High-Fidelity Airliner Modeling for CFD Analysis: Tips, tricks, and lessons learned

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Andy’s Philosophy

• “All models are wrong, but some are useful.” – George E. P. Box
  • Good enough is good enough.

• “Order and fidelity are not the same thing. Order is the number of degrees of freedom a model can account for and fidelity is a measure of its ability to reproduce data correctly. Sometimes a low order model is THE high fidelity method.” – Me
  • Use the lowest order method that does the job.

• “Don't be too proud of this technological terror you've constructed.” - Darth Vader
  • Understand the limitations of your method.

• Avoid copyright infringement and wasting toner.
Fidelity Is A Loaded Term

• The word fidelity is defined as: the degree of exactness with which something is copied or reproduced.

• If you are designing from scratch in OpenVSP, then the geometry is Definitive, and therefore is the highest fidelity possible.

• Building a model in OpenVSP that was defined somewhere else will introduce errors, the only question being, “to what degree and will it matter?”
  • Depends on the accuracy of source geometry and the skill of the modeler.

• Even CAD isn’t perfect. Not only are there often mismatches and holes, but producing complex, fair (non-wavy) surfaces is unlikely.
NASA/Pratt Energy Efficient Transport

- NASA and Pratt & Whitney performed a joint engine installation wind tunnel test in the mid-eighties.
- That geometry is still relevant today, having similar wing design features, engine class, and aerodynamic performance to the Airbus A320neo.
- Because Pratt designed, built, and tested the model, the definitive CAD geometry and all test data was available in-house.
- This allowed for creating an extremely high-fidelity OpenVSP model for direct outcomes comparison.
  - CAD Wind Tunnel Data to CAD CFD Data to OpenVSP CFD Data
Unique Learning Experience

• Learned about the Pros & Cons of CAD vs OpenVSP.
  • CAD is extremely flexible, whereas OpenVSP is somewhat constrained by parameterization.
  • Cad is more cumbersome with common airframe modifications. OpenVSP was able to make many changes very easily, reducing turnaround time dramatically, often to just minutes.
  • OpenVSP is easier to produce water-tight, fair surfaces with. Importing to CFD was very easy.

• Learned about the Pros & Cons of wind tunnels vs CFD.
  • Accepted Wind Tunnel data as Truth.
  • Learned where CFD was useful, where it broke down, and what OpenVSP model features promoted easy importation and stable convergences.
This Talk

• Unfortunately, I can’t share the NASA/Pratt Energy Efficient Transport Model.
• What I can share is the process that we went through, some of the unexpected problems, and the tricks that we used to overcome them.
• I had CAD to pull from, so the first part is a talk about how I did that.
• The second part is a more traditional, demonstrative showing of modeling tips, tricks, and lessons learned.
• There is no PROPRIETARY or sensitive data in this presentation. All source material is from open literature.
CAD to OpenVSP

• The Fit Model is AWESOME!
• At first, I couldn’t get it to work at all. In fact, it went away for ½ hour before it crashed OpenVSP. Very frustrating.
• Funny, I followed Rob’s tutorial with the pod, and it worked fine. What was different?
• After much trial, error, and head scratching, I noticed that the STLs that the CAD guy gave me were very high resolution. **Tip:** the default settings for STL export are way too fine and are not only overkill, but can cause the Fit Model to bog down or even crash. Adjust settings to be more course overall. Make nodes more dense in curves, less dense where flatter, but not too imbalanced so that the optimizer doesn’t over-prioritize the curves. Keep total number of points below 1500, but lower would be better.
• Remember that we are not printing the geometry, we are fitting it.
CAD to OpenVSP

• Don’t try to give the fit model a lot of design variables with a poor starting geometry.

• Do your best to fit the geometry by hand. This does two things.
  • Reduces the chance that the optimizer will find a poor local minimum or even blow up the geometry with an “unintuitive” solution.
  • Helps you figure out which design variables to manipulate, and in what order.

