UNIVERSITY OF GLASGOW

DEPARTMENT OF

AERONAUTICS & FLUID MECHANICS

THE COLLECTED DATA FOR RAMP FUNCTION TESTS ON A NACA 23012 AEROFOIL

VOLUME 1: DESCRIPTION AND PRESSURE DATA

by

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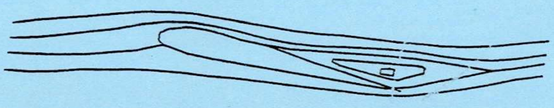

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Summary

Here in is presented the collected data for tests in which a NACA 23012 aerofoil was subjected to a variety of ramp type displacements in pitch about the quarter chord position. The data clearly illustrates the effect of reduced frequency on the aerofoil characteristics and the chordal pressure distribution at the midspan position of the aerofoil model.

Contents

1 Introduction

One of the limitations in performance of contemporary helicopter rotors during forward flight is the retreating blade stall. This phenomenon is generally characterised by a large pitching moment gradient and associated stall at an angle of attack well in excess of the static stall value. As is to be expected, attempts to analyse and predict rotor performance have little success when an assessment, albeit fairly crude, of the retreating blade stall is ommitted[1]. As yet, dynamic stall (as it is known) is not fully understood and is the subject of much research.

An experimental investigation of retreating blade stall on a model helicopter rotor, together with an analysis of rotor boundary layers by McCroskey et al[2,3] pointed to the modelling of dynamic stall by oscillating aerofoil in the nominally two-dimensional flow of a standard wind tunnel. Many experiments of aerofoils oscillating through stall with a prescribed amplitude have been performed and data gathered to form a database for future design purposes and to study the details of the phenomenon. The analysis of these data have brought to light the associated dominant feature of vortex shedding, but, as yet, no definitive description of the detailed process of flow breakdown at the instant of stall for a large range of reduced frequencies has been forth coming. Whilst such experiments mimic the necessary cyclic pitching of the rotor, the flow is complicated by the highly non-linear motion, oscillation amplitude and mean angle, and finally the reduced frequency. These effects are coupled and, of course, aerofoil shape and test set up etc, influence the stall. These latter influences are mostly unavoidable.

As there is no accurate theoretical methods available, the unsteady characteristics of current and new aerofoils can only be obtained experimentally, and even then approximately. It is because of this that the dynamic stall rig at Glasgow University[4,5,6] provides a useful complimentary facility to those already in existance, and recently, a set of data was obtained for a NACA 23012 aerofoil under ramp displacement, to study the effects of pitch rate alone. This report presents the collected data for these tests. A brief description of the rig and testing procedures is also included.

Nomenclature

c	= chord
C_m	= pitching moment coefficient
C_n	= normal force coefficient
C_p	= pressure coefficient
D.P.	= dynamic pressure = $1/2\ \rho V^2$
k	= reduced frequency = $\frac{\dot{\alpha} c}{2V}$
R_e	= Reynolds number
t	= time
x/c	= non-dimensional chord
V	= velocity
α	= angle of attack
$\dot{\alpha}$	= pitch rate
ρ	= air density

2 Description of Tests

2.1 Aerofoil and Wind Tunnel

The general arrangement of the aerofoil in the wind tunnel was as shown in Fig. 1. The aerofoil, a NACA 23012 of chord length 0.55 m and a span of 1.52 m (profile and co-ordinates shown in Table 1), was constructed of laminated mahogany with a tufnol centre instrumented section mounted on a steel spar and fitted vertically in The Glasgow University "Handley Page" wind tunnel. This wind tunnel is a low speed closed - return type with a 1.61 x 2.13 m octagonal working section (Fig. 2). The model was pivoted about the quarter chord position on two tubular steel shafts connected to the main support via two self aligning bearings (Fig. 1), with the weight being taken by a single thrust bearing on the top support beam. The dynamic and aerodynamic loadings from the aerofoil were reacted to the wind tunnel framework by two transversly mounted beams (the two main supports).

2.2 Pitch Drive Mechanism

Angular movement of the model was obtained using a linear hydraulic actuator and crank mechanism. The actuator was mounted horizontally below the wind tunnel working section on a supporting structure, with the crank rigidly connected to the tubular part of the spar by a welded sleeve and keyway. The actuator used was a UNIDYNE 907/1 type with a normal dynamic thrust of 6.1 kN operated from a supply pressure of 20 MNm^{-2}. A MOOG 76 series 450 servo valve was used via a UNIDYNE servo controller unit. A suitable feedback signal for the controller was provided by a precision linear angular displacement transducer.

The input signal to the actuator controller for incrementing the models angle of attack during the "static test" was provided under software control by the data acquisition unit's own D/A converter. This was possible because sufficient time between sampling was available and, during the sampling, the angle of attack was fixed. The two activities are separate and may be carried out sequentially. Such is not the case for the ramp tests, however, where sampling and model motion are required simultaneously.

This facility was not available on the DEC MINC (the data logging unit) and so, for the present tests, a ramp signal was provided by a separate ramp-function generator.

This generator comprised of a PET microcomputer and a 8-bit D/A converter which transformed the digital outputs of the PET into analogue form for input purposes to the controller. In built in the D/A converter was a scaler to provide manual adjustment of the maximum desired voltage output when all the digital inputs were high, thus insuring the maximum resolution of 255 increments being achieved. The parallel I/D part of the PET was configured as output lines by software and used to communicate with the D/A converter. A ramp signal was obtained by simply incrementing the PET's output lines sequentially from 0000 0000 to 1111 1111, while the desired delay between increments was generated by software using a memory location as a counter.

A signal thus generated is, of course, simply a series of small steps and, if actuation of the model were "IDEAL", one would not expect a smooth ramp motion from the aerofoil. Fortunately, the bandwidth of the electronics, the control value, the actuator itself and the polar inertia of the system, all act against the original input signal and the result is a smooth ramp as shown in Fig. 3.

2.3 Instrumentation and Data Logging

Thirty miniature pressure transducers were installed just below the surface on the tufnol centre section of the model to provide the chordwise static pressure distribution at mid-span. The transducers were of sealed gange type with one side of the pressure sensitive diaphram sealed to a reference pressure during its manufacture. The locations of the pressure transducers on the aerofoil are shown in Fig. 4.

The dynamic pressure in the wind-tunnel working section was determined by a pitot-static probe mounted on the tunnel sidewall approximately one chord length upstream of the aerofoil leading edge. This probe was connected to a FURNESS MDC FC 002 micromanometer which, in addition to the digital display of the dynamic pressure in mmH_2O, provided a differential voltage output to the multiplexer via a low drift operational amplifier circuit.

The instantaneous angle of attack of the aerofoil was determined by an angular displacement trandsucer that was geared to the model's tabular spar. Output voltage from the transducer was fed into an amplifier/splitter to produce three signals for the following purposes:

1) connection to the multiplexer for recording of the aerofoil's angle of attack.
2) connection to a Schnitt trigger for initiation of data sampling when a preset angle (voltage) was reached.
3) a feedback signal to the hydraulic actuator controller.

The low voltage outputs from the thirty pressure transducers were suitably amplified and conditioned in a bank of differential amplifiers of similar design to an R.A.E. signal conditioning system[8] before passing to a sample and hold unit[9] to overcome the time skew problem which arises with sequential analogue multiplexing and A/D conversion. The actual data acquisition unit was a DEC MINC - 11 microcomputer, configured with an LSI - 11/23 16-bit microprocessor and loboratory modules which included:

a) an A/D converter module, with a 16-channel multiplexer incorporated. This is a successive approximation type that converts the instantaneous value of a voltage applied to one of its inputs into a 12-bit binary value. Conversion time was approximately 30 μs, but multiplexer settling time channel selection and transfer of data from the A/D converter register to memory increased the conversion time to 44 μs[6].
b) a multiplexer module, of 16 single-ended channels. This increased the number of channels that could be sampled to a total of 32.
c) a real-time clock module, with two Schmitt triggers. This was used as a time-base generator to accureately set the sampling frequency. The desired overflow value of the counter was determined from the pitch rate at run time, with the constraint that 128 sweeps be obtained during ramp up. One of the Schmitt triggers was used for data sampling initiation and counter start, by settling the trigger voltage to that from the angular displacement transducer corresponding to a given angle of attack.

d) a D/A converter module which housed four independent 12-bit D/A converters. This was used to power the angular displacement transducer and provided a signal to the actuator controller to set the model's angle of attack during static tests.

The path of data flow and system layout is shown diagrammatically in Fig. 5. The main control programs for static and ramp tests were written in FORTRAN and they prompt the user for specific run information before calling a specialised sub-program written in MACRO 11 assembly language to receive converted A/D data. The timing and control of the A/D converter and associated circuitry was performed by the processor, but channel selection and data transfer and management was done under software control which optimised the conversion code for the specific task.

All data was stored on floppy disks and a library of programs is available for data reduction and presentation.

2.4 Test Series and Procedure

The series of tests cover pitch rates from ≐0°/sec to 330°/sec, corresponding to a range of reduced frequencies, k, of of 0 to 0.04 as shown in Table II. The datum angle was generally set at 0° and the model pitched up to a maximum angle of 40°. All tests were run at a Reynolds number of 1.5 million based on model chord c) which is optimal for the rig configuration used. Whilst other Reynolds numbers could have been considered, these would simply be in the range 1.0×10^6 Re $\leq 2.0 \times 10^6$.

Due to the thermal characteristics of the tunnel and the problem of pressure transducer drift, a precise test sequence had to be followed before initialising a test. Prior to any test, the tunnel was run for approximately 20-25 minutes to achieve thermal stability at about 26°C, and also to bring the pressure transducers into a temperature range where the offset drift compensation unit was more effective. After this period, the tunnel was shut down and the air flow allowed to cease before the transducer offsets were logged. Immediately after this logging, the appropriate data acquisition routine was initiated whilst the tunnel was brought up to speed and thence data gathered as per the software prompts.

Generally, five cycles of data were collected for each pitch rate. If, on completion of a run, the overall change in air temperature was less than 2°C, further tests could proceed. If, however, the temperature change exceeded 2°C, the tunnel was shut down and offsets re-logged. This procedure minimised the effect of thermal offsets on the transducers.

2.5 Data Presentation

The data collected by the data acquisition routine were, for reasons of speed and storage space, stored in unformatted form and processed at a latter stage. A data reduction program was written to convert the five cycles of raw data into averaged or unaveraged non-dimensional pressure coefficients by applying offsets, gain, calibration, etc, to the raw data; the result being stored in formatted form. These coefficients were then displayed as chordwise pressure surface plots and appropriately integrated to yield C_n, C_m values as illustrated in Fig. 10. This is the standard presentation format used for the main data of this report, and also includes time dependant incidence and tunnel dynamic pressure.

3 Results and Discussion

3.1 Tunnel Performance

Assessment of the quality of the ramp data can only be made after a clear insight of tunnel effects. Unfortunately the tunnel performance is such, that for the time scales of the model motion, the dynamic pressure in the working section cannot be held constant whilst the blockage alters due to the pitching of the model. During the static test (ie, k = 0.0). This variation is as given in Fig. 6, where it may be seen that there is about a 30% reduction between 0° and 30° angle of attack. As may be seen in Figs. 10-40, this reduction decreases with increasing k which is to be expected.

3.2 Averaging of the Data

The main data presented in this report is the average of five consecutive ramp tests. Individual runs are presented on Figs. 7 where it may be seen that, whilst differences do exist, the salient features are indeed highlighted by the averaging process. The given data (Figs. 10-40) may be considered as typical aerofoil performance for such conditions, but not that which would be obtained in a given test. This is particularly relevant when considering the detailed flow phenomena of separation and reattachment.

3.3 Static Data

The static data presented in Fig. 9 was obtained during continuous running of the tunnel whilst the model's angle of attack was first incremented, from a low value around -2°, in decrete steps of 1/2° through a 30° change, and then decremented in a similar manner. After each ioncidence change, a delay of a few seconds took place before the data was sampled. One hundred sweeps of the transducers were taken and averaged at each incidence.

It may be seen from the plot of the upper surface pressure, that the NACA 23012 section exhibits a trailing edge type stall at around 14°. The suction peak does not, however, completely collapse until the aerofoil is close to 20° and there after it acts as a bluff body. For a decreasing incidence, the reluctance to re-attach is best illustrated by the pitching moment curve where there is an evident hysteresis when returning from bluff body type flow to that of a partially stalled aerofoil. No such lag exist for the subsequent return to fully attached flow.

A further discussion on these characteristics is given in Seto et al[7].

3.4 Ramp Test Data

The ramp test data as presented in Figs. 10-40 and compact details of the specific tests are as given in Table 2. All data is currently stored on floppy disks compatible to DEC MINC 11/23, but data transfer to other machines is possible.

Included in the data are the time histories of the angular displacement and the dynamic pressure. Care must be taken not to be misled by the drastic reduction of dynamic pressure during a test. As may be seen for the larger reduced frequency tests, the model was pitched to an angle of 40° so that uniform ramp conditions existed at the stall. Once the aerofoil stalled, however, the data of interest had been collected and the corresponding dynamic pressure reduction was only in the region of 10%. The subsequent data is of little relevance to the current work and is presented merely for completeness. It is, none the less, interesting to note that the periodic and decaying fluctuations in lift, best illustrated in Fig. 37, are all close to a frequency of 18 Hz, corresponding to a strouhal number of approximately 0.27.

Whilst it is not the purpose of the report to discuss the details of the data relevant to dynamic stall, one can hardly avoid noticing the very clear and profound effect of reduced frequency. This manifests itself in a transition from typically static behaviour, to rapid collapse of the leading edge pressure followed by weak vortex like disturbances and thence to very strong vortex dominance. The effect of this on the lift and pitching moment is also most striking, in that $C_{n\ max}$, at the high reduced frequencies, is a remarkable 3.2 at an incidence of ≈30°.

It is unlikely however that such values could be usefully obtained for contemporary craft.

4 Conclusions

The single-degree-of-freedom pitch rig at Glasgow University was found to perform satisfactorily in providing ramp data for the NACA 23012. The slight difference observed between cycles is believed to be inherent in unsteady aerodynamics, and the data obtained are representative aerofoil data.

Acknowledgements

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RAE-TR-77155, 1977.

9) Galbraith, R.A.McD., Barrowman, J. and Leishman, J.G. "Description of the sample and hold circuits for the Glasgow University dynamic stall facility".
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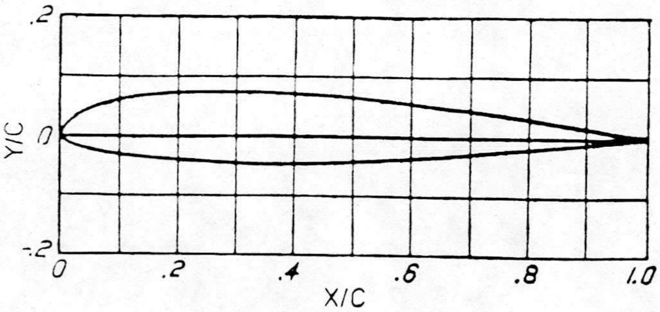
List of Figures



NACA 23012
(Stations and ordinates given in
per cent of airfoil chord)

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	......	0	0
1.25	2.67	1.25	− 1.23
2.5	3.61	2.5	− 1.71
5.0	4.91	5.0	− 2.26
7.5	5.80	7.5	− 2.61
10	6.43	10	− 2.92
15	7.19	15	− 3.50
20	7.50	20	− 3.97
25	7.60	25	− 4.28
30	7.55	30	− 4.46
40	7.14	40	− 4.48
50	6.41	50	− 4.17
60	5.47	60	− 3.67
70	4.36	70	− 3.00
80	3.08	80	− 2.16
90	1.68	90	− 1.23
95	0.92	95	− 0.70
100	(0.13)	100	(− 0.13)
100	......	100	0

L.E. radius: 1.58
Slope of radius through L.E.: 0.305

TABLE I : NACA23012 AEROFOIL PROFILE AND CO-ORDINATES

Run No	Pitch Rate (deg/sec)	Reduced Frequency $\dot{\alpha}c/2v$	Sampling Frequency(Hz)	Fig
2/034/1	0.59	0.00007	2.44	10
2/033/1	1.18	0.00014	4.89	11
2/032/1	2.36	0.00029	9.78	12
2/031/1	3.52	0.00043	14.67	13
2/030/1	4.72	0.00058	18.56	14
2/035/1	7.67	0.00093	24.46	15
2/036/1	15.32	0.00184	48.92	16
2/037/1	30.84	0.0037	97.84	17
2/038/1	46.58	0.00572	146.76	18
2/039/1	61.57	0.00748	195.66	19
2/040/1	77.44	0.00947	244.56	20
2/041/1	92.88	0.01124	293.51	21
2/042/1	108.64	0.01317	342.47	22
2/043/1	120.34	0.01453	391.39	23
2/044/1	134.01	0.01616	440.33	24
2/045/1	151.25	0.01845	489.24	25
2/046/1	163.53	0.01985	538.21	26
2/047/1	178.58	0.02155	550.05	27
2/048/1	193.09	0.02332	550.05	28
2/049/1	207.21	0.02496	550.05	29
2/090/1	221.95	0.02739	550.05	30
2/091/1	231.71	0.02851	550.05	31
2/092/1	246.36	0.03021	550.05	32
2/093/1	255.29	0.03132	550.05	33
2/094/1	268.88	0.03291	550.05	34
2/095/1	278.88	0.03437	550.05	35
2/096/1	289.67	0.03533	550.05	36
2/097/1	302.93	0.03707	550.05	37
2/098/1	314.49	0.03841	550.05	38
2/099/1	323.40	0.03947	550.05	39
2/100/1	335.54	0.04104	550.05	40

Table II : Summary of Ramp Tests

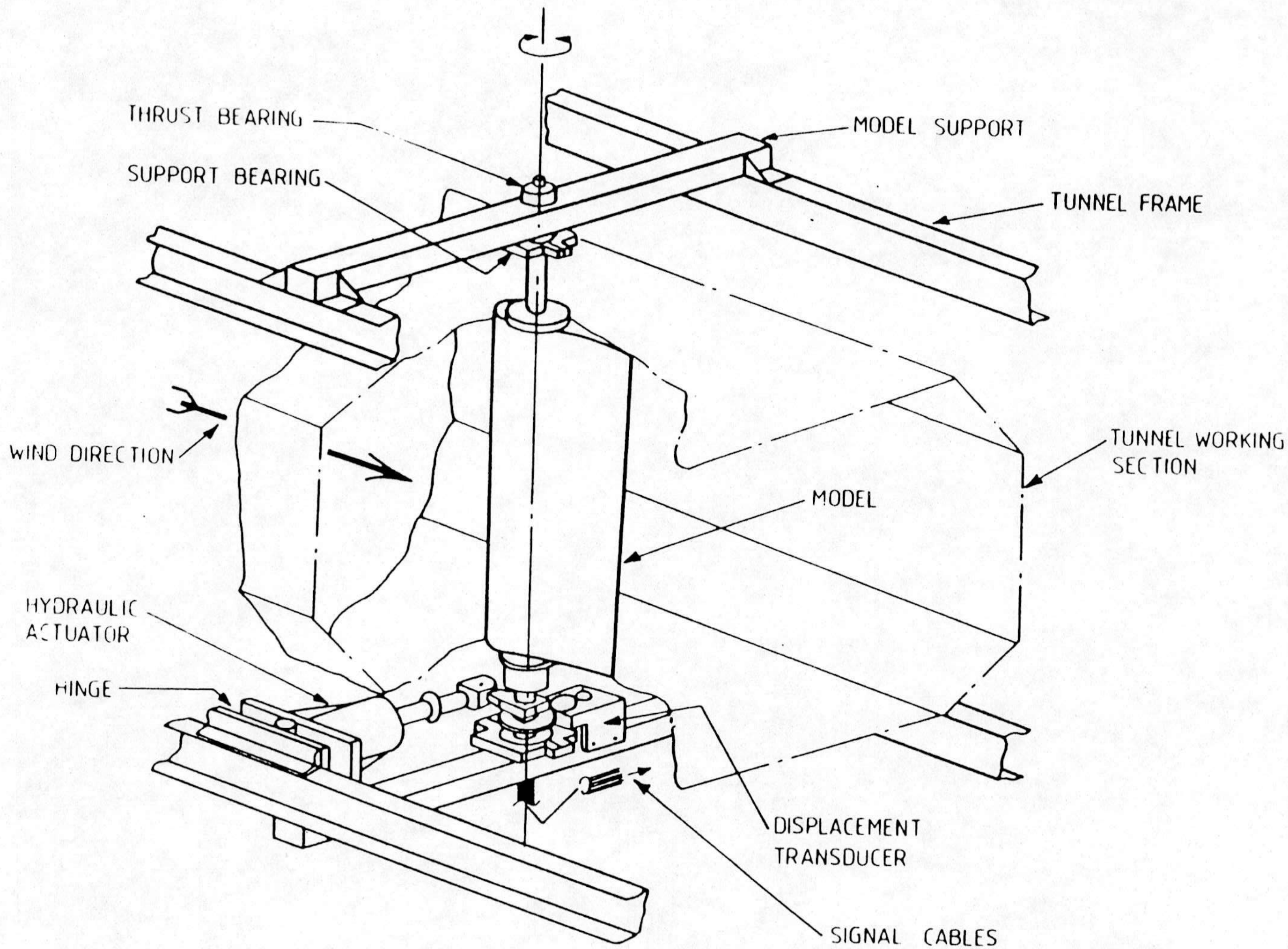


FIGURE 1 : GLASGOW UNIVERSITY'S DYNAMIC STALL RIG

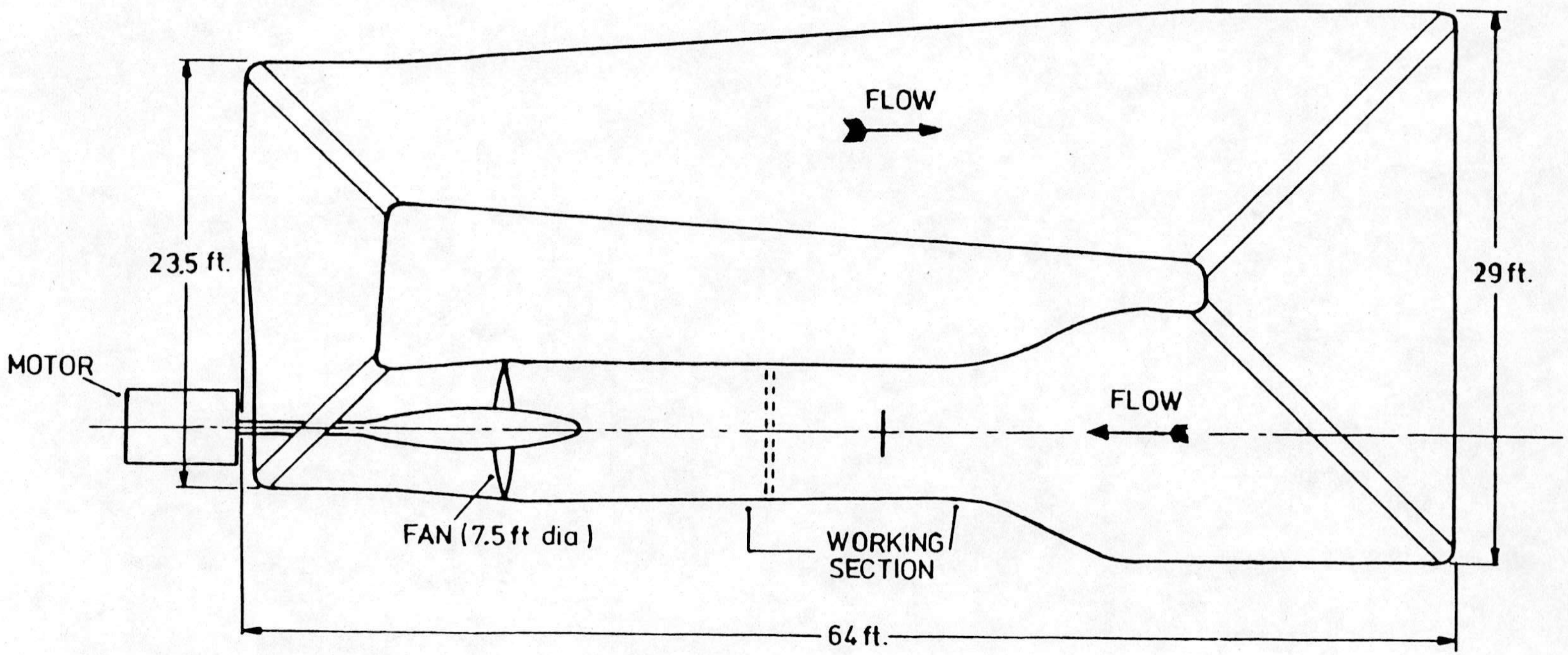


FIGURE 2 : PLAN VIEW OF THE GLASGOW UNIVERSITY "HANDLEY PAGE" 7ft X 5ft 3in WIND TUNNEL

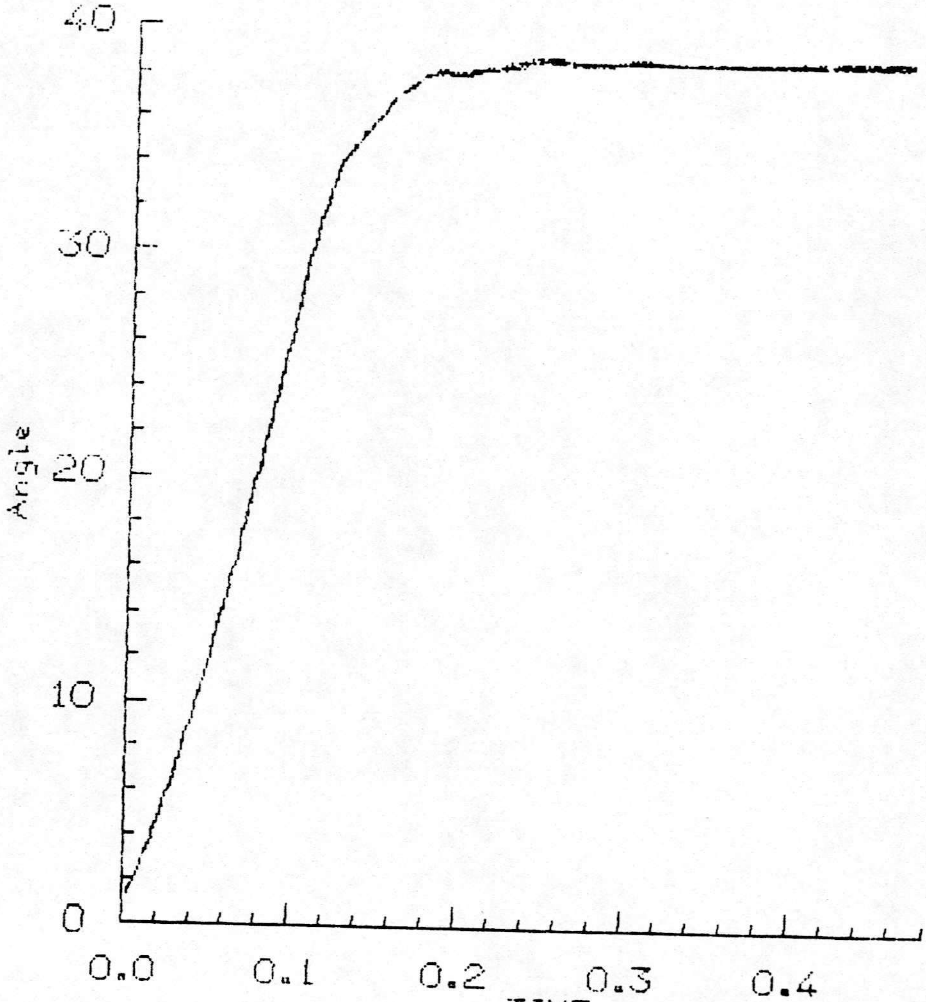
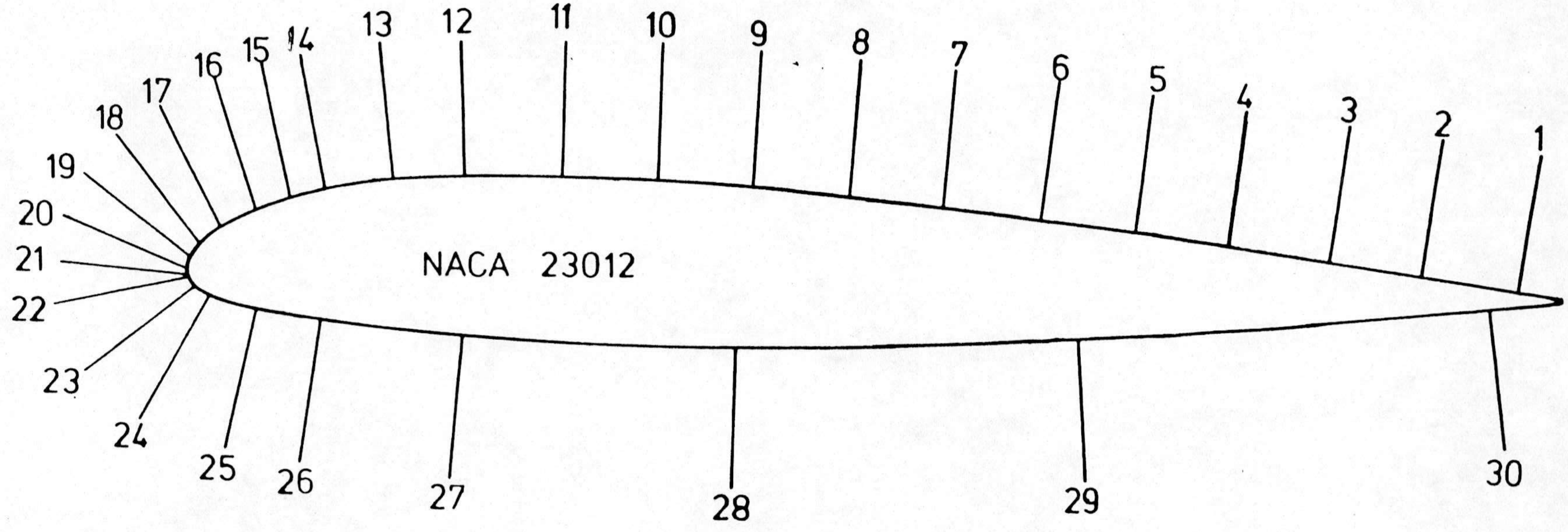


