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Exploratory Wind-Tunnel Investigations on a Bluff Body Containing a Lifting Fan

by

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EXPLORATORY WIND-TUNNEL INVESTIGATIONS ON A BLUFF BODY CONTAINING A LIFTING FAN

by

W. J. G. Trebble
and
J. Williams

SUMMARY

The results from a first series wind-tunnel experiments on a bluff body containing a simple lifting fan are discussed, with the body width only slightly exceeding the duct diameter and body length only two or three times the fan duct diameter. For favourable mainstream interference effects on lift, a relatively large duct diameter and aft location of the duct axis proved beneficial. Both the drag and nose-up pitching moments due to fan operation with an upper surface intake were significantly larger than estimates derived by elementary intake momentum arguments. Side-intakes alleviated considerably the moment problem, but the lifting efficiency became poorer. Some proposals for further experiments are mentioned at the end of the paper.

Previously issued as R.A.E. Tech. Note No. Aero 2754 - A.R.C. 23,059

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1 INTRODUCTION

The demand for VTOL capability of both aircraft and land vehicles has engendered considerable interest in the aerodynamics of wings and bodies containing lifting fans or jets. The designer hopes to obtain direct jet-lift roughly equal to the corresponding resolved vertical component of the installed static thrust (measured away from ground), both close to the ground at zero and possibly low forward speeds, as well as away from ground at all speeds up to the wing-borne transition speed. However, recent aerodynamic research[1] has established that the airflow induced by the fan or jet efflux over adjacent wing or body surfaces can have a marked effect on performance and stability characteristics. Some results already discussed in Ref.1 about a year ago mainly pertained to wing layouts, while subsequent R.A.E. experiments have concentrated on aircraft fuselage and nacelle installations with up to four jet exits.* These investigations have shown that the aerodynamic interference promoted by the gas efflux can vary appreciably with the size of the exits relative to the surrounding planform as well as with their disposition in the planform. Furthermore, the intake suction can influence appreciably the pressure distribution over the neighbouring body surface.

The present single-fan model is distinctive mainly in that the fan occupies a much larger proportion of the planform area or length than with the other models and that the body is much bluffer in shape. This note discusses the first series of tests made in the No.1 $11\frac{1}{2}$ ft × $8\frac{1}{2}$ ft tunnel during the autumn of 1960. The model arrangements (para.2) then included variations in the ratio of fan duct diameter to body length, the fore-and-aft location of the duct axis, and the size of the upper surface intake lip; also, the intake height was lowered by changing to side-intakes. The experiments (para.3) mostly comprised lift, drag and pitching moment measurements over an incidence range centred around zero incidence, for prescribed fan r.p.m. with variation of mainstream speed, to cover ratios of mainstream to duct efflux speeds between zero and unity. A few measurements were also made to ascertain the magnitude of sideslip and ground proximity effects.

The experimental results are discussed in terms of the incremental lift, drag and pitching moment due to fan operation at zero incidence (para.4.1); the variation with incidence (para.4.2); the side-force, rolling moment and yawing moment increments in sideslip due to fan operation (para.4.3); the influence of ground proximity (para.4.4); the effects of changing from upper surface intake to side-intakes (para.4.5). Supplementary investigations already started on the present model, and others planned with a new model, are briefly outlined in para.5.

2 MODEL ARRANGEMENTS

The model essentially comprised a fan of 1 ft diameter fitted inside a bluff body, with its axis of rotation normal to the body lower surface, the overall model size being mainly determined from the dimensions of the electric motor (and its hub fairings) for driving the fan. The basic configuration shown in Fig.1 was of height h = 11 in., streamwise length ℓ = 27.5 in. = 2.5 h, and width w = 15.4 in. = 1.4 h, with a central cylindrical duct shrouding the fan. By the insertion of extra parallel-sided blocks as illustrated in Fig.2, the ratio d/ℓ of fan duct diameter to body length was decreased from 0.44 to 0.31, i.e. the ratio S_D/S of duct to planform area from 0.29 to 0.20, keeping the duct central (x/ℓ = 0.5). Also, the fore-and-aft location of the duct was varied from x/ℓ = 0.5 to 0.64 and 0.36, keeping the diameter to length ratio fixed (d/ℓ = 0.31).

The fan was built from four variable-pitch cropped propeller blades, the blade setting being adjusted to give a reasonable thrust, about 20 lb

* The experiments include tests on a simple multi-fan fuselage model by Wyatt and on a Hawker P.1127 blowing model by Wood.

at 12° blade tip angle and 10,000 r.p.m., without overheating of the air-cooled electric motor. The nominal maximum power rating of this Sawyer three-phase motor at 10,000 r.p.m. was 5 h.p. ($8\frac{1}{2}$ h.p. at 18,000 r.p.m.), its external diameter of 3.75 in. prescribed the hub size for the fan, while its length prescribed the fan location at $1\frac{1}{2}$ in. from the duct exit. The input current, voltage, wattage and power factor were recorded on a Weston analyser, while the fan r.p.m. was obtained from a Maxwell Indicator.

The upper surface intake in its simplest form could have no radius to its lip, but most of the present series of tests were completed with an annular ring fitted to provide a lip radius 0.06d (Fig.1). As expected[2], this modification raised the installed thrust at zero mainstream speed by some 15% (see Fig.5), for example to about 21 lb at 10,000 r.p.m. with a power input of 3.2 kW. Since tuft observations showed flow breakaway in the front part of the intake with the mainstream on, the radius of the forward part of the intake lip was subsequently enlarged to a maximum of 0.20d as shown in Fig.3, the installed lift and power input at zero mainstream speed being sensibly unaltered.

Finally, a side-intake version of the basic model configuration was constructed (Fig.10), instead of the upper surface intake arrangement, to study the likely alleviation of nose-up pitching moment as discussed later. This was formed by cutting a 2 : 1 elliptic hole from side to side of the model, intersecting a circular hole bored normal to the lower surface of the model as at first. Both the intake and exit areas were the same as for the basic configuration with the simple cylindrical duct, the intake lips being again of radius 0.06d. Since this model produced only 16 lb lift at 10,000 r.p.m. with zero mainstream speed, tuft observations then showing appreciable flow breakaway near the duct roof, a large plasticene fairing was added (Fig.10) which raised the installed lift to 19.8 lb with a power input of 3.4 kW.

The model was hung upside down on wires from the tunnel overhead balance, leaving a clearance of over 4 ft (≏ 4d) between the duct exit and the neighbouring tunnel roof, and over 3 ft (≏ 3d) between the upper surface intake and the neighbouring floor. For the few preliminary tests on ground effects, a simple ground-board 6 ft long by 4 ft wide was constructed from $\frac{1}{2}$ in. thick plywood and mounted on adjustable posts to give variable ground clearance.

3 SCOPE OF EXPERIMENTS

Balance measurements of lift, drag and pitching moment were carried out on the various model configurations (para.2) at zero incidence and tunnel speeds ranging from 0 to 80 ft/sec, with prescribed fan r.p.m. of 0, 4000, 6000, 8000, 10,000 and 11,000. The effect of incidence variation between ±15° was investigated at 0 and 10,000 r.p.m. over the tunnel speed range quoted. The few supplementary measurements of side-force, yawing moment and rolling moment over a sideslip range ±15° were completed for 0 and 10,000 r.p.m. with a tunnel speed of 40 ft/sec, at incidences of 0 and ±16° on both the basic model configuration and the side-intake variant.

The influence of proximity to the ground was also explored briefly on the basic model configuration at zero sideslip over the incidence range ±15°, for 0 and 10,000 r.p.m. with tunnel speeds of 0 and 20 ft/sec, the ground clearance being varied from 0.25d to 1.0d. Because of the temporary nature of the ground board, higher tunnel speeds were not acceptable and the major ground effect programme was postponed until the second series of tests when a stronger ground board spanning the tunnel could be installed.

Throughout the experiments, the pivot moment centre of the model was located for convenience at a point on the fan axis 0.13 in. below the base of the model, but the moments have not been converted to a higher position because the practical C.G. could vary significantly with the particular application. As regards tunnel interference, only solid blockage correction to the mainstram dynamic head has been applied here, since conventional wake blockage and lift-constant corrections are of doubtful validity for fan lift tests. But, with the present small ratio of model to tunnel size, the absence of such corrections should not significantly affect the results[3].

In assessing the scatter and degree of correlation of the experimental results, the feasible measuring accuracy of 1/4 lb lift (1/10 lb drag, 1/4 lb ft moment) should be compared with the installed static lift of about 21 lb at 10,000 r.p.m. but only 3 lb at 4000 r.p.m., and with the mainstream dynamic head of about 8 lb/sq ft at 80 ft/sec but only 1/2 lb/sq ft at 20 ft/sec.

4 EXPERIMENTAL RESULTS

The aerodynamic characteristics of the bluff body with the fan stopped are given in Fig.4 for the basic configuration. There was a noticeable change in flow regime at 6° incidence, which was accompanied by forward movement of the aerodynamic-centre position of about 0.4ℓ. For discussion of the basic aerodynamic features, rather than performance aspects, the major results can conveniently be considered as increments ΔL, ΔD, ΔM in the lift, drag and pitching moment due to fan operation at a given incidence and mainstream speed. The non-dimensional increments $\Delta L/T$, $\Delta D/T$ and $\Delta M/Td$, where T denotes the installed lift produced by fan operation at zero mainstream speed, are here plotted against the ratio V_o/V_{JT} of mainstream speed to a nominal jet efflux speed, derived provisionally from the relation $T = \rho V_{JT}^2 S_A$ where S_A signifies the fan annulus area.*

Some preliminary pitot-static explorations of the flow entering the fan annulus have already shown that the mean through-put velocity V_{JA} at 10,000 r.p.m. and zero mainstream speed was some 8% higher than the nominal value V_{JT} of 110 ft/sec. There was also an increase in V_{JA} with mainstream speed at constant fan r.p.m., of the order $0.15\,V_o$ at 10,000 r.p.m. and zero incidence. This was accompanied by a decrease in power, from 3.2 kW, to 2.8 kW, as the mainstream speed was raised from 0 to 60 ft/sec. Changes in through-put velocity and power due to incidence variation seemed relatively small.

4.1 Increments due to fan operation at zero incidence

The lift increments $\Delta L/T$ of the basic model configuration (Fig.6a) correlate reasonably well when plotted against V_o/V_{JT} for the various fan r.p.m., i.e. varying efflux Reynolds number. The scatter of the results at high V_o/V_{JT} is primarily associated with reductions in the percentage accuracy of measurement at the low fan r.p.m. and hence low force levels. For this centrally mounted fan, $(x/\ell = 0.5)$ occupying a relatively large

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* More generally, $\dfrac{\Delta L}{\rho V_J^2 d^2 (\pi/4)}$ etc. can be treated as functions of the speed ratio (V_o/V_J) of mainstream to jet efflux speed, the jet efflux Reynolds number $(V_J d/\nu)$, the attitude of the body to the mainstream, as well as of the body and fan geometry.

proportion of the planform ($d/\ell = 0.44$), the increment $\Delta L/T$ rose above the datum value of unity as V_o/V_{JT} was increased from zero, flattening off to a local maximum of nearly 1.1 at $V_o/V_{JT} \simeq 0.2$, but rising even further beyond $V_o/V_{JT} = 0.5$, the upper limit of the normal practical range. The enlargement of the front lip of the intake led to an earlier rise in $\Delta L/T$ beyond $V_o/V_{JT} = 0.3$. The power input required fell off as the mainstream speed was increased and also when the front lip was enlarged (See Table on Fig.6a).

The lift increments were appreciably improved with the mainstream on by increasing the proportion of planform occupied by the fan duct ($d/\ell = 0.44$ c.f. 0.31) or by rearward movement of the fan axis ($x/\ell = 0.36$, 0.5, 0.64), as shown in Fig.7a.* This complements earlier experience on low aspect-ratio wings[1] with much smaller ratios of jet (or fan) duct exit diameter to wing chord, when areas of high suction were found to arise on the wing lower surface aft of the jet exit due to the interaction of the jet with the mainstream flow past the wing.

The measured drag increments $\Delta D/T$ are compared in Fig.7b with the corresponding nominal value $\rho V_o V_{JT} S_A/T = V_o/V_{JT}$ for the intake momentum drag contribution associated with turning the mainstream air from the mainstream to the duct axis direction. The increments are lowest for the smaller d/ℓ value, but even these are about 1.3 times the nominal intake drag, rising to about 1.4 times for the larger d/ℓ value. The aerodynamic interference drag, arising from the unusual pressure-lift loading induced on the body with the mainstream on, can therefore not be ignored.

The corresponding nose-up pitching moment increments $\Delta M/Td$ plotted in Fig.7c were lowest for the larger d/ℓ value, i.e. the higher lift. They were about twice the nominal estimates $0.98\ (V_o/V_{JT})$ from the intake momentum drag assumed acting in the plane of the intake at a height 0.98d above the moment centre. The extra moments are expected to be due mainly to the large suction region behind the exit on the lower surface. Thus, there was effectively a steady forward movement of the centre of lift position with increasing mainstream speed, about half a fan diameter by $V_o/V_{JT} = 0.4$, to add to the intake momentum drag contribution.

4.2 Increment variation with incidence

The variation with incidence of the lift, drag and pitching moment increments due to fan operation are shown in Figs.6b, 6c and 6d for the basic model configuration at several V_o/V_{JT} values. At moderate speed-ratios, the lift increments $\Delta L/T$ fell slightly with increasing positive incidence, at a rate slightly faster than the estimate $\cos\alpha$ from simple resolution of the installed lift, but remained practically constant over the negative incidence range 0 to -16^o. At high speed-ratios, for example $V_o/V_{JT} = 0.73$, the lift increments grew with increasing incidence over most of the range. The drag increment $\Delta D/T$ varied roughly as $\sin\alpha$ at moderate speed ratios, as would again be expected by simple resolution. The pitching moment increment $\Delta M/Td$ rose slightly with increasing positive incidence, tending to fall more rapidly with increasing negative incidence. As an

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* The installed lift at zero mainstream speed was unchanged by the alterations of body planform and fan axis location.

illustration, in the absence of exit deflector vanes or auxiliary propulsive thrust, some 15° of negative incidence would be needed for steady level flight (zero nett drag) of the basic configuration at $V_o/V_{JT} \simeq 0.2$. Furthermore, for trim with the C.G. at the geometrical centre of the model, an upward force about one-fifth of the weight would need to be located at the rear. The model would then be speed-stable in that any increase in speed would tend to produce a nose-up moment and motion which would cause drag, and vice versa.

