Estimation of Nonlinear Aerodynamic Derivatives of a Variable-Geometry Fighter Aircraft

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Theme

THE flowfield over an aircraft in high angle-of-attack flight is highly nonlinear, due to such phenomena as asymmetric flow separation and hysteresis. For this reason, a nonlinear model for the forces and moments must be used to simulate mathematically the dynamics of the aircraft in the vicinity of stalled flight. Wind-tunnel data are helpful in postulating the state dependence of the force model, but they are limited because of such inherent constraints as wall and Reynolds number effects.

In this research, a maximum likelihood algorithm is utilized with the objective of estimating longitudinal and lateral stability and control derivatives of a high-speed variable-geometry jet aircraft with twin vertical tails in stalled flight. The results of the estimation are compared to wind-tunnel data when possible.

Contents

Several studies have been made recently on the nonlinear problem in aircraft identification.[1-3] The particular approach used in the present effort is that of Ref. 1. The method is a maximum likelihood formulation in which process noise is assumed absent and measurement noise is white Gaussian. The aerodynamic force and moment coefficients are expressed as a Taylor's series expansion about a nominal state and certain second-order terms retained in addition to the standard first-order linear terms. In particular, the terms

$$C_{z_{\alpha^2}}(\alpha-\alpha_0)^2 \quad C_{m_{\alpha^2}}(\alpha-\alpha_0)^2$$

$$C_{l_{p\alpha}}(pb/2V)\,(\alpha-\alpha_0) \quad C_{n_{\beta\alpha}}(\alpha-\alpha_0)\,(\beta-\beta_0)$$

were included in the expressions for the normal force, pitching moment, rolling moment, and yawing moment coefficients, respectively.

Two flights of the aircraft were made; one at a wing sweep of 68°, an initial Mach number of 0.5, and an altitude of 24,000 ft; the other at a wing sweep of 50°, an initial Mach number of 0.46, and an altitude of 27,000 ft. In the first flight, the aircraft was put into a steep pullup by elevator input increasing from 5° to 32° in 1 sec. The aircraft stalled at 45° angle of attack. The altitude remained constant, while the Mach number had dropped to about 0.2 by the end of the test. This was the test from which the longitudinal derivatives listed in Table 1 were extracted. In the second flight, the aircraft was slowly pulled up to an angle of attack of 35° to stall, with the elevator deflection held at 30° after stall. Rudder was activated to excite the lateral mode, with the angle of attack at 25°. The altitude dropped to 22,000 ft and the final Mach number was 0.27. This was the test from which the lateral derivatives listed in Table 1 were extracted.

Longitudinal stability and control derivatives were estimated using a nonlinear model for the angle of attack range $8° \leq \alpha \leq 42°$. Figures 1-3 give a comparison of some of these derivatives to wind tunnel values.[4] Figure 1 indicates very good agreement between wind-tunnel and flight test results for both C_z and C_{z_α}. Figure 2 indicates less perfect agreement between wind-tunnel and flight test results for C_m and C_{m_α}, but it is still reasonable. Such results are not unusual for studies of this type. Figure 3 gives the normal

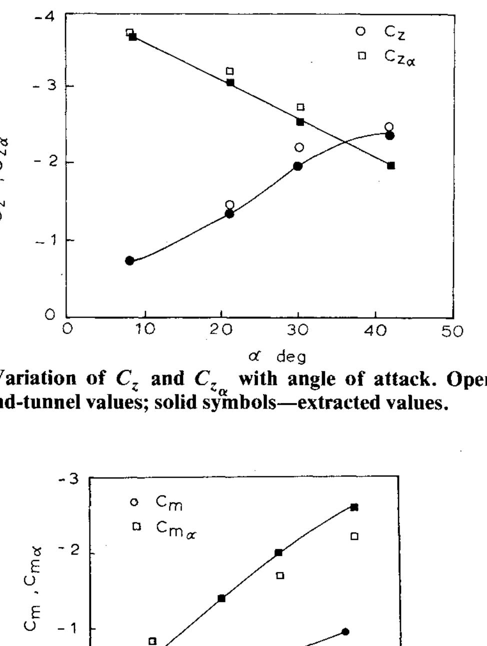

Fig. 1 Variation of C_z and C_{z_α} with angle of attack. Open symbols—wind-tunnel values; solid symbols—extracted values.

