JOURNAL OF AIRCRAFT
Vol. 34, No. 4, July–August 1997

Technical Comments

Comment on "Effect of Thrust Vectoring on Level-Turn Performance"

Karl L. Sanders*
Lomita, California 90717-3631

Nomenclature

$C_{L\max}$ = maximum or buffet limit lift coefficient
D_0 = zero-lift drag
i_N = thrust incidence related to body reference line
K = drag caused by lift factor, $\delta C_D/\delta C_L^2$
$N_{\lim}$ = structural or control power-limited load factor
q = dynamic pressure, psf
S = reference wing area, ft^2
W = airplane weight, lb
α = body angle of attack

AXIAL and normal force components of the engine **net** thrust were used by Lee and Lan[1] for the sustained turn load factor and rate equations. A predicted performance so obtained is slightly conservative for the lower T/W ratios. In keeping with the definitions of drag and thrust lines-of-action, the components of **gross** thrust (F_G) must be taken, and the ram drag (D_R) should be accounted for separately.[2] Then, for zero yaw and lateral thrustline incidence, the following equations define lift and drag:

$$L = -F_G \sin(\alpha + i_N) + WN_Z \tag{1}$$

$$D = F_G \cos(\alpha + i_N) - D_R - WN_X \tag{2}$$

or in coefficient form,[3] if so desired. Then, for the conditions that $N_X = 0$, $\gamma = 0$, and D varies parabolically with L, the level turn load factors are predicted by

Sustained:

$$N_{\text{sus}} = \frac{F_G \sin(\alpha + i_N)}{W} + \sqrt{\left(\left(\frac{F_G \sin(\alpha + i_N)}{W}\right)^2 + \frac{qS}{KW^2}\left\{F_G \cos(\alpha + i_N) - D_R - D_0 - \frac{K[F_G \sin(\alpha + i_N)]^2}{qS}\right\}\right)} \le N_{\lim} \tag{3}$$

Instantaneous:

$$N_{\text{ins}} = [C_{L\max}Sq + F_G \sin(\alpha + i_N)]/W \le N_{\lim} \tag{4}$$

Specific excess power for the above:

$$P_S = \{F_G \cos(\alpha + i_N) - D_0 - D_R - K[NW - F_G \sin(\alpha + i_N)]^2/qS\}V_{(\text{fps})}/W \tag{5}$$

Since $\alpha = f(C_L, M)$ and $C_L = NW/qS$, Eq. (3) must be evaluated for several i_N, and by iterating on C_L until N_{sus} converges. A plot of C_L vs α for several M is therefore indispensable. The work is conveniently done in a spreadsheet with iteration option. Results for various wing planforms, loadings, and engine cycles indicated that Eq. (3) predicts only slightly higher ($\approx$5% for $H \le 36$ K, $M < 1$, and $\approx$0 for $H > 36$ K, $M > 1$) than Eq. (6), in Ref. 1 for net-thrust vectoring. The maxima of N_{sus} lie in the range $0 < i_N \le 15$ deg for the previous altitude/speed range. However, the gross thrust effect on N_{ins} and P_S is substantially more beneficial, as has been demonstrated in X-31 flight tests.[4]

References

[1]Lee, P., and Lan, C. E., "Effect of Thrust Vectoring on Level-Turn Performance," *Journal of Aircraft*, Vol. 29, No. 3, 1992, pp. 509–511.

[2]Rooney, E. C., "Development of Techniques to Measure In-Flight Drag of a U.S. Navy Fighter Airplane and Correlation with Wind-tunnel Data," CP-124, AGARD, 1973 (Paper 24).

[3]Whitten, P. D., Woodrey, R. W., and Hames, J. E., "Application of Thrust Vectoring for STOL," AIAA Paper 81-2616, 1981.

[4]Francis, M. S., "X-31: An International Success Story," *Aerospace America*, Feb. 1995, pp. 22–27, 32.

Received Feb. 25, 1996; accepted for publication April 16, 1997.

*Aeronautical Engineering Consultant. Associate Fellow AIAA.