4.3 Sideslip effects

The variation, with sideslip angle β, of the sideforce, rolling-moment and yawing-moment increments ($\Delta Y/T$, $\Delta \ell/Td$ and $\Delta n/Td$) associated with fan operation, are shown in Fig.8 for the basic model configuration with $V_o/V_{JT} = 0.36$ at $\alpha = 0°$ and $\pm 16°$. The sideforce derivative $\partial(\Delta Y/T)/\partial\beta$ becomes increasingly negative as incidence is reduced, so promoting greater tendency to drift. Both the rolling and yawing moment curves are somewhat non-linear, but tend to give negative values for the rolling-moment derivative $\partial(\Delta \ell/Td)/\partial\beta$ and yawing-moment derivative $\partial(\Delta n/Td)/\partial\beta$, corresponding to dihedral effect and slight weathercock instability. At zero sideslip, the torque from the single fan produced a yawing-moment increment $\Delta n/Td$ of 0.06.

4.4 Influence of ground

At zero mainstream speed and prescribed fan r.p.m. the installed lift of the basic model configuration increased when the ground clearance H was reduced below $H/d \simeq 0.75$, as was expected with such a central hub (annular jet), but the power required also increased (Fig.9a). For example, with the smallest ground clearance ($H/d = 0.24$), the lift became about 10% greater than without ground, but the power input was about 20% larger. Thus, assuming that the static power varied roughly as $(\text{lift})^{3/2}$, then the lift close to the ground would have been about 5% lower than away from ground at the same power.

At the mainstream speed of 20 ft/sec ($V_o/V_{JT} = 0.19$), ground proximity increased the value of $\Delta L/T$ for zero incidence by rather less than 10%, again with some increase in power (Fig.9a), while the pitching moment was reduced by up to one-half (Fig.9c).

4.5 Side-intake effects

The change from upper surface intake to side intakes on the basic model configuration (Fig.10) led to a much less favourable variation of lift increment $\Delta L/T$ with speed ratio V_o/V_{JT} at zero incidence (Fig.11a). In fact, $\Delta L/T$ fell below unity for V_o/V_{JT} values between 0.2 and 0.4, being as low as 0.9 halfway between. The power input at constant r.p.m. continued to decrease slowly with increasing mainstream speed, as illustrated in the Table in Fig.11a. Again, lift benefits were noticeable from increase in the ratio d/ℓ of duct diameter to body length and rearward movement of the fan axis location (Fig.12a). The drag increment $\Delta D/T$ was slightly lower than for the upper surface intake, being about 1.2 to 1.3 times the nominal intake momentum drag contribution V_o/V_{JT} (Fig.12b).

The primary reason for introducing side-intakes was to alleviate the strong nose-up pitching moments by lowering the line-of-action of the intake momentum drag vector. Fig.12c shows that the resulting moment increments on the side-intake version of the basic configuration were only about half those with the upper surface intake. The lower nose-up moments are again associated with the larger d/ℓ value.

The effects of incidence on the lift, drag and pitching moment increments due to fan operation on the side-intake version (Fig.11) are similar to those for the upper surface intake model. The sideforce, rolling-moment and yawing-moment derivatives associated with sideslip are also not greatly changed (Fig.13 c.f. Fig.8).

5 CONCLUDING REMARKS

These exploratory investigations have clearly demonstrated that, even with a body as distinct from a wing, and with the fan duct occupying a relatively large proportion of the planform, the interaction of the efflux with the mainstream flow past the body can introduce marked variations in the lift, drag and nose-up pitching moments produced by fan operation. The intake momentum contributions to the body drag and pitching moment can also be large. Increase in the duct-diameter to body-length ratio produces greater lift and less pitching moment, but slightly larger drag as would be expected. Rearward movement of the duct axis seems particularly favourable to lift. Enlargement of the front lip of the upper surface intake, beyond the minimum required for static considerations, gives appreciably improved efficiency in a mainstream, while side-intakes can lead to considerably less pitching moments with slight loss in lifting efficiency. Naturally, with a good intake, the fan through-put at constant r.p.m. and blade setting tends to rise steadily with increasing mainstream speed and simultaneously the power input required falls off.

More comprehensive measurements of the variation in fan through-put and velocity distribution with mainstream speed have already been started on the basic model configuration with the enlarged intake lip. The effects of ground proximity and the addition of stub wings on the model characteristics are also being examined for various mainstream to efflux speed ratios. Subsequent experiments on a new model are planned to study the effects of tilting the duct axis, the incorporation of deflector vanes at the exit, further modifications to the intake, streamlining the body to simulate a nacelle, and the provision of higher fan disk loadings.

LIST OF SYMBOLS

Geometric

d	duct diameter = 12.1 in.
h	body height = 11.0 in.
ℓ	body length = 27.5, 33.0 or 38.5 in.
w	body width = 15.4 in.
x	distance of fan axis behind nose of body
H	clearance of duct exit from ground
S	body planform area = 397, 482, 567 sq.in.
S_A	fan annulus area = 103.9 sq.in.
S_D	duct exit area = 115.0 sq.in.
S_B	fan blade area = 25.05 sq.in.

LIST OF SYMBOLS (CONTD.)

α, β	body incidence and sideslip angle to mainstream

Speeds

n	fan r.p.m.
V_J	mean efflux speed
V_{JT}	nominal efflux speed = $\sqrt{T/\rho\ S_A}$
V_{JA}	mean fan through-put speed (measured)
V_o	mainstream speed

Forces and Moments

T	installed lift due to fan operation, measured at zero mainstream speed and incidence
$\Delta L, \Delta D, \Delta M, \Delta Y, \Delta \ell, \Delta n$	increments in lift, drag, pitching moment, sideforce, rolling moment and yawing moment, due to operation of fan

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2	Taylor, R. T.	Experimental investigation of the effects of some shroud design variables on the static thrust characteristics of a small-scale shrouded propeller submerged in a wing. NACA TN 4126. 1958.
3	Butler, S. F. J. Williams, J.	Further comments on high-lift testing in wind tunnels with particular reference to jet blowing models. Ae. Quart., Vol. XI, pp.285 to 308. 1960.

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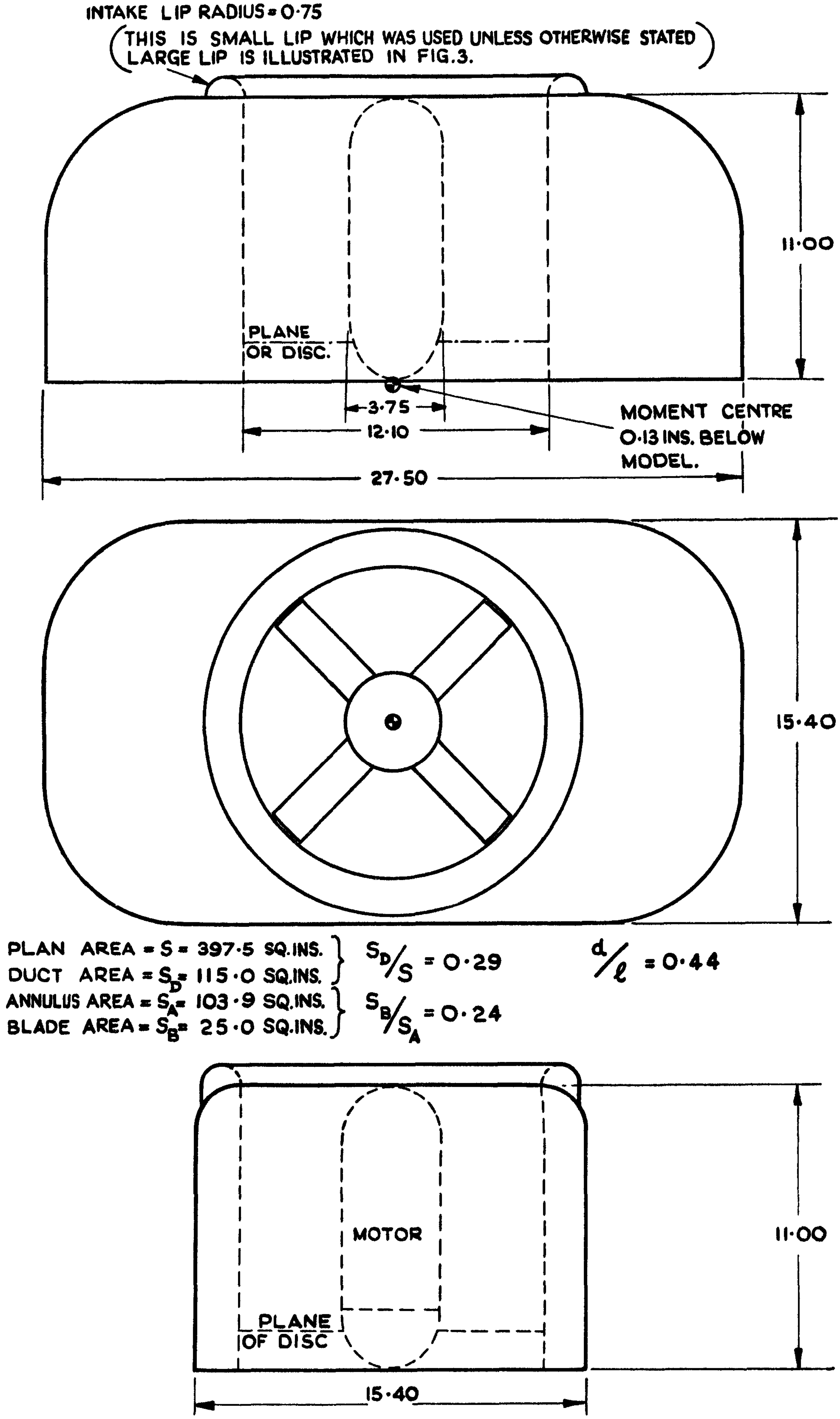
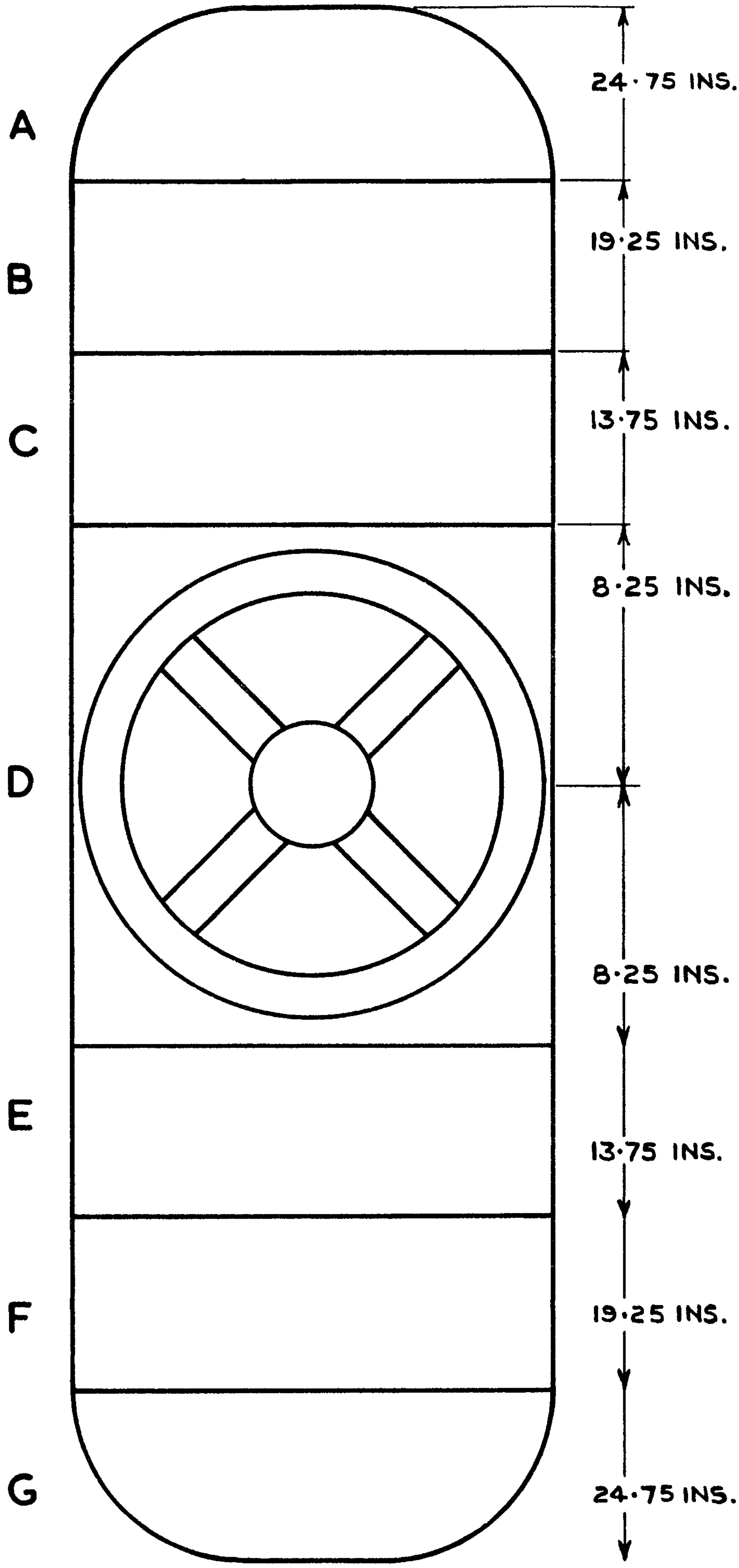


FIG. 1. G.A. OF BASIC MODEL CONFIGURATION

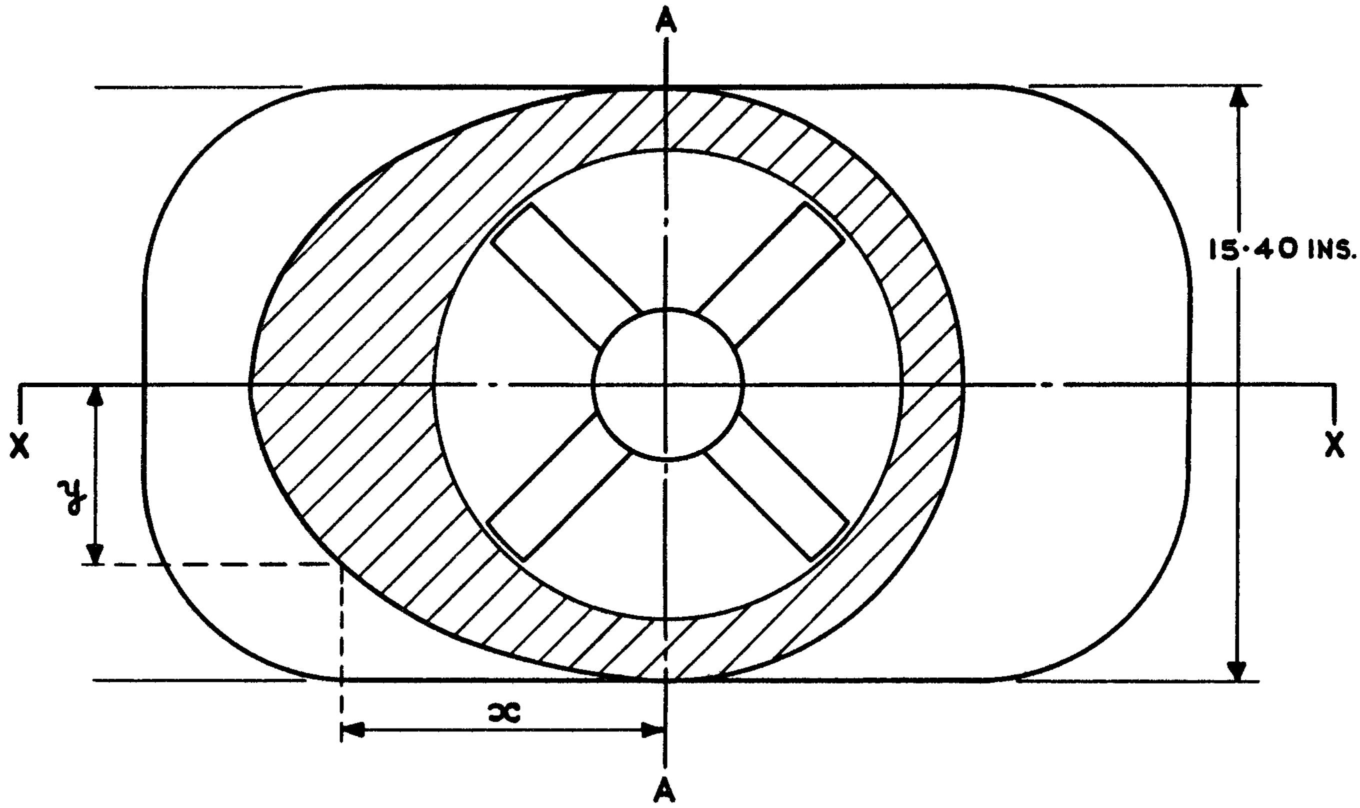
[SCALE = 1/5; ALL DIMENSIONS ARE GIVEN IN INCHES]

