ESTIMATION OF AFTERBODY DRAG WITH JET TEMPERATURE EFFECTS FOR THE AFTERBODY-NOZZLE CONFIGURATION OF A COMBAT AIRCRAFT

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Abstract

An empirical correlation, developed and validated at NAL (Refs. I and 2) has been utilized to make an estimate of afterbody drag with jet temperature effects from the cold jet tests drag data available for two afterbody-nozzle configurations of a combat aircraft. These results of drag estimates show afterbody drag reduction in the range of 10-25% (With respect to cold jet tests drag results) depending on the operating conditions of the nozzle of the combat aircraft.

Introduction

Modern turbo-jet and turbo-fan engines of combat aircraft operating over a wide range of power settings experience jet exhaust temperature typically varying from 1000 K-2000 K (Refs. 3 and 4). Thus there remains a problem to determine the extent to which jet total temperature (and its associated gas constants) affects the afterbody drag of the combat aircraft under various operating conditions of its nozzle during the flight operation. Results available (Refs. 5-8) show that underexpanded jet(s) - freestream interactions taking place near the aft-end of an aerospace vehicle can have strong influence on its performance. In particular, afterbody drag characteristics is greatly influenced by its plume blockage and entrainment which depends largely on the temperature and velocity gradients existing between the jet and the external flow (Refs. 9 and 10).

Aircraft development programmes generally require afterbody drag estimates with hot jet exhaust for the evaluation of its aerodynamic performance under various operating conditions of the nozzle. Since the experiments with hot jet exhaust are quite involved, costly and require high safety standards during wind tunnel experiments, simple methods of estimation of afterbody drag are very much preferred during the preliminary design stage. Also, calculation of afterbody drag with hot jet exhaust is quite involved and computationally intensive. In this effort of estimation of afterbody drag with hot jet exhaust, Price et al (Ref. I 1) had proposed a data " correction technique" where the afterbody drag data with cold jet can be corrected for jet temperature effects i.e., both the effects of jet plume shape (termed as y effect, ACDY) and the effects associated with jet entrainment (termed as T effect, ACDT). The first correction term was obtained (Ref. 3 and 11) through a series of experiments by matching the jet plume diameter ratio of hot jet plume by a cold jet at different jet pressure ratios. The second correction term was assumed to be related to the respective internal energy of the jet stream and entrained external flow (Ref.3). This drag data correction procedure (Ref. 3 and l 1) which itself is quite involved is limited to subsonic freestream Mach numbers only. In the present investigations, a relatively simple correlation developed and validated at NAL (Refs. 1 and 2) for the subsonic, transonic and low supersonic Mach number range has been used for the estimation of afterbody drag with jet temperature effects from the cold jet test data.

Correlation for the estimation of afterbody drag with jet temperature effects

The correlation (Refs 1 and 2) is:

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

where

$C_{DA(c)}$ is afterbody pressure drag with cold jet exhaust,
$C_{DA(h)}$ is afterbody pressure drag with hot jet exhaust,
γ_{jc} and γ_{jh} are specific heat ratios of the cold and hot jets respectively.

This correlation has been validated against available test data at subsonic and transonic Mach numbers with

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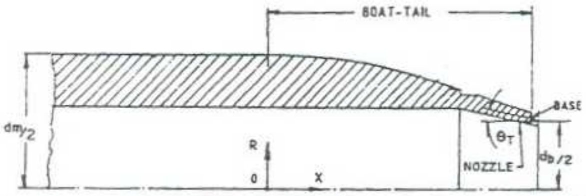
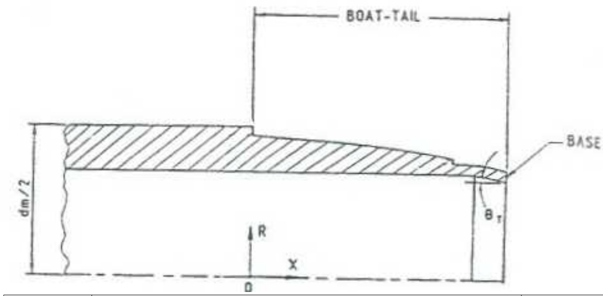


Sl.No.	NOZZLE OPERATING CONDITION	θ_T deg.
1.	REHEAT	5°
2.	INTERMEDIATE	15°
3.	DRY	30°

(Configuration - A)

Fig. 1 Aterbody-nozzle geometry of combat aircraft configuration for three operating conditions of the nozzle



SI.No.	NOZZLE OPERATING CONDITION	6Tder.
1.	REHEAT	5°
2.	INTERMEDIATE	20°
3.	DRY	

(Configuration - B)

