AERODYNAMIC CHARACTERISTICS OF A LARGE-SCALE LIFT-ENGINE FIGHTER MODEL WITH EXTERNAL SWIVELING LIFT ENGINES

Jerry P. Barrack and Jerry V. Kirk

Ames Research Center
Moffett Field, Calif. 94035

July 1972
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NASA-AMES RESEARCH CENTER
MOFFETT FIELD, CA. 94035
NOTATION

A nozzle exit area, sq. m (sq. ft.), or wing aspect ratio
b wing span, m (ft.)
c mean aerodynamic chord, m (ft.), \(2/\pi \int_{0}^{b/2} c^2 dy\)
\(C_D\) drag coefficient, \(D/\rho S\)
\(C_1\) rolling moment coefficient, \(\ell/\rho Sb\)
\(C_L\) lift coefficient, \(L/\rho S\)
\(C_m\) pitching moment coefficient, \(M/\rho S\bar{c}\)
\(C_n\) yawing moment coefficient, \(N/\rho Sb\)
\(C_T\) thrust coefficient, \(T/\rho S\)
\(C_Y\) side force coefficient, \(Y/\rho S\)
D drag, N (lb.)
i_t horizontal tail incidence angle, deg.
\(\ell\) rolling moment, mN (ft. Lb.)
L total lift on model, N (lb.)
M pitching moment, mN (ft. lb.)
N yawing moment, mN (ft. lb.)
\(\rho\) free stream dynamic pressure, \(N/m^2\) (lb./ft.²)
S wing area, sq. m (sq. ft.)
T engine gross thrust, N (lb.)
v air velocity, m/sec. (ft./sec.)
V free stream velocity, m/sec. (knots or ft./sec.)
Y side force, N (lb.)

\( \alpha \) angle of attack of the wing chord plane, deg.

\( \beta \) angle of sideslip, deg.

\( \rho \) density Kg/m\(^3\) (lb.-sec.\(^2\)/ft.\(^4\))

\( \sigma \) thrust angle from horizontal, deg.

\( \delta_f \) flap deflection angle measured normal to the hinge line, deg.

\( \delta_s \) slat deflection angle measured normal to the hinge line, deg.

Subscripts

\( c \) lift-cruise

\( L \) lift

\( s \) static

\( u \) uncorrected
INTRODUCTION

Previous investigations have determined the exhaust gas reingestion, inlet flow distortion, and aerodynamic characteristics of various lift-engine VTOL configurations in the transition speed range. Both small-scale (Ref. 1 through 9) and large-scale (Ref. 10 through 17) models were used for these investigations. In general, these configurations incorporated either wing mounted lift-engine-pods or internally mounted lift-engines in the fuselage. In contrast, the model used for this investigation had lift engines mounted in pairs on each side of the fuselage and was representative of a high-performance supersonic fighter VTOL aircraft.

This report presents the aerodynamic characteristics of a six-engine (four (4) lift, two (2) lift-cruise) lift-engine model obtained in the Ames 40- by 80-foot wind tunnel. The model was an approximate one-half scale representation of a lift-engine VTOL fighter aircraft with a variable-sweep wing. The four (4) lift-engines were mounted in pairs on each side of the aircraft. The two (2) lift-cruise engines were housed in the aft fuselage with the inlets located above the wing.

Longitudinal and lateral-directional force and moment data are presented for a range of exhaust gas momentum ratios (thrust coefficients). Wind tunnel forward speed was varied from 0 to 140 knots corresponding to a maximum Reynolds number of 6.7 million. The data contained herein are presented without analysis.

MODEL DESCRIPTION

The model was representative of a variable sweep lift engine fighter aircraft and was approximately one-half scale. Six YJ85-5 turbojet engines (without after burners) were used as the propulsion system.
(four (4) engines as direct lift and two (2) as lift-cruise engines) for this low-speed wind tunnel investigation. Photographs of the model mounted in the Ames 40- by 80-foot wind tunnel are given in Fig. 1. Figure 2 is a sketch of the model showing pertinent details.

Fuselage

The fuselage was slab sided with rounded corners. The maximum width and depth were 134.6 cm (53 in.) and 168.9 cm (66.5 in.), respectively. The aft fuselage housed the two lift-cruise engines. The lift-cruise engine inlets were on top of the fuselage just behind the wing leading edge.

