Paper No. 37

A Preliminary Wind Tunnel Investigation of the Aerodynamic characteristics of a simplified 'Lift plus Lift/Cruise'. Strike Aircraft Model in the V/STOL Flight Regime

P. G. Knott   British Aircraft Corporation
Military Aircraft Division

1. INTRODUCTION

The 'lift and lift/cruise' concept is one of the possible solutions to the next generation of strike aircraft with V/STOL capability that is being studied. Included in the preliminary project study was an experimental investigation of the aerodynamic characteristics in the V/STOL flight regime, where the operation of lifting jets can have a profound and unpredictable influence on the aerodynamic characteristics.

This paper presents and discusses some of the results of this study carried out in the B.A.C. V/STOL tunnel at Warton under Company funding.

Because of the preliminary nature of the investigation the model was kept simple (figure 1). The geometry is based on Jaguar type aircraft but with wing flap, slat and rear fuselage details which differ from the Jaguar aircraft. The jet efflux is simulated by cold compressed air, no engine intake flows are represented, and the airframe loads are measured, independent of the direct jet thrust forces, on a 6 component internal strain gauge balance.

The investigation included zero forward speed hover tests in addition to the main investigation which concerned the influence of the lifting jet at forward speed both in and out of ground effect.

Some tests were carried out with the lift engines only operating and with wings and tail removed to indicate the source and distribution of the jet induced force and moment increments. A brief study of the influence of yaw was also included.

2. TEST CONDITIONS

The Warton V/STOL tunnel (figure 2) currently has a working section size of 18' wide (5.5m) and 15' high (4.5m) a maximum working section speed of 65ft/sec (20 m/s) and is equipped with a moving ground belt and compressed air up to 40 atmospheres supplied to both the working section and a calibration and static test laboratory. The model has a span of 3.5ft (1.06m) and a total jet area of 0.136 ft^2 (0.0126m^2) giving values of span to tunnel width and jet area to working section area about 20% and 0.05%. These values are indicative that the model is small enough to be free of any measurable wall constraints. No corrections have been applied to the test data.

3. POWER OFF CHARACTERISTICS

This model is based on the Jaguar aircraft which is designed for conventional take-off and land. Although the flap on this model is different from Jaguar the wing and flap system is designed for good power off lift, unlike for example the Harrier/P1127 which was designed for V.T.O. from the onset. Comparison of the power off lift coefficient (figure 3) shows that this model has a relatively good flap. Ground effect at undercarriage height reduces the lift and drag very slightly in the flap down case ($\Delta C_L = 0.04$).

4. HOVER CHARACTERISTICS

In hover the jet entrainment creates a reduced static pressure on the lower surfaces causing a loss of lift, ΔL. Hover lift loss data is shown plotted on figure 4 as a percentage of the jet thrust and as a function of height above ground. Away from ground effect i.e. at heights above about one wing span (b) this loss of lift is typically a few percent of the thrust; about 3% for this configuration. In ground effect the losses increase to between 8% and 12% at undercarriage height depending on incidence and jet angle. This increase in ground effect is caused by the additional entrainment field from the wall jets which spread out from the jet, on ground impact. In the case of the P1127/Harrier type the 'four poster' layout of the jets also creates a fountain effect between the jets producing a region of positive pressure. On the P1127 this effect more than compensates for the wall jet suck-down and the losses are reduced at undercarriage height. On this L + L/C configuration this favourable effect is much less marked due to the particular location of the lifting jets. The case with incidence and rearward deflected jets, showing losses at 8%, indicates that improvements are possible.

Other tests have shown that the ground effect characteristics can be improved by variation of the jet exit location, by attention to detail around the jet exits and by ground treatments which either shield the aircraft from the wall jets or re-direct them to reduce their influence. In one case tested the lift engine exhaust was split into four discrete nozzles in 'four poster' fashion. This improved the lift at undercarriage height considerably with no noticeably adverse influence at forward speed.

