NASA/CR—2014–218371

11-by 11-Foot Transonic Leg of the Unitary Plan Wind Tunnel (UPWT) CAD Model

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July 2014

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Nomenclature

CAD	: computer aided drafting/design
TS	: tunnel station, all values shown are in inches
Cart3D	: Cartesian 3 Dimensional
LAV	: Launch Abort Vehicle

1.0 Overview

A ProEngineer CAD model of the 11-Foot Unitary Plan wind tunnel test section, diffuser inlet, plenum chamber, strut and aft diffuser has been created for use with analysis tools such as Cart3D and Star CCM+. Figure 1 shows an overview of the model. The primary reference coordinate system is located at TS 0 (Tunnel Station 0) with X positive towards the downstream direction, Y positive out the right wall and Z positive up. Separate parts of the tunnel are created as parts files and assembled in an assembly file. Two merged solid parts are used for meshing. This report describes each of the parts files and features of the merged models.

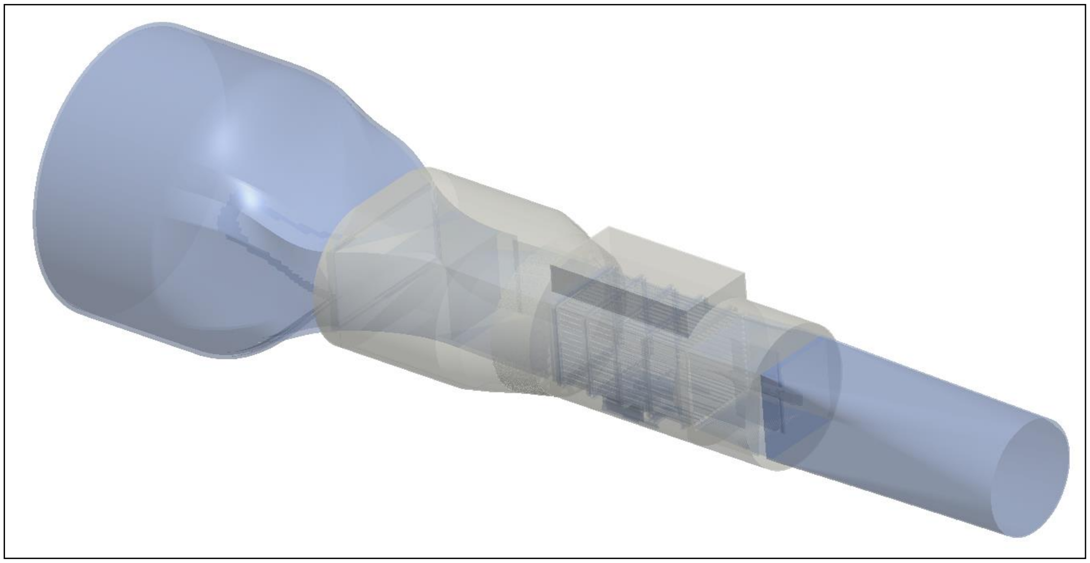

Figure 1 CAD Model of 11-Foot Wind Tunnel

2.0 Process

The parts created for use in CFD analysis are based on previous early CAD models, drawings obtained from the 11-Foot wind tunnel group and the Ames ERC library as well as measurements taken directly in the tunnel.

Table 1 lists the drawings used along with a brief description of the drawing. Additional information and details about the tunnel were gleaned from various papers and reports including those given in the reference list below[1234].

Table 1 List of Drawings

Drawing Number	Description
327-5021-M4 2 of 2	Sectional Plan (top view) forward tunnel
327-5201-M4 E 1 of 2	Sectional Plan (top view) forward tunnel
327-5201-M5 C 1of 2	Sectional Elevation (side view) aft tunnel
327A-5201-M5 2 of 2	Sectional Elevation (side view) forward tunnel
327A-5201-M33 B	Side and front view of ring 36 (TS -14)
A327A-5201-M21 B	Front view ring 34 (TS -345)
A327A-5201-M23 B	Front view rings 34 A, 34 B, and 34 C (TS -307, -269 and -231)
A327A-5201-M27 B	Front view ring 35 (TS -193)
A327A-5201-M29 B	Front view ring 35A (TS -155)
A327A-5201-M31	Front view rings 35B and 35C (TS -117 and -74)
A327A-5201-M61 C	Front view ring 37 (TS 276)
A327A-5201-M62 B	Front view ring 38 (TS 420)
A327A-5201-M63 E	Front and side view A-63 – blade housing
A327A-5201-M71 B	Front view rings 39 and 40 (TS 630 and 840)
A327A-5201-M72 B	Side view aft diffuser
A327A-5201-M82 A	Front view rings 36 and 37 (TS -14 and 276)

3.0 Part Details

The main tunnel model is made up of eight parts. Additional features are added to the merged part. Table 2 lists the separate parts with a brief description of each of them.

Table 2 Parts List

Part/Assembly	Description	File Name
Forward Diffuser	Tunnel section forward of the inlet nozzle	vwt_11_fwd_diffuser.prt
Inlet Nozzle	Variable flex wall for left and right sides driven by Mach number input	vwt_11_nozzle.prt
Plenum Chamber	Outer plenum chamber around main test section and diffuser	vwt_11_plenum_chamber.prt
Test Section	Main test section with slotted walls. Includes aft diffuser section	vwt_11_test_section.prt
Baffles	Test section slot fillers	vwt_11_baffles.prt
Strut and Centerbody (Includes additional merged parts.)	Blade with centerbody. Centerbody location is angle of attack dependent. Also used to include sting assembly when model is present.	vwt_11_strut_centerbody.prt
Aft Diffuser	Tunnel section aft of the test section	vwt_11_aft_diffuser.prt
Sting	Sting used for cev-las_hpa testing Merged in to strut/centerbody part when model is present.	vwt_11_sting.prt
Knuckle Sleeve	Connection between strut centerbody and adapter. Merged in to strut/centerbody part.	vwt_11_knuckle_sleeve.prt
10 Degree Adapter	Adapter used for lav 26 aa testing. Merged in to strut/centerbody part when model is present.	vwt_11_upwt_sr-42_10-deg_adptr.prt
Structure	Structure around main test section.	vwt_11_structure.prt
Turntable	Simplified turntable structure under main test section to account for its blockage	vwt_11_turntable.prt
Merged Main Tunnel	Single dependent merged part used for final meshing. Includes additional features for computational grid box. Does not include strut, centerbody, sting assembly or model.	vwt_11.prt (includes vwt_11_fwd_diffuser.prt, vwt_11_nozzle.prt, vwt_11_plenum_chamber.prt, vwt_11_test_section.prt, vwt_11_baffles.prt, vwt_11_aft_diffuser.prt, and vwt_11_structure.prt)
LAV (Sample Test Article)	Based on LAV 26 aa test article	vwt_11_lav_26-aa.prt

3.1 Forward Diffuser

The forward diffuser is attached to the forward portion of the flexible wall inlet nozzle and is shown in blue in Figure 2. The cross-sections are per the available drawings. The transitions between are CAD artifacts and do not necessarily represent the actual geometry. The forward portion which is circular is extended further forward to provide a good region for starting the computational code via a boundary condition set on the forward most face.

