Correlation for the Estimation of Afterbody Drag with Hot Jet Exhaust

*N. B. Mathur**
National Aerospace Laboratories,
Bangalore 560 017, India

Introduction

MODERN turbojet and turbofan engines of combat aircraft operating over a wide range of power settings experience jet exhaust temperature typically varying from 1000–2000 K, whereas much of afterbody-nozzle testing is conducted with a cold jet near 300 K.[1–5] Thus there remains a problem to determine the extent to which jet total temperature (and its associated gas constants) affects the afterbody drag of a combat aircraft under various operating conditions of its nozzle during the flight operation.[6–8] Physical modeling of jet freestream interactions with temperature effects is quite difficult; and, calculations of afterbody drag with hot jet exhaust are computationally intensive. Efforts made earlier for the es-

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*Scientist, Experimental Aerodynamics Division. Member AIAA.

Table 1 Afterbody tests with hot jet exhaust: AEDC and NASA experiments

Experiments	AEDC	NASA
Wind tunnel	16 ft, PWT	Langley, 16 ft
Maximum diameter of afterbody model	250 mm	152 mm
d_b/d_m	0.42	0.51
d_j/d_m	0.40	0.50
Boat-tail angle (β)	10, 15, and 25 deg	10 and 20 deg
Freestream Mach number (M_∞)	0.6–1.5	0.6–1.2
Reynolds number ($Re_{N/m} \times 10^{-6}$)	4–16	10–14
Nozzle	Convergent	Convergent and convergent–divergent
Jet Mach number (M_j)	$M_j = 1$	$M_j = 1$ and 2
Hot jet generation	Ethylene–air combustor housed inside model	Decomposition of hydrogen peroxide inside model
Jet pressure ratios (P_{0j}/p_∞)	Jet-off to 8.0	Jet-off to 20.0
Jet plume temperature (T_{0j} K)	300, 1165, 1580	300, 646, 1013
Specific heat ratio of jet exhaust (γ_j)	1.40, 1.30, 1.28	1.40, 1.30, 1.26

Notes: d_m, d_b, and d_j are forebody (maximum), base, and jet diameters, respectively. Re_N is Reynolds number/meter. P_{0j} and p_∞ are stagnation pressure of jet and freestream static pressure, respectively.

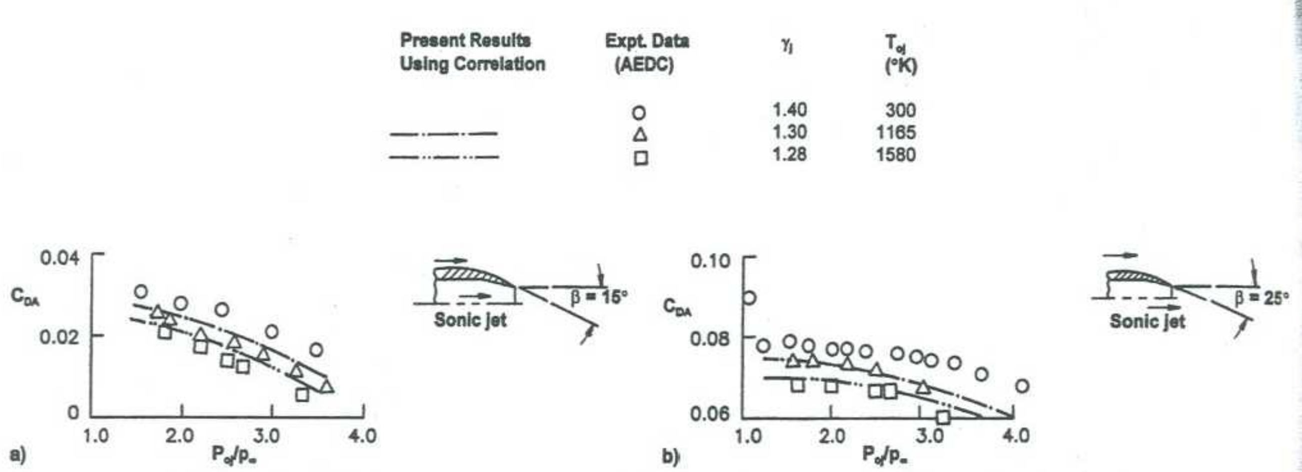

Fig. 1 Estimation of afterbody drag with sonic hot jet exhaust, $M_\infty = 0.60$. β = a) 15 and b) 25 deg.