For short take-off and vertical or short landing reduction in lift loss at undercarriage height is not important. If vertical take-off performance is required however improvement is vital as it impacts directly on the installed thrust.

The ground effect 'suck-down' is accompanied by a small nose up pitching moment.

5. POWER ON CHARACTERISTICS AT FORWARD SPEED

5.1 Away from ground effect

On figure 5a. the airframe lift coefficient C_L is plotted against the jet thrust coefficient C_μ. The lift coefficient therefore does not include the vector component of the direct thrust and the thrust coefficient is defined in the usual way, as gross thrust nondimensionalised by the free stream dynamic pressure and wing reference area. Values of C_L at $C_\mu = 0$ are thus the power off values and which form the datum for the 'jet interference' term ΔL. The hover case cannot be shown on this presentation ($C_\mu = \infty$) but it has been found that the high C_μ region can be well fitted by a straight line whose slope is equal to the hover lift loss. The data appears to fall into two regimes; low thrust coefficient (high speed end of transition) and high thrust coefficient (low speed end). In hover and at the low speed end of transition the aircraft is mainly or entirely jet lift supported, hence $\Delta L/T$ is the significant parameter. At the other end of transition as the aircraft becomes progressively wing supported, the airframe C_L is what matters. It is therefore necessary to present the data in both forms, looking at the left hand end of both presentations i.e. up to Ve of about 0.15 for $\Delta L/T$ for V.T.O. and initial transition and from C_μ of about 3 down to zero for the conversion to wing borne flight. In both these regimes it is clear that the jet interference is negative but modest, $\Delta C_L < -0.5$ and $\Delta L/_T < 15\%$.

Figure 5b shows that these losses are very similar to the P1127/Harrier, but the basic wing lift (fig. 3) is higher of course.

Some tests were carried out with the lift jets only operating, in a brief S.T.O.L. study using the horizontal tail to trim. As a proportion of the thrust applied, these losses are higher than the four jet case. It has been established from other tests that the rearward location of the lift/cruise nozzles is advantageous in reducing lift loss and that the counter-balancing lift engines in the forward location are responsible for a good deal more than half the total lift loss. Some tests were also done with the wing and tail removed, which showed that a little more than half the lift loss acts on the fuselage. From these and other studies it is now appreciated that this configuration is far from optimum in terms of what can be accomplished to reduce lift loss on the basic L + L/C layout. On this arrangement the L/C nozzles exhaust from the lower surface of a wide fuselage with extensive horizontal surface to the rear of the jets. If the nozzles were placed on the fuselage side, a little further aft, and the rear fuselage made slimmer, the losses on the fuselage, the losses due to the rear jets and the total lift loss would be reduced.

The jet induced lower surface negative pressure field tends to occur to the sides and rear of the jet location, producing a nose up increment in pitching moment. Over the later, mainly wing borne, part of transition this change, relative to the power off condition, amounts to a C.P. shift of about a quarter chord. These tests exclude engine inlet flow simulation and in practice the nose up pitching characteristic will be considerably greater by virtue of the lift engine inlet flow.

At zero incidence there is a small increase in drag, but at 15° of incidence a significant drag reduction ($\Delta C_D = -0.15$) results from the forward rotation of the negative pressure field. The absence of inlet flow again means that some features are missing from these tests, in particular, the lift engine intake momentum drag and its interference field.

5.2 In ground effect

Figure 6 shows results for the same configuration at undercarriage height ($h/b = 0.3$), tested over a continuous belt 'moving' ground. It is apparent from figure 6a and 6b that ground effect has increased the lift loss in hover (as in figure 4) and at low forward speed, but reduced the loss at higher speeds to the point where there is a small lift augmentation at very low thrust coefficient.

The lift and pitching moments are sensitive to incidence in ground effect and it is clear that the presence of ground is changing the lower surface pressure field considerably.