Fig. 2 Aterbody-nozzle geometry of combat aircraft configuration for three operating conditions of the nozzle

sonic hot jet and contoured boat-tailed afterbodies having negligible base thickness and boat-tail angles (β) in the range of 10° to 25° (Refs.1 and 2)

Drag estimation of afterbody-nozzle configurations of a Combat aircraft

The above correlation has been utilized to get a broad idea of jet temperature effects on two (representative) afterhody configurations of a combat aircraft for which cold jet drag results are available (Ref.15-17). Since this correlation is valid mainly for afterhodies with negligible base area (Ref. 1). the base drag contribution of the each of these configurations is subtracted from their total drag to get the afterhody pressure drag data with cold jet simulation (Refs. 15-17). This particular exercise of drag estimation has been carried out especially to study the changes in afterbody drag level due to jet temperature effects under various operating conditions of the nozzle, information generally required during the preliminary design stage, of an aerospace vehicle. However to obtain more precise values of afterbody drag, it will essentially be required to simulate nozzle flow operating conditions with hot jet exhaust and associated afterbody-nozzle geometry during wind tunnel experiments. The geometry details of these two afterbody configurations corresponding to dry, reheat and intermediate nozzle operating conditions are as given in the Figs. I and 2. It may be noted that the configurations A and B have maximum base thickness of 18 % and 16 % of the maximum diameter respectively for the dry nozzle configurations as compared to 7% and 5% respectively for the reheat nozzle configuration.

For the estimation of afterbody drag with jet temperature effects, specific heat ratios of hot jet exhaust (yh)

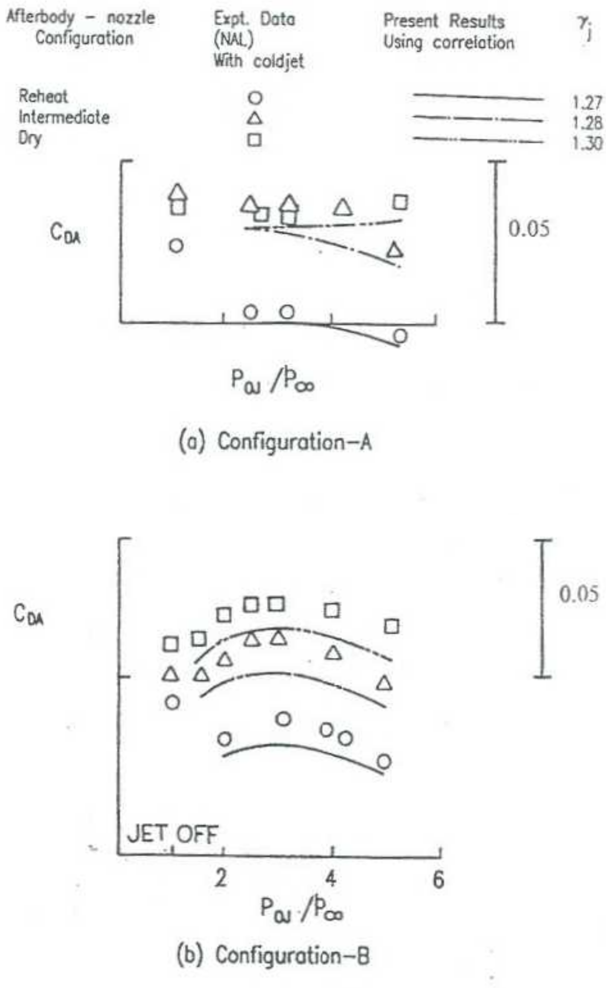
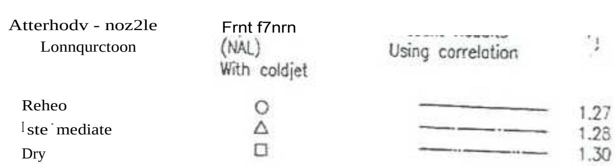


Fig. 3 Estimation of afterbody drag with sonic hot jet exhaust, $M_\infty = 0.80$