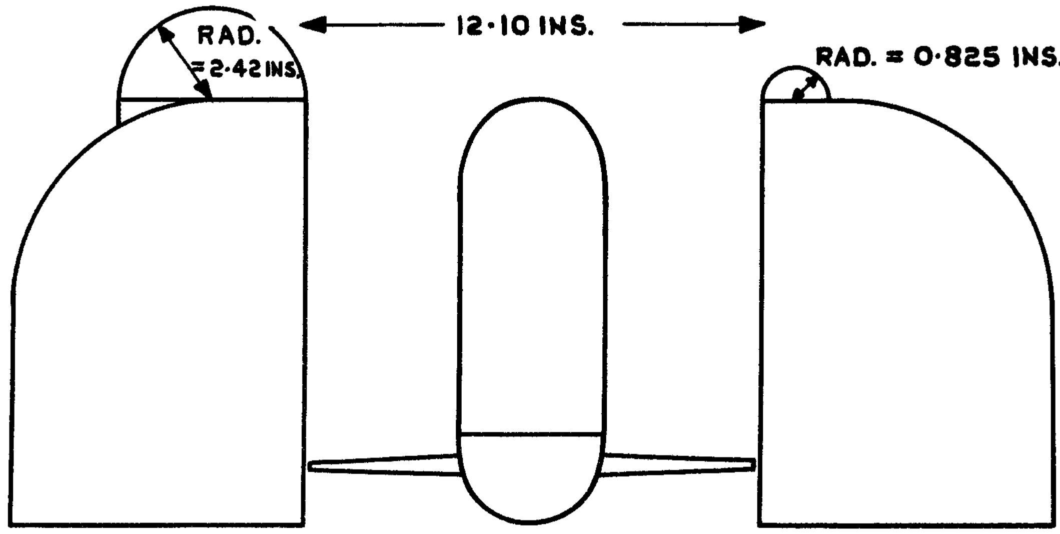


MODELS TESTED	A D G	A B D G	A D F G	A B C D G	A B D F G	A D E F G
x/ℓ	0·50	0·58	0·42	0·64	0·50	0·36
d/ℓ	0·44	0·37	0·37	0·31	0·31	0·31

x = DISTANCE FROM NOSE OF MODEL TO CENTRE OF FAN.

FIG. 2. VARIATIONS IN MODEL PLANFORM.





SECTION X–X

x INS. AHEAD OF AA	y INS. OUT FROM ℄	LOCAL LIP RADIUS (INS.)
0	7·70	0·825
2·00	7·57	0·89
4·00	7·16	1·075
6·00	6·43	1·37
7·00	5·90	1·55
8·00	5·23	1·75
9·00	4·34	1·92
9·50	3·76	2·085
10·00	3·05	2·20
10·25	2·60	2·26
10·50	2·04	2·33
10·75	1·23	2·385
10·89	0	2·42

AFT OF A–A THE LIP RADIUS IS CONSTANT (0·825 INS.)
AHEAD OF A–A SEE TABLE.

FIG. 3. DETAILS OF LARGE INTAKE LIP.
(USED ONLY FOR TESTS REPORTED IN FIGS. 5 & 6(a))

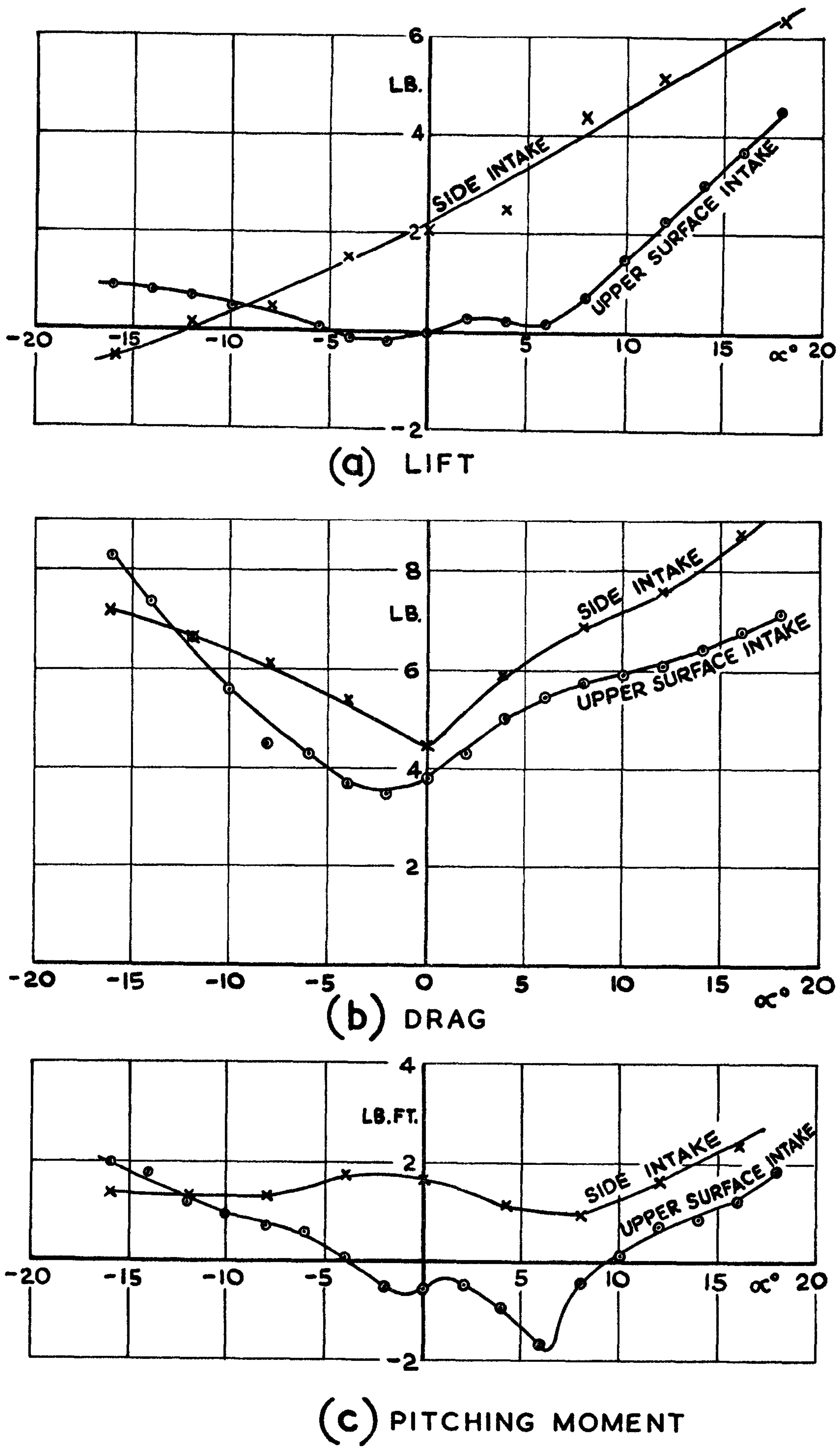
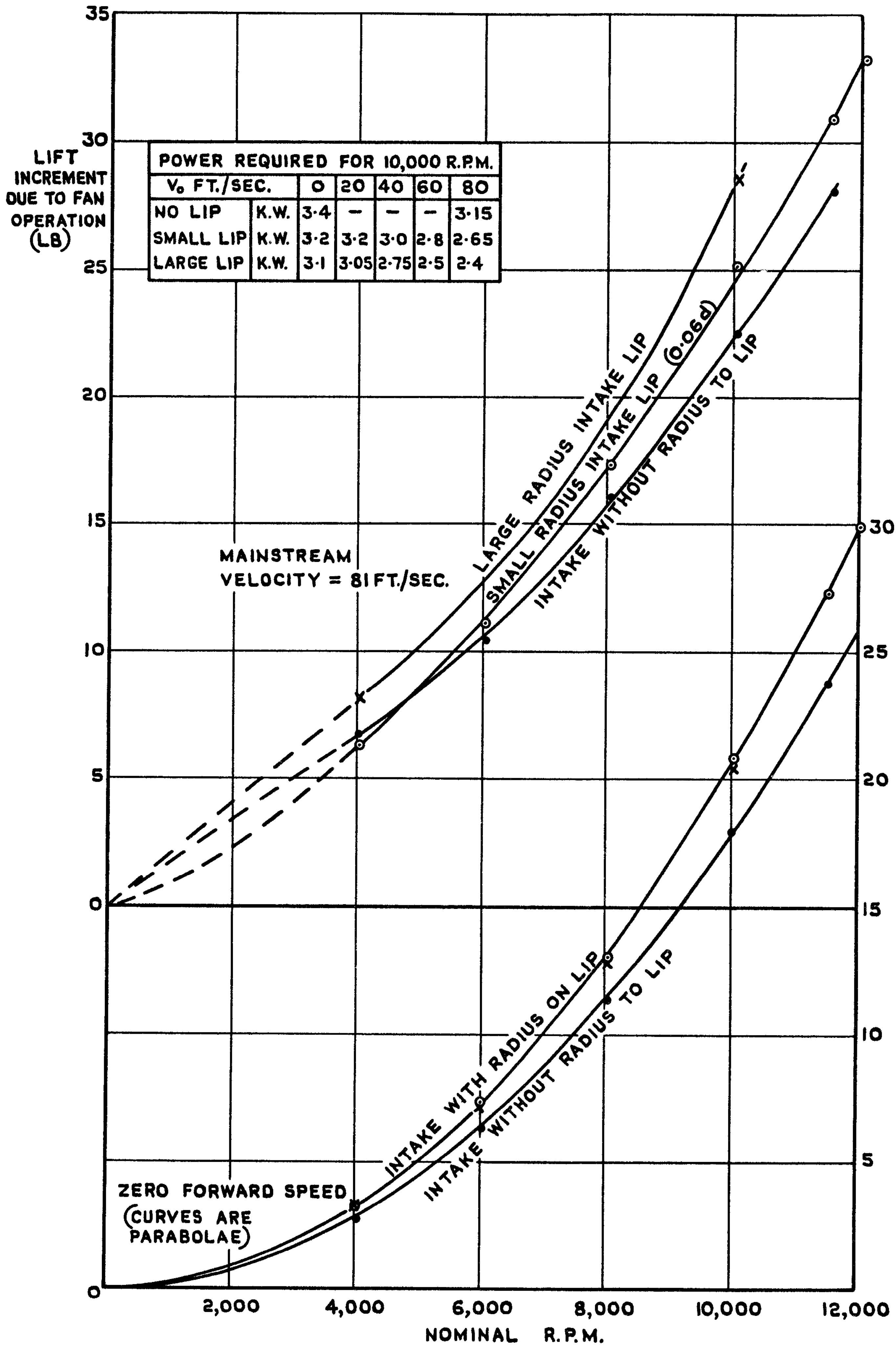


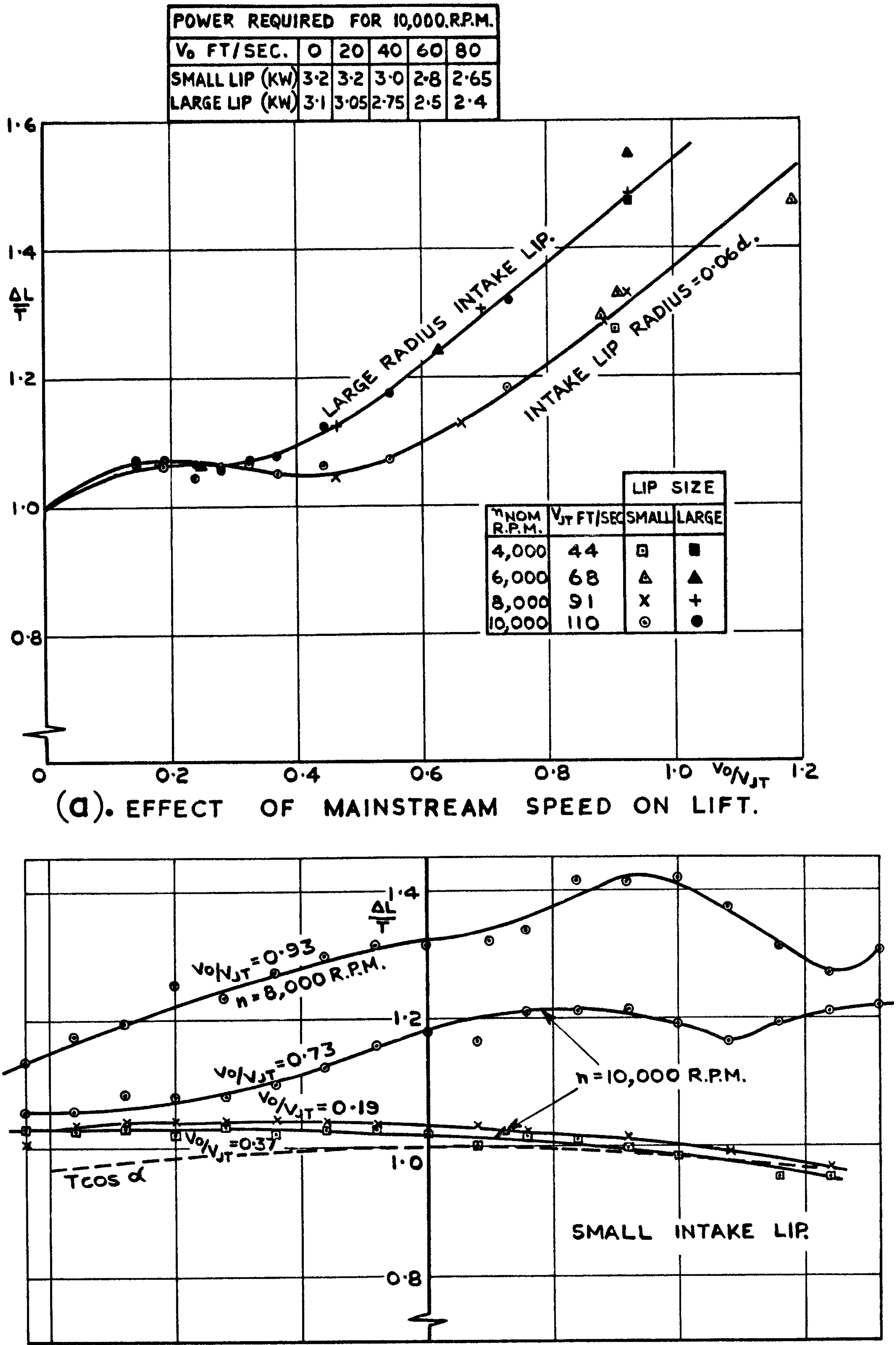
FIG.4. LIFT, DRAG AND PITCHING MOMENT OF BASIC MODEL (ADG) WITH INTAKES OPEN BUT FAN STOPPED.