This data is of interest in the S.T.O.L. mode. Typically when over loaded for V.T.O., S.T.O. would occur in the region $0.10 < V_e < 0.15$ ($6.7 > C_\mu > 3.0$). Positive incidence has a favourable effect on lift in ground effect and in a typical S.T.O. ($\alpha = 12^\circ$, $\delta_j = 60^\circ$, $\delta_f = 30^\circ$) lift losses are within 10% of thrust. The favourable lift effects at higher speeds could not be utilised because the aircraft would be ascending away from ground influence to conditions shown on figure 5a.

Again the results are very similar to the P1127/Harrier and again it should be made clear that there is considerable scope for improvement within the basic L & L/C concept, compared with this model, for the reasons already stated.

6. CHARACTERISTICS IN YAW

Figure 7 shows the lateral characteristics due to lift power at 10° of yaw. The model is stable in yaw (fig. 7a) at $C_\mu = 0$ and the effect of the lifting jets is to slightly increase the yaw stiffness. The model rolls in the direction of yaw at $C_\mu = 0$, (fig. 7b). This tendency is increased at low thrust coefficients but reduced slightly at the higher values. Sideforce increases in the direction of yaw (fig. 7c) at $C_\mu = 0$ and the effect of the lifting jets is to increase this slightly. No untoward characteristics are evident from this brief investigation.

7. CONCLUSIONS

1) In hover away from ground effect some loss of lift is inevitable through the mechanism of free jet entrainment. These losses influence the installed

thrust to aircraft weight ratio, but can be kept to a few percent of thrust.

2) In ground effect in hover, the lift and pitching moments depend on jet: planform location, aircraft attitude and local geometry. Acceptable characteristics for the L + L/C aircraft can be developed.

3) Despite the higher basic wing lift, the losses both in and out of ground effect at forward speed are no worse than the P1127/Harrier type of configuration and could be improved with appropriate wind tunnel development.

4) The lift characteristics at forward speed could be improved by re-location of the lift/cruise nozzles together with a reduction in fuselage horizontal area behind the jets.

5) Care must be taken in drawing conclusion from the pitching moment results because the lift engine upper surface inlet flow field is not represented in these tests.

6) No untoward characteristic in yawed flight were apparent from this study.

7) Further study is desirable in the following areas:-

i) Optimisation of the lift/cruise nozzle location

ii) Tests which include the lift engine inlet flows.

iii) Experiments to reduce the hover ground effect lift losses.

iv) A more detailed study of lateral characteristics.

8. NOMENCLATURE

A_j	total jet area	
b	wing span	
$\bar{c}$	geometric mean chord	
C_L	lift coefficient	$L/q_o.S$
C_m	pitching moment coefficient	$m/q_o.S.\bar{c}$
C_D	drag coefficient	$D/q_o.S$
C_l	rolling moment coefficient	$l/q_o.S.b$
C_n	yawing moment coefficient	$n/q_o.S.b$
C_y	side force coefficient	$y/q_o.S$
C_μ	jet thrust coefficient	$T/q_o.S$
d_j	jet diameter	
h	height above ground of horizontal fuselage datum	
S	gross wing area $0.382\ m^2$ ($4.1 ft^2$)	
T	jet gross thrust	
V_e	equivalent velocity ratio	$\left(\rho_o V_o^2/\rho_j V_j^2\right)^{\frac{1}{2}}$

V_o	free stream velocity
V_j	jet velocity
α	angle of incidence
δ_j	jet efflux angle (measured from the horiz. fus. datum)
δ_f	flap deflection angle
ψ	yaw angle
Δ_L	change in lift (power on - power off)
Δ_M	change in pitching moment (power on - power off)

