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11 Foot Unitary Plan Tunnel Facility Optical Improvement Large Window Analysis

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February 2015

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The NAS user services group was very helpful in getting the cases to run efficiently on the NAS computers despite numerous issues with the machines themselves.

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Acronyms/Abbreviations

AIAA	:	American Institute of Aeronautics and Astronautics
CAD	:	Computer Aided Drafting/Design
Cart3D	:	Cartesian 3 Dimensional
CRM	:	Common Reference Model
DPW	:	Drag Prediction Workshop
ITAR	:	International Traffic in Arms Regulations
STAR-CCM+	:	Simulation of Turbulence in Arbitrary Regions-Computational Continuum Mechanics
TS	:	Tunnel Station, all values given are in inches
UPWT	:	Unitary Plan Wind Tunnel

1.0 Overview

The test section of the 11 by 11-foot Unitary Plan Transonic Wind Tunnel (11-foot UPWT) may receive an upgrade of larger optical windows on both the North and South sides. These new larger windows will provide better access for optical imaging of test article flow phenomena including surface and off body flow characteristics. The installation of these new larger windows will likely produce a change to the aerodynamic characteristics of the flow in the Test Section. In an effort understand the effect of this change, a computational model was employed to predict the flows through the slotted walls, in the test section and around the model before and after the tunnel modification. This report documents the solid CAD model that was created and the inviscid computational analysis that was completed as a preliminary estimate of the effect of the changes.

2.0 Geometry

The solid CAD geometry baseline used for this study is documented in Reference (1) and a cut-away view is shown in Figure 1. It is a full CAD model of the 11-foot UPWT from the forward nozzle/inlet diffuser to the end of the aft diffuser for use with computational fluids codes. An image of the original tunnel test section is shown in Figure 2. In preparation for the half body model installations the floor of the tunnel was closed as shown in Figure 3 (open) and Figure 4 (closed). The test section was also modified to represent the intended study geometry by closing off two rows of slots and baffles with a large window plate feature. Two versions were analyzed, one with an extra row of slots next to the upper and lower slots and one without, as shown in
Figure 5 and
Figure 6 respectively. Two different representative half-body models were used in this study. Due to time constraints, the first model chosen was a readily available simplified (non-ITAR) version of the Boeing 757 tail described in Reference (2) and shown installed in Figure 7. The Common Reference Model (CRM) shown in Figure 8 was used for the latter portion of the study and its implementation is described in Section 2.1 below.

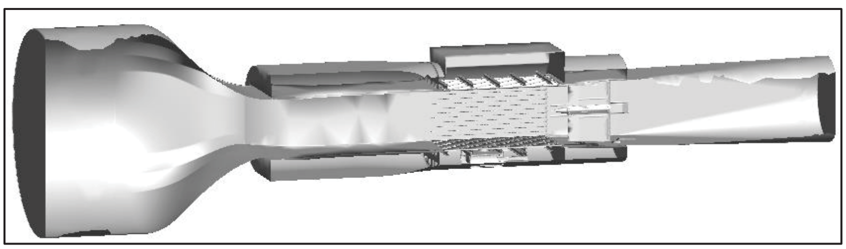

Figure 1 Full Original Geometry

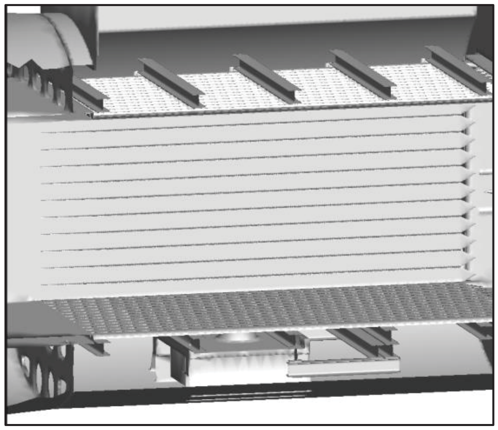

Figure 2 Original Test Section

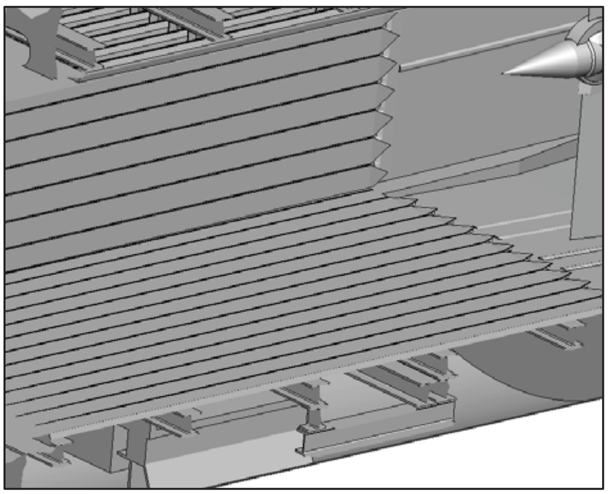

Figure 3 Open Floor Test Section

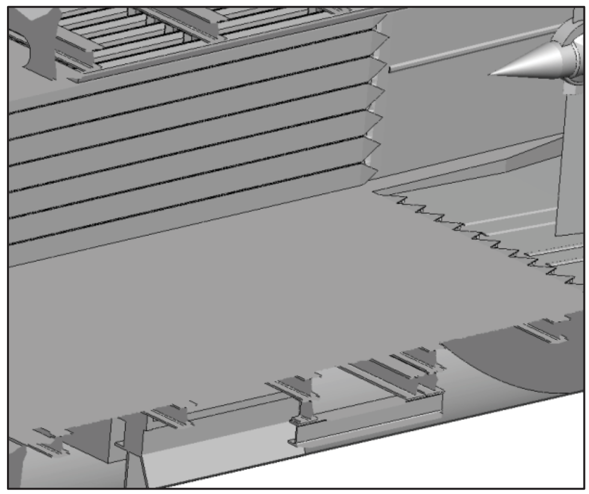

Figure 4 Closed Floor Test Section

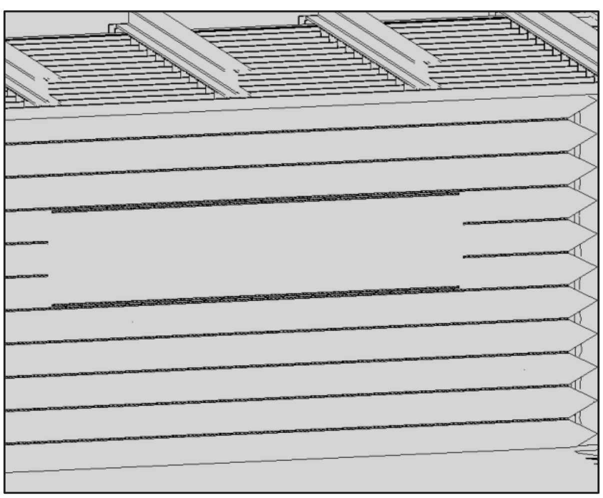

Figure 5 Large Window with Extra Slots

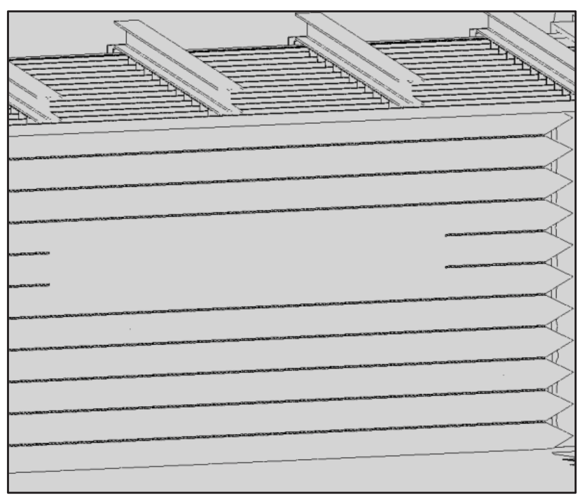

Figure 6 Large Window without Extra Slots

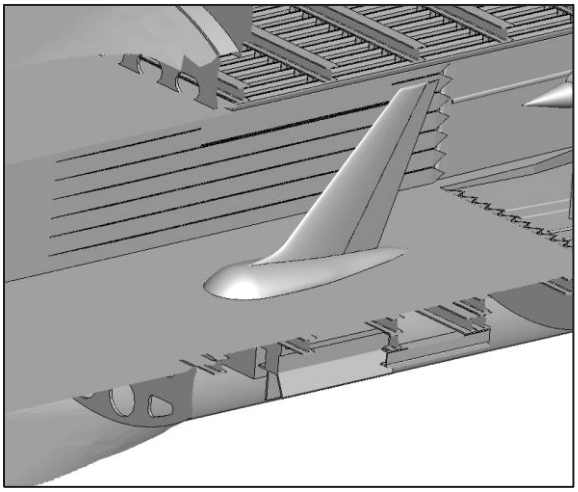

Figure 7 Tail Installed in Test Section

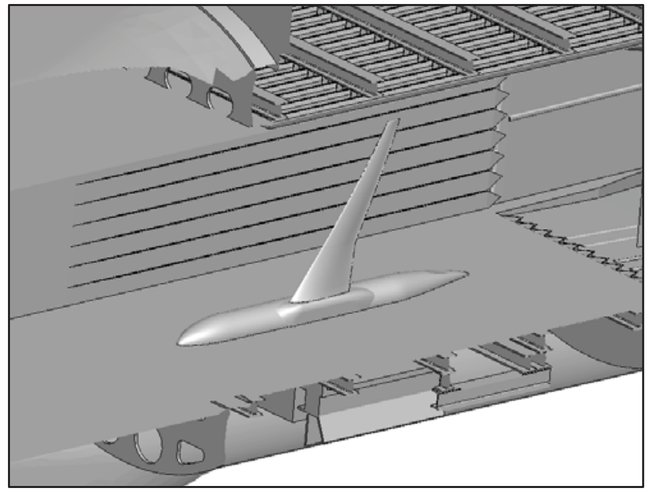

Figure 8 CRM Installed in Test Section

2.1 CRM Modeling

The wing body sample model chosen for this study was the AIAA CRM (Common Research Model) used for Drag Prediction Workshop 5 (DWP5).The geometry was obtained in a triangulated format and not as solid CAD geometry. It was scaled and located to meet the needs of this study. Figure 8 shows the CRM installed in the computational model. Details of how the CRM was integrated into the model follow.