[MAINSTREAM VELOCITY = 81 FT./SEC.]



POWER REQUIRED FOR 10,000 R.P.M.						
V_0 FT./SEC.		0	20	40	60	80
NO LIP	K.W.	3·4	–	–	–	3·15
SMALL LIP	K.W.	3·2	3·2	3·0	2·8	2·65
LARGE LIP	K.W.	3·1	3·05	2·75	2·5	2·4

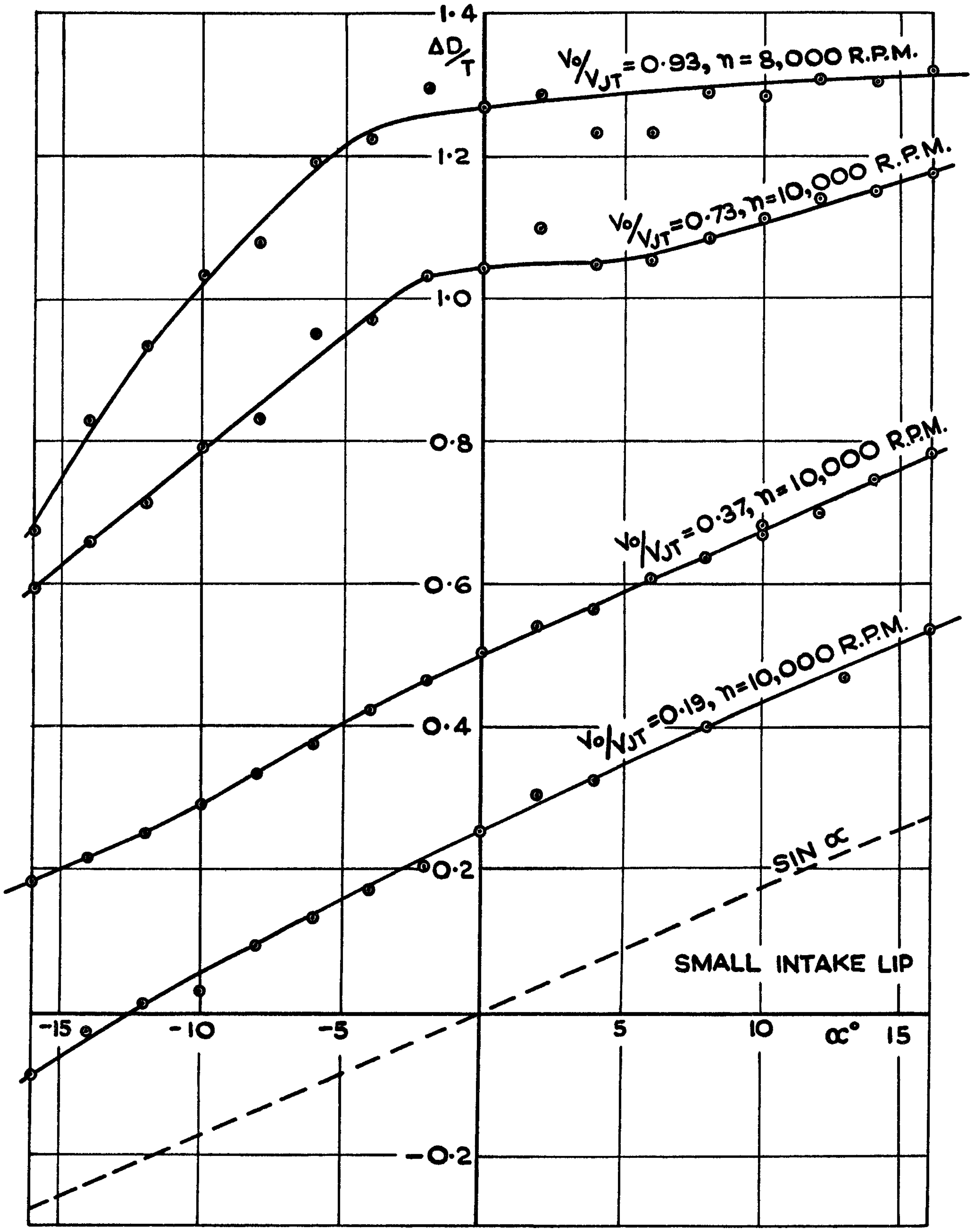
FIG. 5. EFFECT OF LEADING-EDGE RADIUS ON INSTALLED LIFT.



(a). EFFECT OF MAINSTREAM SPEED ON LIFT.

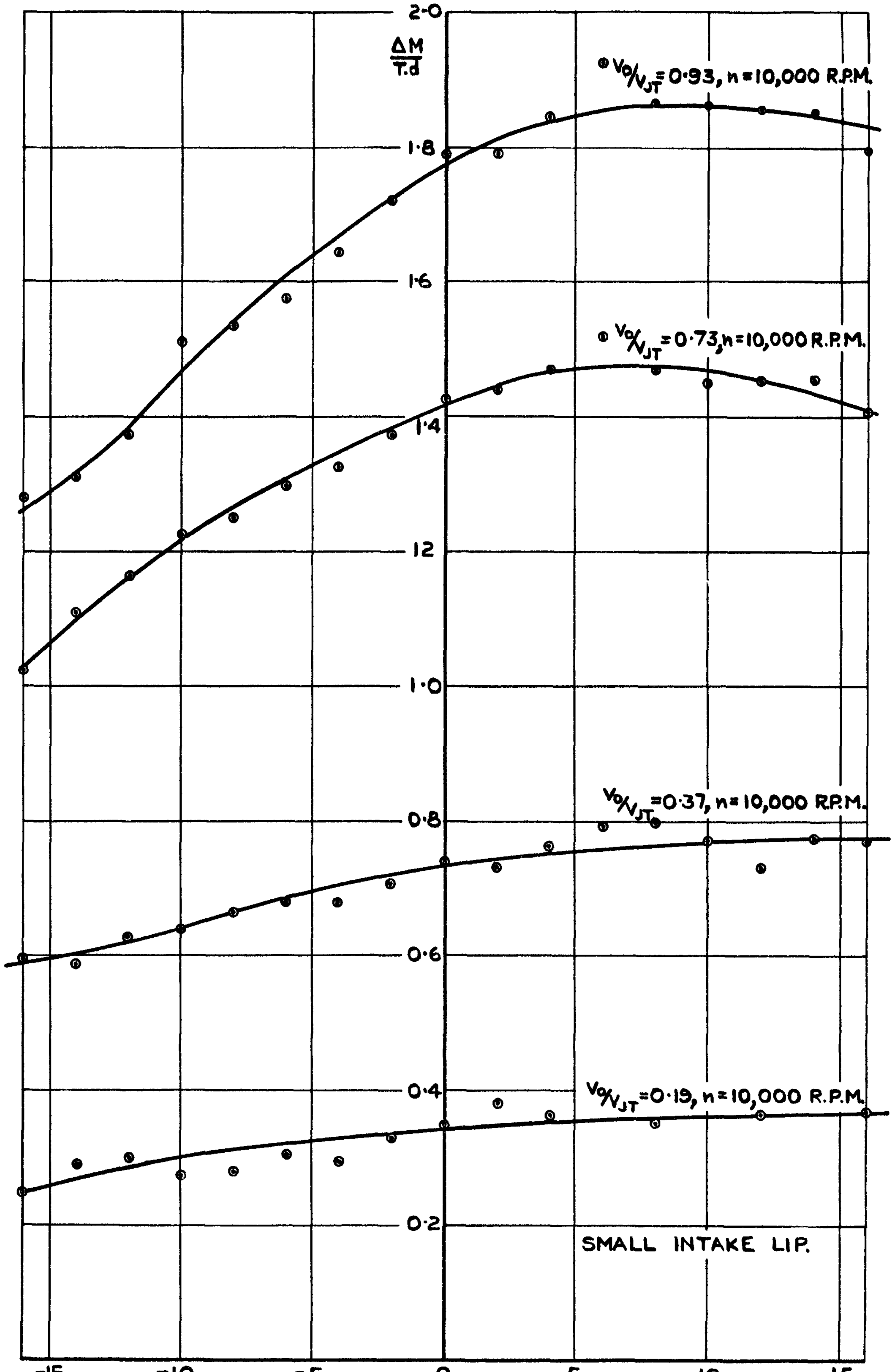
(b). EFFECT OF INCIDENCE ON LIFT.

FIG. 6. EFFECTS OF MAINSTREAM SPEED AND INCIDENCE ON BASIC MODEL (ADG).



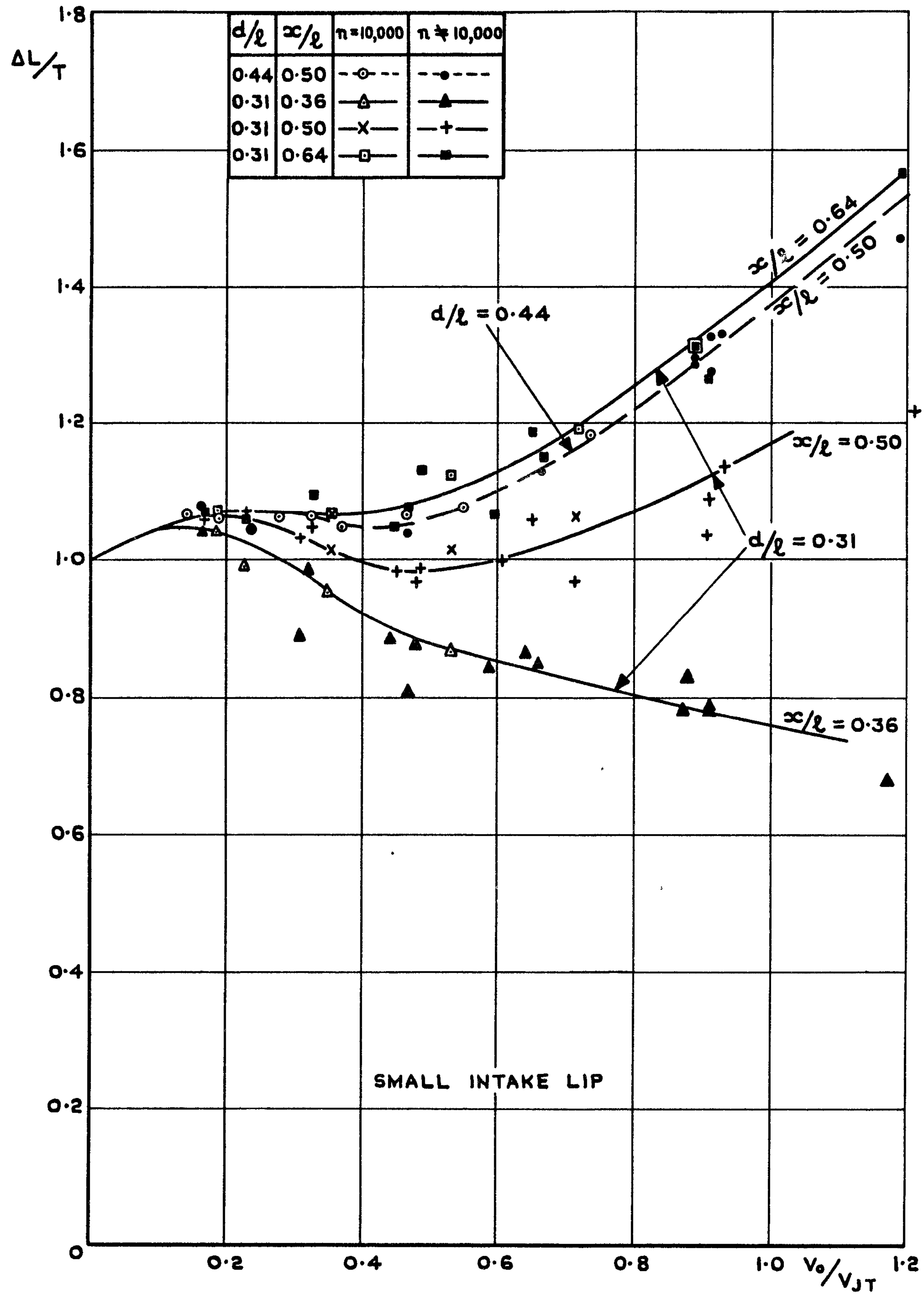
(c) EFFECT OF INCIDENCE ON DRAG.

FIG.6. EFFECTS OF MAINSTREAM SPEED AND INCIDENCE ON BASIC MODEL (ADG).



(d) EFFECT OF INCIDENCE ON PITCHING MOMENT.