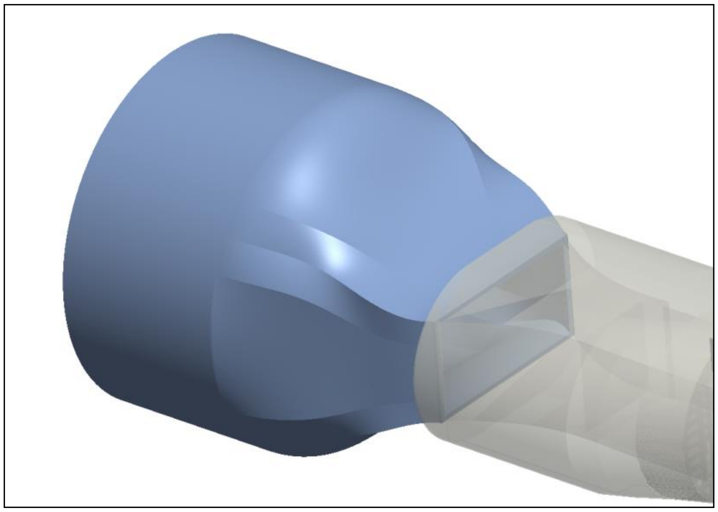

Figure 2 Forward Diffuser

3.2 Inlet Nozzle

Figure 3 shows the inlet nozzle highlighted in blue. In the tunnel the variable flexwall inlet shape is driven by 3 jack screws forward of the test section at fixed tunnel stations. The CAD model mimics the flexwall jack positions and uses a spline curve to model the inlet side walls. The user is able to set an input Mach parameter that in turn drives the CAD model shape. An Excel spreadsheet was used to come up with appropriate equations for each of the jack position curves to allow for the variable Mach number to be set. Each of the "jack positions" is dependent on equations that model the table provided by the wind tunnel group. Appendix A has the list of equations as implemented in ProEngineer to model the jack positions and the table from the wind tunnel group that they are based on.

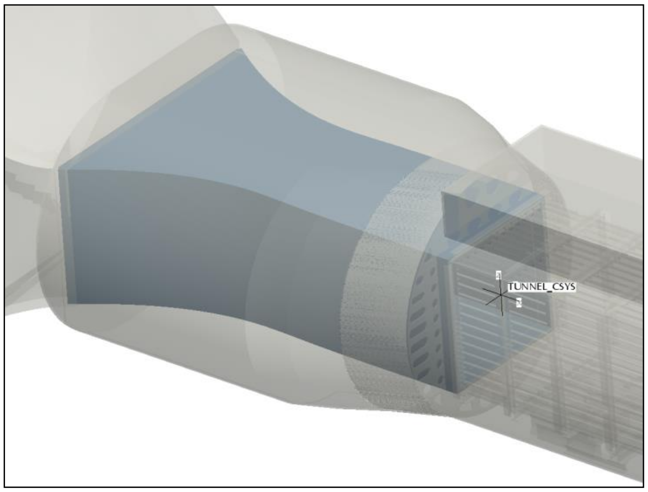

Figure 3 Inlet Nozzle

3.3 Plenum Chamber

Figure 4 shows a view of the outer plenum chamber. It includes the forward bulkheads cutouts as shown in Figure 5 and its cross-sections are based on the drawings listed in Table 1 above.

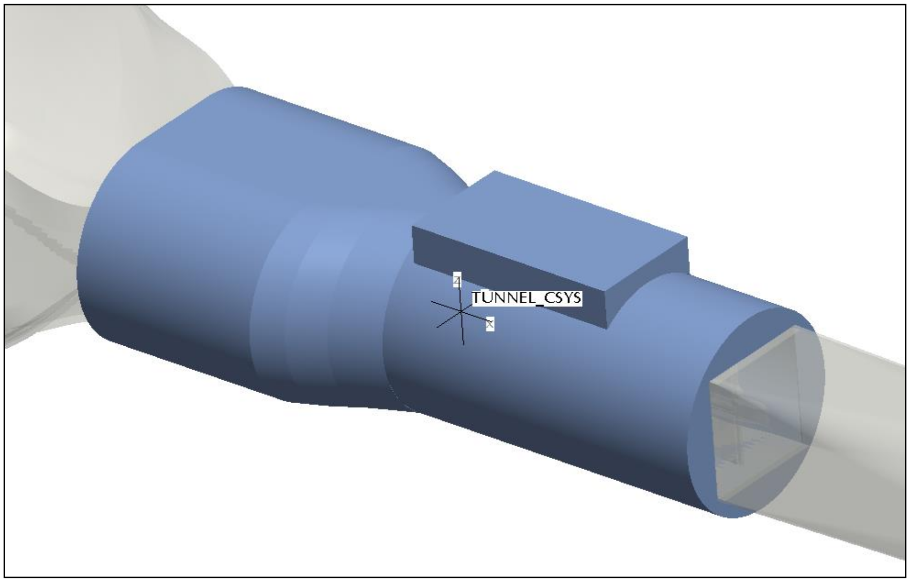

Figure 4 Plenum Chamber

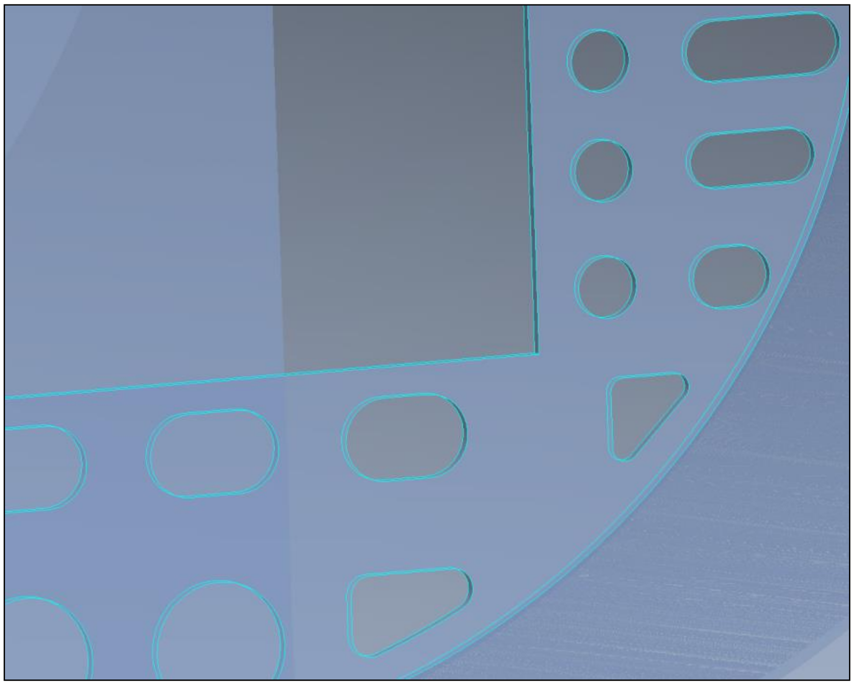

Figure 5 Plenum Chamber Cutouts Detail

3.4 Test Section

The test section part shown in blue in Figure 6, includes many details of the 11-Foot test section in addition to the aft area by the strut and the diffuser. Included are the forward transition triangles that allow the slotted walls to open from 0 to 100% in the first 40 inches of the main test section and corrugated walls. Also included are the vortex generators at the main test section exit The tunnel side walls diverge slightly from tunnel station 0 to tunnel station 264.

