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Aerodynamic Data for the BAC 221 up to a Mach Number of 0.955 as Measured in Wind Tunnel Tests

by

Dorothy M. Holford

Structures Dept., R.A.E., Farnborough

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AERODYNAMIC DATA FOR THE BAC 221 UP TO A MACH NUMBER OF 0.955 AS MEASURED IN WIND-TUNNEL TESTS

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SUMMARY

The results of various wind-tunnel tests have been used to produce a set of aerodynamic data for the BAC 221 at Mach numbers from 0.2 to 0.955. The data have been reduced to the reference condition used by BAC, viz. S = 448 sq ft and a CG position 154 in forward of the datum, on the body datum. Data for both clean and approach configurations are presented.

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* Replaces RAE Technical Report 70252 - ARC 33464

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1 INTRODUCTION

The need for a critical look at the aerodynamic data available for the BAC 221 became apparent when Structures Department RAE undertook to do the necessary calculations for the Phase II autostabiliser clearance. Phase II involves flying the aircraft with an high authority autostabiliser which is a single-channel device. The presence clearance is to a Mach number of 0.95.

The present Report is concerned with the production of the set of aerodynamic data which will be used for response and load calculations. Results of the wind-tunnel tests reported in Refs.1 to 5 have been used to produce aerodynamic data for the BAC 221 for Mach numbers from 0.2 to 0.955. The tabulated data used to produce Ref.2 were made available to the author.

The large range of flight conditions to be investigated means that aerodynamic data are required over a wide range of incidence and sideslip. For low Mach numbers the range of incidence is 0^o to 24^o while at $M = 0.95$ it is 0^o to 16^o. Lateral data are required over the sideslip range $|\beta| \leqslant 8^o$. Over this range some of the aerodynamic coefficients vary in a highly non-linear way. In particular, the low-speed behaviour of C_n indicates that there is a range of incidences for which the aircraft should be statically unstable and this is to a large extent borne out by flight tests. Taking account of these non-linearities makes the classical derivative approach impossible since the value of the derivative obtained depends on the range chosen for the independent variable. However, the derivative approach has been retained where possible and the derivatives are then functions of incidence and Mach number.

The coefficients or derivatives are known at various combinations of their independent variables and in the response calculations a scheme of multivariate interpolation will be used to calculate the coefficient (or derivative) at the desired combination of the independent variables. For interpolation in n variables, numerical values of the coefficient are required at the end points of an n-dimensional element. The end points chosen in a particular variable depend upon the variation of the coefficient with that variable.

The data to be used in the calculations are given in tabular form; these were produced by smoothing raw wind-tunnel data and interpolating and extrapolating where necessary. The data are also presented graphically together with the appropriate wind-tunnel results. Considerable extrapolation has been necessary to produce data at the incidences required for high Mach numbers.

The data presented are referred to aerodynamic body axes with the exception of the oscillatory derivatives which are referred to datum body axes. In the reduction of data, the reference area has been taken as 448 sq ft, the chord as 21 ft and the span as 25 ft. The data apply to a CG position 154 in forward of datum, on the body datum. The ailerons have a 2^{o} up-rig and all control angles are measured in a plane normal to the hinge line.

Data are given for both clean and approach configurations. The approach configuration has a nose droop of 8^{o} and the undercarriage is lowered.

2 LONGITUDINAL DATA

Low-speed wind-tunnel results[1] are available for elevator angles within the range -10^{o} to 10^{o}. At higher Mach numbers data[3] are available for $\eta = 2^{o}, 0^{o}, -2^{o}$ and -4^{o}. The data are tabulated for two elevator angles -10^{o} and $+10^{o}$, and were produced by linear extrapolation of the smoothed data, shown in the figures, appropriate to $\eta = 0^{o}$ and -10^{o} for M = 0, 0.4 and $\eta = 0^{o}$ and -4^{o} for the higher Mach numbers.

2.1 $C_L(\alpha, \eta, M)$

The smoothed values of C_L are tabulated in Table 1 for $\eta = \pm 10^{o}$ for the Mach numbers 0, 0.4, 0.7, 0.8, 0.937 and 0.955. Fig.1 shows the low-speed (M = 0, 0.4) C_L v. α for $\eta = 0^{o}$ and -10^{o} for both clean and approach configurations. The wind-tunnel results[1] are also shown on the figure.

C_L v. α curves for M = 0.7, 0.8, 0.937, 0.955 are shown in Figs.2 ($\eta = 0^{o}$) and 3 ($\eta = -4^{o}$). The wind-tunnel results shown are reported in part (i) of Ref.3.

2.2 $C_D(C_L^2, \eta, M)$

C_D is tabulated in Table 2 for $\eta = \pm 10^{o}$ and two values of C_L^2, 0 and 2, for the same Mach numbers as C_L. C_D is assumed to be linear with C_L^2. Fig.4 compares the low-speed data from Table 2 with wind-tunnel data[1] for $\eta = 0^{o}$ and 10^{o} for both clean and approach configurations. Fig.5 shows C_D v. C_L^2 for $\eta = 0^{o}$ and -4^{o} for the Mach numbers 0.7, 0.8, 0.937 and 0.955. The wind-tunnel results shown are reported in part (ii) of Ref.3.

2.3 $C_m(\alpha, \eta, M)$

C_m is tabulated in Table 3 for $\eta = \pm 10^o$ for the same Mach numbers as C_L. Fig.6 shows the low speed C_m v. α for $\eta = 0^o$ and -10^o. Wind-tunnel data[1] are also shown on the figure.

C_m v. α curves for M = 0.7, 0.8, 0.937 and 0.955 are shown in Figs.7 ($\eta = 0^o$) and 8 ($\eta = -4^o$). The wind-tunnel results shown are reported in part (i) of Ref.3. From Figs.7 and 8 it can be seen that considerable extrapolation was necessary to provide data for the higher incidences. From the available wind-tunnel data[3] it is evident that C_m changes markedly as the Mach number increases. As far as possible the extrapolation has taken into account the trends predicted by the wind-tunnel results but the values of C_m assumed for high incidence are not as reliable as those of C_L and C_D.

2.4 $C_{m_q}(M)$

The analytical expression relating C_{m_q} with Mach number, M is chosen to be

$$C_{m_q} = -0.3936 - 0.032M.$$

Data given in Ref.6 were found to be in error by a factor of 2 and the above expression approximates the corrected data as shown in Fig.9.

3 LATERAL DATA

C_Y, C_ℓ and C_n are taken to be functions of α, β, K_F and M, where K_F is the quasi-static aeroelastic fin efficiency. The smoothed values of C_Y, C_ℓ and C_n are assumed to be odd functions of β and are tabulated for positive β in Tables 4, 5 and 6. Data are given for two values of K_F:- $K_F = 1$ giving the value of the particular coefficient for the whole aircraft with a rigid fin and $K_F = 0$ giving the value for the aircraft without a fin. The value of the particular coefficient for the aircraft with a flexible fin is given by

$$C_{K_F=0} + K_F(C_{K_F=1} - C_{K_F=0}) \quad .$$

The fin contributions for clean and approach configurations are assumed to be identical. The elevator contributions to C_Y, C_ℓ and C_n are assumed to be zero.

Low-speed wind-tunnel data are available from Refs.1 and 2. At higher Mach numbers the lateral data[7] supplied by BAC have been used together with more recent wind-tunnel data[3]. At low-speeds C_n v. β and C_ℓ v. β are markedly non-linear with β at incidences above about 18^o. At high Mach numbers wind-tunnel data[3] are available up to $\alpha = 8^o$ and the coefficients are linear with β. It is assumed that C_n, C_ℓ and C_Y are linear with β at incidences up to 18^o for all Mach numbers. Graphical data are presented in coefficient form for low Mach numbers and derivative form for the higher Mach numbers. The data in the tables are in coefficient form for all Mach numbers.

3.1 $C_Y(\alpha,\beta,K_F,M)$

3.1.1 Rigid aircraft

Low-speed C_Y v. β is shown in Figs.10 and 11 for the clean and approach configurations respectively, together with appropriate wind-tunnel data[1,2]. The flattening of C_Y with β at high angles of sideslip shown in Fig.10 for $\alpha = 22^o$ is supported by results from Ref.1 with a point at $\beta = 9^o$.

y_v for Mach numbers 0.6, 0.8, 0.9 and 1.0 is shown in Fig.12. The data points shown in Fig.12 are those obtained from BAC[7], which do not differ significantly from results of more recent wind-tunnel tests as ARA[3].

3.1.2 Fin contribution

$y_{v_{fin}}$ is shown on Fig.12 for Mach numbers 0, 0.4, 0.6, 0.8, 0.9 and 1.0. The data shown were supplied by BAC[7] and agree fairly well with recent wind-tunnel tests[2,3].

3.2 $C_\ell(\alpha,\beta,K_F,M)$

3.2.1 Rigid aircraft

Low-speed C_ℓ v. β is shown in Figs.13 and 14 for clean and approach configurations respectively, together with appropriate wind-tunnel data[1,2].

ℓ_v for the Mach numbers 0.6, 0.8, 0.9 and 1.0 is shown in Fig.15. This is based on the low-speed data[1,2] C_ℓ v. β which are linear with β up to about 18^o of incidence and wind-tunnel results[3] for the higher Mach numbers where data are available up to $\alpha = 8^o$.

3.2.2 Fin contribution

$\ell_{v_{fin}}$ is shown in Fig.15 for Mach numbers up to 1.0. $\ell_{v_{fin}}$ is based on the low-speed measurements[2] for the approach configuration and a few measurements at low incidence and high Mach numbers[3].

3.3 $C_n(\alpha,\beta,K_F,M)$

3.3.1 Rigid aircraft

Low-speed C_n v. β is shown in Figs.16 and 17 for clean and approach configurations respectively. Wind-tunnel data[1,2] are also shown in the figures.

n_v for Mach numbers 0.6, 0.8, 0.9 and 1.0 is shown in Fig.18. This is based on the data[7] which had been used to produce data for the fin efficiency (section 7). These fin efficiency data are the only data available for this parameter and so it is logical to retain the n_v used to produce them. However it is worth noting that the new wind-tunnel tests[3] produce similar results over the incidence range 0° to 8°.

3.3.2 Fin contribution

$n_{v_{fin}}$ is shown in Fig.18 for all Mach numbers under consideration. The data are again based on the BAC data[7]. Data from low-speed wind-tunnel tests[2] for the approach configuration are also shown on Fig.18; these tests produced a rather different result in the incidence range 10° to 20°. The BAC data[7] showed a recovery of $n_{v_{fin}}$ between $\alpha = 16^\circ$ and 18° whereas the new data[2] do not. In the extrapolation from 16° to 24° of incidence the recovery of $n_{v_{fin}}$ has been ignored and the trend adopted is that shown by the wind-tunnel tests at Bedford[2].

4 LATERAL OSCILLATORY DERIVATIVES

Recent wind-tunnel tests[4,5] have measured these oscillatory derivatives in the form of $n_r - n_{\dot{v}} \cos\alpha$, $\ell_r - \ell_{\dot{v}} \cos\alpha$, $n_p + n_{\dot{v}} \sin\alpha$ and $\ell_p + \ell_{\dot{v}} \sin\alpha$. The results[4,5] are given for a flight CG 161 in forward of the datum. $n_{\dot{v}}$, $\ell_{\dot{v}}$ are assumed to be small so that the quantities measured can be taken as n_r, ℓ_r etc. The data exhibit a certain amount of scatter compared with which the difference in values of a derivative for CG positions of 161 in and 154 in (the reference CG used in this report) is small.

Therefore the smoothed data are assumed to apply to a CG 154 in forward of the datum. The model used for these tests[4,5] had a 3^o up-rig on the ailerons; however, it is assumed that the results apply equally for the 2^o up-rig actually employed on the aircraft.

The low-speed wind-tunnel tests[4] cover a wide range of incidence ($\alpha = 0^o$ to 26^o) and three sideslip angles, 0^o and $\pm 5^o$. There is insufficient evidence to include a variation with β. The results are assumed to apply for both clean and approach configurations although only a model in the clean configuration was tested. The results[4] were studied in conjunction with Ref.8 and were found to be in agreement with the trends of the theoretical and experimental data reported therein.

At high Mach numbers measurements[5] were made at $\alpha = 0^o$, 2^o and 4^o and in some cases exhibit a considerable amount of scatter. In smoothing these data account was taken of the more consistent data from the low-speed measurements[4].

The variations of the yaw-rate derivatives and roll-rate derivatives with Mach number, referred to datum body-axes, are shown in Figs.19 and 20 respectively. The data at M = 0.18 are from Ref.4 while those at high Mach numbers are from Ref.5. With reference to Fig.19 it can be seen that the high values at $\alpha = 4^o$ and a Mach number of 1.0 have been ignored. Data are required up to a Mach number of 0.955 and this steep rise is assumed to occur (if in fact it does so in reality) very close to a Mach number of 1.0. Further, this rise is not found at $\alpha = 0^o$ and $\alpha = 2^o$.

From Fig.20 it can be seen that the high-speed values of n_p at $\alpha = 0^o$ have been ignored. These particular values are extremely high compared with the rest of the data, viz. at $\alpha = 2^o$ and 4^o, which do not show such a variation with Mach number.

4.1 Yaw rate derivatives

n_r and ℓ_r are functions of α, K_F and M where K_F is the quasi-static aeroelastic fin efficiency. Data are tabulated for two values of K_F, 0 and 1, and data for the aircraft with a flexible fin is found by a method analogous to that mentioned in section 3.

4.1.1 $\ell_r(\alpha, K_F, M)$

The data are tabulated in Table 7.

(a) Rigid aircraft

The smoothed data from Fig.19 together with the low-speed wind-tunnel results[4] were used to produce the variation of ℓ_r with incidence and Mach number as shown in Fig.21. The sharp drop in low-speed ℓ_r at about 20° of incidence, although unexplained, may well be genuine since a similar variation was found with tests on a model of Concorde[4]. However the variation of ℓ_r with incidence does not take into account this drop in ℓ_r. Extrapolation to high incidence at high Mach numbers was achieved by assuming $\ell_{r_{finoff}}$ invariant with Mach number and using the epxression for $\ell_{r_{fin}}$ given in section 4.1.1(b).

(b) Fin contribution

The following expression is assumed for $\ell_{r_{fin}}$:-

$$\ell_{r_{fin}} = n_{v_{fin}} \times \frac{\ell_{v_{fin}}}{y_{v_{fin}}}$$

where all quantities are referred to body axes. $\ell_{r_{fin}}$ is shown in Fig.21.

4.1.2 $n_r(\alpha, K_F, M)$

The data are tabulated in Table 8.

(a) Rigid aircraft

The smoothed lines of Fig.19 are used to provide data from 0° to 4° of incidence. The variation of n_r with incidence and Mach number is shown in Fig.22 together with the low-speed wind-tunnel results[4]. The data for high Mach numbers were extrapolated to the required incidence by consideration of the fin effect (see section 4.1.2(b)), the low-speed values, and some data supplied by BAC[7].

(b) Fin contribution

The following expression is assumed for $n_{r_{fin}}$:-

$$n_{r_{fin}} = \frac{n^2_{v_{fin}}}{y_{v_{fin}}}$$

where all quantities are referred to body axes. $n_{r_{fin}}$ is shown in Fig.22.

4.2 Roll rate derivatives

4.2.1 $\ell_p(\alpha,M)$

The variation of ℓ_p with incidence and Mach number is shown in Fig.23 and tabulated in Table 9. The low-speed wind-tunnel results[4] are also shown in Fig.23. The smoothed data of Fig.20 were used to give the value of ℓ_p at $\alpha = 0^o$, 2^o and 4^o for Mach numbers of 0.8 and 1.0. From these data it was evident that ℓ_p was linear with α over the range 0^o to 4^o and the linear relationship so produced was extrapolated to the higher incidences required.

4.2.2 $n_p(\alpha,M)$

The variation of n_p with incidence and Mach number is shown in Fig.23 and tabulated in Table 10. The low-speed wind-tunnel results[4] are also shown in Fig.23. The smoothed data of Fig.20 were used to produce data at high Mach numbers and low incidence. Extrapolation to high incidence at Mach numbers 0.8 and 1.0 was achieved by keeping the Δn_p between the Mach numbers constant at the low-incidence value throughout the incidence range.

5 AILERON POWERS

5.1 $\frac{\partial C_\ell}{\partial \xi}(\alpha,M)$ and $\frac{\partial C_n}{\partial \xi}(\alpha,M)$

$\frac{\partial C_\ell}{\partial \xi}$ and $\frac{\partial C_n}{\partial \xi}$ are tabulated in Tables 11 and 12 for both clean and approach configurations and are also shown graphically in Fig.24 together with appropriate wind-tunnel data[1,3]. The data are given for an anti-symmetric aileron deflection.

5.2 $\frac{\partial C_m}{\partial \xi}(\alpha,M)$ and $\frac{\partial C_L}{\partial \xi}(\alpha,M)$

A variation of $\frac{\partial C_m}{\partial \xi}$ and $\frac{\partial C_L}{\partial \xi}$ with Mach number, for a single aileron deflection, at low incidence was obtained from BAC[9]. The variation of $\frac{\partial C_m}{\partial \xi}$ and $\frac{\partial C_L}{\partial \xi}$ with incidence and Mach number is shown in Fig.25 and tabulated in Tables 13 and 14. Data for both clean and approach configurations are shown. The variation with α, for any Mach number, was obtained from the variation of $\frac{\partial C_\ell}{\partial \xi}$ with α. $\frac{\partial C_m}{\partial \xi}\left(\text{or } \frac{\partial C_L}{\partial \xi}\right)$ at a particular incidence was found by factoring $\frac{\partial C_m}{\partial \xi}$ $\left(\text{or } \frac{\partial C_L}{\partial \xi}\right)$ at low incidence in the ratio of $\frac{\partial C_\ell}{\partial \xi}$ at that incidence to $\frac{\partial C_\ell}{\partial \xi}$ between $\alpha = 0^o$ and 4^o.

6 RUDDER POWERS

6.1 *$\frac{\partial C_\ell}{\partial \zeta}$, $\frac{\partial C_n}{\partial \zeta}$ and $\frac{\partial C_Y}{\partial \zeta}$ for the rigid aircraft*

$\frac{\partial C_\ell}{\partial \zeta}$, $\frac{\partial C_n}{\partial \zeta}$ and $\frac{\partial C_Y}{\partial \zeta}$ are tabulated in Tables 15, 16 and 17 and are also shown graphically in Fig.26 together with the appropriate wind-tunnel data[1,3].

From Ref.3 it can be seen that at high Mach numbers $\frac{\partial C_n}{\partial \zeta}$ is constant between $\alpha = 0^o$ and $\alpha = 9^o$ and extrapolation to higher incidence is based on the low-speed values. At M = 0.9 and 0.94, $\frac{\partial C_n}{\partial \zeta} = -0.0607$ whereas $\frac{\partial C_n}{\partial \zeta}$ at M = 1 is -0.0640 (Ref.3). The data shown in Fig.26 give $\frac{\partial C_n}{\partial \zeta} = -0.0615$ at M = 1.0 and $\frac{\partial C_n}{\partial \zeta} = -0.0607$ at M = 0.9 so that the interpolated $\frac{\partial C_n}{\partial \zeta}$ at M = 0.94 shall be fairly close to the experiment result.

At high Mach numbers $\frac{\partial C_Y}{\partial \zeta}$ is given by Ref.3 only at $\alpha = 2.3^o$ and is assumed constant throughout the incidence range in accordance with the low-speed results[1].

7 AEROELASTIC FIN AND RUDDER EFFICIENCY

These data were supplied by BAC[6] and are reproduced here. The aeroelastic fin efficiency, K_F, is presented in Table 18 and Fig.27.

The aeroelastic rudder efficiency, K_R, is shown in Table 19 and Fig.28. Thus the rudder powers for the flexible aircraft are derived from the rigid aircraft values by multiplying them by K_R.

8 CONTROL HINGE MOMENTS

The control hinge moment derivatives are tabulated in Table 20. These are based on data supplied by BAC[9,10]. The data in Ref.9 are based on wind-tunnel results[3] at ARA.

8.1 Elevator hinge moment

$\frac{\partial C_{H\eta}}{\partial \alpha}$, $\frac{\partial C_{H\eta}}{\partial \eta}$ and $\frac{\partial C_{H\eta}}{\partial \xi}$ are shown in Fig.29 and are taken from Ref.9. The low-speed $\frac{\partial C_{H\eta}}{\partial \alpha}$ shown in Fig.29 differs from that of Ref.9 and is based on some flight test results on the Fairey Delta 2 [11] which have been factored to agree with ARA results[3] at M = 0.7. ARA results[3] and factored Fairey Delta 2 results are shown on Fig.29. The two data points shown at the same Mach number in $\frac{\partial C_{H\eta}}{\partial \eta}$ correspond to measurements on the port and starboard elevators.

8.2 Aileron hinge moment

$\frac{\partial C_{H\xi}}{\partial \alpha}$, $\frac{\partial C_{H\xi}}{\partial \eta}$ and $\frac{\partial C_{H\xi}}{\partial \xi}$ are shown in Fig.30 and are taken from Ref.9. Wind-tunnel test results[3] are also shown in the figure.

8.3 Rudder hinge moment

$\frac{\partial C_{H\zeta}}{\partial \beta}$ and $\frac{\partial C_{H\zeta}}{\partial \zeta}$ are shown in Fig.31. These are reproduced from some data supplied by BAC[10], which were based on FD2 and early BAC 221 wind-tunnel tests. No new data are available.