FIGURE 3 : MODEL ANGULAR MOVEMENT, $\dot{\alpha}$ = 314.49 deg/sec



X/C (1)=0.97	(9)=0.41	(17)=0.025	(24)=0.02
X/C (2)=0.90	(10)=0.34	(18)=0.01	(25)=0.05
X/C (3)=0.83	(11)=0.27	(19)=0.005	(26)=0.10
X/C (4)=0.76	(12)=0.20	(20)=0.0005	(27)=0.20
X/C (5)=0.69	(13)=0.15	(21)=0.000	(28)=0.40
X/C (6)=0.62	(14)=0.10	(22)=0.000	(29)=0.65
X/C (7)=0.55	(15)=0.075	(23)=0.01	(30)=0.95
X/C (8)=0.48	(16)=0.05		

FIGURE 4 : PRESSURE TRANSDUCER LOCATIONS

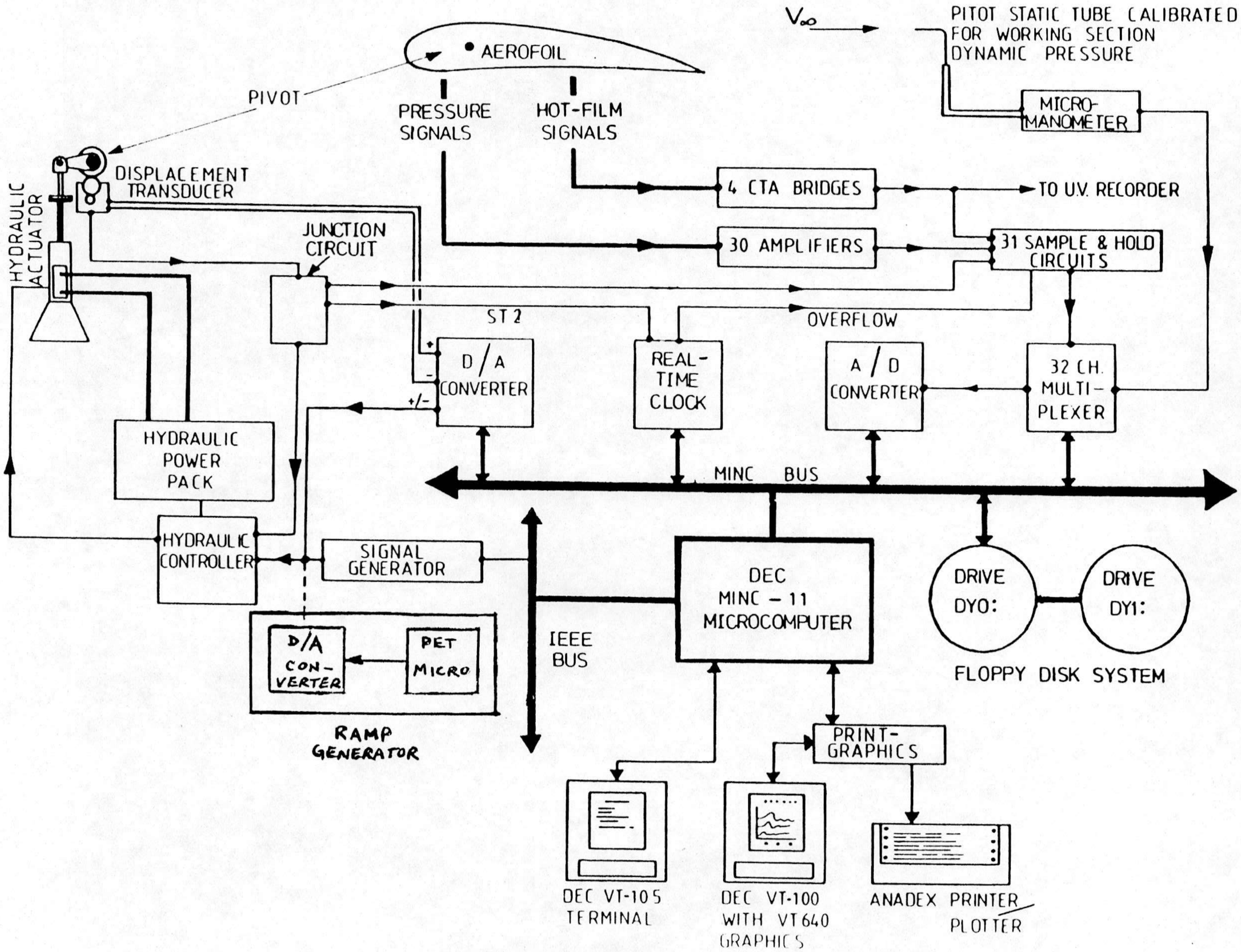


FIGURE 5 : SYSTEMATIC ARRANGEMENT OF DATA ACQUISITION AND CONTROL SYSTEM

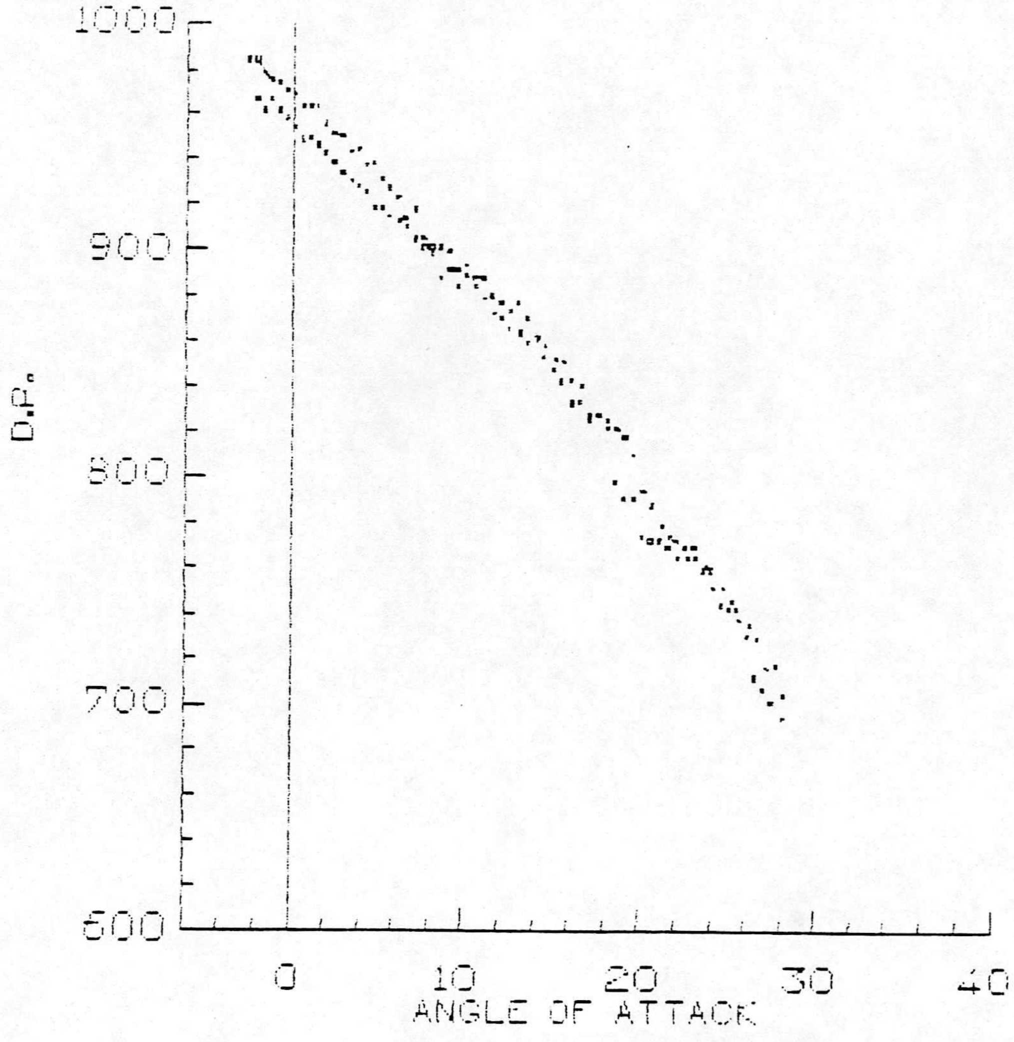
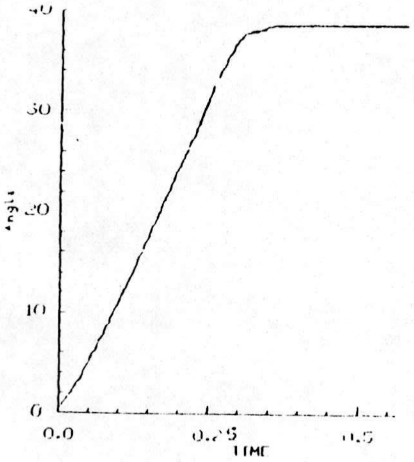


FIGURE 6 : DYNAMIC PRESSURE REDUCTION DURING STATIC TEST

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20441	DATE OF TEST: 24/ 5/84
REYNOLDS NUMBER= 1523954.	MACH NUMBER= 0.114
DYNAMIC PRESSURE= 1008.07 N/sq.M	AIR TEMPERATURE= 30.0 Deg.C
NUMBER OF CYCLES= 5	SAMPLING FREQUENCY= 440.39 Hz.
MOTION TYPE: RAMP	REUCED FREQUENCY = 0.01616
PITCH RATE= 134.01 DEG./SEC	AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



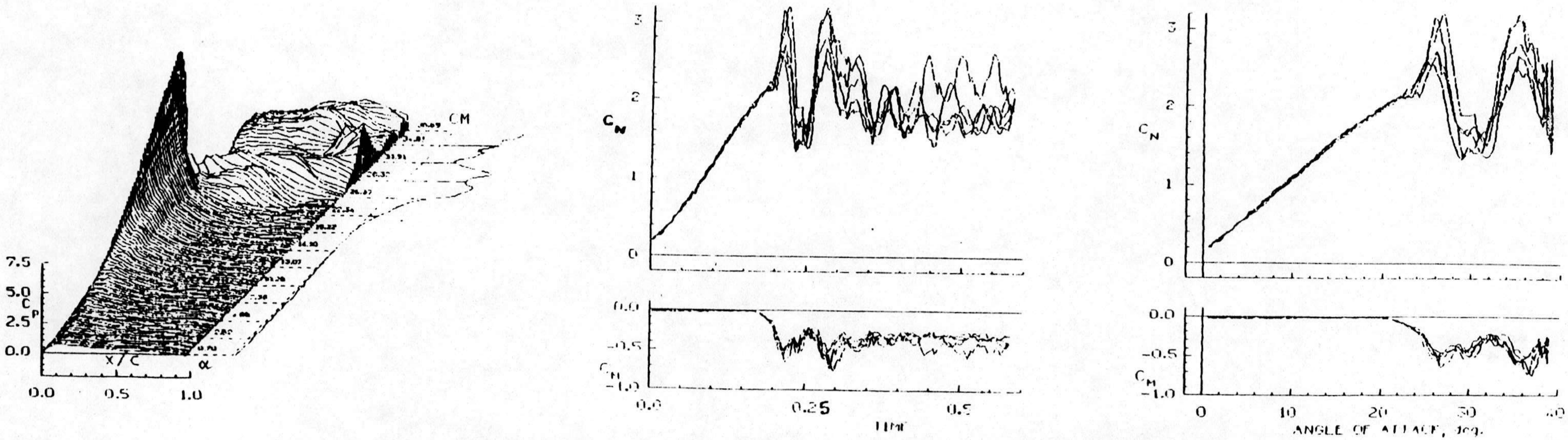


FIGURE 7 : TYPICAL UNAVERAGED DATA

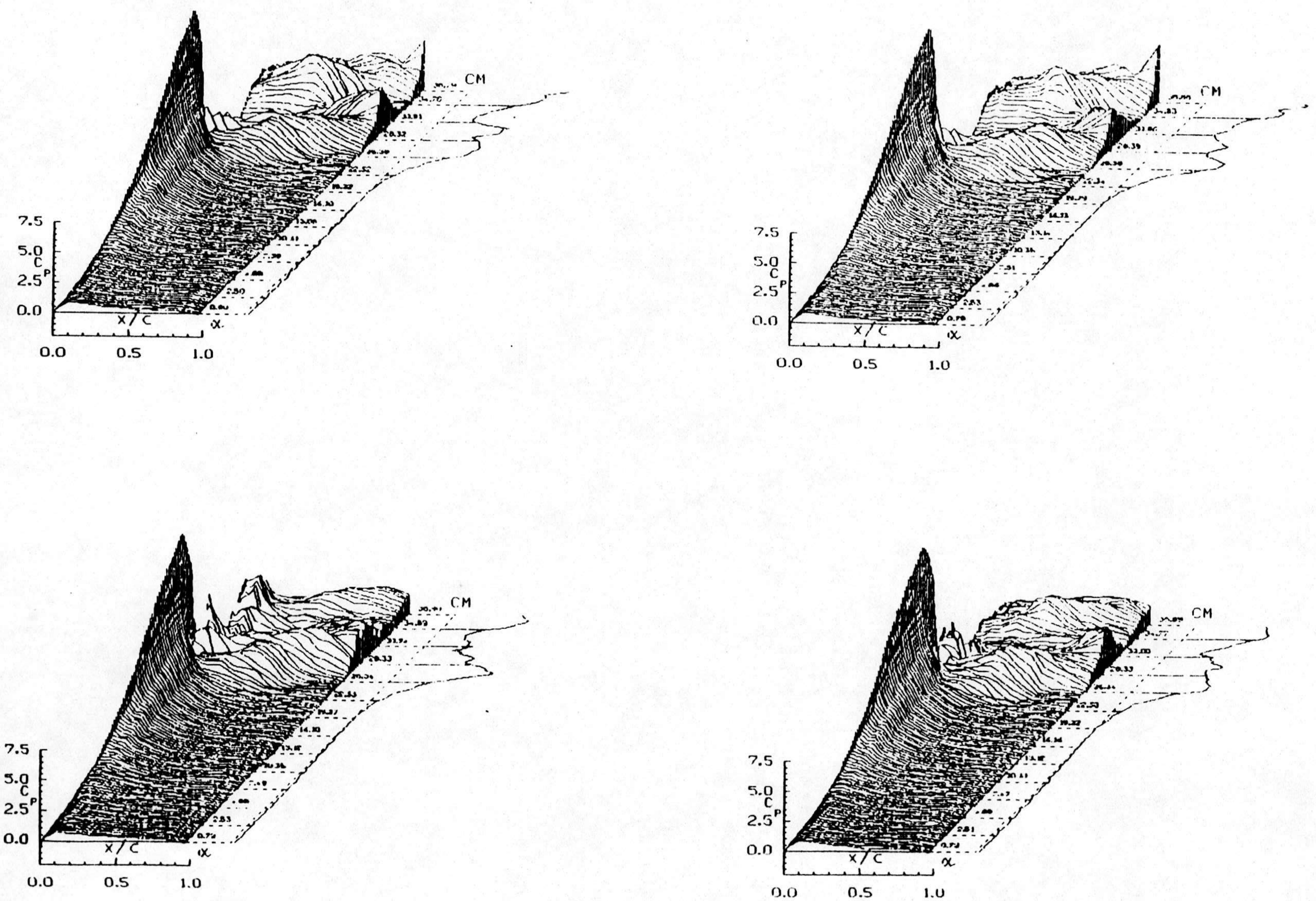
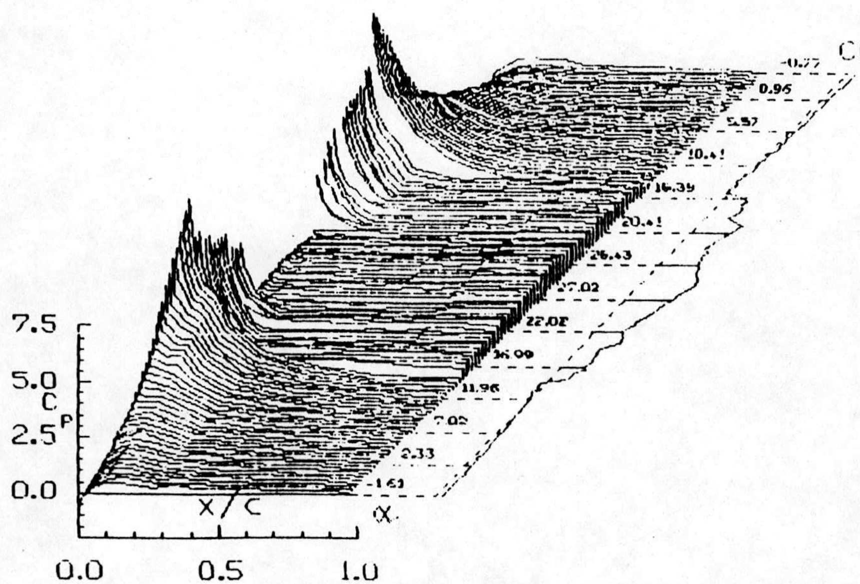


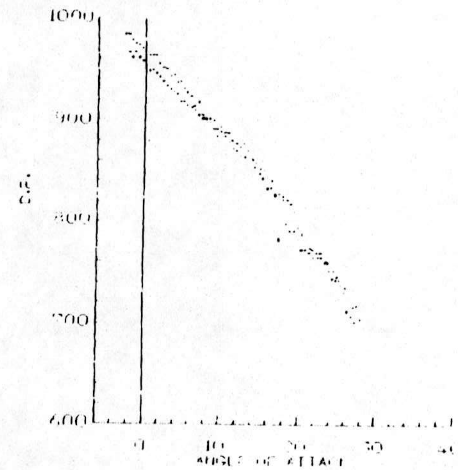
FIGURE 8 : TYPICAL UNAVERAGED DATA

STATIC RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 642	DATE OF TEST: 23/ 5/84
REYNOLDS NUMBER= 1517312.	MACH NUMBER= 0.113
DYNAMIC PRESSURE= 977.40 N/sq.M	AIR TEMPERATURE= 26.0 Deg.C
NUMBER OF CYCLES= 1	SAMPLING FREQUENCY= 100.00 Hz.
MOTION TYPE: STATIC	REDUCED FREQUENCY = 0.00000
PITCH RATE= 0.00 DEG./SEC	

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE





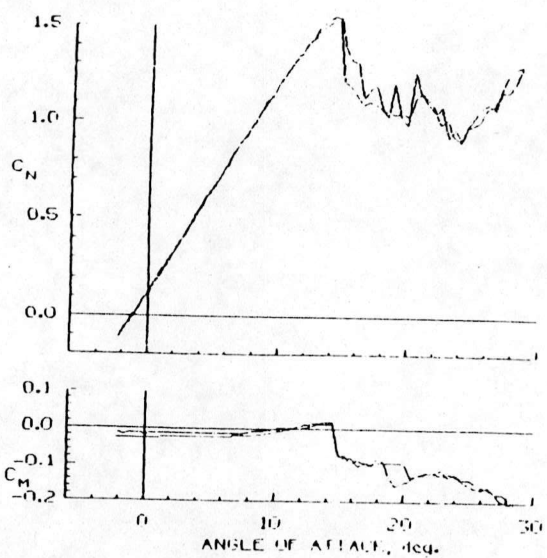


FIGURE 9 : STATIC DATA

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20341 DATE OF TEST: 23/ 5/84

REYNOLDS NUMBER= 1508327. MACH NUMBER= 0.112

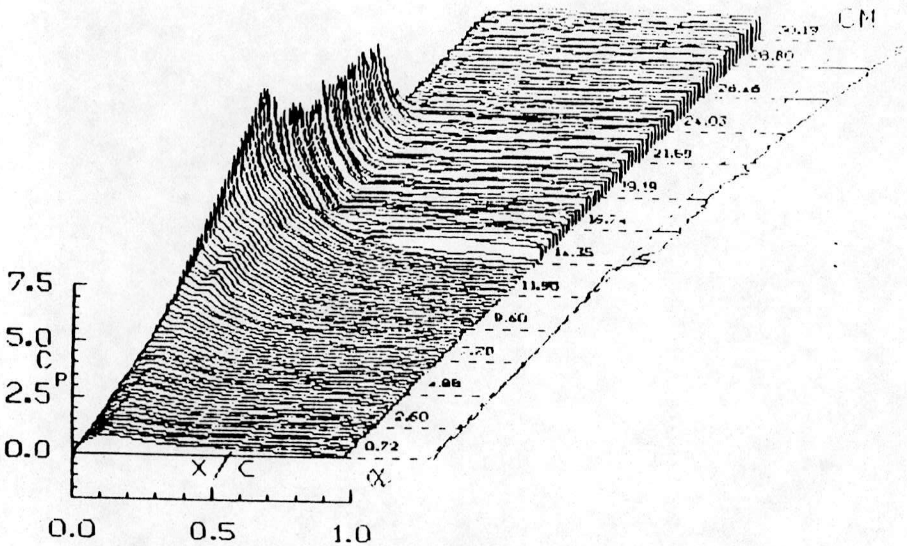
DYNAMIC PRESSURE= 976.66 N/sq.M AIR TEMPERATURE= 28.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 2.44 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.00007

PITCH RATE= 0.59 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



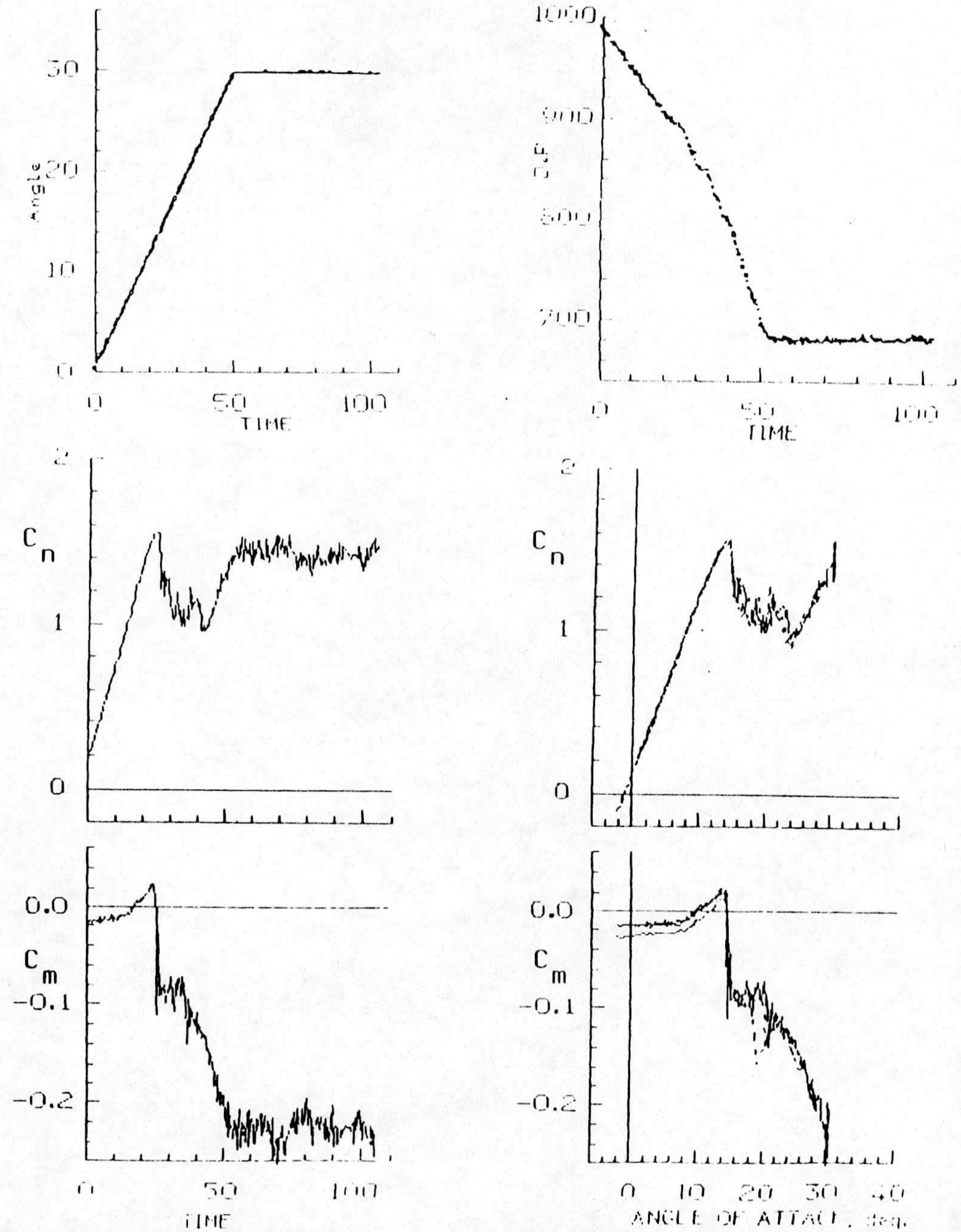
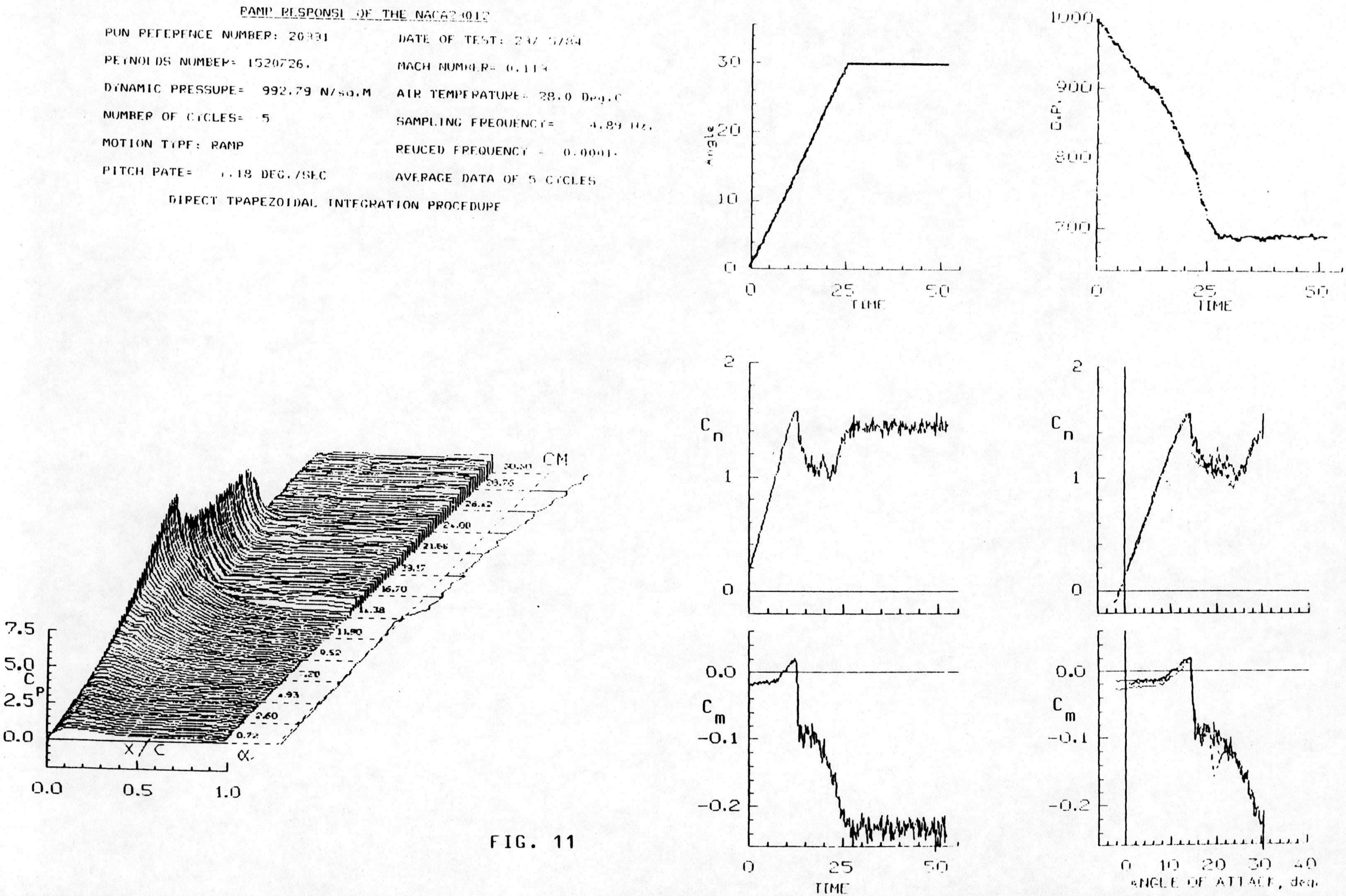


