AIAA 96-0808

SPACE SHUTTLE ORBITER AERODYNAMICS INDUCED BY ASYMMETRIC BOUNDARY-LAYER TRANSITION

Michael Y. An, K. C. Wang
Lockheed Martin Engineering & Science Services
Houston, Texas

Charles H. Campbell
NASA Johnson Space Center
Houston, Texas

Ronald L. Pelley
Rockwell International
Houston, Texas

34th Aerospace Sciences Meeting & Exhibit

January 15-18, 1996 / Reno, NV

For permission to copy or republish, contact the American Institute of Aeronautics and Astronautics
370 L'Enfant Promenade, S.W., Washington, D.C. 20024

w	Wall value
∞	Free stream value

Superscript

*	Eckert's reference value

Introduction

Background

During the entry phase of several Space Shuttle Orbiter flights, boundary-layer transition on the windward side of the vehicle has occurred much earlier than normal and in some cases, transition has occurred asymmetrically. Nominally, boundary-layer transition occurs at approximately 1200 secs. from entry interface at a free stream Mach number of 8[1]. However, during STS-28, surface thermocouples indicated that transition began at 900 secs. into the entry at a Mach number of 18. Thermocouples on the Orbiter structure also indicated an increased temperature which verified that the vehicle had experienced a higher heat load due to turbulent heating. As presented in Fig. 1, transition has also occurred early on other flights. During STS-50, Orbiter elevon deflections and RCS jet firings indicated that the vehicle began experiencing a yawing moment during the same time that transition occurred. Surface thermocouple data confirmed that transition occurred on the right side of the vehicle 80 secs. prior to occurring on the left side of the vehicle. These anomalies in the Orbiter entry have raised concerns about the understanding of boundary-layer transition and its effect on the Orbiter aerodynamic performance during entry. Even though the phenomenon of early boundary-layer transition and asymmetric boundary-layer transition are not totally unrelated, this paper will only concentrate on the effect of asymmetric boundary-layer transition on Orbiter aerodynamics during entry. The discussion on early boundary-layer transition will be presented in a separate paper.

Objectives

In order to address the issues raised by the occurrences of early and asymmetric boundary-layer transition on the Orbiter, an Orbiter Transition Working Group was organized. This Working Group was divided into three teams: the Analysis and Ground Test team, the Transition Database team, and the Flight Test team. The Analysis and Ground Test team consisted of engineers from NASA-Johnson Space Center (JSC), LMES in Houston, NASA-LaRC, and Rockwell International in Houston. This team was tasked with analyzing Orbiter flight data, with predicting the earliest conditions for transition during entry, and with predicting the aerodynamic moments induced by asymmetric boundary-layer transition. Furthermore, the group was tasked with planning ground tests that would support and verify the analyses. Given these assignments, the Transition Analysis and Ground Test Team has defined the following objectives for the ABLT-induced aerodynamic moment task:

1) Develop and verify methods to predict the aerodynamic forces and moments induced by asymmetric boundary-layer transition.

2) If necessary, create new or update existing ABLT-induced aerodynamic moment models for the Orbiter.

3) Make recommendations to Orbiter Flight Control personnel concerning the new/updated ABLT-induced aerodynamic moment models.

This paper presents a summary of the efforts to accomplish these objectives.

Analytical Methods

As stated in the previous section, one of the primary objectives of this study is to develop and verify methods to predict the aerodynamic forces and moments induced by asymmetric boundary-layer transition. In order to compute aerodynamic forces and moments, both pressure and skin friction must be known for the entire surface of the vehicle. One way to obtain these information at one time is to compute viscous (i.e., Navier-Stokes) Computational Fluid Dynamics (CFD) solutions for both laminar and turbulent flows. However, this approach is very time consuming, and unrealistic due to time constraints and/or lack of computational resources. In addition, turbulence modeling technology has not been well validated–especially for very high speed flows. Therefore, the computation of viscous solutions for both laminar and turbulent flows was deemed unsuitable for this study.

