VSP Aircraft Analysis User Manual

Modeling and Analyzing Aircraft Designs Using Parametric Geometry Tools and Vortex Lattice Software

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Introduction

This document will serve as a guide in the use of software designed for developing a drag profile for aircraft in Vehicle Sketch Pad.

For more detailed information on the use of the programs, please visit the website of each to find full user manuals and descriptions.
Outline

• Modeling with OpenVSP
• XFOIL
• VSPAERO
• Identifying Software Issues
Modeling with OpenVSP
Modeling with OpenVSP

• OpenVSP (Vehicle Sketch Pad) is a parametric aircraft geometry tool which allows the creation of a 3D model of an aircraft defined by common engineering parameters. The model can then be processed for engineering analysis.

• Since the early 1990’s, OpenVSP predecessors have been developed for NASA by J.R. Gloudemans and others. Open VSP was released as an open source project under the NASA Open Source Agreement (NOSA) version 1.3 on January 10, 2012.
Modeling with OpenVSP

- The two basic shapes that determine almost all of the aircraft’s components are FUSE2 and MS_WING. Other components may be used for more complex aircraft geometries but may not be used for VSPAero analysis.
Modeling with OpenVSP

- By describing the cross-sections throughout each body, the user is able to shape each component into a representative model.
Modeling with OpenVSP

- By describing the cross-sections throughout each body, the user is able to shape each component into a representative model.
Modeling with OpenVSP

- In general, if a user can find a scaled diagram of the model from different angles, then the model can be matched to the aircraft.
Modeling with OpenVSP

Piper Seminole

Vought V-173

Tecnam P2006T
Pitfalls

• Avoid “Clay” modeling practices
  – Don’t just push/pull until the model matches the diagram
  – Location and dimensions will become gibberish
  – Understand and apply the dimensions correctly

• If modeling for analysis, do NOT leave open components
  – The geometry analysis tools will crash the program
  – Start and finish Fuse2 objects with points

• Make backup files!
  – Always have at least one model that serves as the unaltered base for changes. This will save you hours of work correcting a simple mistake.
More Information

For information on additional modeling techniques and for a full user manual please go to
http://openvsp.org/
XFOIL

• XFOIL is an interactive program for the design and analysis of subsonic isolated airfoils. It consists of a collection of menu-driven routines which perform various useful functions such as:
  – Viscous (or inviscid) analysis of an existing airfoil, allowing
    • forced or free transition
    • transitional separation bubbles
    • limited trailing edge separation
    • lift and drag predictions just beyond CLmax
    • Karman-Tsien compressibility correction
    • fixed or varying Reynolds and/or Mach numbers
  – Airfoil design and redesign by interactive modification of surface speed distributions, in two methods:
    • Full-Inverse method, based on a complex-mapping formulation
    • Mixed-Inverse method, an extension of XFOIL's basic panel method

*Information from web.mit.edu XFOIL homepage
XFOIL

- XFOIL is primarily used to collect profile drag data under various flight conditions.
  - Max cruise, best endurance cruise, best climb and high lift scenarios.
- Also used to determine a rough estimation of ideal $C_{L_{\text{max}}}$ (VSPAERO has none).
XFOIL

Source NACA 65(2)-415 (42 nodes)

Refined NACA 65(2)-415 (140 nodes)

NACA 65(2)-415 w/ Flaps @ 40°
Results are loaded into the drag buildup worksheet
Results are loaded into the drag buildup worksheet
Using XFOIL to obtain Airfoil Polars

This is only a guide to obtain values for a specified airfoil and not a total user manual for XFOIL. For complete instructions go to http://web.mit.edu/drela/Public/web/foil/foil_doc.txt

RED = CMD command

Type ? at any command line to see a list of available commands and their descriptions.

1. Open CMD.
2. Change the directory to the folder location of xfoilp4.exe
3. Execute XFOILP4
   a) You may also preload your .dat airfoil coordinates by adding the argument after the command. For example: XFOILP4 NACA0015 or XFOILP4 NACA652415.DAT
XFOIL

4. The number of nodes should be at LEAST 100. You may get a warning that the number of nodes is too small. This is a warning that the resolution of your coordinate file is too low. This is fixed using the PANE or PPAR commands.
   a) PANE will set the number of panels to be sufficient for XFOIL. You may not see a change in the profile.
   b) PPAR will show the new paneling if you changed the number with PANE. If not, you may begin with PPAR.
      i. Type N to change the number of nodes. Use the PANE number shown as a guide. More nodes have a higher resolution but run slower.
      ii. When finished, the profile should be smooth. Enter key until XFOIL is displayed.