• I start out with a few design variables, adding new variables as needed, letting the optimizer choose the best combination at each stage.
Getting Started

- Add a Blank component. The location will default at the Global Origin.
- I like to call my Blank components “Something” Assembly. In this case, “Engine Pod” Assembly.
- All subsequent components will be children of this blank, unless there is a good reason to attach to a different component.
- This will allow for convenient translation and rotation of the whole Engine Pod as a unit.
Duct Modeling (1) Xsecs

- Add Stack as a child to Engine Pod Assembly. Attach to Parent= Translate & Rotate Comp
- Choose Design:Design Policy=Loop;
- Make Xsec 0, the reference, the fan location. Choose Type=Circle. Diameter=6.75 (81 inches).
  - This is because the fan is the most static component that everything else indexes to. It also allows easy inlet and exit modifications.
- Make Xsec 3 the Exit Outer Diameter. Delta X=7.51. Choose Type=Circle. Diameter=7.08.
- Insert Cross Section.
- Make Xsec 4 the Exit Inner. Delta X=0.00. Choose Type=Circle. Diameter=7.08-0.04. Make Offset Parameter Link between Xsec 3 Diameter & Xsec 4 Diameter. We found that blunt trailing edges helped with CFD convergence. Setting the link allows changing the diameter while maintaining the blunt edge.
- Insert Cross Section.
- So, where did I get all of these values? I measured them off of the drawing. Once entered, I could then Adjust View to overlay the VSP component Xecs onto the drawing imported into the Background. Since this is a side view, I held shift+F3 to set this as my custom side view.
- This looks like a mess, but I will clean it up by fixing the skinning.
Duct Modeling (2) Skinning

• If the Duct is axisymmetric, for each Xsec, choose Skinning; Skin Cross Section=All Sym. Even if it isn’t axisymmetric, this is a good thing to do at the start, and then undo only as needed.

• Xsec 0: Left Angle=180.0. Left Strength=2.12. Ignore Right parameters.

• Xsec 1: Left Angle=90.0. Left Strength=0.40. Right Angle=equal. Right Strength=0.54.

• Xsec 2: Left Angle=0.0. Left Strength=0.90. Right Angle=equal. Right Strength=2.60.

• Xsec 3: Left Angle=-7.0. Left Strength=1.00. Right Angle=-90.0. Right Strength=1.00.

• Xsec 4: Left Angle=90.0. Left Strength=1.00. Right Angle=180.0. Right Strength=7.50.

• Xsec 5: Left Angle=-175.0. Left Strength=2.50. Right Angle=equal. Right Strength=1.00.

• Xsec 6: Left Angle=-180.0. Left Strength=3.25. Right Angle=equal. Right Strength=1.00.

• So, where did I get all of these values? Set the angle to be tangent to the drawing at each Xsec, then adjust the Strengths to get the best fit. It is a lot of trial and error.

• This looks a lot better, but we can do a little refining.
Duct Modeling (3) Refining

• The upper and lower parts of the Duct are not the same everywhere.
• Xsec 0 is OK.
• Xsec 1: Deselect All Sym & T/B Sym. Bottom Side: Right Strength=0.65.
• Xsec 2: Deselect All Sym & T/B Sym. Bottom Side: Right Strength=3.46.
• Xsec 3: Uncheck all Right Set.
• Xsec 4: Uncheck all Left Set.
• Xsec 5: Deselect All Sym & T/B Sym. Bottom Side: Left Angle=-171.0. Left Strength=2.60. Right Angle=equal. Right Strength=0.50. Be careful not to have inner and outer surfaces intersect near the thin trailing edge.
• Xsec 6: Deselect All Sym & T/B Sym. Bottom Side: Left Strength=2.30.
• Once again, match Angles to Bottom lines first, then trial and error on the strengths.
Duct Modeling (4) CFD Prep

