CFD Simulations of Boundary Layer Transition Flight Experiment Catalytic Coating Data

Grant Palmer
ERC Inc. At NASA Ames, Moffett Field, CA 94035

Karen Berger
NASA Langley Research Center, Hampton, VA

Charles H. Campbell
NASA Johnson Space Center, Houston, TX

Introduction

The Space Shuttle Boundary Layer Transition Flight Experiment (BLT FE) was performed over a series of five Shuttle flights (STS-119, STS-128, STS-131, STS-133, and STS-134) from March 2009 to June 2011. This effort was motivated by a repair spacewalk performed during STS-114 to remove two protruding gap fillers[1]. The spacewalk was deemed necessary because at the time the risks involved with the spacewalk (which were considerable) were deemed to be lower than those associated with the uncertainties of boundary layer transition and turbulent heating predictive capabilities at that time. The BLT FE was designed to install a protuberance on the windward surface of the Orbiter that would purposely trip the boundary layer at a prescribed Mach number to gain flight data of boundary layer transition. Another element of the flight experiment was that certain tiles on flights STS-128, 131, 133, and 134 were partially covered with a catalytic coating that caused a spike in heating when the flow traversed from a non-catalytic portion of the tile to the part that was catalytic. An example of the catalytic tile and thermocouple location for STS-131 is shown in Fig. 1. The resulting thermocouple data was intended to validate predictive capabilities of CFD cides.

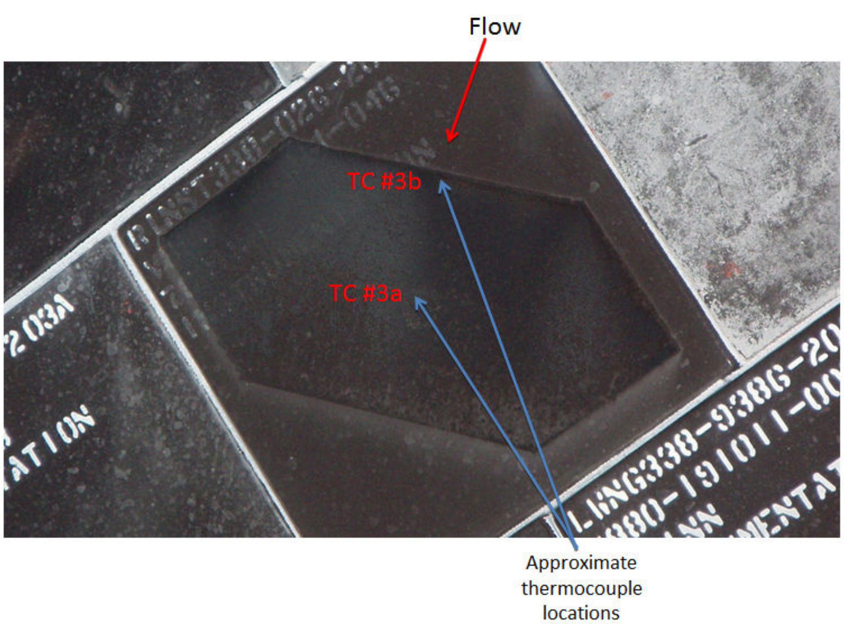

Fig. 1. Location of catalytic coating on tile for STS-131.

An example of temperature measurement time histories taken during STS-131 over the catalytic tile is shown in Fig. 2. The green line in the figure was taken at thermocouple TC6 and represents a baseline, non-catalytic profile. The two thermocouples located on the catalytic coating, TC3a and TC3b, show a rise in surface temperature compared to the non-catalytic values. The region of relatively constant temperatures between 400 and 700 seconds can be used for CFD validation.