FIG. 1 L + L/C WIND TUNNEL MODEL

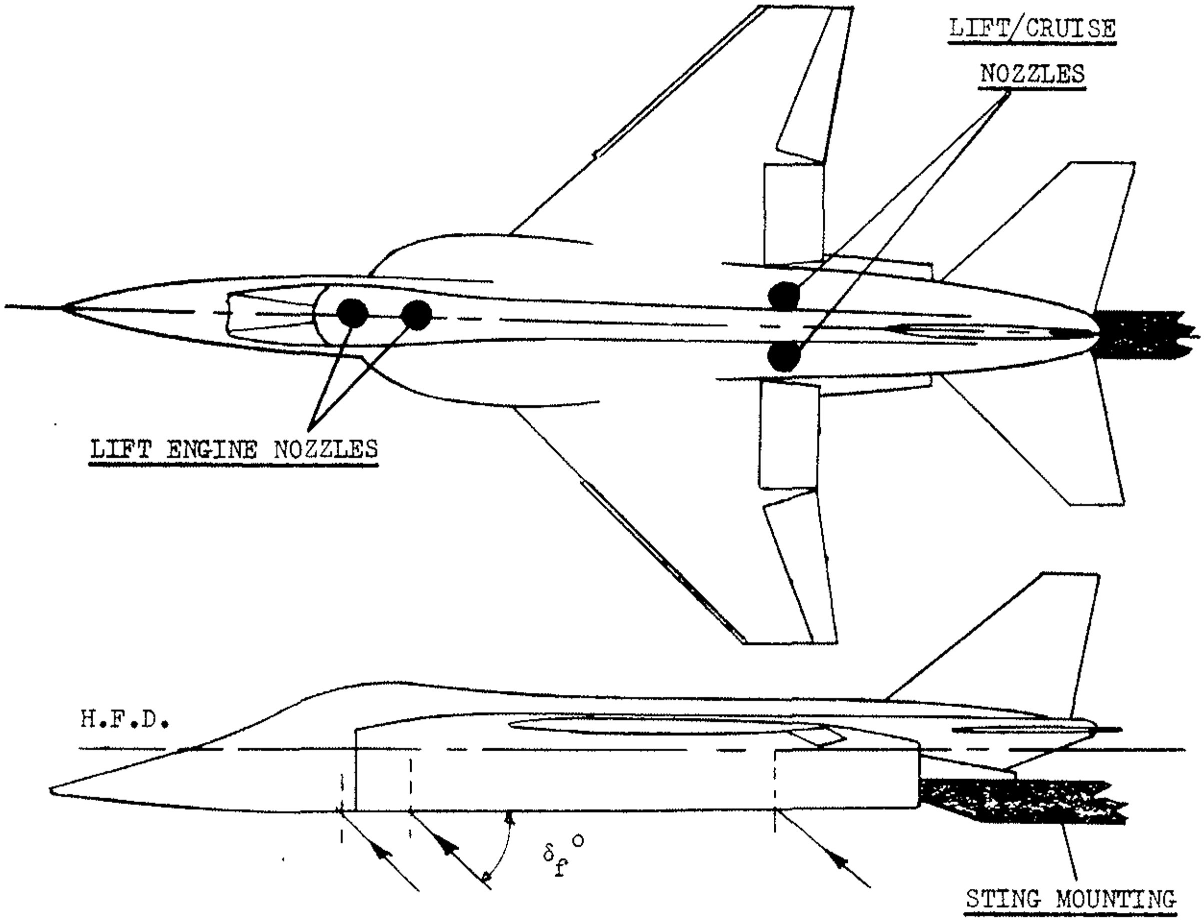
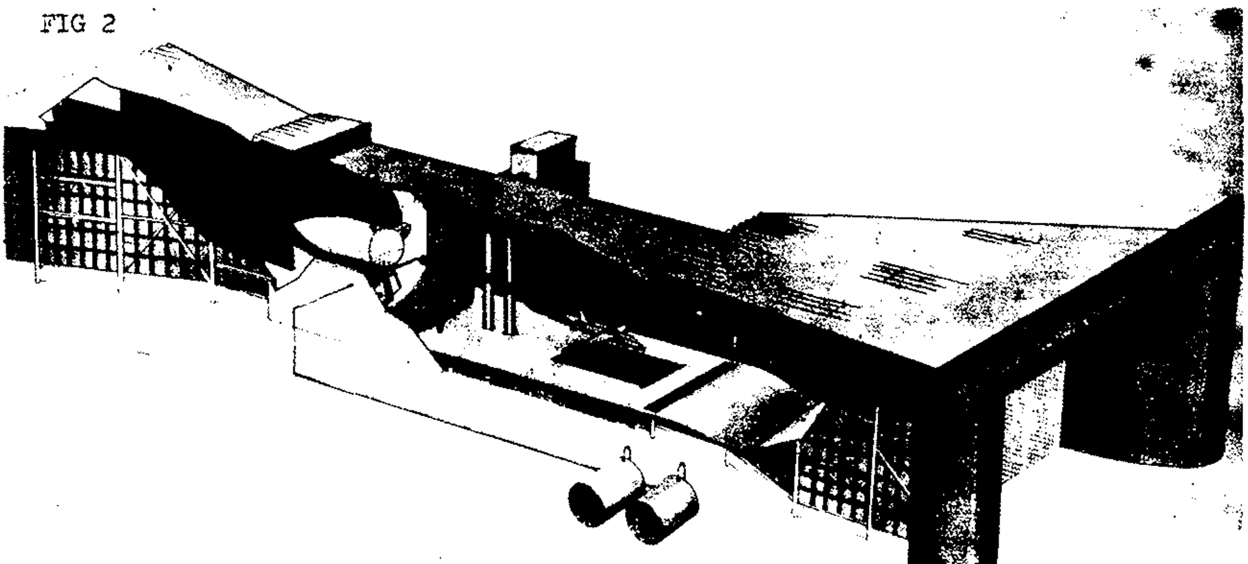