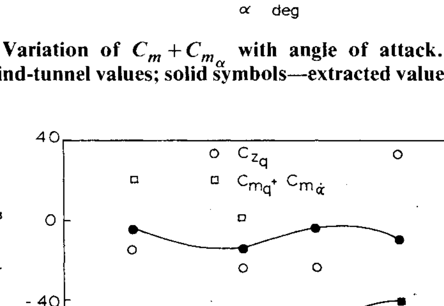

Fig. 2 Variation of $C_m + C_{m_\alpha}$ with angle of attack. Open symbols—wind-tunnel values; solid symbols—extracted values.

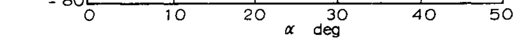

Fig. 3 Variation of $C_{m_q} + C_{m_{\dot\alpha}}$ and C_{z_q} with angle of attack. Open symbols—wind-tunnel values; solid symbols—extracted values.

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Table 1 Estimated parameters (longitudinal $\alpha_0 = 8.26°$, $\Lambda = 68°$; lateral $\alpha_0 = 36.5$, $\Lambda = 50°$)

Parameter	Estimated value	Wind tunnel	Parameter	Estimated value	Wind tunnel
C_{x_0}	0.11±00	0.02	C_{y_0}	-0.013±0.005	...
C_{x_α}	0.18±0.01	-0.19	C_{y_β}	-0.845±0.082	-0.97
C_{z_0}	-0.76±0.01	-0.75	C_{y_r}	1.039±0.699	-2.0
C_{z_α}	-3.65±0.08	-3.7	C_{ℓ_0}	-0.004±0.001	...
$C_{z_{\alpha^2}}$	1.36±0.14	...	C_{ℓ_β}	-0.775±0.002	-0.6
C_{z_q}	-62.0±1.9	18.0	$C_{\ell_{\delta r}}$	-.033±0.001	...
$C_{z_{\delta e}}$	-1.21	0.087	C_{ℓ_p}	-0.203±0.007	-0.2
C_{m_0}	-0.09±00	-0.1	C_{ℓ_r}	0.400	...
C_{m_α}	-0.57±0.05	-0.85	C_{n_0}	-0.007±0.001	...
$C_{m_{\alpha^2}}$	-1.89±0.07	...	C_{n_β}	-0.113±0.005	-0.11
$C_{m_q}+C_{m_{\dot\alpha}}$	-7.00±0.24	-17.0	C_{n_r}	-0.099±0.034	-0.2
$C_{m_{\delta e}}$	-1.34±0.02	...	$C_{n_{\delta r}}$	0.036±0.002	...
			$C_{\ell_{p\alpha}}$	-3.438±0.284	0.5
			$C_{n_{\beta\alpha}}$	1.577±0.195	0.4

force and pitching moment damping coefficients variations with angle of attack. In the case of $C_{m_q}+C_{m_{\dot\alpha}}$, $C_{m_{\dot\alpha}}$ was fixed at an assumed value and C_{m_q} was estimated. Poor agreement between estimated and wind-tunnel results are noted for both coefficients.

For the lateral analysis, the nominal angle of attack was chosen as the stall angle for zero tail incidence, which was 36.5°. The estimated values are given with wind-tunnel values in Table 1.

The values of $C_{n_{\delta\alpha}}$ and $C_{l_{\delta\alpha}}$ could not be estimated accurately, due to insufficient aileron input. Also C_{l_r} and C_{l_p} could not be estimated independently, due to high correlation. The same was true for C_{n_p} and C_{n_r}. Convergence was extremely sensitive to the starting values of force and moment coefficients and the sign of C_{n_β}, which was negative at stall.

In summary, it was found that the nonlinear model provided estimates of the first-order stability and control derivatives that were often in reasonable agreement with wind-tunnel values. However, it does not provide reliable values for such parameters as $C_{m_q}+C_{m_{\dot\alpha}}$, and C_{z_q}, which are highly nonlinear with angle of attack. In addition, high correlations were found to exist between certain first and second-order derivatives.

References

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