First, the half model of the CRM wing and body was created from the original overset triangulated grids. Two versions, coarse and refined were produced. In the end the coarse mesh was deemed adequate for the window study purposes and so was used for the remainder of the process. STAR-CCM+ was used to close the mesh along the vehicle centerline symmetry plane to create a water tight geometry. The model was then opened in Overgrid and scaled, translated, and rotated to the correct location for use in the 11-foot UPWT CAD model. A 1" high standoff skirt at the CRM symmetry plane was added in STAR-CCM+. Attempts were then made to union the CRM model with the 11 foot tunnel geometry mesh using Cart3D tools. While it was possible to union it with a large flat plate that represented the tunnel floor, it was not readily possible to incorporate the resulting geometry back into the full tunnel geometry using tools such as MatLab in the same way the strut is merged with the full model. STAR-CCM+ was used to do the final union of the CRM model with the full tunnel and output the combined triangulation.

3.0 Computational Analysis

To get an initial check of the effect of the large windows, Cart3D (3) analysis was conducted on various configurations. Three sets of results were delivered. The first included a tail model (referenced above), the second consisted of the CRM geometry in the test section with an extra set of slots included above and below the large windows, and the third was with CRM installed and the extra slots removed.

Table 1 gives configuration and other information for the cases delivered. The first set studied had the strut centerbody positioned at a z-offset of zero. All subsequent studies with the CRM model installed had the centerbody z-offset at +38 inches to replicate the usual position for half body testing in the 11-foot UPWT. All cases were run with a target centerline Mach number of 0.85 to represent the highest expected Mach number for this type of geometry. The geometry was selected as representative of the larger (highest blockage) type of model that would most likely be affected by changes in the wall porosity and flow. All cases averaged around 32 – 33 million grid cells for the solution and contained about 2.1 – 2.3 million surface mesh elements to define the geometry. The cases listed in the table represent the best obtained solution for the given configuration in a given set. In all sixty-two Cart3D runs were made for this study. Results are shown for the tunnel centerline, along two lines of pressure ports in the test section, and on three sections of the wing for the CRM cases. Figure 9 through Figure 21show the surface Mach numbers for a left and right isometric view for each of the configurations.

Table 1 Cart3D Cases Run for Large Window Study

Case Name	Set	Floor Closed	Large Window	Extra Baffles	Model in Test Section	Nose Angle of Model (deg.)	Centerbody Z offset (in)	Average Reference Mach
wsrun4	1,2,3	no	no	-	no	-	0	0.849
wsrun7	1,2,3	yes	no	-	no	-	0	0.846
wsrun21	1,2	no	yes	yes	no	-	0	0.853
wsrun29	1	yes	no	-	tail	0	0	0.857
wsrun30	1	yes	yes	yes	tail	0	0	0.859
wsrun37	2	yes	no	-	CRM	0	38	0.867
wsrun38	2	yes	yes	yes	CRM	0	38	0.872
wsrun39	2,3	yes	no	-	CRM	4	38	0.847
wsrun40	2	yes	yes	yes	CRM	4	38	0.860
wsrun46	3	yes	yes	no	CRM	0	38	0.854
wsrun49	3	yes	yes	no	CRM	4	38	0.851
wsrun51	3	yes	no	-	CRM	0	38	0.852
wsrun53	3	yes	yes	no	no	-	38	0.853

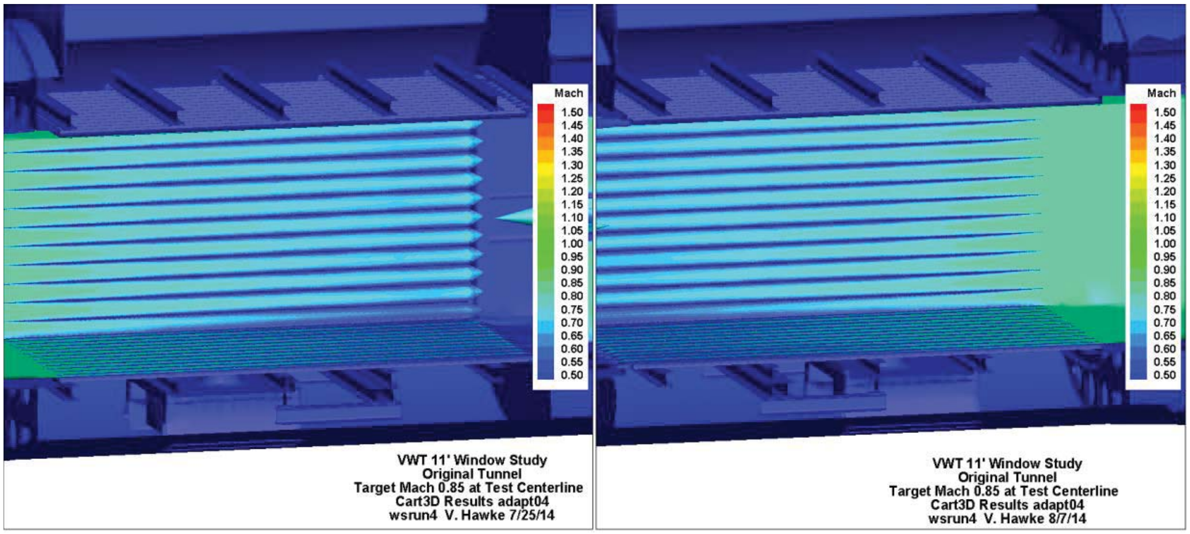

Figure 9 Floor Open, Original Windows/Tunnel, wsrun4, Sets 1, 2 and 3

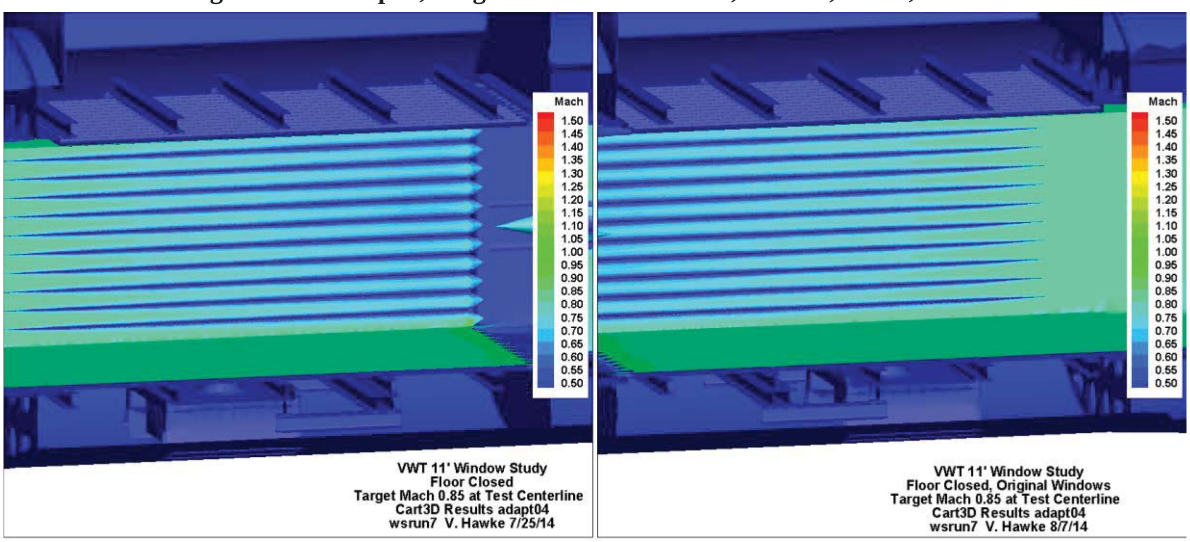

Figure 10 Floor Closed, Original Windows/Tunnel, wsrun7, Sets 1, 2 and 3

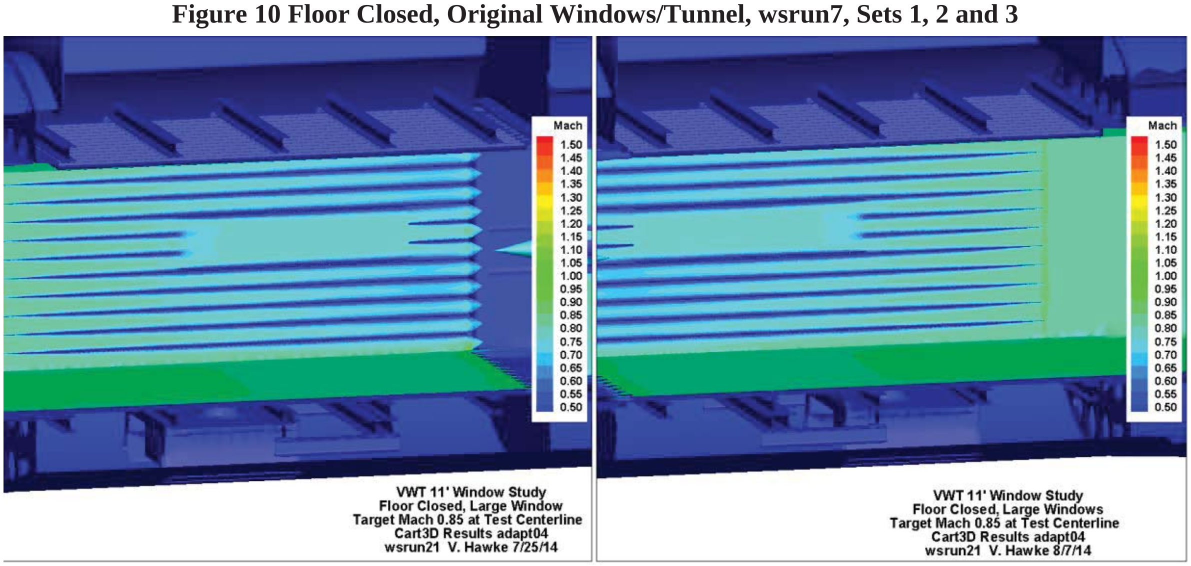

Figure 11 Floor Closed, Large Windows, Extra Slots, wsrun21, Sets 1 and 2

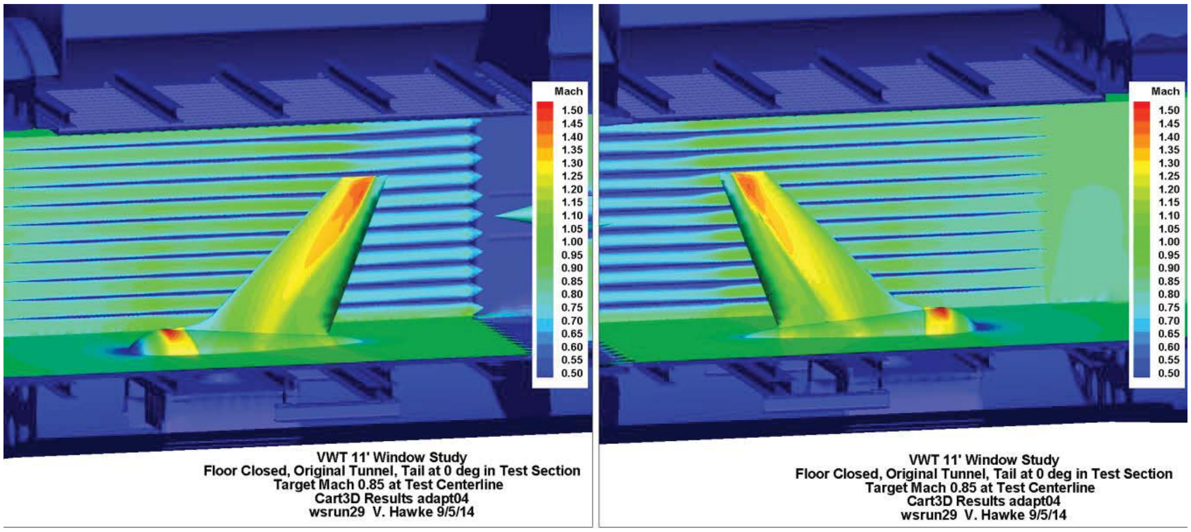

Figure 12 Floor Closed, Original Windows/Tunnel, Tail in Test Section, wsrun29, Set 1