Wing

The high-mounted wing represented a variable sweep configuration. However, the outer panels were fixed at a 25-percent-chord sweep angle of 13.75° for this investigation. The inboard fixed section (strake or glove) had a leading edge sweep of 70° and joined the fuselage at station 327.4 (128.9). The strake faired into the outer wing panel at fuselage station 565.2 (222.5) and wing station 128.5 (50.6). The wing span was 7.32 m (24 ft.); wing aspect ratio was 5.82 (based on panel dimensions); and the taper ratio was 0.36. An NACA 65-412 modified airfoil section was used for the wing.

High-Lift Devices

A 40% chord, trailing-edge, single-slotted flap extended from the fuselage juncture to 75% of the wing semispan (see Fig. 2b). Flap
deflections of $0^\circ$ and $45^\circ$ were tested. Twenty percent chord leading edge slats spanned the outer wing panel and were tested at $0^\circ$ and $25^\circ$ deflection.

Empennage

The vertical tail had an NACA 64-009 airfoil section. The horizontal tail was wedge shaped with an aspect ratio of 2.87 and a taper ratio of 0.18. The horizontal tail was remotely controlled to give deflection angles of $-30^\circ$ to $+25^\circ$.

Propulsion System

Four YJ85-5 turbojet engines were mounted in pairs at the sides of the fuselage as direct-lift engines with the axis of rotation $70^\circ$ from the streamwise direction. Rotation was remotely controlled and angles from $90^\circ$ (thrust axis vertical) through $30^\circ$ were tested in $15^\circ$ increments. When the lift engines were vertical, the tops of the inlets were in the wing chord plane. Two lift-cruise engines were installed in the aft fuselage. The lift-cruise engine exit nozzles were manually positioned to correspond to the lift-engine angles.

TEST PROCEDURE

Longitudinal force and moment data were obtained with the model on the normal strut system in the 40- by 80-foot wind tunnel for an angle of attack range from $-4^\circ$ to $22^\circ$. Lateral-directional force and moment data were obtained at $0^\circ$ and $8^\circ$ angle of attack for sideslip angles ranging from $-16^\circ$ to $+12^\circ$. Wind tunnel forward speed was 0 to 140 knots corresponding to a maximum Reynolds number of 6.7 million.
Tests at Constant Angle of Attack

As angle of attack and wind tunnel forward speed were held constant, the engine thrust was varied to give a range of thrust coefficients (exhaust gas momentum ratios) at each engine vector angle. At selected thrust coefficients, horizontal tail incidence was varied. Model sideslip angle was also varied at 0° and 8° angle of attack.

Tests with Variable Angle of Attack

Engine thrust and wind tunnel speed (thrust coefficient or momentum ratio) were held essentially constant as the angle of attack was varied. Horizontal tail on and off results were obtained for various thrust coefficients at each engine vector angle.

CORRECTIONS

All force and moment data obtained with the engines not operating (power-off) have been corrected for the effect of the wind tunnel walls using the following equations:

\[ \alpha = \alpha_u + 0.2348 C_{Lu} \]

\[ C_D = C_{Du} + 0.0041 C_{Lu}^2 \]

\[ C_M = C_{Mu} + 0.00058 C_{Lu} \text{ (tail on only)} \]

Results obtained with the engines operating have not been corrected for wind tunnel wall interference effects. However, Ref. 18 indicates that the wall corrections for a model of this disk loading would be small.

All tests were conducted without a fairing on the tail strut. Appropriate tare corrections have been applied to the data to account for the
resulting tail strut drag.

All the data have been corrected to equal thrust levels in cases where all engines were not operating at equal thrust. This was accomplished by adding or subtracting an increment to the forces and moments equal to the direct thrust excess or decrement for each engine. These corrections were usually small.

Interference Factors

Interference factors have been computed for the model and are a part of each figure. These factors represent the difference between measured results and results that would be obtained by summing the direct thrust effects with the power-off force and moment data. These factors represent not only the effect of the jet on the airframe, but also the jet wake effect. Engine and nozzle vector angles were taken into account in these calculations.
RESULTS

Table 1 is an index to the figures presented.