Another way of obtaining the vehicle surface pressure and skin friction is to use the two-layer method. In short, this method involves first computing an inviscid CFD solution around the vehicle. The surface velocity components, density, and pressure from the inviscid CFD solution serve as inputs to an engineering code which approximates the boundary layer based on these

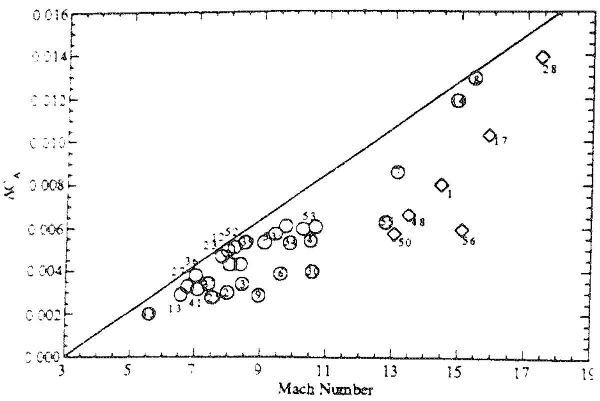


Figure 12 - Orbiter axial force coefficient increment (ΔC_A) due to transition.

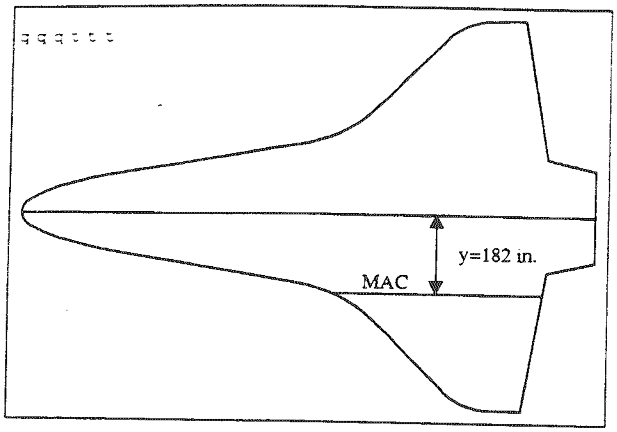


Figure 13 - Location for applying axial force change to compute yawing moment.

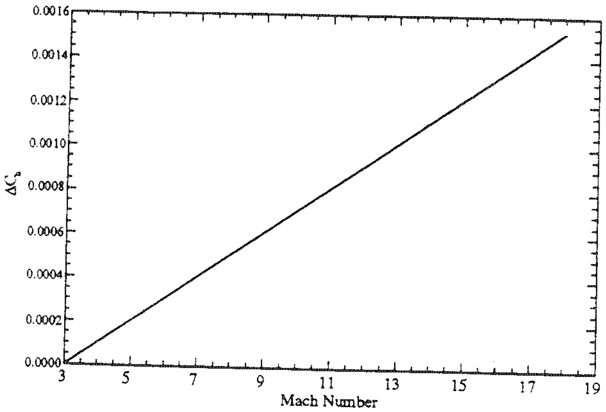
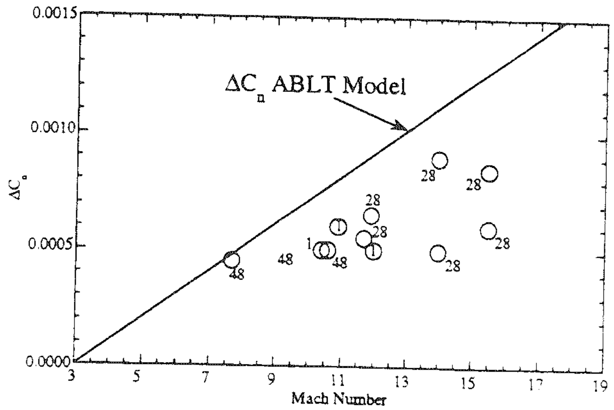
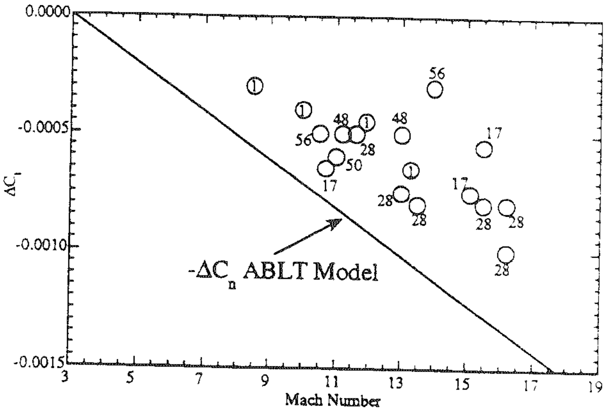


