# Conversion of Component-Based Point Definition to VSP Model and Higher Order Meshing

Irian Ordaz*

*NASA Langley Research Center, Hampton, VA 23681*

**Vehicle Sketch Pad (VSP) has become a powerful conceptual and parametric geometry tool with numerous export capabilities for third-party analysis codes as well as robust surface meshing capabilities for computational fluid dynamics (CFD) analysis. However, a capability gap currently exists for reconstructing a fully parametric VSP model of a geometry generated by third-party software. A computer code called GEO2VSP has been developed to close this gap and to allow the integration of VSP into a closed-loop geometry design process with other third-party design tools. Furthermore, the automated CFD surface meshing capability of VSP are demonstrated for component-based point definition geometries in a conceptual analysis and design framework.**

## Nomenclature

**Acronyms**

**CFD** = computational fluid dynamics

**OFF** = object file format

**RMS** = residual mean square

**STL** = stereo lithography

**TRI** = Cart3D surface triangulation

**VSP** = Vehicle Sketch Pad

**XML** = extensible markup language

## I. Introduction

Vehicle Sketch Pad[1] has evolved into a powerful parametric tool for conceptual design capable of exporting several file formats for input to third-party analyses and tools, including stereo lithography (STL) and component-based point definition (Hermite). However, the capability to import geometries from third-party tools back into VSP has not been available. This capability is necessary with the use of design tools such as WINGDES,[2] BOSS,[3] and other geometry-shaping and optimization tools. This paper demonstrates a new capability for reconstructing fully parametric VSP models from geometries defined as a component-based point definitions (i.e., Hermite and Plot3D). In addition, an automated computational fluid dynamics (CFD) analysis process that uses the CFD surface meshing[4] capability of VSP is demonstrated for cases in which the user has a point-definition geometry.

## II. Geometry Modeling Approach

GEO2VSP was developed to allow for the geometrical reconstruction of a fully parametric VSP model from a Hermite or Plot3D formatted geometry. A key requirement imposed on GEO2VSP was that it must reconstruct the original point definition geometry accurately and independent of the configuration complexity. This is accomplished by using the parameterization of complex fuselage cross sections with Bezier curves. This parameterization is compatible with the parametric schemes implemented in VSP.

*Research Engineer, Aeronautics Systems Analysis Branch, Systems Analysis and Concepts Directorate.

The tool also has several built-in checks for the input geometry to improve robustness, fix orientation issues and eliminate degenerate sections that can cause problems during the generation of a surface mesh.

GEO2VSP can currently handle any number of components which can be modeled as fuselage, wing, or duct-type components. These components are tagged in the standard VSP Hermite file as types 1, 0, and 1, respectively. However, in the case of a duct component, the type tag must be modified as type 2 to differentiate it from a fuselage component. Alternatively, a nacelle or duct fan can be modeled as two fuselage components to represent the inner and outer surfaces.

An input file can be used to control the modeling of specific components, such as cross section and airfoil type, as well as the number of interpolated points and sections. The input file also can be used to group the modeling characteristics of the component types (i.e., fuselage, wing, etc.) when a large number of components exist in the model. This feature helps avoid the need to specify modeling properties for all components. The code also can be executed without the use of an input file; in this case, all components are modeled explicitly using the original data points, and the parameterization of the fuselage cross sections and the airfoils is lost. This mode sacrifices parameterization control in order to ensure that the outer mold line is modeled as accurately as possible in the absence of modeling information. A nonparameterized VSP model is still valuable when VSP is simply being used to generate a triangulated surface mesh for CFD analysis.