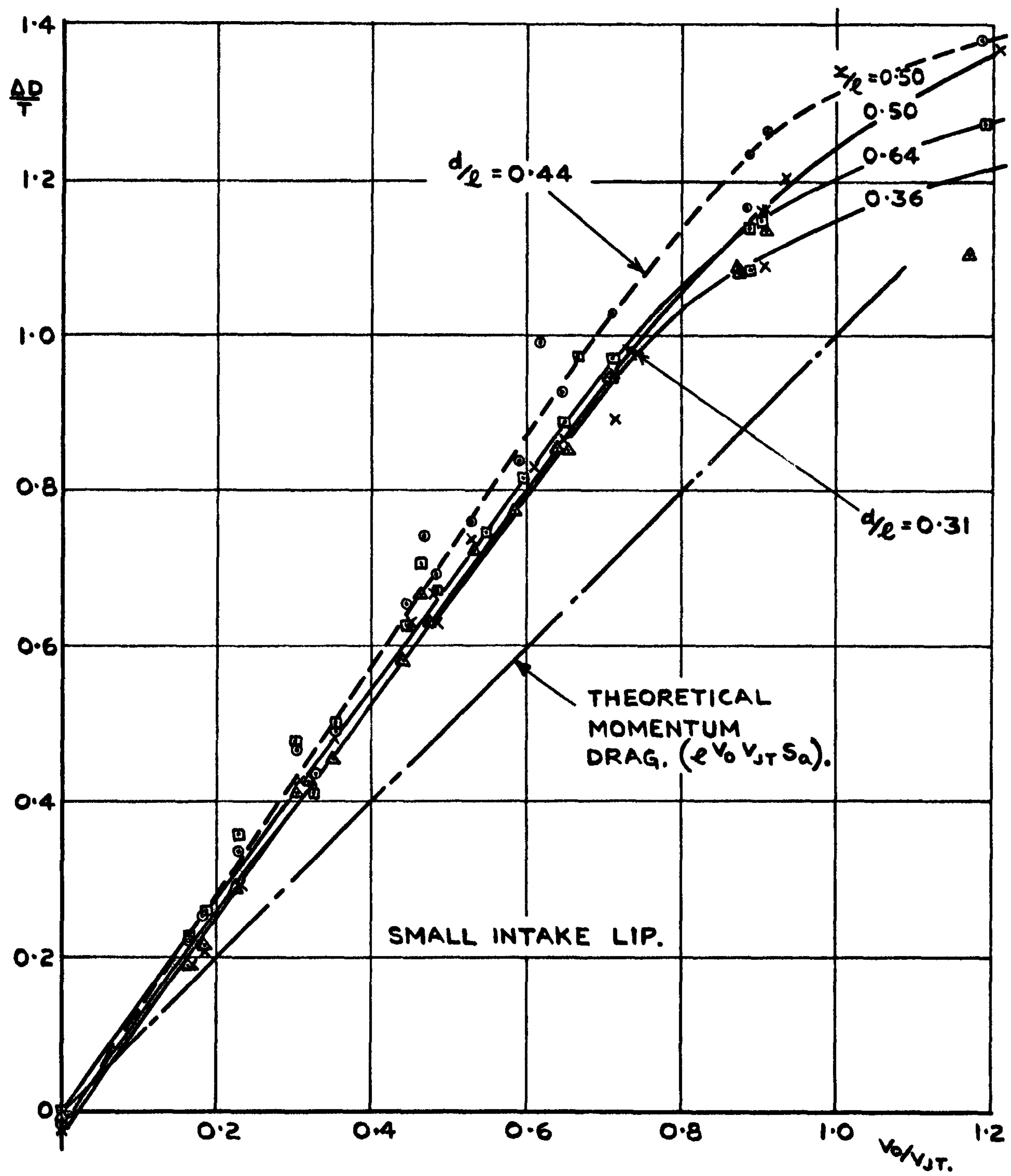
FIG. 6. EFFECTS OF MAINSTREAM SPEED AND INCIDENCE ON BASIC MODEL (ADG).



(a) LIFT

FIG. 7. EFFECT OF MODEL GEOMETRY AND MAINSTREAM SPEED.

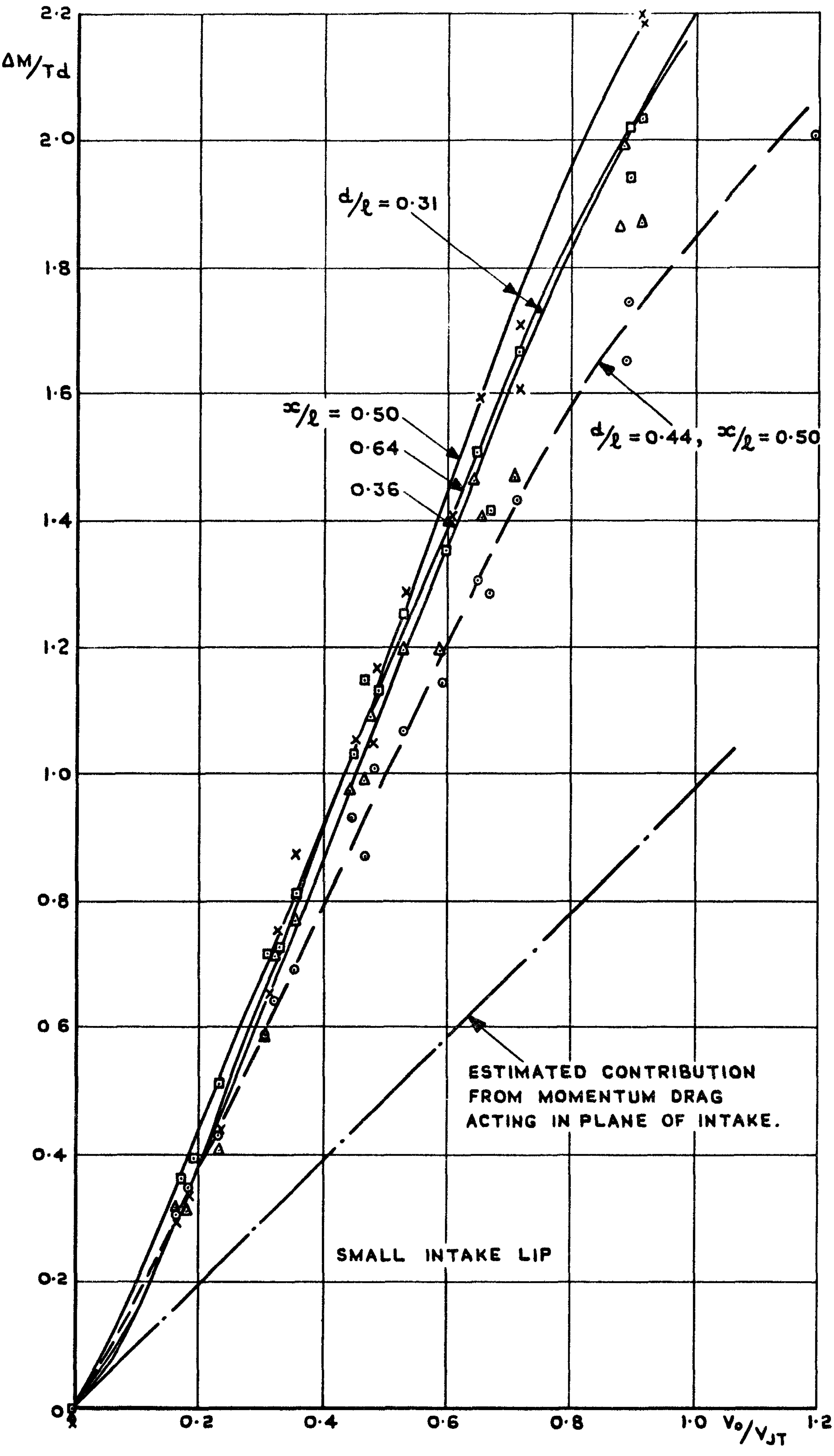
[4,000 ⩽ n ⩽ 11,500 R.P.M.]



(b). DRAG.

FIG. 7. EFFECT OF MODEL GEOMETRY AND MAINSTREAM SPEED.

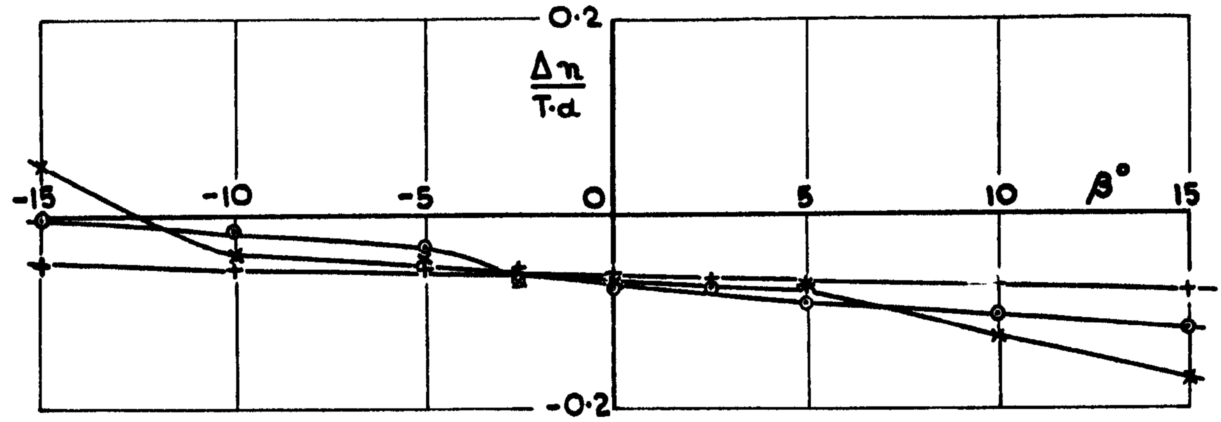
[4,000 ≤ n ≤ 11,500 R.P.M.]



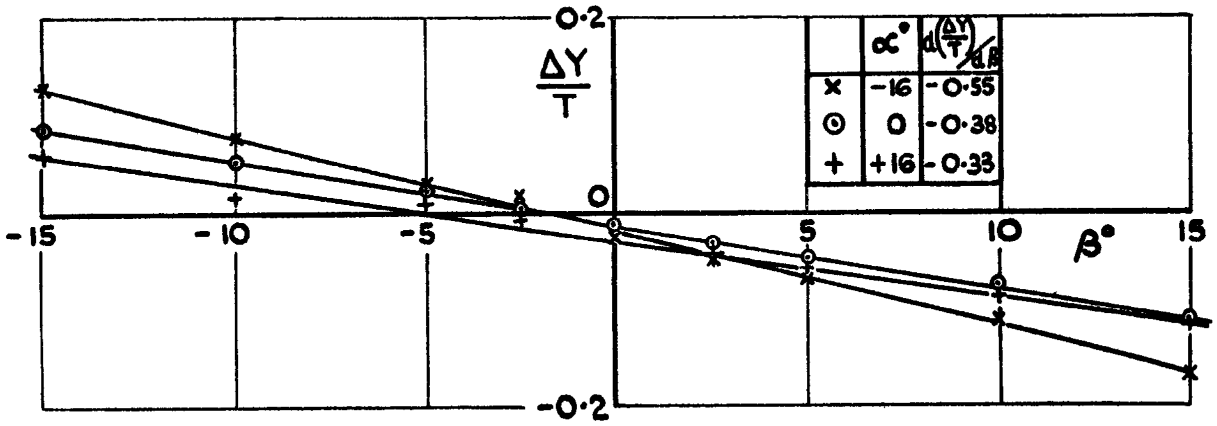
(C) PITCHING MOMENT

FIG. 7. EFFECT OF MODEL GEOMETRY AND MAINSTREAM SPEED.

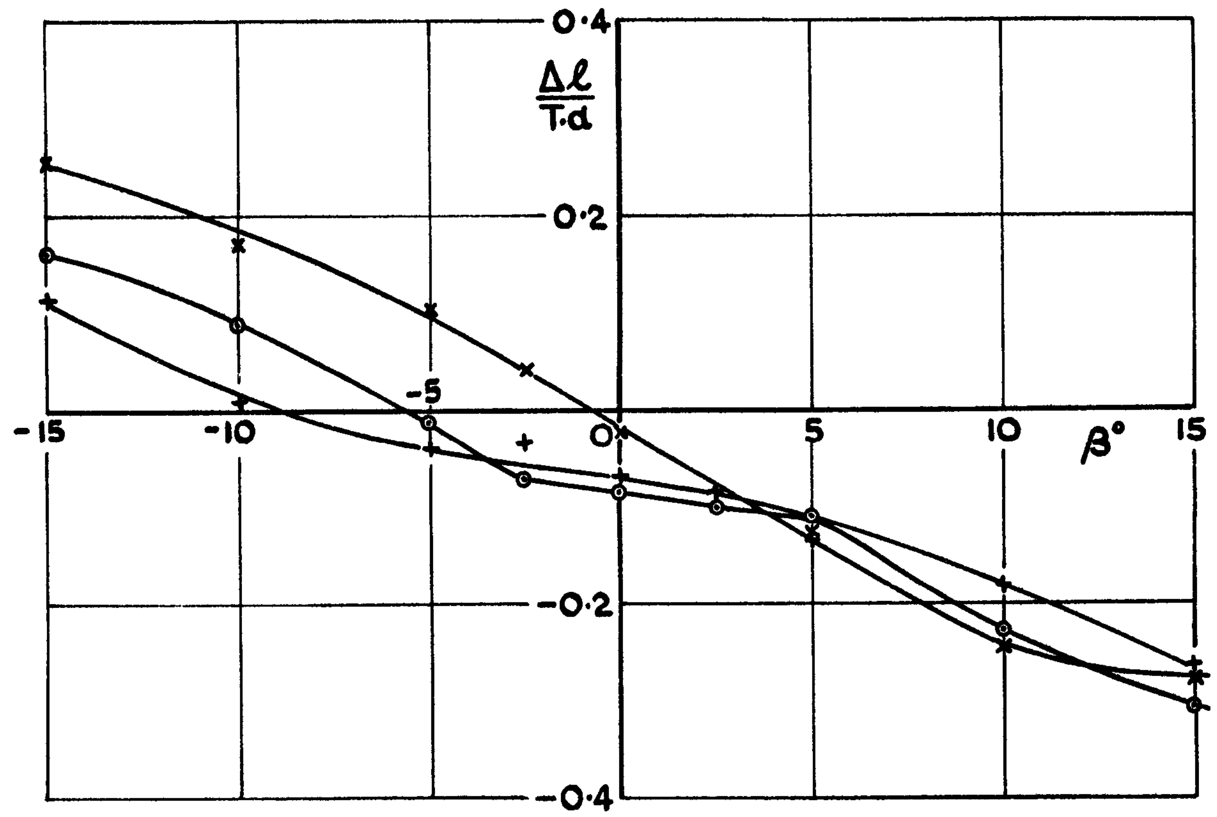
[$4{,}000 \leqslant n \leqslant 11{,}500$ R.P.M.]