FIG 2



British Aircraft Corporation (Military Aircraft Division)
5·5m. Low Speed Wind Tunnel

FIG. 3 'POWER OFF' LIFT

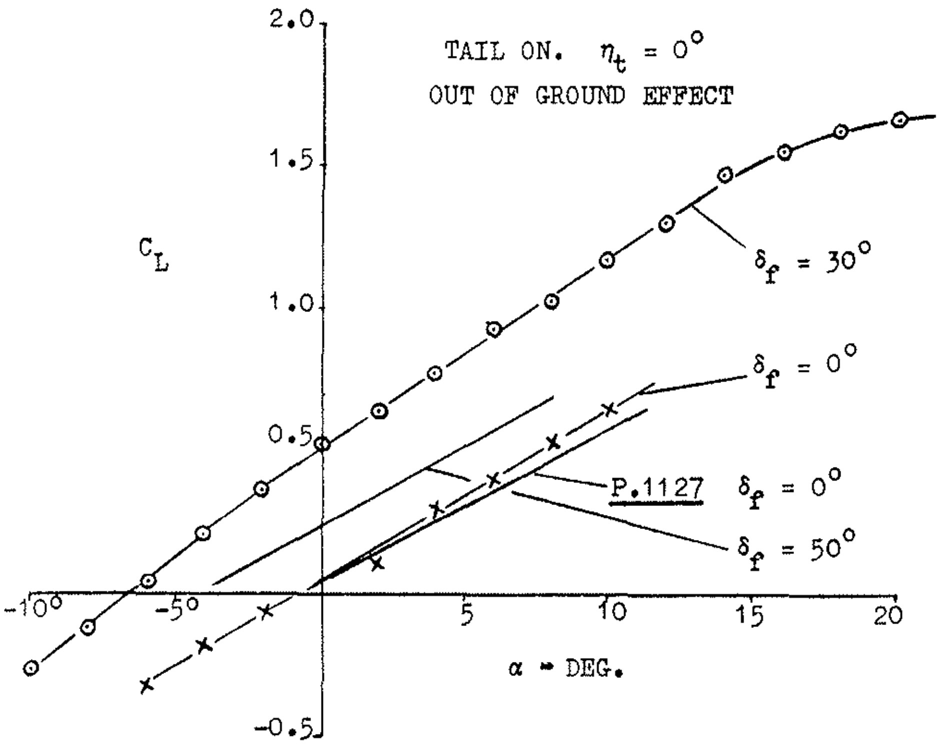