FIG. 10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REYNOLDS NUMBER= 1520726.
MACH NUMBER= 0.113
DYNAMIC PRESSURE= 992.79 N/sq.M
AIR TEMPERATURE= 28.0 Deg.C
NUMBER OF CYCLES= 5
SAMPLING FREQUENCY= 4.89 Hz.
MOTION TYPE: RAMP
REDUCED FREQUENCY = 0.0001
PITCH RATE= 1.18 DEG./SEC
AVERAGE DATA OF 5 CYCLES
DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE
CM
C
P
X/C
α
Angle
TIME
C.P.
C
n
C
m
ANGLE OF ATTACK, deg

FIG. 11

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20321 DATE OF TEST: 23/ 5/84

REYNOLDS NUMBER= 1508968. MACH NUMBER= 0.112

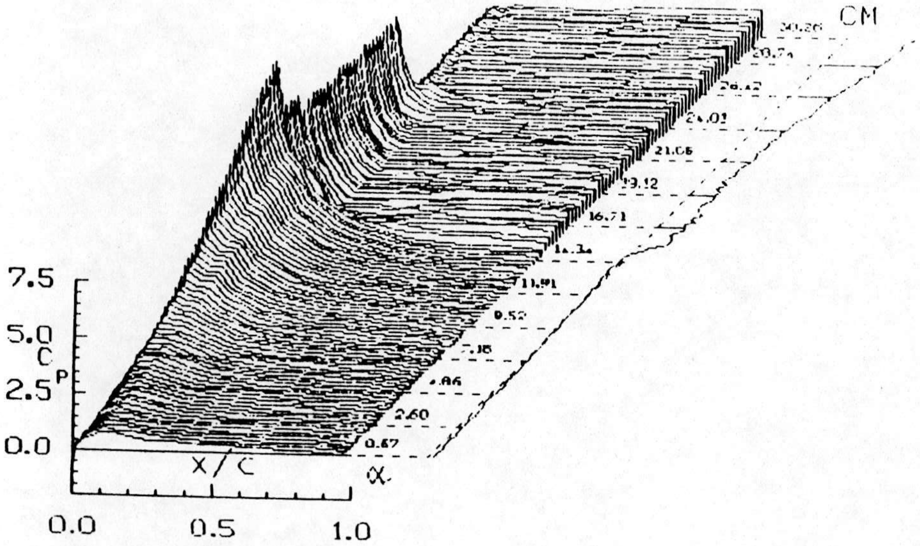
DYNAMIC PRESSURE= 977.49 N/sq.M AIR TEMPERATURE= 28.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 9.78 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.00029

PITCH RATE= 2.36 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



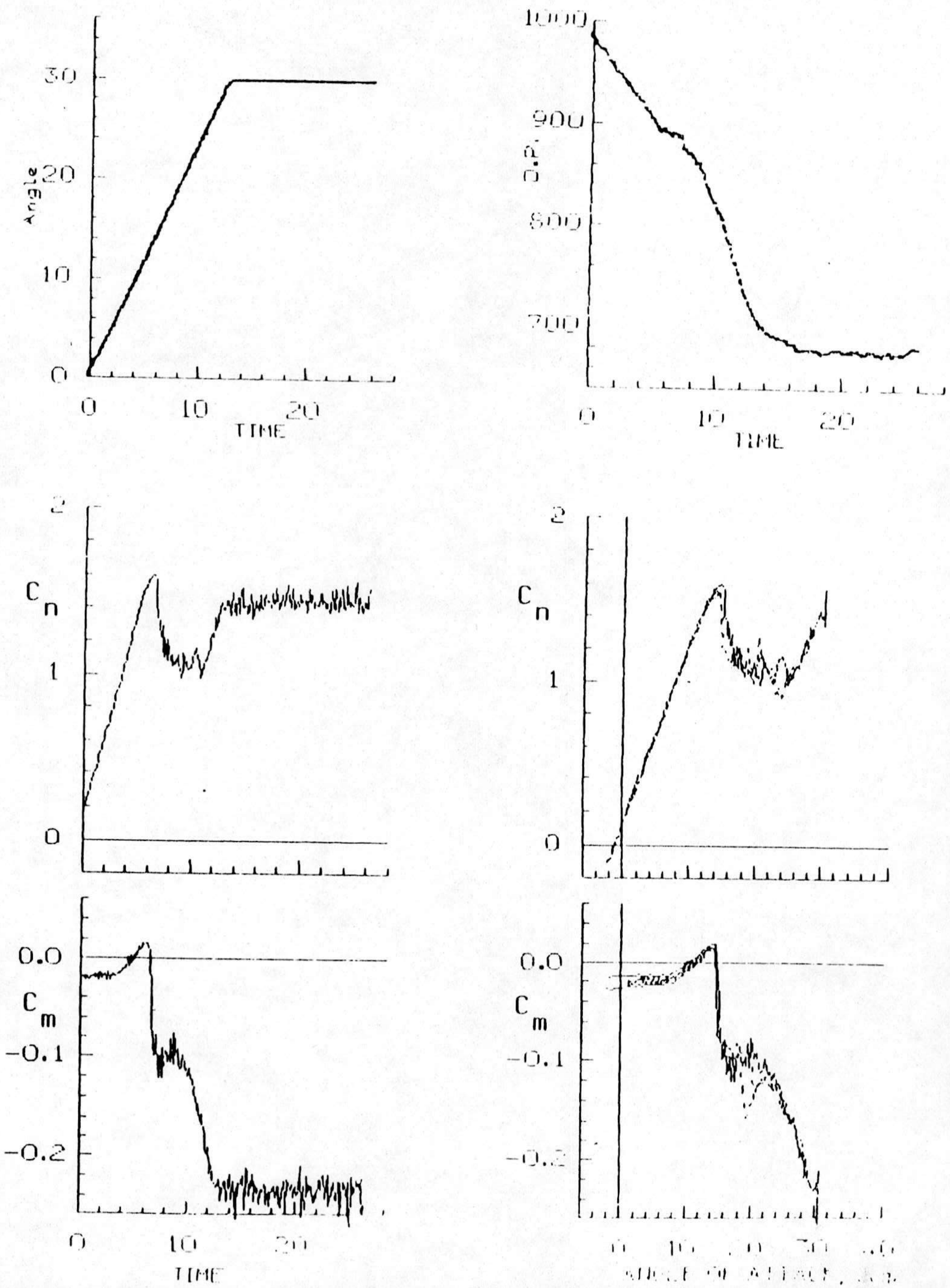


FIG. 12

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20311 DATE OF TEST: 23/ 5/84

REYNOLDS NUMBER= 1498551. MACH NUMBER 0.112

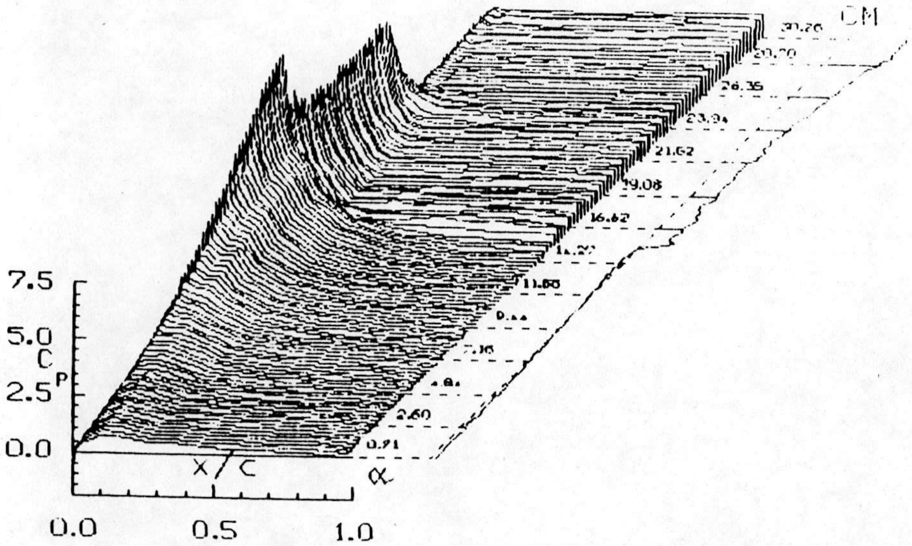
DYNAMIC PRESSURE= 964.04 N/sq.M AIR TEMPERATURE= 28.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 14.67 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.00043

PITCH RATE= 3.52 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



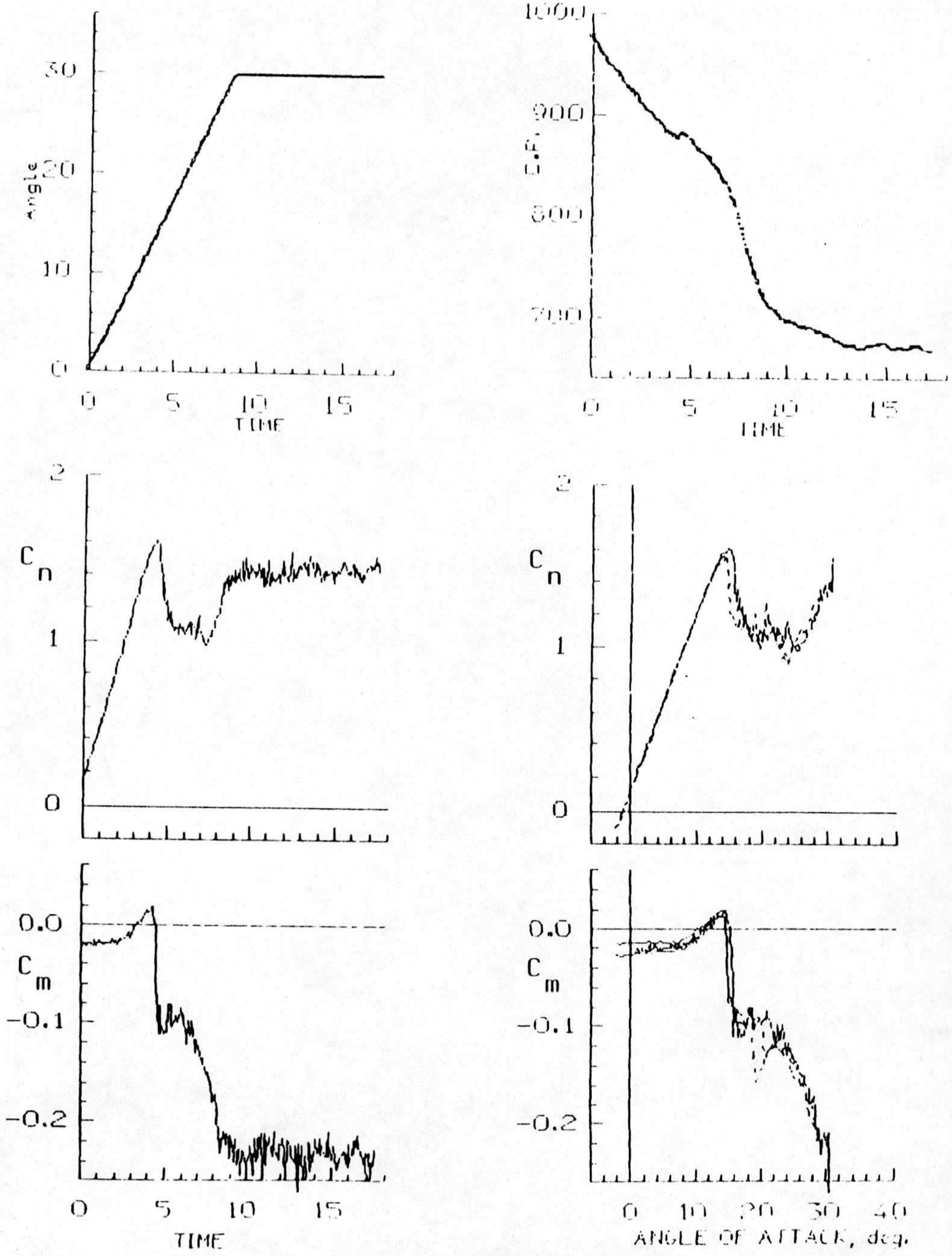
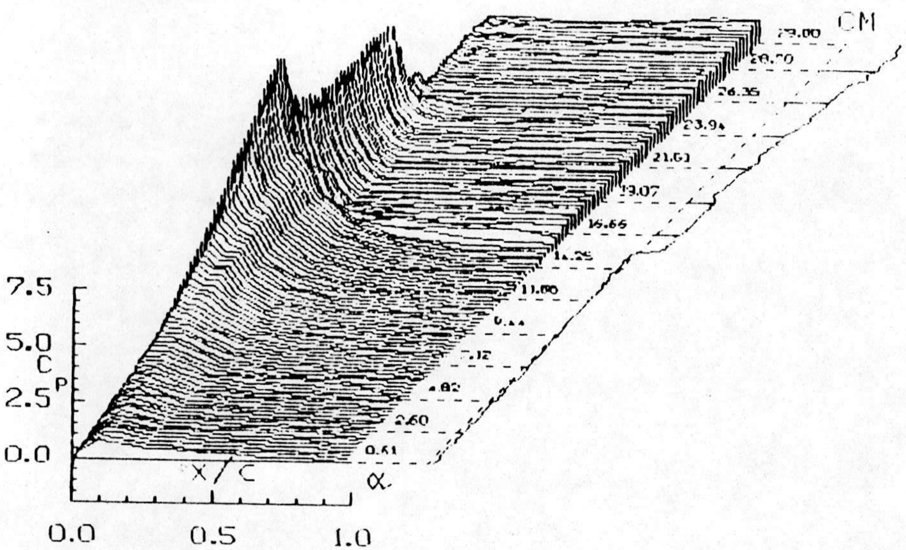


FIG. 13

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20401	DATE OF TEST: 23/ 5/84
REYNOLDS NUMBER= 1512721.	MACH NUMBER= 0.113
DYNAMIC PRESSURE= 976.92 N/sq.M	AIR TEMPERATURE= 27.0 Deg.C
NUMBER OF CYCLES= 5	SAMPLING FREQUENCY= 19.56 Hz.
MOTION TYPE: RAMP	REDUCED FREQUENCY = 0.00058
PITCH RATE= 4.72 DEG./SEC	AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



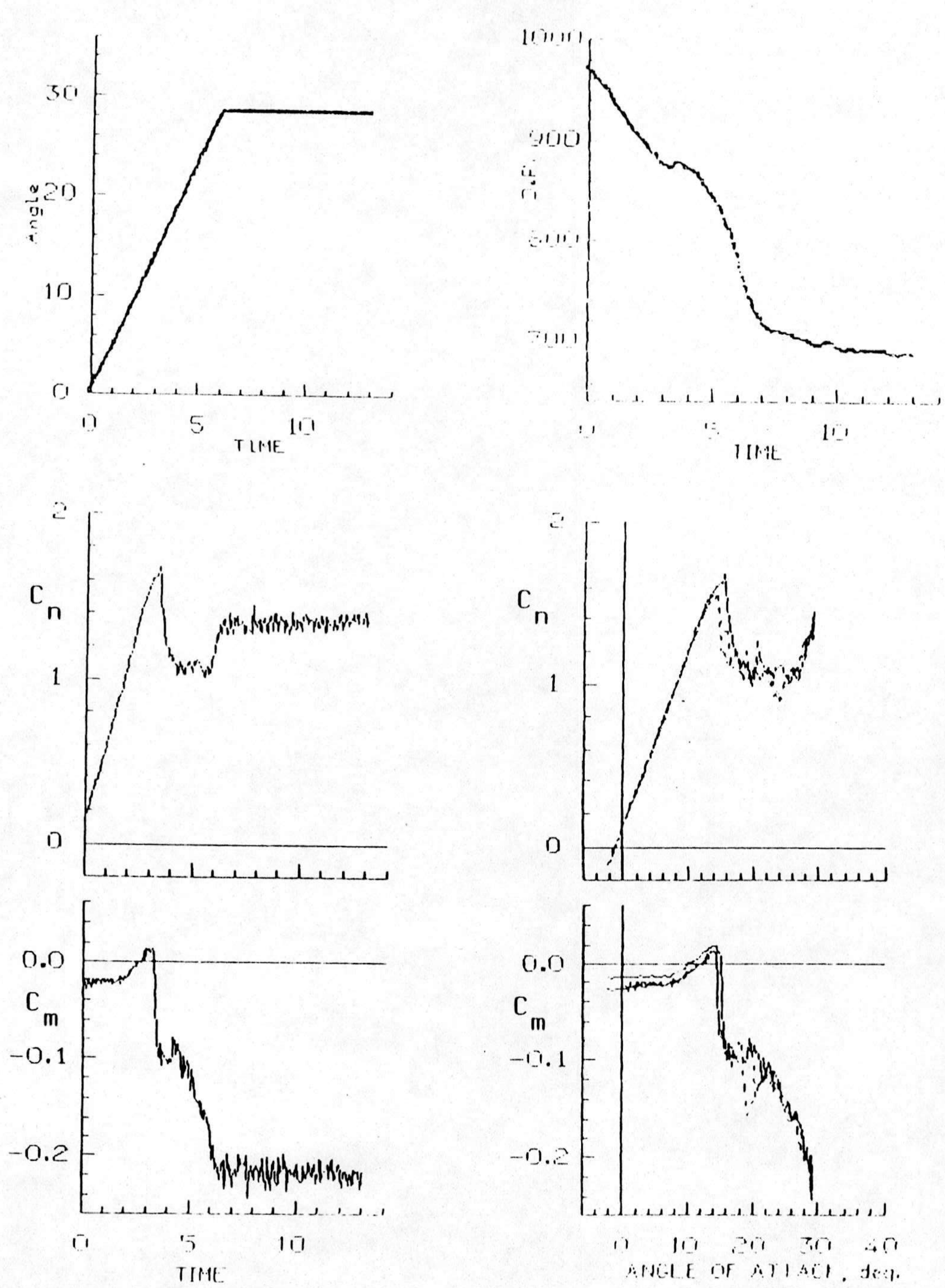
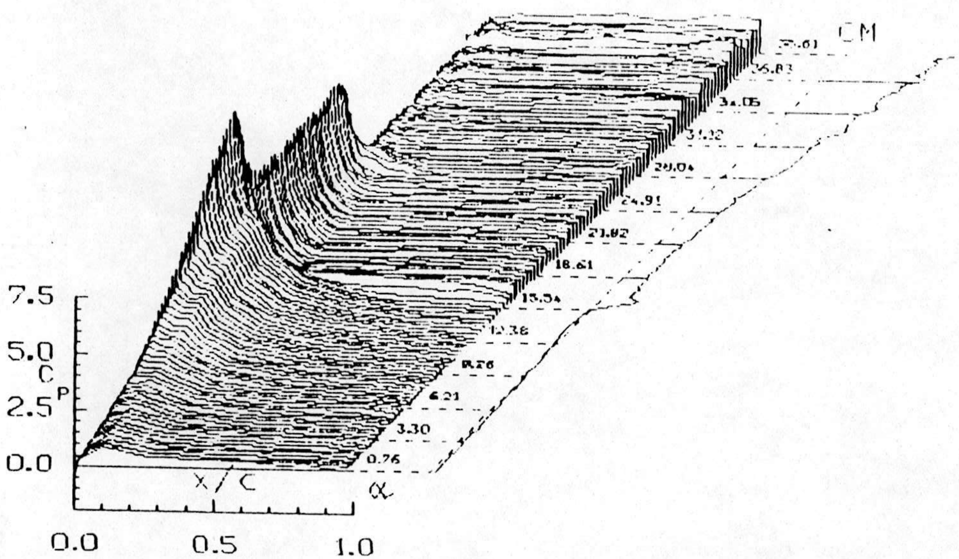


FIG. 14

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20351	DATE OF TEST: 24/ 5/84
REYNOLDS NUMBER= 1522166.	MACH NUMBER= 0.113
DYNAMIC PRESSURE= 994.67 N/sq.M	AIR TEMPERATURE= 28.0 Deg.C
NUMBER OF CYCLES= 5	SAMPLING FREQUENCY= 24.46 Hz.
MOTION TYPE: RAMP	REUCED FREQUENCY = 0.00093
PITCH RATE= 7.67 DEG./SEC	AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



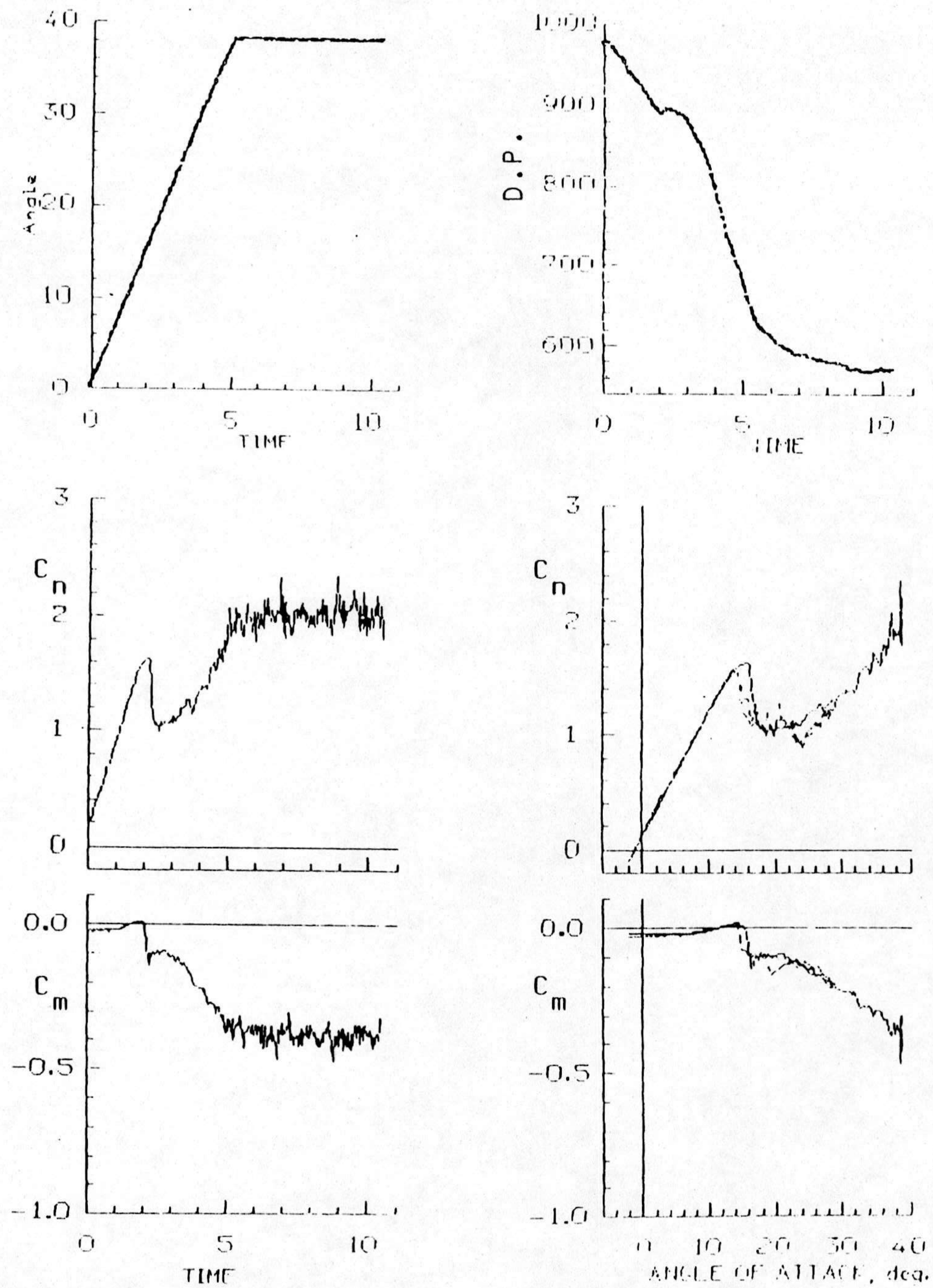


FIG. 15

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20361 DATE OF TEST: 24/5/84

REYNOLDS NUMBER= 1534716. MACH NUMBER= 0.114

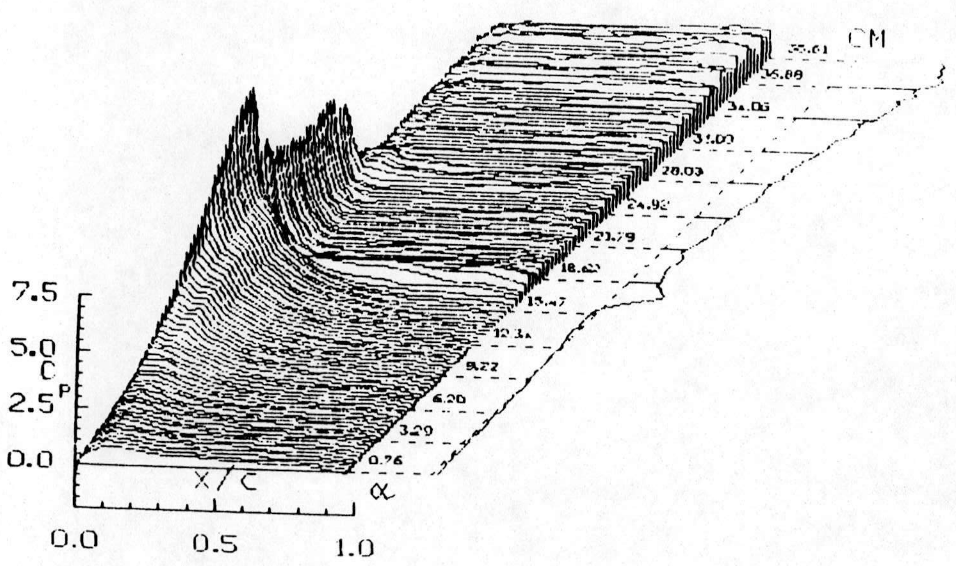
DYNAMIC PRESSURE= 1013.94 N/sq.M AIR TEMPERATURE= 28.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 48.92 Hz.