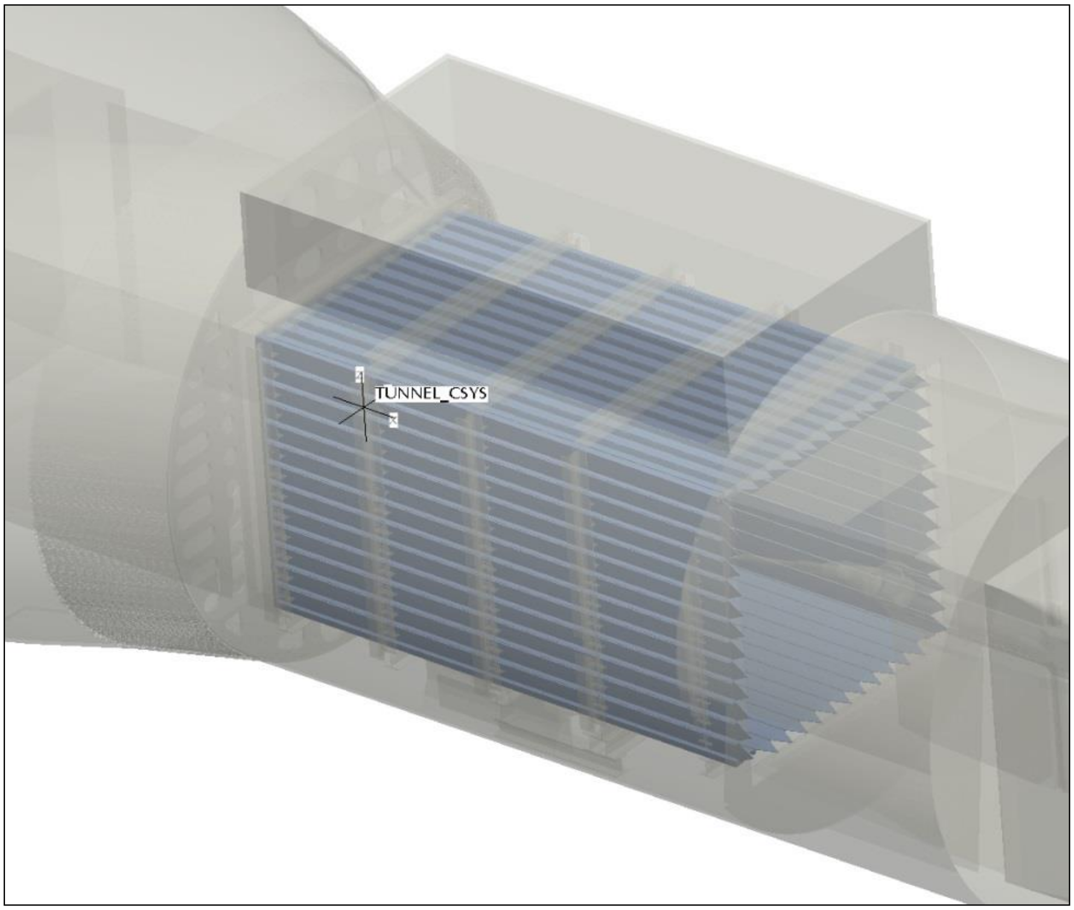

Figure 6 Test Section

Figure 7 shows a close-up view of the transition region used to ease the flow characteristics of the slotted walls from zero to one hundred percent from tunnel station 0 to tunnel station 40. It also shows some detail of the slot corrugation available in the model. Figure 8 has further detail of the corrugation in the slots showing some of the dimensions and constraints used in the construction.