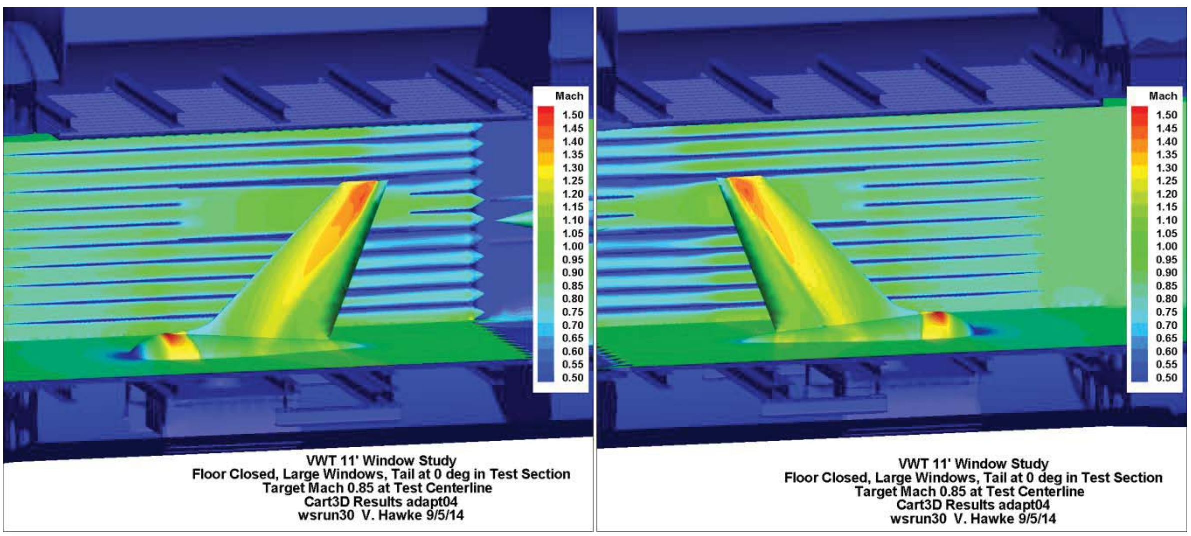

Figure 13 Floor Closed, Large Windows, Extra Slots, Tail in Test Section, wsrun30, Set 1

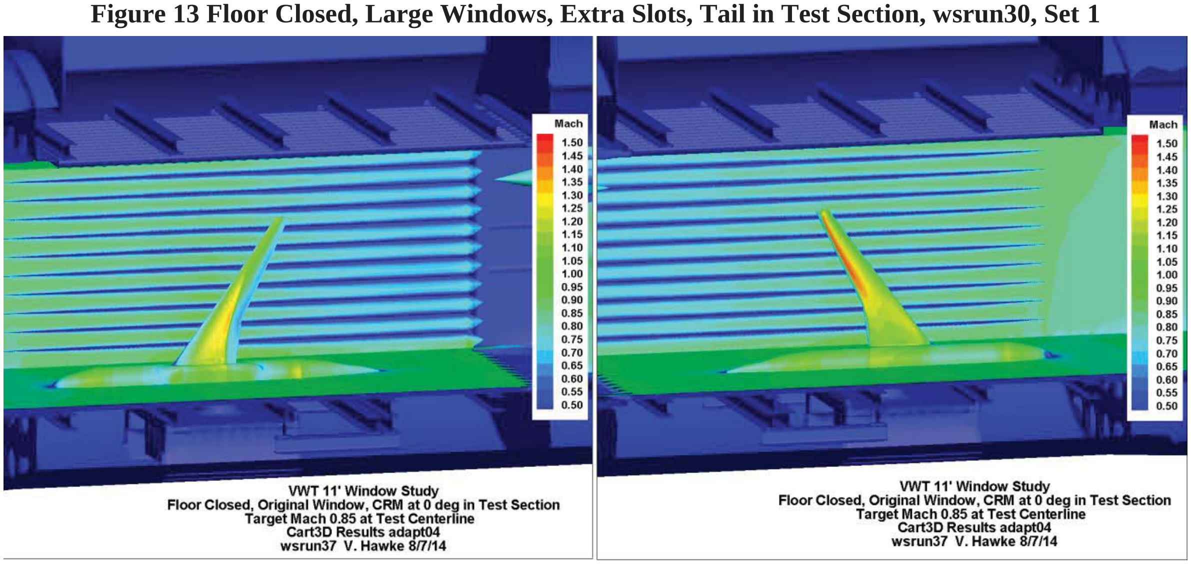

Figure 14 Floor Closed, Original Windows/Tunnel, CRM in Test Section, wsrun37, Set 2

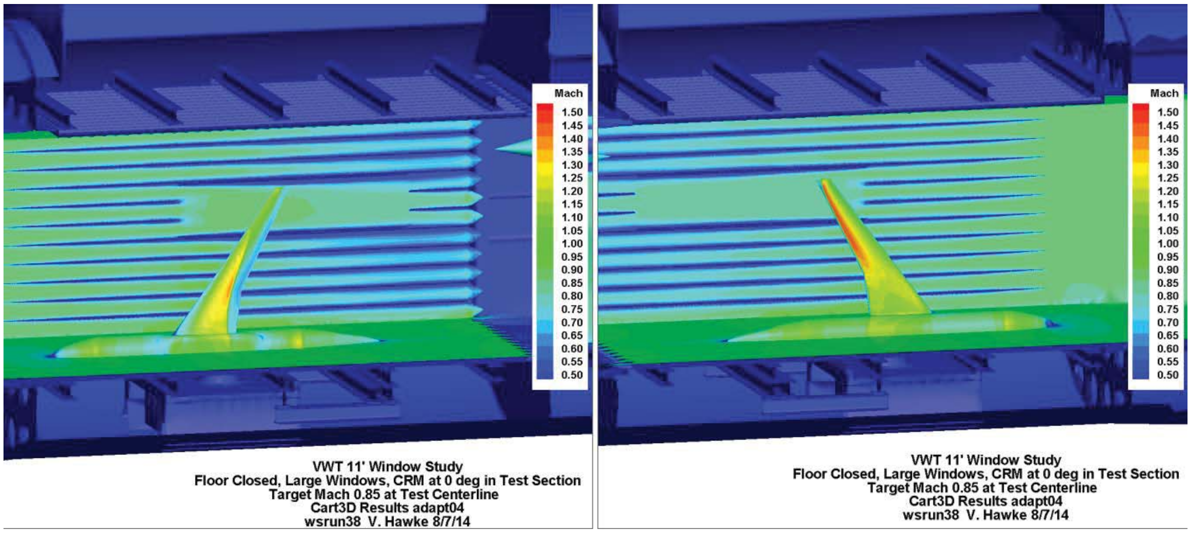

Figure 15 Floor Closed, Large Windows, Extra Slots, CRM in Test Section, wsrun38, Set 2

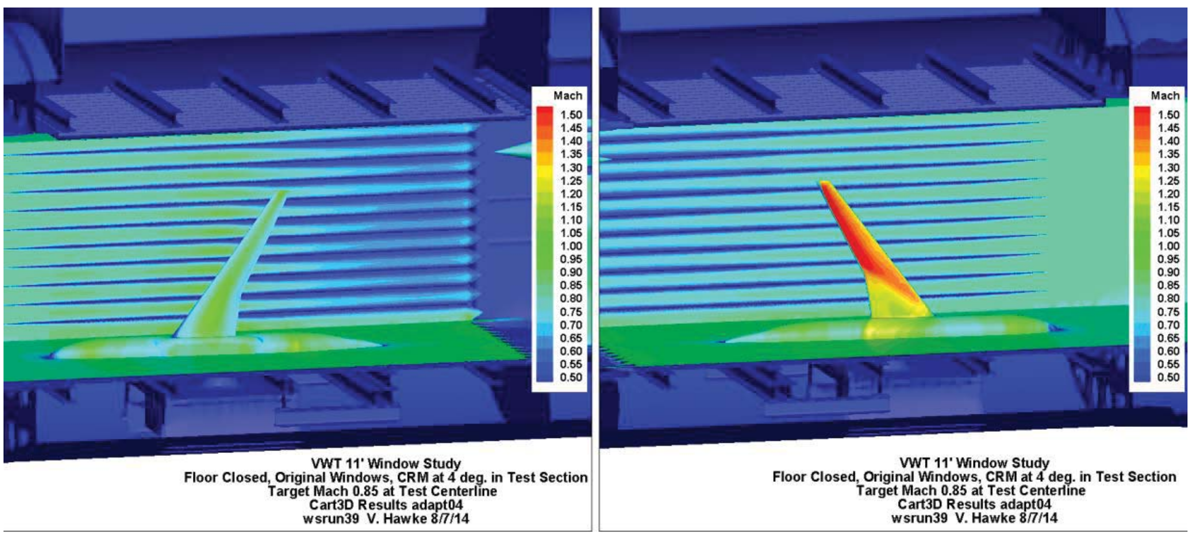

Figure 16 Floor Closed, Original Window/Tunnel, CRM in Test Section at 4 deg., wsrun39, Sets 2 and 3