The square root of the free stream to exhaust gas momentum ratio is used as the correlating parameter in the presentation of results. The relationship between thrust coefficient and momentum ratio is shown in figure 3.

Figures 4 through 6 present the variation in power-off longitudinal aerodynamic characteristics with angle of attack. The effects of flap deflection, slat deflection, removal of the lift engines and lift-cruise engine exhaust nozzles are shown.

The power-on longitudinal aerodynamic characteristics at selected exhaust gas momentum ratios are shown in figures 7 through 18 for engine vector angles of 90° through 30°, horizontal tail on and off. Each figure presents basic data along with interference increments.

The interference increments or factors were calculated by subtracting the direct thrust and power-off contributions from the measured data.

The trailing edge flaps were set at 45° and the leading edge slats deflected 25° for all results shown.

Figures 19 through 28 show the variation in the longitudinal aerodynamic characteristics with change in momentum ratio at 0° angle of attack. As with preceding figures, engine vector angles of 90° to 30° are presented. The effects of running lift engines only, lift-cruise engines only, and all engines simultaneously are included.

The variation in the lateral-directional aerodynamic characteristics as a function of sideslip angle are presented in figures 29 through 33 for angles of attack of 0° and 8°. Interference increments are presented as part of each figure.

The final section of figures is devoted to the effects of horizontal tail deflection on longitudinal characteristics.
Figures 34 through 39 show the effect of horizontal tail incidence on the longitudinal aerodynamic characteristics at 0° and 10° angle of attack. Power-off data as well as power-on data with engine vector angles from 90° to 30° is shown. Results are also presented at 16° angle-of-attack for a 45° engine vector angle.
REFERENCES


### TABLE 1

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<th>FIGURE</th>
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## EFFECT OF HORIZONTAL TAIL DEFLECTION ON LONGITUDINAL CHARACTERISTICS

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10
Figure 1. - Model mounted in 40- by 80-foot wind tunnel
Figure 2. General arrangement of the model
b- details of the high lift devices

Figure 2.- Concluded.
Figure 3.- Relationship between thrust coefficient and exhaust gas momentum ratio.
Figure 4.- Effect of slats and flaps on longitudinal aerodynamic characteristics. Power off. Lift engines removed. Cruise engine nozzles removed. Horizontal tail off.
Figure 5.- Effect of slats and flaps on longitudinal aerodynamic characteristics. Power off. Lift engines removed. Cruise engine nozzles removed. $i = 0^\circ$. $\beta = 0^\circ$. 
Figure 6. - The effect of removing the lift engines and lift/cruise nozzles on longitudinal aerodynamic characteristics; power off, horizontal tail off, $\beta = 0$, $\delta_r = 45^\circ$, $\delta_s = 25^\circ$.

(a) Effect of lift/cruise nozzles
Figure 6.- concluded

b- Effect of lift engines
Figure 7.- Effect of angle of attack on longitudinal aerodynamic characteristics; \( \alpha = 90^\circ \), All engines at equal thrust, Horizontal tail off, \( \beta = 0^\circ \), \( \delta_f = 45^\circ \), \( \delta_s = 25^\circ \).

\[ a- C_L \text{ vs } C_D, \quad \alpha, C_M \]
Figure 7.- Continued.
Figure 7.- Concluded.

c- Interference increments.
Figure 8. - Effect of angle of attack on longitudinal aerodynamic characteristics; $\alpha = 90^\circ$, All engines at equal thrust $i_t = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

- $C_L$ vs $C_D$, $\alpha$, $C_M$
Figure 8.- Concluded

c- Interference increments
Figure 9.- Effect of angle of attack on longitudinal aerodynamic characteristics; $\alpha = 75^\circ$, All engines at equal thrust, Horizontal tail off, $\beta = 0^\circ$.

a- $C_L$ vs $C_D$, $\alpha$, $C_M$
c- Interference increments.

