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Space Shuttle Orbiter Static Stability and Control Derivatives Obtained from Wind-Tunnel and Flight Tests

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Nomenclature

b	= reference wing span, m
C_ℓ	= rolling moment coefficient, rolling moment/$q_\infty Sb$
C_{ℓ_β}	= effective dihedral parameter, $\Delta C_\ell/\Delta\beta$
C_m	= pitching moment coefficient, pitching moment/$q_\infty S\bar{c}$
C_{m_α}	= $\Delta C_m/\Delta\alpha$, per degree
$C_{m_{\delta_e}}$	= $\Delta C_m/\Delta\delta_e$, per degree
C_N	= normal force coefficient, normal force/$q_\infty S$
C_{N_α}	= $\Delta C_N/\Delta\alpha$, per degree
$C_{N_{\delta_e}}$	= $\Delta C_N/\Delta\delta_e$, per degree
C_n	= yawing moment coefficient, yawing moment/$q_\infty Sb$
C_{n_β}	= directional stability parameter, $\Delta C_n/\Delta\beta$, per degree
C_Y	= side force coefficient, side force/$q_\infty S$
C_{Y_β}	= side force parameter, $\Delta C_y/\Delta\beta$, per degree
$\bar{c}$	= mean aerodynamic chord, m
ℓ	= body length, m
q_∞	= freestream dynamic pressure, Pa
S	= reference area, m^2
α	= angle of attack, deg
β	= angle of sideslip, deg
δ_e	= elevon deflection, positive for testing edge down, deg

Abstract

THIS Synoptic presents a comparison of the results of tests conducted in the Langley 8 ft transonic pressure tunnel with the static stability and control parameters extracted from the Space Shuttle Orbiter approach and landing flight tests (ALT). To obtain the wind-tunnel values of the static longitudinal and lateral directional stability and control derivatives, an 0.02 scale model of the orbiter with remotely driven elevons, ailerons, and body flap was tested at flight values of angle of attack, Mach number, trimmed elevon deflection, bodyflap deflection, and speed-brake position. Utilizing these data, a comparison has been made of stability and control parameters determined from the wind tunnel, ALT flight tests, and the Space Shuttle Orbiter Design Data Book.

Contents

The Space Shuttle Orbiter approach and landing test (ALT) program has been completed, and aerodynamic flight test data have become available for analysis and for comparison with wind-tunnel test results. Comparison of wind-tunnel data with the ALT results offers an opportunity to assess the validity of using the wind tunnel to predict the full-scale stability and control characteristics of the Orbiter for a limited portion of the subsonic speed regime. Because of the nature of the ALT flight program, all data obtained are subsonic over a Mach number range of 0.41-0.56 and over an angle-of-attack range of approximately 2-10 deg. The complete comparison of wind-tunnel and ALT flight values of the static stability and control derivatives is presented in Ref. 1 and a comparison of the dynamic derivatives is presented in Ref. 2.

A comparison of the stability and control derivatives measured in the Langley 8 ft transonic pressure tunnel with those extracted by both the Air Force and NASA from ALT flights 4 and 5[3,4] and those presented in the aerodynamic design data book[5] are presented in Figs. 1-3 (c.g. at 0.65 ℓ). The values from Ref. 5 were determined from a large volume of wind-tunnel data obtained prior to the ALT flights. Each of the data points represents a different flight condition (Mach number and angle of attack). An uncertainty band (variations), defined in Ref. 5, is presented on the comparison figures. The variations were determined using wind-tunnel and flight data for aircraft similar to the Orbiter.[4]

Longitudinal Stability and Control

The comparisons show that the longitudinal stability derivatives C_{m_α} determined from the wind-tunnel tests are in good agreement with the flight data. The data book values indicate a lower level of stability over the test angle-of-attack range than for either the flight or wind-tunnel results. In all cases, both the wind-tunnel and flight values of C_{m_α} fall within the variations band.

There are three sets of flight values of C_{N_α} presented in Fig. 1. Reference 3 provided C_{N_α} data from both a primary and a backup accelerometer, but only one set of data is presented in

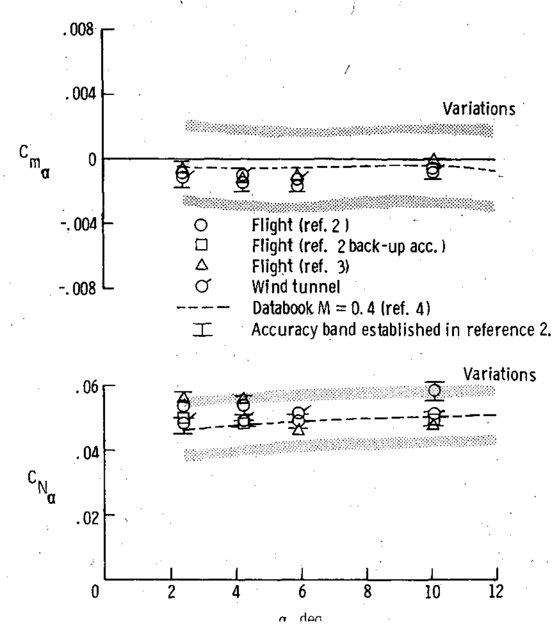

Fig. 1 Comparison of wind-tunnel and flight values of C_{m_α} and C_{N_α}.