As mentioned earlier, GEO2VSP attempts to accurately reconstruct a model from the point definitions. This requires back solving all geometry parameters, including fuselage cross sections, chord, sweep, camber, twist, dihedral, component location and orientation angles, and so on. All component sections in the original point definition become VSP sections. A reconstructed VSP model is most accurately modeled when all of the VSP requirements for the data structure are met. An example of a VSP requirement is that of planar airfoils sections. For a case in which the airfoils are nonplanar, GEO2VSP first computes the average normal for all points. Each plane is defined by a point on the upper or lower surface, and the leading- and trailing-edge points which are shared by all planes. All nonplanar airfoil points are then projected to the plane of the computed average normal. This adds robustness to the code, but could introduce error if the original airfoil points are highly nonplanar.

Bezier curve parameterization has been implemented for nonstandard and complex fuselage cross sections. This means that complex cross sections can be controlled by using the "Edit" menu in the fuselage property box within VSP. This provides the best curve fit and minimizes the number of Bezier segments for smooth sections. The tool is capable of handling nonsmooth sections, but the fit around discontinuities will not be exact, and the number of Bezier segments will increase significantly. Nonetheless, fuselage cross section discontinuities can still be handled without difficulty if they occur at the $XZ$ symmetry plane (i.e., a keel).

The orientation of the sections ($u$) and points on each section ($v$) in the Hermite and Plot3D files must adhere to the rules that are given in the appendix. This data structure is the same as that of the Hermite format, which is exported by VSP. GEO2VSP is able to identify and remove the nonrequired wing tip faces from the watertight components in the Plot3D format. For a summary of the input data requirements, refer to Table 1.

**Table 1. Data Requirements**

| No. | Description |
|---|---|
| 1 | Proper $u$- and $v$-orientation, as shown in the appendix. |
| 2 | Planar sections for greater accuracy. |
| 3 | For fuselage sections, two points (upper and lower) on the centerline plane, with an equal number of points on either side of the symmetry plane. |
| 4 | For airfoil sections, the desired leading- and trailing-edge points defined explicitly, with an equal number of points placed on upper and lower surfaces. |
| 5 | Duct-type components redefined as type = 2. |

## III. Demonstration and Verification of GEO2VSP tool

Several reconstructed geometries with distinct and challenging features are shown in Fig. 1. In this figure, the shaded surfaces correspond to the original points, and the blue wire frames show the reconstructed VSP models.

