Production Unstructured Grid Generation using Nemesis™, powered by Boeing's AGPS

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The Nemesis grid interface package has been developed as a front-end for NASA's Vgridns grid generation software to improve productivity and quality by automating best practices from the knowledgeable user community. This novel grid generation system provides expert level tools that provide superior control so that even novice users can produce better grids with less training and expert users won't have to perform as many routine tasks manually. Resulting grids still require expert review, and advancements should not be confused with complete hands-off automation. Current users of Nemesis report 90% reduction in flow time compared with the existing involved processes.

I. Introduction

Since productivity, accuracy, and repeatability of grid generation results still prevail as the major bottleneck for engineers, the need for a system that can reliably provide these attributes would be substantial. This paper introduces a novel grid generation system that provides expert level tools in an easy to use environment that intends to provide just such superior control to the engineer. The Nemesis Gridding Interface was created with and is powered by the Aero-Grid and Paneling System (References 1-3) and was developed with one goal in mind, to ease the grid-generation process and cut preparation time by providing exceptional expert level tools so that even novice users can produce better grids.

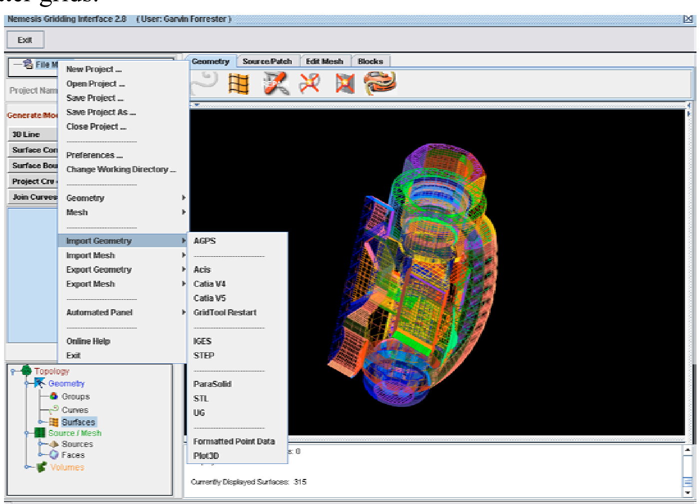

Figure 1. The Nemesis™ graphical interface created with AGPS.

The Aero-Grid and Paneling System (AGPS) is developed by The Boeing Company and is licensed for commercial resale to Calmar Research Corporation's Software Technologies group (Reference 9). Spawned from a culture of process oriented engineering, AGPS has succeeded at Boeing, as a driver for its large production CFD needs.

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II. Nemesis Overview

The maturation of Nemesis™ was sparked by exploratory conversations with NASA Langley concerning using AGPS as a geometry engine to enhance and support their TETRUSS Euler/Navier-Stokes (ENS) solution system (References 5-7). This solution system utilizes GridTool/Vgridns for the generation of tetrahedral based viscous, unstructured grids and USM3Dns for the corresponding ENS flow solutions. GridTool manually prepares surface patch-based representations of geometry, and defines grid characteristics such as grid spacing and stretching. Vgridns generates viscous grids using advancing layers to resolve the viscous boundary layer and the advancing front method to resolve the remaining portion of the volume grid. Vgridns is known as a very robust, high quality unstructured grid program developed by Shahyar Pirzadeh while at Vigyan, and since then continuously developed at his new post at NASA Langley. However, since it is a research code, Vgrid's power and usability have been limited to practiced users.

When it was clear that not only could AGPS act as a geometry engine but also encapsulate and automate parts of the GridTool/Vgridns process, there was interest from the Lockheed Martin Aeronautics Company for further investigation. Lockheed engineers wished for a mostly automated system that could handle their complex geometries and hopefully save them hours of pre-processing and massaging of topologies to satisfy GridTool/Vgridns requirements. To satisfy this need a standalone precursor to Nemesis was created as an AGPS add-on called the AGPS/Vgrid Pre-Processor™. The AGPS/Vgrid Pre-Processor hands-off automatically prepares any topology for input directly into GridTool or Vgrid (depending on the level of complexity) alleviating about 90% of the laborious preparation usually needed. This package performed better than expected actually translating into days of labor savings for the engineers at Lockheed as reported in a recent AIAA paper (Reference 5).

The next logical step was to eliminate GridTool and Vgrid interactions all together, by having a centralized user-friendly system that encompassed the lessons learned in developing the AGPS/Vgrid Pre-Processor. This included support for multiple CAD systems, geometry repair, tools to create and manipulate topology, automatic checks for surface patch consistency, gaps, normal direction, and real-time preview of mesh as changes were made.