FIG. 4 HOVER CHARACTERISTICS

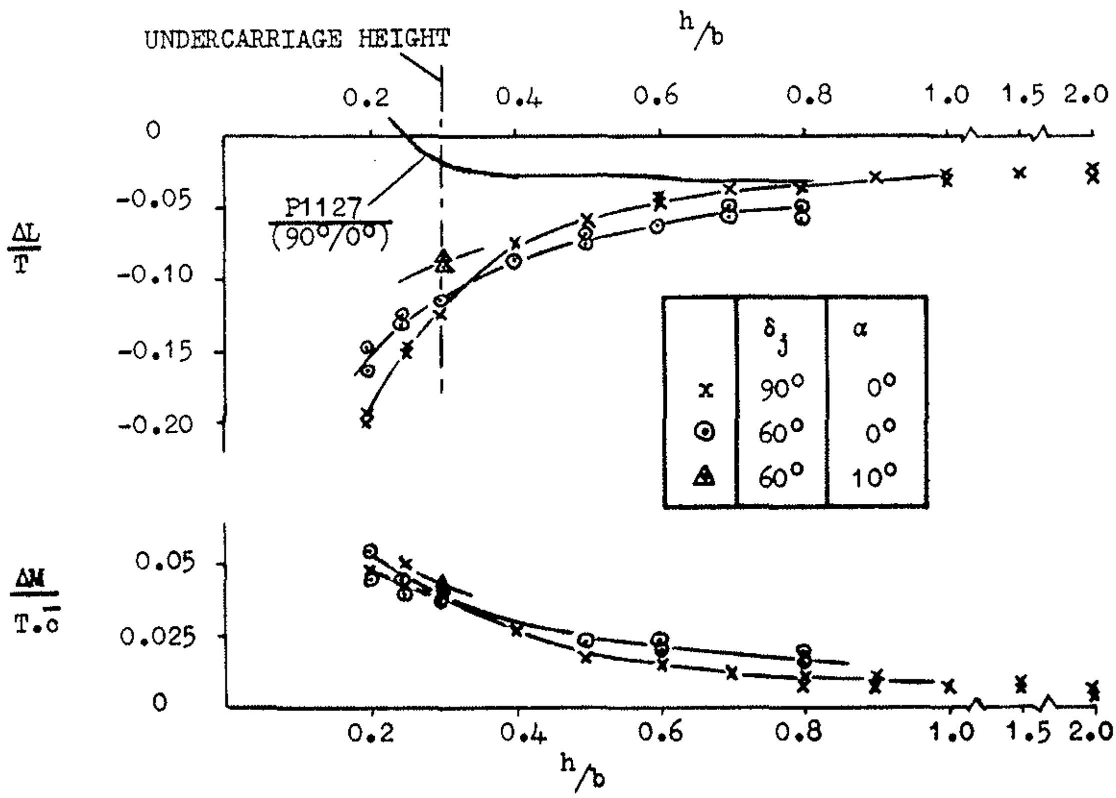


FIG. 5 POWER ON. FORWARD SPEED. OUT OF GROUND EFFECT

$\delta_j = 60^\circ \quad \delta_f = 30^\circ \quad h/b = 1.0$