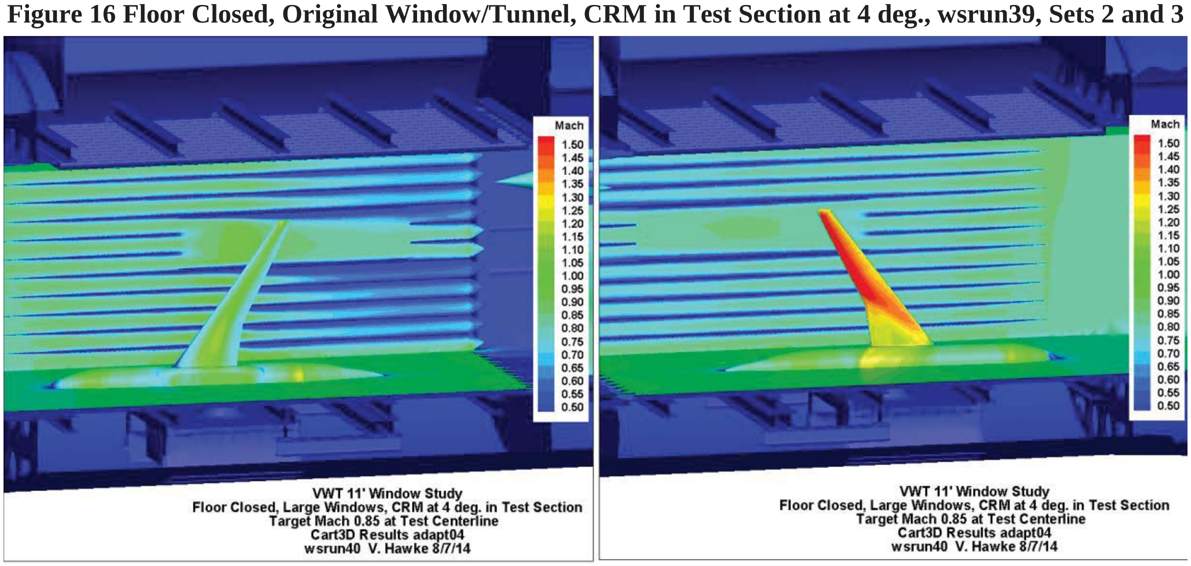

Figure 17 Floor Closed, Large Windows, Extra Slots, CRM in Test Section at 4 deg., wsrun40, Set 2

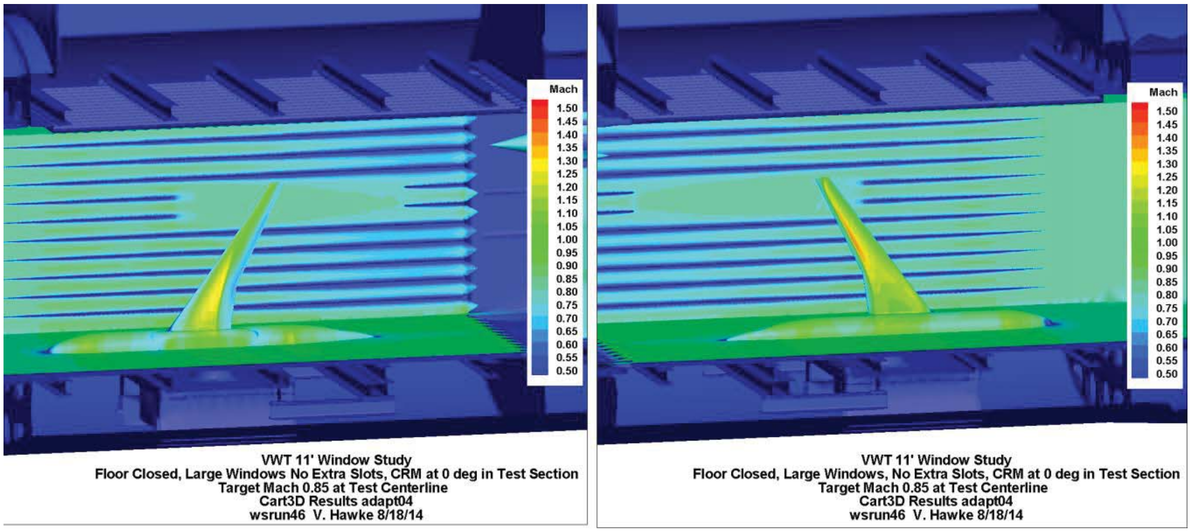

Figure 18 Floor Closed, Large Windows, No Extra Slots, CRM in Test Section, wsrun46, Set 3

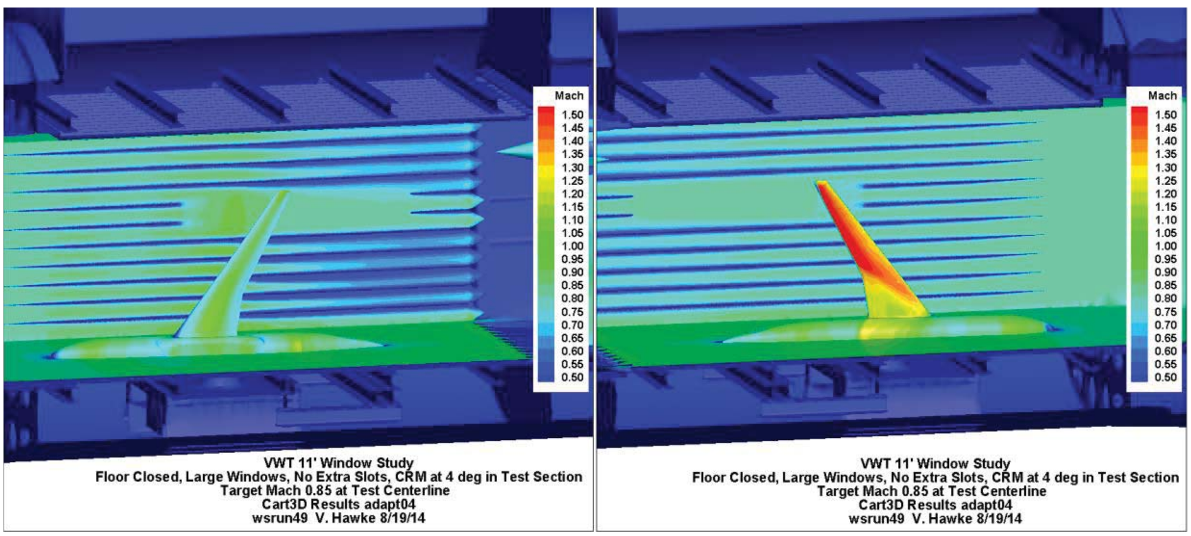

Figure 19 Floor Closed, Large Windows, No Extra Slots, CRM in Test Section at 4 deg., wsrun49, Set 3

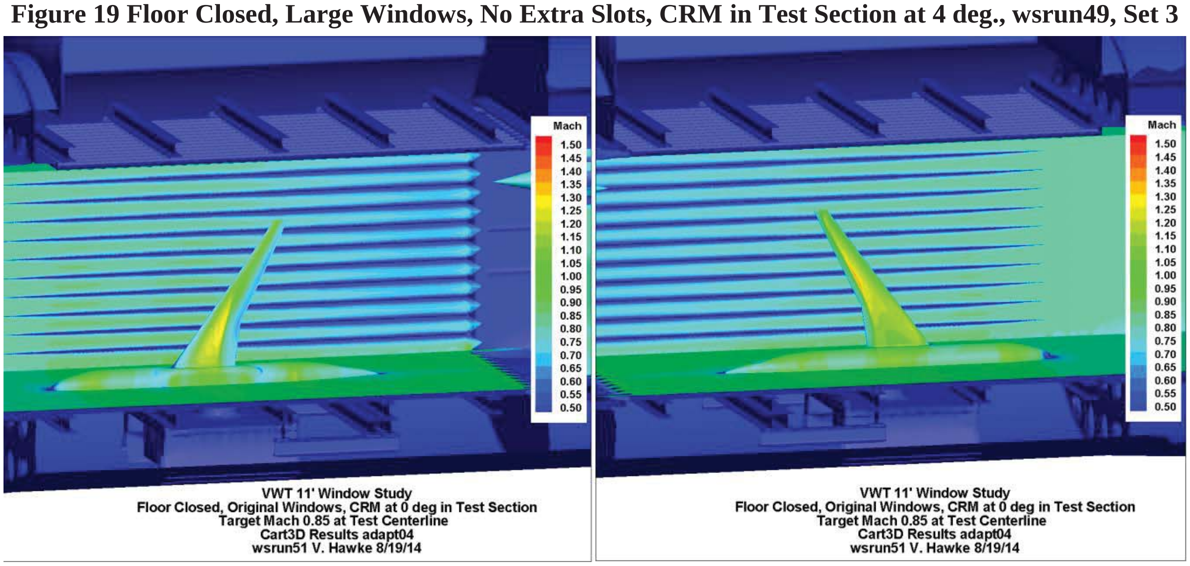

Figure 20 Floor Closed, Original Windows/Tunnel, CRM in Test Section wsrun51, Set 3

