Base Drag Determination for STS Flights 1–5

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Abstract

THE base drag characteristics of the Space Shuttle Orbiter have been determined from the first five return flights of the Space Transportation System (STS). These flight-derived data are compared with predicted base drag values. The base drag is shown to account for as much as 50% of the total Orbiter drag.

Contents

Precise techniques for estimating the aerodynamic performance characteristics of blunt-based gliding vehicles must include an accurate accounting of the base drag contribution. Base drag estimates are usually obtained from wind-tunnel pressure measurements which can be affected by model support techniques, wall reflected shocks, model size and the impracticality of duplicating base geometries. Additionally, test Reynolds number differences and the interactions produced by deflection of adjacent control surfaces can significantly alter base drag. The first five Space Shuttle Orbiter flights (STS 1-5) offered the unique opportunity to compare base pressure measurements for an interference-free gliding vehicle with wind-tunnel estimates and prompted the present study.

The onboard Development Flight Instruments (DFI) provided 10 Hz raw pressure data during the return-from-orbit flights (STS 1-5) at the 12 base orifice locations shown in Fig. 1 which include four orifices on the Orbital Maneuvering System (OMS) pods. Signals from the high-range, low-sensitivity 15 psia pressure transducers were interpolated to a 1 Hz signal to allow time synchronization with the Best Estimated Trajectory (BET) data and control deflection data for each flight. Some of the pressure readings were determined to be erroneous and were, therefore, ignored. Some instrumentation failures further limited the data. The readable pressure data were corrected for biases, which were determined for the final and initial flight conditions, namely, the ambient pressure immediately after landing rollout and the on-orbit vacuum condition, respectively. The pressure data were converted to base pressure coefficients using the time-synchronized freestream static and dynamic pressures obtained from the BET data. Figure 2 shows typical base

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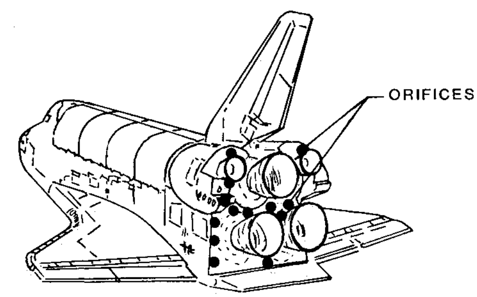

Fig. 1 Base pressure orifice locations.

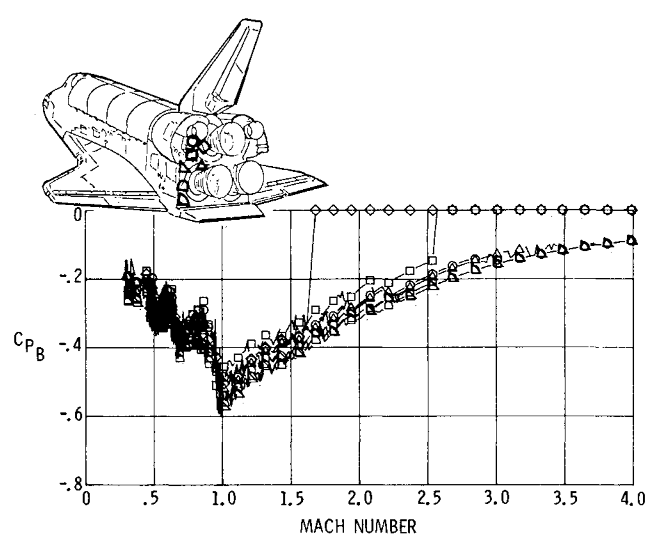

Fig. 2 Base pressure coefficients determined from flight.

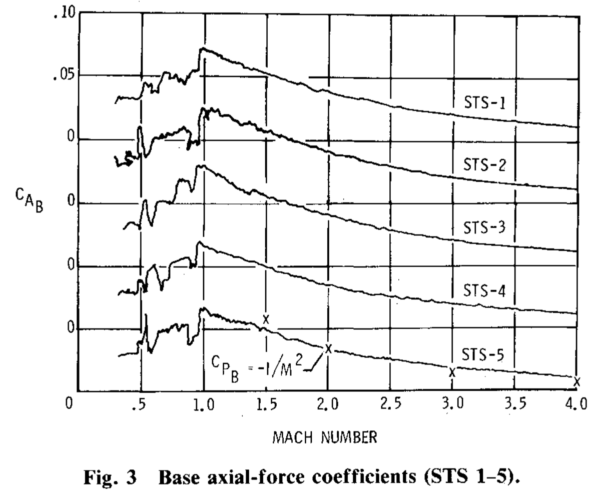

Fig. 3 Base axial-force coefficients (STS 1–5).

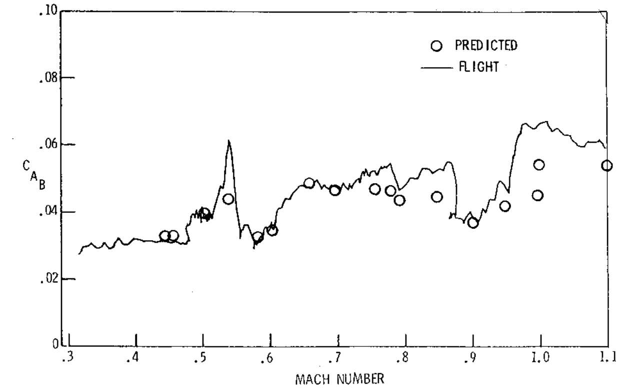

Fig. 4 STS-5 base axial-force coefficients data.