Figure 9.- Concluded.
Figure 10.- Effect of angle of attack on longitudinal aerodynamic characteristics; $\sigma = 75^\circ$. All engines at equal thrust, $i_t = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$

$a - C_L \text{ vs } C_D, \alpha, C_M$
Figure 10.- Concluded.

b- Interference increments.
Figure 11.- Effect of angle of attack on longitudinal aerodynamic characteristics; $\sigma = 60^\circ$, All engines at equal thrust, Horizontal tail off, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 35^\circ$.

\[ a - C_L \text{ vs } C_D, \alpha, C_M \]
Figure 11.- Concluded.

b- Interference increments.
Figure 12. - Effect of angle of attack on longitudinal aerodynamic characteristics; $\sigma = 60^\circ$. All engines at equal thrust, $i_t = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

$C_L$ vs $C_D$, $\alpha$, $C_M$
Figure 12.— Concluded.

b- Interference increments.
Figure 13 - Effect of angle of attack on longitudinal aerodynamic characteristics; θ = 45°. All engines at equal thrust, 
Horizontal tail off, β = 0°, 6 = 6; C_L vs C_D, C_M.
Figure 13.— Concluded.

b- Interference increments.
Figure 14 - Effect of angle of attack on longitudinal aerodynamic characteristics; \( \sigma = 45^\circ \), all engines at equal thrust, \( I_t = 0^\circ \), \( \beta = 0^\circ \), \( \delta_f = 45^\circ \), \( \delta_g = 25^\circ \).

a - \( C_L \) vs \( C_D \), \( \alpha \), \( C_M \)
Figure 14.- Concluded.

b- Interference increments.
Figure 15.- Effect of angle of attack on longitudinal aerodynamic characteristics; $\phi = 30^\circ$, All engines at equal thrust, Horizontal tail off, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

\[ a \left( C_L \right. vs C_D, \alpha, C_M \)
Figure 15.- Concluded.

b- Interference increments.
Figure 16.— Effect of angle of attack on longitudinal aerodynamic characteristics; \( \sigma = 30^\circ \); All engines at equal thrust, 
\( \theta_t = 0^\circ \), \( \theta = 0^\circ \), \( \delta_f = 45^\circ \), \( \delta_s = 25^\circ \).

a- \( C_L \) vs \( C_D \), \( \alpha \), \( C_M \)
Figure 16. Concluded.

b- Interference increments.
Figure 17. - Effect of lift and cruise engine operation on longitudinal aerodynamic characteristics; $\sigma = 60^\circ$, $i_t = 0^\circ$, $\beta = 0^\circ$, $\delta^\prime = 45^\circ$, $\delta_s = 25^\circ$.

$C_L$ vs $C_D$, $\alpha$, $C_m$
Figure 17.— Concluded.

b- Interference increments.
Figure 18. - Effect of lift engine operation on longitudinal aerodynamic characteristics; \( \alpha = 45^\circ \), Horizontal tail off, \( \beta = 0^\circ \),
\( \delta_f = 45^\circ \), \( \delta_s = 25^\circ \).

\[ a - C_L \text{ vs } C_D, \alpha, C_m \]
Figure 18.- Concluded.

b- Interference increments.
Figure 19.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\alpha = 90^\circ$
All engines operating, Horizontal tail off, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$. 
Figure 20.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\gamma = 90^\circ$, All engines operating, $i_t = 0^\circ$, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$. 
Figure 21. Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\alpha = 75^\circ$, Horizontal tail off, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) Lift engines only operating
Figure 21.— Continued.

(b) Cruise engines only operating
Figure 21.- Concluded.

(c) All engines operating
Figure 22.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\alpha = 75^\circ$, All engines operating, $i_t = 0^\circ$, $\alpha = 0^\circ$, $\beta = 0^\circ$. 
Figure 23.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\sigma = 60^\circ$, Horizontal tail off, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) Lift engines only operating
Figure 23. Continued.

(b) Cruise engines only operating.
Figure 23.- Concluded.

(c) All engines operating.
Figure 24. Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\sigma = 60^\circ$, $i_t = 0^\circ$, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta = 45^\circ$, $\delta_s = 25^\circ$.

(a) Lift engines only operating
Figure 24.— Continued.

(b) Cruise engines only operating.
Figure 24.- Concluded.

(c) All engines operating.
Figure 25. - Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\sigma = 45^\circ$, Horizontal tail off, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_g = 25^\circ$. 
Figure 25. - Continued.