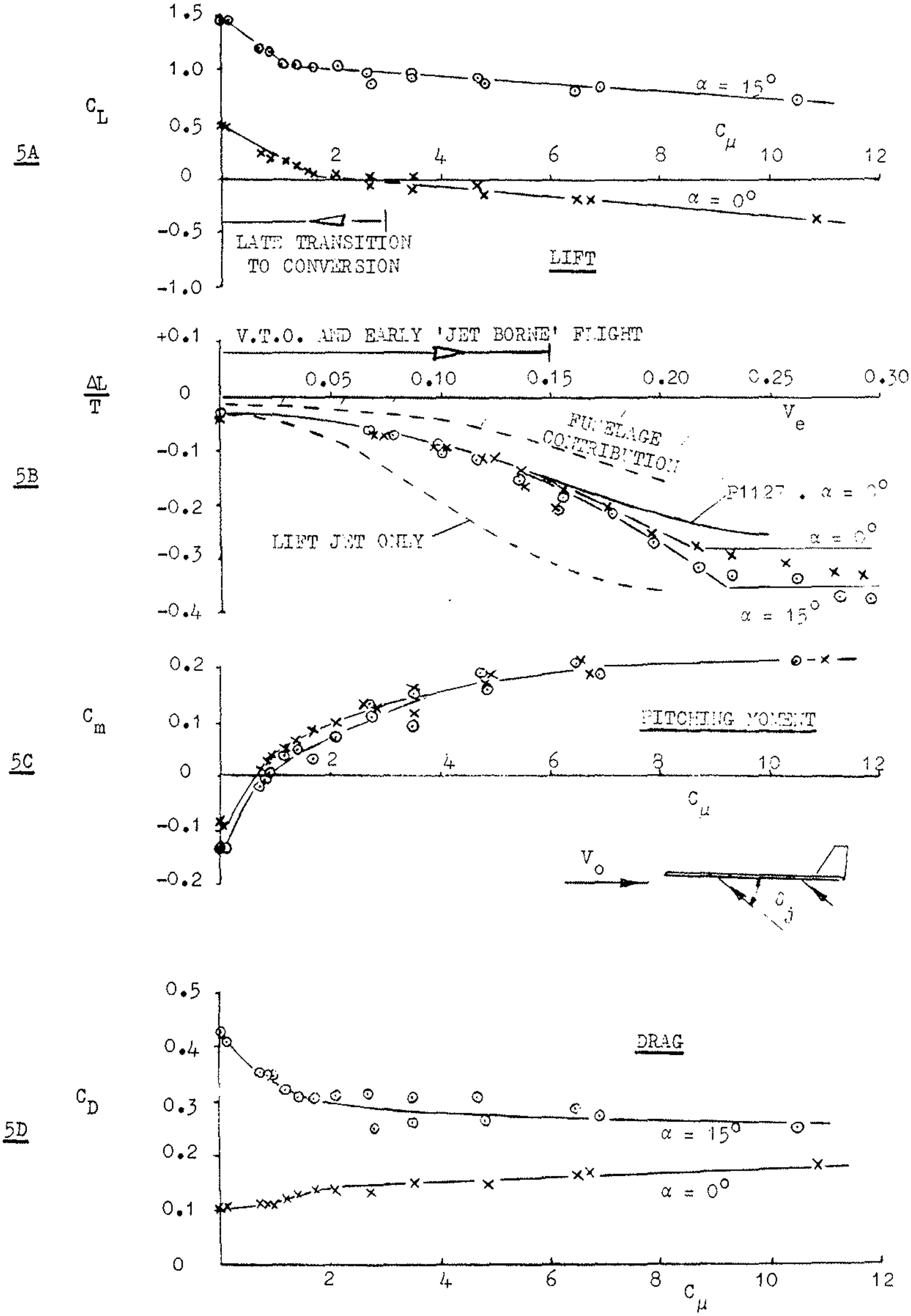


FIG. 6 POWER ON. FORWARD SPEED. IN GROUND EFFECT

$\delta_j = 60^\circ \quad \delta_f = 30^\circ \quad h/b = 0.3$