(a) YAWING MOMENT



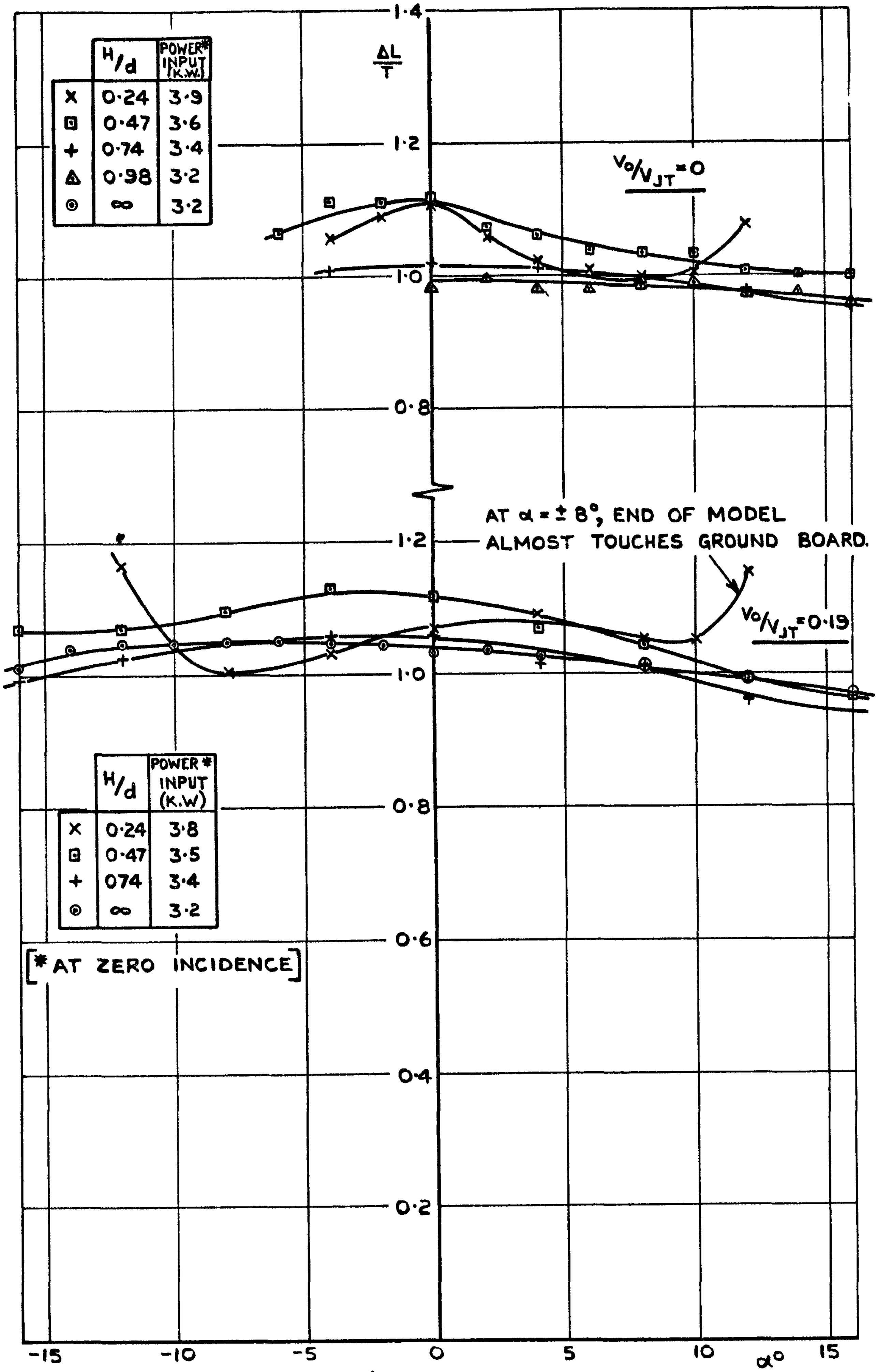
(b) SIDEFORCE



(c) ROLLING MOMENT

FIG.8. LATERAL STABILITY OF BASIC MODEL (ADG)

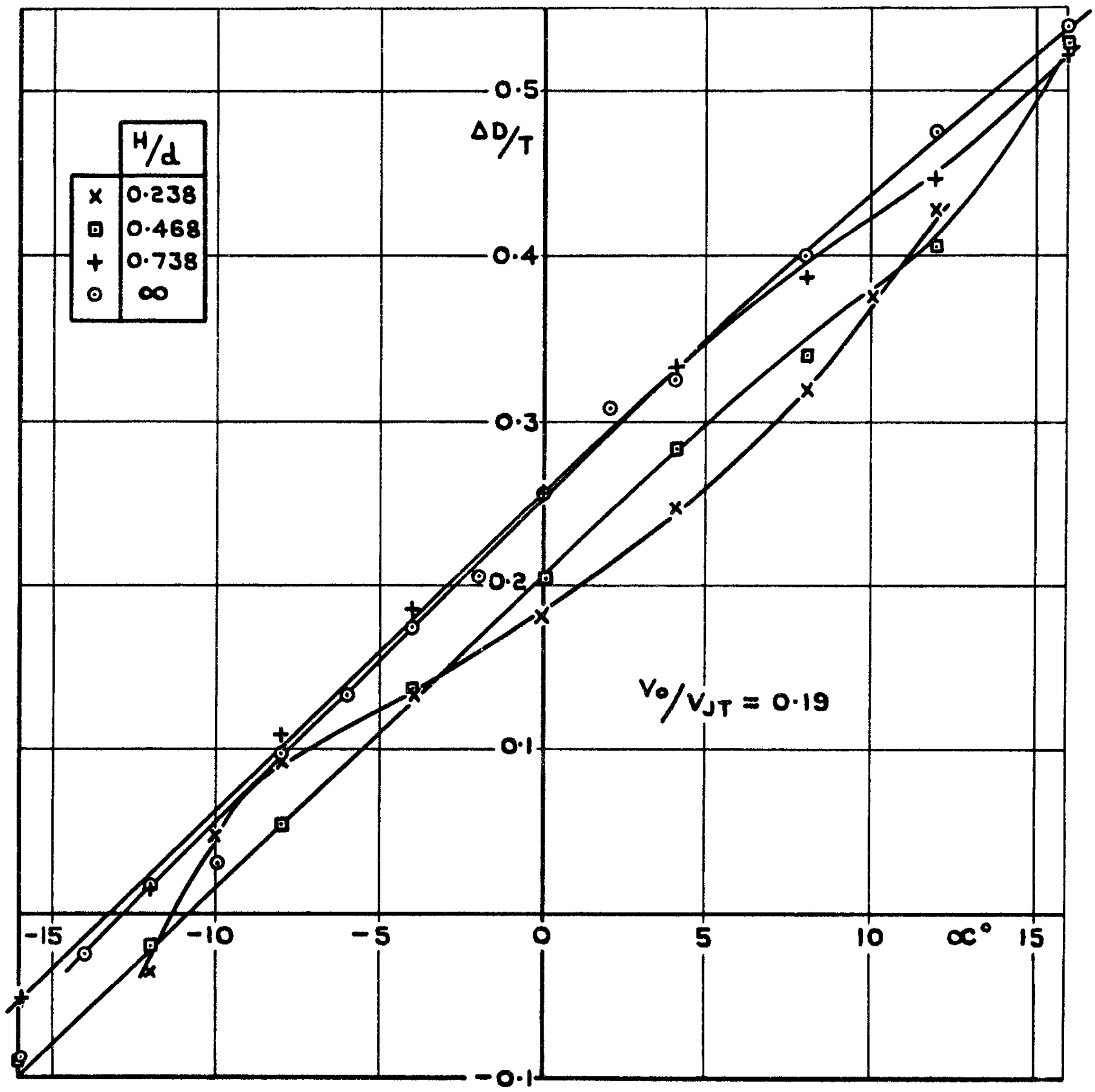
$\left[V_0/V_{JT} = 0{\cdot}36;\ n = 10{,}000\ \text{R.P.M.}\right]$



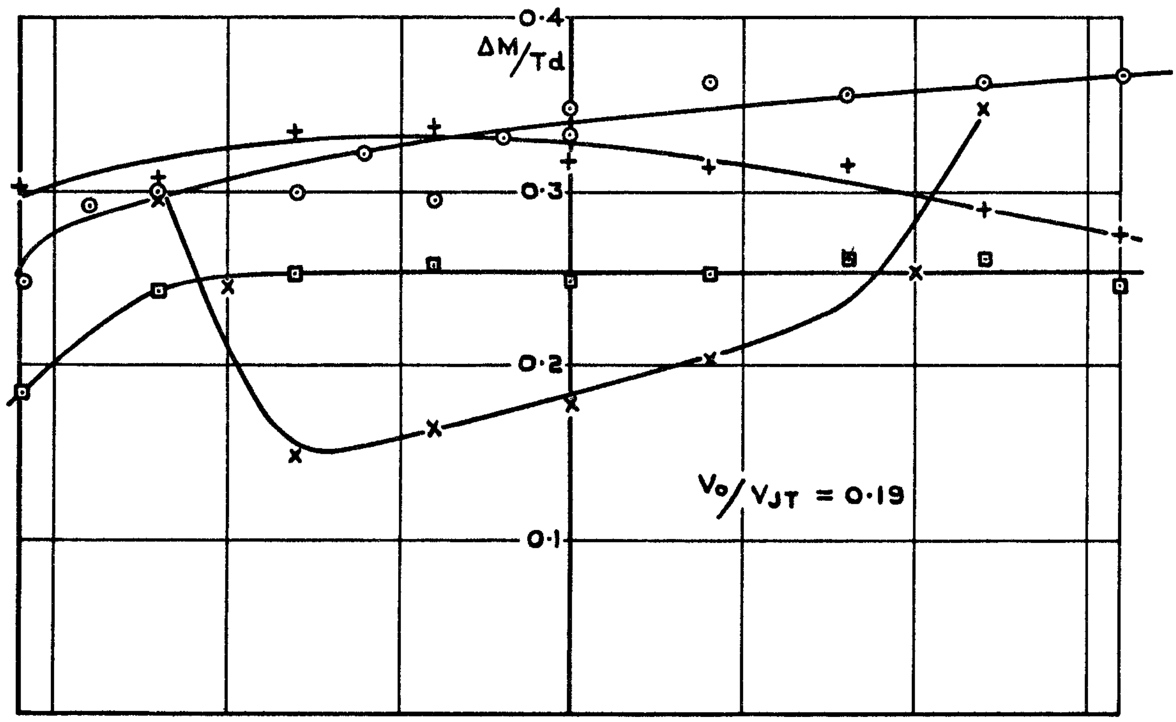
(a) LIFT.

FIG. 9. GROUND EFFECT ON BASIC MODEL (ADG).

[n = 10,000 R.P.M.]



(b) DRAG



(c) PITCHING MOMENT

FIG. 9. GROUND EFFECT ON BASIC MODEL (ADG).

[n = 10,000 R.P.M.]