Specifically, Nemesis employs a unique combination of knowledge-based tools and an integrated grid generation interface, utilizing and directly communicating with the unstructured Vgridns toolkits. The Nemesis product also leverages capabilities from the AGPS modeling environment which allows Nemesis to ease, completely integrate, and automate, all the pre- and post processing for Vgridns (including the actual grid generation and process management).

Those familiar with the current GridTool/Vgrid process should appreciate the enhancements provided by the Nemesis Gridding Interface, which strengthen and ease the Vgrid experience.

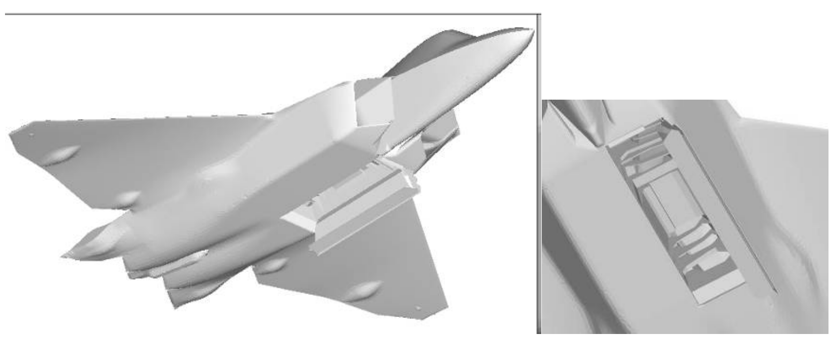

Figure 2. AGPS/Vgrid pre-processor a precursor to Nemesis. When used a weapons bay mesh was added on the F/A-22 in ~7 labor hours which previously required 60 hours.

II.1 Nemesis Gridding Interface – the Role of AGPS, Vgrid, and Nemesis

The Nemesis Gridding Interface was developed with one goal in mind, to ease the grid-generation process and cut user preparation time by providing superior knowledge based tools. Nemesis appears and performs similarly to commercial mesh generation software – it actually produces grids. The major differences and benefits of Nemesis stem from leveraging the combined capabilities of AGPS and Vgrid, which utilize very accurate, powerful, and superior tools.

The strategic evolution of the Nemesis product has relied on four criteria:

1. Using the flexibility of AGPS to enhance and develop other processes around the grid-generation task.
2. Automate the surface definition and preparation with the AGPS modeling environment.
3. Take advantage of Vgrid's well-known robustness and high quality.
4. Have the experienced user community be the primary designer of key functionality.

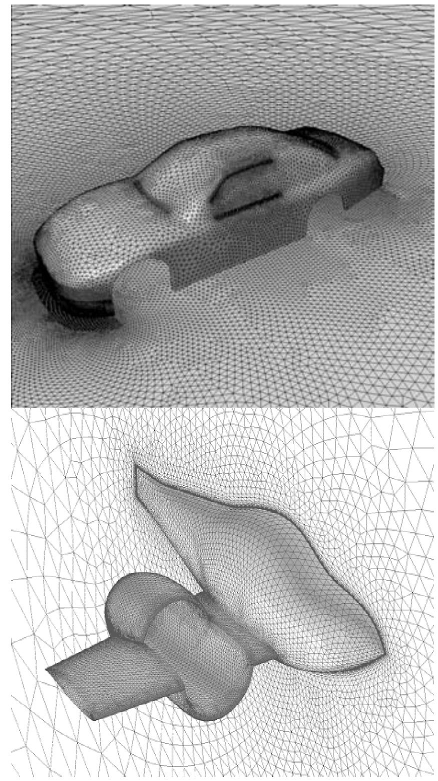
Figure 3. Sample meshes created with Nemesis.

The role played by AGPS can be best described as a modeling and integrated development platform built around a surface geometry system focusing on the engineering analysis needs of technical staffs such as aerodynamicists. It's greatest attribute is it's flexibility to perform both automated intelligent tasks based on engineering know-how and providing the user/programmer control to investigate novel concepts. This foundation allows the Nemesis product to be very dynamic and manageable. The Nemesis development team was able to make strategic decisions on feature capabilities, such as, where complete automation was feasible and even where guided control or complete user-control was best suited. The data structure of AGPS houses a catalogue of parametric geometric object types that made interrogation, extraction, and manipulation of topology all self contained and very tractable. The development environment of AGPS provided all the high-level programming constructs that the team desired allowing minimal external code writing or third-party applications. For example, the entire graphical interface (GUI) and macro capability of Nemesis leverages built in AGPS directives, gadgets, and commands. With geometry as core competency, the modeling environment within AGPS allowed Nemesis immense process automation and productivity improvements by repairing underlying geometry and applying expert best practices with an intuitive user interface.