MOTION TYPE: RAMP REUCED FREQUENCY = 0.00184

PITCH RATE= 15.32 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



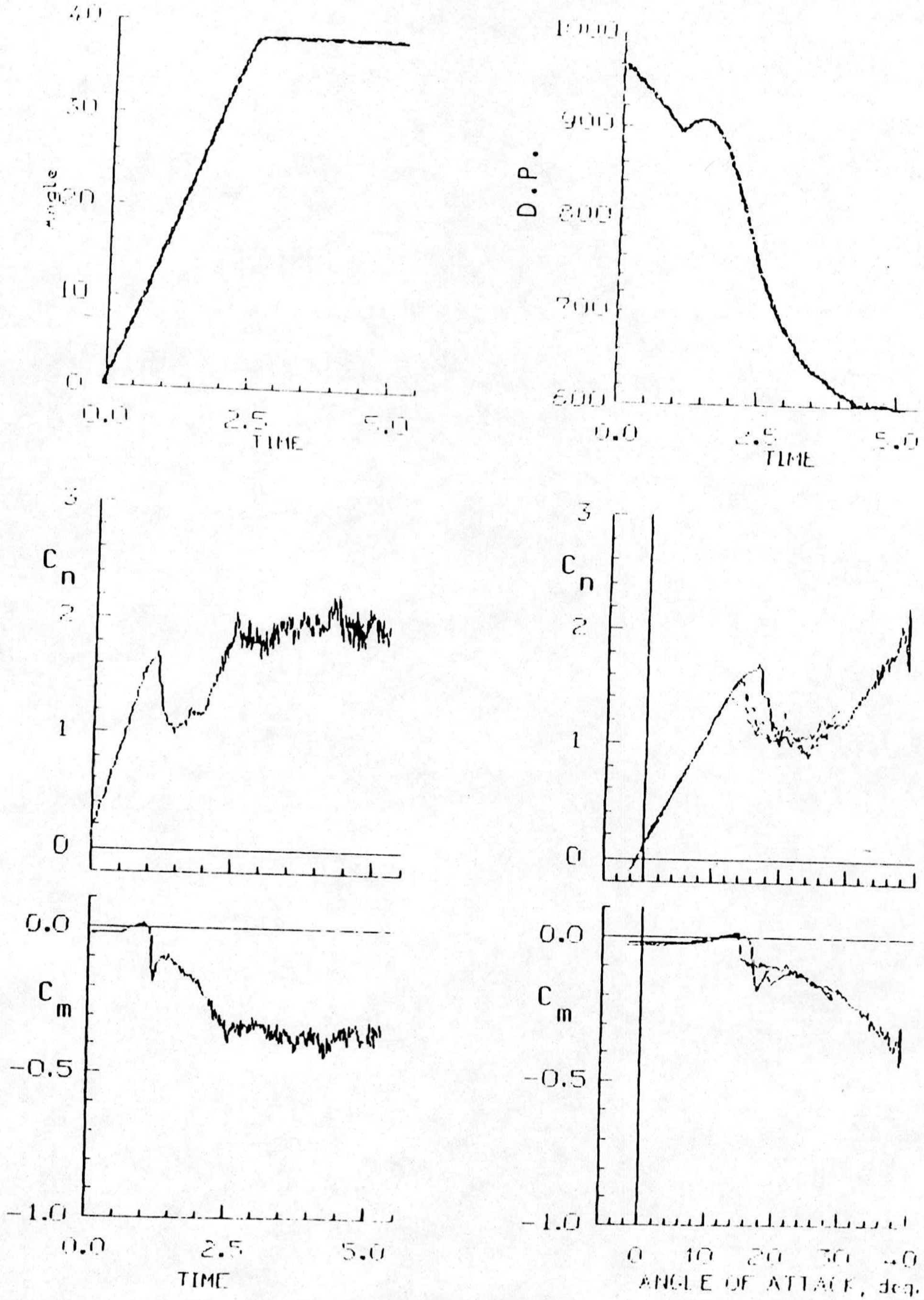
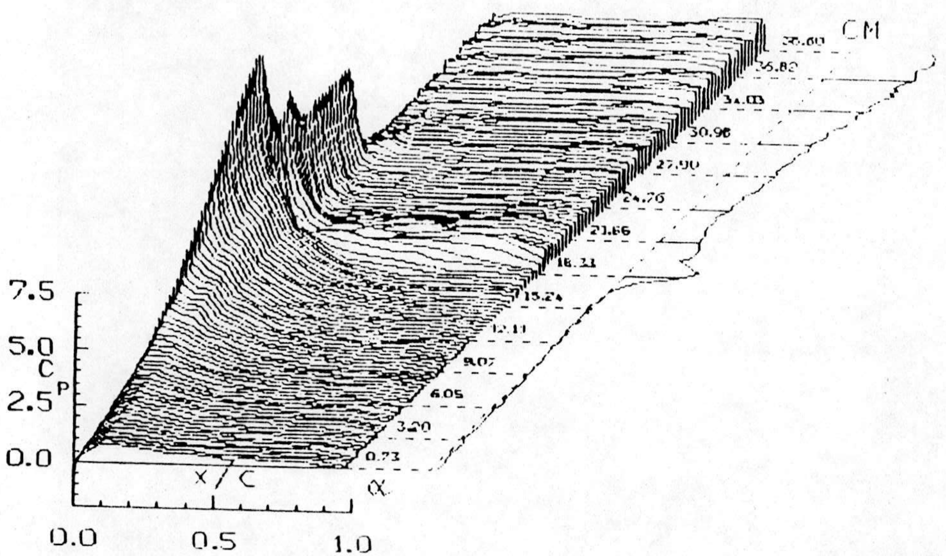
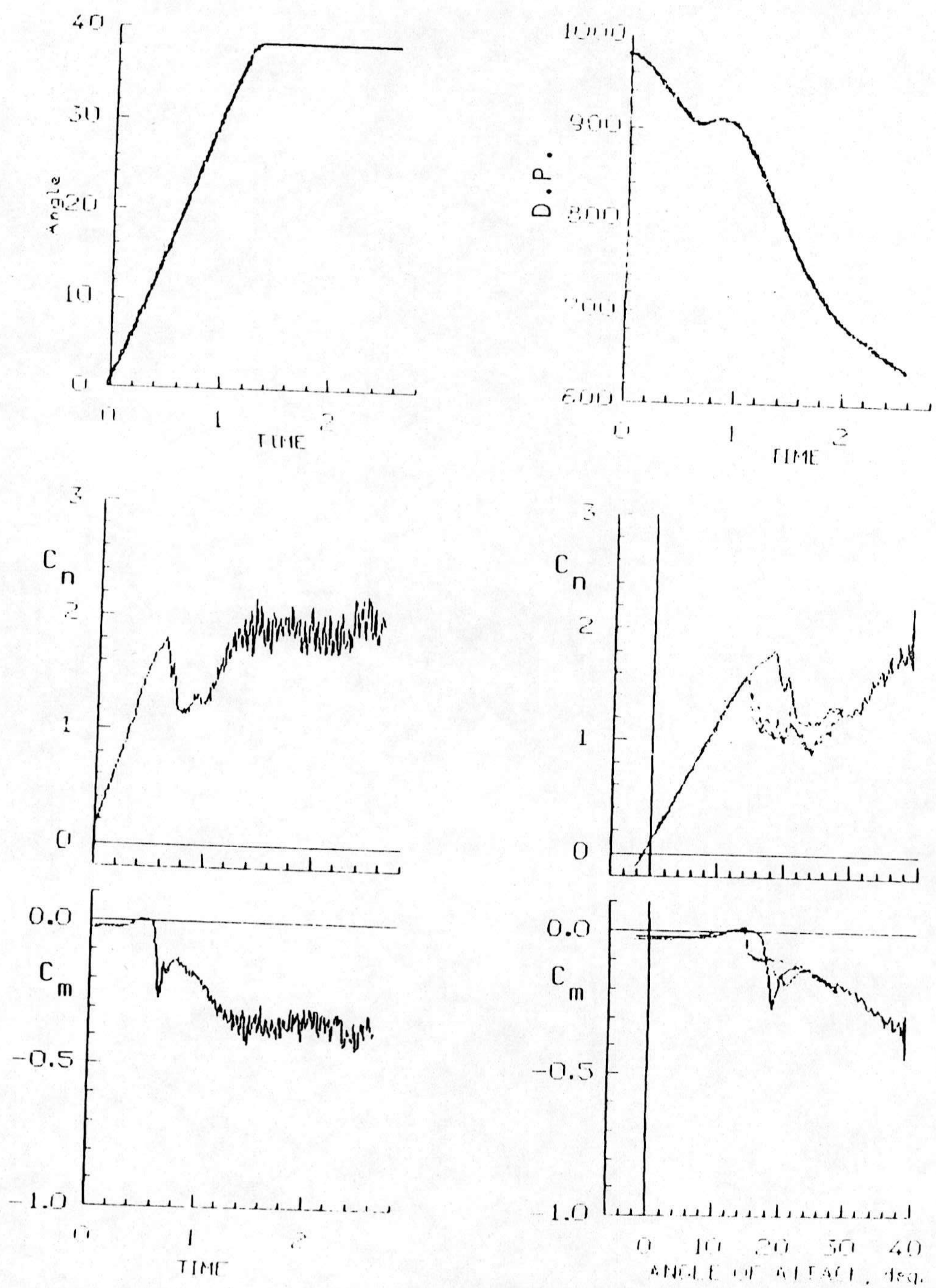


FIG. 16



RAMP RESPONSE OF THE NACA23012
RUN REFERENCE NUMBER: 20371
DATE OF TEST: 24/ 5/84
REYNOLDS NUMBER= 1537479.
MACH NUMBER= 0.115
DYNAMIC PRESSURE= 1020.41 N/sq.M
AIR TEMPERATURE= 29.0 Deg.C
NUMBER OF CYCLES= 5
SAMPLING FREQUENCY= 97.84 Hz.
MOTION TYPE: RAMP
REDUCED FREQUENCY = 0.00370
PITCH RATE= 30.84 DEG./SEC.
AVERAGE DATA OF 5 CYCLES
DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE
CM
7.5
5.0
2.5
0.0
C
P
X / C
0.0
0.5
1.0
α
0.73
3.20
6.05
9.07
12.11
15.24
18.31
21.66
24.76
27.90
30.98
34.03
36.82
38.60



Angle
D.P.
C
n
C
m
TIME
ANGLE OF ATTACK, deg.

FIG. 17

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20381	DATE OF TEST: 24/ 5/84
REYNOLDS NUMBER= 1506382.	MACH NUMBER= 0.112
DYNAMIC PRESSURE= 974.15 N/sq.M	AIR TEMPERATURE= 28.0 Deg.C
NUMBER OF CYCLES= 5	SAMPLING FREQUENCY= 146.76 Hz.
MOTION TYPE: RAMP	REUCED FREQUENCY = 0.00572
PITCH RATE= 46.58 DEG./SEC	AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE

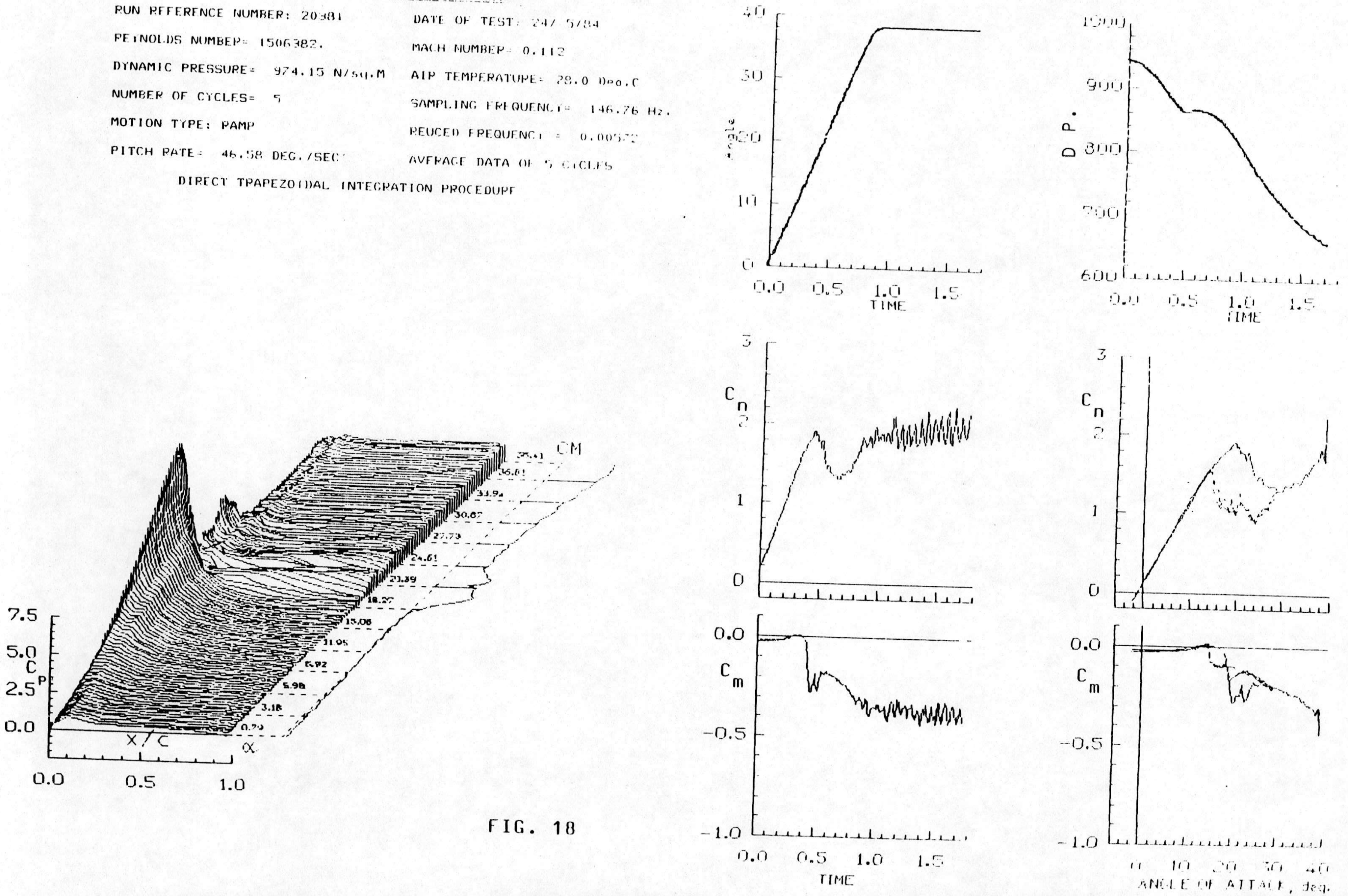


FIG. 18

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20391   DATE OF TEST: 24/ 5/84

REYNOLDS NUMBER= 1519387.   MACH NUMBER= 0.113

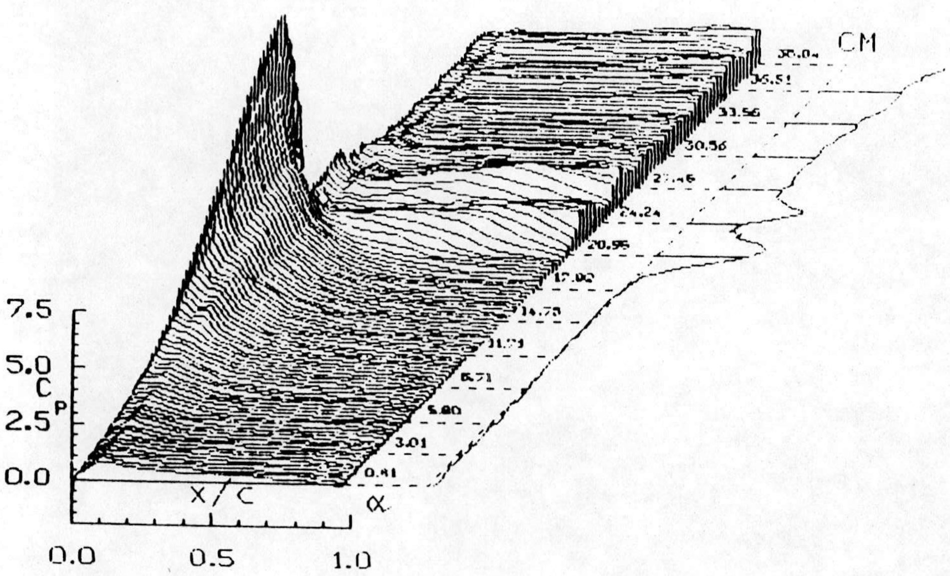
DYNAMIC PRESSURE= 992.48 N/sq.M   AIR TEMPERATURE= 28.5 Deg.C

NUMBER OF CYCLES= 5   SAMPLING FREQUENCY= 195.66 Hz.

MOTION TYPE: RAMP   REUCED FREQUENCY = 0.00748

PITCH RATE= 61.57 DEG./SEC   AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



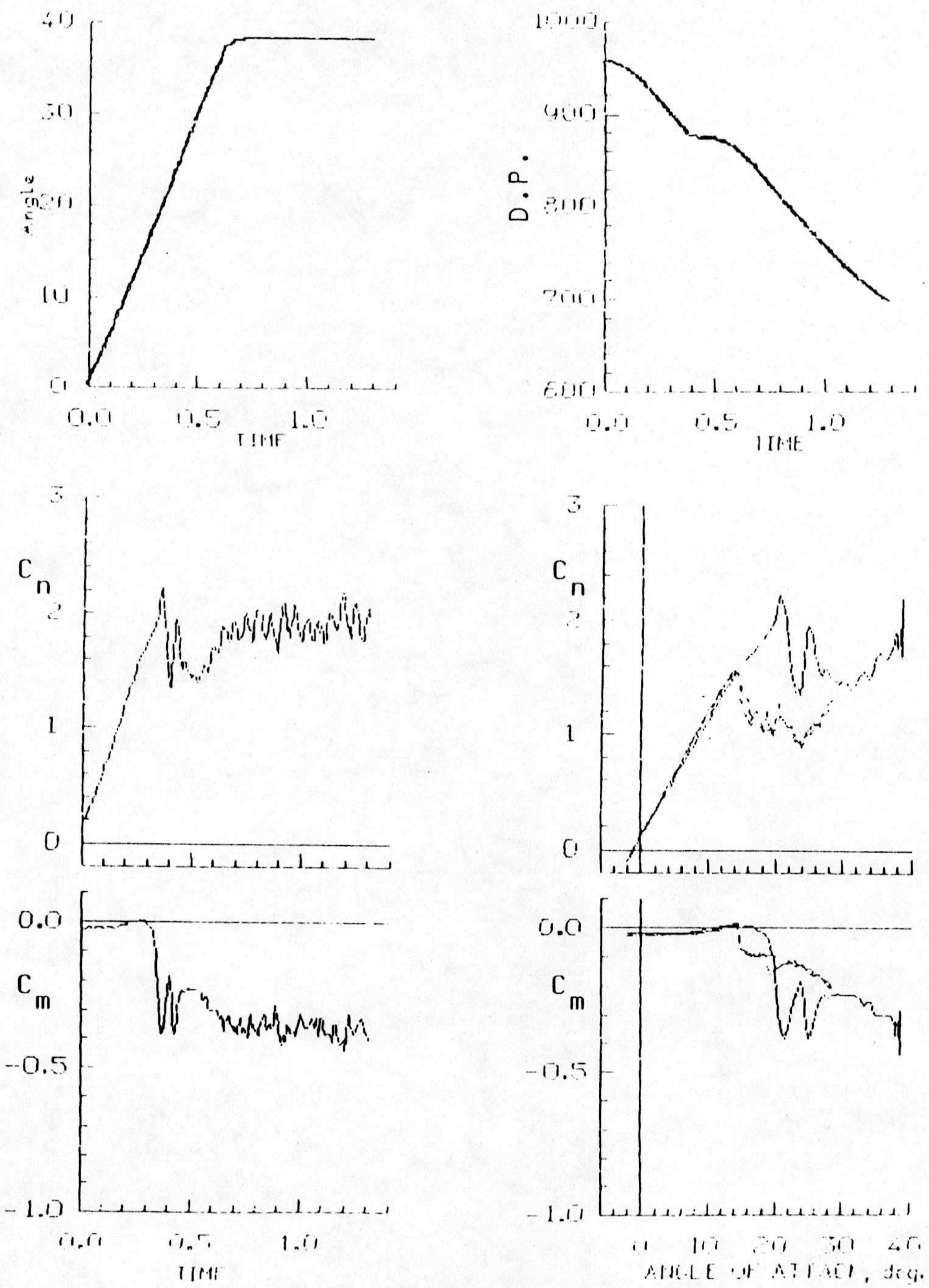


FIG. 19

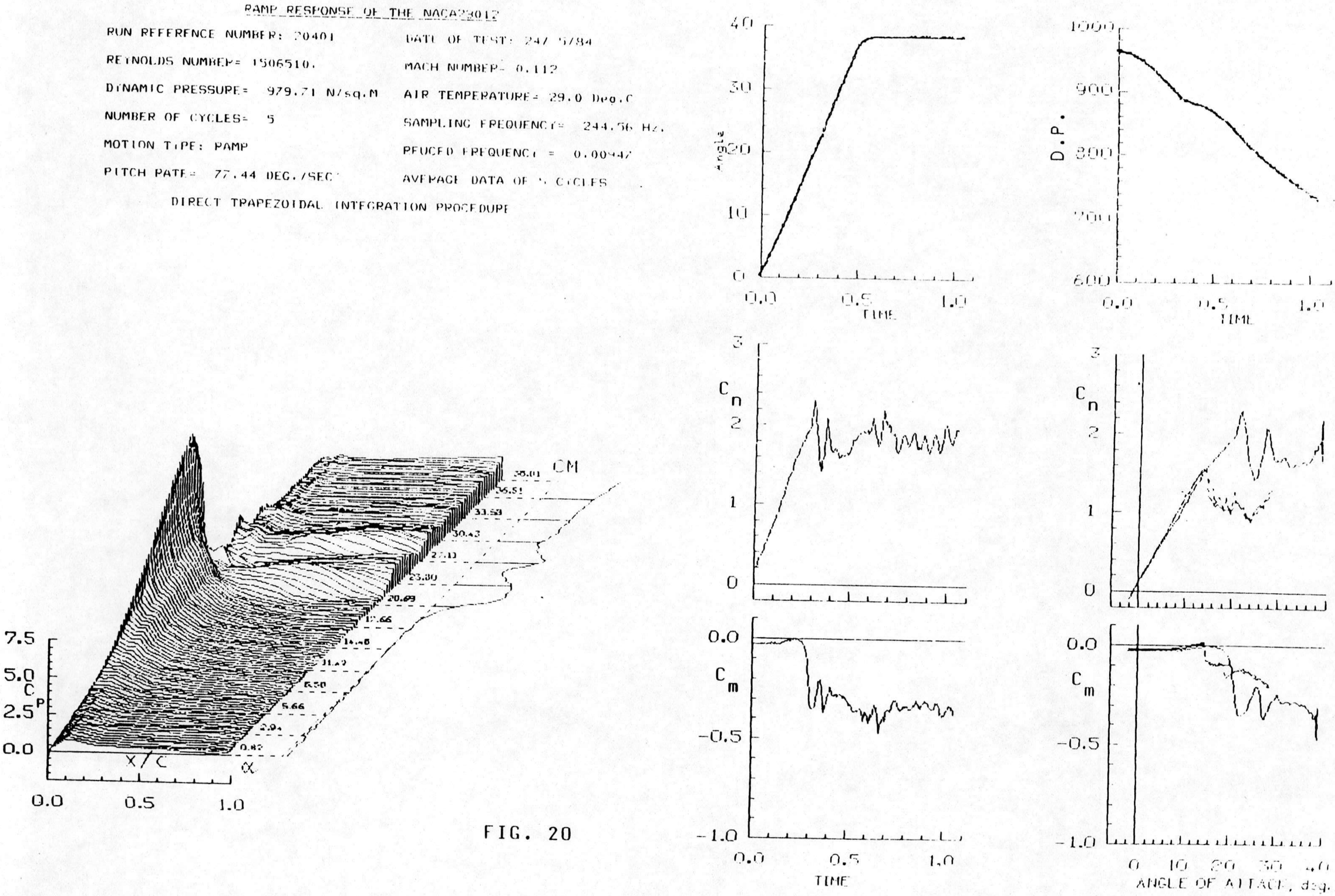

RAMP RESPONSE OF THE NACA23012
RUN REFERENCE NUMBER: 20401
DATE OF TEST: 24/ 5/84
REYNOLDS NUMBER= 1506510.
MACH NUMBER= 0.112
DYNAMIC PRESSURE= 979.71 N/sq.M
AIR TEMPERATURE= 29.0 Deg.C
NUMBER OF CYCLES= 5
SAMPLING FREQUENCY= 244.56 Hz.
MOTION TYPE: RAMP
REDUCED FREQUENCY = 0.00947
PITCH RATE= 77.44 DEG./SEC
AVERAGE DATA OF 5 CYCLES
DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE
CM
38.01
36.51
33.59
30.43
27.11
23.80
20.69
17.66
14.48
11.42
8.50
5.66
2.94
0.82
α
X/C
C_P
7.5
5.0
2.5
0.0
0.0
0.5
1.0
Angle
40
30
20
10
0
D.P.
1000
900
800
700
600
TIME
0.0
0.5
1.0
C_n
3
2
1
0
C_m
0.0
-0.5
-1.0
ANGLE OF ATTACK, deg.
0
10
20
30
40

FIG. 20

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20411 — DATE OF TEST: 24/ 5/84

REYNOLDS NUMBER= 1522869. — MACH NUMBER= 0.114

DYNAMIC PRESSURE= 1001.11 N/sq.M — AIR TEMPERATURE= 29.0 Deg.C

NUMBER OF CYCLES= 5 — SAMPLING FREQUENCY= 293.51 Hz.