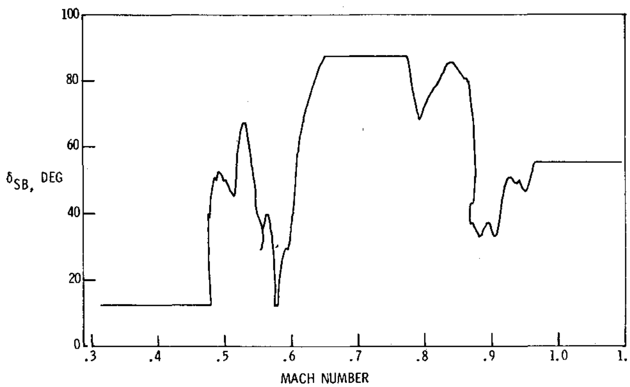

Fig. 5 STS-5 speed-brake deflections.

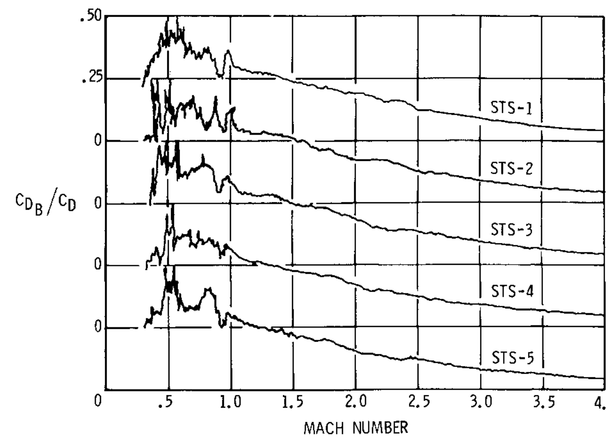

Fig. 6 STS flight-determined base drag-to-total drag ratio.

pressure coefficient data for STS-1. The data are relatively independent of the geometric location of the orifices within the base region, including the OMS pod location. The exception is two offscale traces at Mach numbers above 1.5, which have been zeroed. The base pressure coefficients were used to calculate base axial-force coefficients for each flight using

$$C_{A_B} = \frac{-S_{\text{Base}}}{nS_{\text{ref}}} \sum_{i=1}^{n} C_{p_B}$$

where n is the number of operative pressure transducers $S_{\text{Base}} = 375.7$ ft^2, and $S_{\text{ref}} = 2690$ ft^2.

The base axial-force coefficients determined for the STS 1-5 flights are shown in Fig. 3, at Mach numbers from about 0.3–4.0. The lowest subsonic data were obtained at the landing descent flight condition prior to entering ground effect. Distinct irregularities characterized the data at high subsonic speeds with a gradually increasing trend in base axial-force coefficients at higher speeds. The maximum value of C_{A_B} occurred near $M = 1.0$ for each of the five (about 0.07) flights. With further increases in Mach number, the base axial-force coefficients declined gradually and smoothed out with a value of approximately 0.01 occurring at $M = 4.0$. The x-symbols, shown on the STS-5 plot at supersonic speeds, are estimates of based axial-force coefficient using $C_p = -1/M^2$.

Figure 4 shows a comparison of the wind tunnel and flight values of the base axial-force coefficients at transonic speeds. The wind-tunnel data were taken from the Aerodynamic Design Substantiation Report of the Space Shuttle Orbiter Aerodynamic Design Data Book. These data have been interpolated to the Mach number, angle of attack, and control deflection settings of the flight data points. In general, the comparison shows the flight data fall within $\pm 10\%$ of the predictions at $M < 0.65$. At higher transonic speeds, the wind-tunnel results tend to underestimate the flight values of C_{A_B} with most of the flight data falling within 15% of the predicted values. Significant improvements in the quality of the base drag predictions would be expected if the transonic wind-tunnel investigation had been designed to isolate and eliminate the effects of the conventional sting support on the base pressures.

The irregular variations in transonic base axial-force coefficients noted earlier can be explained by comparing Figs. 4 and 5. Figure 5 shows the STS-5 flight variations of speed brake deflections, δ_{SB}, with Mach number. A careful correlation of the peaks and troughs in the data traces reveals a very strong dependence of the base pressure on speed brake deflection. The irregularities in base axial-force coefficient are the result of pressure variations acting solely on the Orbiter base region (including the OMS pods) and do not include drag increases on the vertical tail base produced by deflecting the speed brakes.

The base drag contribution to the total drag of the Orbiter is presented in Fig. 6. The variation of base-to-total drag ratio, as a function of Mach number, is shown for the first five STS flights. The total aerodynamic drags were obtained from the Best Estimated Trajectory, time-synchronized data for each appropriate flight. The irregular transonic base axial-force data are further scattered by rationing the base drag to the total drag data, which also vary rapidly with control deflection. This comparison indicates that base drag constitutes from 25–50% of the Orbiter's total drag at transonic speeds. Supersonically, the contribution of base drag diminishes gradually with increasing Mach number and accounts for 5% or less of the total drag at Mach numbers of 4.0 and higher.