The role of grid quality and consistency within Nemesis is freeloaded by direct communication with Vgrid. The user never actually runs or sees Vgrid, all inter-processing is handled by Nemesis. Hence, all the attributes appreciated about Vgrid can be expected with Nemesis. The salient features of Vgrid are well documented and proven. Smooth grid refinement is achieved by using a method of distributing grid points using "Sources", which act like heat sources that dissipate heat in a conducting medium, except that they propagate smooth grid spacing throughout the computational domain. A special Patch type allows direct surface triangulation on CAD/NURBS surfaces ensuring grid points are actually projected onto desired surfaces. Anisotropic grid stretching allows localized cell stretching that provides substantial reduction in grid size without loss of computational accuracy. For typical full aircraft configurations, the multi-directional anisotropic stretching saves ~40% of the grid size and corresponding run times.

The role of Nemesis is the glue, the application provides a very concise interface geared towards making all associated functions related to the grid generation process more efficient. Features like geometry import allow processing of Trimmed surfaces/faces and numerous other surface types and CAD systems such as, CATIA V4/V5, IGES, STEP, UG, and more. Furthermore, the geometry translation and repair capabilities handle low quality geometry and geometry groupings. Other features of Nemesis include automatic Patching, topology tools for creation of curves, surfaces, and mesh density. As with most software systems Nemesis also features easy maintenance of database display and attributes supported by an interactive online help system.

II.2 Nemesis Gridding Interface – the Features

The features within Nemesis provide capabilities that were missing in GridTool/Vgrid and also strengthen others that already exist.

1. Geometry Translation - handling Trimmed Surfaces

Nemesis supports surface geometry, specifically Trimmed surfaces, from CAD systems, which GridTool was not designed to handle. Nemesis has provisions for multiple CAD systems such as, CATIA V4/V5, IGES, STEP, UG, GridTool, and more.

2. Surface Repair & Healing

Beyond data translation/import Nemesis leverages the AGPS modeling environment to repair problems that plague Trimmed surfaces imported from other systems, namely minute openings or overlaps in the parametric definition of the Trimmed surface. Nemesis will automatically detect and fix these occurrences. Topology healing is achieved by leveraging the built-in Cadfix® technology that automatically heals low quality geometry.

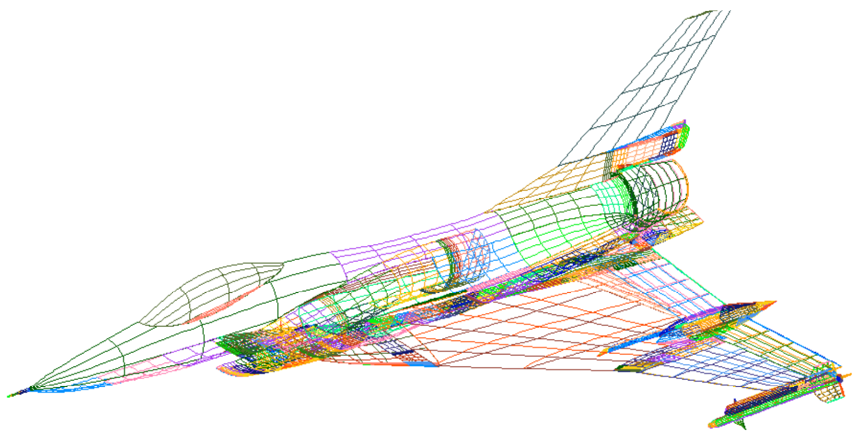

Figure 4. Complex topology of F16-XL readily imported into Nemesis.

3. Patch Concavity check

Users familiar with Vgrid are aware that it is cautioned not to create a Patch that forms a convex interior corner with the adjoining edges of the start and end of a Patch. This situation although known to most users is only visibly detectable but usually goes unnoticed until the Vgrid process is begun. Nemesis automatically detects and fixes this undesired state during Patch creation by rotating the patch until the convex corner does not exist.