5. You may choose to save the new, smooth profile to the folder using the SAVE command.

6. Enter operating point mode by entering OPER.

7. OPERi indicates that you are operating in inviscid mode. For the purposes of finding reasonable data, you will generally want to operate in viscous mode. Enter Visc to toggle modes. OPERv should be displayed.

8. If you have not already done so, a Reynold’s number will be requested. Enter the value at this line.

9. Initially, the iteration number is very low. Change this to at least 200 using ITER.
XFOIL

10. You must now specify the operating conditions using commands.
   a) Change the Mach number with Mach. Similar to other commands this may be followed by an argument if you like. Enter the Mach number.
   b) If only a single angle of attack value is needed, use Alfa. This will show the results in the display. If a sequence of attack angle is needed, proceed to the next step.

11. In order to write the polar to a file to read, you MUST designate that you want the data points to be saved. This is done using the Pacc command.
   a) Specify the polar save file name and file extension.
   b) Specify the dump file name and file extension if needed. Otherwise, hit Enter to skip.
   c) OPERva should be displayed.

12. Specify the attack angle range using Aseq. If you are performing a range of speeds, proceed to step 14.
   a) Enter the minimum alpha.
   b) Enter the maximum alpha.
   c) Enter the angle step size.
XFOIL

13. The program should run through many iterations and display that the information was saved to your polar file. The display should also reflect the new information and you can see the distribution of CD there.

14. If you are performing a range of speeds for cruise conditions:
   a) Enter the Reynolds number
   b) Enter the Mach number
   c) Enter the CL required for steady flight

15. The program will run through several iterations. If the program returns a “not converged” error, the speeds may be too slow for flight (i.e. stall). Slightly change the CL to see if this is simply a case of computation error or if the wing is actually stalled (stall will result in non-convergence repeatedly).

16. The polar file is now ready for import or view.
   a) If using MS Excel, use File>Load>All Files>Polar File Name
   b) Click Finish to open the data as a spreadsheet.
VSPAERO

• Fast vortex lattice analysis tool for VSP degenerate geometry files
• Contains integrated actuator disks that can be accurately described for fast/easy aero-propulsive analysis
• Comes with Viewer app which displays wakes and Delta-Cp (Pressure coefficient change) gradient
• Open source software developed by Dave Kinney at Ames
• Will be released with VSP 3.0 in August
VSPAERO: Use

- Analyzes the DegenGeom output file from VSP
- Must define operating conditions from an input file
- May be used with or without actuator disks
- Drag output is from induced only
- Use of components in the DegenGeom build file that do not affect lift will cause excessive operating times with no valuable return
The Beginning

• You want to start with your high detail model from openVSP. This is going to be your baseline for adjusting the components for analysis.

• **Note that you want to immediately save the model file under another name!** Ensure that you are working from this model by saving then re-opening the new saved working file. This will give you a “clay” model that you can always toss if mistakes are made and revert back to the original high detail model.
Setting Up the Model

- VSPAero will analyze each interpolated section of the model and present values that represent the overall characteristics of the vehicle. While accurate, the time and processor power required to perform this task is immense. At some degree of detail, usually very low by your original model’s standards, the diminishing returns will be evident. For this reason, you should reduce the detail of your model to something that VSPAero can handle reasonably quickly with a high enough level of accuracy.

- For example: If your tessellation on all of your components (adjusted under the “Gen” tab of the component window) is set at 60+, your model will look smooth but will most likely crash the geometry algorithms. Try setting the tessellation back to the original setting of 21. Notice that the detail diminishes slightly but the overall shape is the same. If increased accuracy is needed, the tessellation may be set higher, avoiding values greater than 61.
Setting Up the Model

- A large number of interpolated cross sections will also adversely affect the software’s ability to analyze the vehicle quickly. Reducing these numbers will cause the more complex geometries to suffer slightly but the effect on the results in VSPAero will be negligible.

- If you have more than 4 interpolated sections in the model between ANY small cross sections, the time will increase significantly. Experience has shown that except for complex wing geometries, having at most 3 interpolated sections is sufficient to obtain accurate results without sacrificing time.