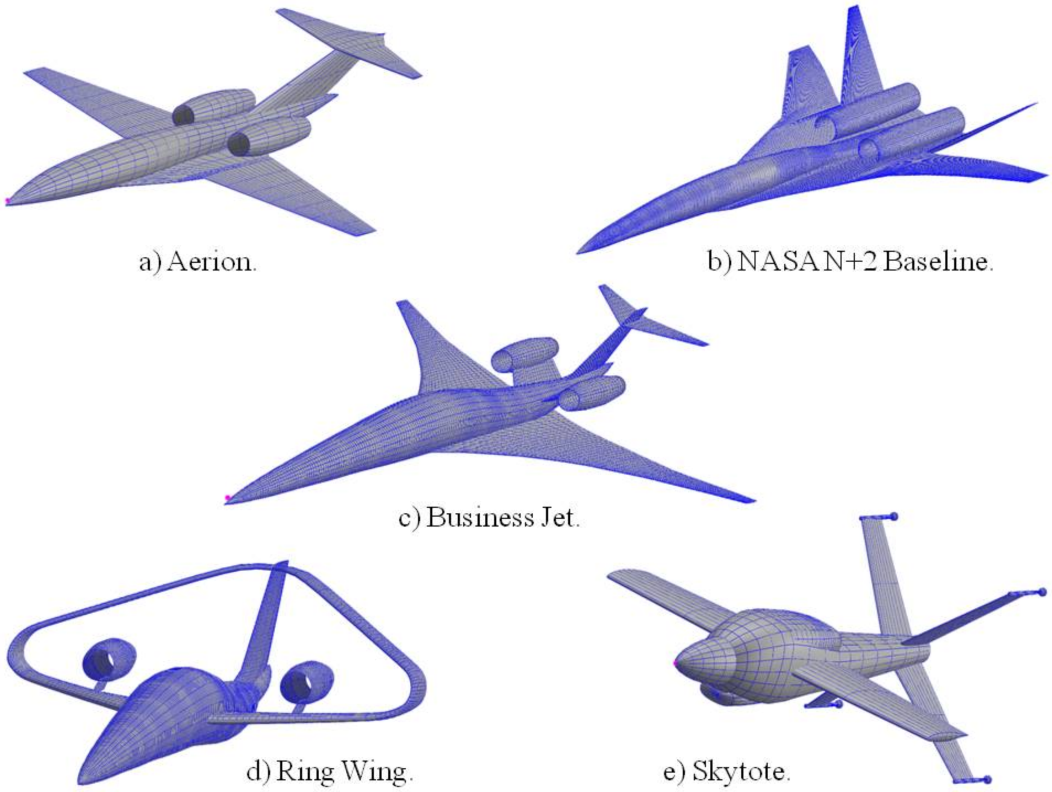


**Figure 1. Sample geometries reconstructed by GEO2VSP.**

The accuracy of the model is affected by machine error but most importantly by the adherence to the data structure requirements. For the NASA N+2 baseline vehicle,[5] shown in Fig. 1b, a statistical analysis was performed to better evaluate the accuracy of the reconstructed VSP model. The NASA N+2 configuration was reconstructed explicitly by using the data points from the Hermite geometry. This means that the fuselage sections were not modeled as circles or ellipses and the airfoils sections were not prescribed airfoils (i.e., NACA series airfoils). The reconstructed VSP model was opened with VSP, and a newly reconstructed Hermite geometry file was exported. The data points from the reconstructed and the original Hermite file were then analyzed, and the statistical data for the error is given in Table 2. The error in this analysis is based on the Euclidean distance between the corresponding points of the model.

Note that this statistical analysis does not present the results in the best light because when prescribed airfoils sections are used, VSP re-samples the points at $x$-locations that may not necessarily be identical to the original prescribed points. Despite this, very good agreement is observed between the reconstructed and the original data. The maximum percentage of error for any given point relative to the length of the vehicle (154 ft) is only 0.34 precent.

**Table 2. Statistical Analysis of Reconstructed Configuration**

| Description | Residual mean square error (ft) |
|---|---|
| Fuselage | 0.1112 |
| Tail | 0.0058 |
| Nacelle | 0.0009 |
| Wing | 0.0934 |
| Total | 0.0621 |
| Average | 0.0227 |
| Maximum | 0.5247 |

## IV. Automated CFD Surface Meshing and Analysis

A design and analysis framework in ModelCenter[6] is used to demonstrate the automated CFD meshing capability of VSP. In the ModelCenter model, Cart3D[7] is integrated to perform the CFD analysis. The capability for automated volume mesh generation in Cart3D is a key enabler for the infusion of high-fidelity aerodynamics analysis into the conceptual design phase. An additional requirement for automated surface meshing in conceptual design is satisfied by the implementation of high-order CFD meshing within VSP. Default rules are built into VSP to automate the placement and sizing of sources depending on the component type. In addition, a parameter can be passed to VSP when it is executed in batch mode to control the global refinement level of the triangulation.

The geometry process to obtain a surface triangulation for Cart3D using VSP is illustrated in Fig. 2. The process starts with a VSP parametric geometry in extended markup language (XML) format and makes use of VSP's built-in CFD surface meshing capability, which is executed in an automated manner through batch mode. Admesh and off2tri are surface triangulation conversion tools included in the Cart3D package.