MOTION TYPE: RAMP — REUCED FREQUENCY = 0.01124

PITCH RATE= 92.88 DEG./SEC — AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE

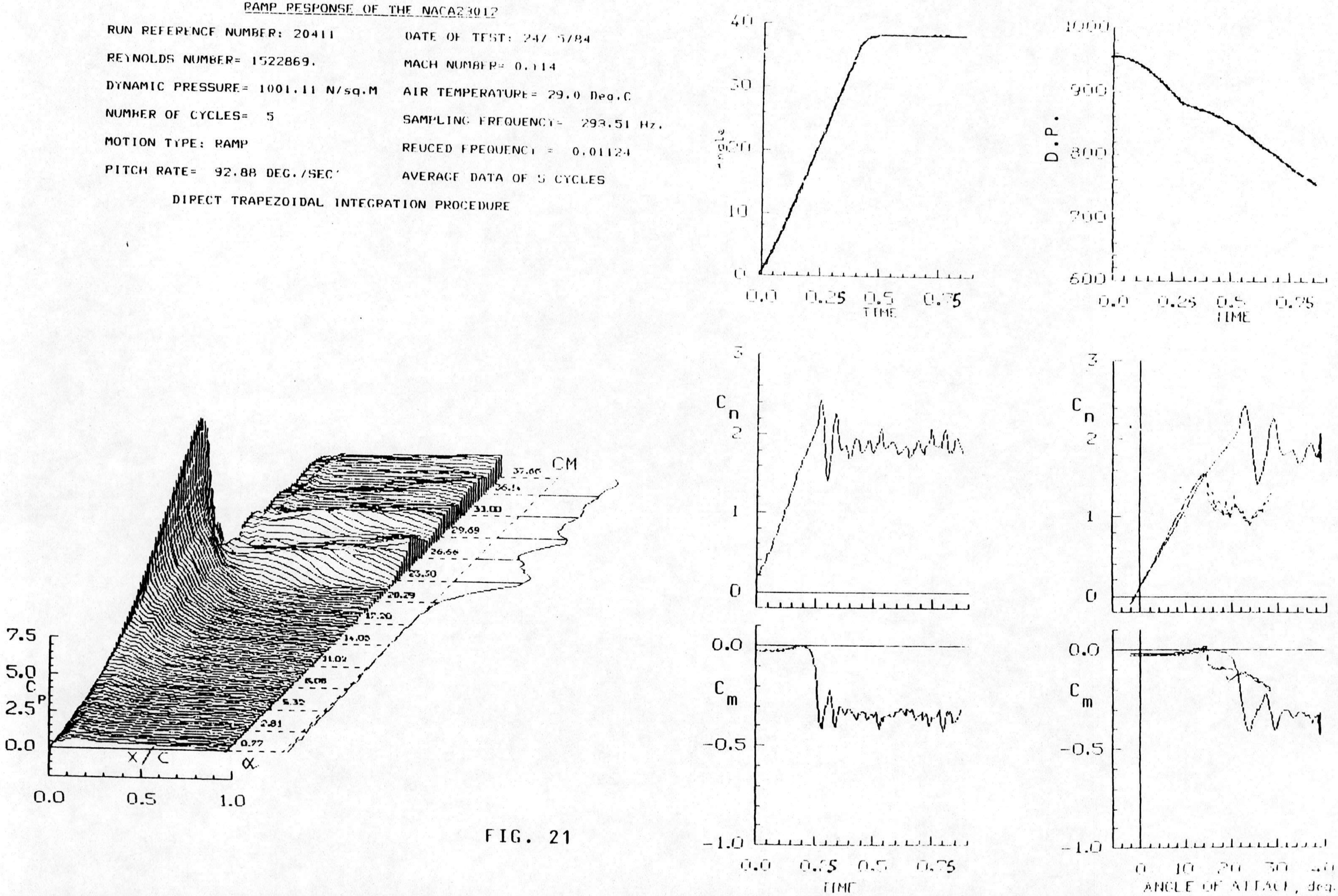


FIG. 21

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20421 DATE OF TEST: 247 5/84

REYNOLDS NUMBER= 1518624. MACH NUMBER= 0.113

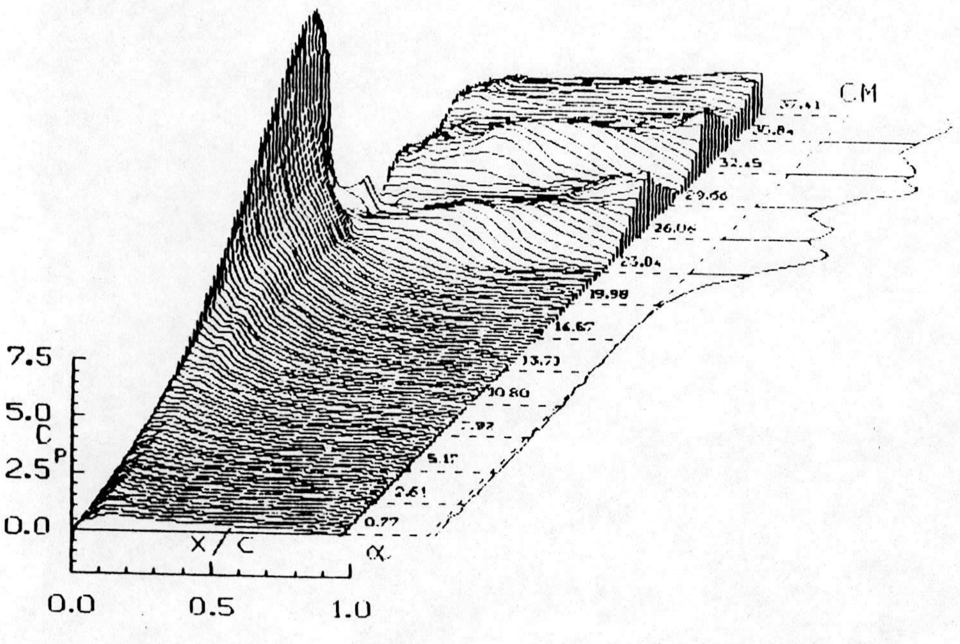
DYNAMIC PRESSURE= 998.28 N/sq.M AIR TEMPERATURE= 29.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 342.47 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.01317

PITCH RATE= 108.64 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



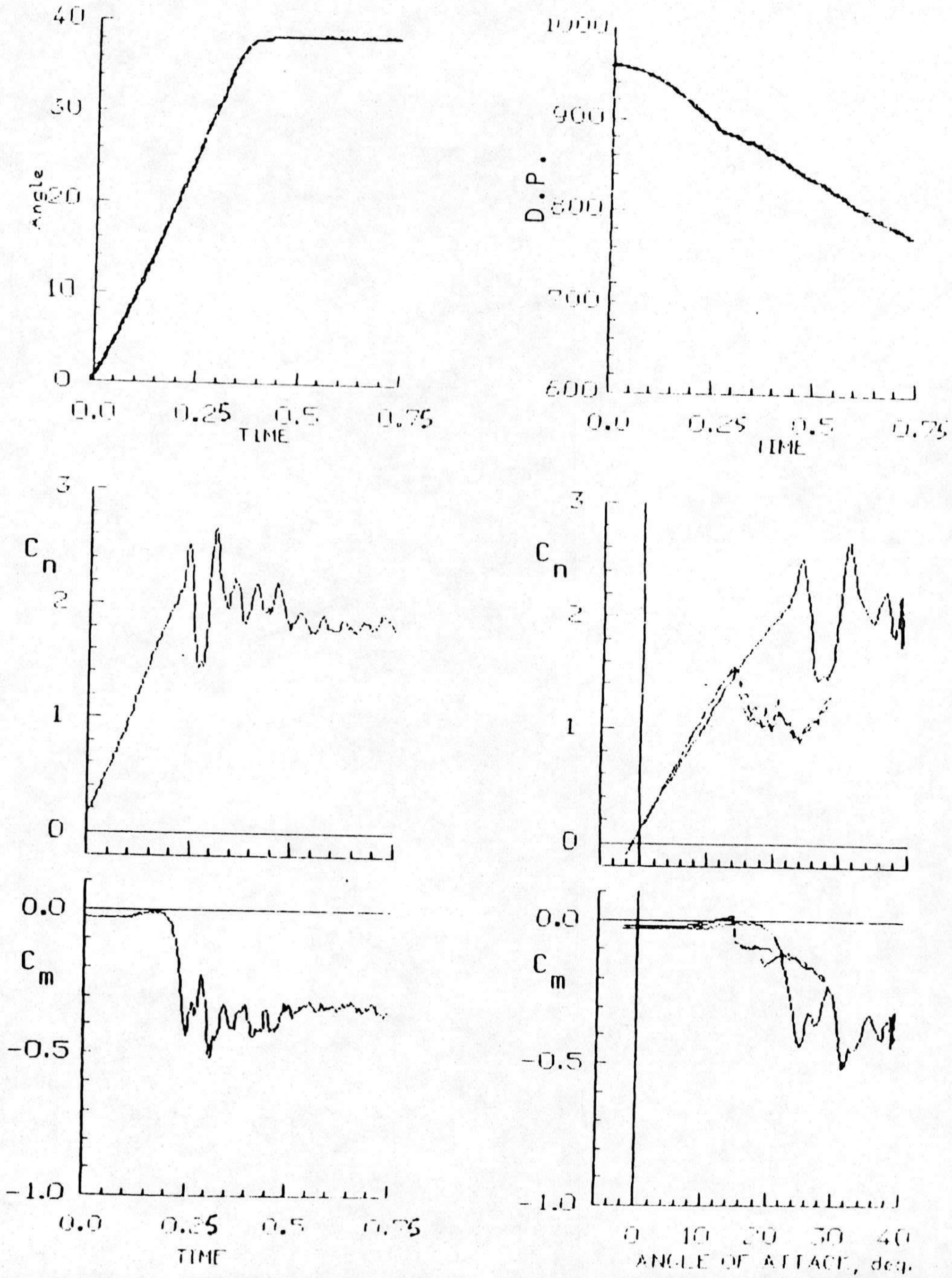


FIG. 22

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20431 DATE OF TEST: 247 5/84

REYNOLDS NUMBER= 1521981. MACH NUMBER 0.114

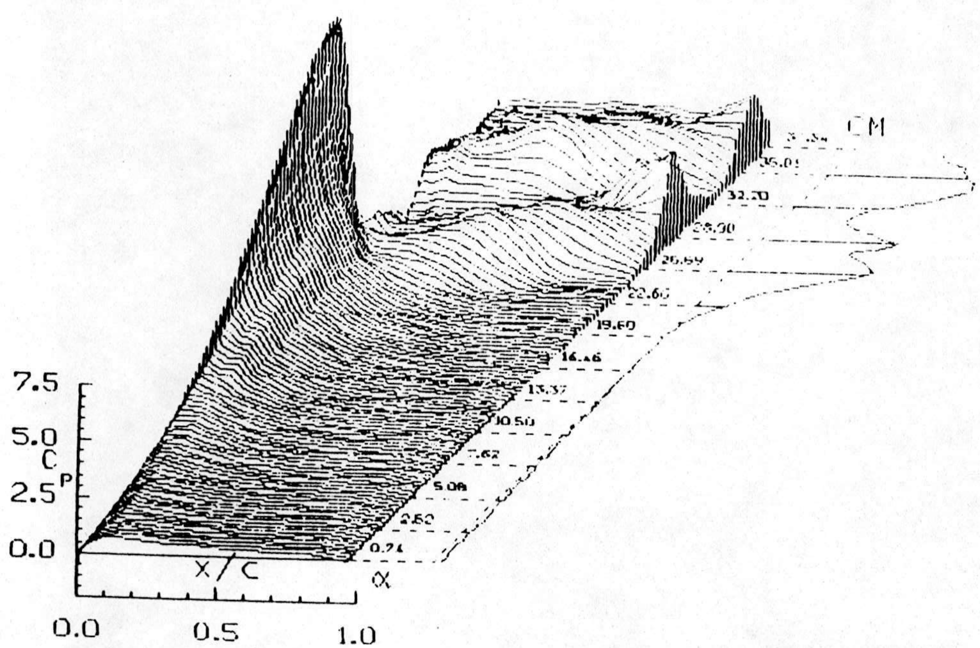
DYNAMIC PRESSURE= 1005.47 N/sq.M AIR TEMPERATURE= 30.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 391.49 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.01453

PITCH RATE= 120.34 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



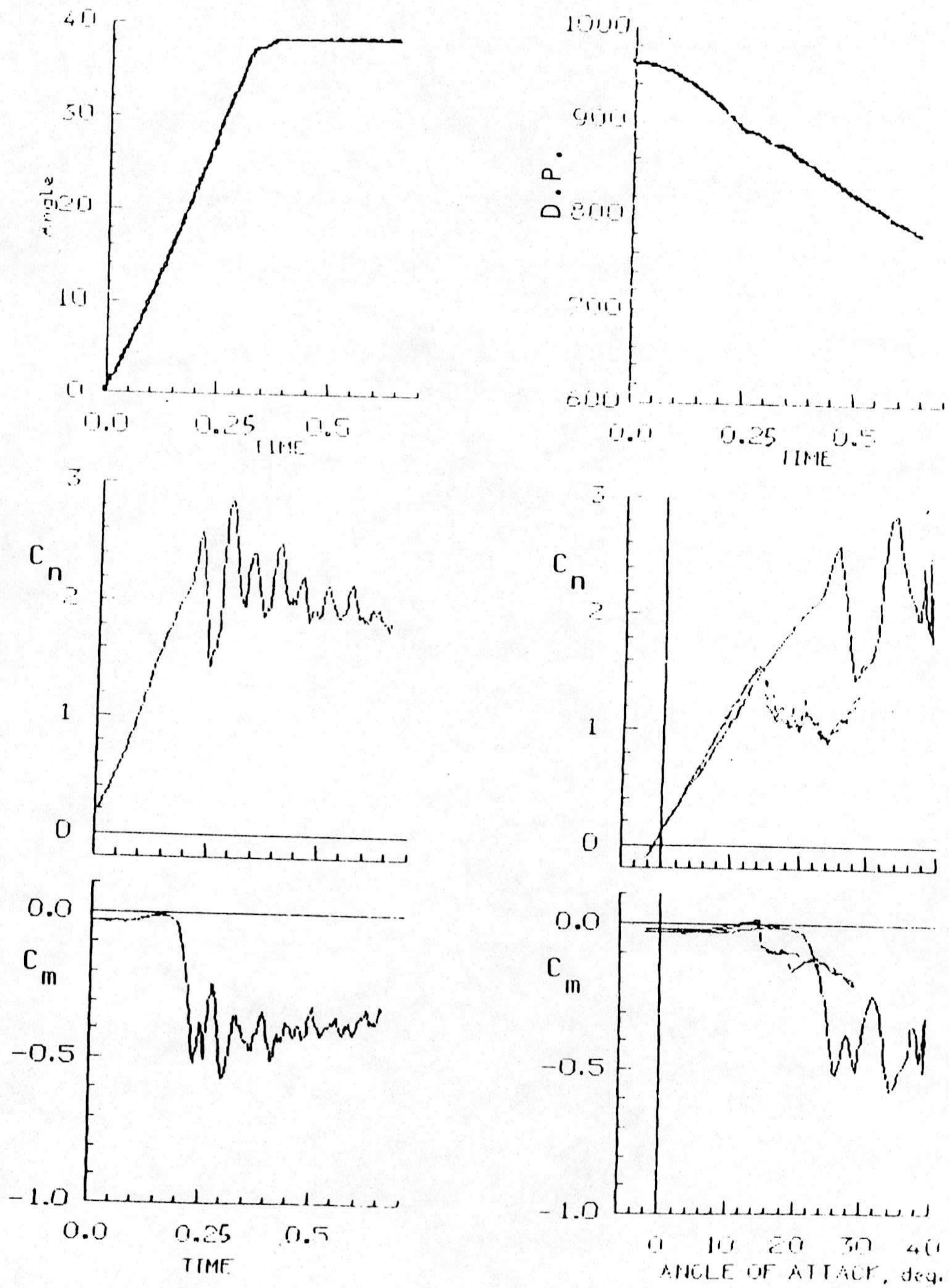


FIG. 23

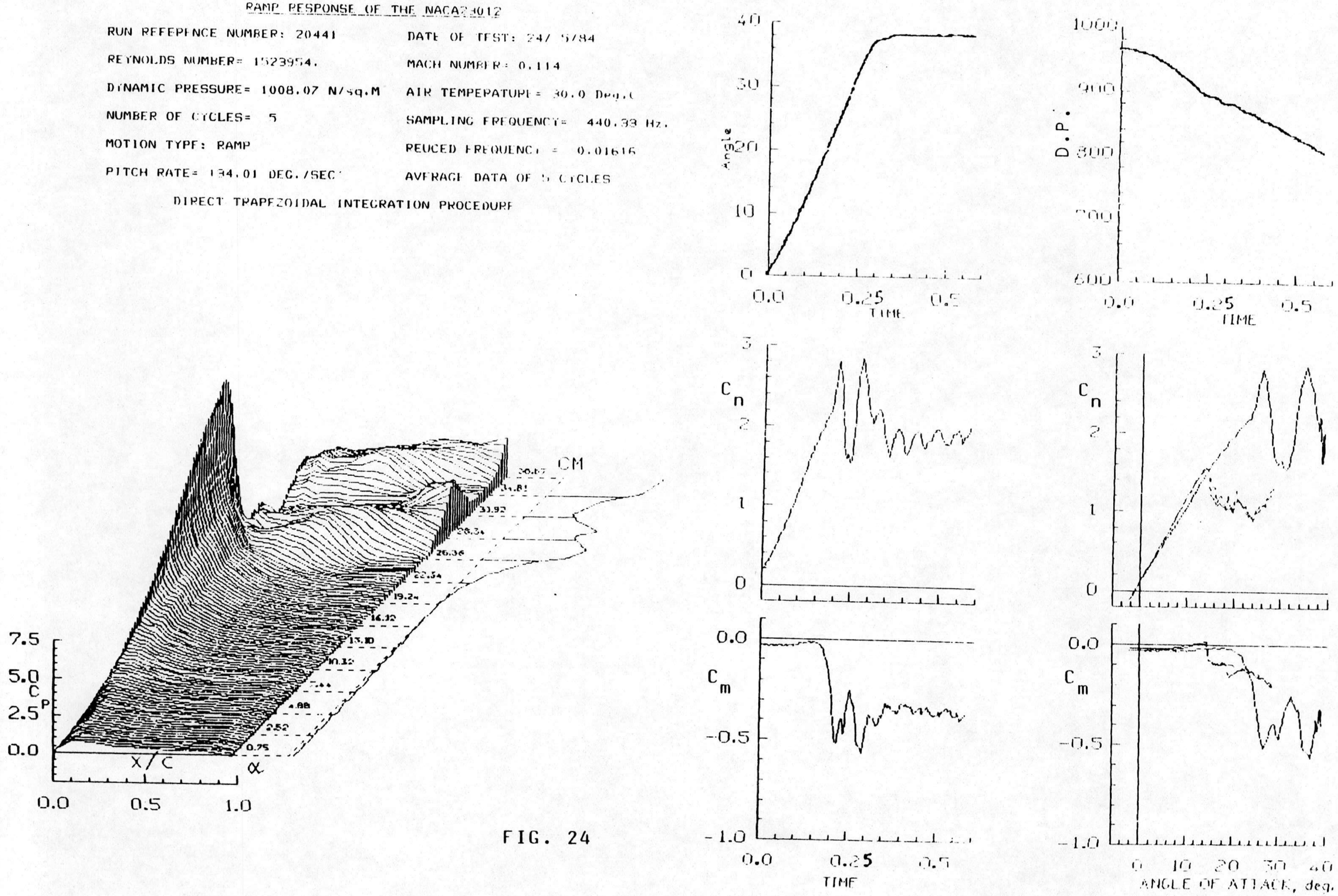

RAMP RESPONSE OF THE NACA23012
RUN REFERENCE NUMBER: 20441
DATE OF TEST: 24/ 5/84
REYNOLDS NUMBER= 1523954.
MACH NUMBER= 0.114
DYNAMIC PRESSURE= 1008.07 N/sq.M
AIR TEMPERATURE= 30.0 Deg.C
NUMBER OF CYCLES= 5
SAMPLING FREQUENCY= 440.33 Hz.
MOTION TYPE: RAMP
REDUCED FREQUENCY = 0.01616
PITCH RATE= 134.01 DEG./SEC
AVERAGE DATA OF 5 CYCLES
DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE
CM
X/C
α
Angle
D.P.
TIME
ANGLE OF ATTACK, deg.

FIG. 24

RAMP RESPONSE OF THE NACA23012

PUN REFERENCE NUMBER: 20451 DATE OF TEST: 24/ /84

REYNOLDS NUMBER= 1510862. MACH NUMBER= 0.113

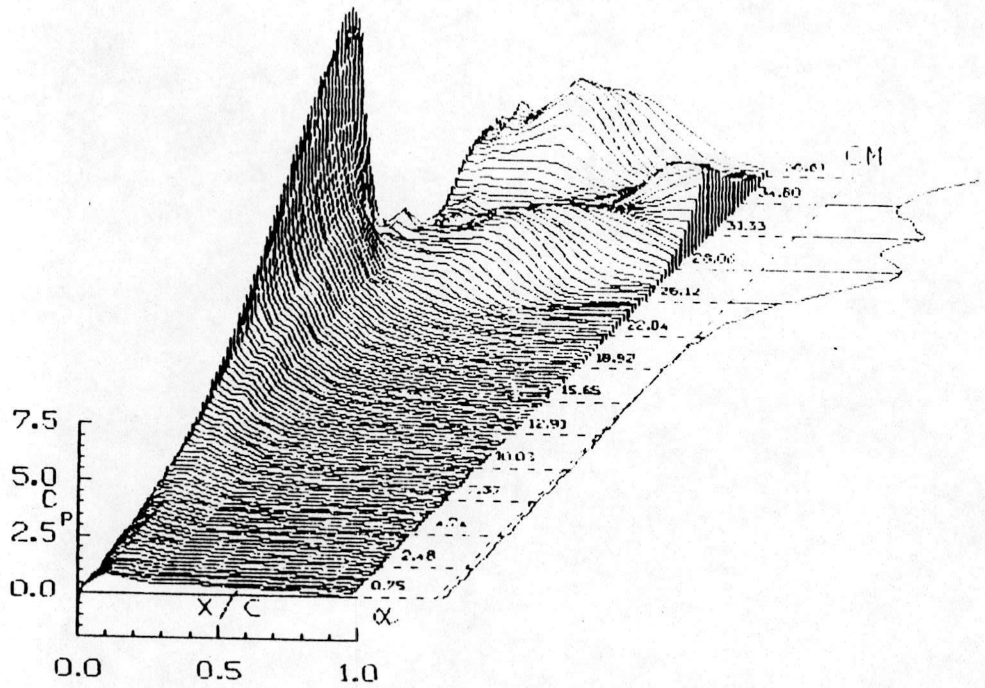
DYNAMIC PRESSURE= 985.38 N/sq.M AIR TEMPERATURE= 29.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 489.24 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.01845

PITCH RATE= 151.25 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



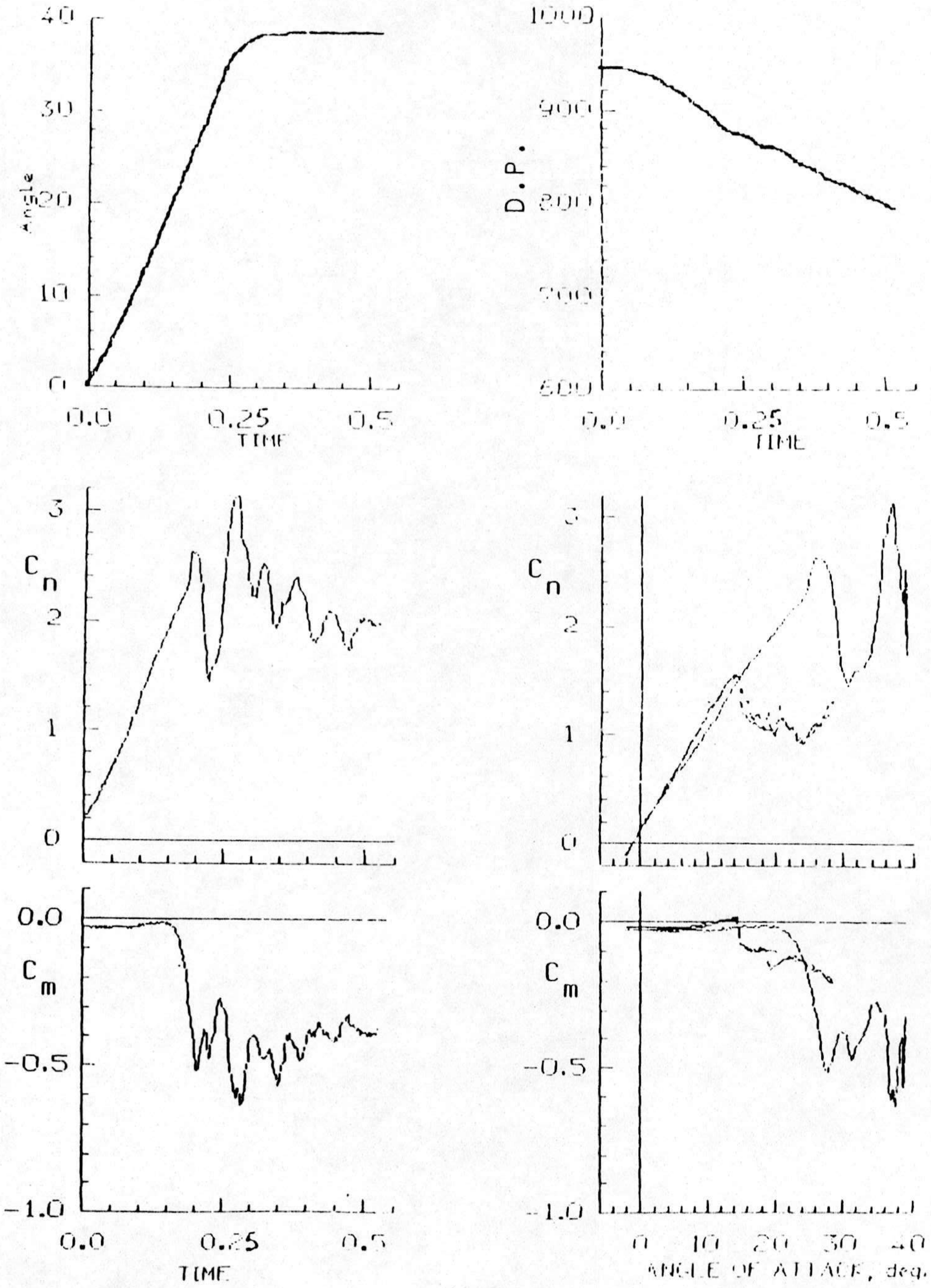


FIG. 25

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20461

DATE OF TEST: 24/ 5/84

PEYNOLDS NUMBER= 1518295.

MACH NUMBER= 0.113

DYNAMIC PRESSUPE= 995.10 N/sq.M

AIR TEMPERATUPE= 29.0 Deg.C

NUMBER OF CYCLES= 5

SAMPLING FREQUENCY= 538.21 Hz.