Figure 1: High vs. Low Interpolated Cross Sections
Setting Up the Model

- The method that VSPAERO uses to calculate the segment lift coefficient (Cl) will not recognize that the wing is one solid piece. So to obtain accurate lift coefficients, you must make a small section near the center of the wing (section ID zero) that has a very small span (~0.3 ft) and at least one interpolated section. This will provide a “throw away” value in the LOD file that VSPAERO will list as excessively low. This also increases the accuracy of the integrated value of CL.

Figure 1: High vs. Low Interpolated Cross Sections
Setting Up the Model

Figure 2: Comparison of high detail model to low detail model.
Setting Up the Model

• Keep in mind that VSPAero computes the values it outputs by analyzing a representative section of the body. By reducing the number of sections you reduce the number of computations. However, if there are sections in your model where two surfaces align vertically (near perpendicular) or almost exactly overlap, the software will recognize this as an error and freeze.

• To avoid this problem ensure that any vertical components, such as the vertical stabilizer, are slightly raised above the attached component. If the gap is sufficiently small, the software will show values that treat it as if it were attached without the resulting freeze.

• Similarly, avoid the overlay of several small components. When at all possible, use a single component to represent a complex geometry to ensure that the object is “water tight”.

Setting Up the Model

- Another very important consideration is that, to date, VSPAero will not recognize “open” components such as ducts, engines, etc.

- When using objects similar to these, it is important to simply model them as FUSE2 components for the outer shape and to make sure that the ends of the component come to a point. If any component is left open ended, the model is not water tight and the computed mesh will fail. This will cause significant errors in VSPAero.

- Additionally, any component that is not modeled as a FUSE2, MS WING, or BLANK will most likely not run in VSPAero due to how the component is written. Remember that openVSP is for modeling complex geometries with simple components.
Building Files: CFD Mesh

• When you believe that your model is ready to begin building files for analysis, there are several steps that will increase the success of the software.

1. Under the “Geom” tab in the menu bar, click CFD Mesh. By default, “Rigorous 3D Growth Limiting” is not selected. Click “Mesh and Export”.

2. The CFD mesh will run and the mouse cursor may show that it is busy and the window may say “(Not Responding)”. This is normal. Wait for the mesh to build and export and when complete your model will be shown in the newly built CFD mesh (lots of small triangles).

3. Note in the CFD Mesh window, the result should say “Is Water Tight” at the end of the process. If this is not the case, then one or more of your components have a broken edge and must either be corrected or removed to proceed. If this process is unsuccessful, you can also select “Rigorous 3D Growth Limiting” to see if the process will work.
Building Files: CFD Mesh

Figure 3: CFD mesh verification
Building Files: Component Geometry

4. The next step is to build the component geometry file. Under the “Geom” tab, click “Comp Geom (Union)”. You will also want to ensure that the “.tsv” button is active (yellow) under the title “Parasite Drag Output”. This will create a drag build file in the directory for later use.

5. Click “Execute”. Again, your model will be shown in the new mesh. This new component may be cut/deleted. The values for your vehicle will be displayed in the Comp Geom window.
Building Files: Component Geometry

Figure 4: Component geometry verification

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6. Under the “Geom” tab, now select “DegenGeom”. Click “Execute”. The result will show that a number of components have been written to files. Note that lifting surfaces placed over another lifting surface will generally cause this process to crash openVSP. If your model requires that there be multiple, stacked lifting surfaces, attempt to account for this by offsetting one of the lift surfaces such that they are not directly overhead.
Building Files: Degenerate Geometry

Figure 5: Degenerate geometry verification
When using VSPAero, the main components which control the output values of are the lifting surfaces such as the wing and horizontal stabilizer. While the other body components will have some small effect on the profile drag of the vehicle, the induced drag which VSPAero determines is based primarily on the lift coefficient.

Knowing this, we can step the model down further by cutting the body components out of the model. First, save this reduced detail model under the chosen file name for your “clay” model. This file will be the backup for any reduced detail component that you wish to analyze.

Cut all but the lifting components from the model using the geometry browser. Under a new title, save the lift component model in the desired file location. This new model will be the base for VSPAero analysis. Remember to OPEN this new file or the resulting output files will overwrite the clay model files!
Building Files

- Now that the lifting surfaces have been isolated, you can create another DegenGeom file in the same way that you did for the aircraft. These files will be the source for VSPAero later. Note the location of these files!