4. Automatic Surface Association & Patch Orientation

Vgrid supplies a special Patch type that allows direct surface triangulation on CAD/NURBS surfaces ensuring grid points are actually projected onto the desired surface. Usually the user manually selects the preferred surface and accepts the choice to achieve this. Nemesis has the ability to automatically determine the surface selection for the user and of course supplies them with override control.

5. Patch/Grid preview

Nemesis provides real-time mesh preview at any point in the mesh generation process. Users can automatically see the effects of their mesh density choices and topology choices has they wish. Usually in the GridTool/Vgrid process, mesh preview is only possible after completion of a watertight contiguous topology and actually running of Vgrid without error.

III. Nemesis Enhancements

The enhancements presented in this paper highlight efforts to improve grid generation productivity and quality by automating best practices from the expert Vgrid user community. These expert level tools provide superior control so that even novice users can produce better grids with less training and expert users won't have to perform as many routine tasks manually. While these enhancements are not completely hands-off automation, they do provide rapid turnaround and meshing consistency as needed in large complex demanding design cycles.

Three major enhancements have recently been added to Nemesis to aid in productivity, consistency and accuracy of aircraft. These enhancements are specifically tailored towards mesh density (Sources) productivity. Within Vgrid Sources act like heat sources that dissipate heat in a conducting medium, except that they propagate smooth grid spacing throughout the computational domain. The three enhancements are, topologically based source placement, corner junction sources, and wake sources. All three are designed to automate what experts would do manually. Nemesis is a general grid generation application although most of the innovative enhancement tools have been geared towards air vehicles. However, similar efficiency extensions for automotive, marine, and other industries are quite attainable.

III.1 Topologically Based Source Placement

The first enhancement is topologically based source placement. Most aircraft are composed of consistent elements such as wings, bodies, and nacelles (Figure 5). The meshing philosophies for these elements are usually approached in a consistent manner between configurations. Based on the metrics used by some of the most experienced Vgrid users, the Nemesis development team was able to extract a set of topological parametric rules for wings and bodies.

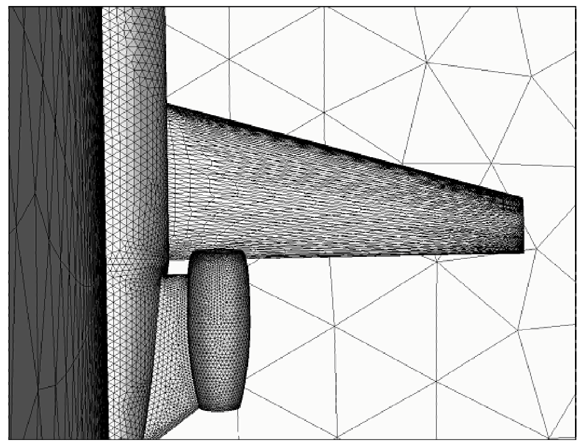

Figure 5. Sample grid on a Business Jet.

Wings should have tight, stretched cells at the leading edge with the stretching oriented out the span. Bodies should have tight spacing at the nose with stretched cells oriented downstream. An input table (Table I) systematizes this approach, which can be applied for topologically consistent configurations. The input table for a wing consists of cell sizes laid out in rows of constant x/c and columns at constant η. The wing planform is automatically extracted, and discontinuity breaks or curvature in the leading or trailing edge are automatically determined and added to the table. Isotropic sources are added at the inboard and outboard edges and then faired to the stretched values from the input table (Figure 6). A similar method is applied to the body. Crown and keel curves are typically input so that multiple line segments may be extracted using a chord-height tolerance approach.

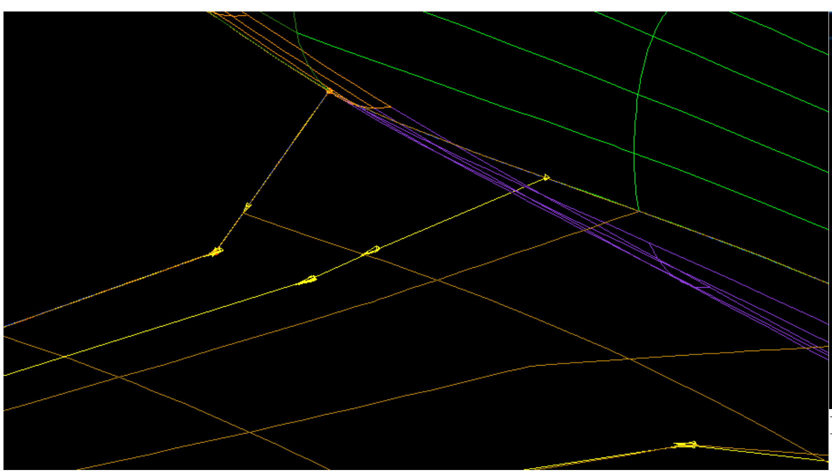

Figure 6a. Source placement on strake-wing (in yellow). Inputs for this procedure are a formatted input deck and selection of the Patches that define either the upper surface of the wing or the aircraft body.