Table 1

CLEAN CONFIGURATION C_L

α^o	M = 0, 0.4		M = 0.7		M = 0.8		M = 0.937		M = 0.955	
	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$
0	-0.120	0.096	-0.140	0.100	-0.142	0.092	-0.163	0.112	-0.168	0.118
2	-0.060	0.166	-0.064	0.166	-0.075	0.180	-0.086	0.194	-0.081	0.189
4	0.008	0.236	0.013	0.243	0.008	0.248	-0.003	0.282	0.019	0.249
6	0.091	0.323	0.097	0.337	0.087	0.347	0.082	0.387	0.108	0.348
8	0.178	0.412	0.182	0.448	0.175	0.455	0.187	0.482	0.198	0.472
10	0.265	0.507	0.271	0.561	0.270	0.570	0.301	0.571	0.294	0.614
12	0.356	0.600	0.362	0.678	0.359	0.709	0.410	0.690	0.402	0.762
14	0.448	0.700	0.456	0.802	0.463	0.843	0.523	0.833	0.533	0.903
16	0.541	0.811	0.560	0.926	0.564	1.000	0.624	1.004	0.671	1.061
18	0.639	0.917	0.670	1.050	0.656	1.186				
20	0.738	1.028								
22	0.820	1.144								
24	0.870	1.240								

APPROACH CONFIGURATION C_L

α^o	M = 0, 0.4	
	$\eta = -10^o$	$\eta = 10^o$
0	-0.103	0.103
2	-0.036	0.168
4	0.034	0.246
6	0.112	0.324
8	0.194	0.410
10	0.278	0.502
12	0.368	0.592
14	0.458	0.690
16	0.552	0.800
18	0.644	0.900
20	0.728	1.016
22	0.784	1.092
24	0.840	1.172

Table 2

CLEAN CONFIGURATION C_D

C_L^2	M = 0, 0.4		M = 0.7		M = 0.8		M = 0.937		M = 0.955	
	η=-10°	η=10°	η=-10°	η=10°	η=-10°	η=10°	η=-10°	η=10°	η=-10°	η=10°
0	0.0230	0.0130	0.0198	0.0038	0.0195	0.0045	0.0226	0.0050	0.0236	0.0070
2	0.8924	0.5944	0.8280	0.7180	0.8921	0.6119	0.9234	0.5720	0.9178	0.5204

APPROACH CONFIGURATION C_D

C_L^2	M = 0, 0.4	
	η = -10°	η = 10°
0	0.0550	0.0430
2	0.9084	0.6496

Table 3

CLEAN CONFIGURATION C_m

α^o	M = 0, 0.4		M = 0.7		M = 0.8		M = 0.937		M = 0.955	
	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$	$\eta=-10^o$	$\eta=10^o$
0	0.0420	-0.0356	0.0491	-0.0439	0.0534	-0.0466	0.0726	-0.0614	0.0791	-0.0679
2	0.0408	-0.0356	0.0479	-0.0451	0.0515	-0.0475	0.0709	-0.0641	0.0713	-0.0637
4	0.0396	-0.0376	0.0494	-0.0506	0.0529	-0.0541	0.0701	-0.0729	0.0650	-0.0650
6	0.0380	-0.0404	0.0430	-0.0510	0.0481	-0.0589	0.0632	-0.0808	0.0610	-0.0770
8	0.0368	-0.0432	0.0420	-0.0580	0.0435	-0.0615	0.0558	-0.0902	0.0576	-0.0944
10	0.0362	-0.0458	0.0388	-0.0616	0.0382	-0.0638	0.0475	-0.0995	0.0520	-0.1240
12	0.0360	-0.0480	0.0352	-0.0642	0.0309	-0.0661	0.0346	-0.1074	0.0210	-0.1370
14	0.0366	-0.0502	0.0317	-0.0673	0.0238	-0.0702	0.0226	-0.1194	-0.0005	-0.1635
16	0.0374	-0.0518	0.0283	-0.0707	0.0170	-0.0770	0.0106	-0.1334	-0.0250	-0.1950
18	0.0382	-0.0534	0.0248	-0.0738	0.0099	-0.0831				
20	0.0400	-0.0560								
22	0.0474	-0.0622								
24	0.0440	-0.0400								

APPROACH CONFIGURATION C_m

α^o	M = 0, 0.4	
	$\eta = -10^o$	$\eta = 10^o$
0	0.0322	-0.0382
2	0.0326	-0.0370
4	0.0324	-0.0380
6	0.0314	-0.0414
8	0.0300	-0.0432
10	0.0292	-0.0452
12	0.0296	-0.0472
14	0.0300	-0.0492
16	0.0300	-0.0504
18	0.0300	-0.0512
20	0.0424	-0.0632
22	0.0416	-0.0376
24	0.0400	-0.0428

Table 4

CLEAN CONFIGURATION C_Y

M = 0.4

α \ β	K_F = 0: 0	1	2	4	6	8	K_F = 1: 0	1	2	4	6	8
0	0.0000	-0.0020	-0.0039	-0.0078	-0.0116	-0.0156	0.0000	-0.0066	-0.0131	-0.0263	-0.0394	-0.0526
6	0.0000	-0.0026	-0.0046	-0.0098	-0.0149	-0.0216	0.0000	-0.0070	-0.0135	-0.0275	-0.0415	-0.0570
10	0.0000	-0.0038	-0.0066	-0.0117	-0.0199	-0.0285	0.0000	-0.0080	-0.0150	-0.0285	-0.0450	-0.0620
14	0.0000	-0.0056	-0.0108	-0.0191	-0.0289	-0.0382	0.0000	-0.0090	-0.0175	-0.0325	-0.0490	-0.0650
18	0.0000	-0.0050	-0.0103	-0.0201	-0.0299	-0.0412	0.0000	-0.0078	-0.0160	-0.0315	-0.0470	-0.0640
20	0.0000	-0.0061	-0.0110	-0.0180	-0.0304	-0.0379	0.0000	-0.0089	-0.0165	-0.0291	-0.0470	-0.0600
22	0.0000	-0.0052	-0.0106	-0.0192	-0.0271	-0.0260	0.0000	-0.0079	-0.0160	-0.0300	-0.0433	-0.0476
24	0.0000	-0.0052	-0.0097	-0.0185	-0.0297	-0.0409	0.0000	-0.0078	-0.0150	-0.0290	-0.0455	-0.0620

M = 0.6

α \ β	K_F = 0: 0	1	2	4	6	8	K_F = 1: 0	1	2	4	6	8
0	0.0000	-0.0015	-0.0030	-0.0060	-0.0091	-0.0121	0.0000	-0.0061	-0.0123	-0.0246	-0.0368	-0.0491
6	0.0000	-0.0017	-0.0034	-0.0068	-0.0103	-0.0137	0.0000	-0.0061	-0.0123	-0.0246	-0.0368	-0.0491
10	0.0000	-0.0023	-0.0047	-0.0094	-0.0140	-0.0187	0.0000	-0.0065	-0.0130	-0.0261	-0.0392	-0.0522
14	0.0000	-0.0037	-0.0075	-0.0150	-0.0224	-0.0299	0.0000	-0.0071	-0.0142	-0.0284	-0.0426	-0.0567
18	0.0000	-0.0048	-0.0097	-0.0193	-0.0290	-0.0387	0.0000	-0.0077	-0.0154	-0.0307	-0.0461	-0.0614

M = 0.8

α \ β	K_F = 0: 0	1	2	4	6	8	K_F = 1: 0	1	2	4	6	8
0	0.0000	-0.0015	-0.0030	-0.0061	-0.0091	-0.0121	0.0000	-0.0062	-0.0125	-0.0250	-0.0375	-0.0500
6	0.0000	-0.0017	-0.0035	-0.0069	-0.0104	-0.0139	0.0000	-0.0062	-0.0125	-0.0250	0.0375	-0.0500
10	0.0000	-0.0024	-0.0047	-0.0095	-0.0142	-0.0190	0.0000	0.0065	-0.0130	-0.0261	-0.0392	-0.0522
14	0.0000	-0.0035	-0.0070	-0.0140	-0.0209	-0.0279	0.0000	-0.0068	-0.0137	-0.0274	-0.0410	-0.0547
18	0.0000	-0.0044	-0.0088	-0.0176	-0.0264	-0.0352	0.0000	-0.0072	-0.0144	-0.0288	-0.0431	-0.0575

Table 4 (Contd)

CLEAN CONFIGURATION C_Y

M = 0.9

α \ β	K_F = 0: 0	1	2	4	6	8	K_F = 1: 0	1	2	4	6	8
0	0.0000	-0.0015	-0.0030	-0.0061	-0.0091	-0.0121	0.0000	-0.0064	-0.0128	-0.0255	-0.0383	-0.0511
6	0.0000	-0.0017	-0.0035	-0.0070	-0.0105	-0.0140	0.0000	-0.0064	-0.0128	-0.0255	-0.0383	-0.0511
10	0.0000	-0.0024	-0.0048	-0.0096	-0.0144	-0.0193	0.0000	-0.0065	-0.0130	-0.0261	-0.0392	-0.0522
14	0.0000	-0.0033	-0.0066	-0.0133	-0.0199	-0.0265	0.0000	-0.0067	-0.0133	-0.0267	-0.0400	-0.0533
18	0.0000	-0.0041	-0.0082	-0.0163	-0.0245	-0.0327	0.0000	-0.0068	-0.0136	-0.0272	-0.0408	-0.0544

M = 1.0

α \ β	K_F = 0: 0	1	2	4	6	8	K_F = 1: 0	1	2	4	6	8
0	0.0000	-0.0015	-0.0030	-0.0061	-0.0091	-0.0121	0.0000	-0.0067	-0.0134	-0.0267	-0.0401	-0.0535
6	0.0000	-0.0018	-0.0037	-0.0073	-0.0110	-0.0146	0.0000	-0.0067	-0.0134	-0.0267	-0.0401	-0.0535
10	0.0000	-0.0024	-0.0049	-0.0098	-0.0146	-0.0195	0.0000	-0.0066	-0.0133	-0.0265	-0.0398	-0.0530
14	0.0000	-0.0032	-0.0064	-0.0128	-0.0192	-0.0255	0.0000	-0.0065	-0.0131	-0.0262	-0.0393	-0.0524
18	0.0000	-0.0038	-0.0076	-0.0152	-0.0229	-0.0305	0.0000	-0.0065	-0.0129	-0.0258	-0.0388	-0.0517

APPROACH CONFIGURATION C_Y

M = 0, 0.4

α \ β	K_F = 0: 0	1	2	4	6	8	K_F = 1: 0	1	2	4	6	8
0	0.0000	-0.0060	-0.0121	-0.0241	-0.0361	-0.0482	0.0000	-0.0106	-0.0213	-0.0426	-0.0639	-0.0852
6	0.0000	-0.0052	-0.0105	-0.0238	-0.0364	-0.0506	0.0000	-0.0096	-0.0192	-0.0415	-0.0630	-0.0860
10	0.0000	-0.0058	-0.0116	-0.0262	-0.0399	-0.0550	0.0000	-0.0100	-0.0200	-0.0430	-0.0650	-0.0885
14	0.0000	-0.0065	-0.0131	-0.0306	-0.0479	-0.0657	0.0000	-0.0099	-0.0198	-0.0440	-0.0680	-0.0925
18	0.0000	-0.0087	-0.0183	-0.0361	-0.0539	-0.0712	0.0000	-0.0115	-0.0240	-0.0475	-0.0710	-0.0940
20	0.0000	-0.0092	-0.0175	-0.0349	-0.0524	-0.0704	0.0000	-0.0120	-0.0230	-0.0460	-0.0690	-0.0925
22	0.0000	-0.0068	-0.0146	-0.0302	-0.0488	-0.0674	0.0000	-0.0095	-0.0200	-0.0410	-0.0650	-0.0890
24	0.0000	-0.0079	-0.0157	-0.0310	-0.0497	-0.0689	0.0000	-0.0105	-0.0210	-0.0415	-0.0655	-0.0900

Table 5

CLEAN CONFIGURATION C_ℓ

M = 0, 0.4

	$K_F = 0$						$K_F = 1$					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	0.0003	0.0006	0.0012	0.0019	0.0025	0.0000	-0.0001	-0.0003	-0.0006	-0.0008	-0.0011
6	0 0000	-0.0013	-0.0026	-0 0042	-0.0061	-0.0077	0.0000	-0 0015	-0.0030	-0.0050	-0.0073	-0.0094
10	0.0000	-0.0023	-0.0046	-0.0092	-0.0140	-0.0184	0.0000	-0.0023	-0.0046	-0.0092	-0.0139	-0.0183
14	0.0000	-0.0033	-0.0068	-0.0126	-0.0177	-0.0227	0.0000	-0.0030	-0.0062	-0.0115	-0.0160	-0.0205
18	0.0000	-0.0046	-0.0067	-0.0115	-0.0162	-0.0207	0.0000	-0.0044	-0.0063	-0.0107	-0.0150	-0.0190
20	0.0000	-0.0013	-0.0018	-0.0073	-0.0131	-0.0195	0.0000	-0.0011	-0.0015	-0.0066	-0.0121	-0.0181
22	0.0000	0.0013	-0.0012	-0.0086	-0.0150	-0.0212	0.0000	0.0014	-0.0009	-0.0080	-0.0140	-0.0200
24	0.0000	-0.0018	-0.0041	-0.0074	-0.0121	-0.0184	0.0000	-0.0017	-0.0039	-0.0070	-0.0115	-0.0175

M = 0.6

	$K_F = 0$						$K_F = 1$					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	0.0002	0.0004	0.0008	0.0012	0.0016	0.0000	-0.0002	-0.0005	-0.0010	-0.0015	-0.0020
6	0.0000	-0.0013	-0.0026	-0.0052	-0.0078	-0.0105	0.0000	-0.0015	-0.0030	-0.0061	-0.0091	-0.0121
10	0.0000	-0.0023	-0.0046	-0.0093	-0.0140	-0.0186	0.0000	-0.0023	-0.0046	-0.0093	-0.0139	-0.0186
14	0.0000	-0.0030	-0.0060	-0.0119	-0.0179	-0.0239	0.0000	-0.0027	-0.0054	-0.0108	-0.0162	-0.0216
18	0.0000	-0.0031	-0.0062	-0.0124	-0.0186	-0.0248	0.0000	-0.0029	-0.0058	-0.0116	-0.0173	-0.0231

M = 0.8

	$K_F = 0$						$K_F = 1$					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	0.0002	0.0004	0.0007	0.0011	0.0015	0.0000	-0.0003	-0.0005	-0.0010	-0.0016	-0.0021
6	0.0000	-0.0014	-0.0028	-0.0055	-0.0083	-0.0110	0.0000	-0.0016	-0.0032	-0.0064	-0.0095	-0.0127
10	0.0000	-0.0025	-0.0051	-0.0101	-0.0152	-0.0203	0.0000	-0.0025	-0.0051	-0.0101	-0.0152	-0.0202
14	0.0000	-0.0032	-0.0063	-0.0126	-0.0190	-0.0253	0.0000	-0.0029	-0.0058	-0.0115	-0.0173	-0.0230
18	0.0000	-0.0032	-0.0064	-0.0129	-0.0193	-0.0258	0.0000	-0.0030	-0.0060	-0.0120	-0.0181	-0.0241

Table 5 (Contd)

CLEAN CONFIGURATION C_ℓ

M = 0.9

	K_F = 0						K_F = 1					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0 0000	0.0002	0.0004	0.0008	0.0012	0.0016	0.0000	-0.0002	-0.0005	-0.0010	-0.0015	-0.0020
6	0.0000	-0.0014	-0.0029	-0.0058	-0.0087	-0.0116	0.0000	-0.0016	-0.0033	-0.0066	-0.0099	-0.0133
10	0.0000	-0.0027	-0.0054	-0.0108	-0.0163	-0.0217	0.0000	-0.0027	-0.0054	-0.0108	-0.0162	-0.0216
14	0.0000	-0.0032	-0.0065	-0.0130	-0.0195	-0.0260	0.0000	-0.0030	-0.0059	-0.0119	-0.0178	-0.0237
18	0.0000	-0.0033	-0.0066	-0.0131	-0.0197	-0.0262	0.0000	-0.0031	-0.0061	-0.0123	-0.0184	-0.0246

M = 1.0

	K_F = 0						K_F = 1					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	0.0003	0.0006	0.0011	0.0017	0.0022	0.0000	-0.0006	-0.0011	-0.0022	-0.0034	-0.0045
6	0.0000	-0.0016	-0.0032	-0.0063	-0.0095	-0.0126	0.0000	-0.0019	-0.0039	-0.0077	-0.0116	-0.0155
10	0.0000	-0.0029	-0.0058	-0.0116	-0.0173	-0.0231	0.0000	-0.0030	-0.0060	-0.0120	-0.0180	-0.0240
14	0.0000	-0.0033	-0.0066	-0.0133	-0.0199	-0.0265	0.0000	-0.0032	-0.0064	-0.0128	-0.0192	-0.0255
18	0.0000	-0.0034	-0.0068	-0.0136	-0.0204	-0.0272	0.0000	-0.0033	-0.0066	-0.0132	-0.0198	-0.0264

APPROACH CONFIGURATION C_ℓ

M = 0, 0.4

	K_F = 0						K_F = 1					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	0.0006	0.0011	0.0023	0.0034	0.0046	0.0000	0.0001	0.0002	0.0005	0.0007	0 0010
6	0.0000	-0.0005	-0.0017	-0.0033	-0.0050	-0.0064	0.0000	-0.0007	-0.0021	-0.0041	-0.0062	-0.0081
10	0.0000	-0.0015	-0.0033	-0.0072	-0.0107	-0.0138	0.0000	-0.0015	-0.0033	-0.0072	-0.0107	-0.0137
14	0.0000	-0.0027	-0.0053	-0.0101	-0.0142	-0.0172	0.0000	-0.0024	-0.0047	-0.0090	-0.0125	-0.0150
18	0.0000	-0.0026	-0.0048	-0.0074	-0.0112	-0.0162	0.0000	-0.0024	-0.0044	-0.0066	-0.0100	-0.0145
20	0.0000	0.0004	-0.0018	-0.0072	-0.0120	-0.0174	0.0000	0.0006	-0.0015	-0.0065	-0.0110	-0.0160
22	0.0000	-0.0024	-0.0043	-0.0091	-0.0155	-0.0213	0.0000	-0.0022	-0.0040	-0.0085	-0.0145	-0.0200
24	0.0000	-0.0021	-0.0052	-0.0109	-0.0163	-0.0229	0.0000	-0.0020	-0.0050	-0.0105	-0.0157	-0.0220

Table 6

CLEAN CONFIGURATION C_n

M - 0, 0.4

	$K_F = 0$						$K_F = 1$					
α \ β	0	1	2	4	6	8	0	1	2	'4	6	8
0	0.0000	-0.0009	-0.0025	-0.0052	-0.0071	-0.0098	0.0000	0.0017	0.0028	0.0054	0.0088	0.0114
2	0.0000	-0.0010	-0.0027	-0.0056	-0.0076	-0.0105	0.0000	0.0017	0.0028	0.0054	0.0088	0.0114
4	0.0000	-0.0011	-0.0027	-0.0057	-0.0078	-0.0108	0.0000	0.0017	0.0028	0.0054	0.0088	0.0114
8	0.0000	-0.0007	-0.0020	-0.0042	-0.0055	-0.0077	0.0000	0.0017	0.0028	0.0054	0.0088	0.0114
12	0.0000	-0.0005	-0.0016	-0.0035	-0.0045	-0.0063	0.0000	0.0017	0.0028	0.0054	0.0088	0.0114
16	0.0000	-0.0003	-0.0006	-0.0020	-0.0034	-0.0049	0.0000	0.0015	0.0030	0.0052	0.0074	0.0095
18	0.0000	-0.0010	-0.0018	-0.0027	-0.0033	-0.0043	0.0000	0.0006	0.0015	0.0039	0.0066	0.0090
20	0.0000	-0.0009	-0.0018	-0.0025	-0.0030	-0.0036	0.0000	0.0006	0.0012	0.0035	0.0060	0.0085
22	0.0000	-0.0039	-0.0053	-0.0068	-0.0062	-0.0050	0.0000	-0.0025	-0.0026	-0.0013	0.0020	0.0060
24	0.0000	-0.0027	-0.0049	-0.0074	-0.0071	-0.0069	0.0000	-0.0015	-0.0025	-0.0025	0.0002	0.0029

M = 0.6

	$K_F = 0$						$K_F = 1$					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	-0.0013	-0.0027	-0.0054	-0.0081	-0.0108	0.0000	0.0013	0.0027	0.0053	0.0080	0.0107
2	0.0000	-0.0014	-0.0028	-0.0056	-0.0085	-0.0113	0.0000	0.0013	0.0027	0.0054	0.0081	0.0107
4	0.0000	-0.0015	-0.0029	-0.0059	-0.0088	-0.0117	0.0000	0.0014	0.0028	0.0055	0.0083	0.0110
8	0.0000	-0.0011	-0.0022	-0.0043	-0.0065	-0.0086	0.0000	0.0014	0.0028	0.0056	0.0085	0.0113
12	0.0000	-0.0009	-0.0019	-0.0037	-0.0056	-0.0075	0.0000	0.0014	0.0028	0.0056	0.0084	0.0112
16	0.0000	-0.0007	-0.0013	-0.0026	-0.0040	-0.0053	0.0000	0.0013	0.0026	0.0053	0.0079	0.0105
18	0.0000	-0.0006	-0.0011	-0.0023	-0.0034	-0.0045	0.0000	0.0013	0.0026	0.0051	0.0077	0.0103

M = 0.8

	$K_F = 0$						$K_F = 1$					
α \ β	0	1	2	4	6	8	0	1	2	4	6	8
0	0.0000	-0.0013	-0.0027	-0.0053	-0.0080	-0.0107	0.0000	0.0016	0.0033	0.0065	0.0098	0.0131
2	0.0000	-0.0014	-0.0028	-0.0056	-0.0084	-0.0112	0.0000	0.0016	0.0033	0.0066	0.0099	0.0132
4	0.0000	-0.0014	-0.0029	-0.0057	-0.0086	-0.0115	0.0000	0.0016	0.0031	0.0063	0.0094	0.0126
8	0.0000	-0.0011	-0.0022	-0.0043	-0.0065	-0.0086	0.0000	0.0017	0.0034	0.0068	0.0102	0.0135
12	0.0000	-0.0009	-0.0019	-0.0038	-0.0056	-0.0075	0.0000	0.0015	0.0031	0.0061	0.0092	0.0123
16	0.0000	-0.0007	-0.0014	-0.0028	-0.0041	-0.0055	0.0000	0.0015	0.0031	0.0062	0.0092	0.0123
18	0.0000	-0.0006	-0.0013	-0.0025	-0.0038	-0.0051	0.0000	0.0015	0.0030	0.0060	0.0090	0.0119

Table 6 (Contd)

CLEAN CONFIGURATION C_n

M = 0.9

α \ β	$K_F = 0$: 0	1	2	4	6	8	$K_F = 1$: 0	1	2	4	6	8
0	0.0000	-0.0013	-0.0027	-0.0053	-0.0080	-0.0107	0.0000	0.0017	0.0034	0.0067	0.0101	0.0134
2	0.0000	-0.0014	-0.0028	-0.0055	-0.0083	-0.0110	0.0000	0.0017	0.0034	0.0068	0.0103	0.0137
4	0.0000	-0.0014	-0.0028	-0.0057	-0.0085	-0.0114	0.0000	0.0016	0.0032	0.0064	0.0096	0.0128
8	0.0000	-0.0011	-0.0022	-0.0043	-0.0065	-0.0086	0.0000	0.0018	0.0035	0.0070	0.0105	0.0141
12	0.0000	-0.0010	-0.0019	-0.0038	-0.0057	-0.0076	0.0000	0.0017	0.0035	0.0070	0.0105	0.0140
16	0.0000	-0.0007	-0.0015	-0.0029	-0.0044	-0.0059	0.0000	0.0018	0.0037	0.0073	0.0110	0.0146
18	0.0000	-0.0007	-0.0014	-0.0028	-0.0043	-0.0057	0.0000	0.0018	0.0036	0.0072	0.0108	0.0144