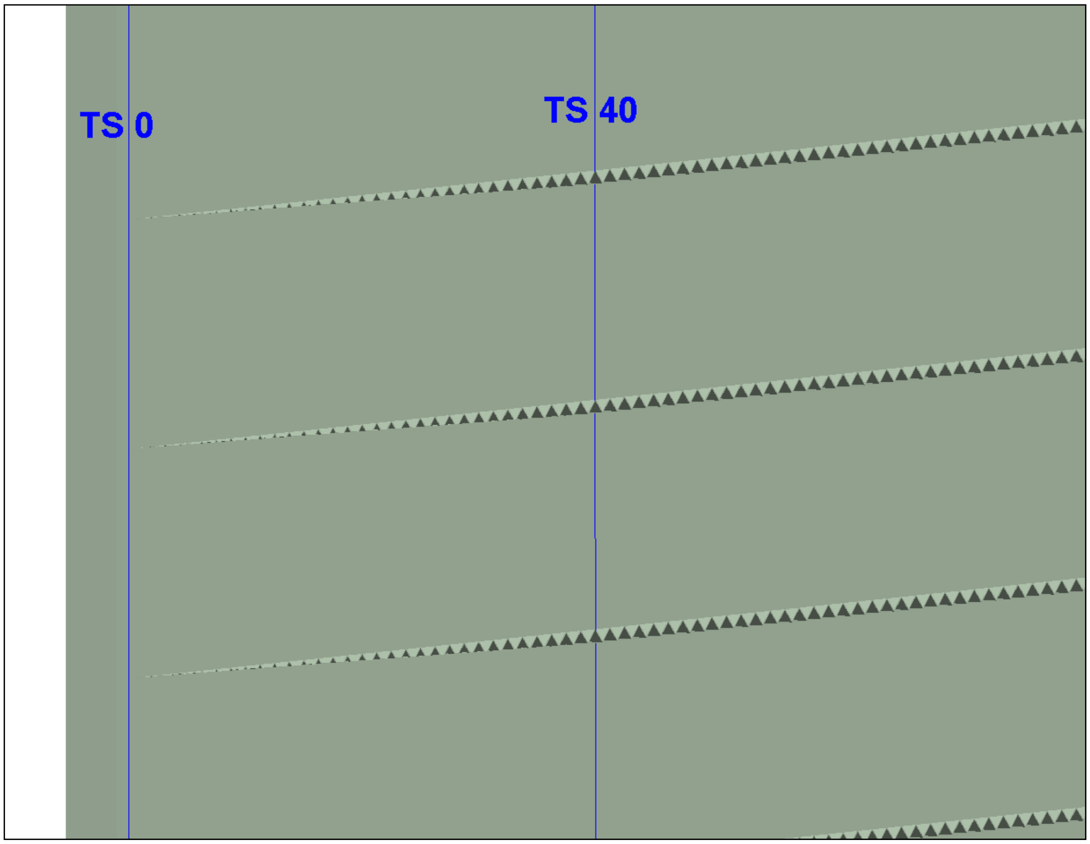

Figure 7 Slot Transition Detail in Tunnel Walls

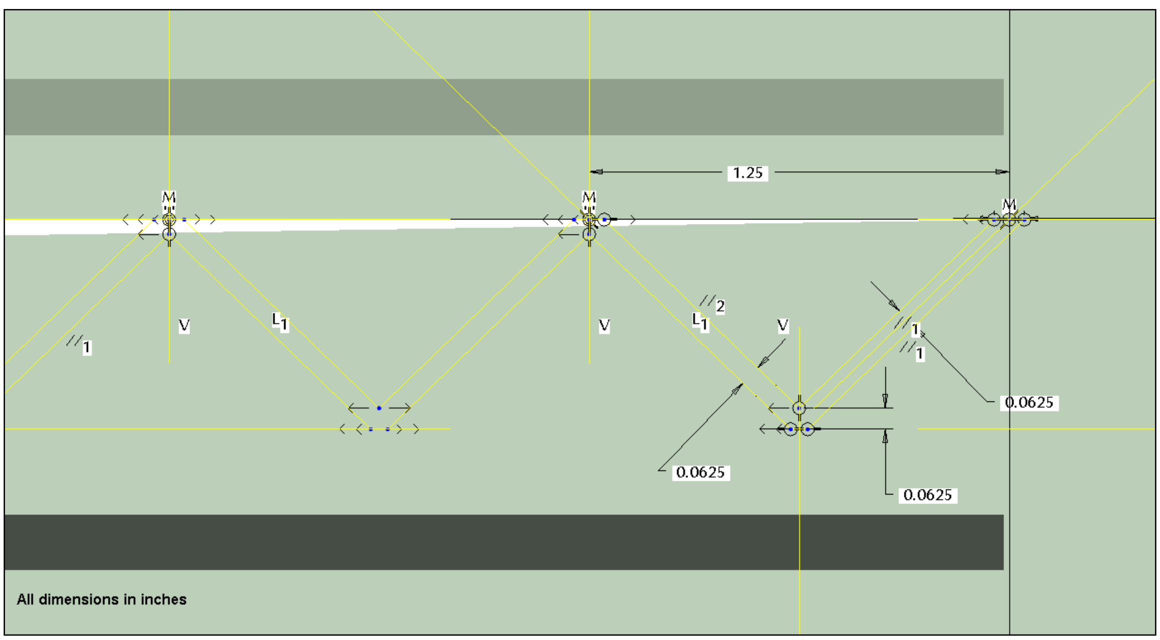

Figure 8 Slot Corrugation Detail

Vortex generators used to energize and entrain the plenum flow back in to the main test section are modeled and are located at the aft of the main test section (TS 264). Figure 9 shows a close up of a couple of the vortex generators. They are angled out of the main test section flow (in to the plenum chamber) by just over 6°. Also visible in Figure 9 is the lower left hand curb just aft of the main tunnel section and a close-up of the baffles inside the slotted tunnel walls. The curbs are present in all four corners of the aft tunnel and are part of the aft diffuser part.

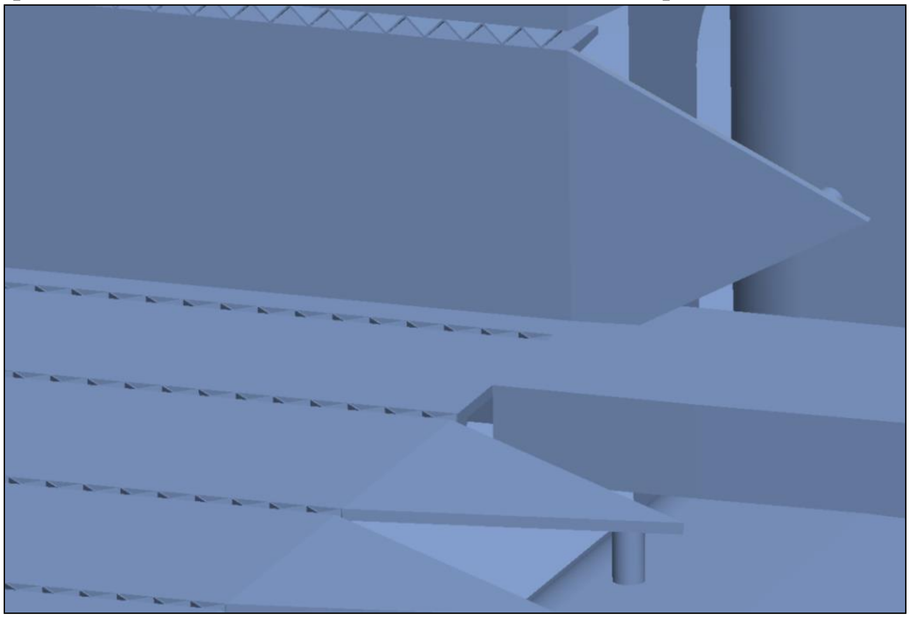

Figure 9 Detail of Vortex Generators and View of Curbs

3.5 Turntable

Since the turntable presents a non-negligible amount of blockage inside of the plenum chamber it has been included in the model. Figure 10 shows the turntable part highlighted in blue.

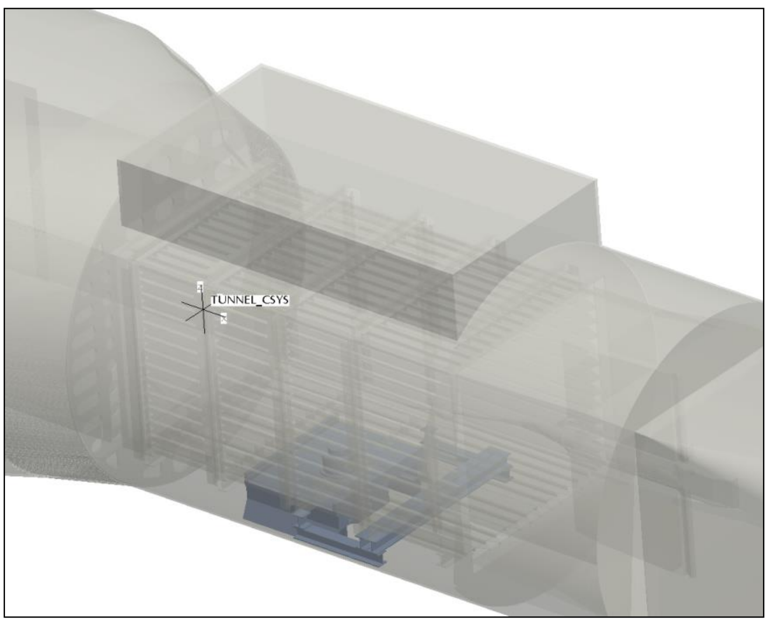

Figure 10 Turntable

3.6 Aft Diffuser

The region aft of the strut (diffuser) transitions from a rectangular cross-section to a circular section as shown in Figure 11. The diffuser includes four curbs and an aft pressure face for setting exit boundary conditions. The diffuser also includes the attachment cylinders for the vortex generators shown in Figure 9 above. They are a representative simplification of the actual hardware shown in Figure 12.