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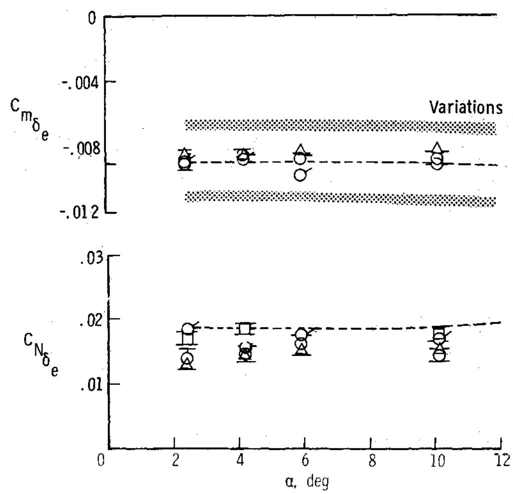

Fig. 2 Comparison of wind-tunnel and flight elevon effectiveness.

Ref. 4. Both references describe some specific data measurement problems that impact the accuracy of certain derivatives. Reference 3 indicates that this accuracy problem does affect C_{N_α} and, therefore, both the primary and backup accelerometer data are presented with no inference as to which is the more accurate. The comparison of the wind-tunnel results with the flight data does not substantiate the accuracy of either set of flight data. The only conclusion that can be drawn about the C_{N_α} comparison is that the wind-tunnel data agree with the data book values of Ref. 5 and that the flight data do differ from the data book values but remain within the variation band.

A comparison of the pitching moment coefficient $C_{m\delta_e}$ and normal force coefficient due to elevon deflection $C_{N\delta_e}$ measured in the wind tunnel and extracted from the ALT flight data is presented in Fig. 2. Generally, the comparison shows very good agreement between the values of $C_{m\delta_e}$ determined from flight, the wind tunnel, and the data book.[4] As with the comparison of C_{N_α}, there is considerable scatter in the $C_{N\delta_e}$ flight data; and because of this scatter, no real conclusion can be drawn about its accuracy. There are no variations presented in Ref. 5 for $C_{N\delta_e}$.

Lateral Directional Stability and Control

The lateral directional stability parameters ($C_{\eta\beta}$, $C_{\ell\beta}$, and $C_{Y\beta}$) determined from the wind-tunnel tests are compared with the flight test results of both Refs. 3 and 4 in Fig. 3. The comparison shows excellent agreement between wind-tunnel and flight values for the effective dihedral parameter $C_{\ell\beta}$ and differences of approximately 15% for the directional stability parameter $C_{\eta\beta}$. The side force due to sideslip parameter $C_{Y\beta}$ shows about the same agreement between the flight and wind-tunnel results as for $C_{\eta\beta}$. The flight and wind-tunnel values of $C_{\eta\beta}$ and $C_{Y\beta}$ generally agree with the data book values; but for some cases for $C_{\ell\beta}$, the data book values are 15% higher than both the flight and wind-tunnel results. All of the flight and wind-tunnel lateral directional stability data fall within the variations established in Ref. 5.

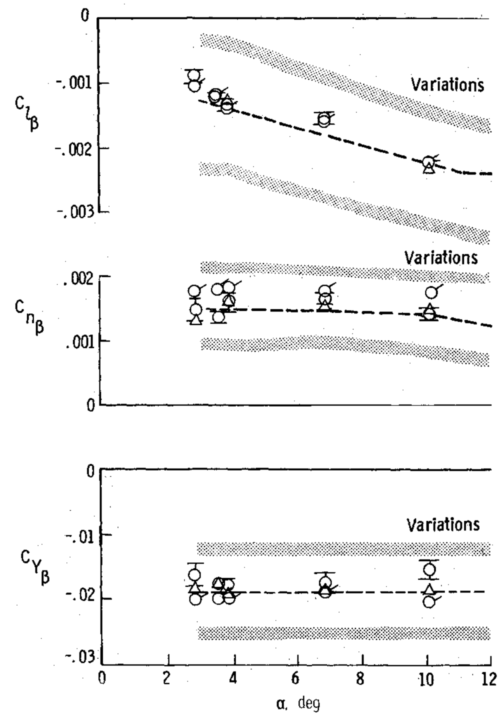

Fig. 3 Comparison of wind-tunnel and flight values of the lateral directional stability parameters.

Conclusion

In general, except for the normal force derivatives where there are known accuracy problems with the flight data, the wind-tunnel test results and flight data agree quite well. The general good agreement between the data determined from the wind-tunnel and flight tests indicates that the predicted flight stability and control characteristics using wind-tunnel results appear to be adequate for entry vehicle design at subsonic Mach numbers in the low angle-of-attack range of the comparisons.

References

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[4] Cooke, D.R., "Subsonic Stability and Control. AIAA Flight Test Results of the Space Shuttle Orbiter (Tailcone Off)," AIAA Paper 80-1604, Danvers, Mass., Aug. 1980.

[5] "Aerodynamic Design Data Book, Orbiter 101, Vol. 4," Space Div., Rockwell International, SD72-SH-0060, Vol. 45, Rev. 2, Oct. 1976.