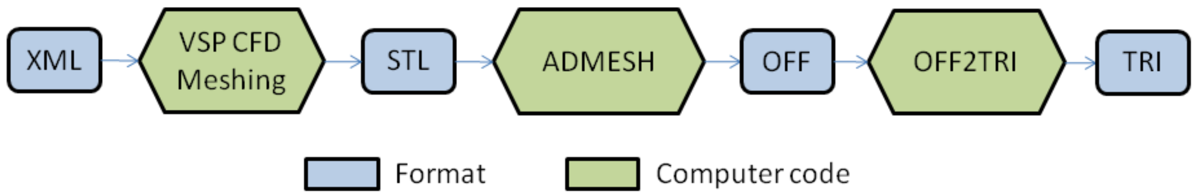


**Figure 2. Geometry process to convert XML to Cart3D triangulated surface.**

The requirement to have a VSP model to generate a surface mesh with VSP is now solved with the implementation of GEO2VSP. Once the XML model is constructed from a component-based point definition, the process described in Fig. 2 can be used to obtain the final surface triangulation. The benefit of converting to a VSP model is the capability to generate a high-quality STL file using VSP's built-in CFD surface meshing for non-VSP geometries. In addition, changes can quickly be made to the original point configuration because the geometry is fully parameterized in VSP. The drawback to this approach is the loss of component information once the monolithic surface triangulation is generated.

A surface triangulation was created using the CFD meshing capability of VSP for the NASA N+2 baseline vehicle as shown in Figs. 3 and 4. Note that this mesh was created with the automated sourcing in batch mode; the mesh quality can be improved further by manually adjusting the placement and strengths of sources within VSP.

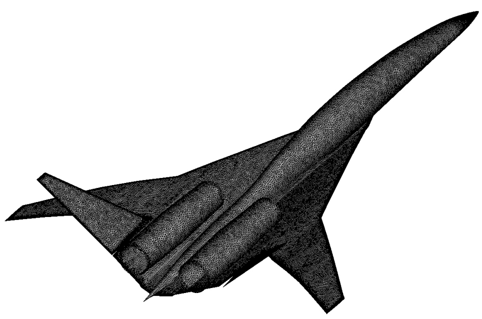

**Figure 3. Surface triangulation using automated CFD meshing in VSP.**

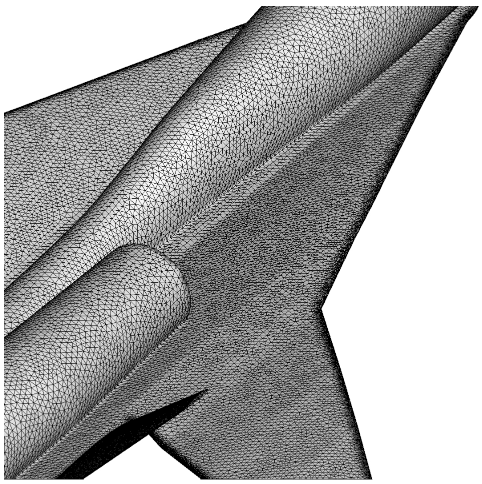

**Figure 4. Zoomed view of surface triangulation.**

Finally, a Cart3D pressure solution for the triangulated surface of the NASA N+2 baseline is shown in Fig. 5. The CFD analysis is performed for a speed of Mach 1.6 and an angle of attack of 0.79 deg. The complete process, starting with the initial conceptual geometry and ending with a complete CFD analysis, can be accomplished within ModelCenter with minimal computational and human resources.