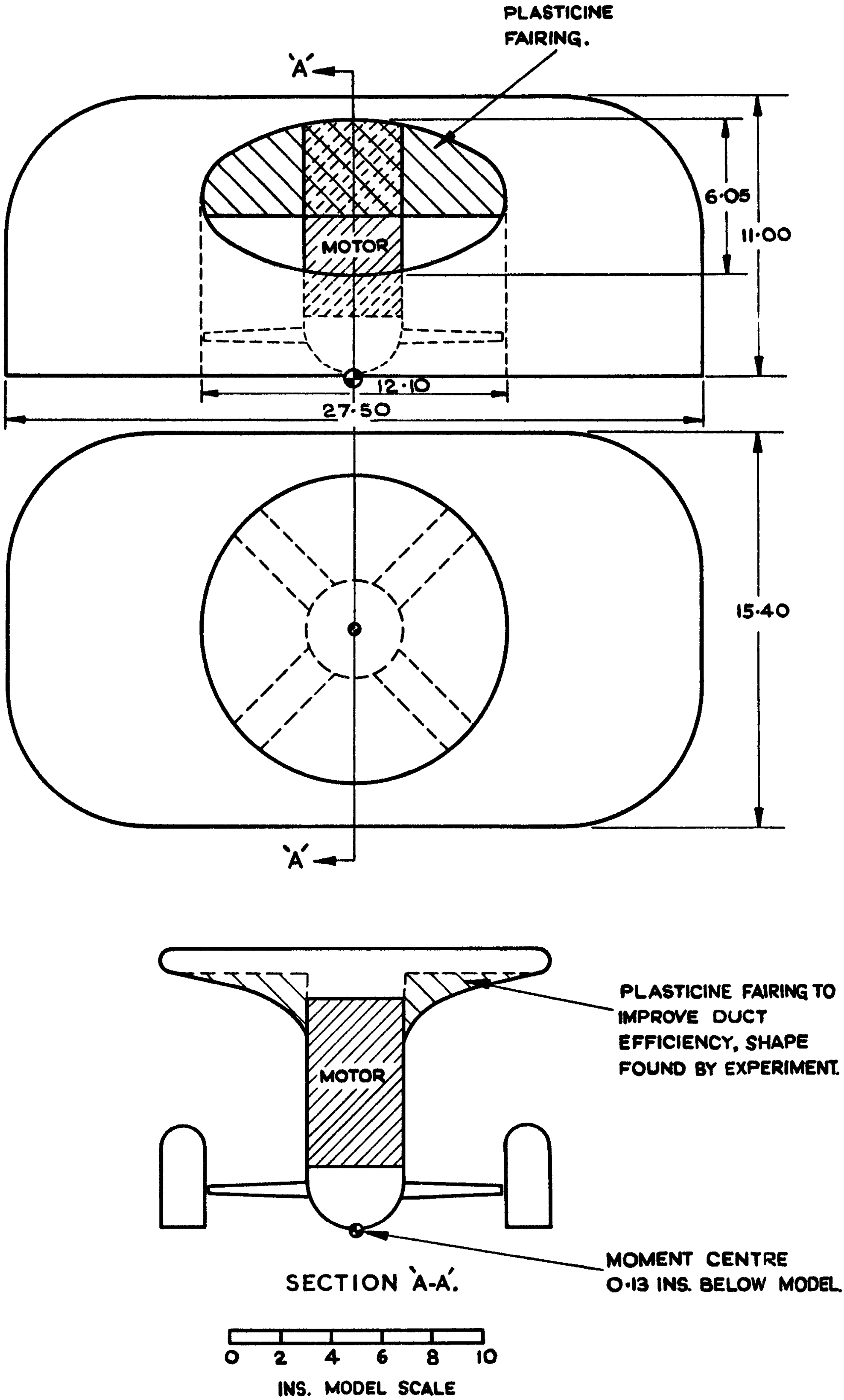
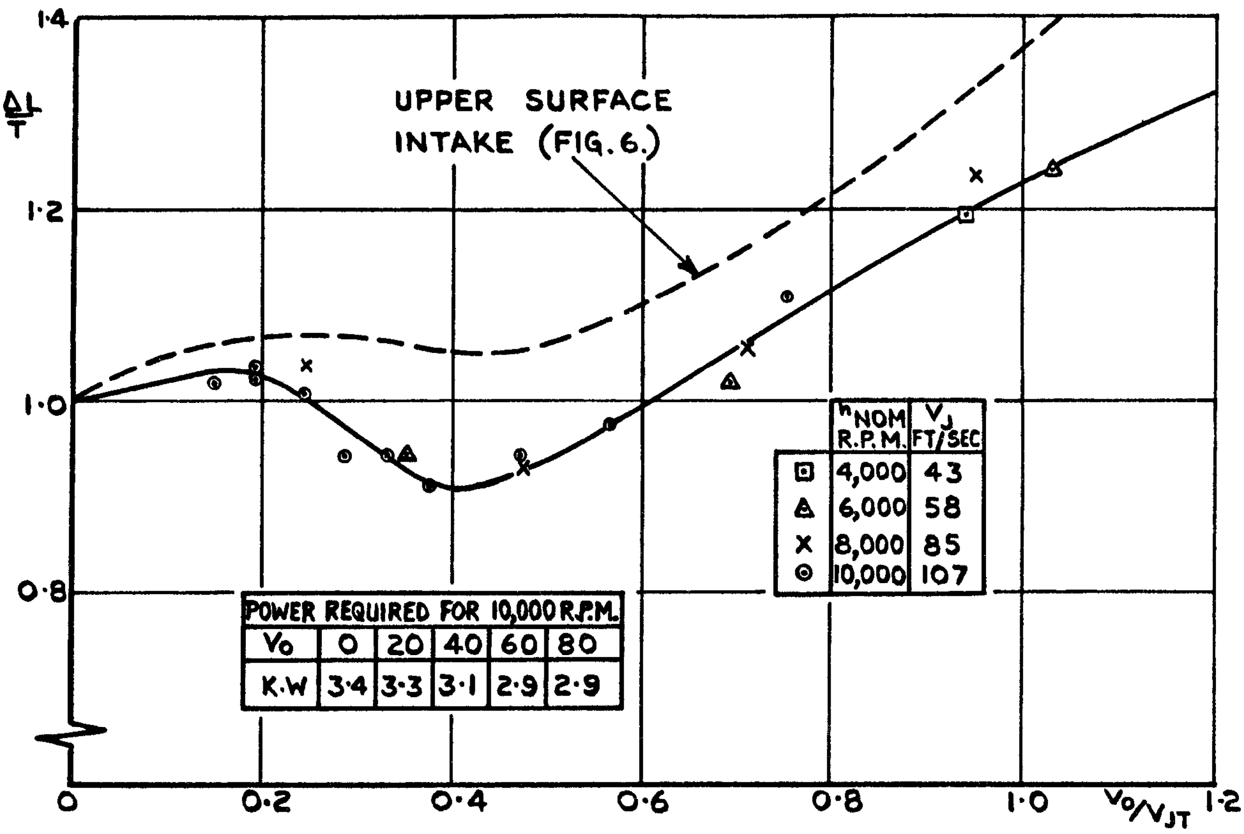
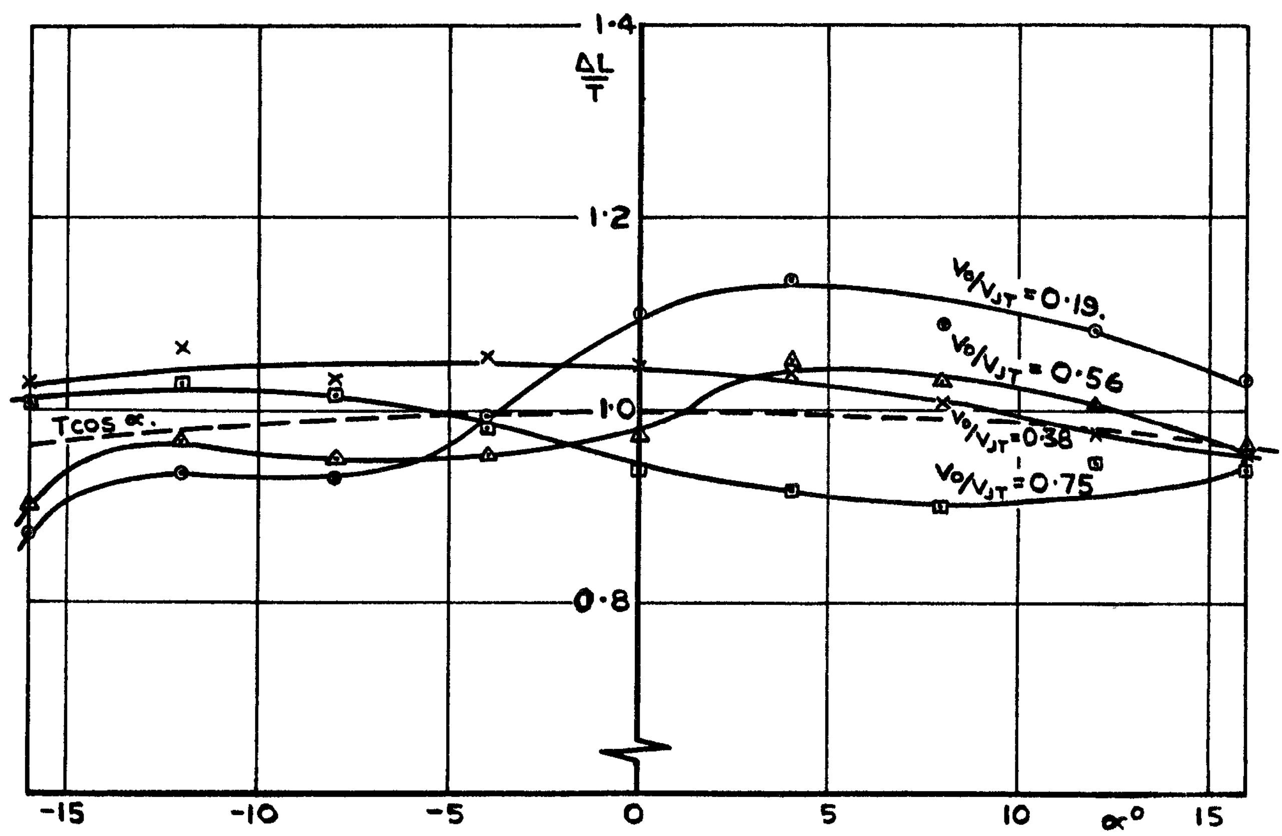


FIG. 10. G.A. OF SIDE - INTAKE MODEL (ADG).



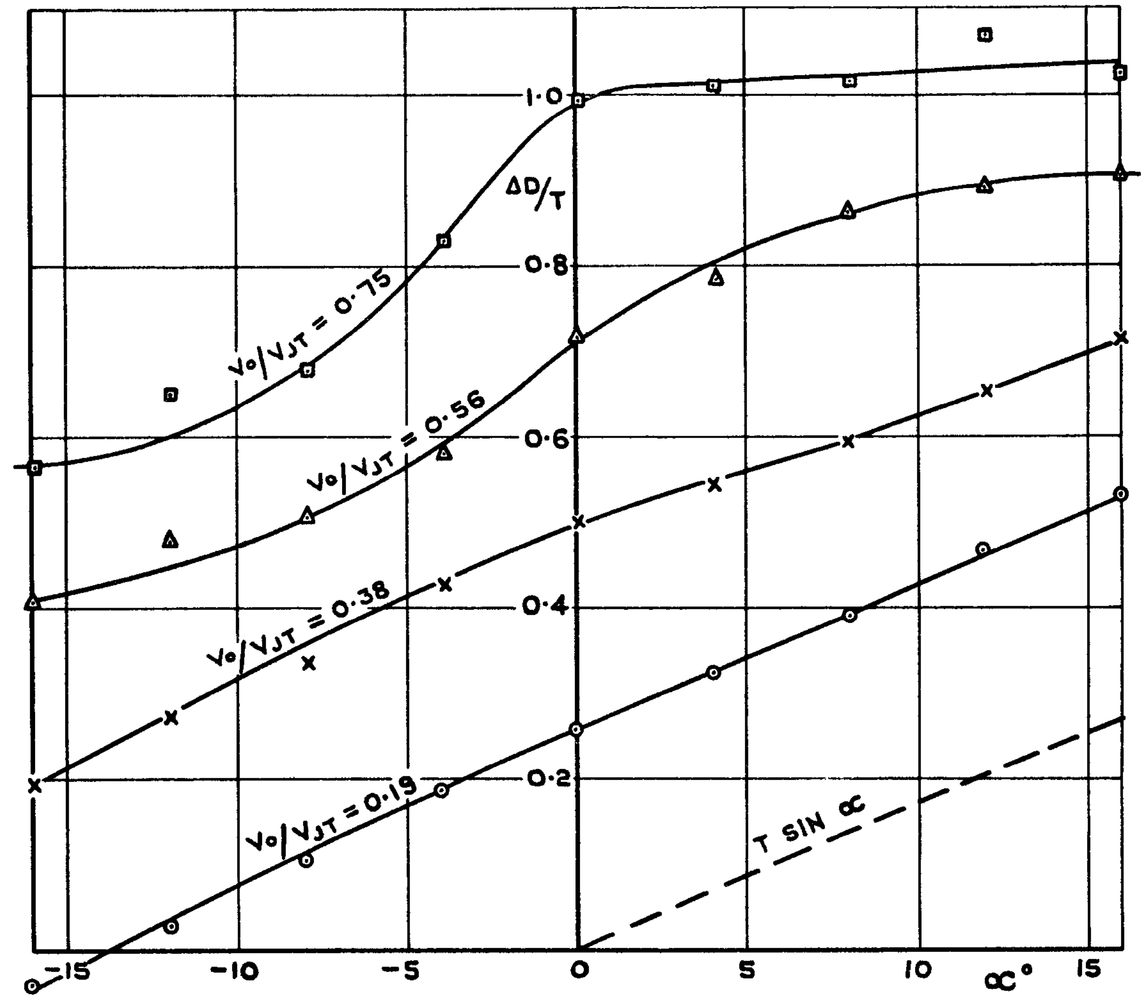
(a). EFFECT OF MAINSTREAM SPEED ON LIFT, $\alpha = 0$.



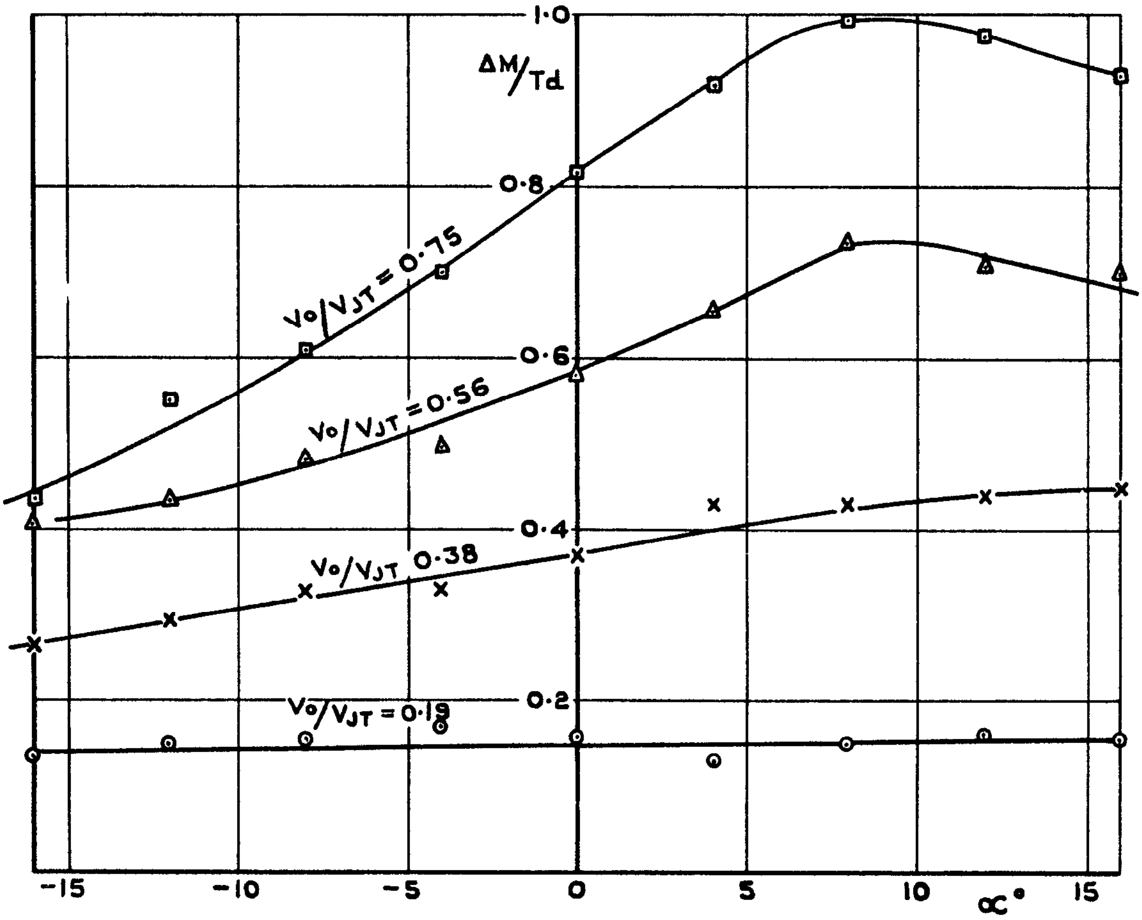
(b). EFFECT OF INCIDENCE ON LIFT,
$n = 10{,}000$ R.P.M., $V_{JT} = 107$ FT./SEC.

FIG. 11. EFFECT OF INCIDENCE AND MAINSTREAM SPEED ON SIDE-INTAKE MODEL (ADG).