Figure 6: Model reduced to lifting components only
Building Files: VSPAero

- There are six files that must be located in the same folder for VSPAero to run properly:
  1. vspaero.exe
  2. vsp_degen.exe
  3. viewer.exe
  4. pthreadGC2.dll
  5. libgomp-1.dll
  6. libgcc_s_dw2-1.dll

- This folder should contain only these six files and the VSPAero files needed to run the software. This is also where VSPAero will create the data files. While not required that only the related files be present, it is strongly recommended due to the high number of files that will be made.
Building Files: VSPAero

- The created Filename_DegenGeom files from openVSP must both be located in the same folder as the vspaero.exe program. Once these two files have been copied to the location, you can create or modify the required .vspaero file that sets the conditions for VSPAero to analyze.

- A text file will be made using notepad or a similar application following the format shown.

- Any extra spaces or returns at the end of each line can cause errors.

- Follow the format shown exactly, changing only the values.

- When complete, you must save the text exactly as the openVSP generated files appear with the extension “.vspaero” in the same folder as the applications.

- Ex) Filename_DegenGeom.vspaero
Building Files: VSPAero

- If the values for the rotors are unknown, leave the number of rotors at zero and delete the rotor information.

*When analyzing high lift conditions such as takeoff and landing or high angles of attack (greater than 15 degrees), perform more than one iteration to analyze wake effects.

<table>
<thead>
<tr>
<th>Title</th>
<th>Meaning</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sref</td>
<td>Wing Face Surface Area (S)</td>
<td>Feet²</td>
</tr>
<tr>
<td>Cref</td>
<td>Mean Aerodynamic Chord (MAC or C)</td>
<td>Feet</td>
</tr>
<tr>
<td>Bref</td>
<td>Wingspan (B)</td>
<td>Feet</td>
</tr>
<tr>
<td>X_cg</td>
<td>X-Axis Center of Gravity Location</td>
<td>Feet</td>
</tr>
<tr>
<td>Y_cg</td>
<td>Y-Axis Center of Gravity Location</td>
<td>Feet</td>
</tr>
<tr>
<td>Z_cg</td>
<td>Z-Axis Center of Gravity Location</td>
<td>Feet</td>
</tr>
<tr>
<td>Mach</td>
<td>The Mach Number (Based on Speed and Air Density)</td>
<td>None</td>
</tr>
<tr>
<td>AoA</td>
<td>Angle of Attack</td>
<td>Degrees</td>
</tr>
<tr>
<td>Beta</td>
<td>Slide Angle</td>
<td>Degrees</td>
</tr>
<tr>
<td>Vinf</td>
<td>Free Stream Velocity</td>
<td>Feet/Second</td>
</tr>
<tr>
<td>Rho</td>
<td>Air Density</td>
<td>Pounds/Feet³</td>
</tr>
<tr>
<td>WakeIters*</td>
<td>The Number of Wake Iterations to Perform</td>
<td>None</td>
</tr>
</tbody>
</table>

*When analyzing high lift conditions such as takeoff and landing or high angles of attack (greater than 15 degrees), perform more than one iteration to analyze wake effects.
If the values for the rotors are unknown, leave the number of rotors at zero and delete the rotor information.

<table>
<thead>
<tr>
<th>Title</th>
<th>Meaning</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>NumberOfRotors</td>
<td>The Number of Rotors for the Model</td>
<td>None</td>
</tr>
<tr>
<td>PropElement_N</td>
<td>The Rotor Element Number</td>
<td>None</td>
</tr>
<tr>
<td>n</td>
<td>The Rotor Number</td>
<td>None</td>
</tr>
<tr>
<td>X, Y, Z</td>
<td>Rotor Center Location Coordinates</td>
<td>Feet</td>
</tr>
<tr>
<td>Xn, Yn, Zn</td>
<td>Rotor Plane Normal Vector</td>
<td>None</td>
</tr>
<tr>
<td>R</td>
<td>Rotor Radius</td>
<td>Feet</td>
</tr>
<tr>
<td>r</td>
<td>Rotor Hub Radius</td>
<td>Feet</td>
</tr>
<tr>
<td>± RPM</td>
<td>Rotor Speed ( minus indicates CCW rotation as seen from front)</td>
<td>Rev/Min</td>
</tr>
<tr>
<td>CT</td>
<td>Thrust Coefficient</td>
<td>None</td>
</tr>
<tr>
<td>CP</td>
<td>Power Coefficient</td>
<td>None</td>
</tr>
</tbody>
</table>
Running VSP\textregistered Aero