• The blunt Fan Exit trailing edge was a good start.
• Define Subsurfaces. Subsurfaces are used to separate surface regions for purposes of integrating forces and applying Boundary Conditions.
  • Outer Trailing Edge: Type=Line. Line Type=U. Test=Greater. Value=0.5000.
  • Highlight: Type=Line. Line Type=U. Test=Greater. Value=0.1650. Separates inner & Outer flow.
  • Inner Trailing Edge: Type=Line. Line Type=U. Test=Greater. Value=0.6650.
• Set Tessellation to adequate density. This may require trial and error for your application. I am setting this model to about what has worked well for us in the past.
  • Gen:Tessellation:Num_W=105.
  • Xsec 1: Num U= Delta X * 5 ~ 25.
  • Xsec 2: Num U= Delta X * 5 ~ 25.
  • Xsec 3: Num U= Delta X * 5 ~ 37.
  • Xsec 4: Num U= 3. (Thin trailing edge)
  • Xsec 5: Num U= Delta X * 5 ~ 20.
  • Xsec 6: Num U= Delta X * 5 ~ 20.
Duct Model vs Source Drawing
Fit Model Tips

• If I have CAD to match to, this is where I would start the Fit Model from. I now know what design variables I will need to set up. I would start at Xsec 0, and add the next Xsec each iteration, Saving an intermediate OpenVSP file each time in case the optimization blows up.

• Since this is just the Duct, you don’t want to have any points from CAD that are not on just the Duct to considered by the optimizer. Instead of selecting or deselecting points from a complete CAD STL, I break the CAD into pieces and create reduced density STLs of just the Outer Duct, just the inner Duct, and separate wetted surfaces for any additional components. This keeps the cumbersome task of selecting points to a minimum.

• I am not asking the Fit Model to do some heroic design task, just to choose the best values for my design variables to minimize modeling error.
Core Modeling (1a) Xsecs

- Add Stack as a child to Engine Pod Assembly; Attach to Parent= Translate & Rotate Comp
- Design:Design Policy=Free.
- Xsec 0: the reference, the nose of the spinner. Type=Point. Xform:Xloc=-1.90.
- Insert Cross Section.
- Insert Cross Section.
- Xsec 5: the Core Exit Inner. Delta X=0.00. Type=Circle. Diameter=2.80-0.04.
Core Modeling (1b) Xsecs

- Insert Cross Section.
- Insert Cross Section.
- Xsec 7: the Turbine Exit Inner. Delta X=0.00. Type=Circle. Diameter=1.60.
- Insert Cross Section.
- Xsec 8: the Onion Middle. Delta X=1.30. Type=Circle. Diameter=1.60.
- Insert Cross Section.
- Xsec 9: the Onion End. Delta X=1.60. Type=Circle. Diameter=0.20.
- So, where did I get all of these values? I measured them off of the drawing.
- The drawing appears to have a T/B asymmetry at the Maximum Diameter, which I don’t think is really there, so I’ll ignore it and just have the diameter be the same, but centered.
- As before, I will clean this up by fixing the skinning.
Core Modeling (2a) Skinning

