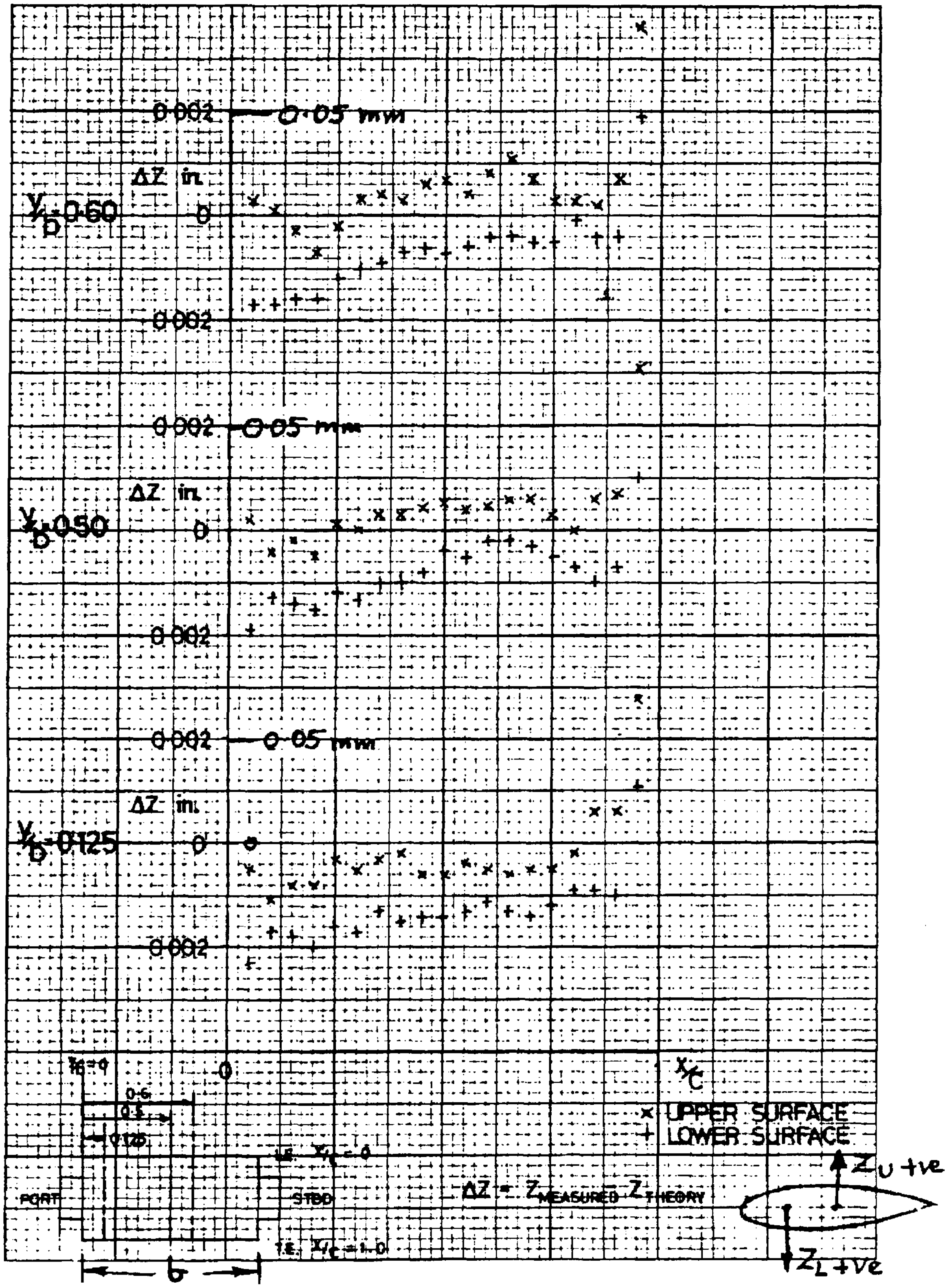

Fig.1 Profile inspection of NACA 0012 wing Z_m - Z_t

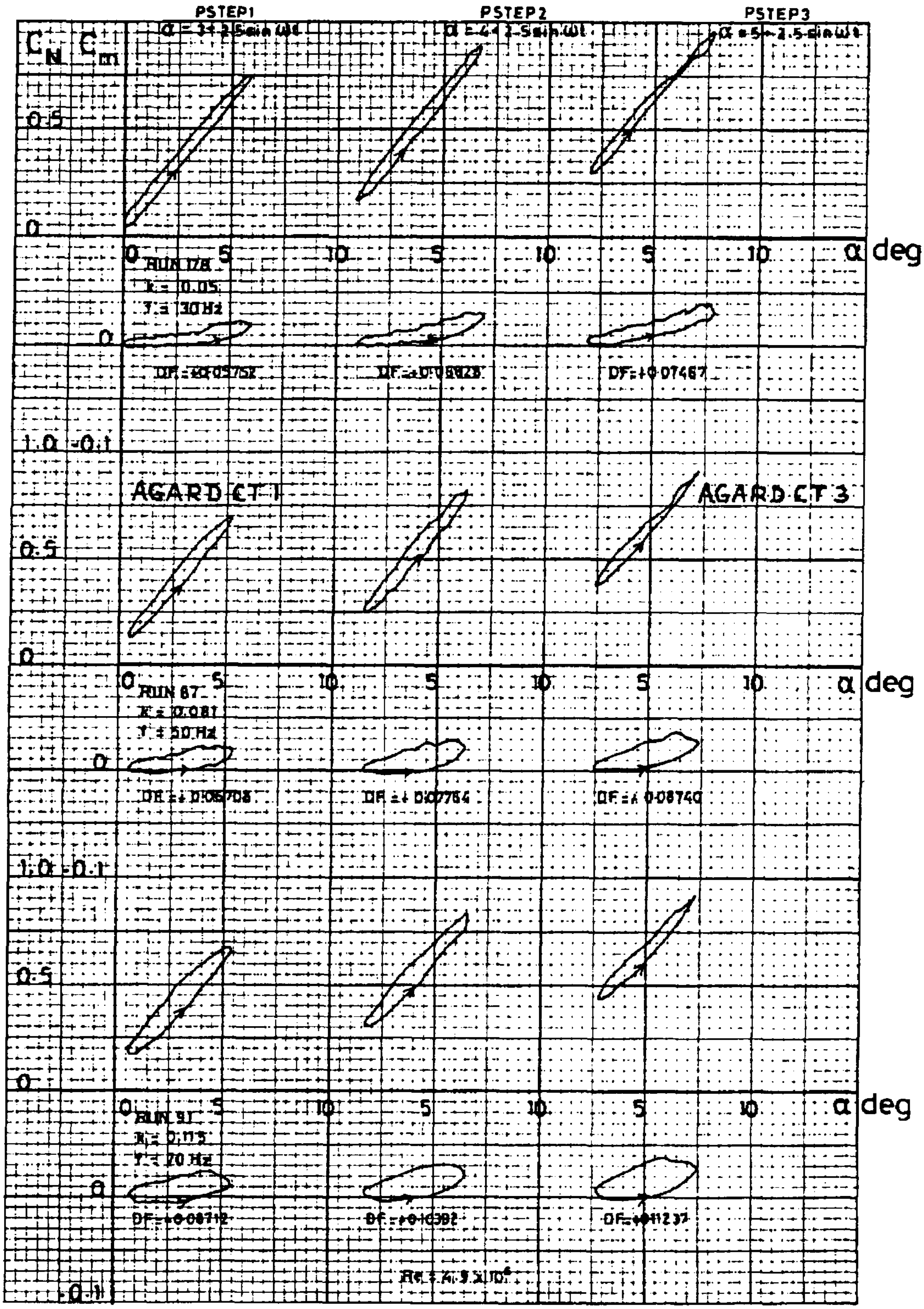

Fig. 2 C_N, C_m **v incidence over range of** $\alpha_m = 3°, 4°, 5°$; $\alpha_o = 2.5°$.
Effect of frequency k=0.05, 0.08, 0.12; M=0.6