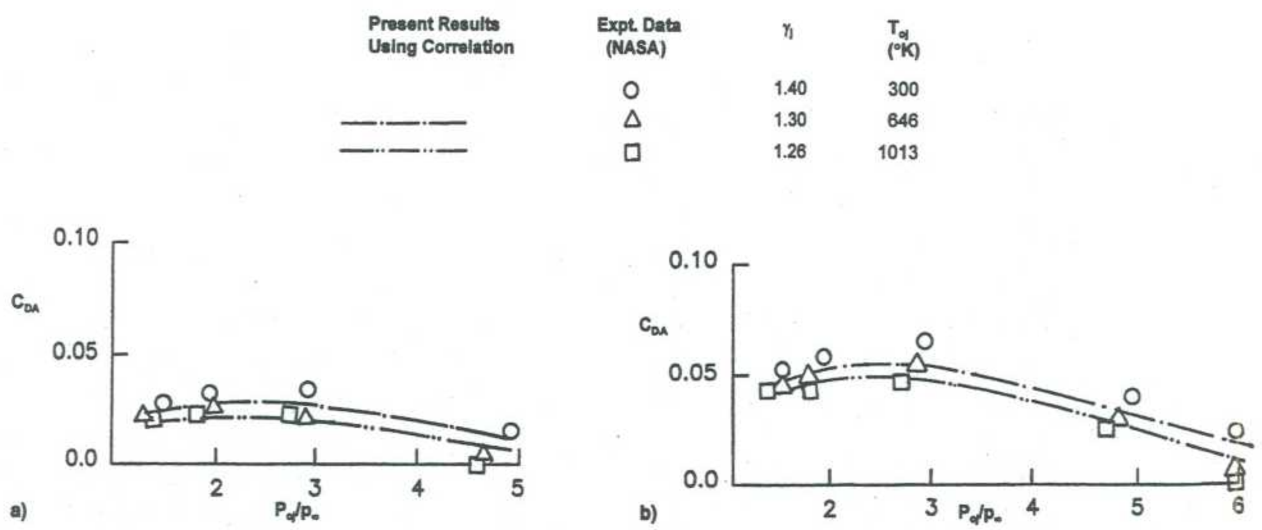

Fig. 2 Estimation of afterbody drag with sonic hot jet exhaust: a) $M_\infty = 0.80$, $\beta = 20$ deg and b) $M_\infty = 0.90$, $\beta = 20$ deg.

timation of afterbody drag with hot jet exhaust had limited success.[1,9,10] In the present analysis, a simple correlation is proposed that can be used in the subsonic and transonic Mach number range for the estimation of afterbody pressure drag with jet temperature effects.

Proposed Correlation of Afterbody Drag with Jet Temperature Effects

Afterbody drag characteristics with an underexpanded jet are influenced predominantly by its jet plume displacement effects.[4–8] Because the specific heat ratio of hot jet (γ_{jh}) is less than that of cold air jet ($\gamma_{jc} = 1.4$), jet plume displacement effects on afterbody drag are relatively larger in the presence of hot jet exhaust than that with the cold jet at the same jet pressure ratio. Hence, if the relative displacement effects of the hot and cold jet could be assessed, it would be possible to estimate, grossly, the jet temperature effects on drag from cold jet test data.

Based on an analysis of the available hot jet test data and experience gained during the cold and hot jet experiments con-

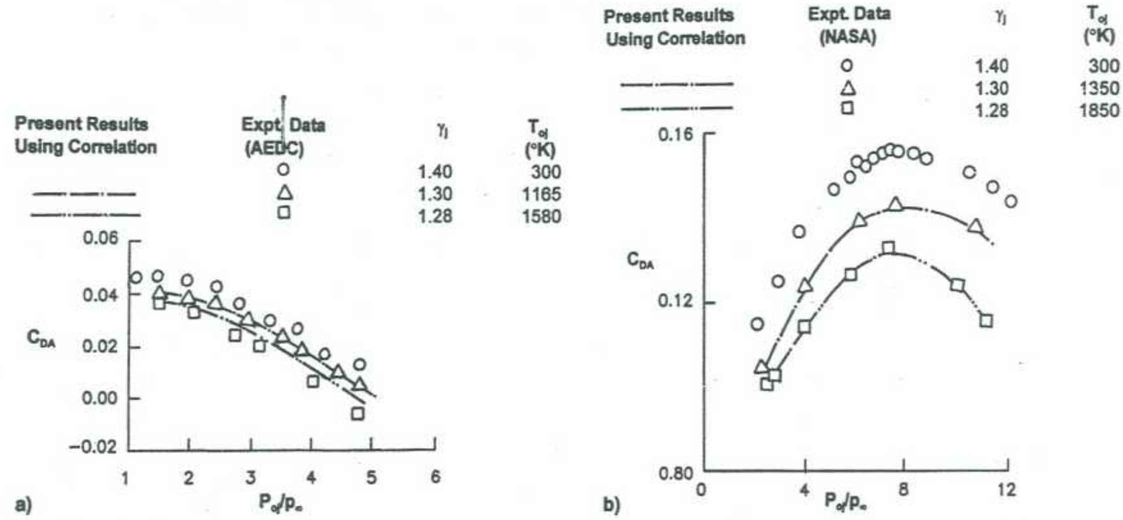

Fig. 3 Estimation of afterbody drag with sonic hot jet exhaust, $M_\infty = 0.90$. β = a) 15 and b) 25 deg.