M = 1.0

α \ β	$K_F = 0$: 0	1	2	4	6	8	$K_F = 1$: 0	1	2	4	6	8
0	0.0000	-0.0013	-0.0026	-0.0053	-0.0080	-0.0106	0.0000	0.0017	0.0034	0.0069	0.0104	0.0138
2	0.0000	-0.0014	-0.0027	-0.0055	-0.0082	-0.0110	0.0000	0.0018	0.0036	0.0072	0.0107	0.0143
4	0.0000	-0.0014	-0.0028	-0.0056	-0.0084	-0.0112	0.0000	0.0017	0.0034	0.0068	0.0102	0.0136
8	0.0000	-0.0011	-0.0022	-0.0043	-0.0065	-0.0086	0.0000	0.0019	0.0038	0.0076	0.0114	0.0152
12	0.0000	-0.0010	-0.0019	-0.0039	-0.0058	-0.0078	0.0000	0.0020	0.0041	0.0082	0.0122	0.0163
16	0.0000	-0.0008	-0.0016	-0.0031	-0.0046	-0.0062	0.0000	0.0022	0.0045	0.0089	0.0134	0.0178
18	0.0000	-0.0008	-0.0015	-0.0031	-0.0046	-0.0061	0.0000	0.0022	0.0044	0.0088	0.0132	0.0176

APPROACH CONFIGURATION C_n

M = 0, 0.4

α \ β	$K_F = 0$: 0	1	2	4	6	8	$K_F = 1$: 0	1	2	4	6	8
0	0.0000	-0.0023	-0.0045	-0.0093	-0.0130	-0.0144	0.0000	0.0003	0.0008	0.0013	0.0029	0.0068
2	0.0000	-0.0024	-0.0047	-0.0097	-0.0135	-0.0151	0.0000	0.0003	0.0008	0.0013	0.0029	0.0068
4	0.0000	-0.0025	-0.0047	-0.0098	-0.0137	-0.0154	0.0000	0.0003	0.0008	0.0013	0.0029	0.0068
8	0.0000	-0.0021	-0.0040	-0.0083	-0.0114	-0.0123	0.0000	0.0003	0.0008	0.0013	0.0029	0.0068
12	0.0000	-0.0018	-0.0034	-0.0069	-0.0099	-0.0107	0.0000	0.0004	0.0010	0.0020	0.0034	0.0070
16	0.0000	-0.0008	-0.0018	-0.0042	-0.0064	-0.0080	0.0000	0.0010	0.0018	0.0030	0.0044	0.0064
18	0.0000	-0.0011	-0.0021	-0.0048	-0.0076	-0.0103	0.0000	0.0005	0.0012	0.0018	0.0023	0.0030
20	0.0000	-0.0021	-0.0031	-0.0053	-0.0074	-0.0097	0.0000	-0.0006	-0.0001	0.0007	0.0016	0.0024
22	0.0000	-0.0024	-0.0047	-0.0075	-0.0094	0.0115	0.0000	-0.0010	-0.0020	-0.0020	-0.0012	-0.0005
24	0.0000	-0.0074	-0.0048	-0.0086	-0.0119	-0.0146	0.0000	-0.0012	-0.0024	-0.0037	-0.0046	-0.0048

Table 7

ℓ_r FOR BOTH CLEAN AND APPROACH CONFIGURATIONS

BODY AXES

	M = 0, 0.4		M = 0.6		M = 0.8		M = 1.0	
α	$K_F = 0$	$K_F = 1$	$K_F = 0$	$K_F = 1$	$K_F = 0$	$K_F = 1$	$K_F = 0$	$K_F = 1$
0	-0.0292	0.0000	-0.0292	0.0000	-0.0292	0.0028	-0.0292	0.0276
4	0.0185	0.0522	0.0185	0.0522	0.0185	0.0550	0.0185	0.0703
8	0.0710	0.0985	0.0710	0.0985	0.0710	0.1065	0.0710	0.1191
12	0.1247	0.1466	0.1247	0.1495	0.1247	0.1533	0.1247	0.1803
16	0.1795	0.1969	0.1795	0.2021	0.1795	0.2094	0.1795	0.2596
20	0.2410	0.2626	0.2410	0.2704	0.2410	0.2884		
24	0.4284	0.4485	0.4284	0.4581				

Table 8

n_r FOR CLEAN AND APPROACH CONFIGURATIONS

BODY AXES

	M = 0, 0.4		M = 0.6		M = 0.8		M = 1.0	
α	$K_F = 0$	$K_F = 1$	$K_F = 0$	$K_F = 1$	$K_F = 0$	$K_F = 1$	$K_F = 0$	$K_F = 1$
0	-0.1630	-0.3380	-0.1630	-0.3380	-0.1475	-0.3610	-0.0491	-0.2626
4	-0.1430	-0.3380	-0.1430	-0.3380	-0.1393	-0.3610	-0.0409	-0.2626
8	-0.1916	-0.3390	-0.1916	-0.3390	-0.1634	-0.3610	-0.0540	-0.2714
12	-0.2136	-0.3610	-0.2010	-0.3610	-0.1830	-0.3661	-0.0670	-0.3311
16	-0.3070	-0.4267	-0.2832	-0.4267	-0.2400	-0.4231	-0.0800	-0.4058
20	-0.4784	-0.5689	-0.4529	-0.5689	-0.3739	-0.5500		
24	-0.7181	-0.7769	-0.6938	-0.7767				

Table 9

ℓ_p FOR CLEAN AND APPROACH CONFIGURATIONS

BODY AXES

α \ M	0, 0.4, 0.6	0.8	1.0
0	-0.1258	-0.1258	-0.1368
4	-0.1422	-0.1641	-0.1851
8	-0.1597	-0.2025	-0.2334
12	-0.1772	-0.2408	-0.2817
16	-0.1936	-0.2792	-0.3300
20	-0.2111	-0.3175	
24	-0.2276		

Table 10

n_p FOR CLEAN AND APPROACH CONFIGURATIONS

BODY AXES

α \ M	0, 0.4, 0.6	0.8	1.0
0	0.0120	0.0180	0.0503
4	-0.0059	0.0000	0.0328
8	-0.0175	-0.0115	0.0212
12	-0.0219	-0.0159	0.0168
16	-0.0214	-0.0154	0.0180
20	-0.0167	-0.0107	
24	-0.0081		

Table 11

CLEAN CONFIGURATION $\frac{\partial C_\ell}{\partial \xi}$

α \ M	0, 0.4	0.7	0.9	1.0
0	-0.0831	-0.1050	-0.1075	-0.1178
4	-0.0831	-0.1050	-0.1075	-0.1178
8	-0.0831	-0.1050	-0.1075	-0.1040
12	-0.0831	-0.0962	-0.1075	-0.0903
16	-0.0831	-0.0875	-0.0975	-0.0765
20	-0.0733	-0.0780	-0.0875	
24	-0.0638			

APPROACH CONFIGURATION $\frac{\partial C_\ell}{\partial \xi}$

α \ M	0, 0.4
0	-0.0882
4	-0.0882
8	-0.0882
12	-0.0882
16	-0.0840
20	-0.0760
24	-0.0638

Table 12

CLEAN CONFIGURATION $\frac{\partial C_n}{\partial \xi}$

α \ M	0, 0.4	0.7	0.9	1.0
0	-0.0235	-0.0242	-0.0273	-0.0352
4	-0.0137	-0.0137	-0.0157	-0.0202
8	-0.0040	-0.0033	-0.0040	-0.0052
12	0.0055	0.0072	0 0075	0.0100
16	0.0152	0.0180	0.0195	0.0250
20	0.0248	0.0282	0.0310	
24	0.0342			

APPROACH CONFIGURATION $\frac{\partial C_n}{\partial \xi}$

α \ M	0, 0.4
0	-0.0165
4	-0.0070
8	0.0025
12	0.0122
16	0.0218
20	0.0310
24	0.0406

Table 13

CLEAN CONFIGURATION $\frac{\partial C_m}{\partial \xi}$

α \ M	0, 0.4	0.7	0.9	1.0
0	-0.0835	-0.0860	-0.0880	-0.0725
4	-0.0835	-0.0860	-0.0880	-0.0725
8	-0.0835	-0.0860	-0.0880	-0.0640
12	-0.0835	-0.0788	-0.0880	-0.0556
16	-0.0835	-0.0717	-0.0798	-0.0471
20	-0.0736	-0.0639	-0.0716	
24	-0.0641			

APPROACH CONFIGURATION $\frac{\partial C_m}{\partial \xi}$

α \ M	0, 0.4
0	-0.0835
4	-0.0835
8	-0.0835
12	-0.0835
16	-0.0795
20	-0.0719
24	-0.0604

Table 14

CLEAN CONFIGURATION $\frac{\partial C_L}{\partial \xi}$

α \ M	0, 0.4	0.7	0.9	1.0
0	0.1800	0.1820	0.1580	0.1250
4	0.1800	0.1820	0.1580	0.1250
8	0.1800	0.1820	0.1580	0.1103
12	0.1800	0.1668	0.1580	0.0958
16	0.1800	0.1517	0.1433	0.0812
20	0.1587	0.1352	0.1286	
24	0.1381			

APPROACH CONFIGURATION $\frac{\partial C_L}{\partial \xi}$

α \ M	0, 0.4
0	0.1800
4	0.1800
8	0.1800
12	0.1800
16	0.1714
20	0.1551
24	0.1301

Table 15

CLEAN CONFIGURATION $\frac{\partial C_\ell}{\partial \zeta}$

α \ M	0, 0.4	0.7	0.9	1.0
0	0.0078	0.0120	0.0140	0.0150
4	0.0034	0.0078	0.0081	0.0084
8	-0.0010	0.0042	0.0044	0.0047
12	-0.0044	0.0005	0.0016	0.0034
16	-0.0099	-0.0030	-0.0012	0.0022
20	-0.0130	-0.0060	-0.0038	
24	-0.0110			

APPROACH CONFIGURATION $\frac{\partial C_\ell}{\partial \zeta}$

α \ M	0, 0.4
0	0.0054
4	0.0012
8	-0.0030
12	-0.0071
16	-0.0113
20	-0.0157
24	-0.0172

Table 16

CLEAN CONFIGURATION $\frac{\partial C_n}{\partial \zeta}$

α \ M	0, 0.4	0.7	0.9	1.0
0	-0.0504	-0.0574	-0.0607	-0.0615
4	-0.0504	-0.0574	-0.0607	-0.0615
8	-0.0504	-0.0574	-0.0607	-0.0615
12	-0.0504	-0.0574	-0.0607	-0.0615
16	-0.0504	-0.0574	-0.0607	-0.0615
20	-0.0504	-0.0574	-0.0607	-0.0615
24	-0.0590			

APPROACH CONFIGURATION $\frac{\partial C_n}{\partial \zeta}$

α \ M	0, 0.4
0	-0.0458
4	-0.0458
8	-0.0458
12	-0.0458
16	-0.0458
20	-0.0458
24	-0.0549

Table 17

CLEAN AND APPROACH CONFIGURATIONS $\frac{\partial C_Y}{\partial \zeta}$

Configuration \ M	0, 0.4	0.7	0.9	1.0
Clean	0.0795	0.0820	0.0834	0.0943
Approach	0.0714			

Table 18

FIN EFFICIENCY K_F

H metre \ M	0.2	0.4	0.6	0.8	0.95	1.0
0	0.970	0.900	0.800	0.686	0.592	0.561
3000	0.980	0.924	0.849	0.759	0.679	0.652
6000	0.989	0.948	0.890	0.822	0.758	0.735
9000	0.995	0.965	0.925	0.876	0.826	0.807
12000	0.998	0.979	0.954	0.922	0.886	0.870
14000	0.999	0.986	0.969	0.945	0.918	0.905

Table 19

RUDDER EFFICIENCY K_R

H metre \ M	0.2, 0.4, 0.6	0.8	0.95	1.0
0	1.000	0.725	0.393	0.203
3000	1.000	0.787	0.519	0.368
6000	1.000	0.844	0.629	0.516
9000	1.000	0.893	0.727	0.643
12000	1.000	0.933	0.811	0.759
14000	1.000	0.953	0.854	0.815

Table 20

CONTROL HINGE MOMENTS

Elevator

M	$\frac{\partial C_{H\eta}}{\partial \alpha}$	$\frac{\partial C_{H\eta}}{\partial \eta}$	$\frac{\partial C_{H\eta}}{\partial \xi}$
0	-0.185	-0.367	-0.167
0.4	-0.185	-0.367	-0.167
0.6	-0.185	-0.367	-0.167
0.8	-0.095	-0.367	-0.185
0.955	-0.214	-0.608	-0.333

Aileron

M	$\frac{\partial C_{H\xi}}{\partial \alpha}$	$\frac{\partial C_{H\xi}}{\partial \eta}$	$\frac{\partial C_{H\xi}}{\partial \xi}$
0	-0.480	-0.170	-0.400
0.4	-0.480	-0.170	-0.400
0.6	-0.480	-0.170	-0.400
0.8	-0.480	-0.170	-0.400
0.955	-0.656	-0.387	-0.545

Rudder

M	$\frac{\partial C_{H\zeta}}{\partial \beta}$	$\frac{\partial C_{H\zeta}}{\partial \zeta}$
0	-0.240	-0.300
0.4	-0.240	-0.300
0.6	-0.240	-0.270
0.8	-0.240	-0.230
0.955	-0.405	-0.323

SYMBOLS, DEFINITIONS OF DERIVATIVES AND REFERENCE DIMENSIONS

Symbols

C_D	drag coefficient $\frac{D}{\frac{1}{2}\rho V^2 S}$
$C_{H\zeta}$	rudder hinge moment coefficient $\frac{H_\zeta}{\frac{1}{2}\rho V^2 S_R c_R}$
$C_{H\eta}$	elevator hinge moment coefficient $\frac{H_\eta}{\frac{1}{2}\rho V^2 S_E c_E}$
$C_{H\xi}$	aileron hinge moment coefficient $\frac{H_\xi}{\frac{1}{2}\rho V^2 S_A c_A}$
C_L	lif coefficient $\frac{L}{\frac{1}{2}\rho V^2 S}$
C_Y	side force coefficient $\frac{Y}{\frac{1}{2}\rho V^2 S}$
C_ℓ	rolling moment coefficient $\frac{\mathcal{L}}{\frac{1}{2}\rho V^2 Sb}$
C_m	pitching moment coefficient $\frac{M}{\frac{1}{2}\rho V^2 Sc}$
C_n	yawing moment coefficient $\frac{N}{\frac{1}{2}\rho V^2 Sb}$
D	drag
H	altitude
H_ζ	rudder hinge moment
H_η	elevator hinge moment
H_ξ	aileron hinge moment
K_F	aeroelastic fin efficiency
K_R	aeroelastic rudder efficiency
L	lift
$\mathcal{L}$	rolling moment
M	pitching moment
N	yawing moment
S, S_A, S_E, S_R	reference areas of wing, aileron, elevator and rudder
b	span
c, c_A, c_E, c_R	aerodynamic mean chord, aileron chord, elevator chord and rudder chord
p	rate of roll
q	rate of pitch
r	rate of yaw

Symbols (Contd)

α	angle of incidence
β	angle of sideslip
ζ	rudder angle
η	elevator angle
ξ	aileron angle
ρ	air density

Definitions of derivatives and their relation to aero-normalised derivatives[12]

$$C_{m_q} = \frac{\partial C_m}{\partial\left(\frac{qc}{V}\right)} = \breve{M}_q$$

$$y_v = \tfrac{1}{2}\,\frac{\partial C_Y}{\partial \beta} = \tfrac{1}{2}\breve{Y}_v$$

$$\ell_v = \frac{\partial C_\ell}{\partial \beta} = \breve{L}_v$$

$$n_v = \frac{\partial C_n}{\partial \beta} = \breve{N}_v$$

$$n_r = \frac{\partial C_n}{\partial\left(\frac{rb}{2V}\right)} = 2\breve{N}_r$$

$$\ell_r = \frac{\partial C_\ell}{\partial\left(\frac{rb}{2V}\right)} = 2\breve{L}_r$$

$$n_p = \frac{\partial C_n}{\partial\left(\frac{pb}{2V}\right)} = 2\breve{N}_p$$

$$\ell_p = \frac{\partial C_\ell}{\partial\left(\frac{pb}{2V}\right)} = 2\breve{L}_p$$

Reference dimensions

S = 448 sq ft

b = 25 ft

c = 21 ft

Aileron reference volume $S_A c_A$ = 67 ft^3

Elevator reference volume $S_E c_E$ = 110.5 ft^3

Rudder reference volume $S_R c_R$ = 16.56 ft^3

CG position:- 154 in forward of datum, on the body datum.

REFERENCES

No.	Author(s)	Title, etc.
1		Type 221 Model A. Stability and control tests at high incidence and with ground effect. BAC (Filton) Report WT 488
2	P.M. Murdin	Low-speed wind-tunnel tests on a 1/7 scale model of the BAC 221 RAE Technical Report 69052 (1969)
3	D. Morton	Tests in the ARA transonic tunnel on a 1/12 scale model of the BAC 221 aircraft. (i) Longitudinal and lateral stability; aileron and rudder power. ARA Model Test Note M 8/3 (1967) (ii) Drag and control hinge moments. ARA Model Test Note M 8/4 (1967) (iii) Summary of longitudinal and lateral stability, drag, control power and control hinge moment results. ARA Model Test Note M 8/5 (1967)
4	C.O. O'Leary	Low-speed wind-tunnel measurements of the oscillatory lateral aerodynamic derivatives of a BAC 221 model and comparison of results with similar Concorde and HP 115 data. RAE Technical Report 70095 (1970)
5	C.O. O'Leary	Transonic wind-tunnel measurements of the oscillatory lateral aerodynamic derivatives of a BAC 221 model. RAE Technical Report 71098 - ARC 33331 (1971)
6		Unpublished document. British Aircraft Corporation FW/SDO-5/7245 (1967)
7		Unpublished document. British Aircraft Corporation Aero IS/221/3 (1965)
8	A.J. Ross	The calculation of lateral stability derivatives of slender wings at incidence, including fin effectiveness and correlation with experiment. RAE Report Aero 2647 (1961)

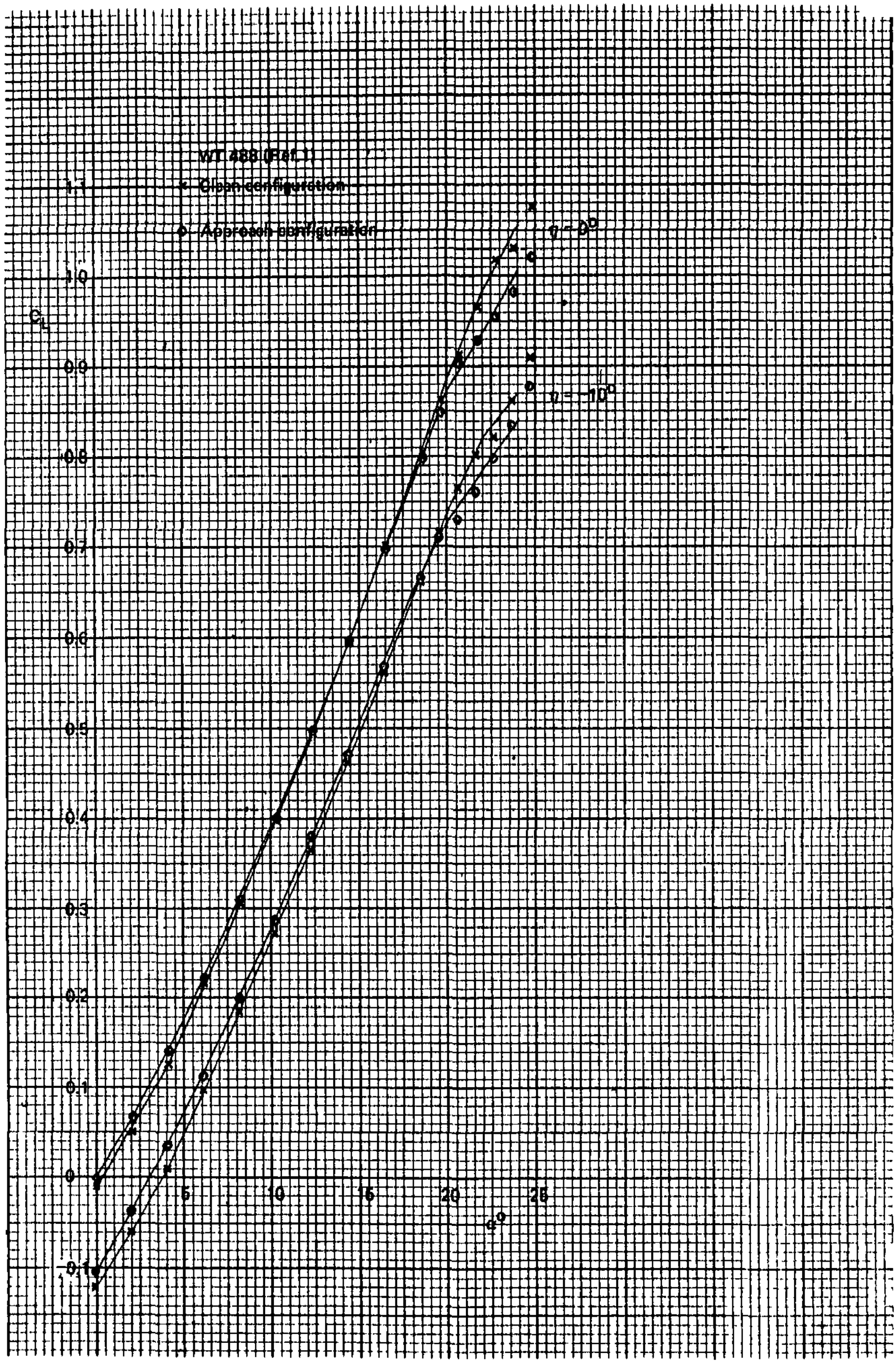

Fig.1 Low-speed C_L v. α

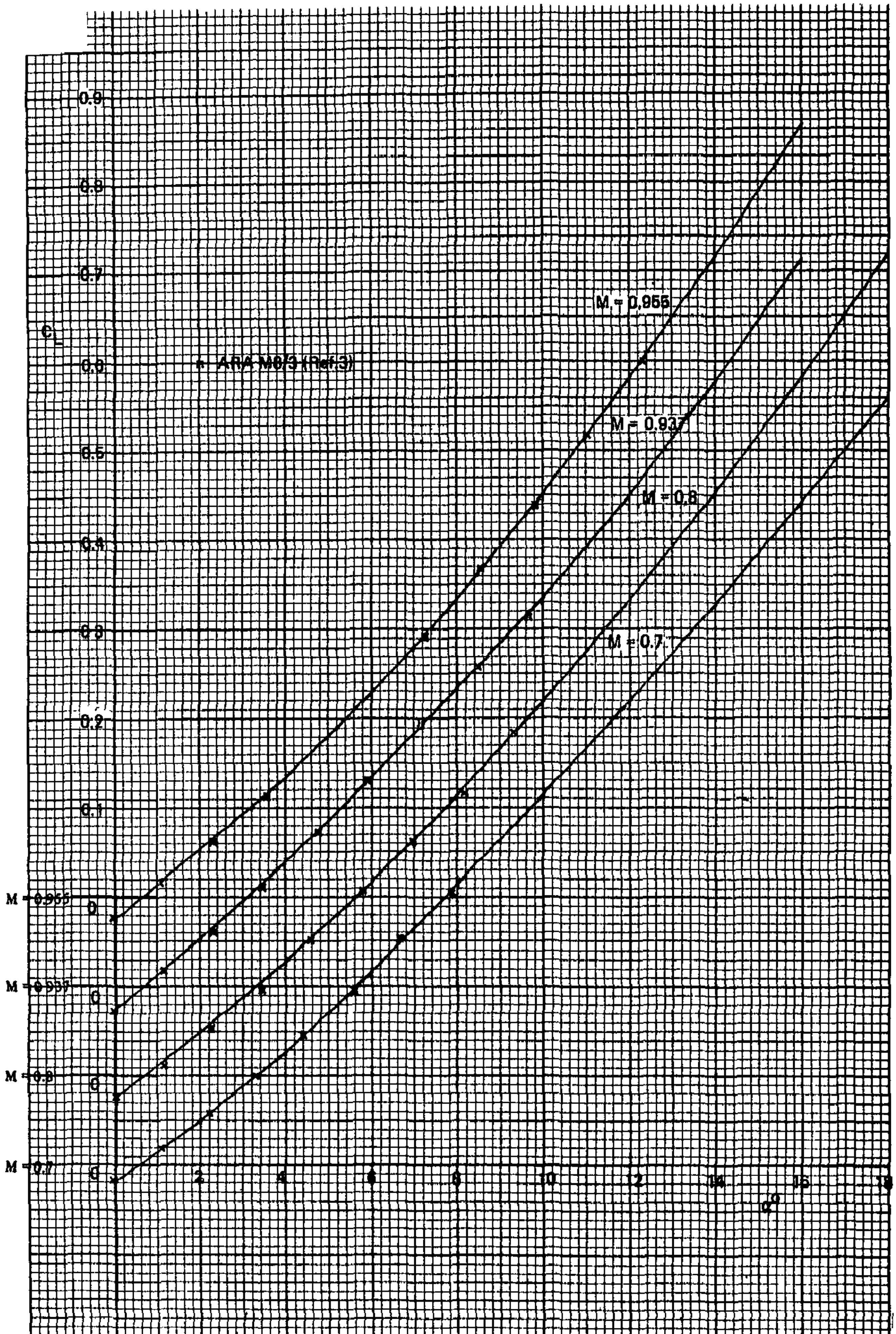

Fig.2 C_L v. α for M = 0.7, 0.8, 0.937, 0.955 ($\eta = 0^o$)