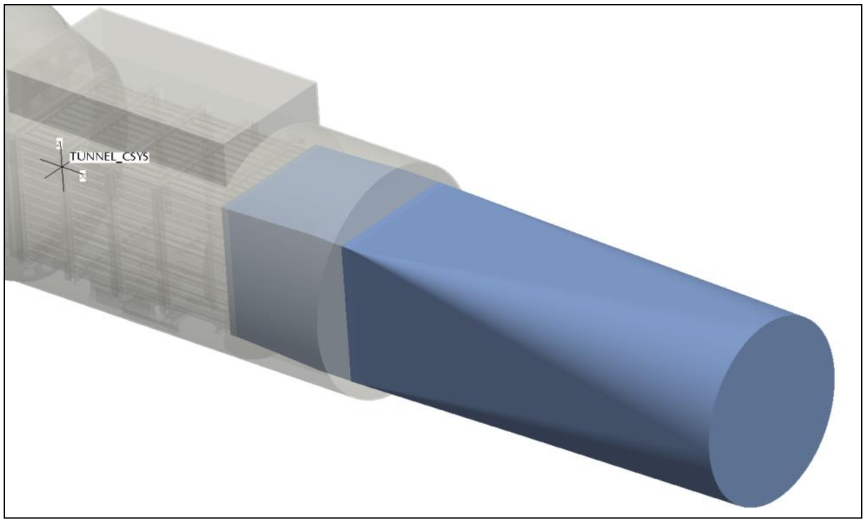

Figure 11 Aft Diffuser

Figure 12 Vortex Generators Attachment Hardware

3.7 Strut and Centerbody Plus Sting Assembly

The strut/sting merged part (vwt_11_strut_centerbody.prt) consists of the main strut (aka blade), knuckle sleeve, 10 degree adapter, and the sting. Table 3 lists the tagged regions. The intersections with the tunnel walls and the LAV model base have mesh controls added along the edge that specifies a fixed number of points to allow for exact matching with main tunnel merged part. See Figure 13 and Figure 14 for close-ups of the edge meshing distribution. The distribution for the lower strut/tunnel interface is the same as for the upper shown in the figure. The same mesh edge distribution is used on the corresponding edges of the tunnel and LAV models. The tagging of the intersecting faces allows for easier removal of the 'inside' faces when the main merged part is combined with the strut/sting merged part.

Table 3 Strut Merged Part Tags

Region	Tag number	Comments
All faces except those listed below	7	
Knuckle sleeve	8	
10 Degree adapter	9	
Sting (except interface)	10	
Sting to model interface	11	To allow for exact mesh alignment and easier removal of 'inside' face
Upper tunnel interface	12	To allow for exact mesh alignment and easier removal of 'inside' face
Lower tunnel interface	13	To allow for exact mesh alignment and easier removal of 'inside' face