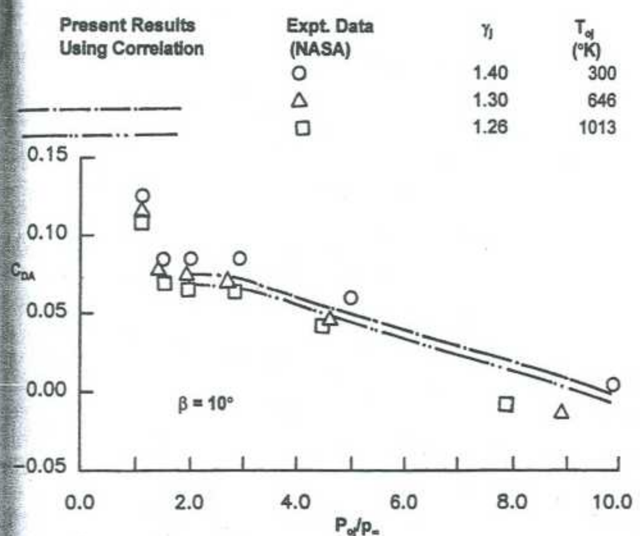

Fig. 4 Estimation of afterbody drag with sonic hot jet exhaust, $M_\infty = 0.95$.

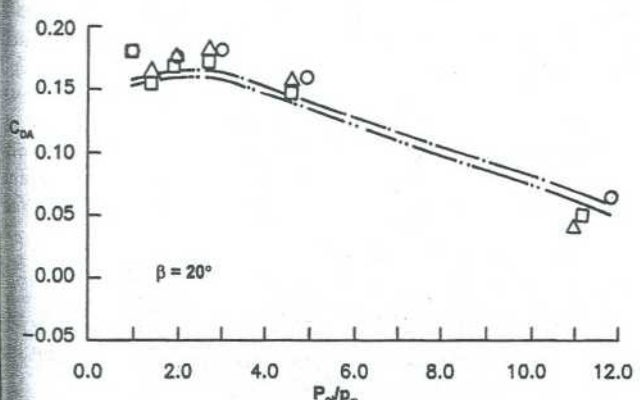

Fig. 5 Estimation of afterbody drag with sonic hot jet exhaust, $M_\infty = 1.20$.

ducted earlier at National Aerospace Laboratories (NAL),[4,11] an empirical correlation for the estimation of afterbody drag with hot jet exhaust is suggested. It is based on the specific heat ratios of cold and hot jet exhaust. The afterbody drag coefficient with hot jet exhaust [$C_{DA(h)}$] is given by

$$C_{DA(h)} = C_{DA(c)}/(\gamma_{jc}/\gamma_{jh})^2$$

where $C_{DA(c)}$ is the afterbody drag (sum of boat-tail and base drag) with cold jet exhaust; γ_{jc} is the specific heat ratio of cold jet at a total temperature (T_c) of 300K; and γ_{jh} is the specific heat ratio of the hot jet exhaust.

Validation

To demonstrate the usefulness of the preceding correlation, afterbody drag data,[12-] ,, obtained from tests at the Arnold Engineering and Development Center (AEDC), and NASA wind tunnels on boat-tailed afterbody configurations with sonic jet exhaust have been used. The jet total temperature involved in these experiments were in the range of 300-1600 K (Table 1). The values of γ_c and γ_h for these cases have been taken from the respective publications and are reproduced in Table I .

Considering the simplicity of the approach, estimates of afterbody drag with jet temperature effects using the preceding correlation show, in general, good agreement (Figs. 1-5) with the hot jet test data generated in AEDC and NASA tunnels. This correlation has been validated against available test data at subsonic and transonic Mach numbers with sonic hot jet (Figs. 1-5) on contoured boat-tailed afterbodies having negligible base thickness and boat-tail angle (/3) in the range of 10-25 deg.

Conclusions

A simple correlation is proposed for the estimation of afterbody drag with hot jet exhaust from the cold jet test data. Good agreement with the available drag data with sonic hot jet exhaust is observed' and the proposed correlation may be very useful during preliminary design phase of combat aircraft. The correlation is now being extended to estimate the afterbody drag in the supersonic freestrearn Mach number range and with supersonic hot jet exhaust.

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