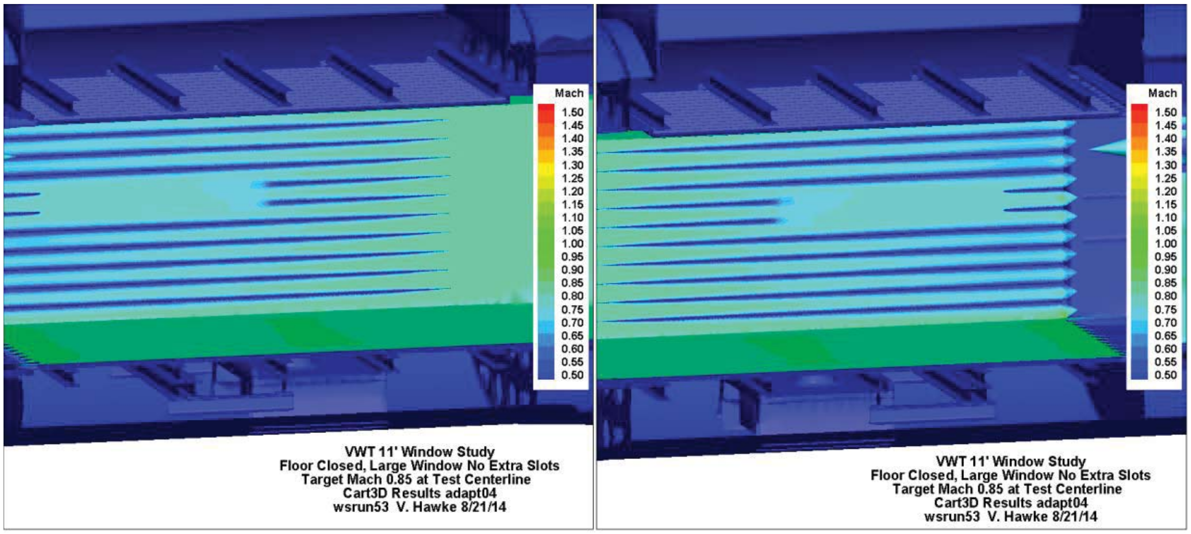

Figure 21 Floor Closed, Large Windows, No Extra Slots, wsrun53, Set 3

3.1 Results for Large Windows with Extra Slots, Tail Model (Set 1)

The first set of results were presented to the wind tunnel group on July 28, 2014. Five configurations were shown to provide a first check of the effects of a large window installation in the 11-foot UPWT. The model used was the Boeing 757 simplified tail scaled down to fit in the tunnel. The tail span was 7.6 feet including the blister. The forward-most tunnel station of the blister/tail was about 55.5 inches and the aft-most was approximately 189.5 inches. The cases with the tail installed were all run at a nominal nose rotation of zero degrees. All of the large window cases for this set included the extra slots both above and below the windows. See Figure 22 for a close-up view of the additional slots on the right (South) window. The large window is installed between tunnel stations 99 and 231 combining the current middle three panel sets. The target Mach number was measured along the primary test section centerline without the model installed and was measured at the forward portion of the tunnel when the model was installed. Figure 23 shows the tunnel centerline Mach number distribution extracted from the Cart3D simulation. Shown also are notional representations of the tunnel window and the extent of the model along the tunnel centerline.

Figure 22 Large Window with Extra Slots Close-Up

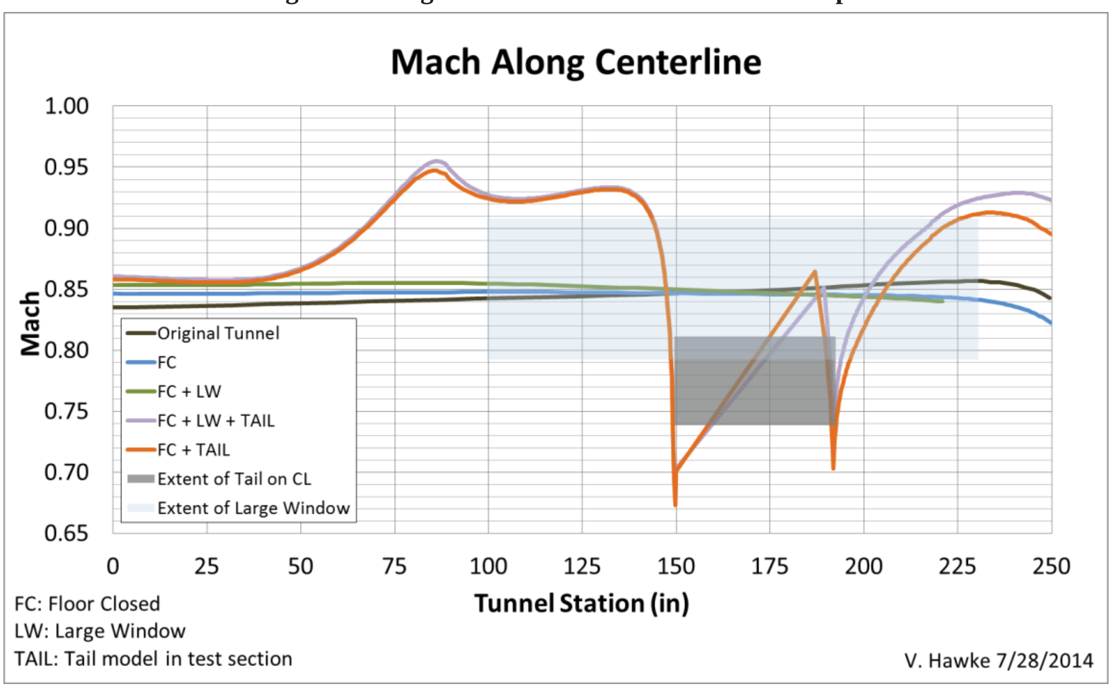

Figure 23 Mach along Tunnel Centerline Cart3D Results for Set 1

Figure 24 shows the positions of the test section pressure tap lines. Pressure data for tunnel tests is collected along these lines. Solution data is also collected from Cart3D along these lines. Figure 25 and Figure 26 show the local surface Mach number along lines 7 (above the right/South wall window) and 4 (to the left of the model on the floor), respectively (highlighted in blue in Figure 24).