- Before running VSP\textregistered Aero, the folder should have the associated files present.
Running VSPAero

- In the Command Prompt, change the directory to the folder that houses vspaero using the “cd” command.
  - Ex) `C:\Users>cd documents\vspaero_files`
- Once in the correct directory, you will need to execute VSPAero.
  - Ex) `C:\Users\Documents\Distro.v0.04\bin.win.32>vspaero pa44play_DegenGeom`
- If you know the number of processors that your computer has, you can force N number of processors to work on VSPAero using: `>vspaero –omp N filename_degenGeom`
- Doing this WILL use close to 100% of the selected processor’s power. System performance may suffer if too many processors are used.
Running VSPAero

• Once VSPAero is running, the screen will show the program operating.

• Depending on the complexity of the model and the number of processors set to run, this can take seconds or hours just for ONE wake iteration. This is why the model must be sufficiently simple for the program to analyze.
Running VSPAero

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Running VSPAero

• If it appears that the process is extraordinarily slow, you may halt the process by typing “CTRL+C”.
• When complete, the prompt will return to the command line and await the next command.
Running VSPAero

- Used to visualize the Delta-Cp gradient over each surface
- Reality check and wake visualization (Identify problem areas)
Running VSP Aero

- If you would like to see what the drag profile looks like, enter: “viewer filename_degengeom” into the command line.
- This will open the visualization application.
- To obtain meaningful gradients, you will most likely need to change some of the menu settings.

Figure 7: Aircraft Δ-Cp Example
Running VSPAero

- If you would like to see what the drag profile looks like, enter: “viewer filename_degengeom” into the command line.
- This will open the visualization application.
- To obtain meaningful gradients, you will most likely need to change some of the menu settings.

![Image of aircraft with text overlay: Figure 7: Aircraft Delta-Cp Example]

If these values do not match what you wrote into the .vspaero file, then the .vspaero file is formatted incorrectly. Check that there are no spaces or returns at the end of each line.
Running VSPAero

- Under Aero, select “delta_cp”.
- Under Options, select “Set Contour Levels” and set the maximum to 1 and the minimum to -2.
- If you would like to see the location and rotation direction of the rotors, under Aero select “Rotors”.

*Figure 7: Aircraft Delta-Cp Example*
Running VSPAero

- To obtain all of the values from VSPAero that are required for drag polar build-ups and lift curves, it is necessary to open the .vspaero file in notepad and change the angle of attack (AoA) to the next value to be computed and save.

- Note that you MUST copy the values in the HISTORY file to another database before you execute VSPAero again. The history file is only temporary storage of values. It is recommended that you copy these values into the attached Excel spreadsheet for analysis and comparison for your vehicle.

- You must then re-execute VSPAero from the command window. Repeat this process for each flight condition that is to be analyzed.
VSPAERO
Output Files

• VSPAERO outputs 3 files
  • The LOD file contains the span wise loading information (for example the sectional $C^* C_L$ is shown for each lifting component)
  • The ADB file contains information for VSPAERO
  • The HISTORY contains the total integrated forces and moments
VSPAERO

Output Files

- The HISTORY File contains the information used for the Drag Buildup calculations
OpenVSP Issues

- DegenGeom is sensitive to surface intersections.
- When making a new file, you must open the new saved file to cause VSP to write geometry files under the new name. Otherwise overwrite will occur.
- Cannot use open engine nacelles.
- Must not have destination file open when computing geometries. VSP will crash.
- Revert only works as long as you have not modified another component. This is not an “undo” function.
XFOIL Issues

• There is a maximum number of stored polars that XFOIL will create in a single operating session.
• The write file for a range of angle of attack will sometimes display the previously stored polar’s Reynolds number, though the values were computed using the user input.
• Cumbersome if the software crashes.
VSPAERO

Debugging/ Limitations

• Only simplified VSP models work
• No maximum coefficient of lift
• Pressure Drag vs Trefftz Drag
• High Lift conditions
• Improperly intersected components can lead to major computation errors