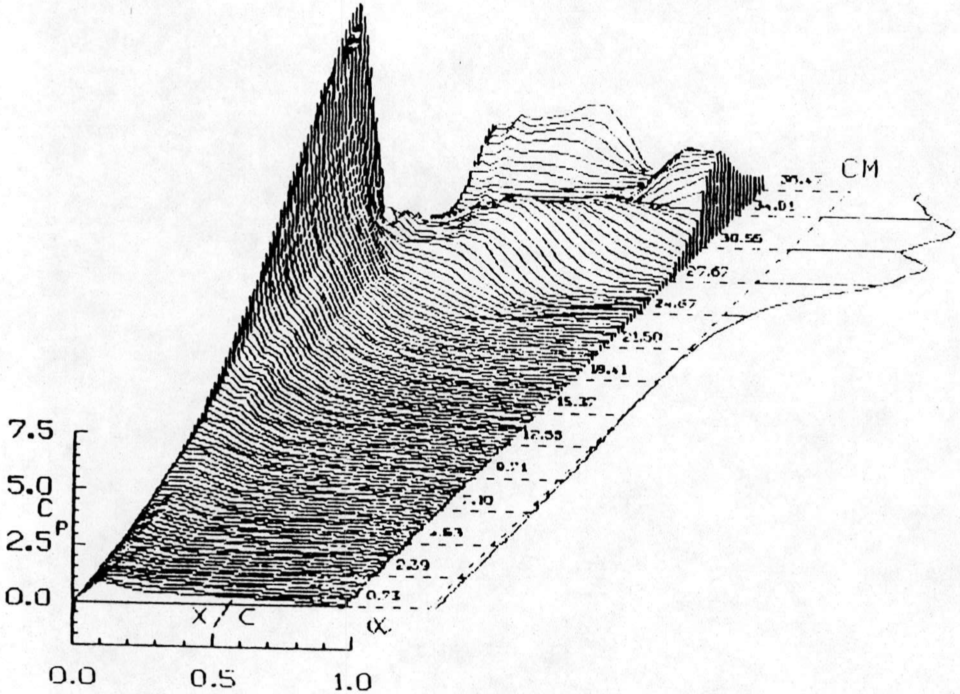
MOTION TYPE: RAMP

REUCED FREQUENCY = 0.01985

PITCH RATE= 163.53 DEG./SEC

AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



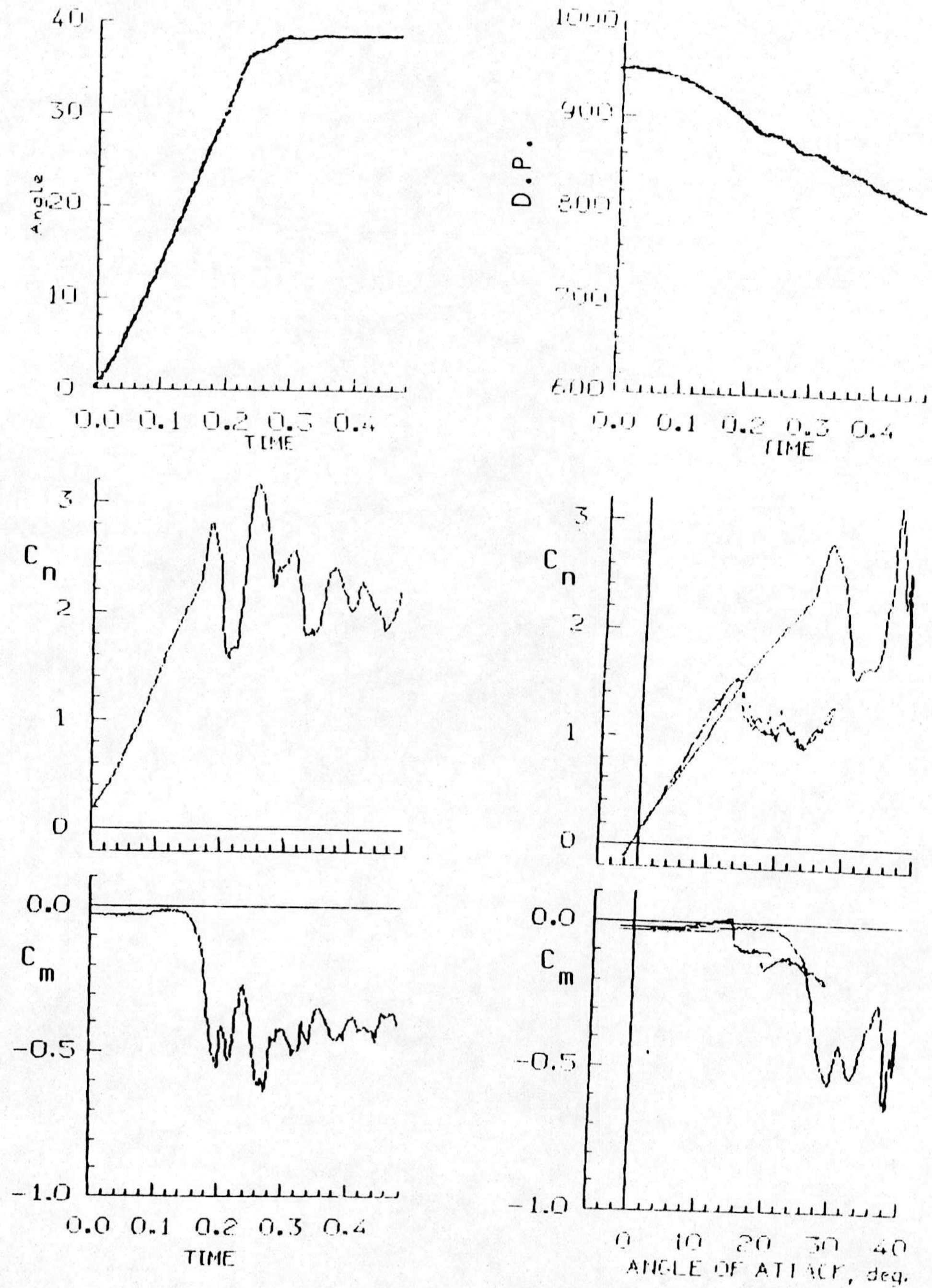


FIG. 26

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20471 DATE OF TEST: 24/ 5/84

REYNOLDS NUMBER= 1525364. MACH NUMBER= 0.114

DYNAMIC PRESSURE= 1007.17 N/sq.M AIR TEMPERATURE= 29.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.02155

PITCH RATE= 178.58 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE

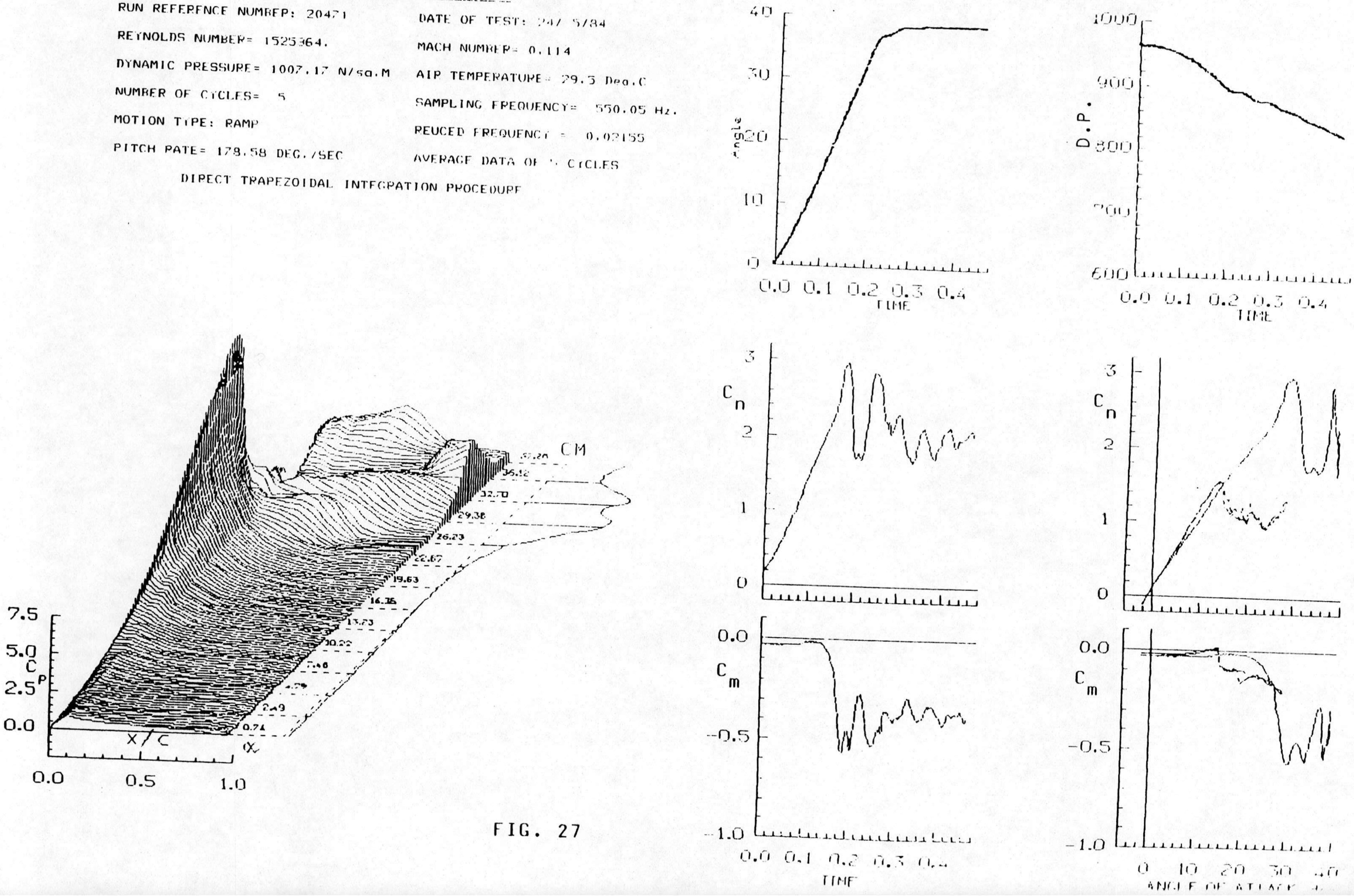


FIG. 27

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20481 DATE OF TEST: 247 5784

REYNOLDS NUMBER= 1521533. MACH NUMBER= 0.114

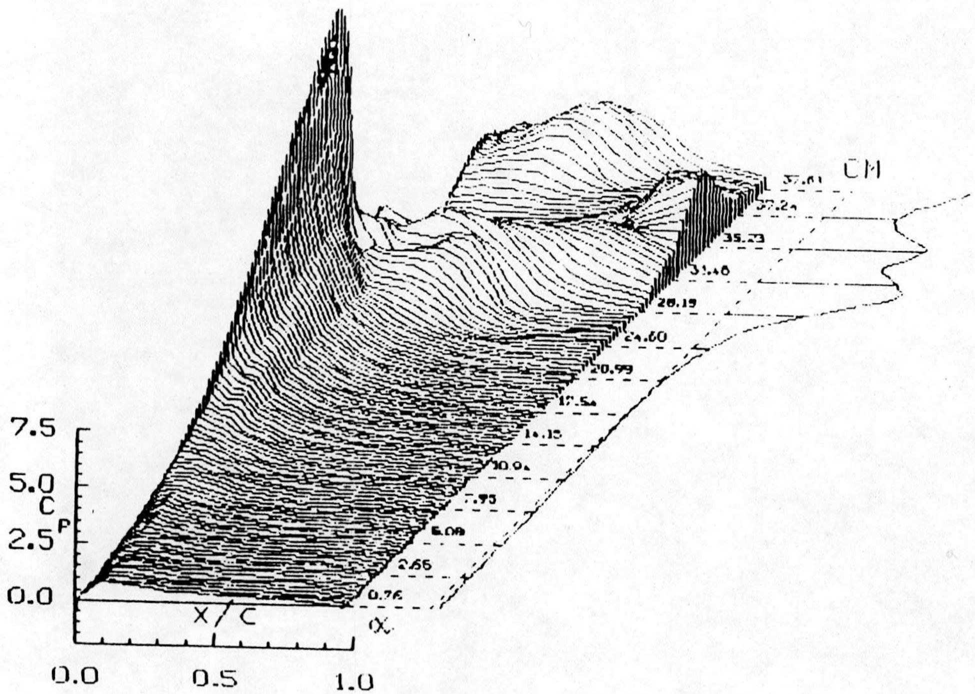
DYNAMIC PRESSURE= 1004.87 N/sq.M AIR TEMPERATURE= 30.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.02332

PITCH RATE= 193.09 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



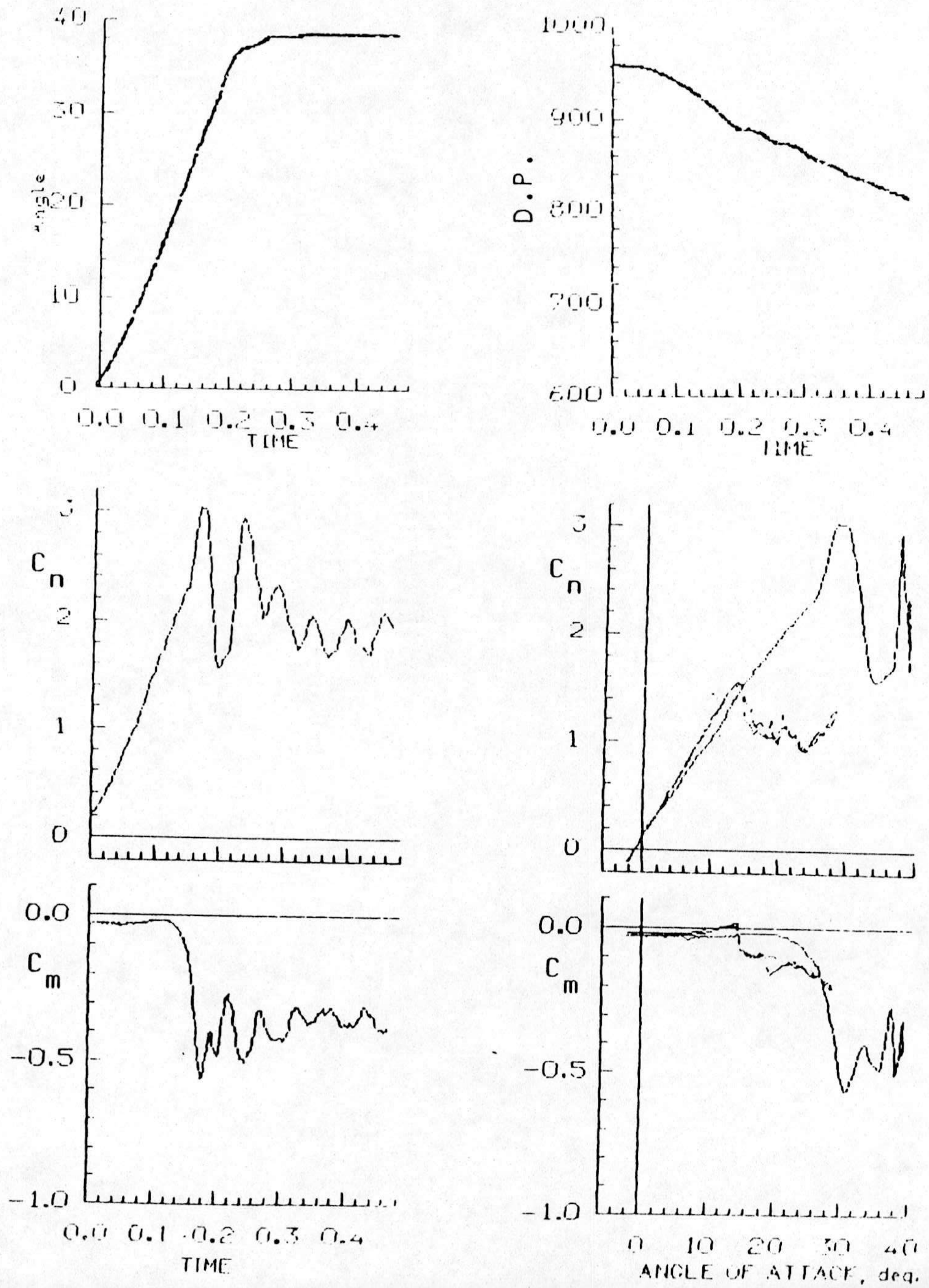


FIG. 28

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20491 DATE OF TEST: 24/ 5/84

REYNOLDS NUMBER= 1523030. MACH NUMBER= 0.114

DYNAMIC PRESSURE= 1009.62 N/sq.M AIR TEMPERATURE= 30.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REUCED FREQUENCY = 0.02496

PITCH RATE= 207.21 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE

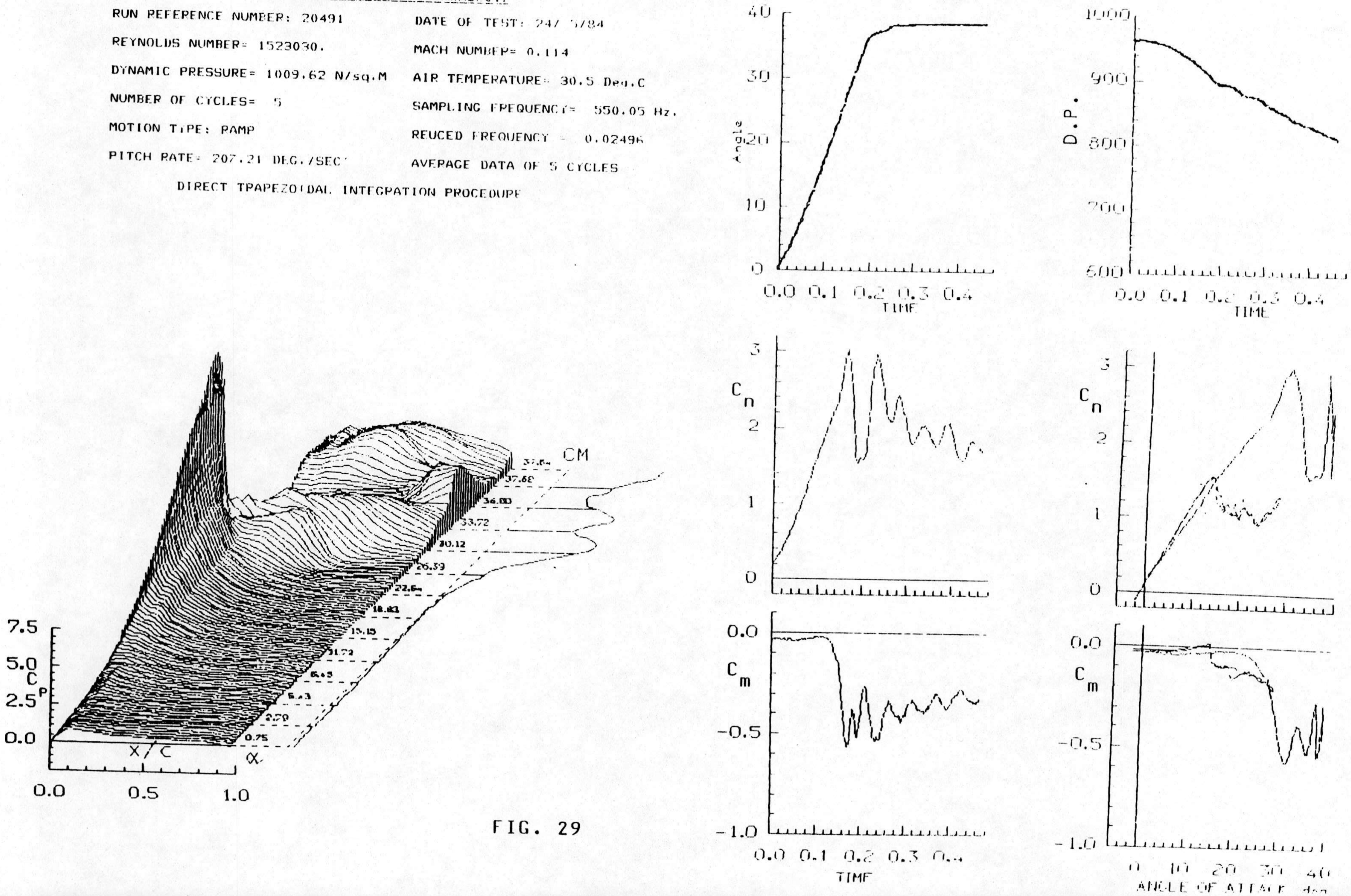


FIG. 29

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20901 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1502769. MACH NUMBER= 0.112

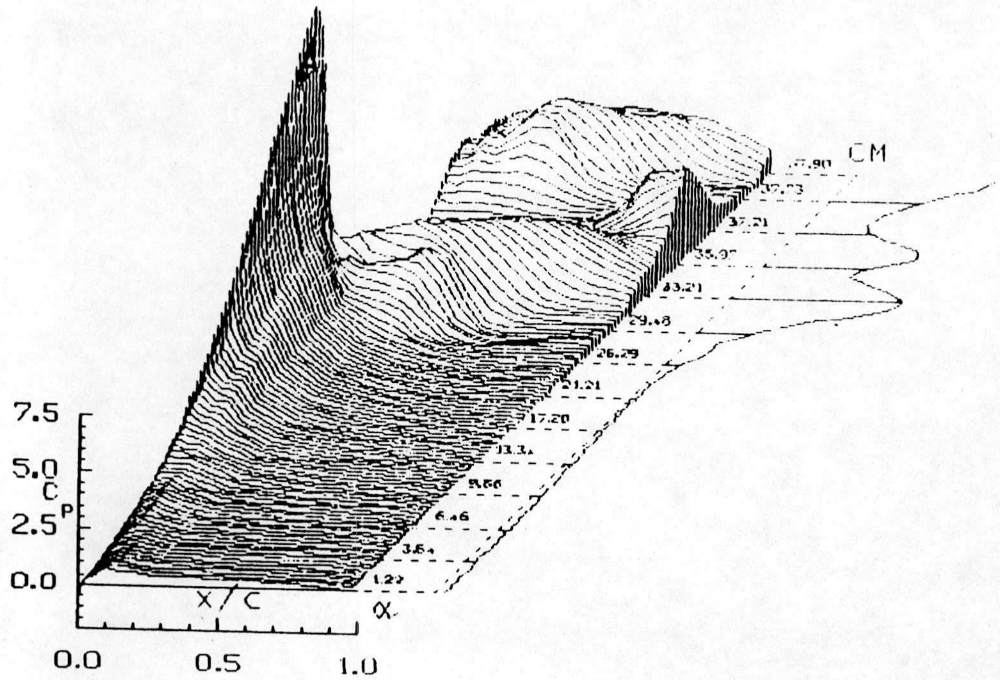
DYNAMIC PRESSURE= 965.96 N/sq.M AIR TEMPERATURE= 28.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.02739

PITCH RATE= 221.95 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



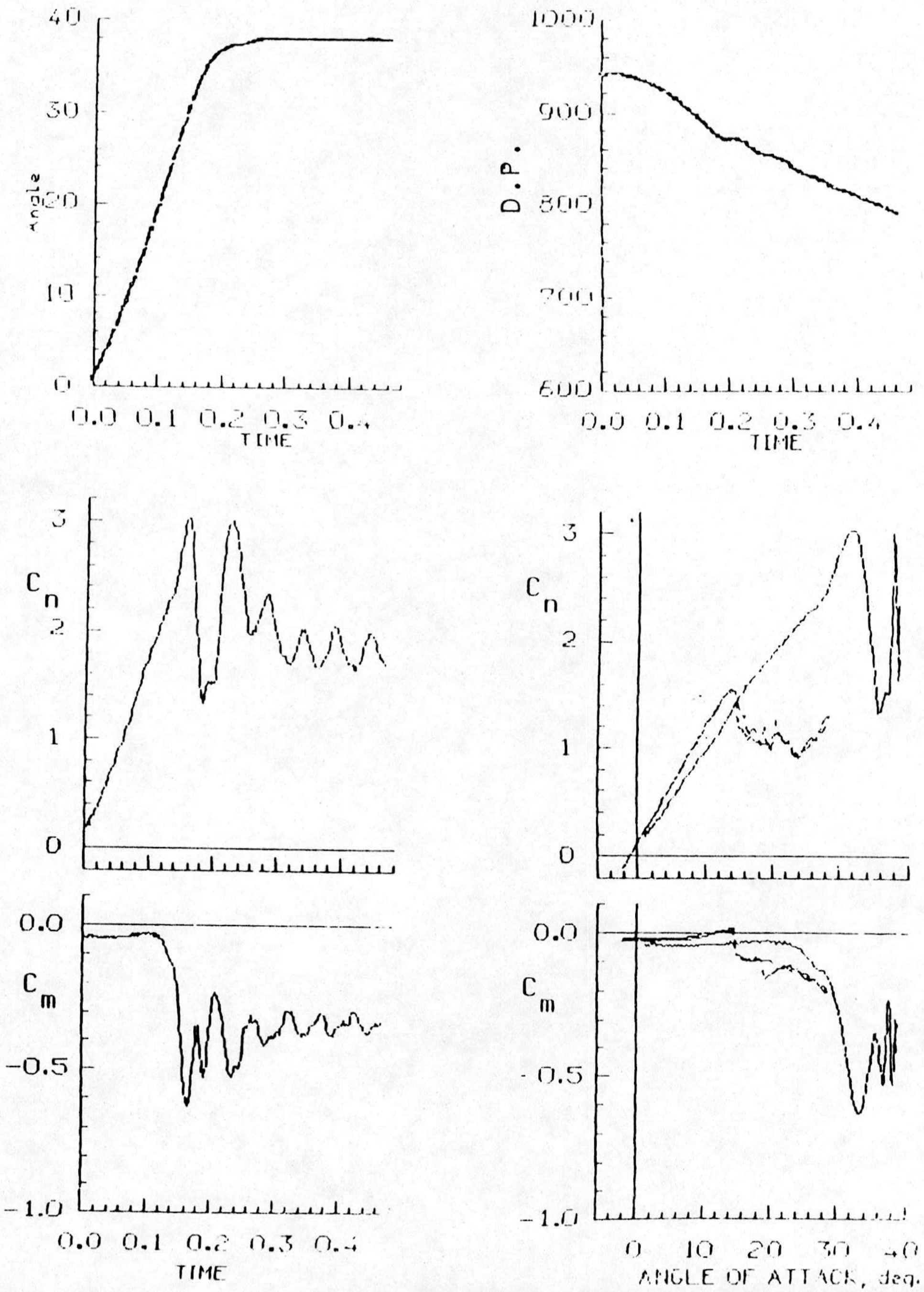


FIG. 30

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20911 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1509078. MACH NUMBER= 0.112

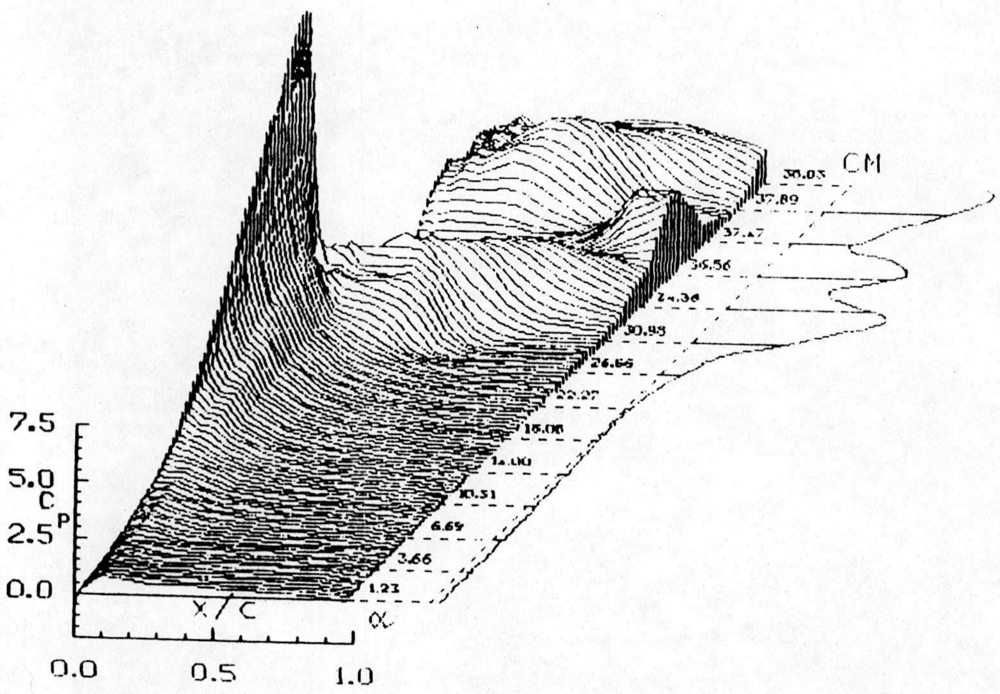
DYNAMIC PRESSURE= 972.04 N/sq.M AIR TEMPERATURE= 27.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REUCED FREQUENCY = 0.02851

PITCH RATE= 231.71 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



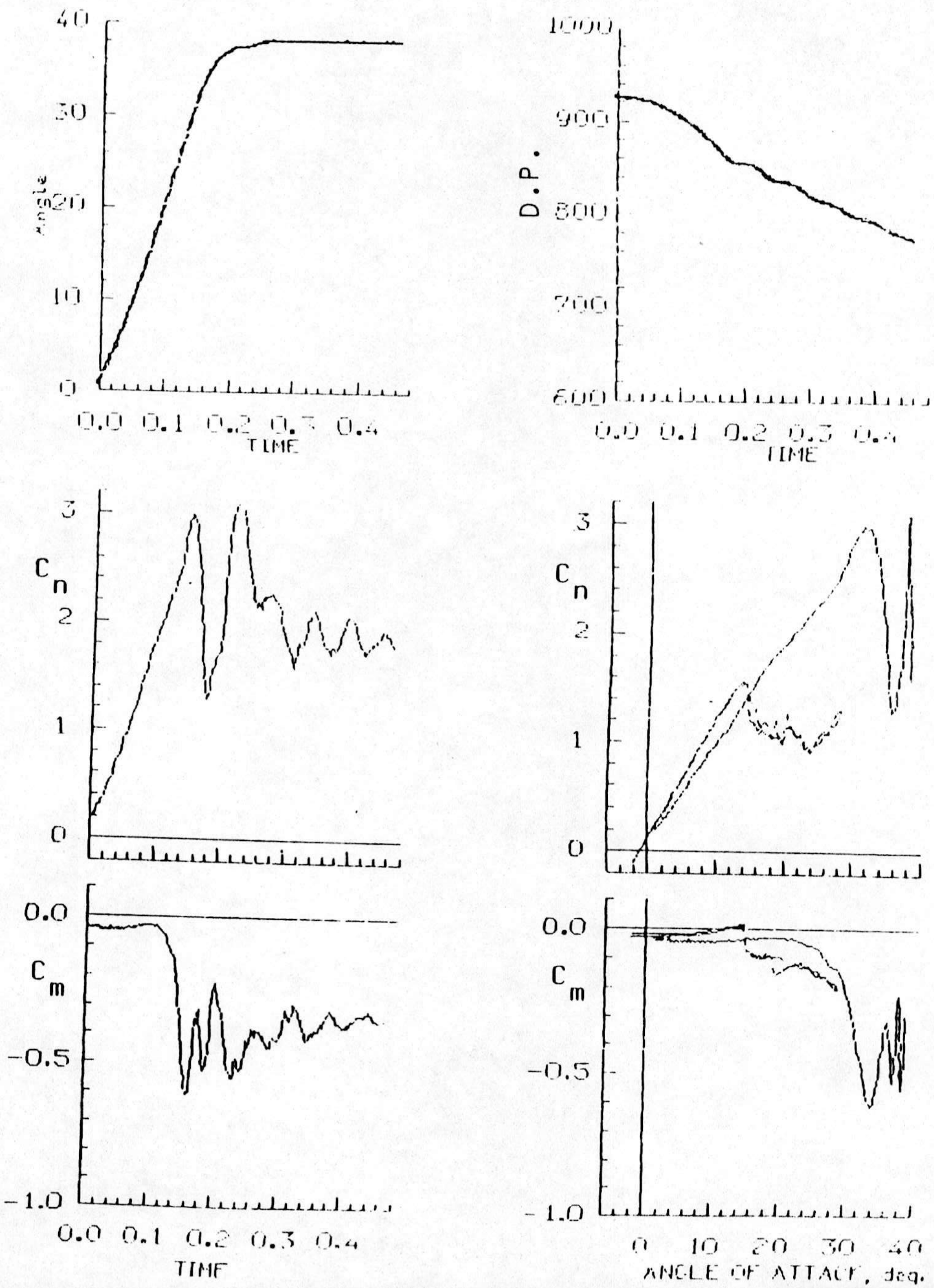


FIG. 31

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20921 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1511825. MACH NUMBER= 0.112