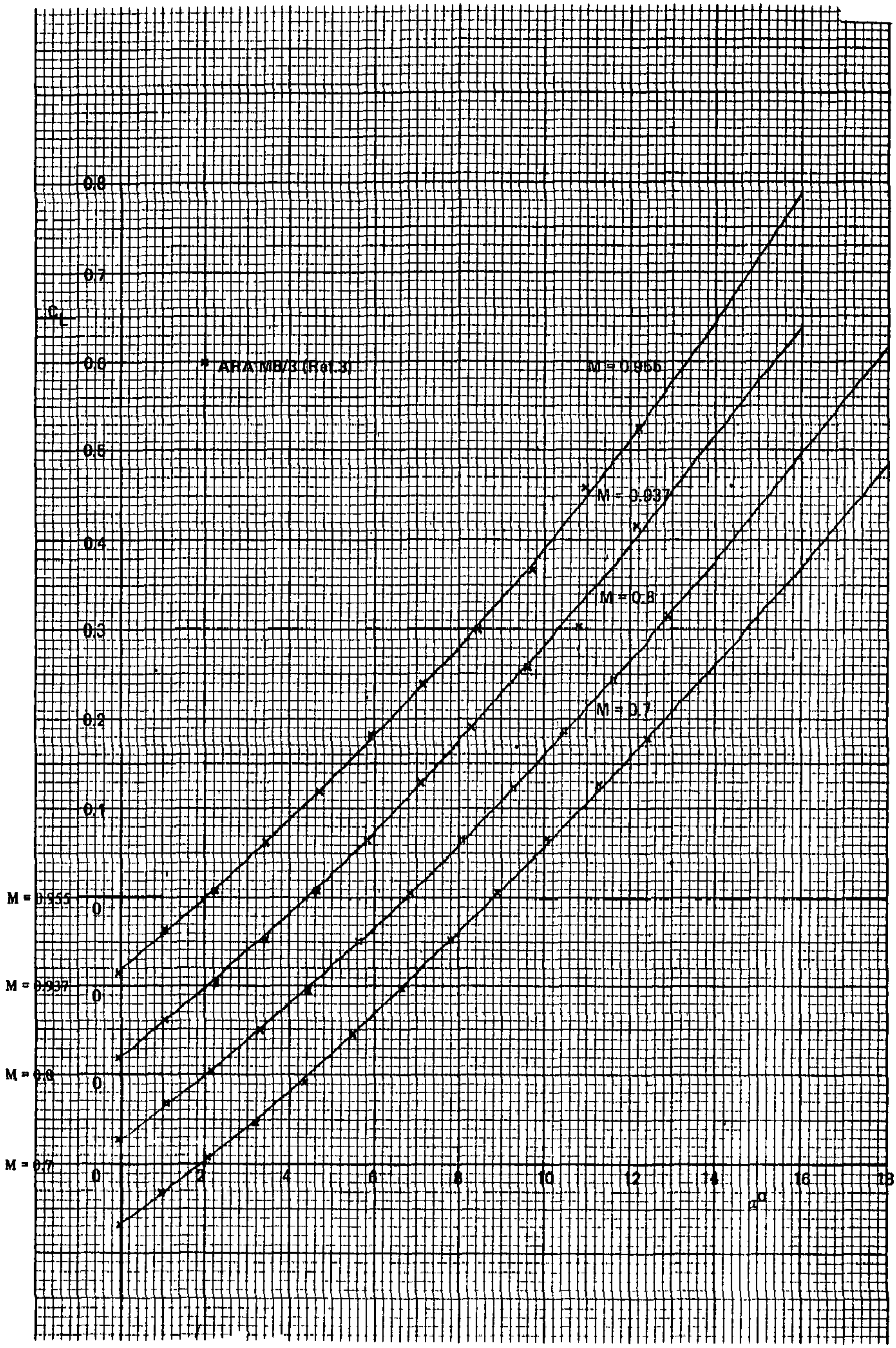

Fig.3 C_L v. α for M = 0.7, 0.8, 0.937, 0.955 ($\eta = -4^o$)

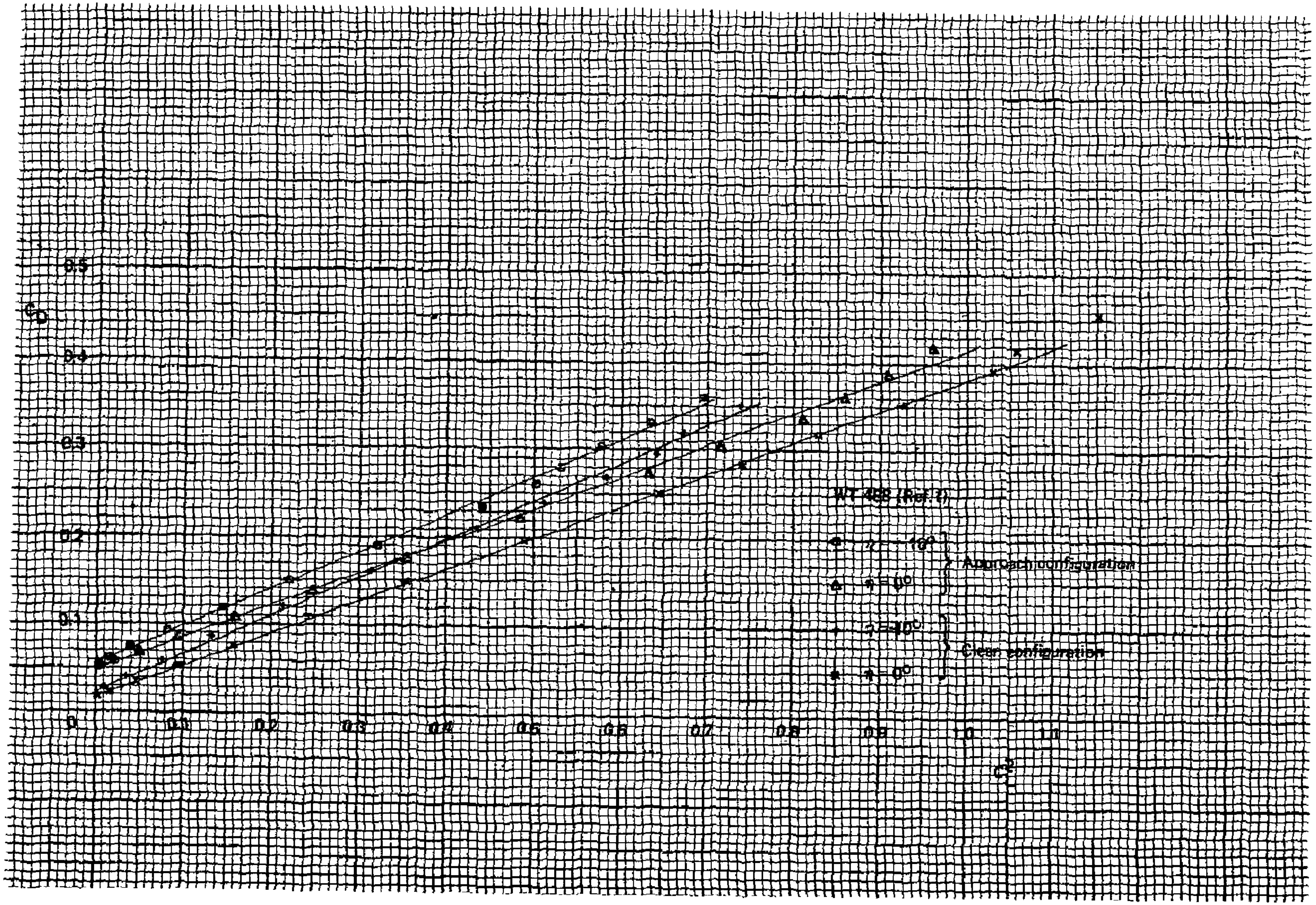

Fig.4 Low-speed C_D v. C_L^2

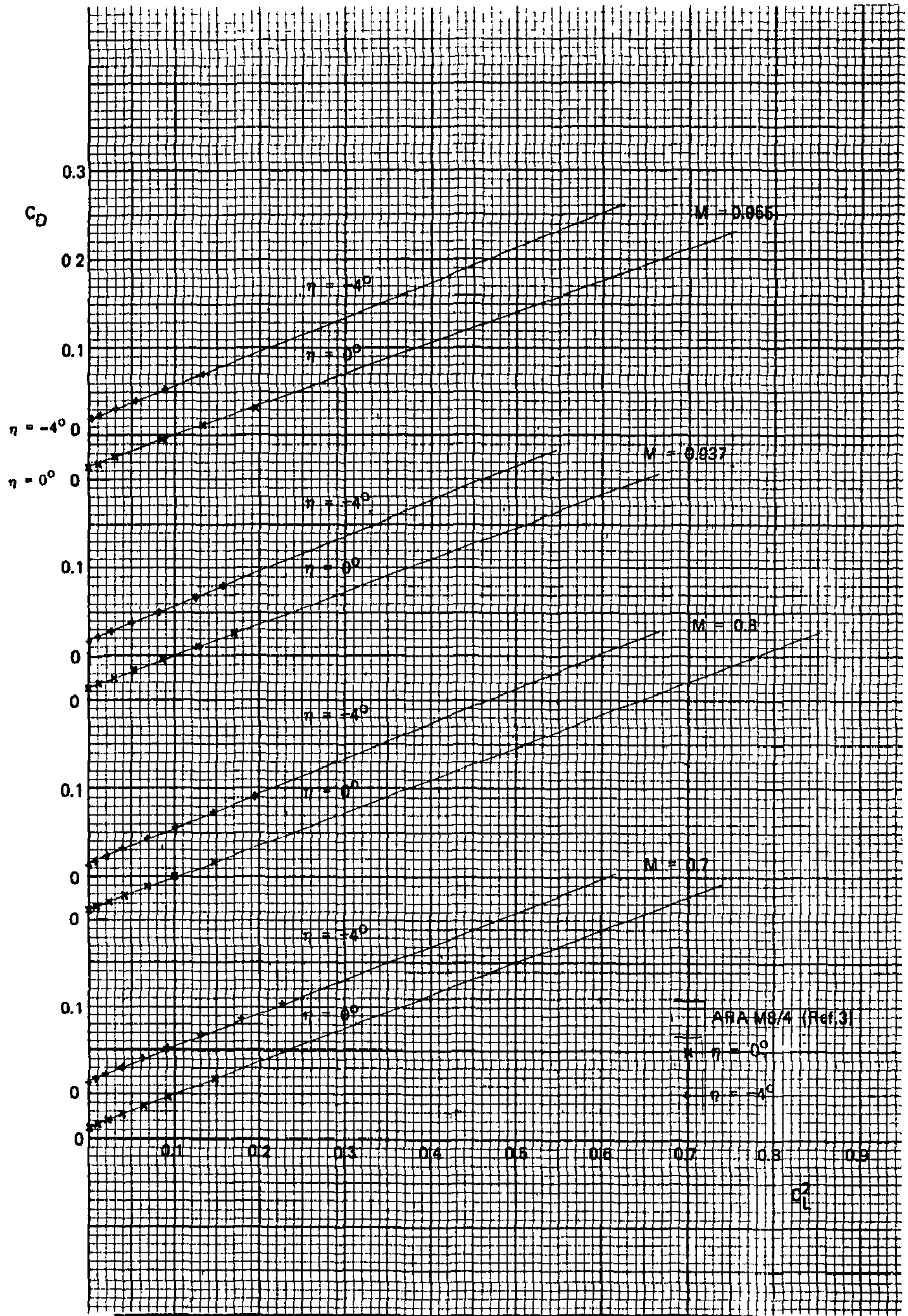

Fig.5 C_D v. C_L^2 for $\eta = 0^o$ and -4^o. M = 0.7, 0.8, 0.937 and 0.955

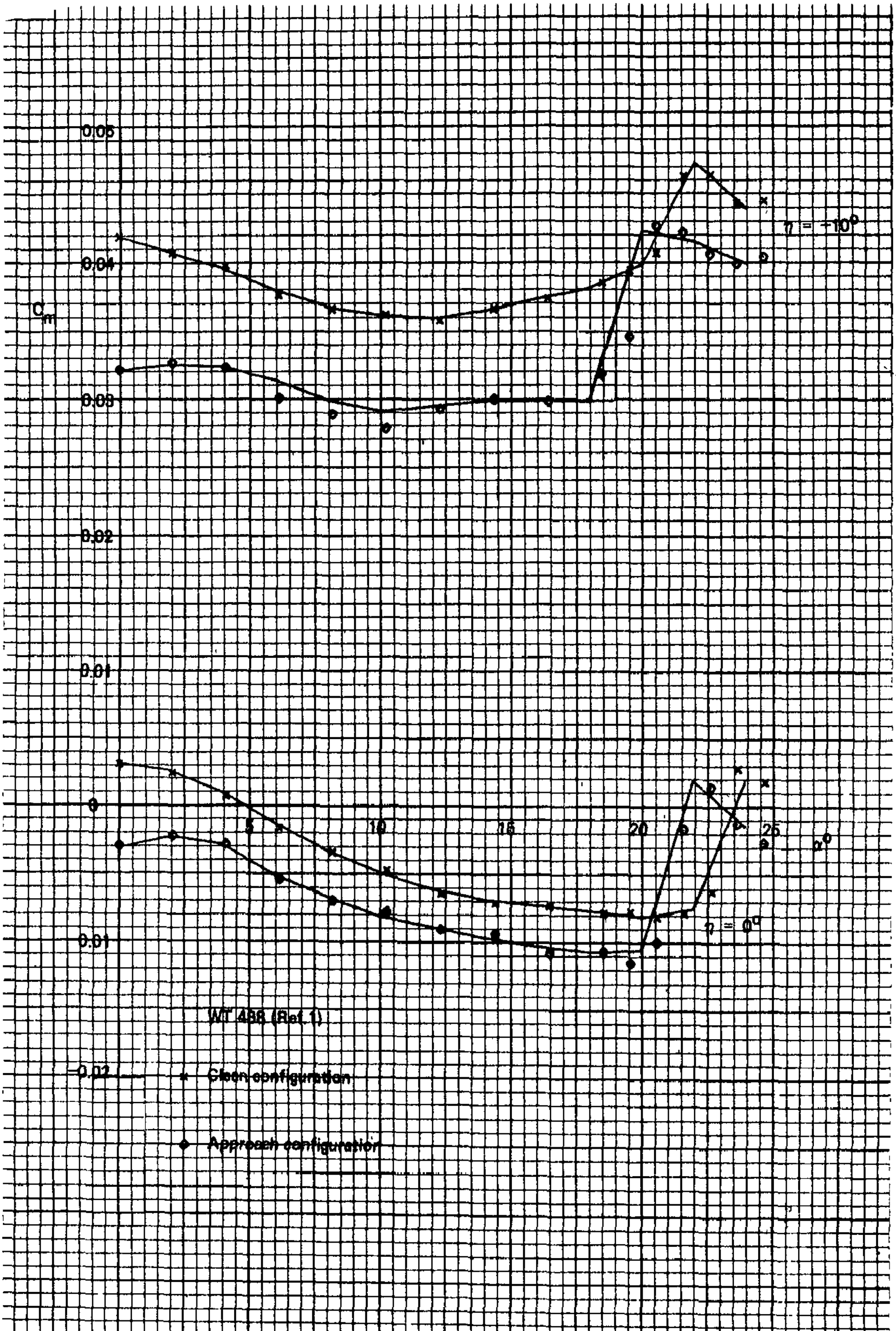

Fig.6 Low-speed C_m v. α

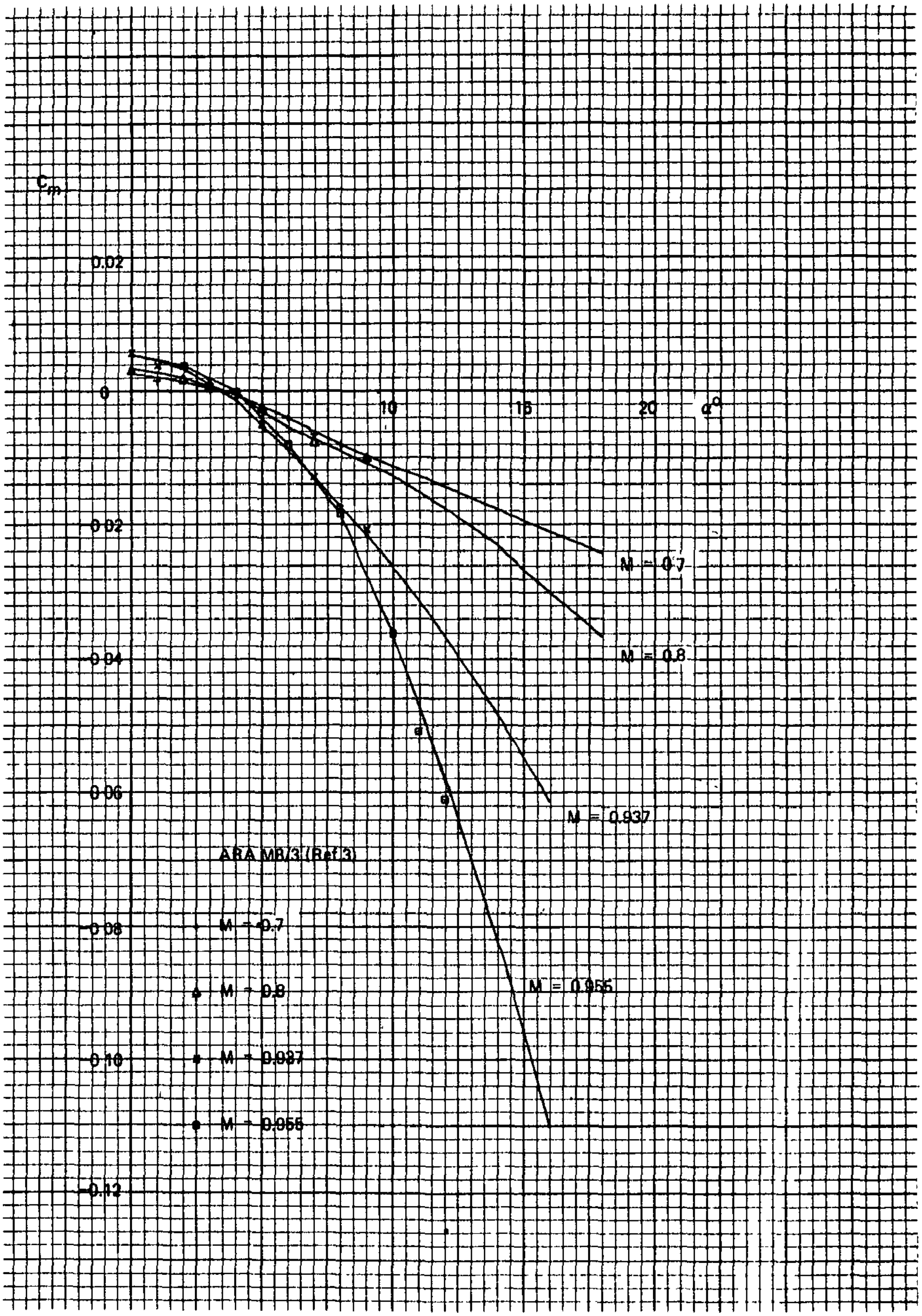

Fig.7 C_m v. α for M = 0.7, 0.8, 0.937, 0.955 ($\eta = 0^o$)