- The Core should be axisymmetric, so for each Xsec, choose Skinning: Skin Cross Section=All Sym.
- Xsec 0: Left Angle=90.0. Left Strength=1.00. Ignore Right parameters. Tip: If the Spinner starts at a sharp point, it is best to blunt it with a small diameter hemisphere. Even though the triangles at the point may look fine in OpenVSP, they often degenerate when the STL file is read into the CFD, requiring manual cleanup.
- Xsec 1: Left Angle=0.0. Left Strength=1.07. Right Angle=equal. Right Strength=1.00.
- Xsec 2: Left Angle=2.0. Left Strength=1.00. Right Angle=equal. Right Strength=4.00.
- Xsec 3: Left Angle=0.0. Left Strength=1.70. Right Angle=equal. Right Strength=0.75.
- Xsec 4: Left Angle=0.0. Left Strength=0.00. Right Angle=-90.0. Right Strength=1.00.
- Xsec 5: Left Angle=90.0. Left Strength=1.00. Right Angle=180. Right Strength=1.00.
- Xsec 6: Left Angle=-180.0. Left Strength=1.00. Right Angle=-90.0. Right Strength=1.00.
- Xsec 7: Left Angle=-90.0. Left Strength=1.00. Right Angle=0.0. Right Strength=1.00.
- Xsec 8: Left Angle=0.0. Left Strength=1.00. Right Angle=equal. Right Strength=0.40.
- Xsec 9: Left Angle=-23.0. Left Strength=3.50. Right Angle=-90.0. Right Strength=0.50.
- Xsec 10: Left Angle=-90.0. Left Strength=0.75. Ignore Right parameters
- So, where did I get all of these values? Set the angle to be tangent to the drawing at each Xsec, then adjust the Strengths to get the best fit. It is a lot of trial and error.
- If you have CAD, follow the same process as in the Duct for the Fit Model.
Fan Puck Modeling (1) Xsecs

- The fan puck is used solely to provide Boundary conditions, regulating the mass flow through the engine and the thrust simulation. It masks the details of the fan/core flow split internally. It is a relatively simple, but important component.

- Xform: Add Fuselage as a child to Core; Attach to Parent= Translate & Rotate Comp. Xloc=1.25.

- Design: length=2.50.

- Xsec 1: Rel X=0.00. Choose Type: Circle. Diameter=7.50. Tip: Don’t choose 7.25 (81 inches) as the Fan actually is. We have already set the Duct inner diameter to 7.25 and having 2 surfaces occupying the same space is ambiguous, not to mention that gaps can open up if all of the touching vertices don’t lie on top of each other. It is much better practice to give generous overlap and let OpenVSP’s intersection routines define the intersection.

- Cut.

- Xsec 2: Rel X=1.00. Choose Type: Circle. Diameter=7.50.
Fan Puck Modeling (2) Skinning

- Xsec 0: Left Angle=90.0. Left Strength=1.00. Ignore Right parameters.
- Xsec 1: Left Angle=90.0. Left Strength=1.0. Right Angle=0.0. Right Strength=1.00.
- Xsec 2: Left Angle=0.0. Left Strength=1.0. Right Angle=-90.0. Right Strength=1.00.
- Xsec 3: Left Angle=-90.0. Left Strength=1.00. Ignore Right parameters.
- Now, this should be fine, but a further refinement is to deselect the Set for all Skin Cross Sections.
- There is no need to define Sub Surfaces because all of the resulting intersected & trimmed surfaces are correct the way that they are.
Core Model vs Source Drawing
Bifurcator Modeling

- Add Wing as a child to Engine Pod Assembly; Attach to Parent= Translate & Rotate Comp.
- Xform: Turn Off Symmetry, Xrot=90.0. Xloc=3.2. Zloc=-3.85.
- Sect 1: Sweep=0.0. Root C=4.85. Tip C=4.85.
- Sect 1: Span=0.30. Root C=3.9.
- Sect 2: Span=4.70.
- Sect 3: Span=0.168. Tip C=10.00.
- Sect 4: Span=3.10. Below Tip C, Select Sec SW=40.0. IMMEDIATELY reselect Tip C to prevent any uncommanded changes in the future. Tip C=12.60.
- Airfoil 0, 1, 2: NACA 0012
- Airfoil 3, 4: NACA 67015
- Define Subsurfaces.
  - Internal Flow: Type=Line. Line Type=U. Test=Less. Value=0.79.
- Tesselate for CFD.
- Bifurcators are much more complex than what is shown here. Either it is designed in OpenVSP, or CAD source geometry is a must. Multiple custom airfoils and large changes over short spans are usual.
Bifurcator Model vs Source Drawing
Add Stack as a child to Engine Pod Assembly; Attach to Parent= Translate & Rotate Comp. Design:Design Policy=Free. Xform:Xloc=-0.20. Zloc=4.15.