Figure 14 - Maximum yawing moment coefficient increment (ΔC_n) due to asymmetric boundary-layer transition



(a) Yawing Moment Increment (ΔC_n)



(b) Rolling Moment Increment (ΔC_l)

Figure 15 - Flight-data-derived moment coefficient increment due to asymmetric boundary-layer transition.

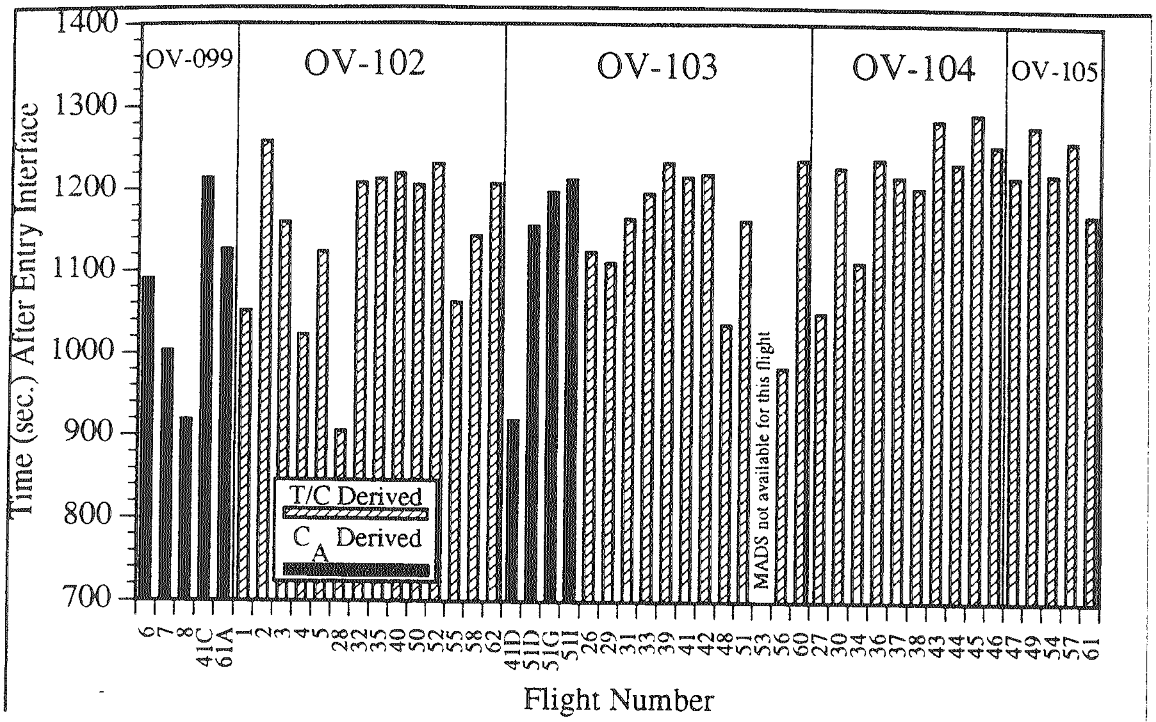


Figure 1 - Orbiter transition experience.