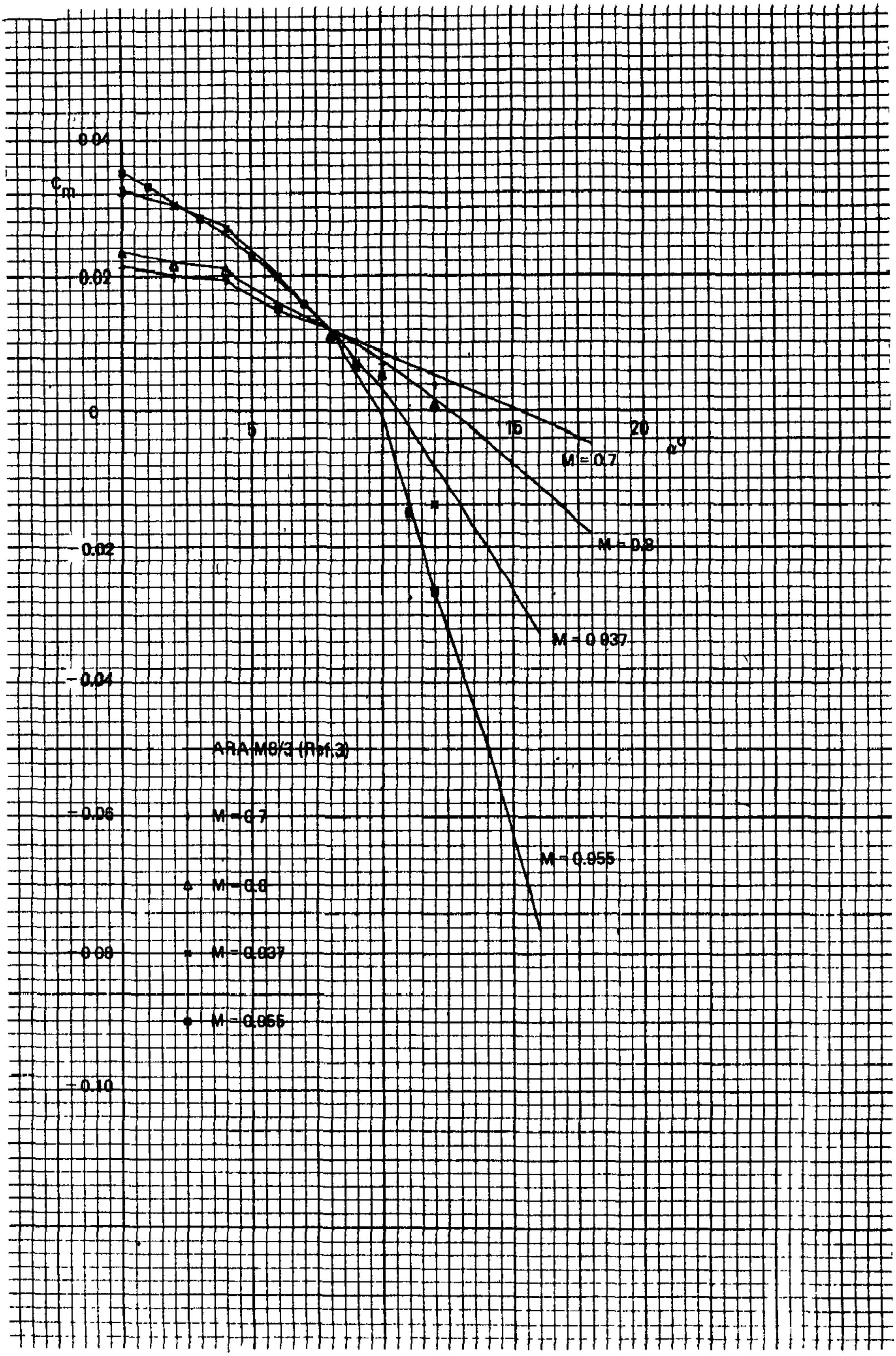

Fig.8 C_m v. α for M = 0.7, 0.8, 0.937, 0.955 ($\eta = -4^o$)

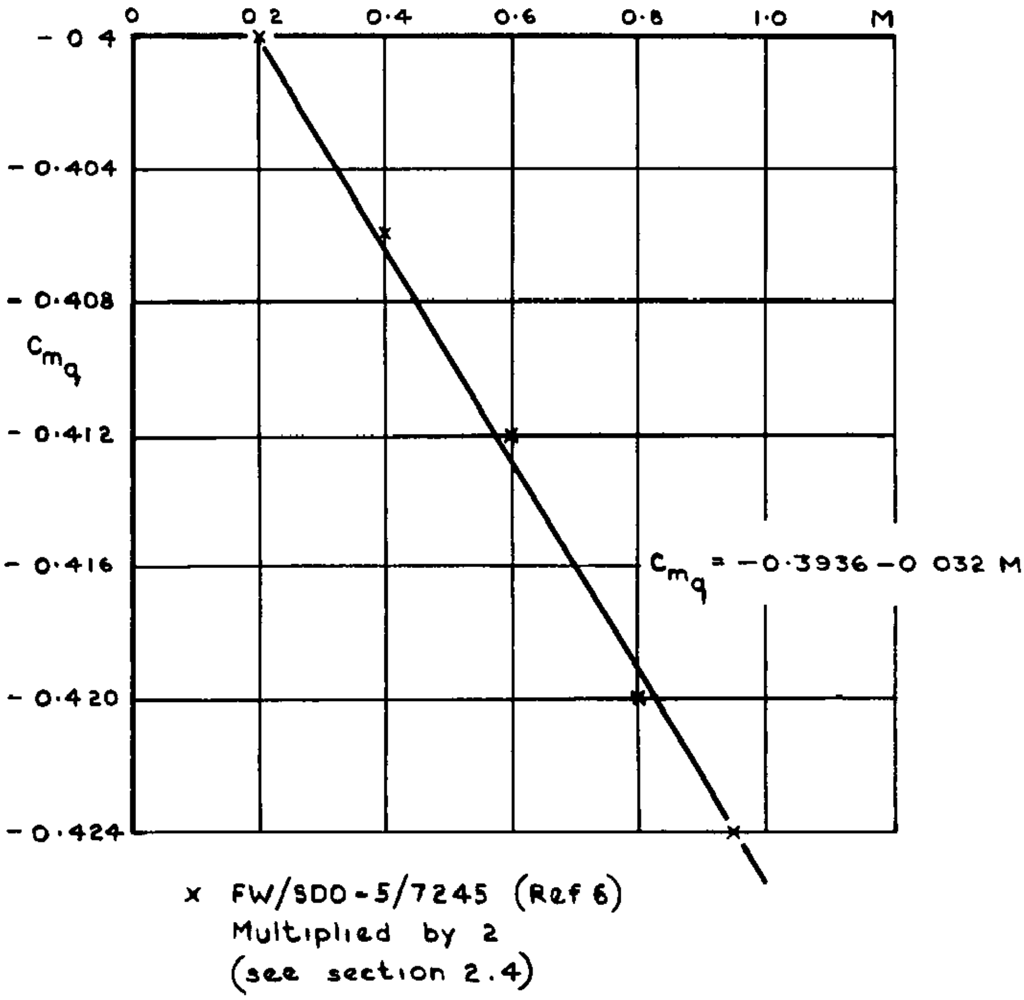

Fig. 9 C_{m_q} v. Mach number

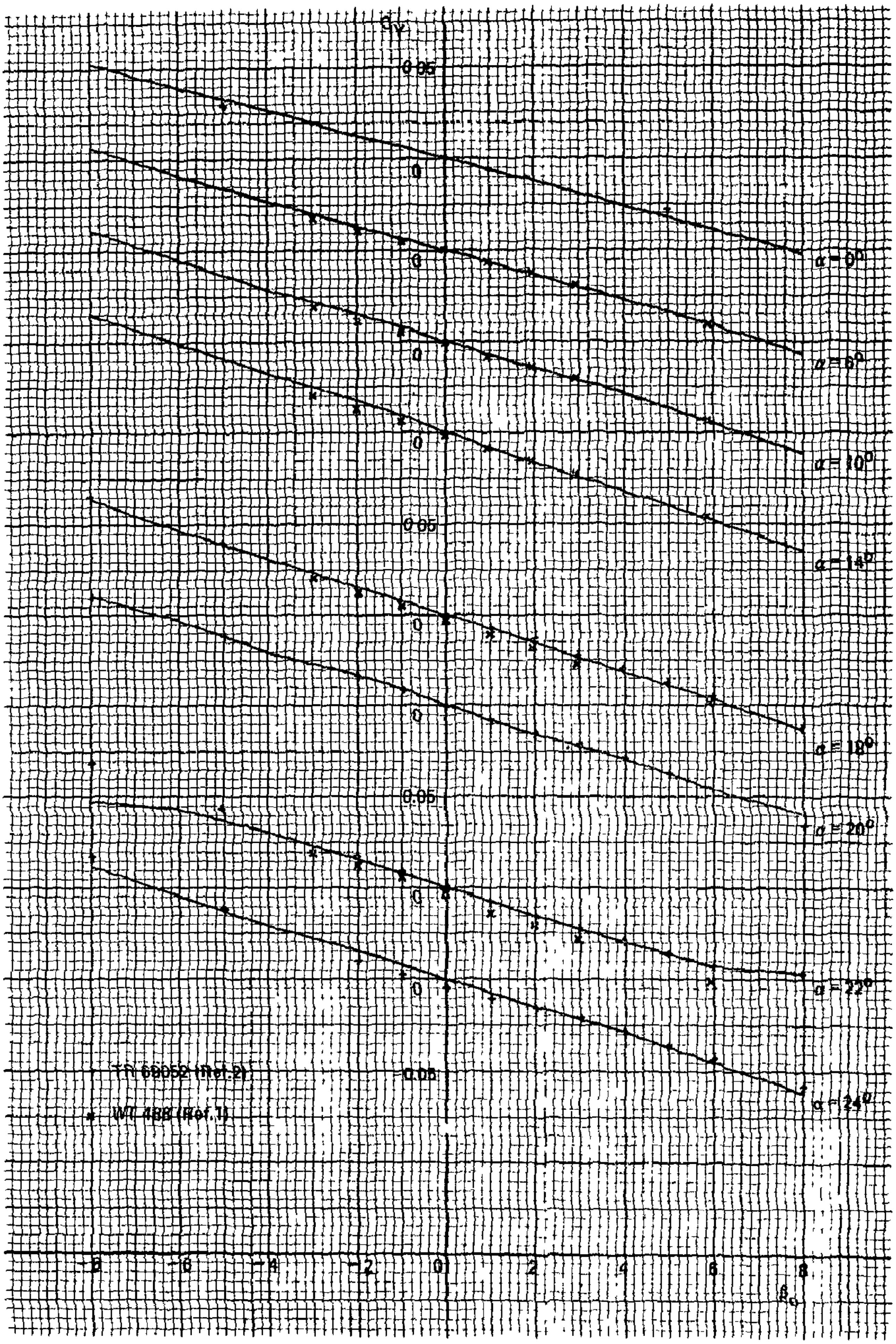

Fig.10 Low-speed C_Y v β. Clean configuration $K_F = 1$

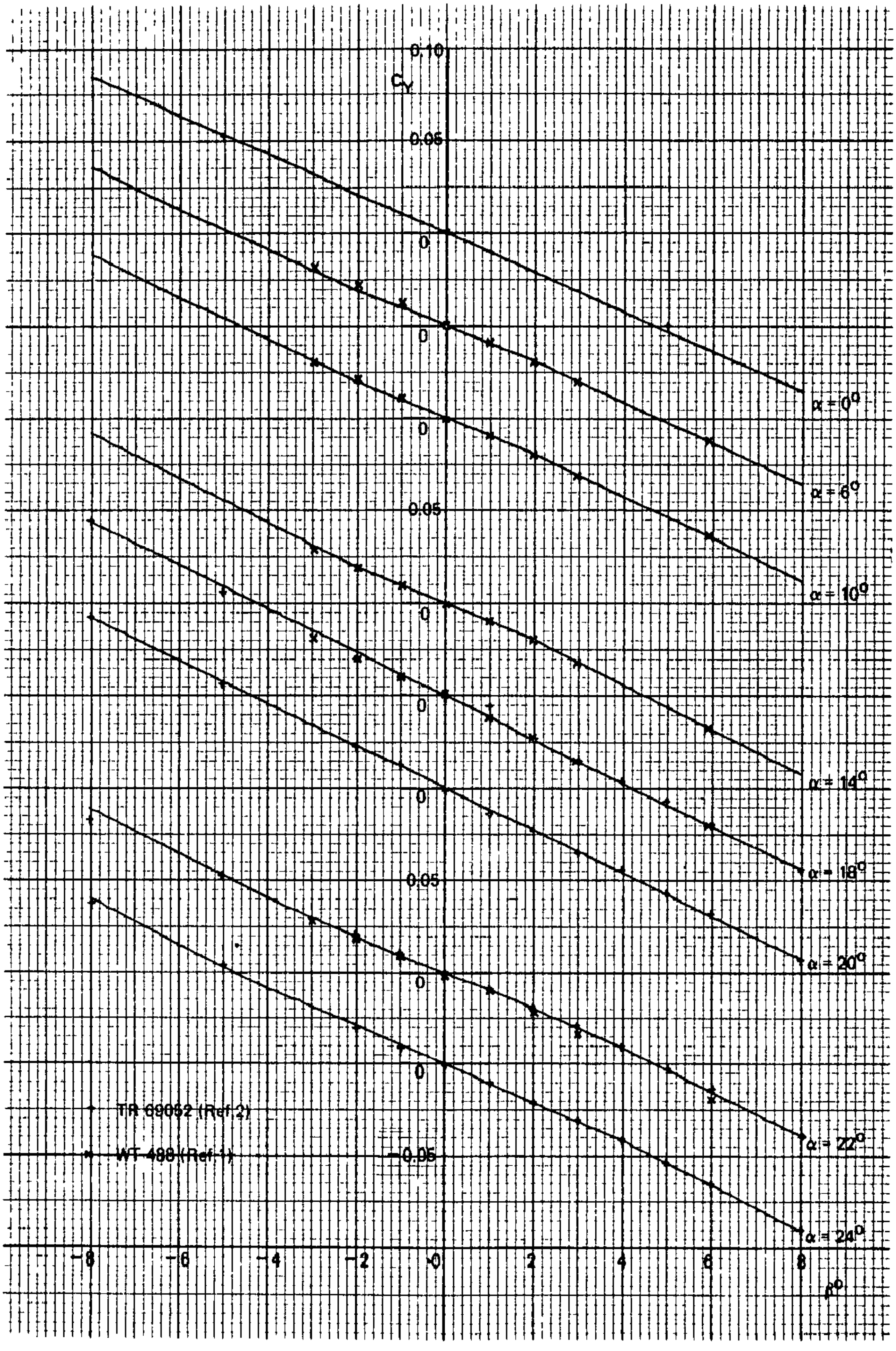

Fig.11 Low-speed C_Y v. β. Approach configuration $K_F = 1$

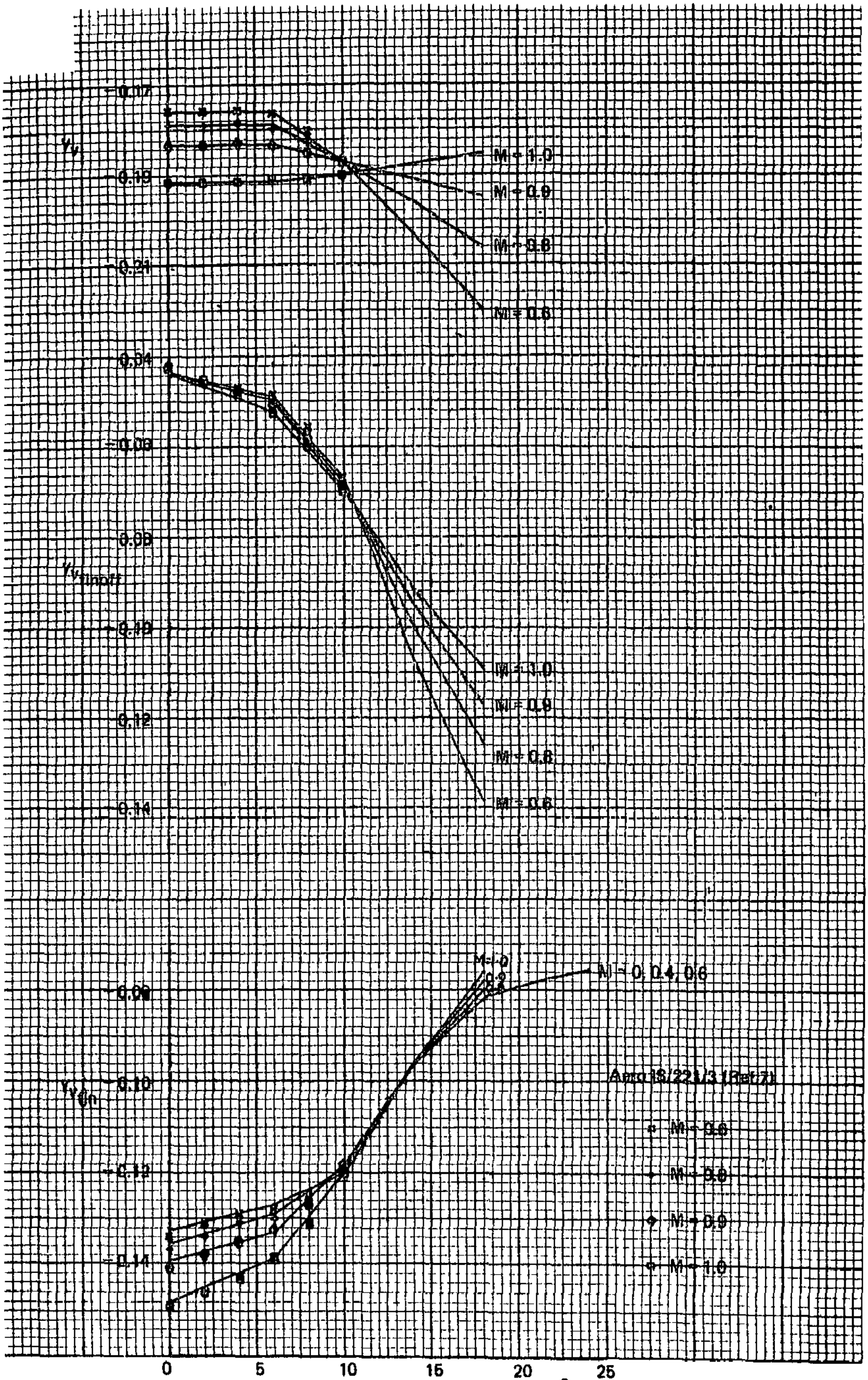

Fig.12 Y_v, $Y_{v_{finoff}}$ for M = 0.6, 0.8, 0.9, 1.0 and $Y_{v_{fin}}$ for M = 0, 0.4, 0.6, 0.8, 0.9 and 1.0