(b) Cruise engines only operating.
Figure 25.- Concluded.
(c) All engines operating.
Figure 26.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\sigma = 45^\circ$, $\lambda = 0^\circ$, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) Lift engines only operating
Figure 26.- Continued.

(b) Cruise engines only operating.
Figure 26.— Concluded.

(c) All engines operating.
Figure 27.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model; $\sigma = 30^\circ$, Horizontal tail off, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_g = 25^\circ$.

(a) Lift engines only operating
Figure 27.- Continued.

(b) Cruise engines only operating.
Figure 27. Concluded.
(c) All engines operating.
Figure 28.- Effect of momentum ratio variation on the longitudinal aerodynamic characteristics of the model: $\sigma = 30^\circ$, All engines operating, $i_t = 0^\circ$, $\alpha = 0^\circ$, $\beta = 0^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$. 
Figure 29. Effect of sideslip angle on the lateral-directional characteristics of the model. $\sigma = 90^\circ$, $\beta = 0^\circ$. All engines set at equal thrust, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) $\alpha = 8^\circ$.

Figure 29.- Continued.
Figure 29.— Concluded.

(c) Interference increments
Figure 30.- Effect of sideslip angle on the lateral-directional characteristics of the model. $\sigma = 75^\circ$, $\delta = 0^\circ$. All engines set at equal thrust, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) \( \alpha = 8^\circ \).

Figure 30. - Continued.
Figure 30. Concluded.
(c) Interference increments.
Figure 31. Effect of sideslip angle on the lateral-directional characteristics of the model. $\sigma = 60^\circ$, $i_e = 0^\circ$. All engines set at equal thrust, $\delta_r = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) \( \alpha = 8^\circ \).

Figure 31.- Continued.
Figure 31. Concluded.

(c) Interference increments.
Figure 32.- Effect of sideslip angle on the lateral-directional characteristics of the model. $\phi = 45^\circ$, $\beta = 0^\circ$. All engines set at equal thrust.

(a) $\alpha = 0^\circ$. 
(b) $\alpha = 8^\circ$.

Figure 32—Continued.
Figure 32.- Concluded.

(c) Interference increments.
Figure 33.- Effect of sideslip angle on the lateral-directional characteristics of the model. $\sigma = 30^\circ$, $\psi = 0^\circ$. All engines set at equal thrust, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) \( \alpha = 8^\circ \).

Figure 33.- Continued.
Figure 33.- Concluded.
(c) Interference increments.
Figure 34.- Effect of horizontal tail deflection on the model longitudinal aerodynamic characteristics; $\beta = 0^\circ$, Lift engines and cruise engine nozzles removed, Power off.

(a) $\alpha = 0^\circ$. 
(b) $\alpha = 10^\circ$.

Figure 34.- Concluded.
Figure 35: Effect of horizontal tail deflection on the model longitudinal aerodynamic characteristics, $\beta = 0^\circ$, $\sigma = 90^\circ$, $\delta_e = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) \( \alpha = 10^\circ \).

Figure 35.— Concluded.
Figure 36.— Effect of horizontal tail deflection on the model longitudinal aerodynamic characteristics, $\phi = 0^\circ$, $\sigma = 75^\circ$, $\delta_f = 45^\circ$, $\delta_g = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) \( \alpha = 10^\circ \).

Figure 36. - Concluded.
Figure 37. Effect of horizontal tail deflection on the model longitudinal aerodynamic characteristics; $g = 0^\circ$, $\sigma = 60^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
(b) \( \alpha = 10^\circ \).

Figure 37.- Concluded.
Figure 38. - Effect of horizontal tail deflection on the model longitudinal aerodynamic characteristics; $\beta = 0^\circ$, $\sigma = 45^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$.

(a) $\alpha = 0^\circ$. 
Figure 38.- Continued.

(b) $\alpha = 10^\circ$. 

Figure 38.- Continued.
(c) \( \alpha = 16^\circ \).

Figure 38.- Concluded.
Figure 39. – Effect of horizontal tail deflection on the model longitudinal aerodynamic characteristics; $\beta = 0^\circ$, $\alpha = 30^\circ$, $\delta_f = 45^\circ$, $\delta_s = 25^\circ$. 