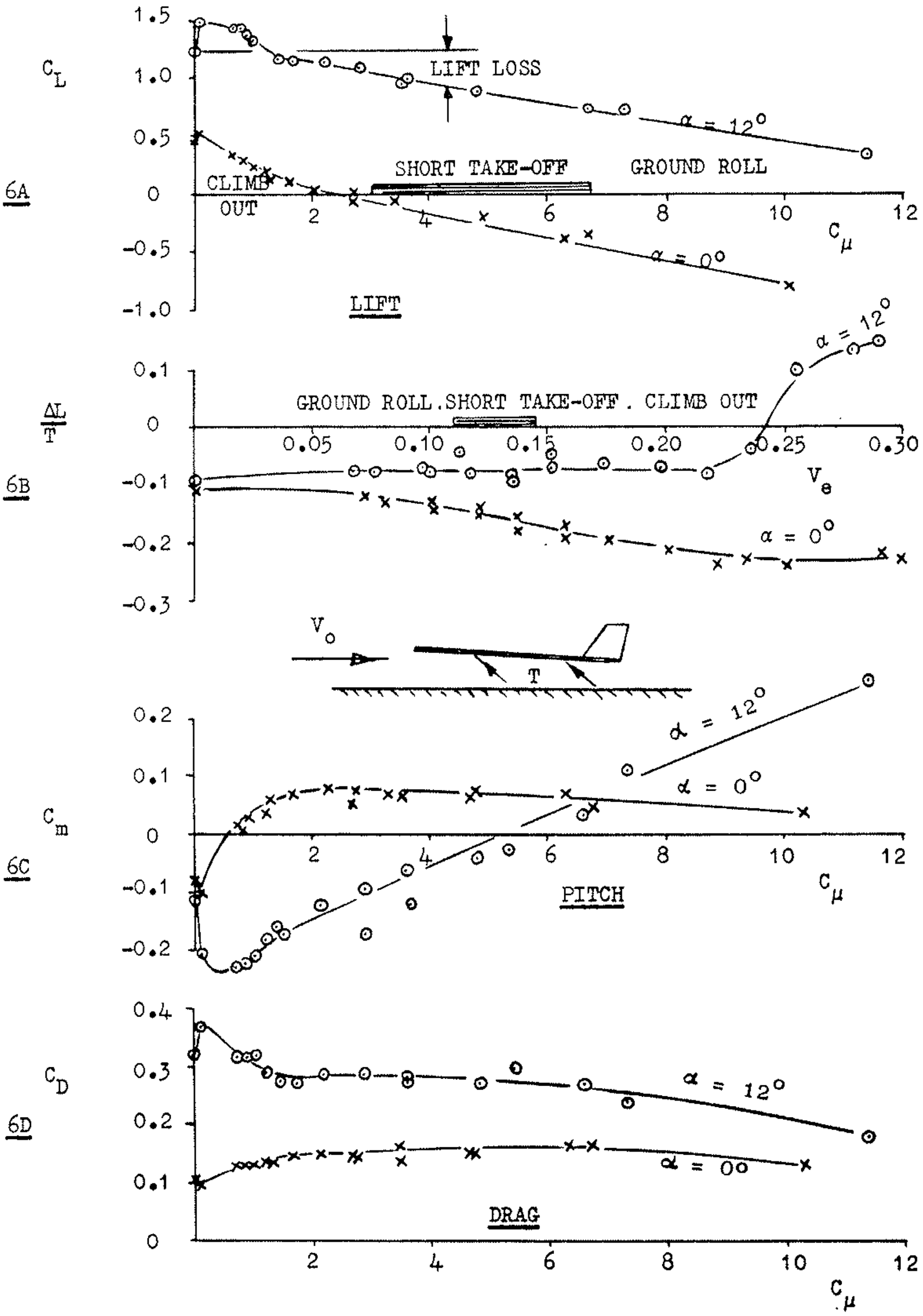


FIG. 7 POWER EFFECTS IN YAW

YAW ANGLE $\psi = 10^{\circ}$ OUT OF GROUND EFFECT

$\delta_f = 60^{\circ}$ $\alpha = 10^{\circ}$