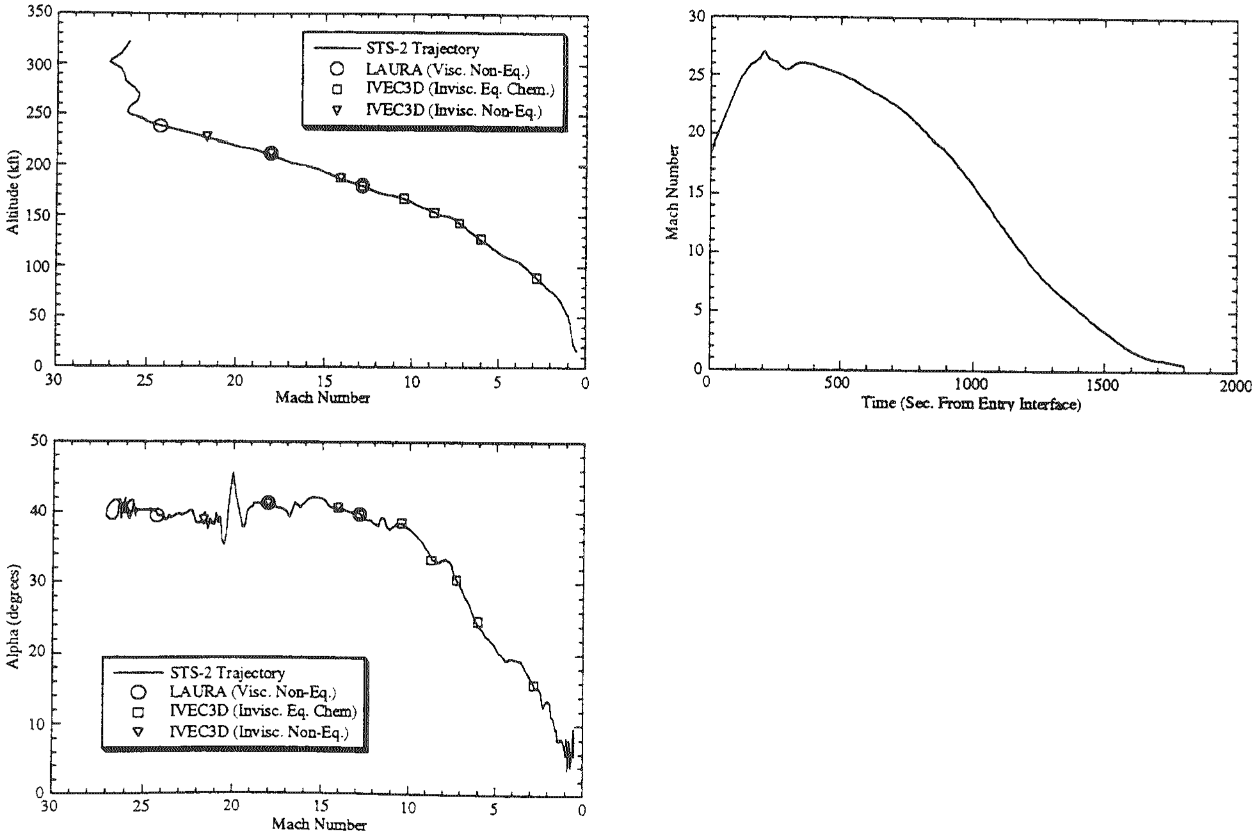


Figure 2 - CFD analysis cases along STS-2 reference trajectory.