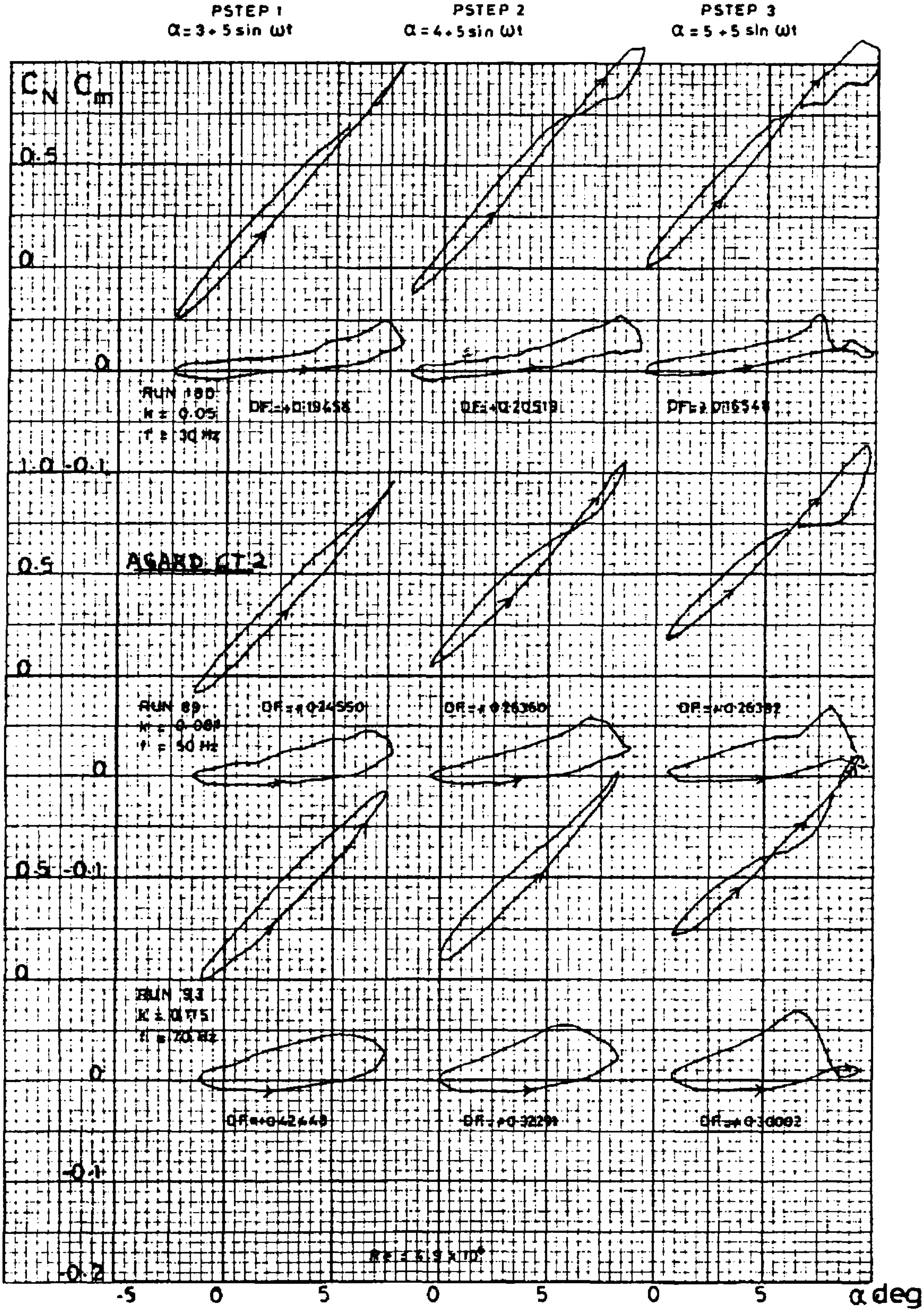

Fig. 3 C_N, C_m v incidence over range of $\alpha_m = 3°, 4°, 5°$; $\alpha_o = 5°$.
Effect of frequency k=0.05, 0.08, 0.12; M=0.6