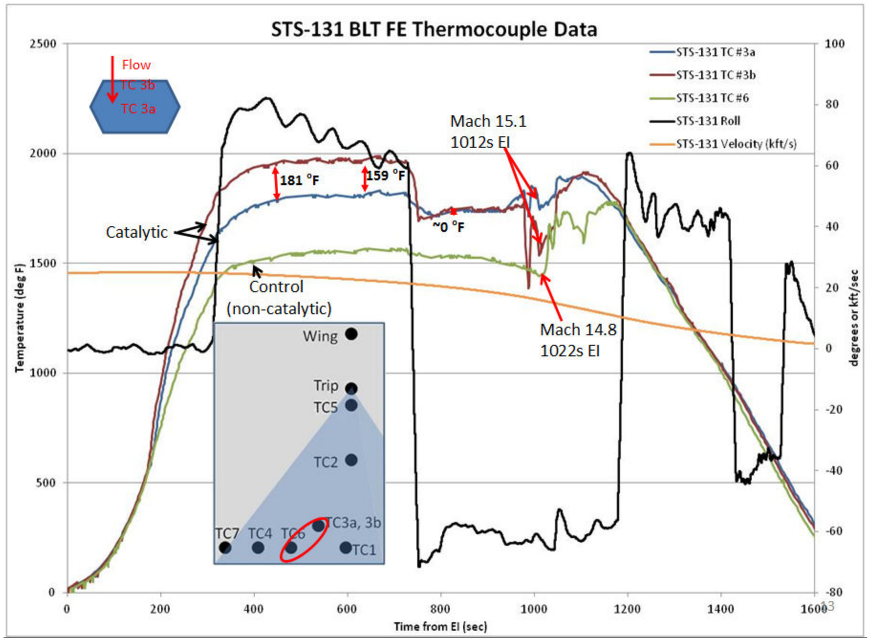

Fig. 1. STS-131 thermocouple data over catalytic tile.

In this paper, the flow over the catalytic tiles will be simulated using the Data-Parallel Line Relaxation (*DPLR*) code [2]. *DPLR* is a 3-D nonequilibrium Navier-Stokes flow solver that uses a modified Steger-Warming flux-splitting scheme [3]. *DPLR* uses a line-relaxation implicit technique that greatly accelerates solution convergence and is directly portable to massively parallel computer architectures. The *DPLR* flow solver has been validated over a wide spectrum of flight and ground-based experimental simulations, a small sample of which can be found in Refs. [4 - 7]. Results will be presented for all of the BLT FE catalytic tiles and conclusions will be drawn regarding the current capability of CFD codes to model catalytic jump conditions for flight vehicles.

References

[1] Berger, K.T., Anderson, B.P., Campbell, C.H., Garske, M.T., Saucedo, L.A., Kinder, G.R., and Micklos, A.M., "Boundary Layer Transition Flight Experiment Overview," AIAA Paper 2011-3323, June 2011

[2] Wright, M.J., Candler, G.V., and Bose, D., "Data-Parallel Line Relaxation Method for the Navier-Stokes Equations," *AIAA Journal*, Vol. 36, No. 9, September 1998.

[3] MacCormack, R.W. and Candler, G.V, "The Solution of the Navier-Stokes Equations Using Gauss-Seidel Relaxation," *Computers and Fluids*, Vol. 17, No. 1, pp. 135-150.

[4] Coblish, J.J., Smith, M.S., Hand, T., Candler, G.V., and Nompelis, I., "Double-Cone Experiment and Numerical Analysis at AEDC Hypervelocity Wind Tunnel No. 9," AIAA Paper 2005-0902, January 2005.

[5] Wright, M.J., Milos, F.S., and Tran, P., "Afterbody Aeroheating Flight Data for Planetary Probe Thermal Protection System Design," *Journal of Spacecraft and Rockets*, Vol. 43, No. 5, May 2006, pp. 929-943.

[6] MacLean, M., Holden, M., Wadhams, T., and Parker, R., "A Computational Analysis of Thermochemical Studies in the LENS Facilities," AIAA Paper 2007-0121, January 2007.

[7] MacLean, M. and Holden, M., "Validation and Comparison of WIND and DPLR Results for Hypersonic, Laminar Problems," AIAA Paper 2004-0529, January 2004.