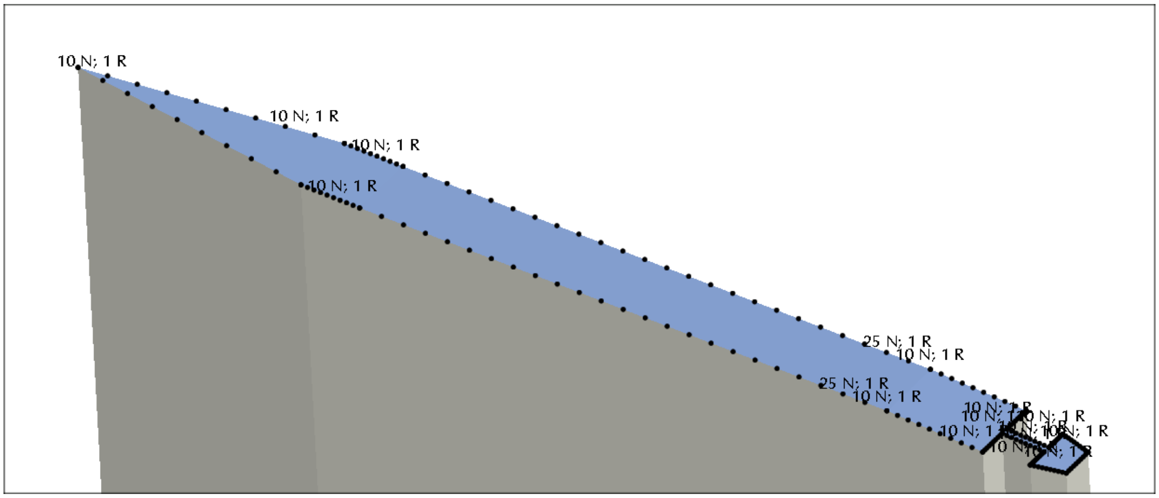

Figure 13 Close-Up of Strut to Tunnel Interface Edge Mesh Distribution

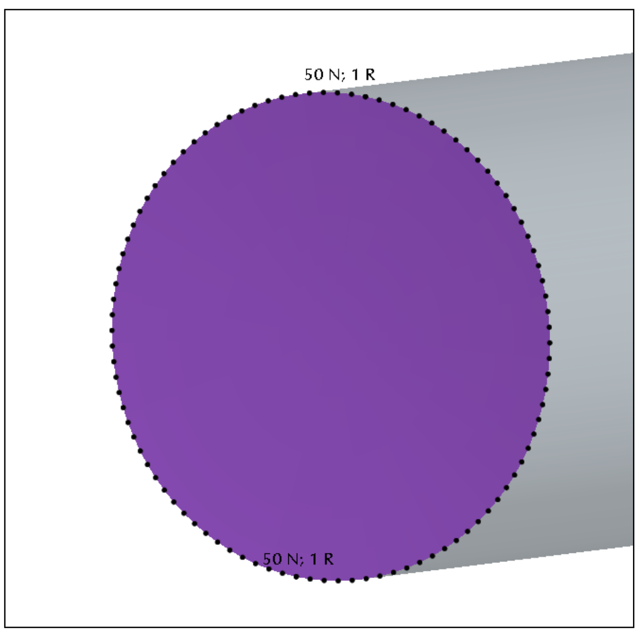

Figure 14 Close-Up of Sting to LAV Interface Edge Mesh Distribution

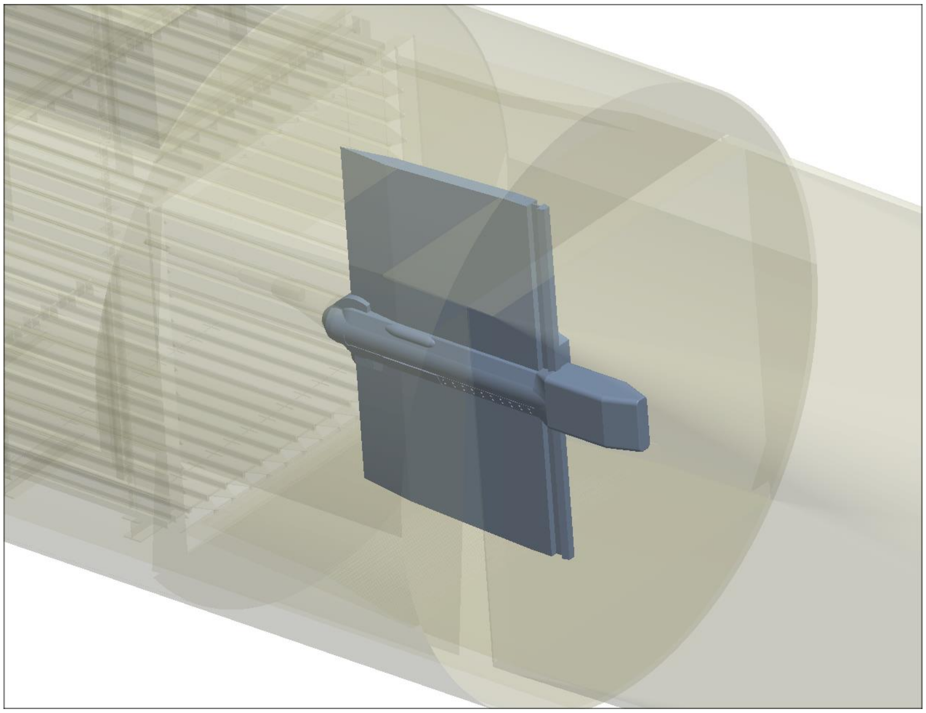

Figure 15 Strut and Centerbody

The virtual wind tunnel sting is made up of three separate parts including the knuckle sleeve, the 10 degree adapter and the main sting. This will allow for future updates for test models with different adapters and stings. The sting coordinate system is driven by matching with the centerbody sting location that allows for correct vertical location and angular orientation based on user input of angle of attack for a given model. This sting currently modeled was used for the LAV 26-AA wind tunnel test.

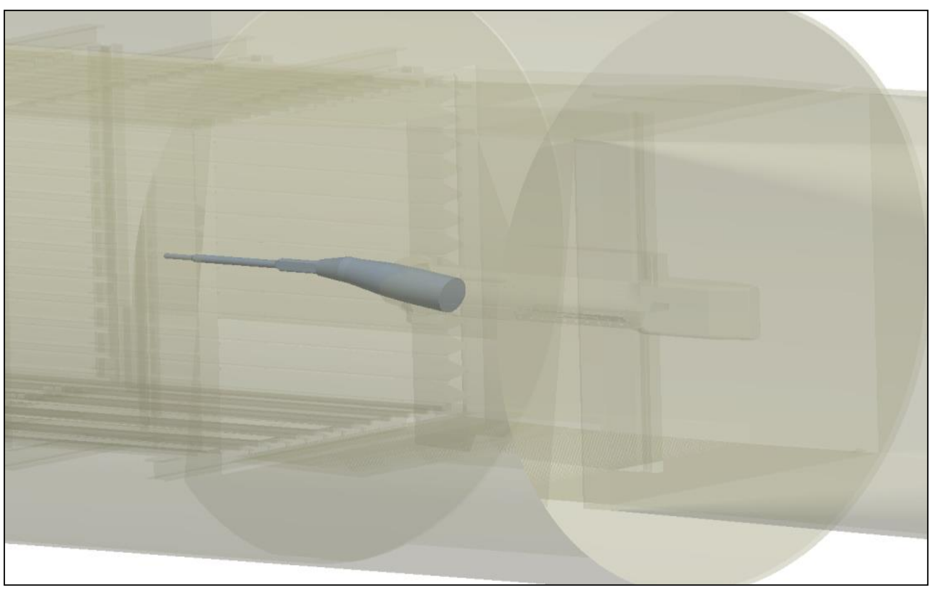

Figure 16 Sting

3.8 Structure

Select portions of the 11-Foot tunnel structure (outer I beams) have been modeled in the virtual wind tunnel. Figure 17 shows the structure modeled in blue. Additional structural detail which is highlighted in blue in Figure 18 was also included. The additional brackets are attached to the outside of the main tunnel wall.

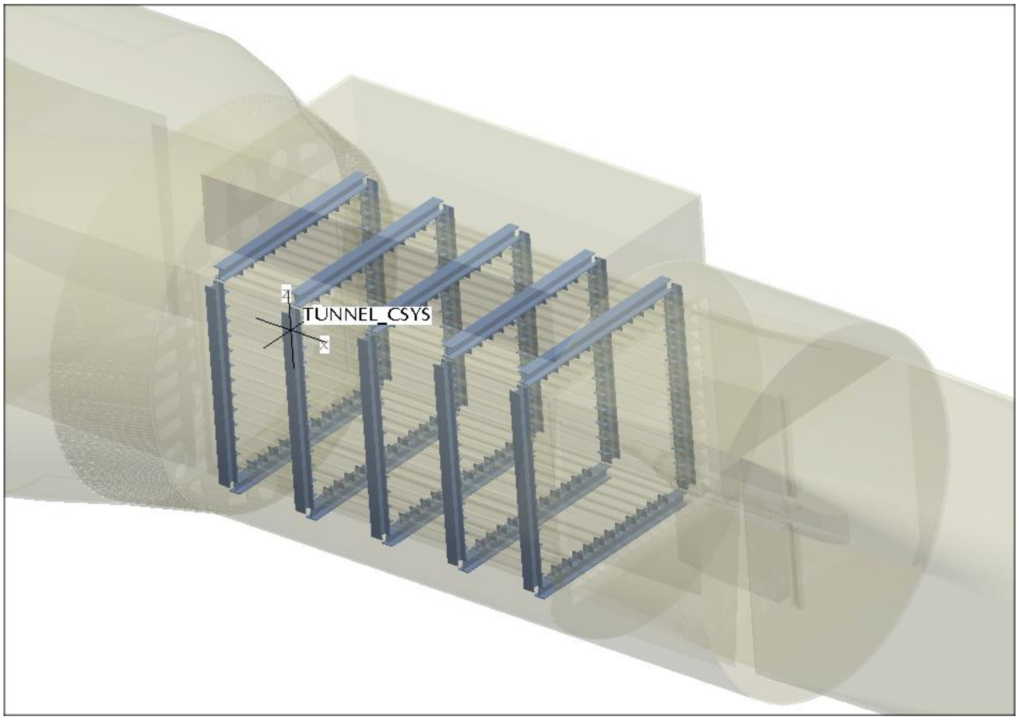

Figure 17 Structure

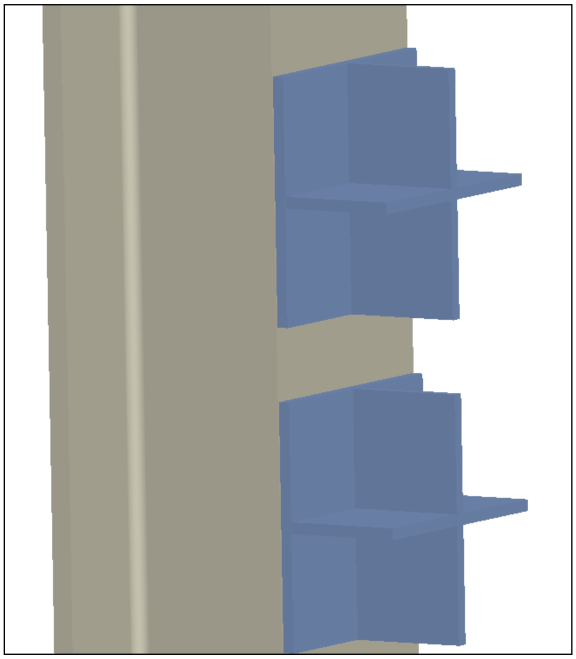

Figure 18 Structural Detail

4.0 Main Merged Model

The merged part contains all of the primary tunnel parts and can also incorporate tunnel test models such as the LAV 26-AA model. The merged solid parts are used for tagging various surfaces and components and for meshing. Figure 19 shows a sample mesh on the geometry.