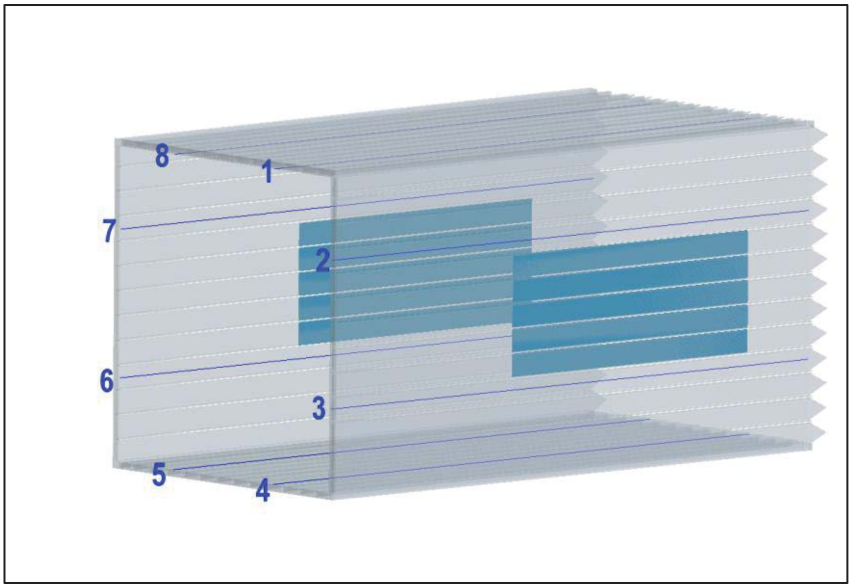

Figure 24 Pressure Tap Lines in Test Section

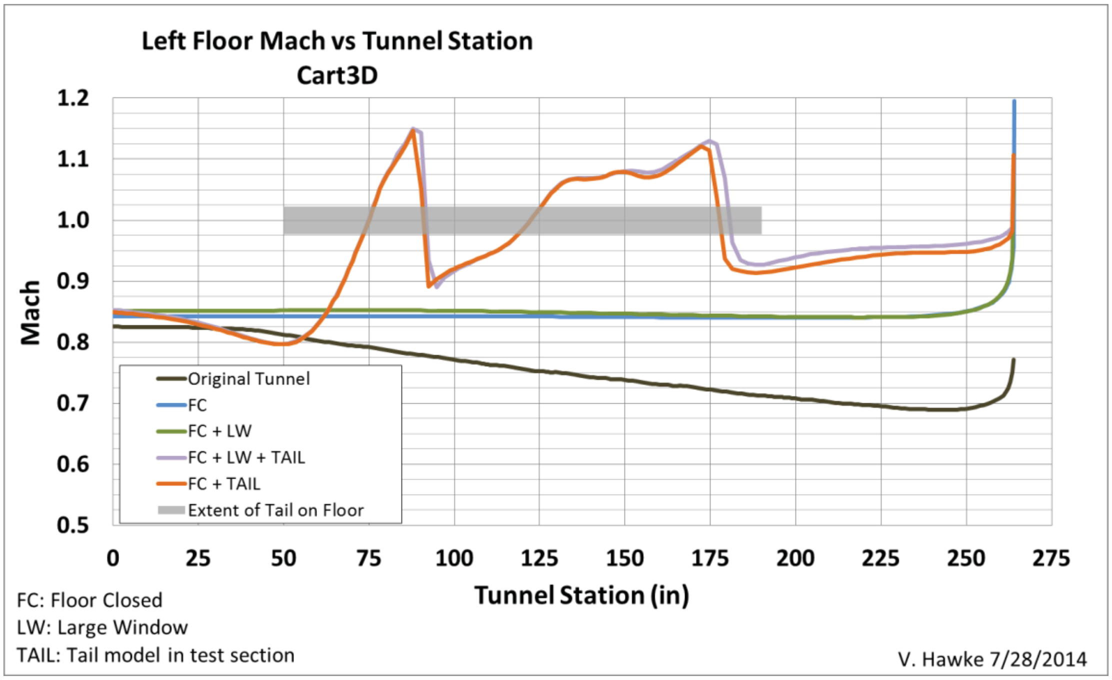

Figure 25 Set 1 Left Floor (Line4) Mach vs. Tunnel Station

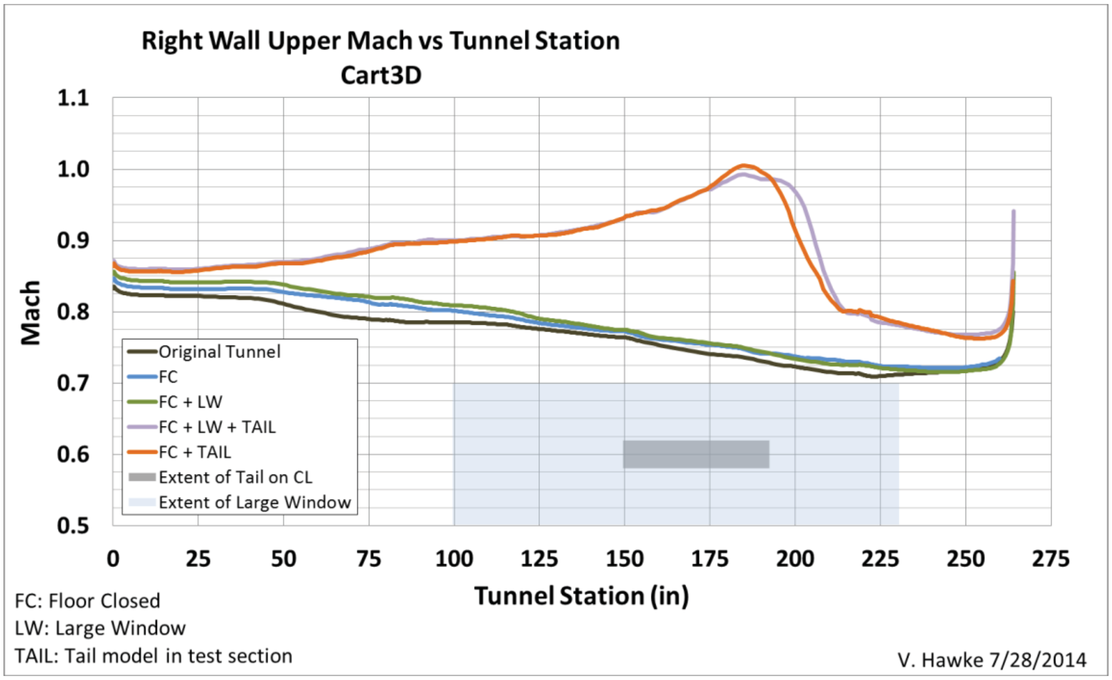

Figure 26 Set 1 Right/South Wall Upper (Line 7) Mach vs. Tunnel Station

3.2 Results for Large Window with Extra Slots, CRM Model (Set 2)

The second set of results with the CRM installed in the test section and showing the effects of a large window with extra sets of slots were delivered to the wind tunnel group via an Excel spreadsheet and PowerPoint slide presentation. The CRM wing half-span was 7.3 feet including the half body. The forward-most tunnel station of the body was about 12.5 inches and the aft-most point was approximately 198.5 inches. The cases with the CRM installed were run at nominal nose rotations of zero degrees and at 4 degrees (nose up/tunnel right). All of the large window cases for this set included the extra slots both above and below the window. The target Mach number was measured along the primary test section centerline without the model installed and was measured at the forward portion of the tunnel when the model was installed. Figure 27 shows the tunnel centerline Mach number distribution extracted from the Cart3D simulation. Shown also are notional representations of the tunnel window and the extent of the model along the tunnel centerline Figure 28 and Figure 29 show the local surface Mach number along tunnel pressure tap lines 7 (above the right/South wall window) and 4 (to the left of the model on the floor), respectively (see Figure 24).

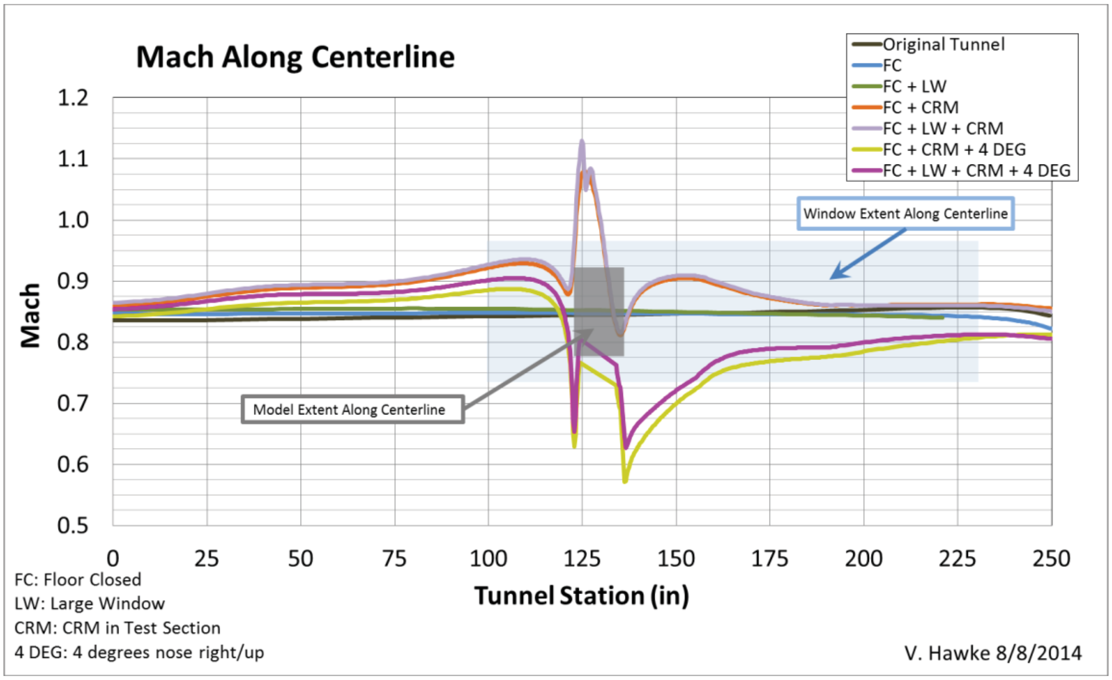

Figure 27 Mach along Tunnel Centerline Cart3D Results for Set 2

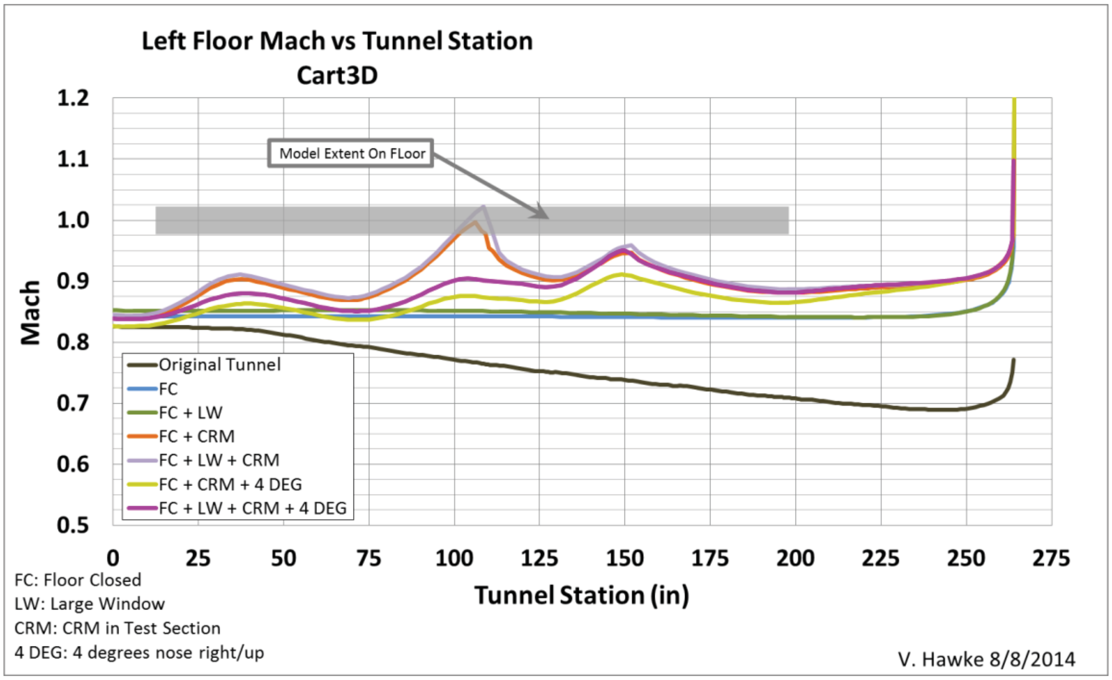

Figure 28 Set 2 Left Floor (Line 4) Mach vs. Tunnel Station

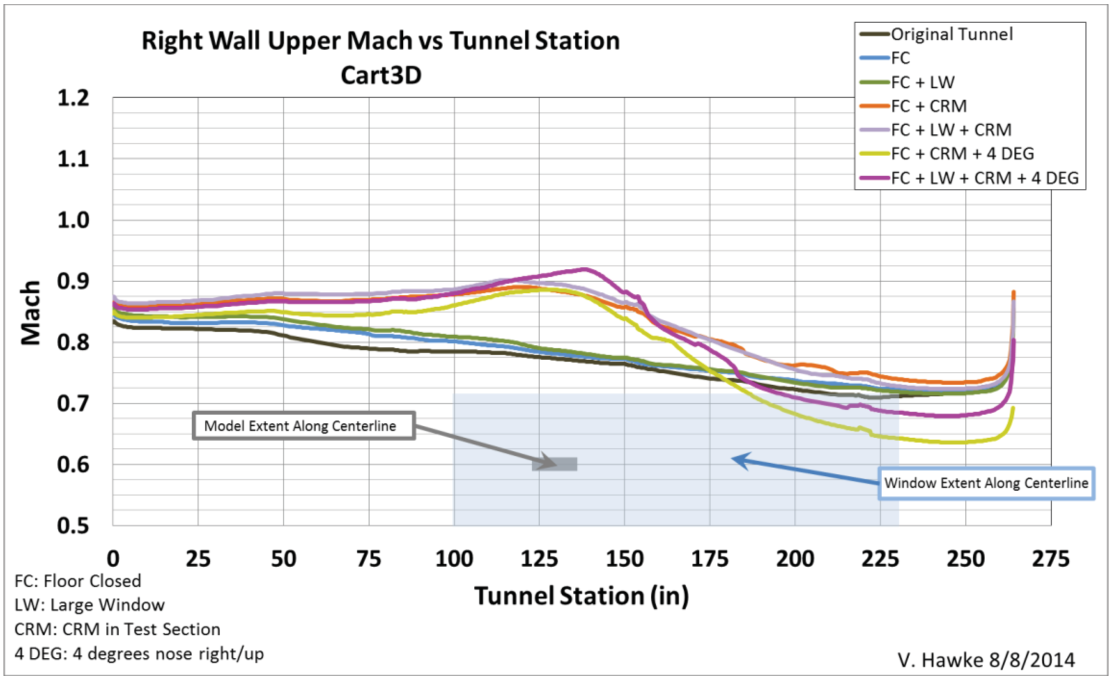

Figure 29 Set 2 Right/South Wall Upper (Line 7) Mach vs. Tunnel Station

Three sections of the CRM wing were compared with and without the large windows (w/extra slots), with the CRM at 0 and 4 degrees. Figure 30 shows the Mach surface values vs. tunnel station for a wing section (both left/bottom and right/upper surface) near the root. Figure 31 and Figure 32 show the Mach values for a mid-span section and a section near the tip, respectively.