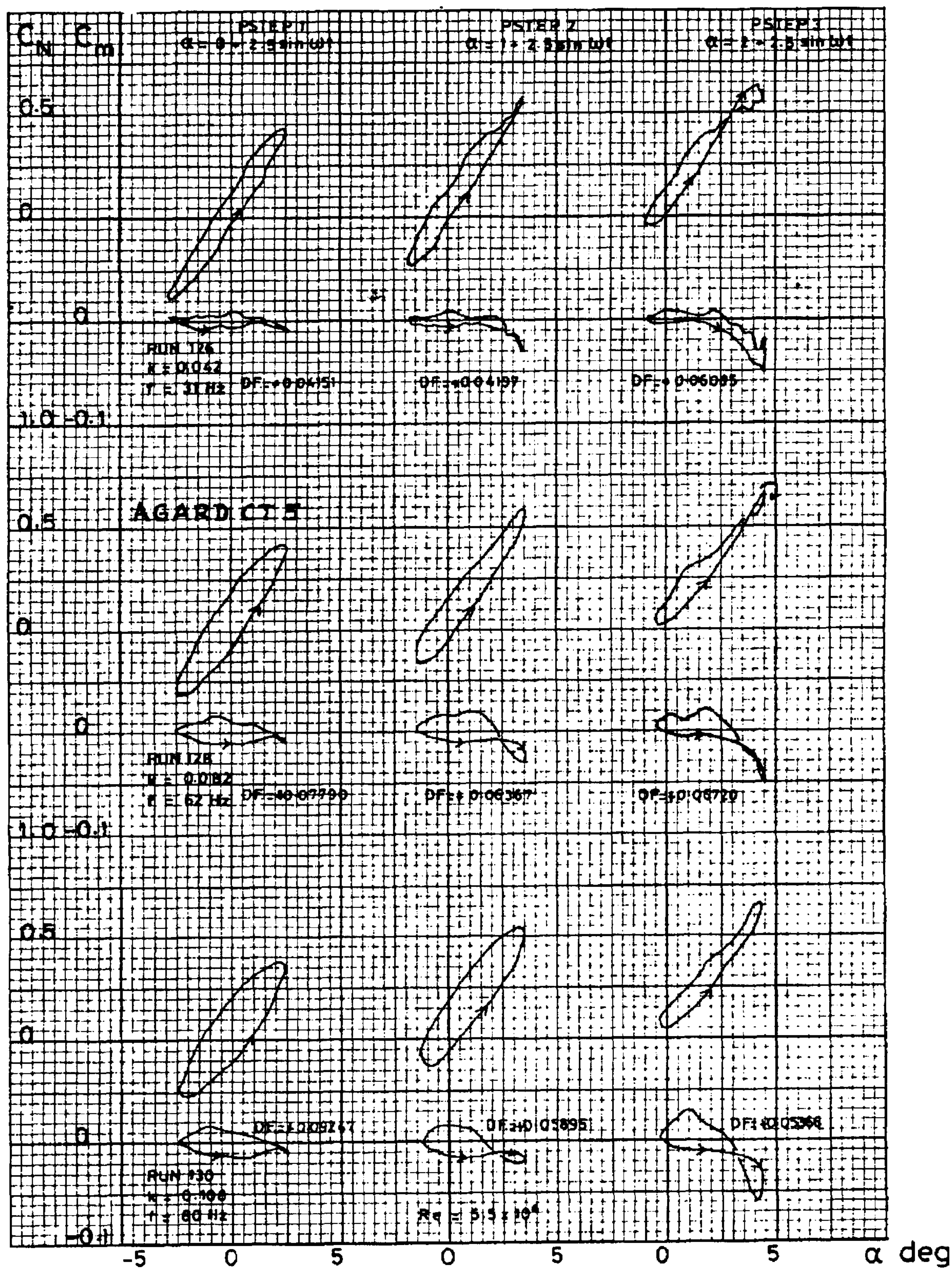

Fig. 4 C_N, C_m **v incidence over range of** $\alpha_m = 0^\circ, 1^\circ, 2^\circ$; $\alpha_o=2.5^\circ$.
Effect of frequency k=0.05, 0.08, 0.12; M=0.6