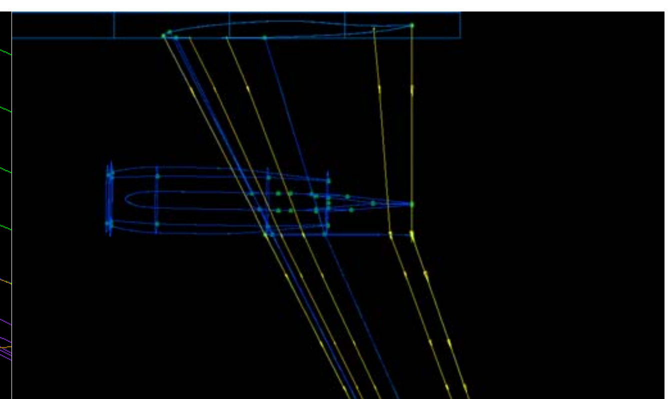

Figure 6b. Source placement on DLR-F6 wing.

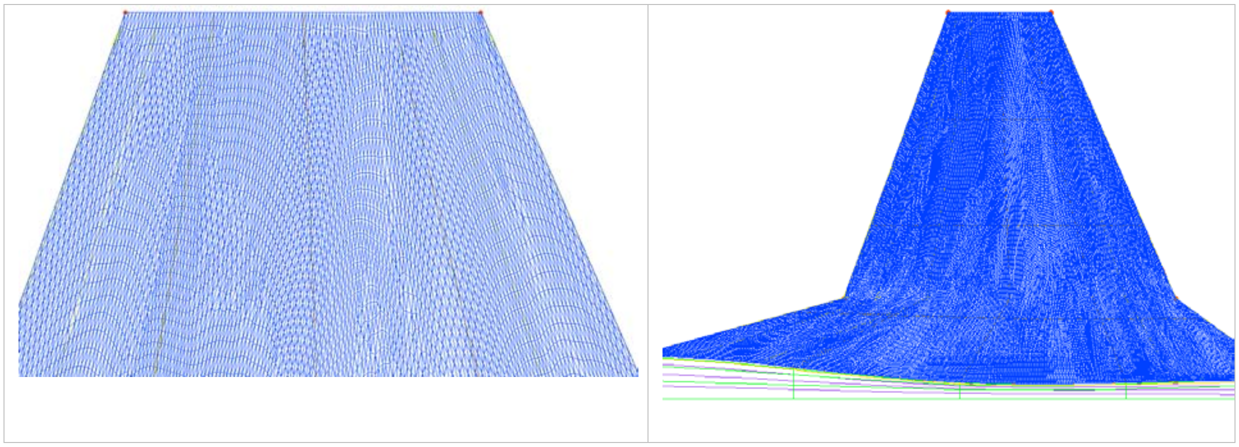

Figure 7. Resulting Mesh generated using Topologically Based Source Placement on strake-wing.

x/c	η	Size	Stretch	η	Size	Stretch
0.	0	1	5	1.0	.5	5
.25	0	5	5	1.0	4	5
1.0	0	10	5	1.0	6	5

Table I. Sample Input table for Wing topological source placement.

III.2 Corner Junction Sources

Wing-body intersection flow-fields have historically been a source of discrepancy for code-code comparisons (Reference 8). A best practice among Vgrid experts is to place a series of line sources around the airfoil root. These line sources should have isotropic cells consistent with wing source sizing. This can be a tedious procedure to perform manually since the airfoil root curve should be discretized into a series of line segments with appropriate isotropic cell sizes to match the wing grid.