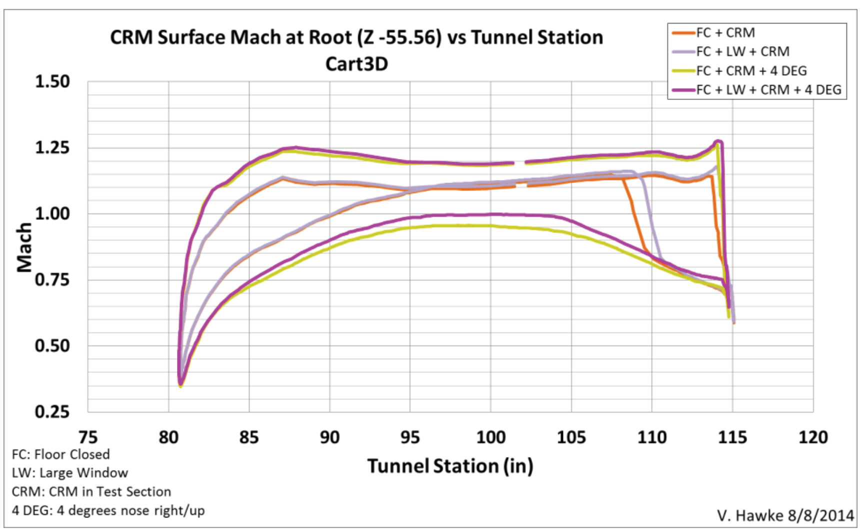

Figure 30 Set 2 Mach Distribution at Root Section of CRM

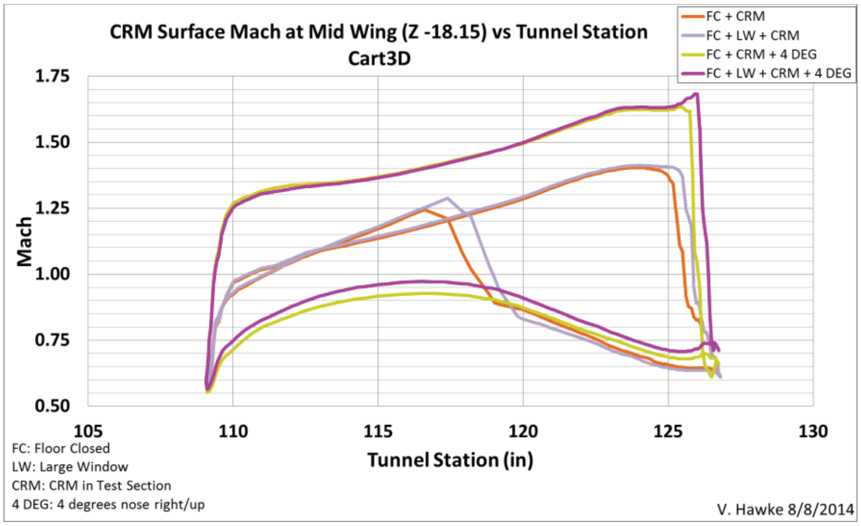

Figure 31 Set 2 Mach Distribution at Mid-span Section of CRM

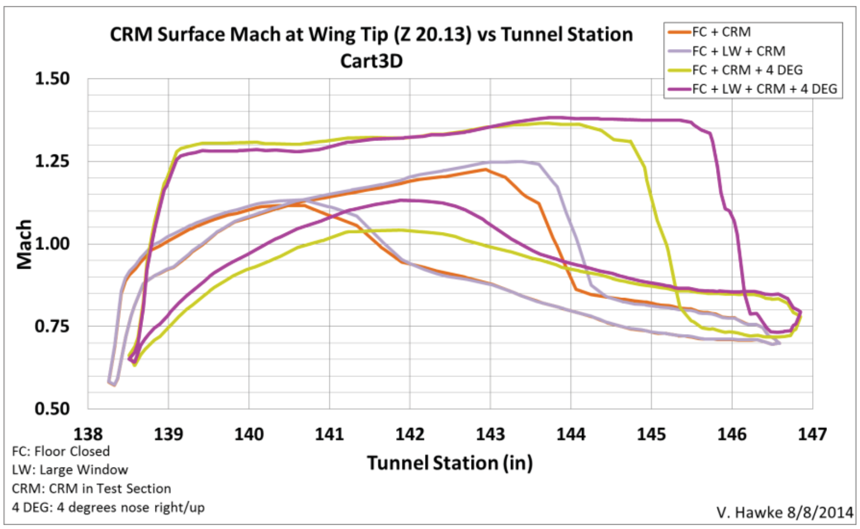

Figure 32 Set 2 Mach Distribution at Tip Section of CRM

3.3 Results for Large Windows without Extra Slots, CRM Model (Set 3)

The third set is similar to the second, using the same wing body model (CRM) in the same positions (0° and 4°), but it does not include the added set of slots along the top and bottom of the windows. A close-up view is shown in Figure 33. This configuration was requested as it more likely reflects the initial test configuration (where the current slots will be taped over in the region of the large windows). Figure 34 shows the predicted Mach distribution along the centerline of the tunnel for set 3. Similar to set 2, Figure 35 and Figure 36 show the local surface Mach number along tunnel pressure tap lines 7 (above the right/South wall window) and 4 (to the left of the model on the floor), respectively (see Figure 24) for set 3.