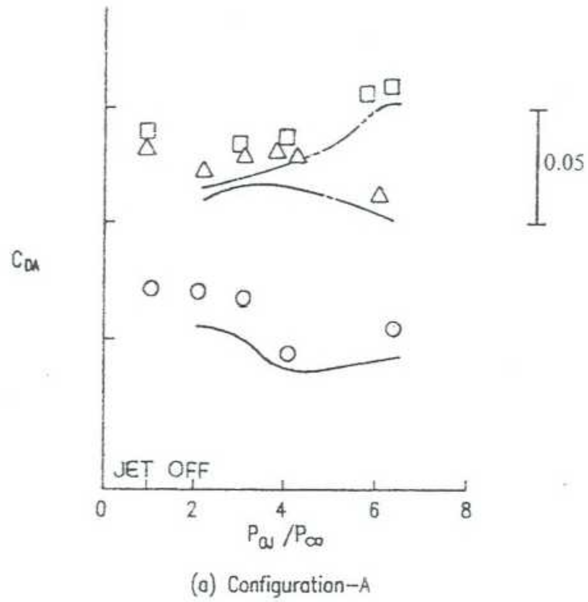


Fig. 4a Estimation *of afterbody drag* with *sonic hot jet exhaust, M_∞ =0.95*

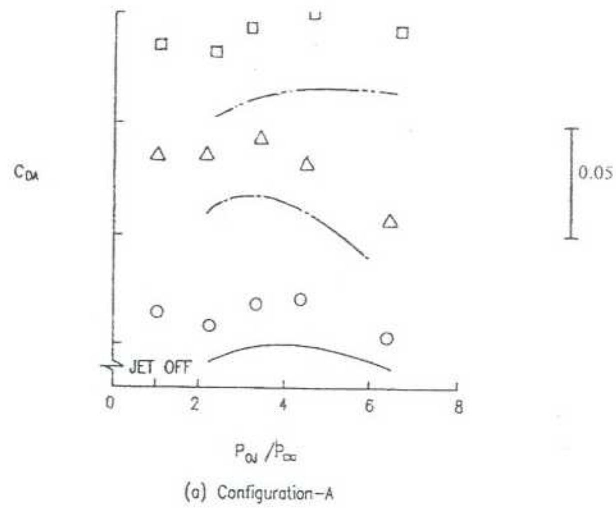


Fig. 5a Estimation *of afterbody drag with sonic hot jet exhaust, M_∞ = 1.22*

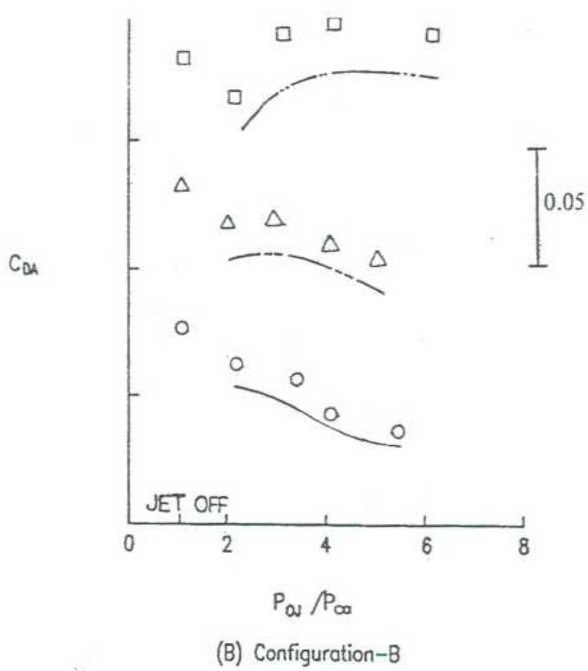


Fig. 4b Estimation of afterbody drag with sonic hot jet exhaust, M_∞ = 0.95

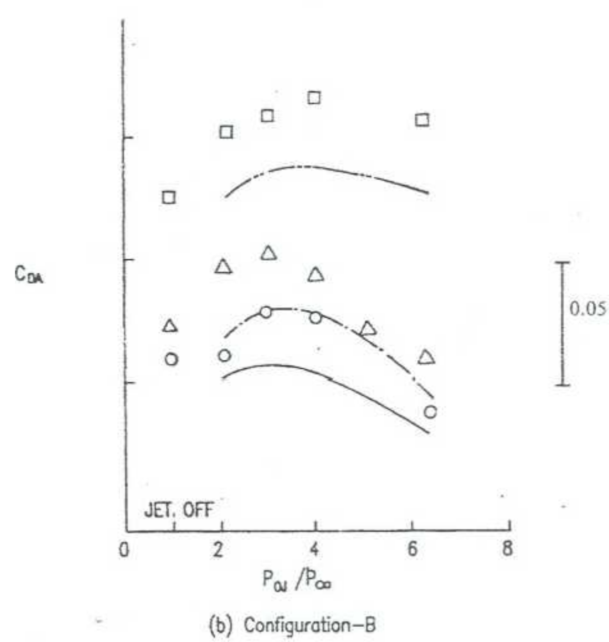


Fig. 5b Estimation of afterbody drag with sonic hot jet exhaust, M_∞ = 1.22

have been calculated based on the simple gas turbine cycle analysis. Following assumptions have been made :

- Fuel as aviation Turbine Fuel (ATF,CnH2n)
- Engine Compression ratio of 20-23
- Turbine inlet temperature of1500 K- 1650 K
- Ratio of actual fuel- air ratio to stoichiometric fuel-air-ratio as 1 ($(F/A)_{Actual}/(F/A)_{Stoich} \approx 1$) i.e. 100% theoretical air
- Jet temperature at nozzle exit for the reheat condition as 1800 K-2000 K and for dry operating condition as 900 K-1000 K

Using the gas tables and the above assumptions, values of γ_{jh} were obtained.