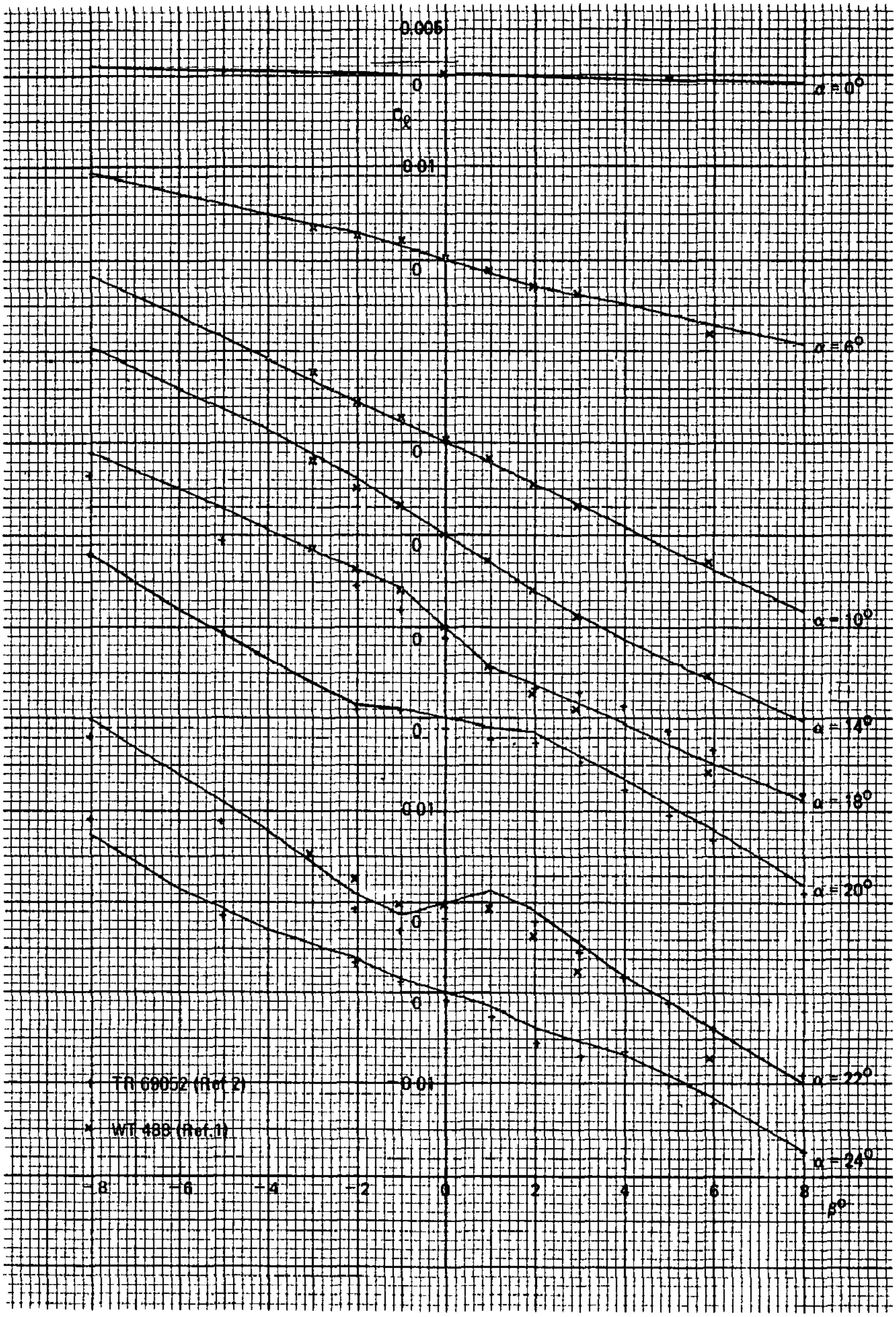

Fig.13 Low-speed C_ℓ v. β. Clean configuration $K_F = 1$

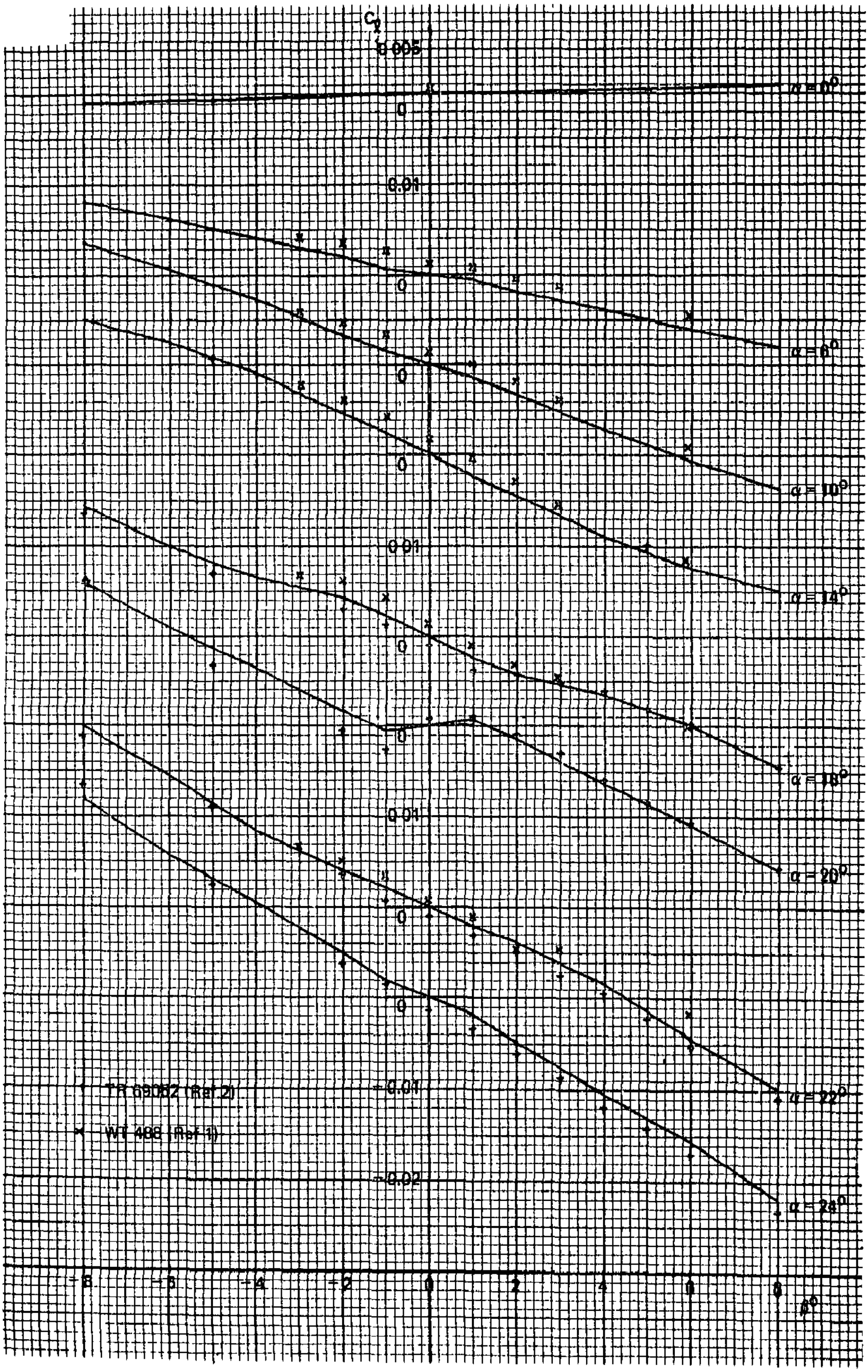

Fig.14 Low-speed C_ℓ v. β. Approach configuration $K_F = 1$

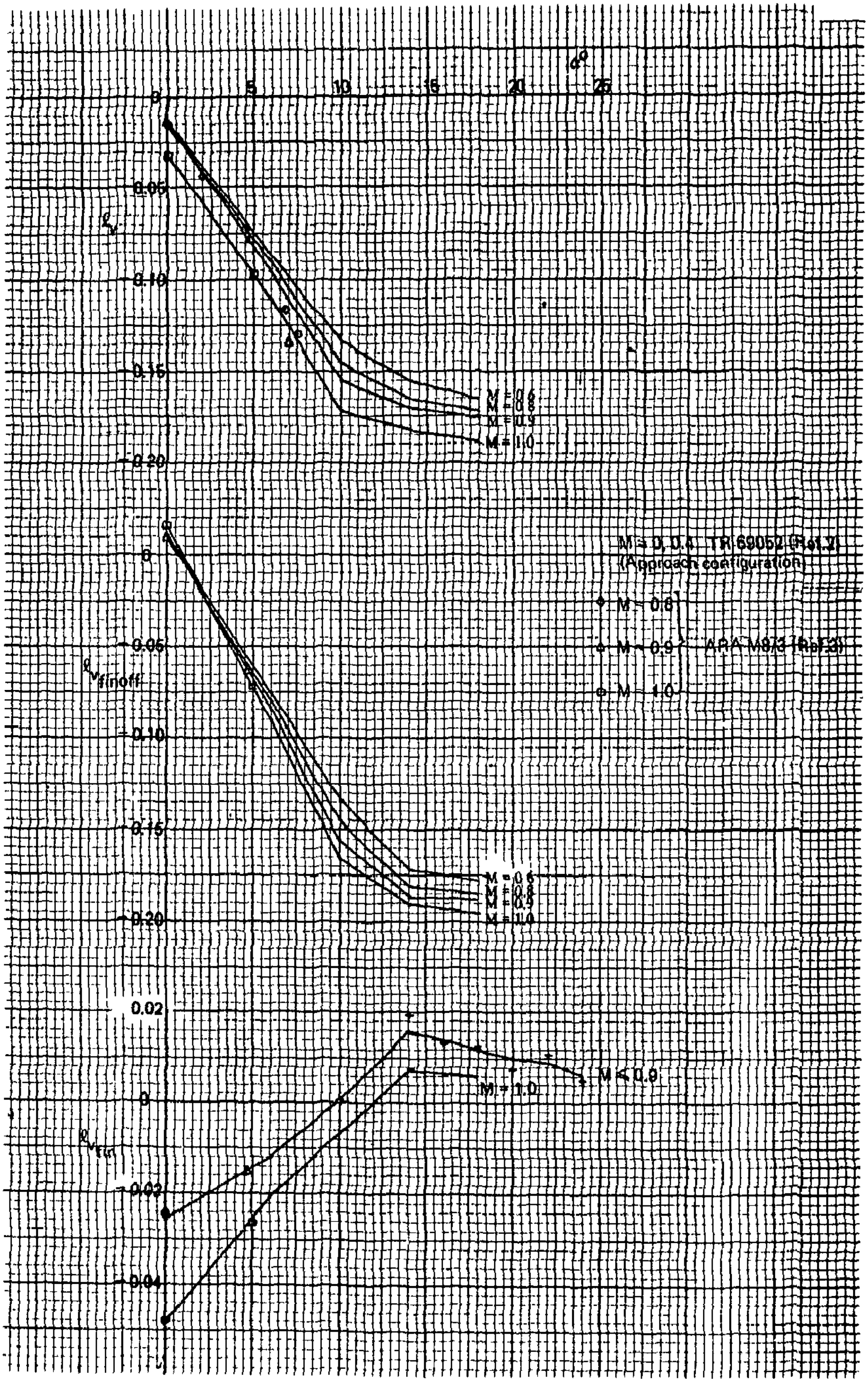

Fig.15 ℓ_v, $\ell_{v_{finoff}}$ for M = 0.6, 0.8, 0.9, 1.0 and $\ell_{v_{fin}}$ for M < 0.9 and 1.0

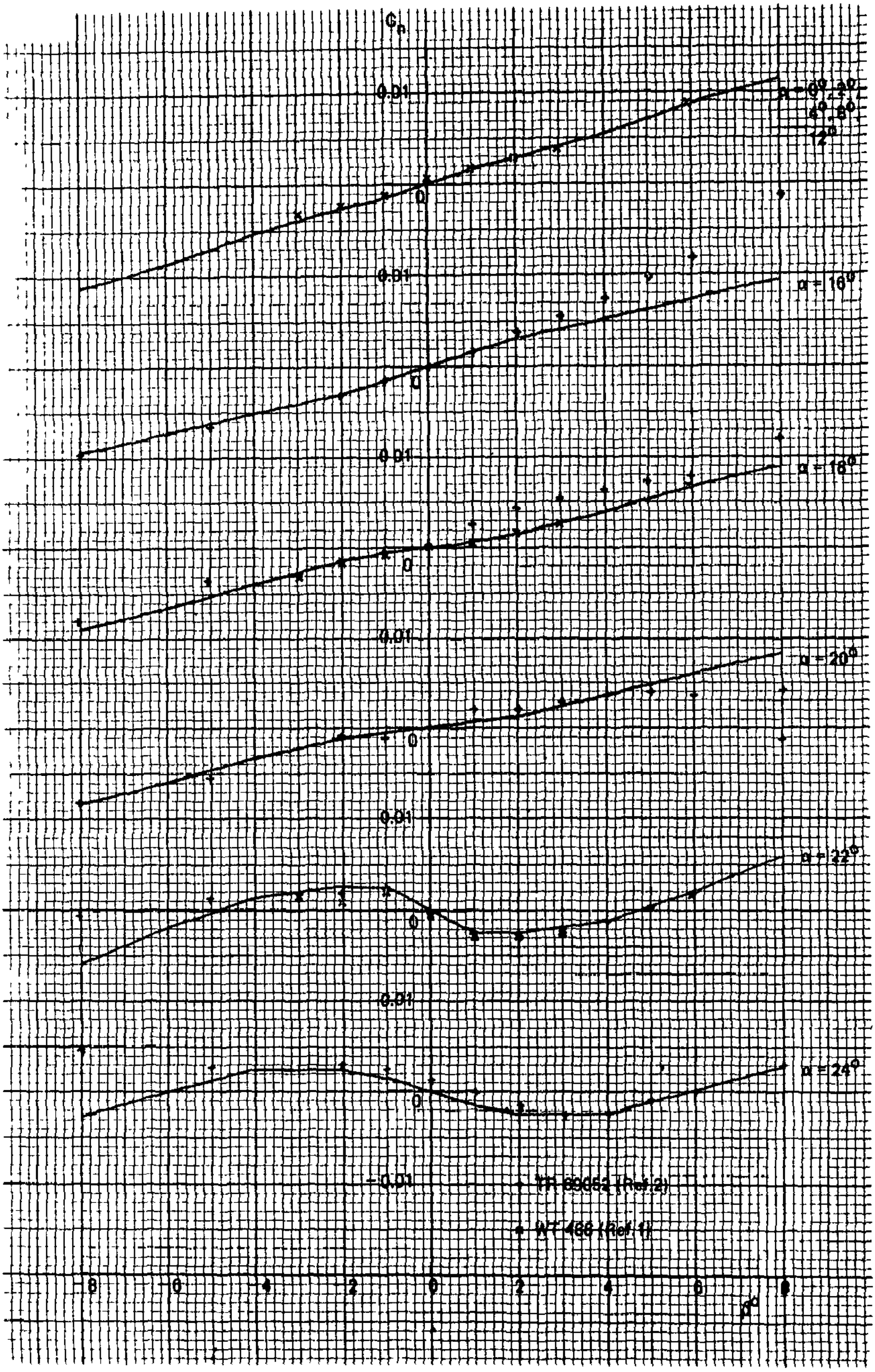

Fig.16 Low-speed C_n v. β. Clean configuration $K_F = 1$

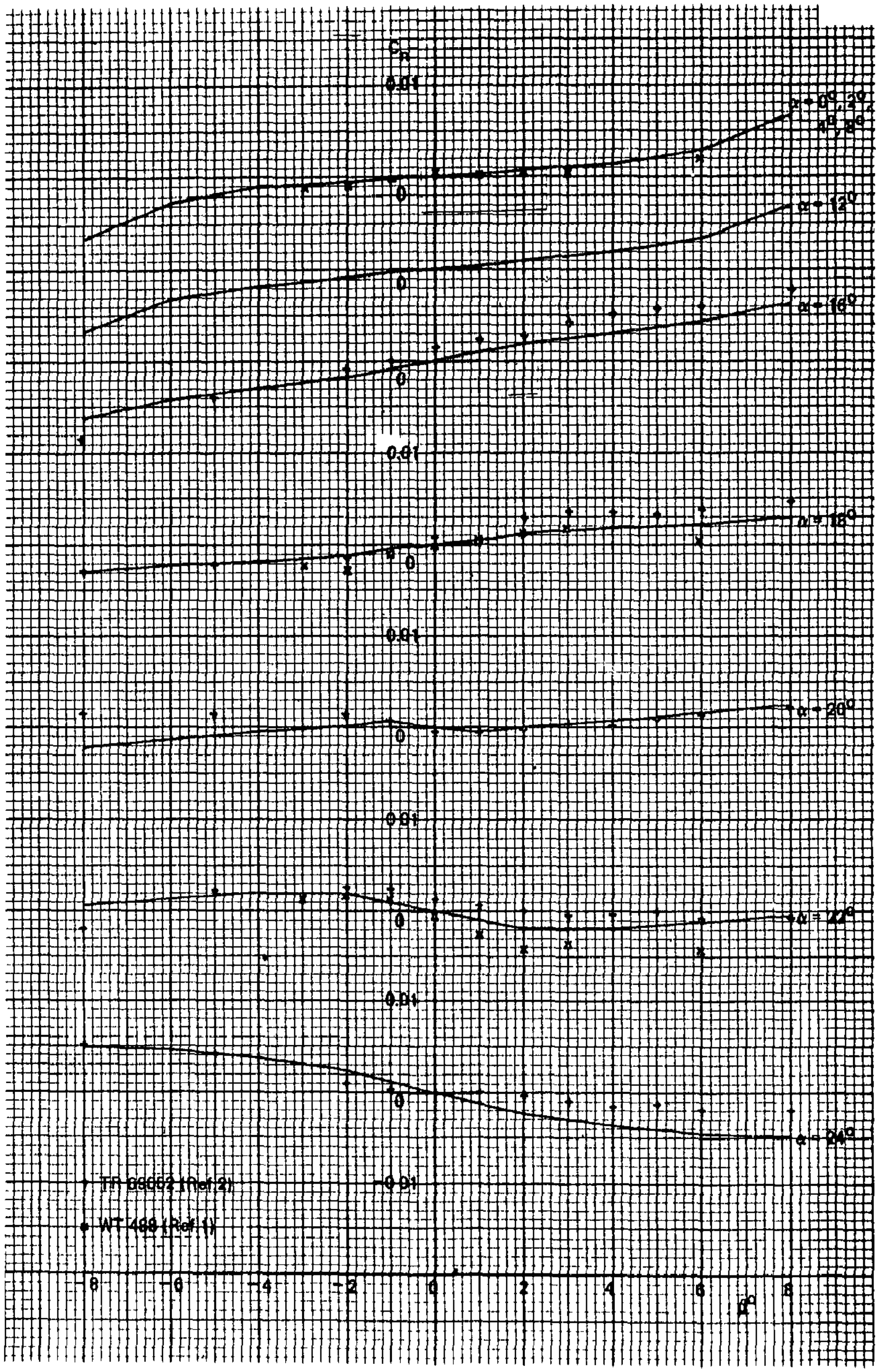

Fig.17 Low-speed C_n v. β. Approach configuration $K_F = 1$

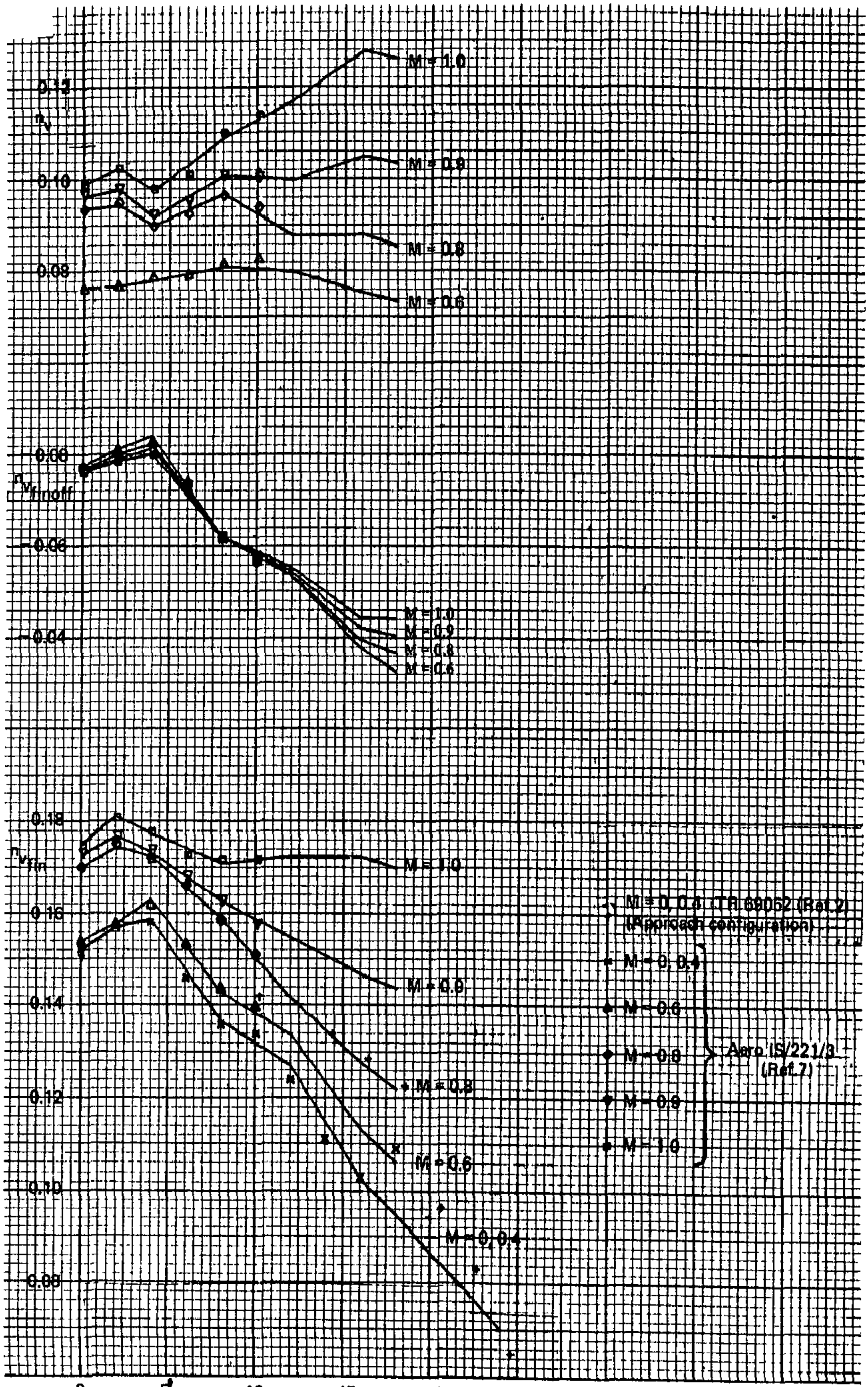

Fig.18 n_v, $n_{v_{finoff}}$ for M = 0.6, 0.8, 0.9, 1.0 and $n_{v_{fin}}$ for M = 0, 0.4, 0.6, 0.8, 0.9 and 1.0

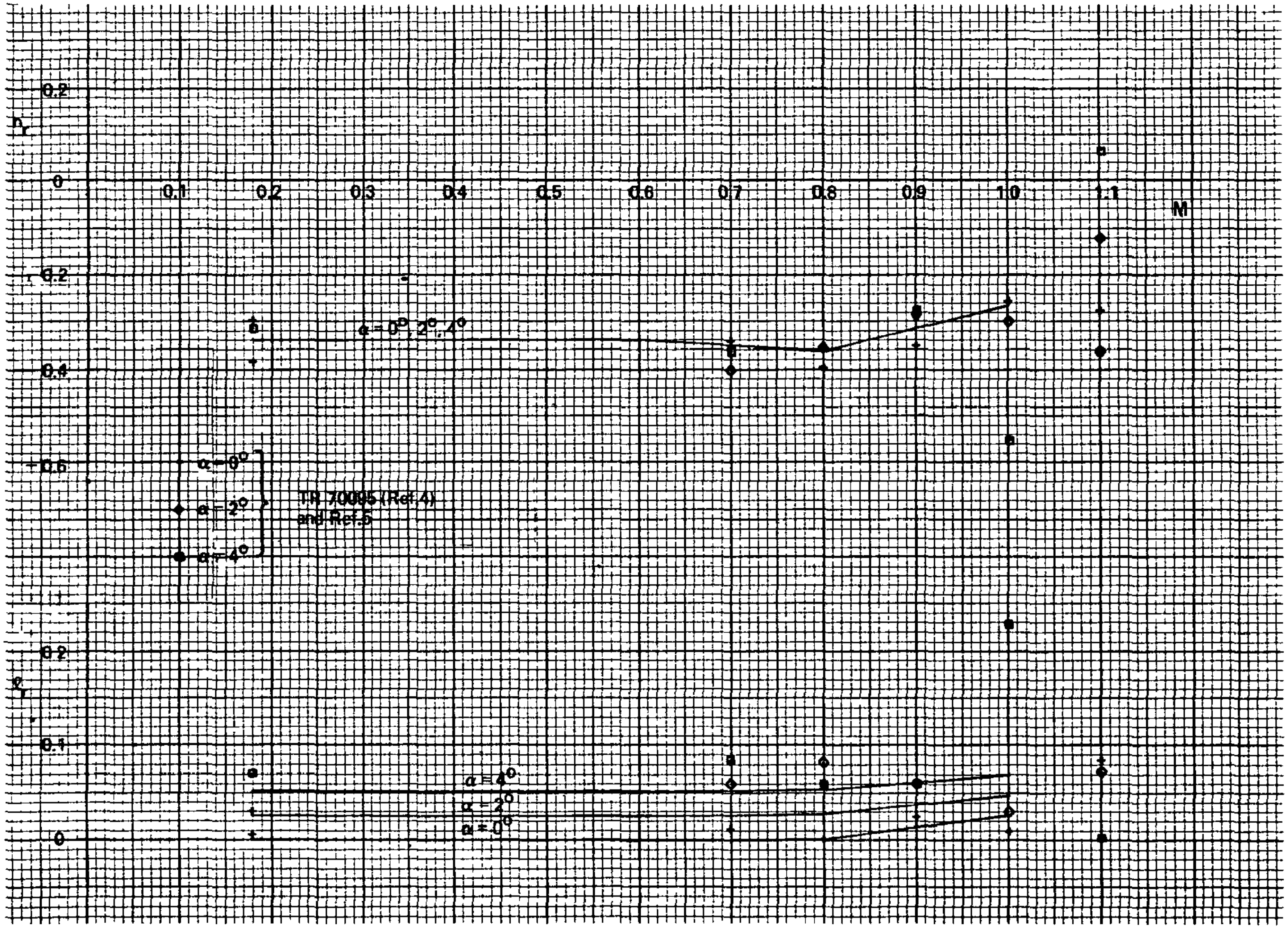

Fig.19 n_r and ℓ_r v. M (Body axes)