Xsec 0: the reference. Type=Point.

Xsec 1: Delta X=0.00. Type=General Fuse. Height=0.42. Width=0.775. MaxWLoc=-0.50. TopStr=0.95.

Xsec 1: Delta X=7.00. Delta Z=0.40. Type=General Fuse. Height=2.00. Width=1.50. MaxWLoc=-0.60. TopStr=1.83. LowStr=0.80. Copy.

Xsec 2: Paste. Delta X=2.00.

Xsec 3: Delta X=7.30. Type=Point.

Tesselate for CFD.
Pylon Modeling (2) Skinning

- **Xsec 0**: Deselect All Sym.
  - Top Side: Left Angle=90.0. Left Strength=1.00. Ignore Right parameters.
  - Right Side: Left Angle=90.0. Left Strength=1.00. Ignore Right parameters.

- **Xsec 1**: Deselect All Sym & T/B Sym.
  - Top Side: Left Angle=90.0. Left Strength=1.00. Right Angle=85.0. Right Strength=5.00.
  - Right Side: Left Angle=90.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.
  - Bottom Side: Left Angle=90.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.

- **Xsec 2**: Deselect All Sym.
  - Top Side: Left Angle=0.0. Left Strength=2.82. Right Angle=equal. Right Strength=1.00.
  - Right Side: Left Angle=0.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.
  - Bottom Side: Left Angle=90.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.

- **Xsec 3**: Deselect All Sym.
  - Top Side: Left Angle=0.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.
  - Right Side: Left Angle=0.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.

- **Xsec 4**: Top Side: Left Angle=0.0. Left Strength=1.00. Right Angle=equal. Right Strength=1.00.
  - If you have CAD, follow the same process as in the Duct for the Fit Model.
Pylon Model vs Source Drawing
Upper Thrust Reverser Fairing Model (1) Xsec

- Xsec 0: the reference. Type=Point.
- Xsec 1: Delta X=2.20. Delta Z=-0.03. Type=General Fuse. Height=0.42. Width=3.00. MaxWLoc=-2.00. BotTanAng=0.0. TopStr=1.64. BotStr=0.90. UpStr=2.00. LowStr=0.00.
- Xsec 2: Delta X=2.00. Delta Z=-0.044. Type=General Fuse. Height=0.05. Width=1.4. MaxWLoc=-2.00. BotTanAng=0.0. TopStr=0.83. BotStr=0.83. UpStr=2.00. LowStr=0.83.
- Xsec 3: Delta X=0.00.
Upper Thrust Reverser Fairing Model (2) Skin

- Xsec 0: Deselect All Sym & T/B Sym.
  - Top Side: Left Angle=6.0. Left Strength=1.00. Right Angle=10.3. Right Strength=5.47.
  - Right Side: Left Angle=90.0. Left Strength=1.30. Right Angle=equal. Right Strength=1.00.
  - Bottom Side: Left Angle=-0.87. Left Strength=0.75. Right Angle=10.3. Right Strength=1.62.
- Xsec 1: Deselect All Sym.
  - Top Side: Left Angle=1.0. Left Strength=0.85. Right Angle=equal. Right Strength=0.90.
- Xsec 2: Deselect All Sym & T/B Sym.
  - Top Side: Left Angle=-5.0. Left Strength=0.00. Unset Right parameters.
  - Right Side: Left Angle=-90.0. Left Strength=0.50. Unset Right parameters.
  - Bottom Side: Left Angle=0.0. Left Strength=0.00. Unset Right parameters.
- Xsec 3: Select All Sym.
  - Top Side: Unset Left & Right parameters.

This last Xsec was added to blunt the component to enhance CFD convergence stability.
Upper TR Fairing Model vs Source Drawing
Lower TR Fairing Model vs Source Drawing
Engine Pod Assembly OpenVSP Model