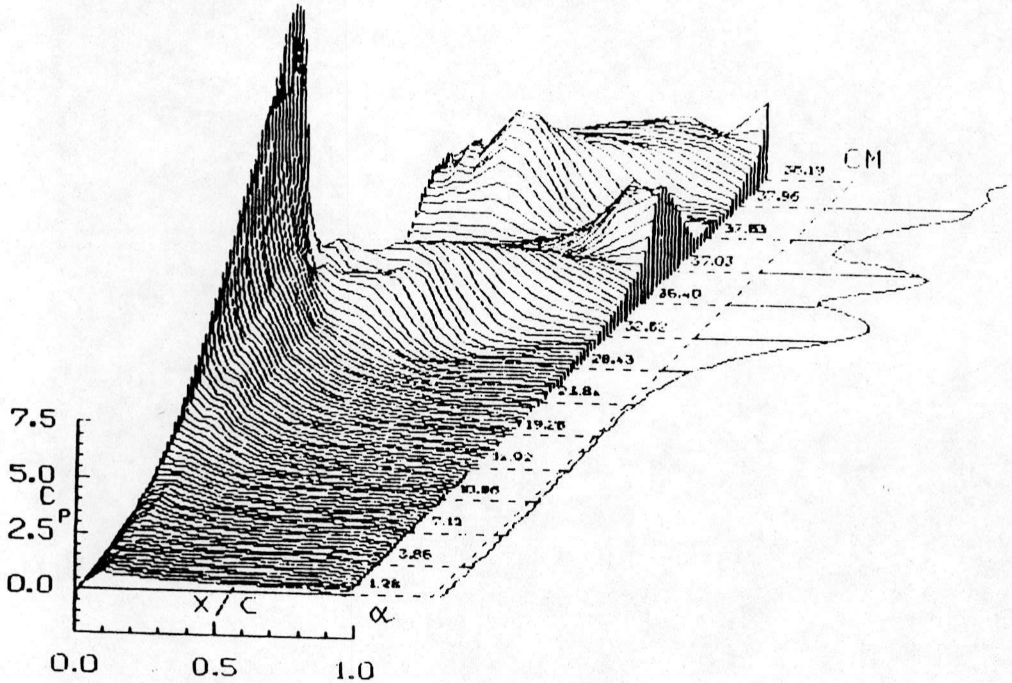
DYNAMIC PRESSURE= 978.29 N/sq.M AIR TEMPERATURE= 28.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REUCED FREQUENCY = 0.03021

PITCH RATE= 246.36 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



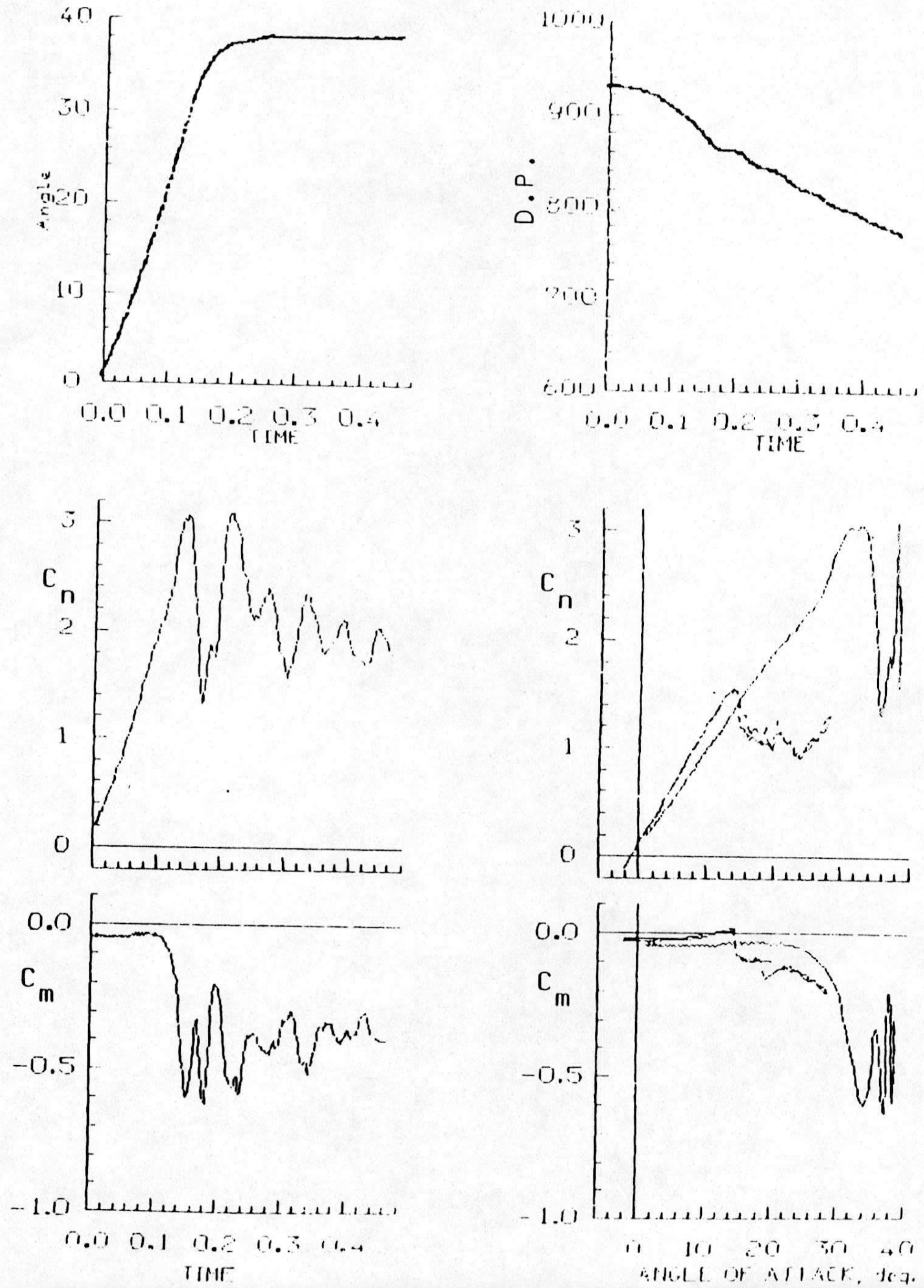


FIG. 32

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20931 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1511082. MACH NUMBER= 0.112

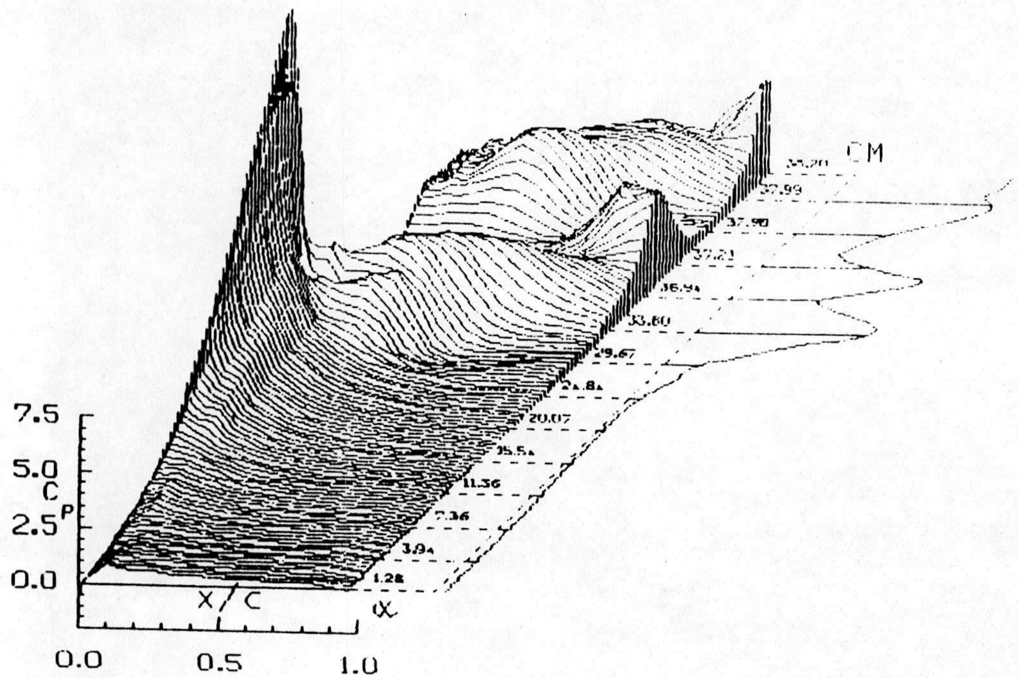
DYNAMIC PRESSURE= 977.33 N/sq.M AIR TEMPERATURE= 28.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.0312

PITCH RATE= 255.29 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



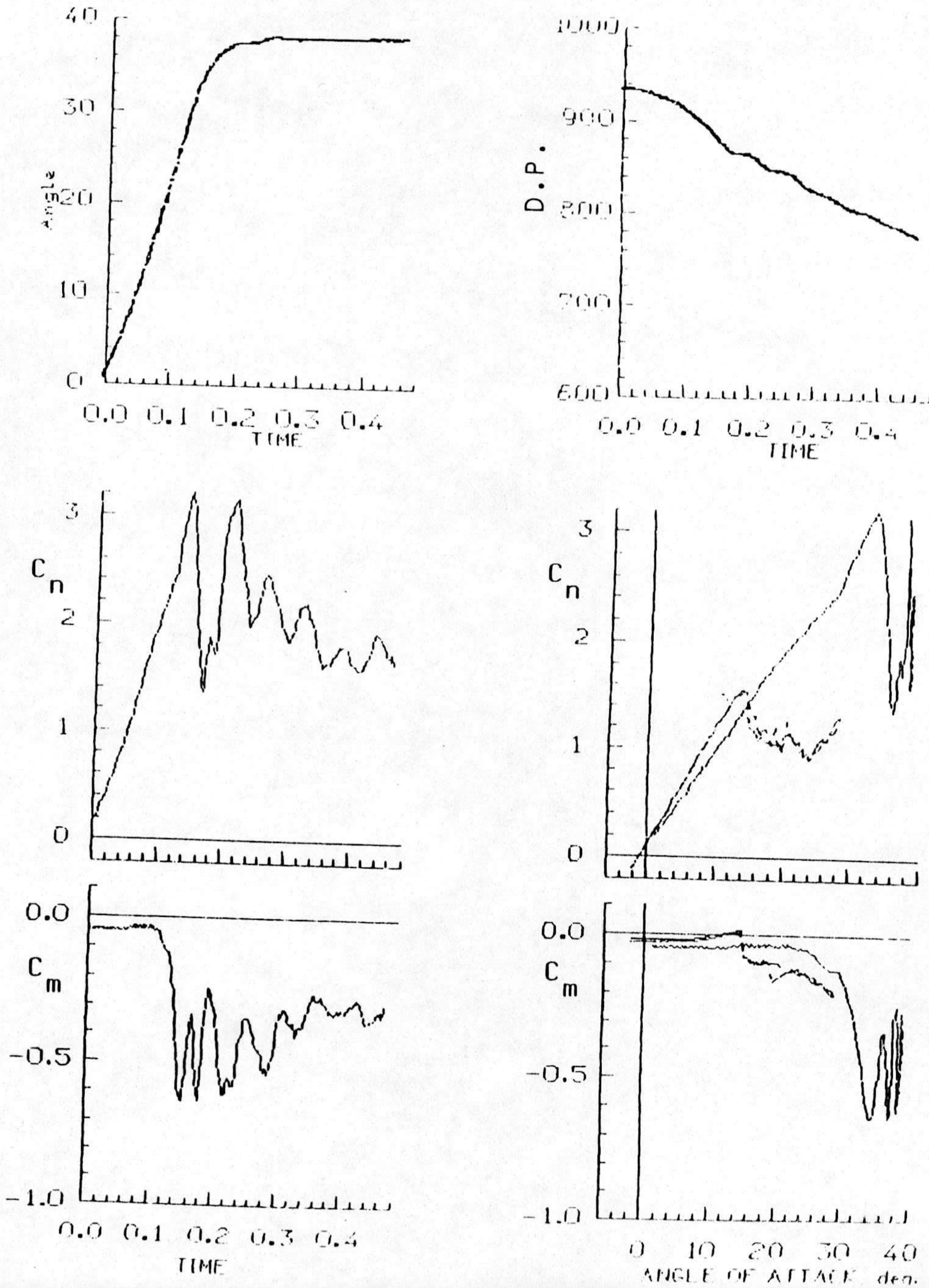


FIG. 33

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20941 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1512415. MACH NUMBER= 0.112

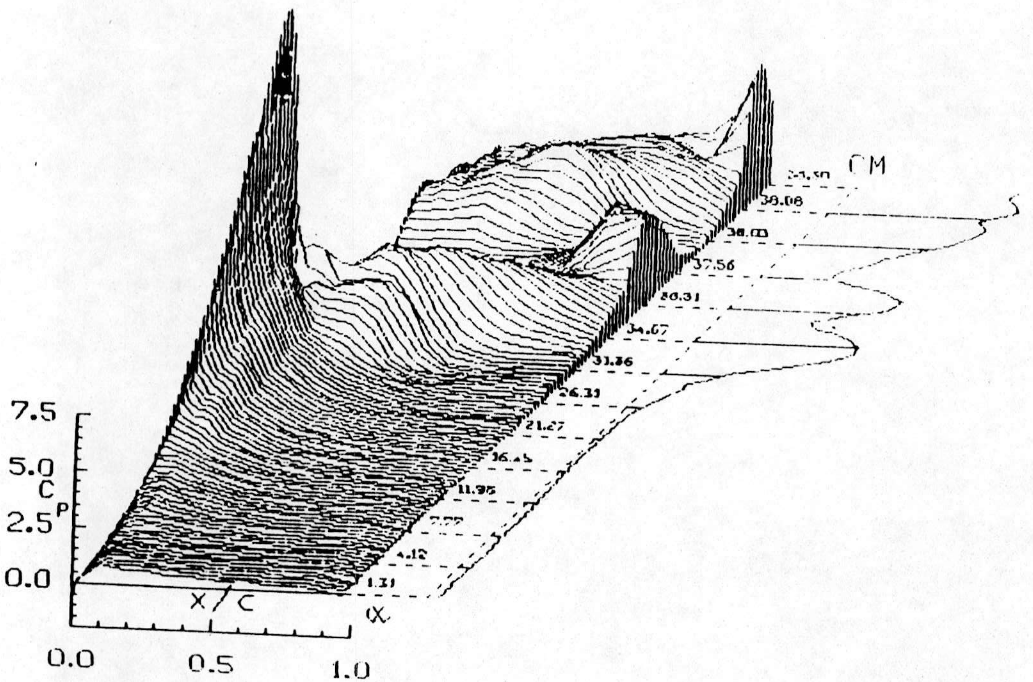
DYNAMIC PRESSURE= 981.77 N/sq.M AIR TEMPERATURE= 28.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.03291

PITCH RATE= 268.88 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



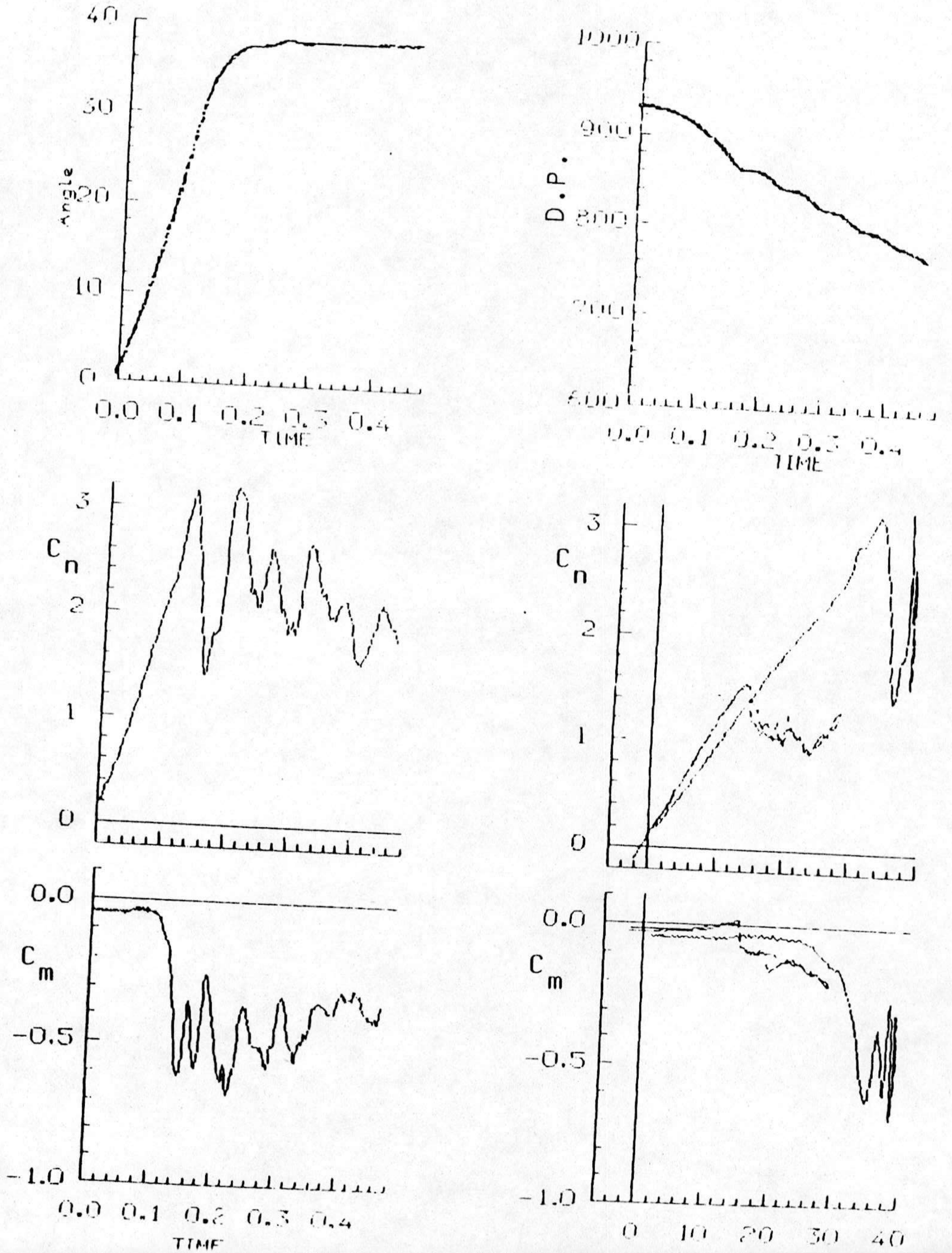


FIG. 34

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20951 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1500225. MACH NUMBER= 0.112

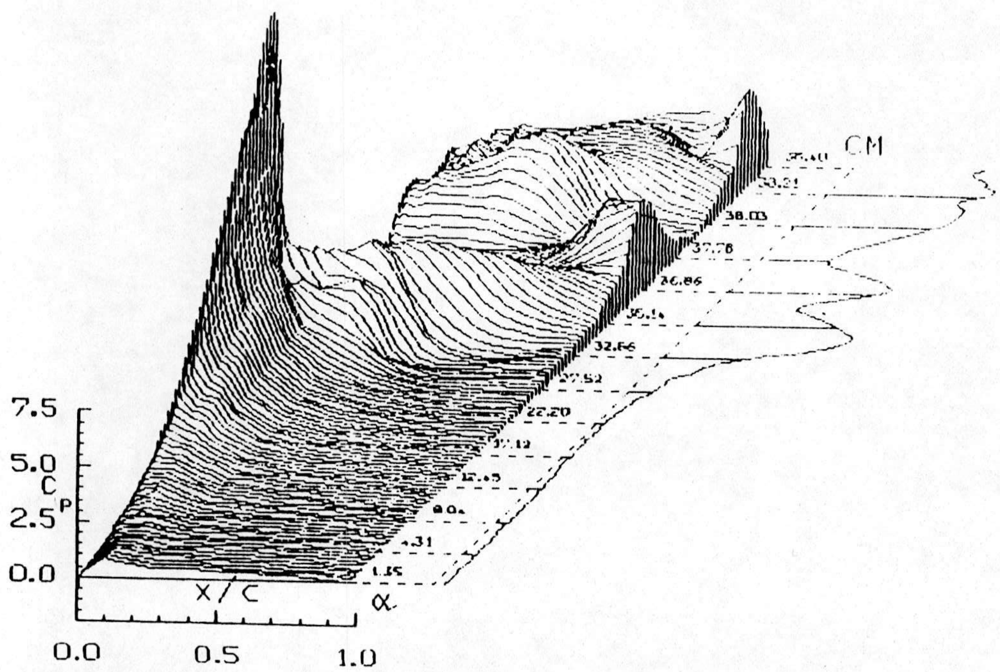
DYNAMIC PRESSURE= 968.68 N/sq.M AIR TEMPERATURE= 29.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY 0.0344

PITCH RATE= 278.88 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



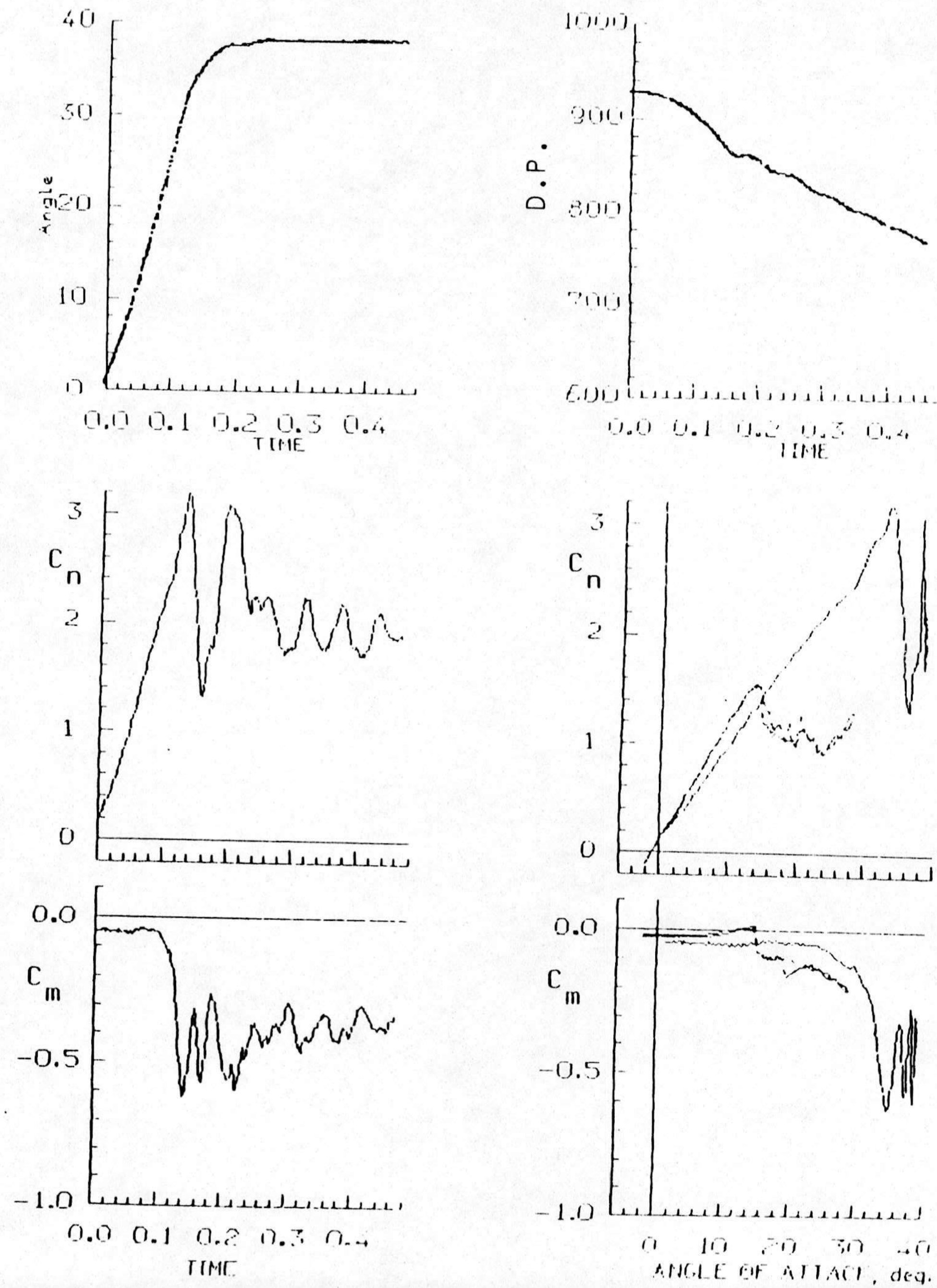


FIG. 35

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20961 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1517760. MACH NUMBER= 0.113

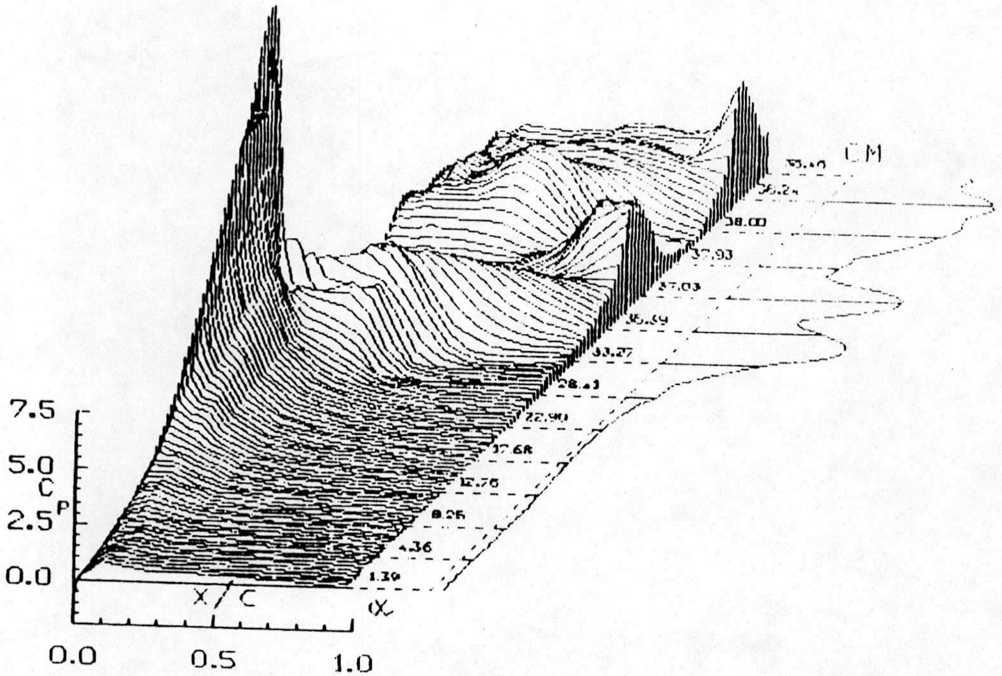
DYNAMIC PRESSURE= 988.72 N/sq.M AIR TEMPERATURE= 28.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REUCED FREQUENCY = 0.03533