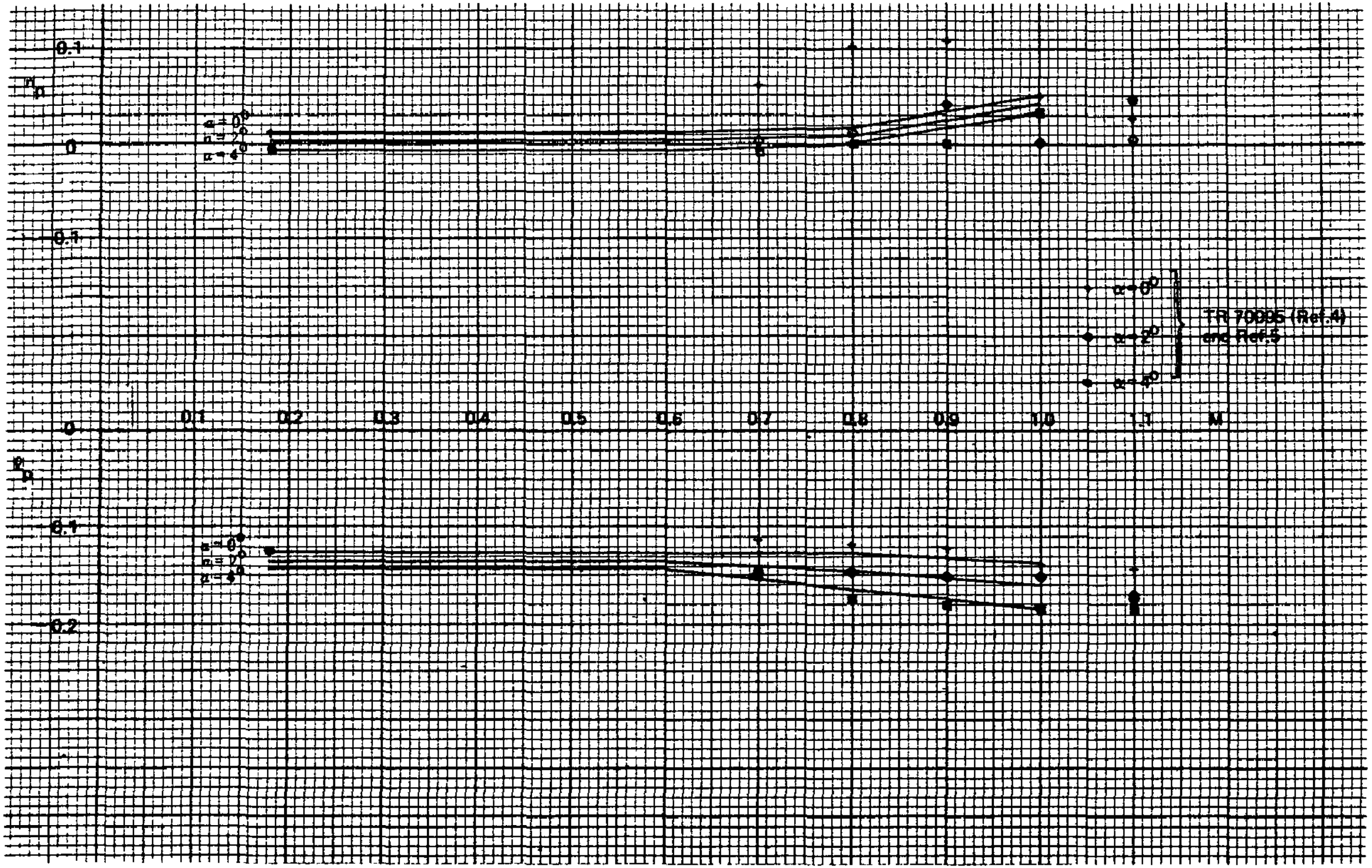

Fig.20 n_p and ℓ_p v. M (Body axes)

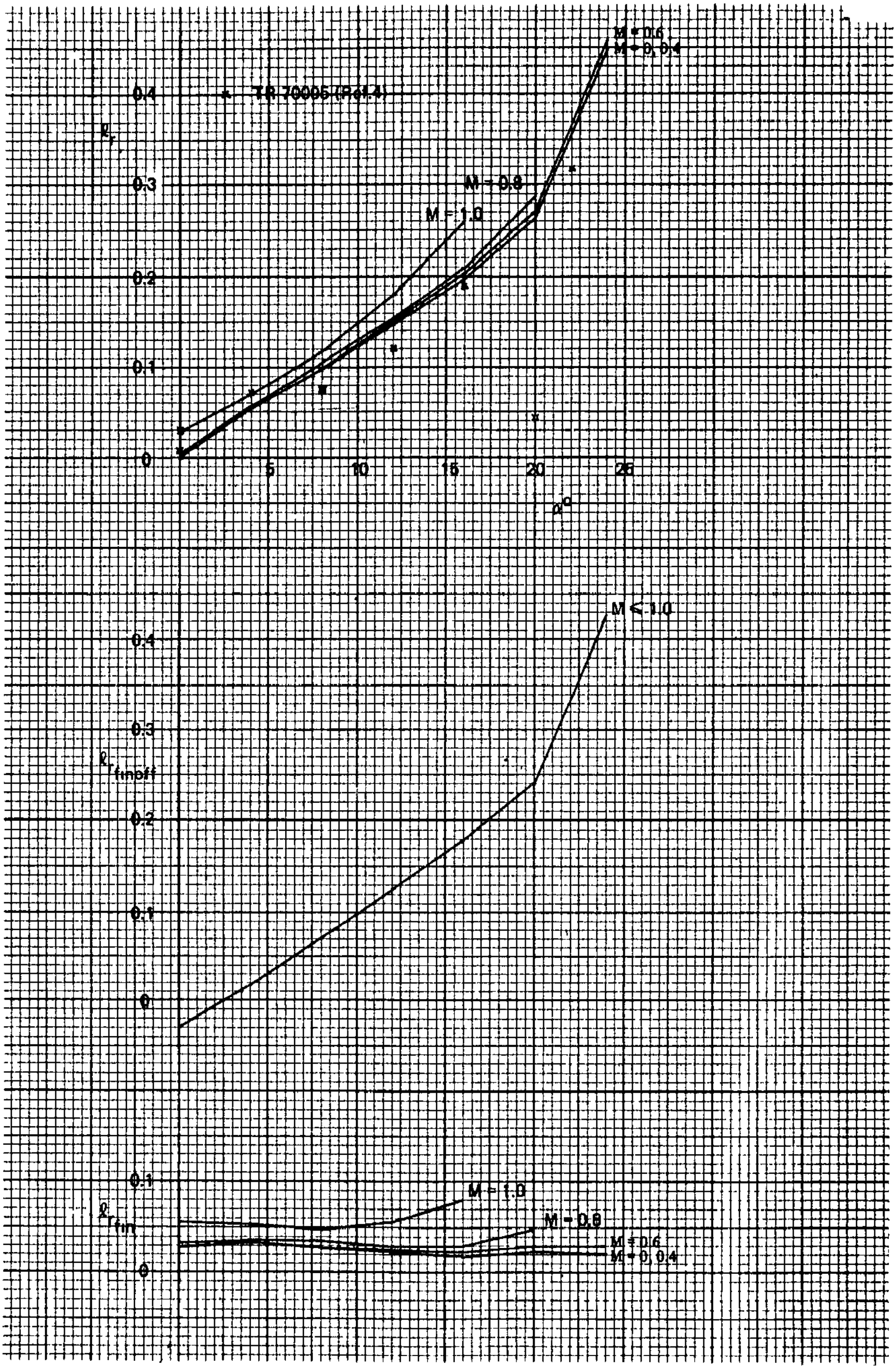

Fig.21 ℓ_r, $\ell_{r_{finoff}}$, $\ell_{r_{fin}}$ for M = 0, 0.4, 0.6, 0.8 and 1.0 (Body axes)

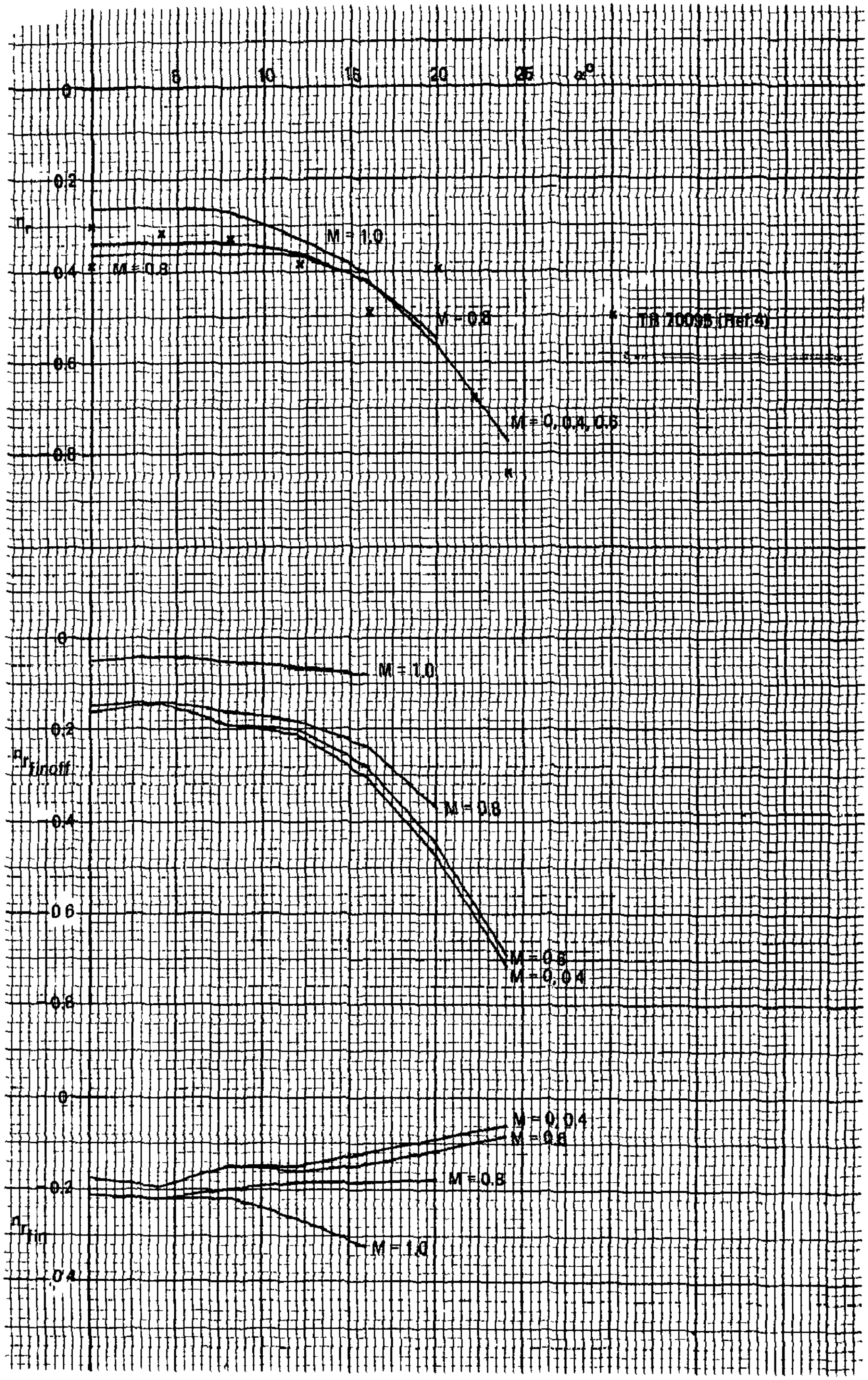

Fig.22 n_r, $n_{r_{finoff}}$, $n_{r_{fin}}$ for M = 0, 0.4, 0.6, 0.8 and 1.0 (Body axes)

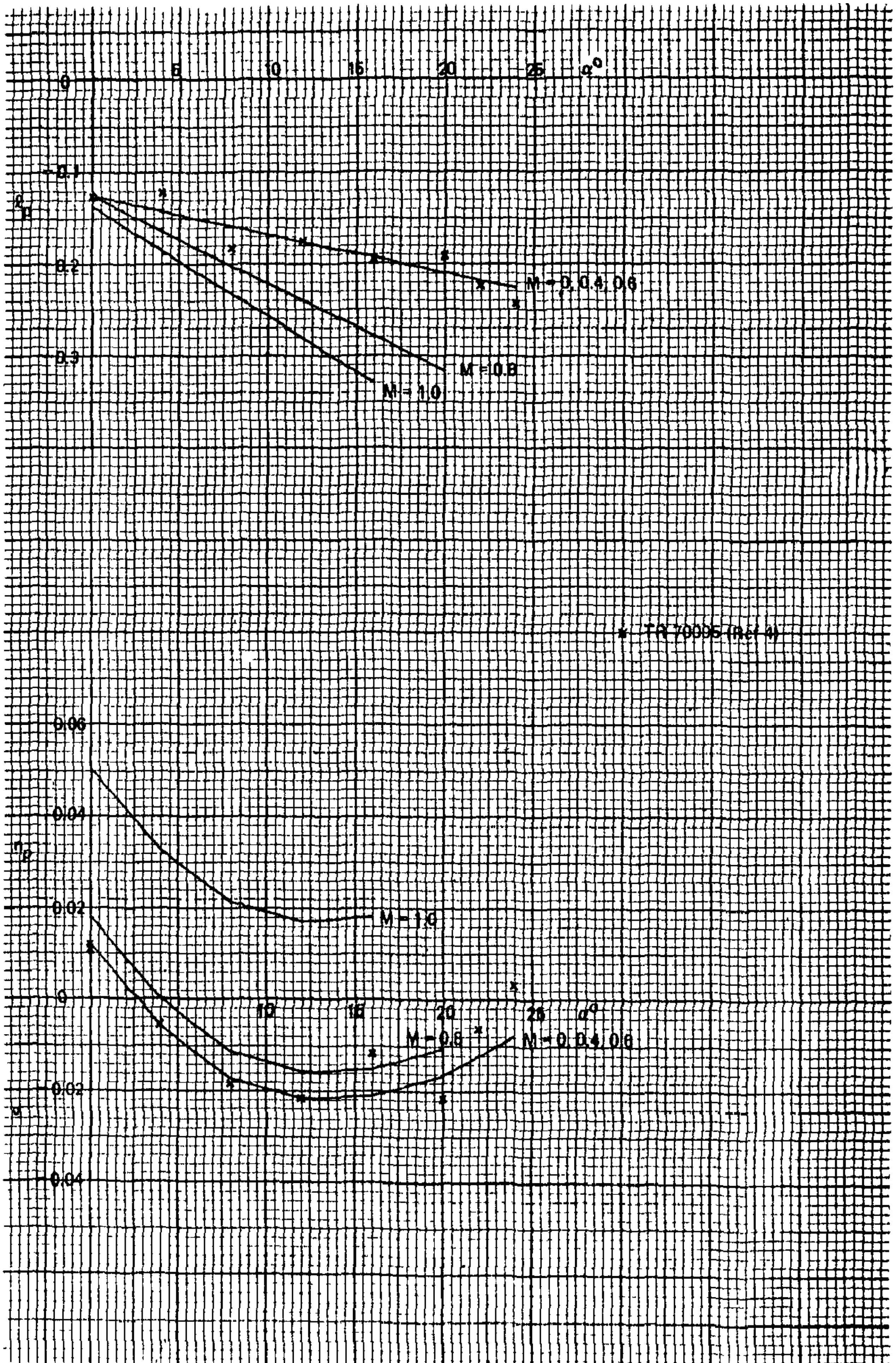

Fig.23 ℓ_p and n_p v. α for M = 0, 0.4, 0.6, 0.8, 1.0 (Body axes)

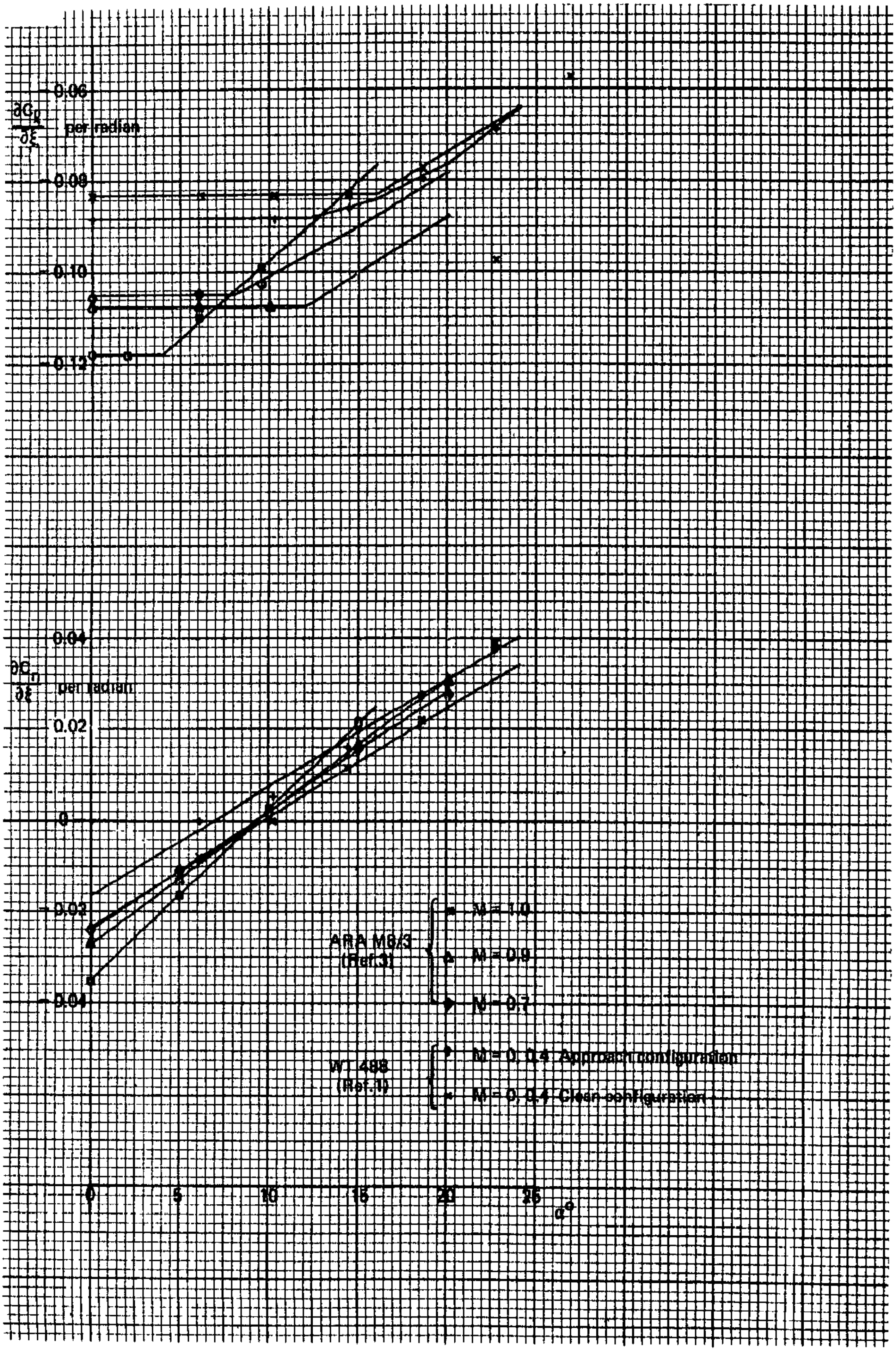

Fig.24 Aileron power, $\frac{\partial C_\ell}{\partial \xi}$ and $\frac{\partial C_n}{\partial \xi}$. Anti-symmetric aileron deflection

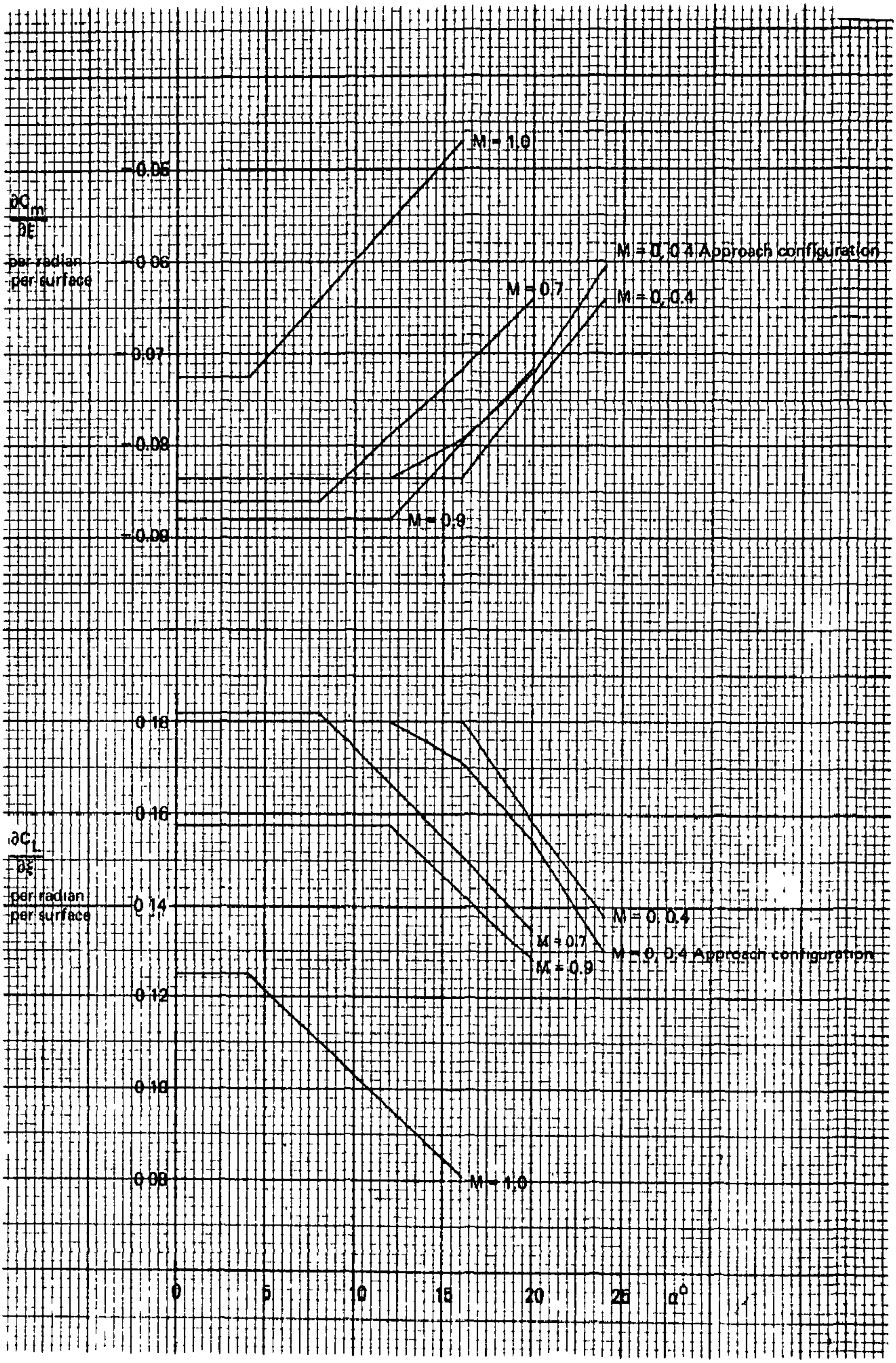

Fig.25 Aileron power $\frac{\partial C_m}{\partial \xi}$ and $\frac{\partial C_L}{\partial \xi}$