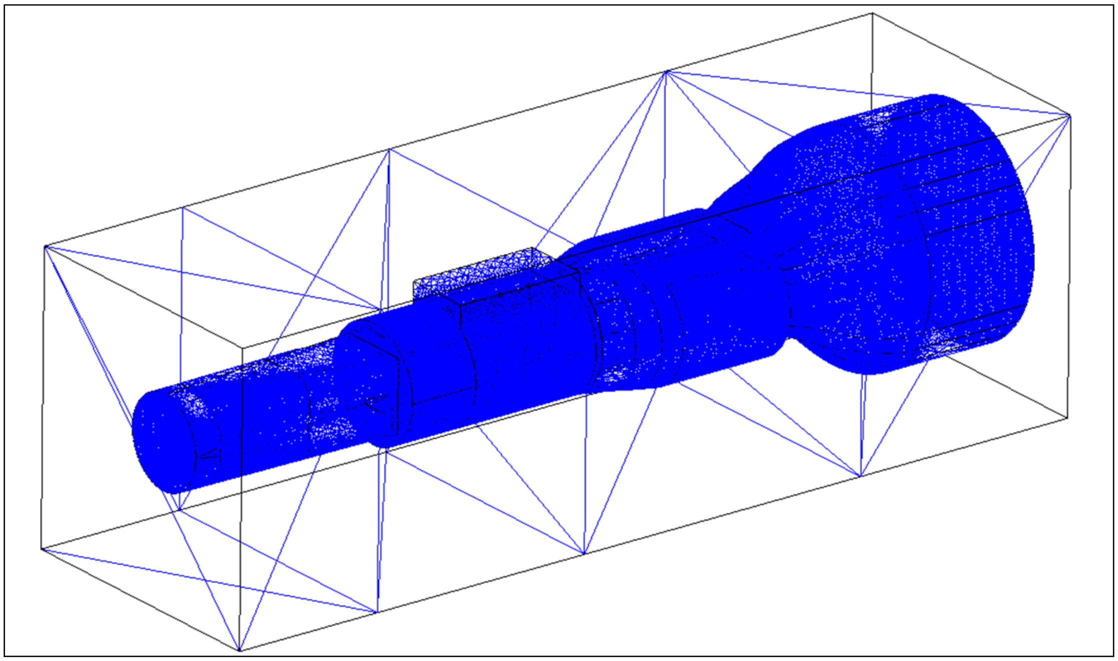

Figure 19 Sample Mesh on Merged Part

The main tunnel merged part (vwt_11.prt) consists of the nozzle, test section, turntable, plenum chamber and structure parts. The outer box is added as an additional feature within the merged part.

Table 4 lists the various tagged regions which includes the outer box, inlet and exit faces as well as the intersections with the strut (upper and lower). The intersections with the strut have mesh controls added along the edge that specify a fixed number of points to allow for exact matching with the strut/sting merged part. The tagging of the intersecting faces allows for easier removal of the 'inside' faces when the main merged part is combined with the strut/sting merged part. Figure 20 has an isometric view of the main tunnel with the various tag regions highlighted in red.

Table 4 Main Tunnel Tags

Region	Tag number	Comments
All faces except those listed below	1	Initial 999 tag overwritten within Matlab script
Outer box	8	Removed via Matlab script for Cart3D computations
Inlet/Nozzle face	2	For setting inlet flow boundary conditions
Outlet/Exit face	3	For setting exit flow boundary conditions
Upper strut interface	5	To allow for exact mesh alignment and easier removal of 'inside' face
Lower strut interface	6	To allow for exact mesh alignment and easier removal of 'inside' face

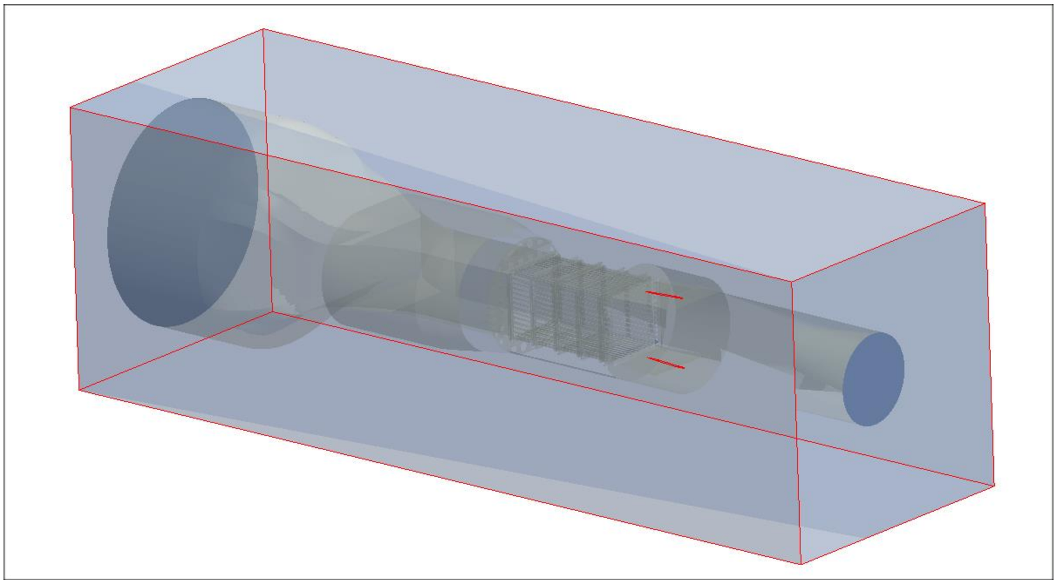

Figure 20 Main Tunnel Tagged Regions

4.1 LAV Vehicle Model

For the initial CAD model the 26-aa LAV vehicle was created as a solid CAD model and integrated in to the 11-Foot tunnel model. The LAV model is shown in Figure 21 with its associated tagged regions highlighted. Table 5 gives a list of the tagged regions. The LAV model includes a tunnel coordinate system copied from an assembly of the parts.

Figure 21 View of the 26-aa LAV CAD Model with Tagged Regions Highlighted

Table 5 List of Tagged Regions on the LAV Model

Region	Tag number	Comments
All faces except those listed below	14	
AM Nozzle 1	15	green upper right
AM Power Face 1	16	green upper right
AM Nozzle 2	17	yellow upper left
AM Power Face 2	18	yellow upper left
AM Nozzle 3	19	pink lower right
AM Power Face 3	20	pink lower right
AM Nozzle 4	21	blue lower left
AM Power Face 4	22	blue lower left
Sting to LAV Interface	23	Outlined in red

5.0 Future Work

There are a handful of possible updates that could be included in future CAD models of the 11-Foot wind tunnel. The possibilities include: modeling of up mass capability, further detail added to the interior of the forward diffuser, and updating of the strut centerbody to higher fidelity measurements.