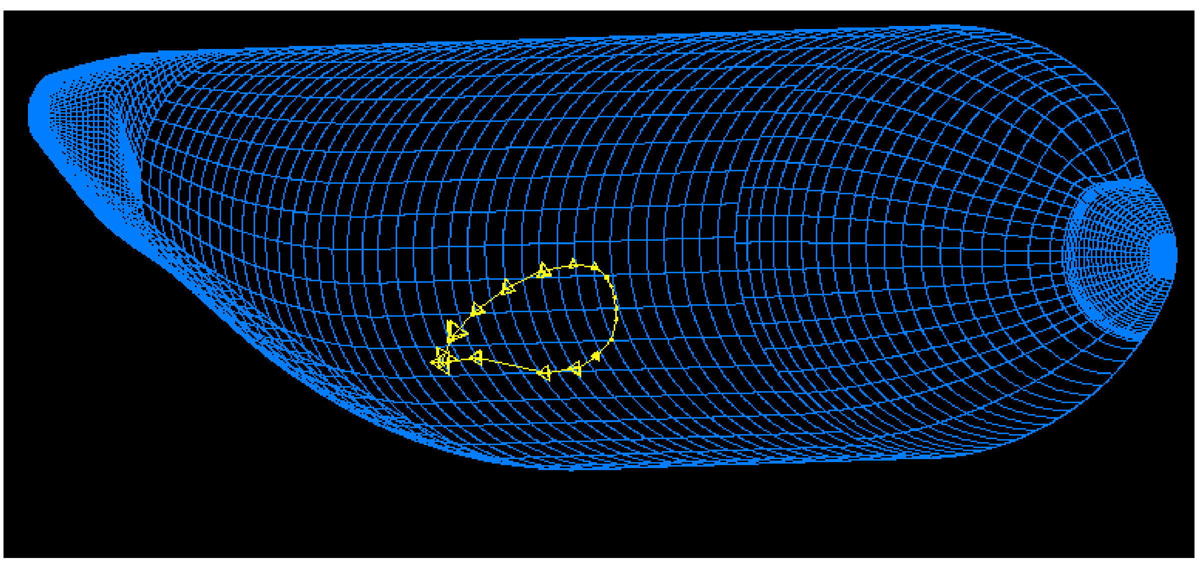

Figure 8. Wing-Body intersection Sources created automatically with Nemesis.

Automation of the procedure is accomplished by first breaking the wing root into a series of line segments within a specified chord-height-tolerance. Cell size determination is accomplished by searching through proximate wing and body sources, selecting the smaller of the two values and then factoring the cell size by the non-dimensionalized angle between the wing and body. The angle is easily determined by taking the arc tangent of the dot product of the normal vectors.

III.3 Wake Sources

Modeling of the wing wake is an essential element if trailing edge characteristics such as aft loading or trailing edge separation are to be modeled properly. Results from the third Drag Prediction Workshop (DPW3) showed erratic grid convergence as measured by linear Richardson extrapolation of drag for unstructured grid. The primary cause of the grid convergence problem was variations in upper surface trailing edge separation. This shouldn't be surprising given that there was no attempt to constrain the grid in the wake region just aft of the wing. Structured grid best practices have utilized C-grids around wings for some time to accurately model the wing wake properly and did not display as much erratic behavior as the unstructured grid convergence. This convinced us that automating wing wake grid generation would enable better grids to be generated quickly.

Wing wake position approximation methods were developed years ago and were even applied to panel methods in the 1980's for a variety of aircraft including high lift configurations. For a single element airfoil, the initial slope of the wake is set to bisect the wing trailing edge and then fair to freestream angle 4-5 chords downstream. Grid controls limit the extent of downstream wake generation. Two wakes are used for thick trailing edges, and they fan out downstream.

It's important to realize the limitations of this method. It is intended as a first cut at the wake position and not optimum wing wake modeling, nor is it a substitute for grid adaptation. The method is more accurately thought of as what an expert would do to approximate the wake before a solution is obtained.

Future Work

There are still more interesting enhancements that are planned for the Nemesis Gridding Interface. These include modeling of:

- Proximate Surfaces
- Vortex Prediction
- Addition of the latest Vgrid updates (volumetric Sources)
- Demonstration on DLR-F6 from DPW3 to show improved linearity in the Richardson extrapolation with the addition of wake and corner grids since the wake is physically critical to modeling the trailing edge separation noted in the workshop.

Conclusion

The Nemesis grid interface system has been shown to significantly improve productivity for unstructured grids. Recent feature enhancements will further improve productivity and consistency for engineering staff involved in large production design cycles. The automated tools although geared to aircraft are proven to improve quality by automating best practices from the knowledgeable user community. Hopefully the large user base familiar with the current GridTool/Vgrid process will appreciate the additions provided by the Nemesis Gridding Interface, which strengthen and ease the Vgrid experience.

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