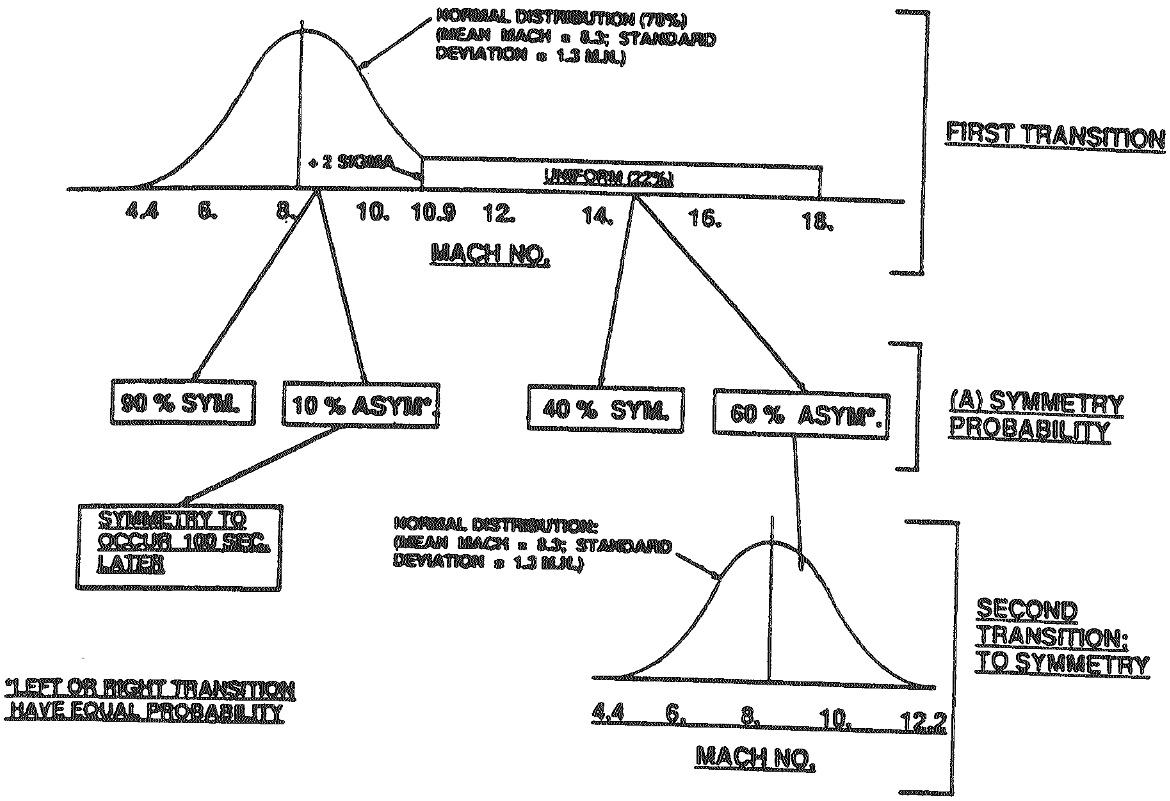
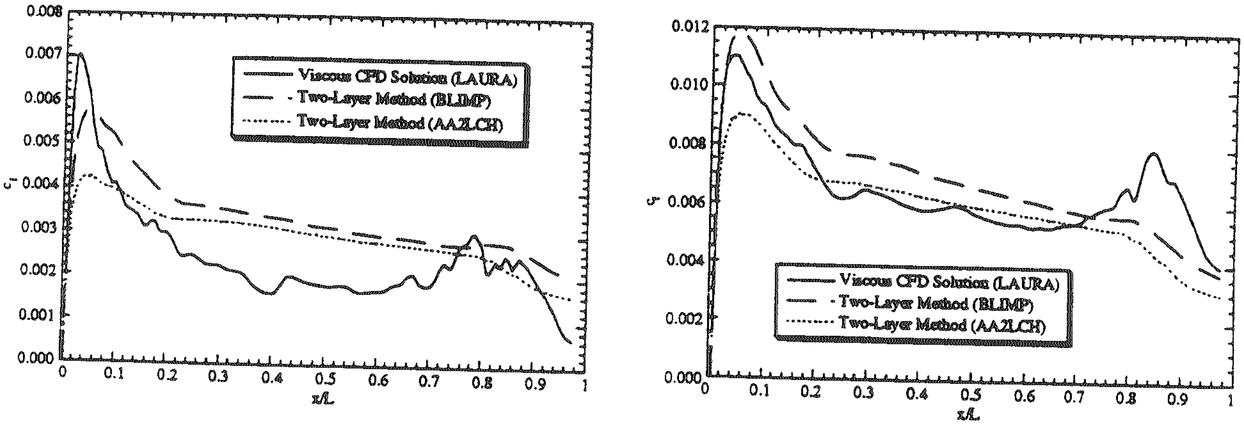


Figure 16 - Probability of symmetric and asymmetric Orbiter boundary-layer transition.



(a) Mach 12.9 Case

(b) Mach 18.1 Case

Figure 17 - Comparisons of skin friction coefficient (c_f) as computed by viscous CFD solution (LAURA), two-layer method (BLIMP), and two-layer method (AA2LCH).