Nozzle-Configuration	Toj (K) (At nozzle exit)	γ_{jh}**(estimated)**
Dry	900 K-1000 K	1.30
Intermediate	1300 K-1400 K	1.28
Reheat	1800 K-2000 K	1.27

These values of γ_{jh} have been used in the present correlation for the estimation of afterbody drag under various operating conditions of the nozzle. Estimates of afterbody drag as obtained for two afterbody nozzle configurations (Figs.1 and 2) at typical freestream Mach numbers of 0.80, 0.95 and 1.22 are as shown in the Figs. 3 to 5. As seen, afterbody drag reduction in the range of 10-25% seems likely depending on the operating conditions of the nozzle.

Conclusions:

1. The correlation provides an easy procedure of estimation of afterbody drag with jet temperature effects from the cold jet tests drag data.

2. Results show that afterbody drag reduction in the range of 10-25% (With respect to cold jet test drag results) depending on the operating condition of the nozzle.

3. This simple procedure of evaluating afterbody drag may be very useful for providing drag estimates generally required during the preliminary design stage of the aerospace vehicles.

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References:

1. Mathur, N. B., "Correlation for the Estimation of Afterbody Drag with Hot Jet Exhaust", Journal of Aircraft, Vol. 35, No 6., Nov-Dec. 1998.

2. Mathur, N. B., "Jet Plume Temperature Effects on Afterbody Drag", National Aerospace Laboratories, PD EA 9706, March 1997.

3. Carter, E.C.,"Aerodynamics of Aircraft Afterbody: Jet Simulation", AGARD AR 226, June 1986.

4. Compton, W. B.,"An Experimental Study of Jet Exhaust Simulation", AGARD CP150-16, March 1975, also NASA TMX- 71975, June 1974.

5. Robinson, C. E. and High, M .D., "Exhaust Plume Temperature Effects on Nozzle Afterbody Performance Over the Transonic Mach No. Range", AGARD-TR-74-9, 1974.

6. Aulehla, F. and Latter, K., "Nozzle / Airframe Interference and Integration", AGARD LS-53, May 1972.

7. Mathur, N.B. and Yajnik, K.S., "Underexpanded Jet-FreeStream Interactions on an Axisymmetric Afterbody Configuration", AIAA Journal ,Vol. 28, No 1,1990

8. Mathur, N.B., "Effects of Underexpanded Jet on Afterbody Drag of an Axisymmetric afterbody Configuration", NAL FM TM-84-2,1984.

9. Mathur, N.B. and Yajnik, K.S., "Jet Plume Temperature Effects on Afterbody Pressure Distribution and

Drag", International Journal of Turbo and Jet Engines. Vol. 3. pp.91-97.1986.

10. Zacharias, A., "An Experimental and Theoretical Investigation of the interaction between the Engine Jet and Surrounding Flow Field AGARD CP-308, Paper No.B, Jan. 1982.

11. Price. E.A. and Peters, W.L., "Test Techniques for Jet Effects on Fighter Aircraft.". AGARD CP-348-24.1984.

12. Galioher, L. L., Yaros, S.F. and Bauer, R.C. , " Evaluation of Boat - Tail Geometry and Exhaust Plume Temperature Effects on Nozzle Afterhody Drag at Transonic Mach Numbers", AEDC TR 76-102. Oct. 1977.

13. Pctcrs.W.L. and Kennedy, T.L., " An Evaluation of Jet Simulation Parameter for Nozzle / Afterhody Testing at Transonic Mach Numbers", AIAA 77-106,1977.

14. Compton III William B., "Effects of Jet Exhaust Gas Properties on Exhaust Simulation and afterhody drag" NASA TR-R444, Oct .1975.

1~. Mathur, N.B.. "Aftcrhodv Pressure Drag Data For The Reheat Intermediate and Dry Nozzle Operating Conditions of a Combat Aircraft Configuration". NAL PD EA 9018, Nov. 1990-

16. Mathur, N.B. "Aerodynamic Performance Characteristics of an Afterbody-nozzle configuration with Different Operating Conditions of Nozzle," NCABE 94-7, Proceedings, 2nd National Conference on Air Breathing Engines arid Aerospace Propulsion. Dec. 1994.

IT Mathur, N.B., "A fterbody- Nozzle Drag Characteristics of a Combat Aircraft Configuration," NAL PD EA 9506.April 1995.