$\left[d/\ell = 0{\cdot}44,\ x/\ell = 0{\cdot}50 \right]$



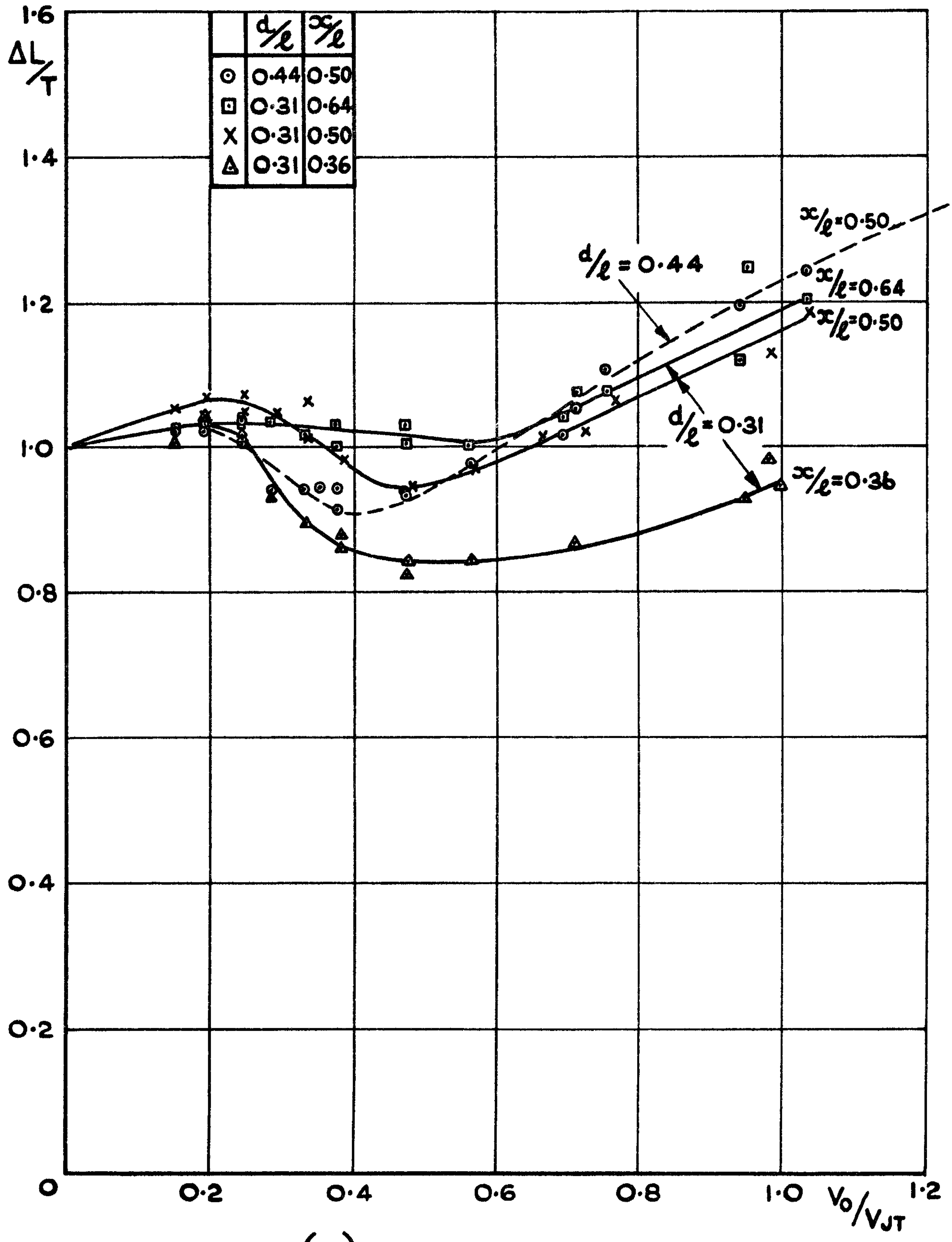
(c) EFFECT OF INCIDENCE ON DRAG



(d) EFFECT OF INCIDENCE ON PITCHING MOMENT

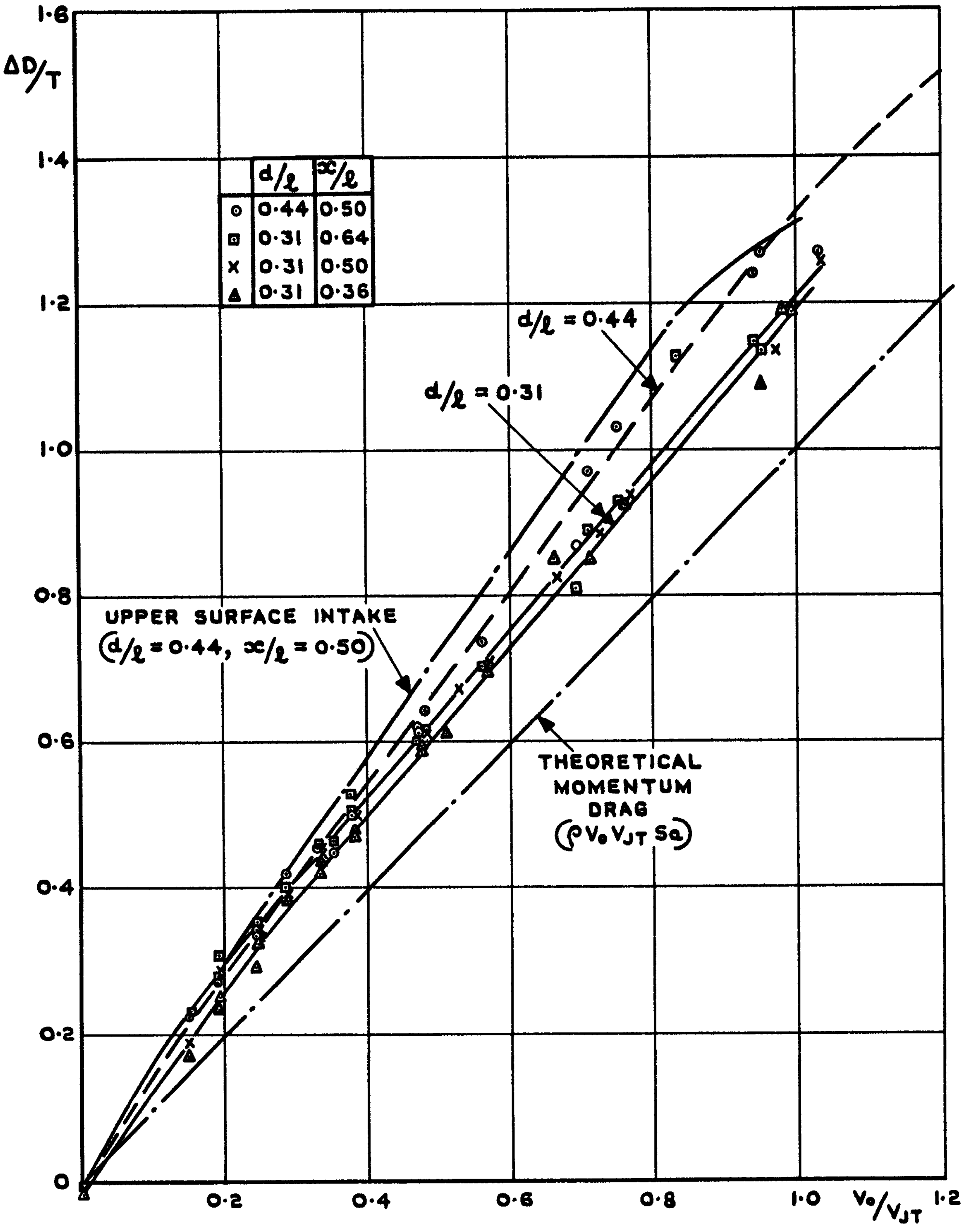
FIG. 11. EFFECT OF INCIDENCE AND MAINSTREAM SPEED ON SIDE-INTAKE MODEL (ADG.).

$[d/\ell = 0{\cdot}44, \; x/\ell = 0{\cdot}50]$



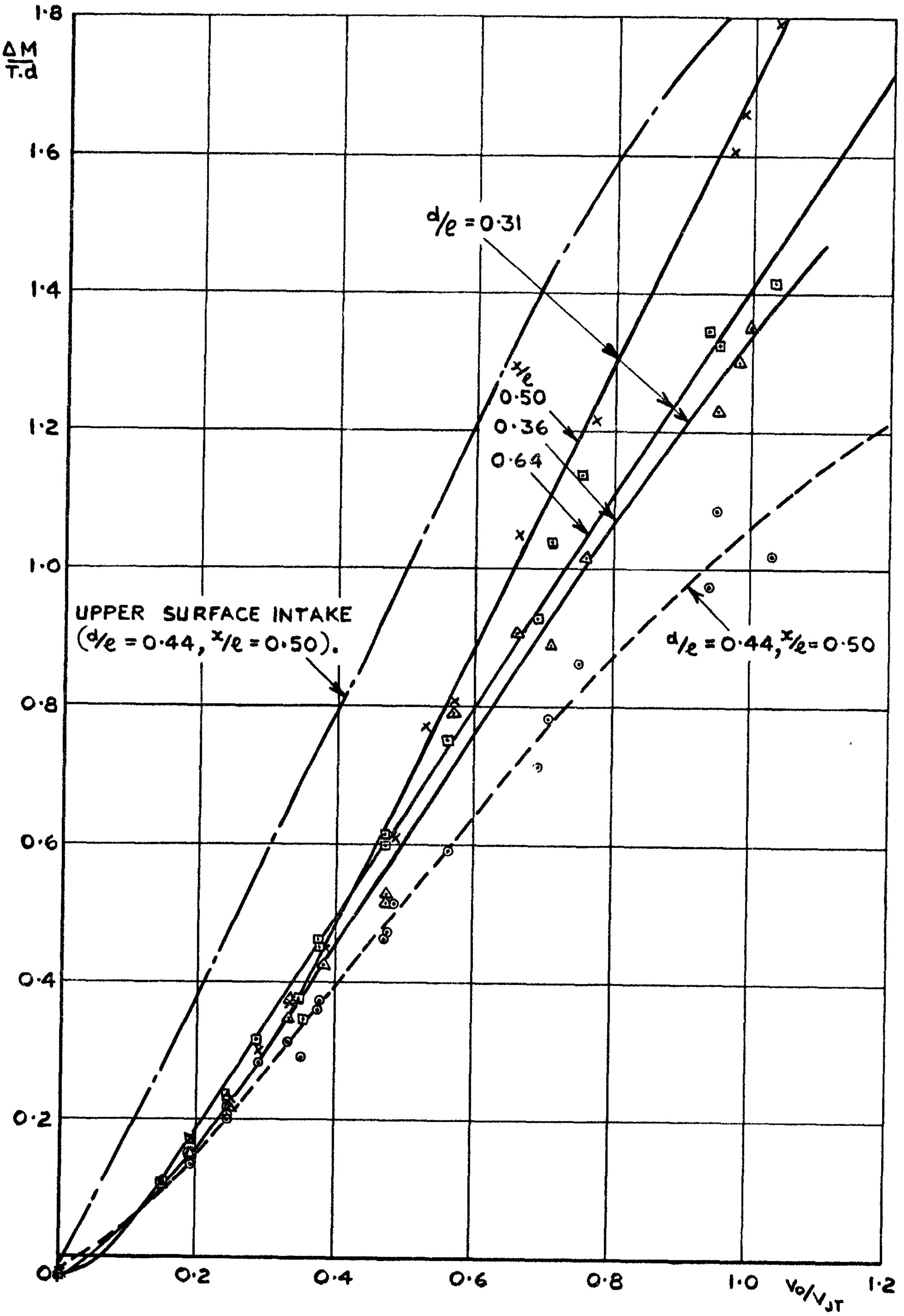
(a) LIFT, α = 0.

FIG.12. EFFECT OF FAN POSITION ON SIDE-INTAKE MODELS.



(b) DRAG, α = 0

FIG. 12. EFFECT OF MAINSTREAM SPEED ON SIDE-INTAKE MODELS.



(c). PITCHING MOMENT, $\alpha = 0$.

FIG. 12. EFFECT OF MAINSTREAM SPEED ON SIDE-INTAKE MODELS.

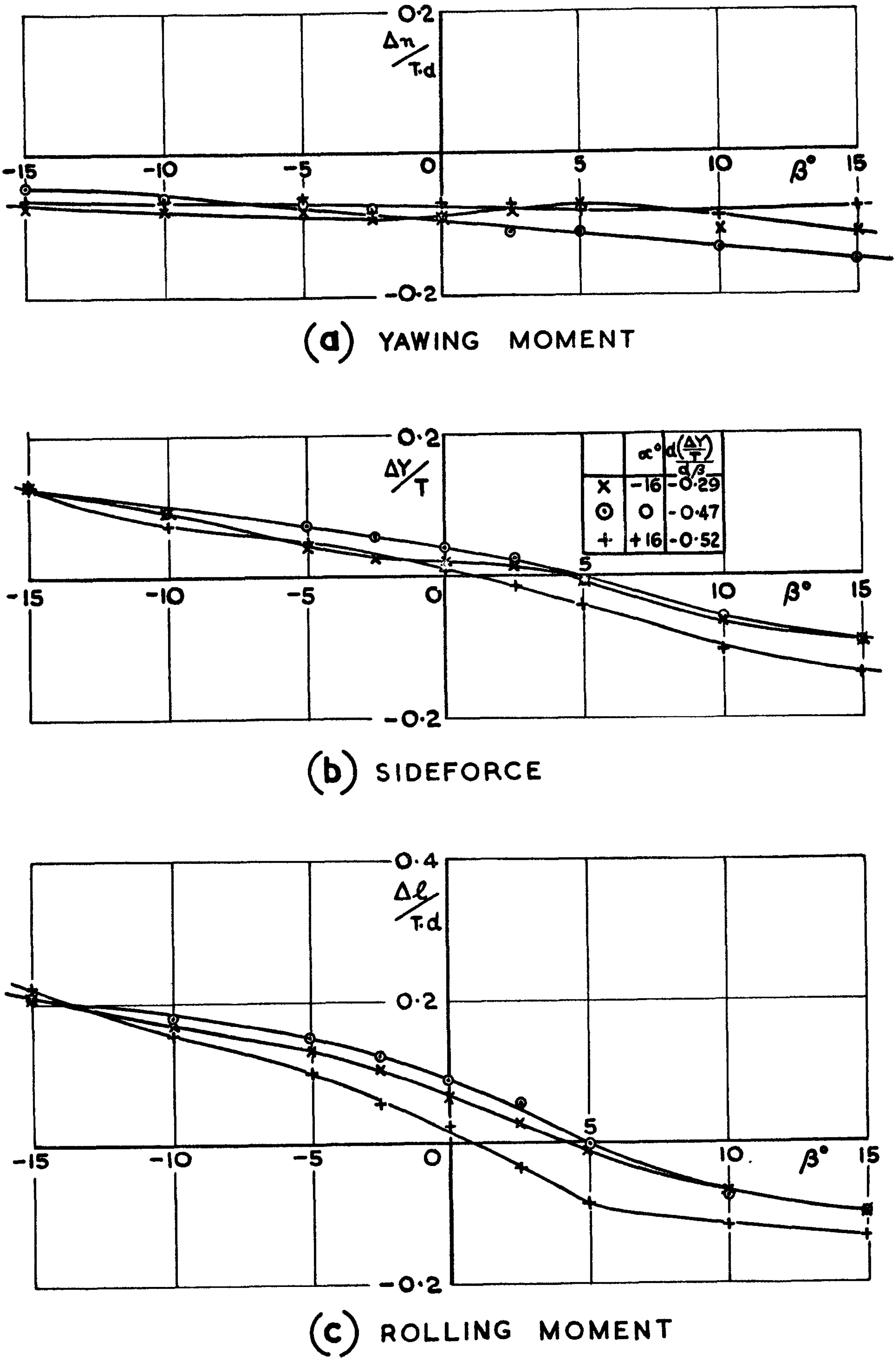


FIG. 13. LATERAL STABILITY OF SIDE - INTAKE MODEL (ADG).

[$V_0/V_{JT} = 0{\cdot}38$; n = 10,000 R.P.M.]

A.R.C. C.P. No.597

533.652.6: 533.695.27:
533.6.071.33: 533.6.013.1:
533.696.7: 533.682
533.662.3:

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BLUFF BODY CONTAINING A LIFTING FAN.
Trebble, W. J. G. and Williams, J. April, 1961.

The results from a first series wind-tunnel experiments on a bluff body containing a simple lifting fan are discussed, with the body width only slightly exceeding the duct diameter and body length only two or three times the fan duct diameter. For favourable mainstream interference effects on lift, a relatively large duct diameter and aft location of the duct axis proved beneficial. Both the drag and nose-up pitching moments due to fan

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