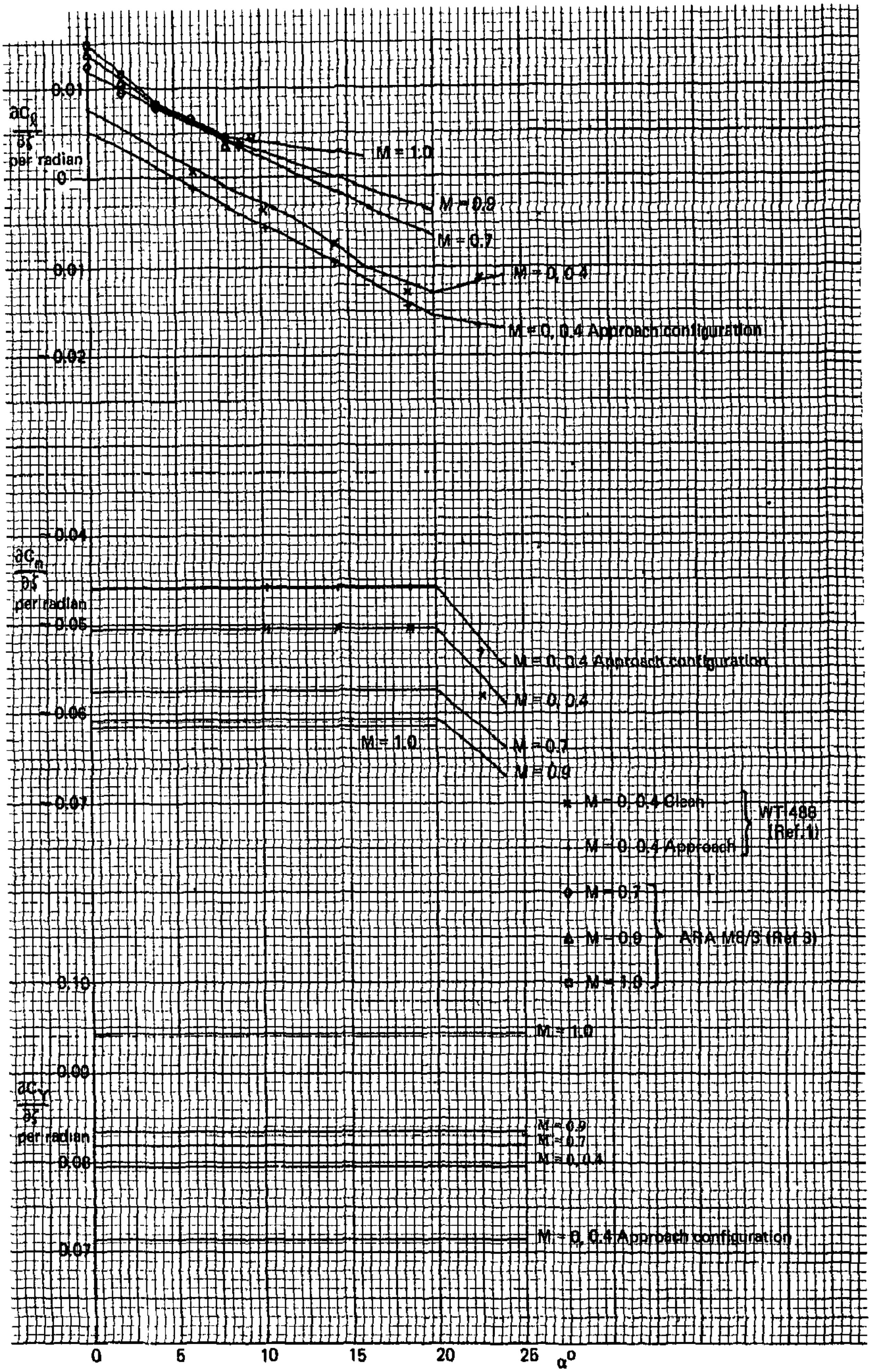

Fig.26 Rudder powers $\frac{\partial C_\ell}{\partial \zeta}$, $\frac{\partial C_n}{\partial \zeta}$ and $\frac{\partial C_Y}{\partial \zeta}$

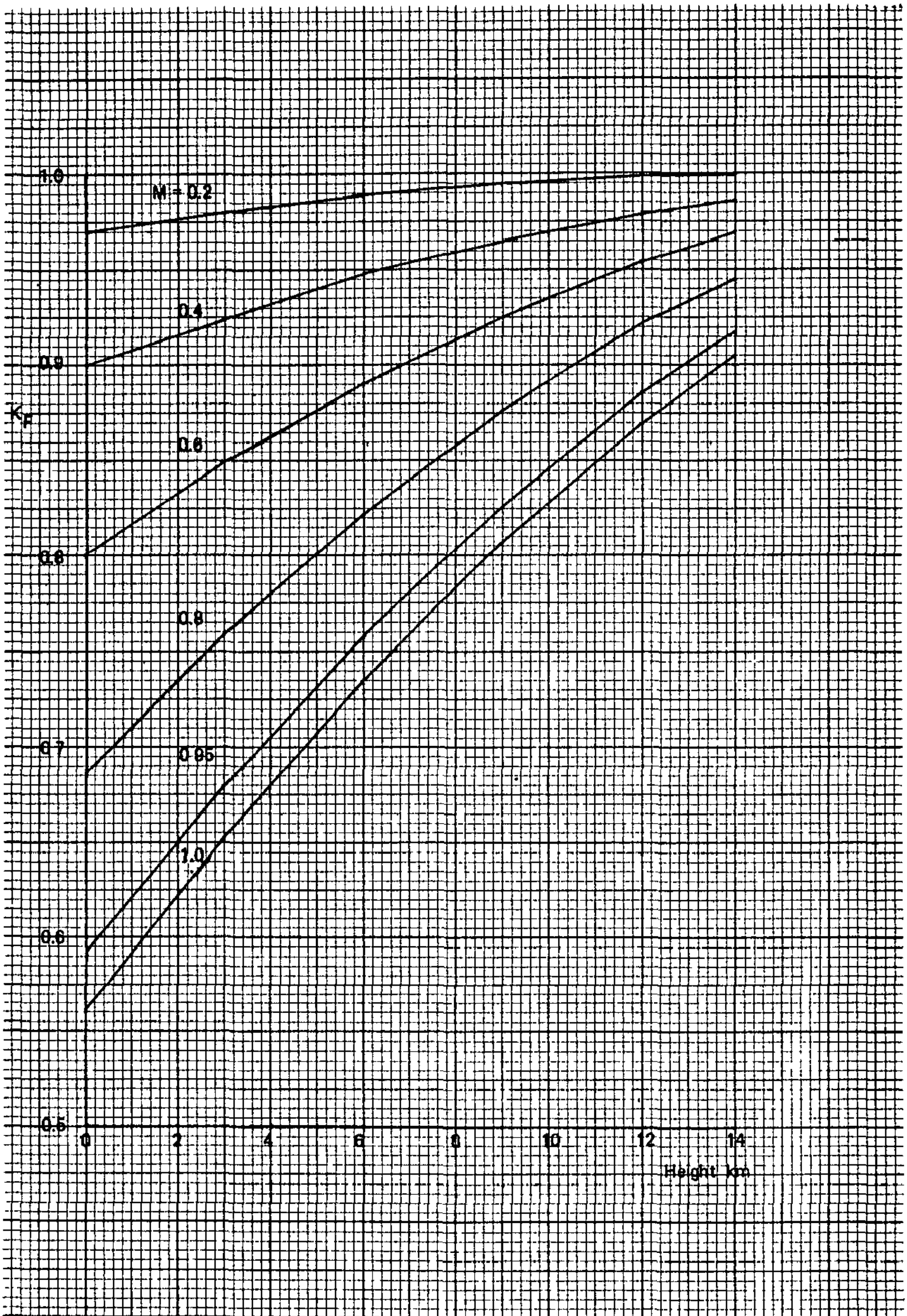

Fig.27 Aeroelastic fin efficiency, K_F

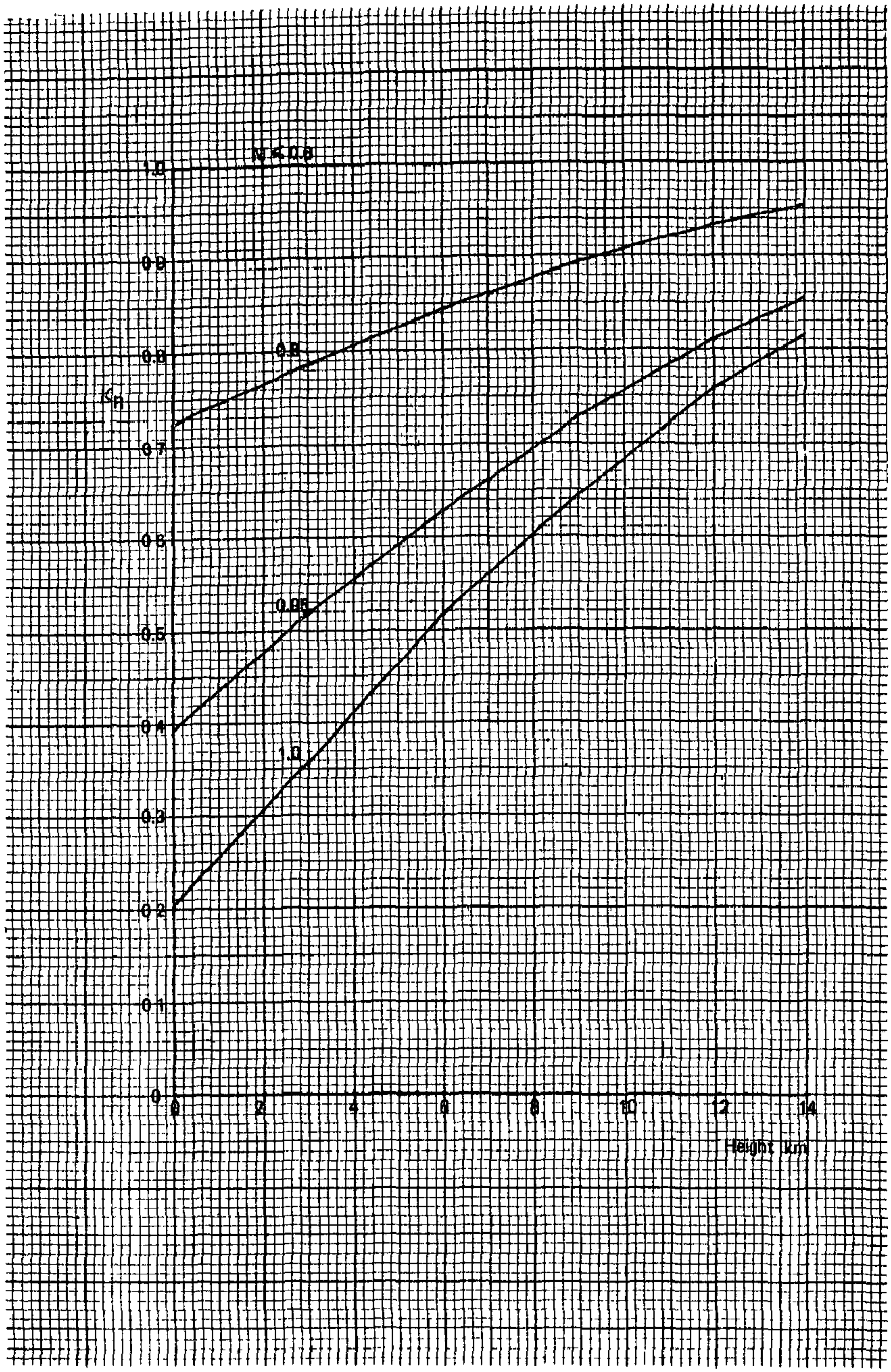

Fig.28 Aeroelastic rudder efficiency, K_R

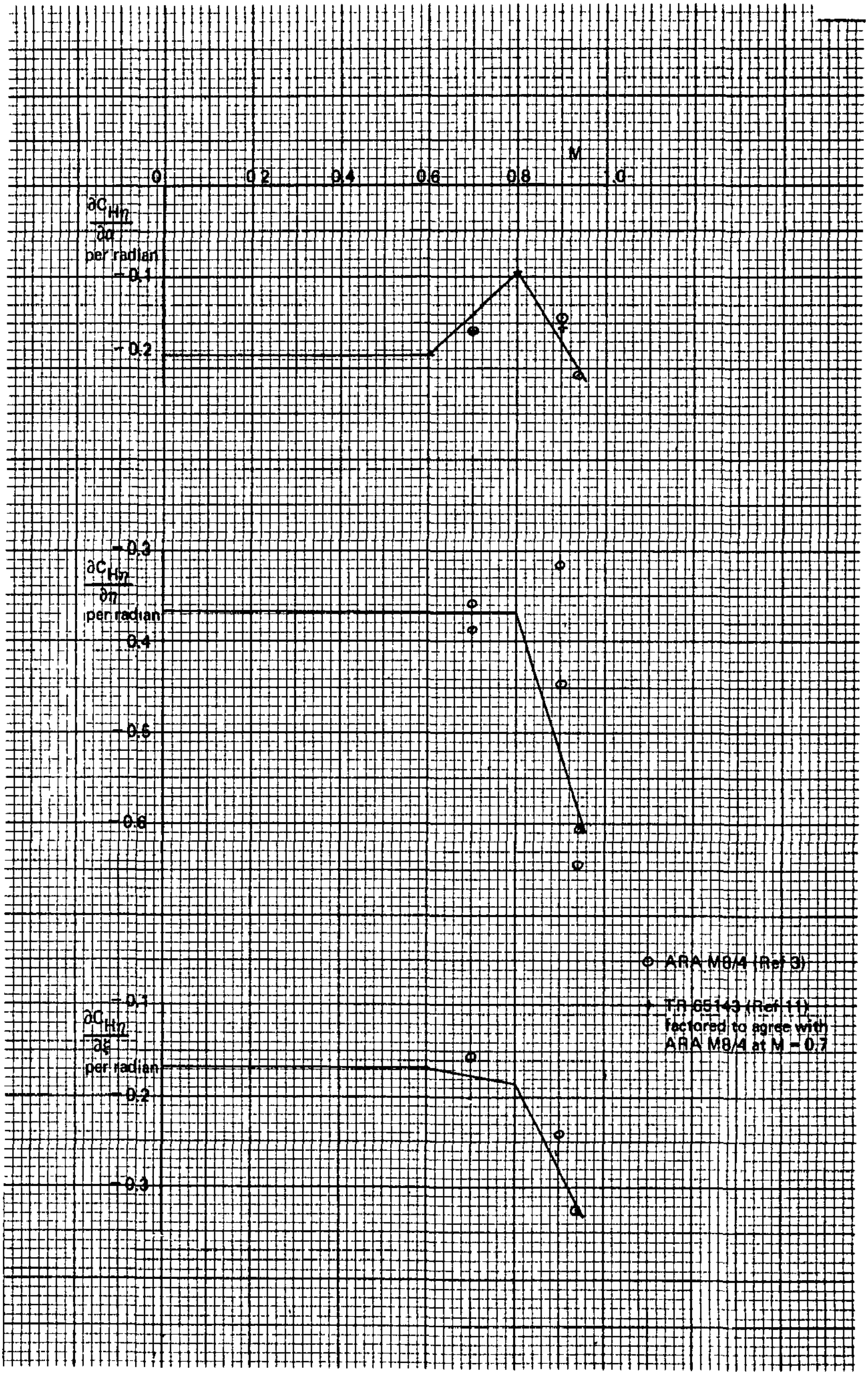

Fig.29 Elevator hinge moments

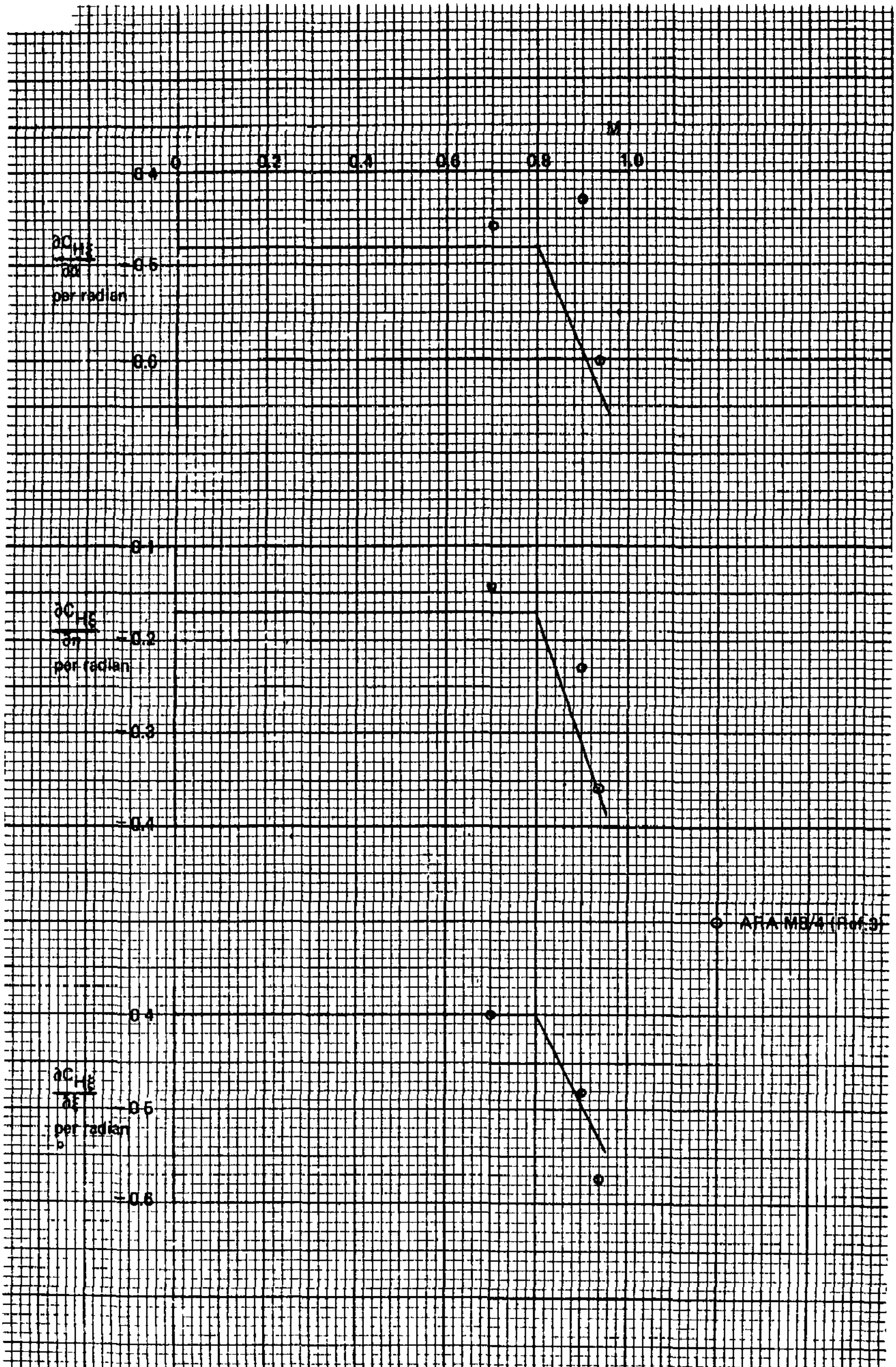

Fig.30 Aileron hinge moments

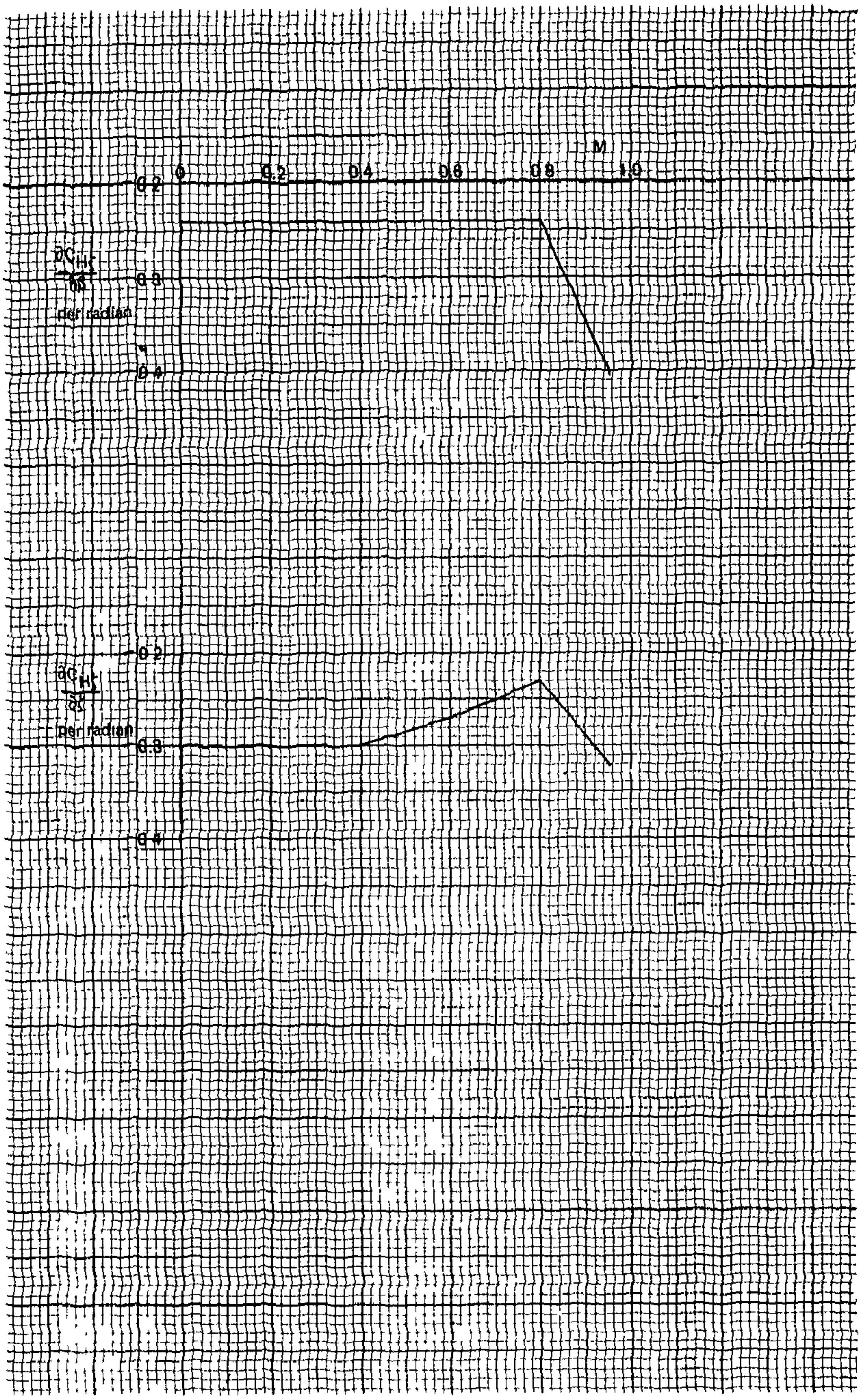

Fig.31 Rudder hinge moment

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The results of various wind-tunnel tests have been used to produce a set of aerodynamic data for the BAC 221 at Mach numbers from 0 2 to 0 955 The data have been reduced to the reference condition used by BAC, viz S = 448 sq ft and a CG position 154 in forward of the datum, on the body datum Data for both clean and approach configurations are presented.

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