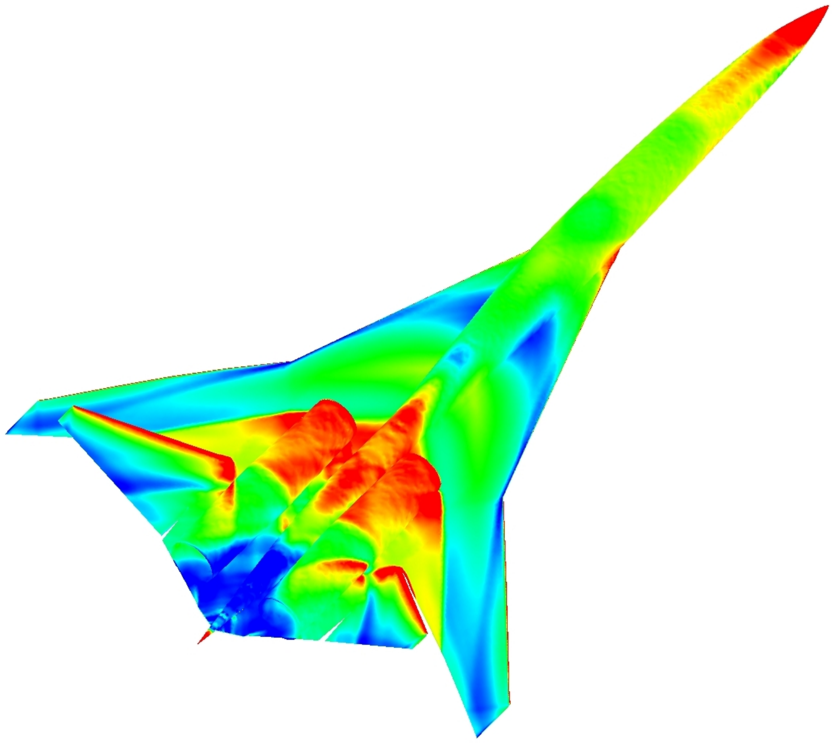

**Figure 5. Cart3D pressure solution for automatically generated VSP surface mesh.**

# V. Concluding Remarks

A long-standing capability gap within VSP has been addressed with the developed GEO2VSP code. GEO2VSP allows conceptual geometries that are modeled as component-based point definitions (i.e., Hermite format) to be imported into VSP. The imported models retain the full parametric capabilities that have been built into VSP. The tool provides a closed-loop geometry process through which geometries that are modified by third-party design tools can be brought back into VSP for further modifications. The VSP model also allows CFD surfaces meshes to be generated for higher order aerodynamic analyses. This capability was demonstrated using the NASA N+2 concept aircraft to obtain a CFD solution with Cart3D.

# References


[1]Hann, A., "Vehicle Sketch Pad: A Parametric Geometry Modeler for Conceptual Aircraft Design," AIAA-2010-657, January 2010.

[2]Carlson, H. W., "Program WINGDES - Release 2001.1," http://www.mae.virginia.edu/meclab/images/WdesMan.pdf, [cited December 2009].

[3]Li, W., Shields, E., and Le, A., "Interactive Inverse Design Optimization of Fuselage Shape for Low-Boom Supersonic Concepts," AIAA-2008-136, January 2008.

[4]Gloudemans, J. R. and McDonald, R., "Improved Geometry Modeling for High Fidelity Parametric Design," AIAA-2010-659, January 2010.

[5]Welge, H. R., Bonet, J., Magee, T., Chen, D., Hollowell, S., Kutzmann, A., Mortlock, A., Stengle, J., Nelson, C., Adamson, E., Baughcum, S., Britt, R. T., Miller, G., and Tai, J., "N+2 Supersonic Concept Development and Systems Integration," NASA CR 2010-216842, August 2010.

[6]"ModelCenter and Optimization Tools," Phoenix Integration, http://www.phoenix-int.com/, [cited December 2009].

[7]Aftosmis, M., "Cart3D Resource Website," http://people.nas.nasa.gov/~aftosmis/cart3d/cart3Dhome.html, [cited December 2009].


# Appendix. Data Orientation

The appendix section illustrates the data orientation required by GEO2VSP for the point definitions of all components in the Hermite or Plot3D input geometry.