PITCH RATE= 289.67 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



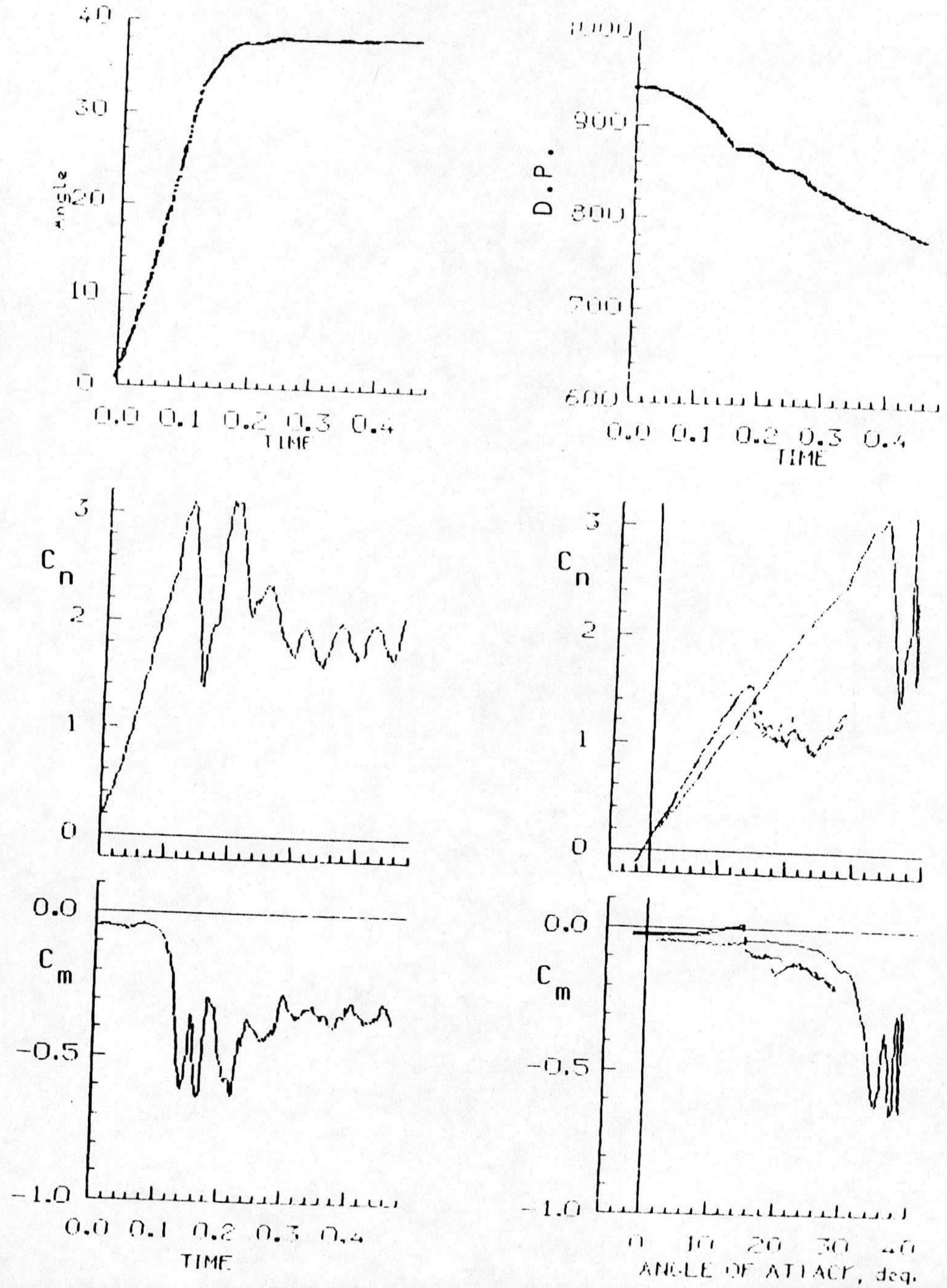


FIG. 36

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20971 DATE OF TEST: 297 5/84

REYNOLDS NUMBER= 1510875. MACH NUMBER= 0.112

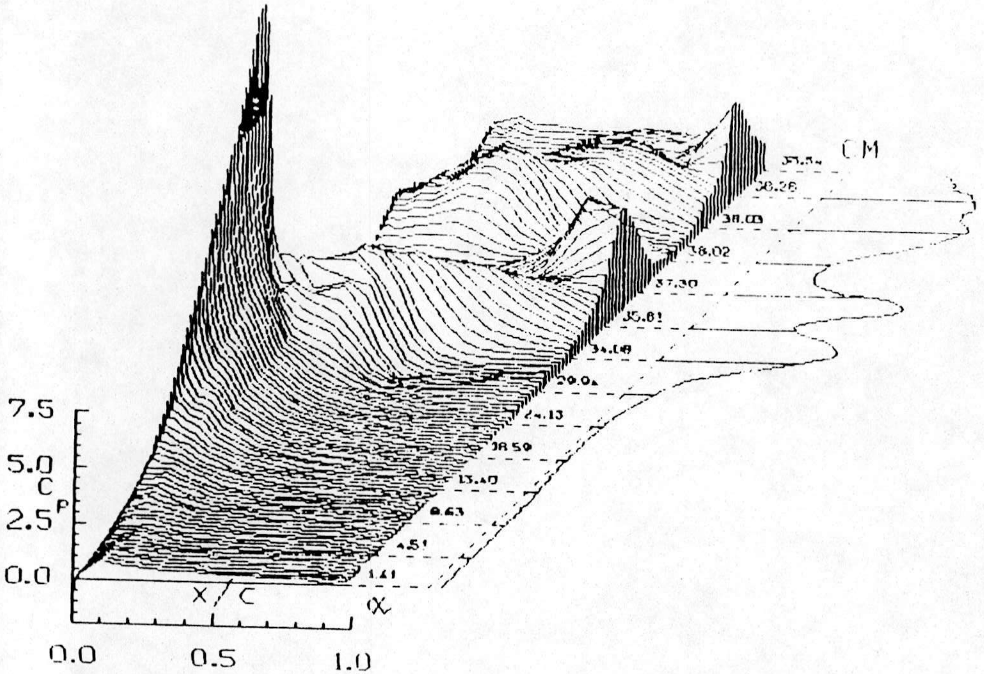
DYNAMIC PRESSURE= 982.48 N/sq.M AIR TEMPERATURE= 29.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REUCED FREQUENCY = 0.03707

PITCH RATE= 302.93 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



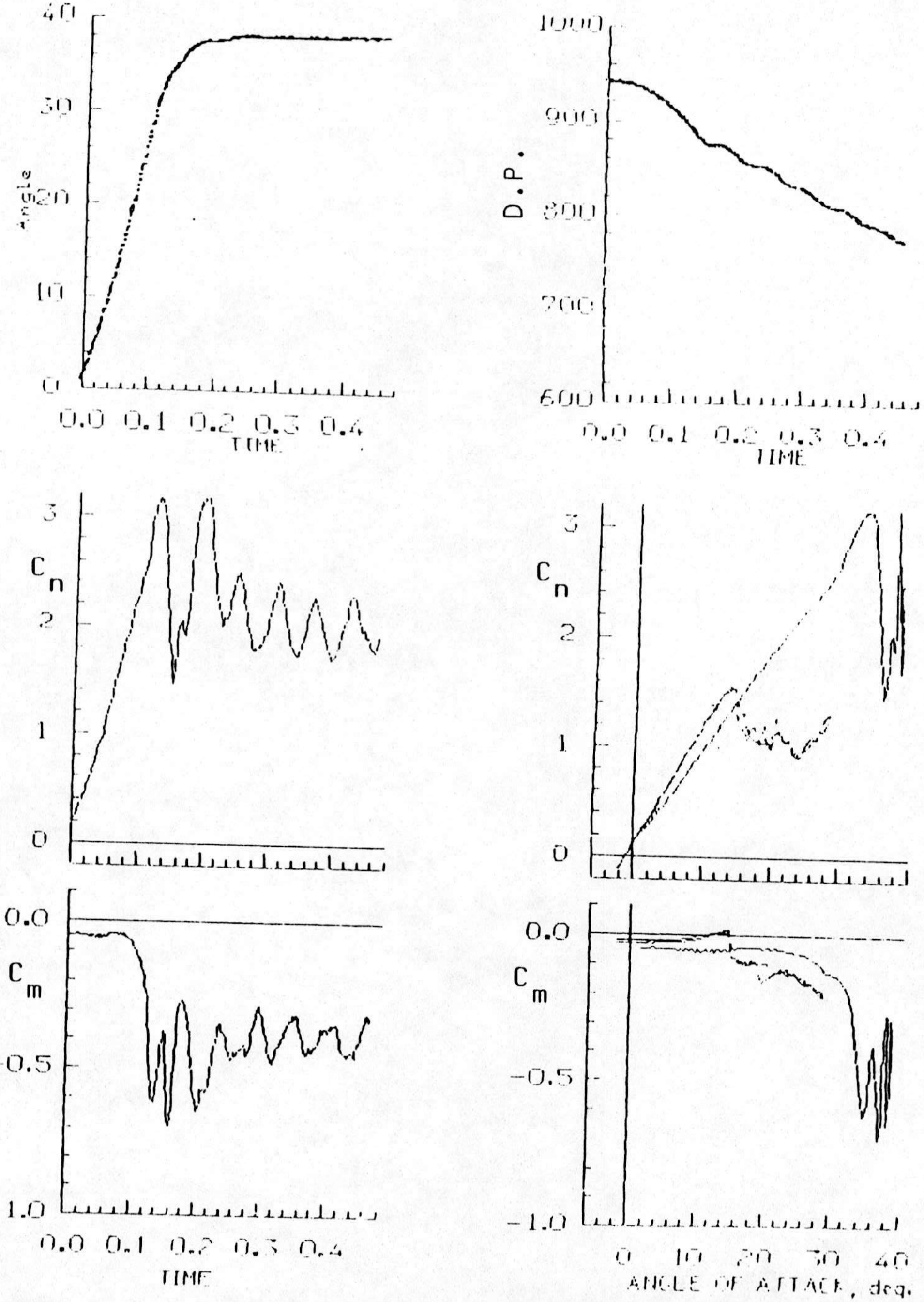


FIG. 37

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBER: 20981 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER= 1511391. MACH NUMBER= 0.112

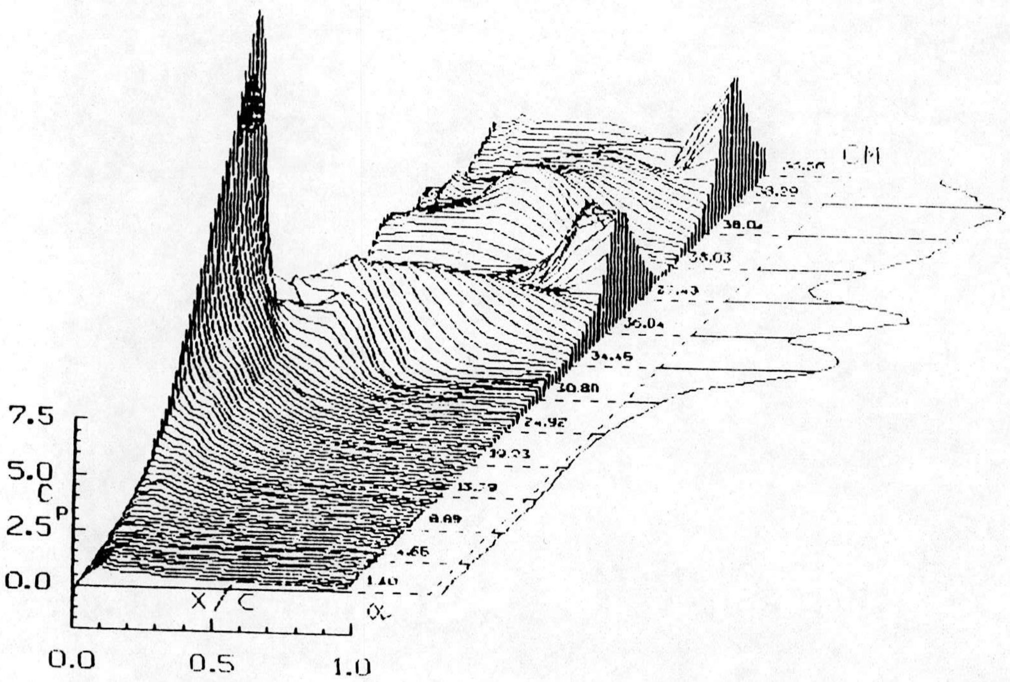
DYNAMIC PRESSURE= 985.87 N/sq.M AIR TEMPERATURE= 29.5 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.03841

PITCH RATE= 314.49 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



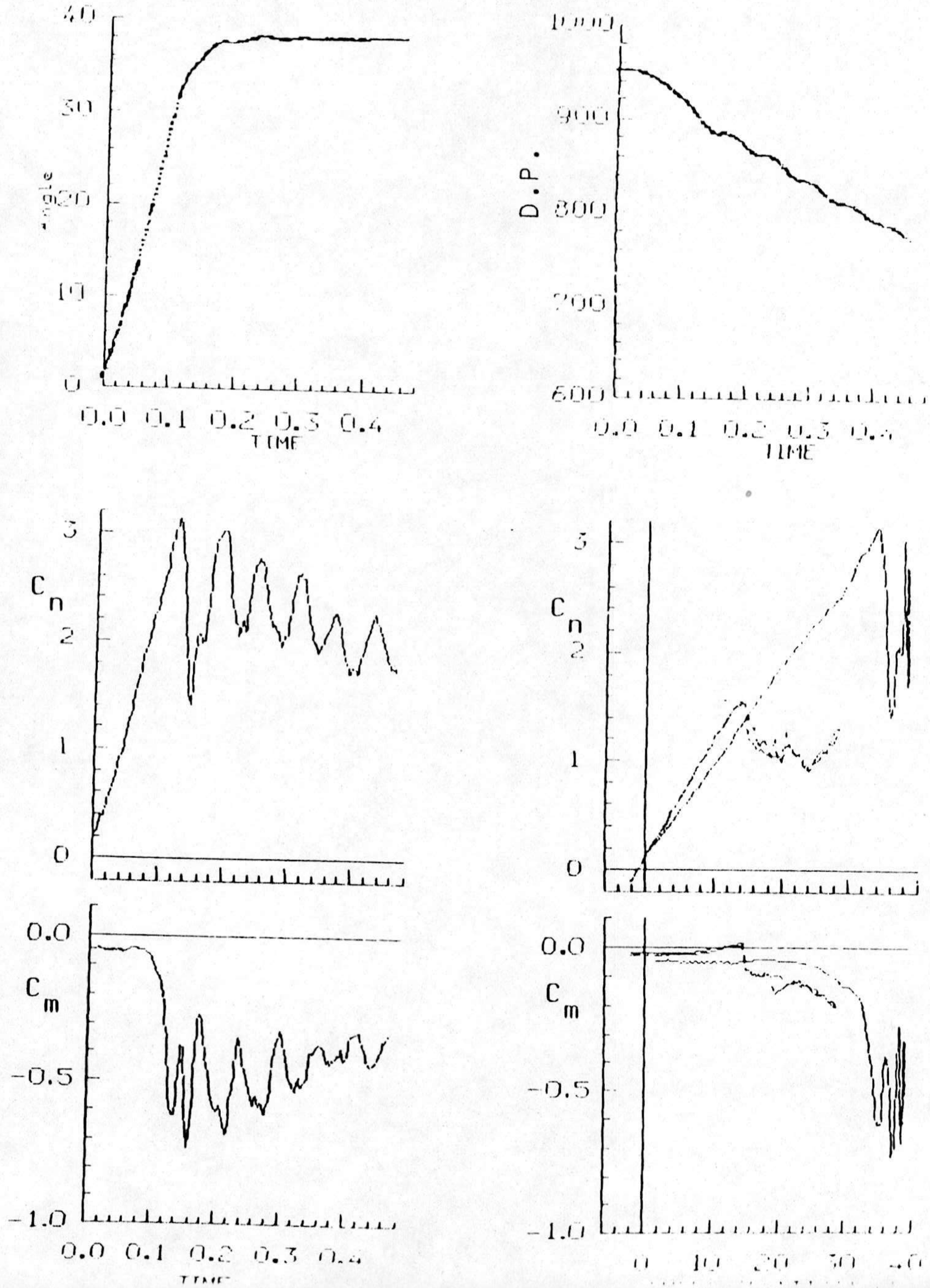


FIG. 38

RAMP RESPONSE OF THE NACA23012

RUN REFERENCE NUMBEP: 20991 DATE OF TEST: 297 5784

PETNOLDS NUMBER= 15,0370. MACH NUMBER= 0.112

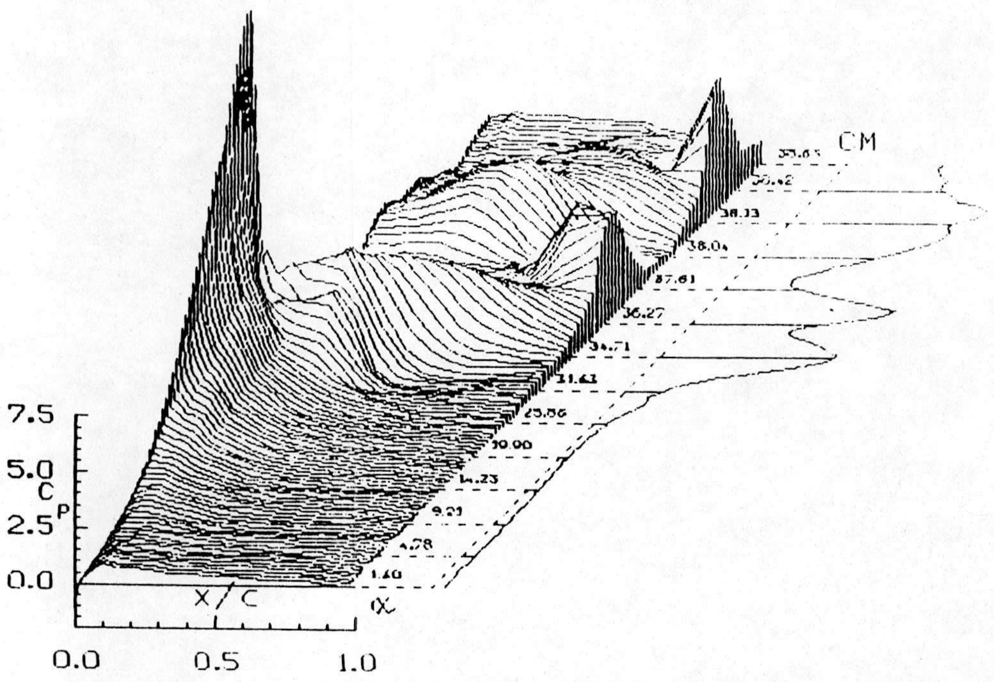
DYNAMIC PRESSURE= 987.25 N/sq.M AIR TEMPERATURE- 30.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REUCED FPEQUENCY = 0.0394?

PITCH PATF= 323.40 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURF



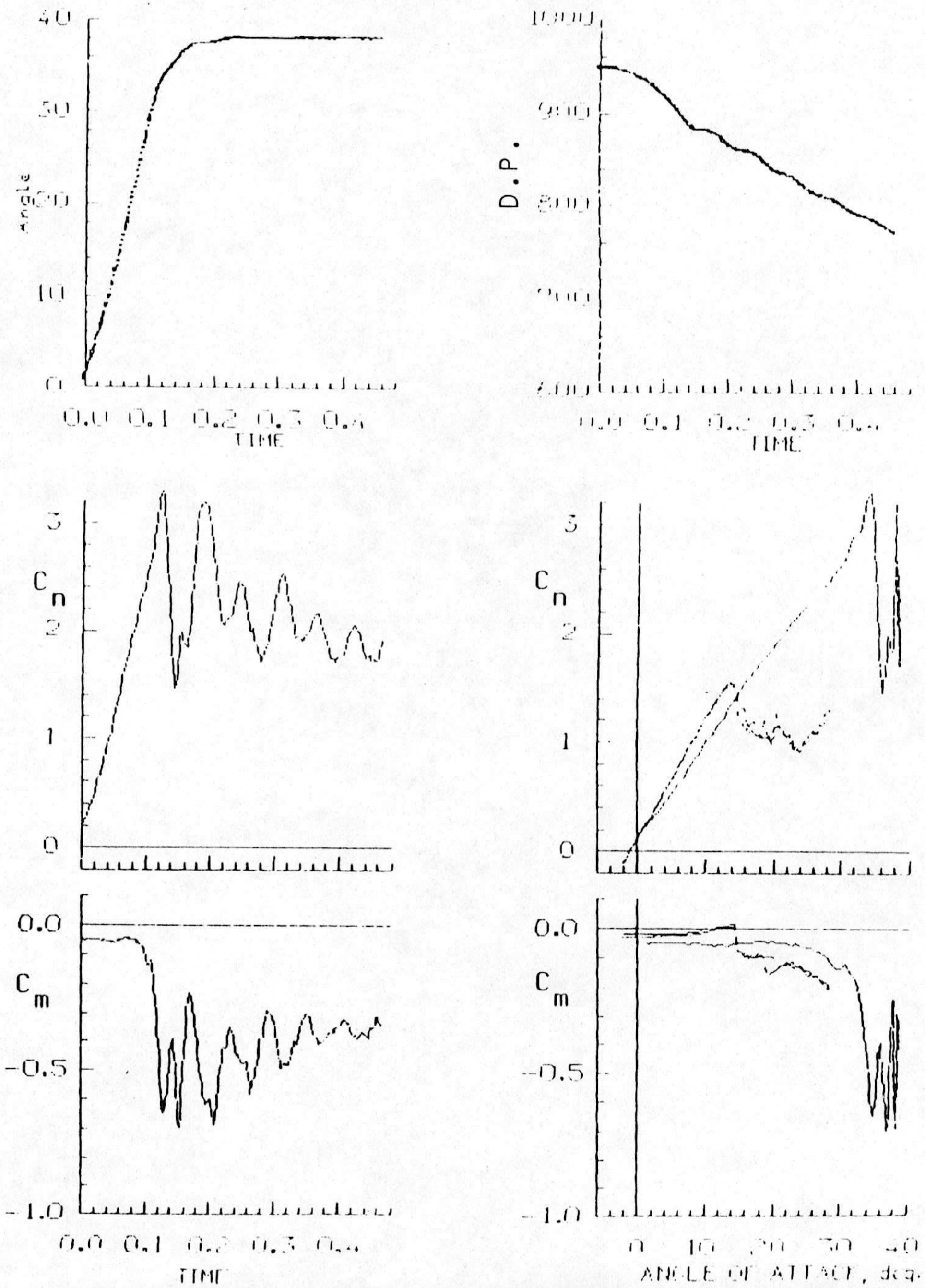


FIG. 39

RAMP RESPONSE OF THE NACA 0012

RUN REFERENCE NUMBER: 21001 DATE OF TEST: 29/ 5/84

REYNOLDS NUMBER: 1507137. MACH NUMBER: 0.112

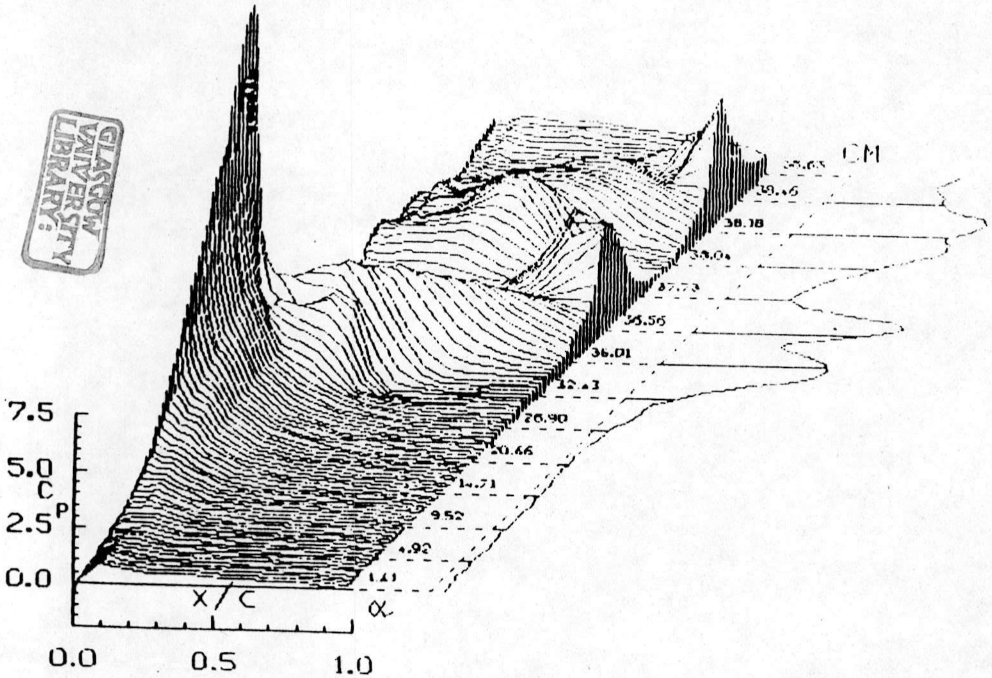
DYNAMIC PRESSURE= 883.03 N/sq.M AIR TEMPERATURE 30.0 Deg.C

NUMBER OF CYCLES= 5 SAMPLING FREQUENCY= 550.05 Hz.

MOTION TYPE: RAMP REDUCED FREQUENCY = 0.04104

PITCH RATE= 335.54 DEG./SEC AVERAGE DATA OF 5 CYCLES

DIRECT TRAPEZOIDAL INTEGRATION PROCEDURE



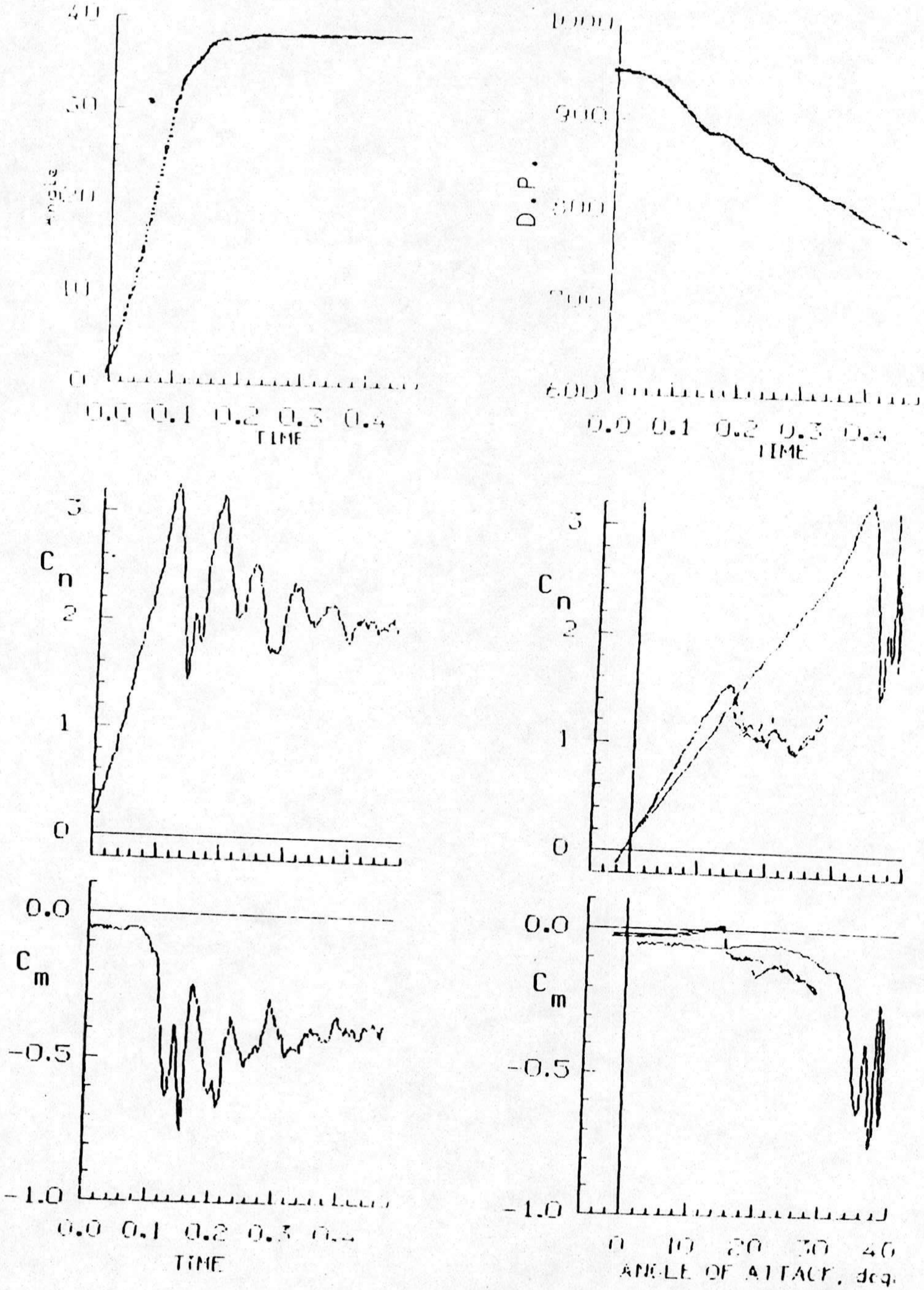


FIG. 40