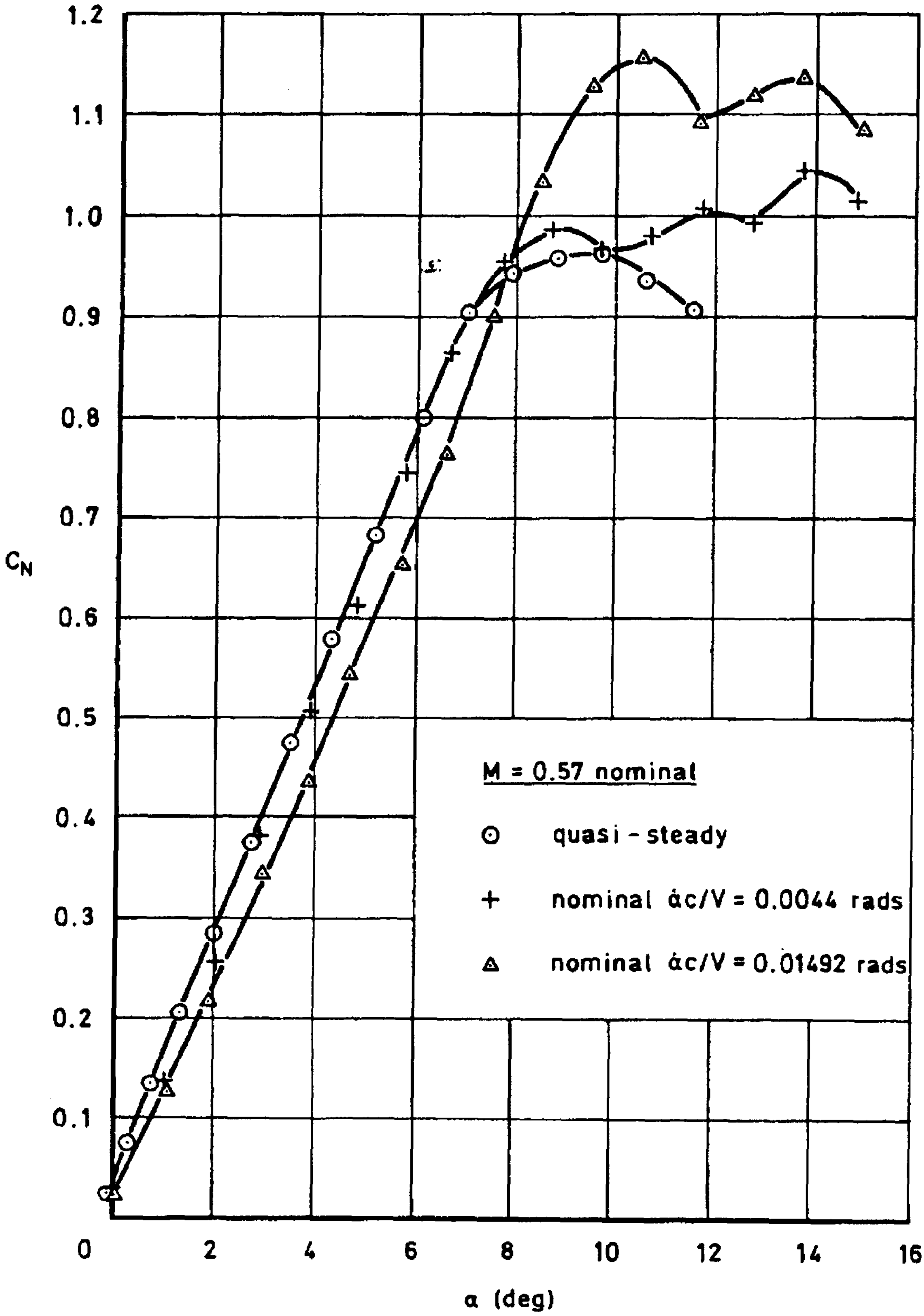

Fig.5 Lift v incidence for different rates of change