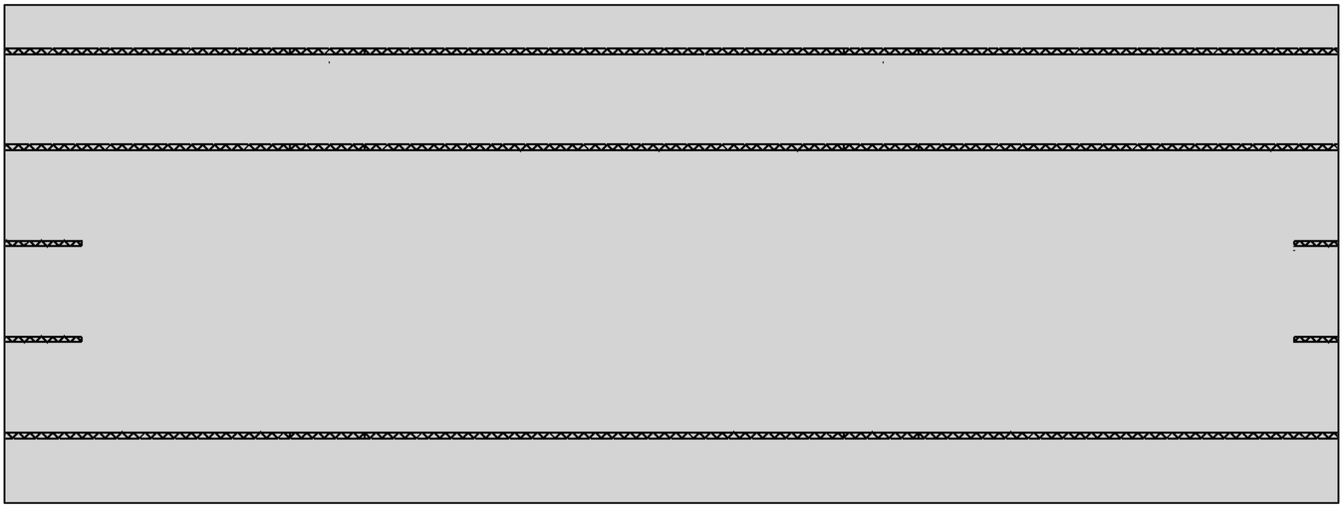

Figure 33 Large Window without Extra Slots Close Up

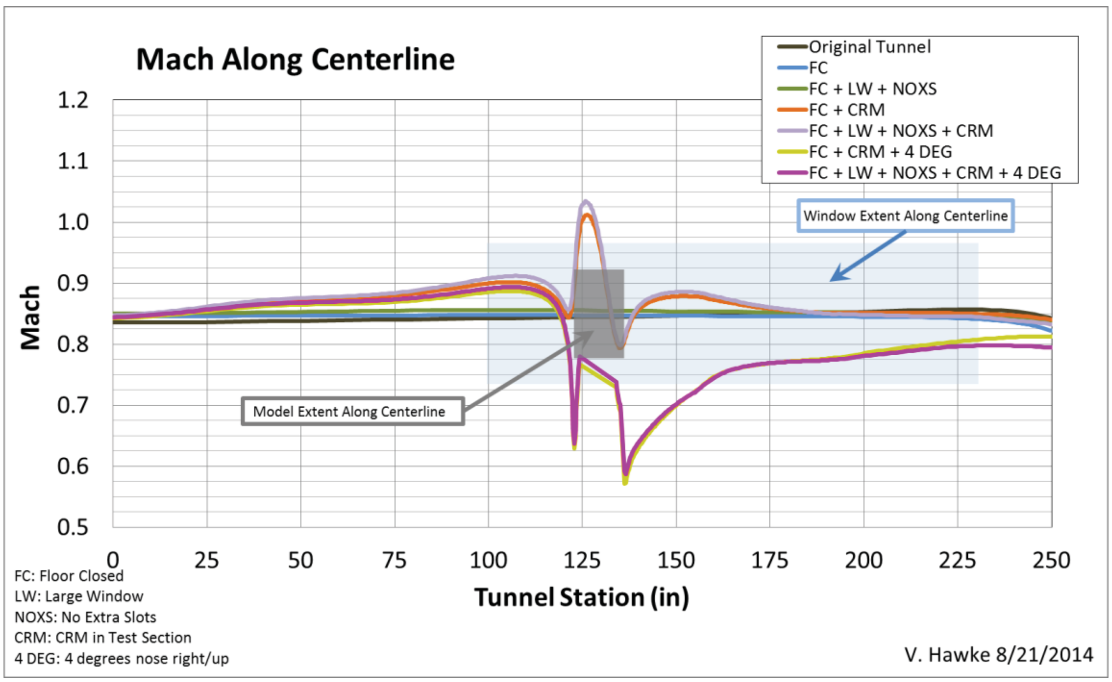

Figure 34 Mach along Tunnel Centerline Cart3D Results for Set 3

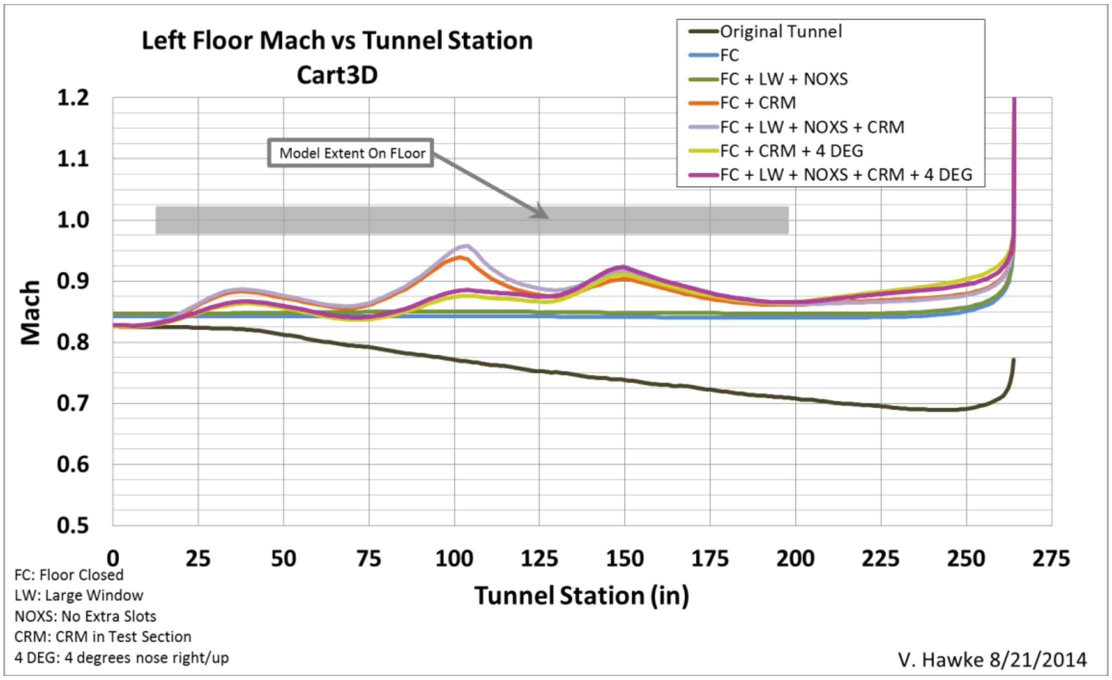

Figure 35 Set 3 Left Floor (Line 4) Mach vs. Tunnel Station

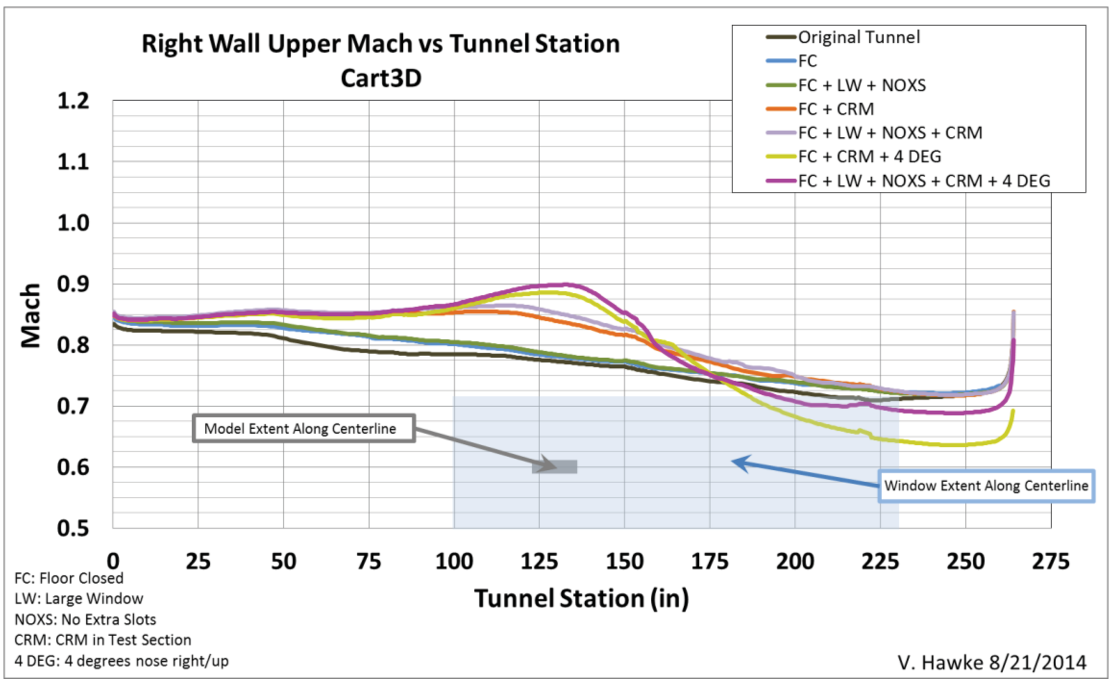

Figure 36 Set 3 Right/South Wall Upper (Line 7) Mach vs. Tunnel Station

Again as with set 2 three sections of the CRM wing were compared with and without the large windows (w/o extra slots), with the CRM at 0 and 4 degrees. Figure 37 shows the Mach surface values vs. tunnel station for a wing section (both left/bottom and right/upper surface) near the root. Figure 38 and Figure 39 show the Mach values for a mid-span section and a section near the tip, respectively.

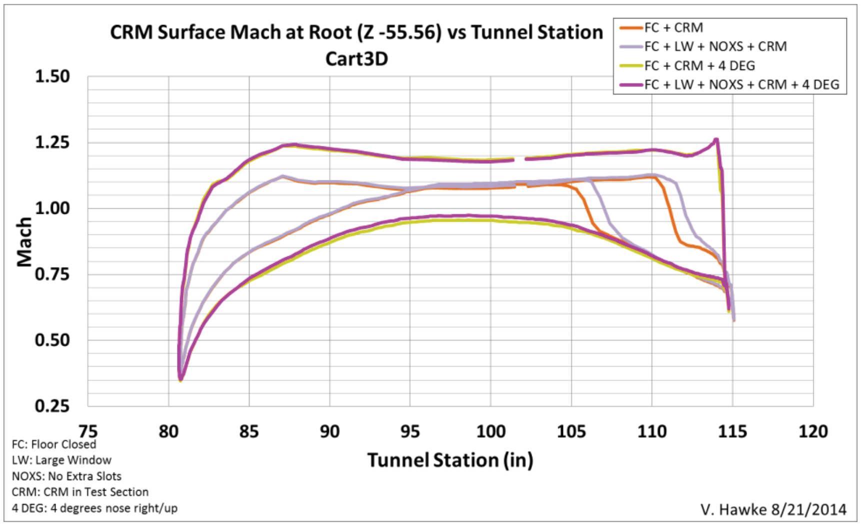

Figure 37 Set 3 Mach Distribution at Root Section of CRM

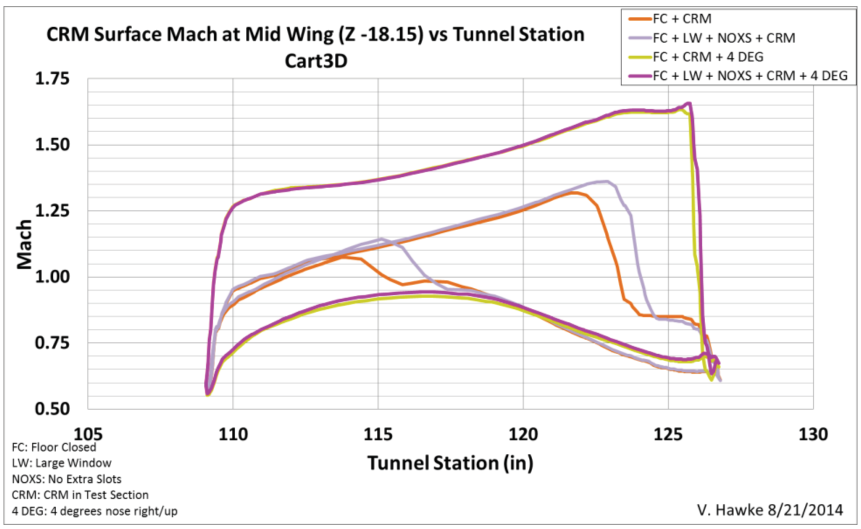

Figure 38 Set 3 Mach Distribution at Mid-span Section of CRM

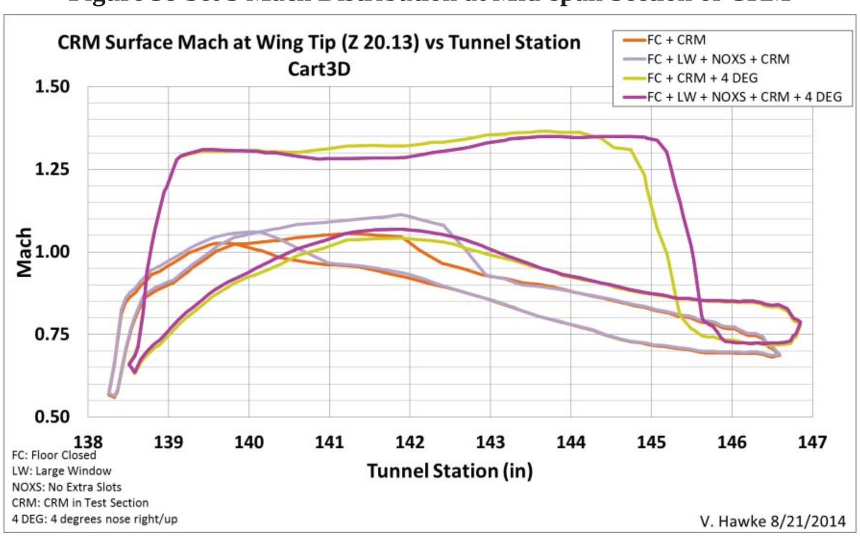

Figure 39 Set 3 Mach Distribution at Tip Section of CRM

4.0 Conclusions/Future Work

On the whole, the results seen from Cart3D followed the expected pattern with the shocks occurring further aft with the large windows installed. The overall shape and characteristics of the solution with and without the large windows seem similar. The sensitivity at the CRM wing tip with and without the extra slots on the large windows could be explored further by checking nearby sections. The choice of tip section may be too close to rapidly changing tip effects and would be better represented by a cut slightly further inboard. Additional simulations at lower Mach numbers closer to those used by other large transports may be useful. Further work can be done to extract C_p values on the wing in order to compare with current data on the CRM.

5.0 References

1. **Hawke, V.** *11-by 11-Foot Transonic Leg of the Unitary Plan Wind Tunnel (UPWT) CAD Model.* 2014. NASA/CR--2014--218371.
2.. *Active Flow Control Vertical Tail CAD Model for Computational Fluid Dynamics Analysis.* 2014. NASA/CR--2014--218355.
3. **Aftosmis, M.** Cart3D Main Page. [Online] [Cited: 8 27, 2014.] http://people.nas.nasa.gov/~aftosmis/cart3d/.