6.0 References

[1] Frank J. Kmak, *Modernization and Activation of the NASA Ames 11-by 11-Foot Transonic Wind Tunnel*, circa late 1990's, report not formally released.

[2] F. Kmak, M. Hudgins and D. Hergert, *Revalidation of the NASA Ames 11-By 11-Foot Transonic Wind Tunnel With a Commercial Airplane Model (Invited)*, AIAA 2001-0453, 39th AIAA Aerospace Sciences Meeting & Exhibit, January 8-11, 2001, Reno, NV

[3] A.R. Boone and N. Ulbrich, *The Development of a Wall Pressure Measurement System For Two NASA Ames Wind Tunnels*, AIAA 2002-3250, 22nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference, June 24-27, 2002, St. Louis, Missouri

[4] http://windtunnels.arc.nasa.gov/

Appendix A

Flexwall Jack-Position Equations in ProEngineer CAD Model

```
/* D233 is Downstream at TS -138
/* D234 is Midstream at TS -179
/* D235 is Upstream at TS -239

IF MACH <=1.06
d233 = 0
D234 = 0
ENDIF

IF MACH > 1.08
TEM6 = -358.26650 * MACH^6
TEM5 = 2696.96290 * MACH^5
$D233 = TEM6 +TEM5 - (8409.12613 * MACH ^4 )+ (13959.24598 * MACH ^3) - (13067.96983 * MACH^2) + ( 6569.56031
* MACH )- 1390.83878
ENDIF

IF MACH >1.06
IF MACH <= 1.08
D233 =  -97.00000*MACH^2 + 213.14000*MACH - 116.93920
ENDIF
ENDIF

IF MACH >1.06
IF MACH < 1.1
d234 = 18.25000 * MACH - 19.34500
ENDIF
ENDIF

IF MACH >= 1.1
 D234 = -39.02592*MACH^4 + 242.98446*MACH^3 - 521.46449*MACH^2 + 479.12189*MACH - 161.60233
ENDIF


D235= 8848.97752*MACH^6 - 68198.86585*MACH^5 + 218391.31924*MACH^4 - 371947.71204*MACH^3 +
355376.67264*MACH^2 - 180622.49375*MACH + 38154.27792

IF MACH <= 1.08
$D235=27.50000*MACH^2 - 9.12500*MACH- 21.22100
ENDIF

IF MACH < 1.06
$D235 = 5.00000*MACH - 5.29450
ENDIF

IF MACH < 1.0599
D235 = 0.083472*MACH - 0.083472
ENDIF


IF MACH <= 1.0
D235=0
ENDIF
```

Table 6 Flexwall Jack Position vs Mach Number

EJN 8/18/2011

11X11 Ft TWT
FLEXWALL CALIBRATION TABLE

Mach Setting	North Upstream Jack position (IN)	North Midstream position (IN)	North Downstream position (IN)	South Upstream Jack position (IN)	South Midstream position (IN)	South Downstream position (IN)
1	0.000	0.000	0.000	0.000	0.000	0.000
1.0599	0.0050	0.000	0.000	0.0050	0.000	0.000
1.06	0.0055	0.000	0.000	0.0055	0.000	0.000
1.07	0.500	0.1825	0.0653	0.500	0.1825	0.0653
1.08	1.000	0.365	0.1112	1.000	0.365	0.1112
1.09	1.105	0.5475	0.1508	1.105	0.5475	0.1508
1.1	1.210	0.730	0.1844	1.210	0.730	0.1844
1.11	1.313	0.7934	0.2126	1.313	0.7934	0.2126
1.12	1.415	0.8565	0.2362	1.415	0.8565	0.2362
1.13	1.525	0.9196	0.2556	1.525	0.9196	0.2556
1.14	1.635	0.9828	0.271	1.635	0.9828	0.271
1.15	1.775	1.0467	0.2828	1.775	1.0467	0.2828
1.16	1.915	1.1115	0.2913	1.915	1.1115	0.2913
1.17	2.093	1.1778	0.2969	2.093	1.1778	0.2969
1.18	2.270	1.2458	0.2997	2.270	1.2458	0.2997
1.19	2.448	1.316	0.3001	2.448	1.316	0.3001
1.2	2.625	1.3888	0.2984	2.625	1.3888	0.2984
1.21	2.800	1.4648	0.2949	2.800	1.4648	0.2949
1.22	2.975	1.5442	0.2898	2.975	1.5442	0.2898
1.23	3.153	1.6276	0.2835	3.153	1.6276	0.2835
1.24	3.330	1.7154	0.2762	3.330	1.7154	0.2762
1.25	3.515	1.8079	0.2682	3.515	1.8079	0.2682
1.26	3.700	1.9056	0.2598	3.700	1.9056	0.2598
1.27	3.910	2.0089	0.2515	3.910	2.0089	0.2515
1.28	4.120	2.1181	0.2433	4.120	2.1181	0.2433
1.29	4.360	2.2335	0.2358	4.360	2.2335	0.2358
1.3	4.600	2.3555	0.2293	4.600	2.3555	0.2293
1.31	4.885	2.4835	0.2244	4.885	2.4835	0.2244
1.32	5.170	2.6174	0.2218	5.170	2.6174	0.2218
1.33	5.455	2.7572	0.2219	5.455	2.7572	0.2219
1.34	5.740	2.9034	0.2252	5.740	2.9034	0.2252
1.35	6.018	3.056	0.2319	6.018	3.056	0.2319
1.36	6.295	3.2154	0.2425	6.295	3.2154	0.2425
1.37	6.583	3.3819	0.2573	6.583	3.3819	0.2573
1.38	6.870	3.5556	0.2767	6.870	3.5556	0.2767
1.39	7.160	3.7368	0.3012	7.160	3.7368	0.3012
1.4	7.450	3.9257	0.331	7.450	3.9257	0.331
1.41	7.755	4.1227	0.3665	7.755	4.1227	0.3665
1.42	8.060	4.3278	0.4082	8.060	4.3278	0.4082
1.43	8.370	4.5415	0.4563	8.370	4.5415	0.4563
1.44	8.680	4.7639	0.5114	8.680	4.7639	0.5114
1.45	9.000	4.9953	0.5737	9.000	4.9953	0.5737
1.46	9.320	5.2359	0.6437	9.320	5.2359	0.6437
1.47	9.735	5.486	0.7217	9.735	5.486	0.7217
1.48	10.150	5.7458	0.8081	10.150	5.7458	0.8081
1.49	10.455	6.0155	0.9033	10.455	6.0155	0.9033
1.5	10.760	6.2955	1.0076	10.760	6.2955	1.0076
Test Sectionl Station	-239	-179	-138	-239	-179	-138
Nozzle Station	0	60	101	0	60	101