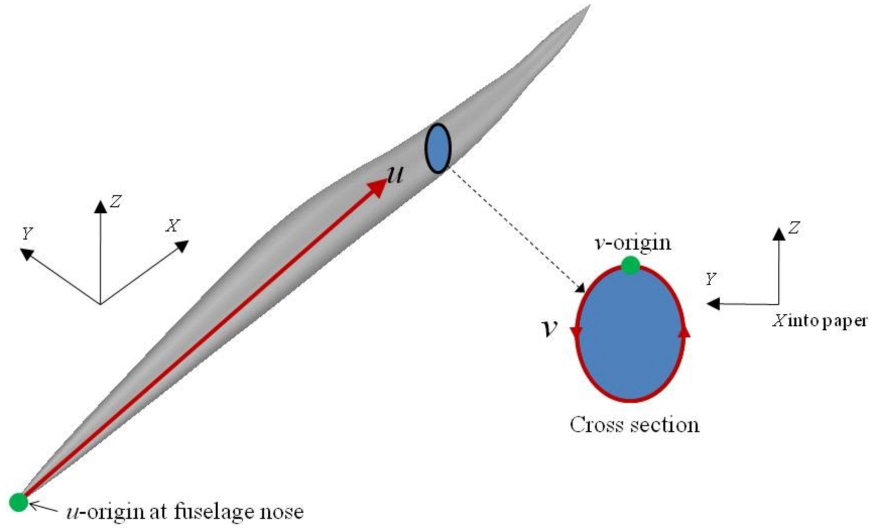


**Figure A-1. Fuselage-component point orientation.**

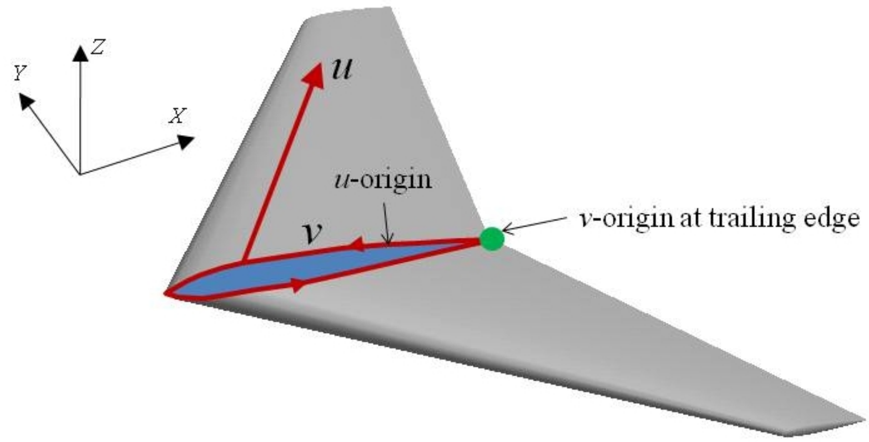


**Figure A-2. Wing-component point orientation.**

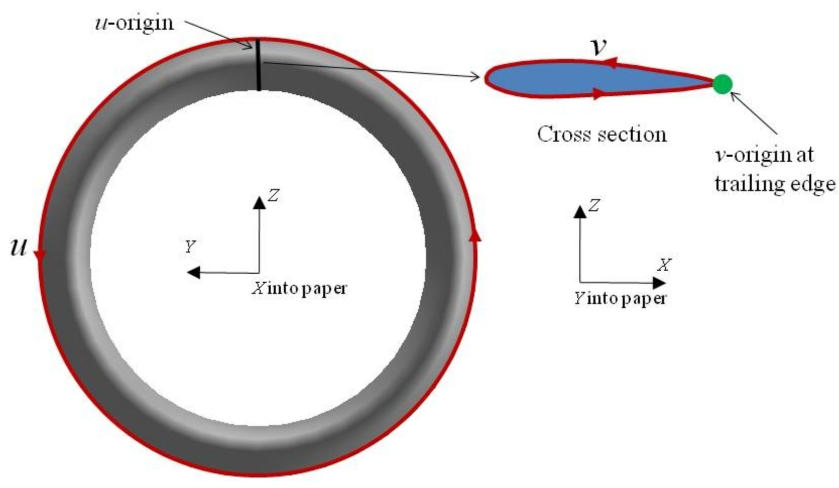


**Figure A-3. Duct-component point orientation.**