PEGASUS 5: An Automated Pre-Processor for Overset-Grid CFD

Stuart Rogers
NASA Ames Research Center
http://people.nas.nasa.gov/~rogers/home.html
rogers@nas.nasa.gov

Pegasus Authors:

Norman Suhs, William Dietz, Stuart Rogers
Steve Nash, William Chan, Robert Tramel, Jeff Onufer

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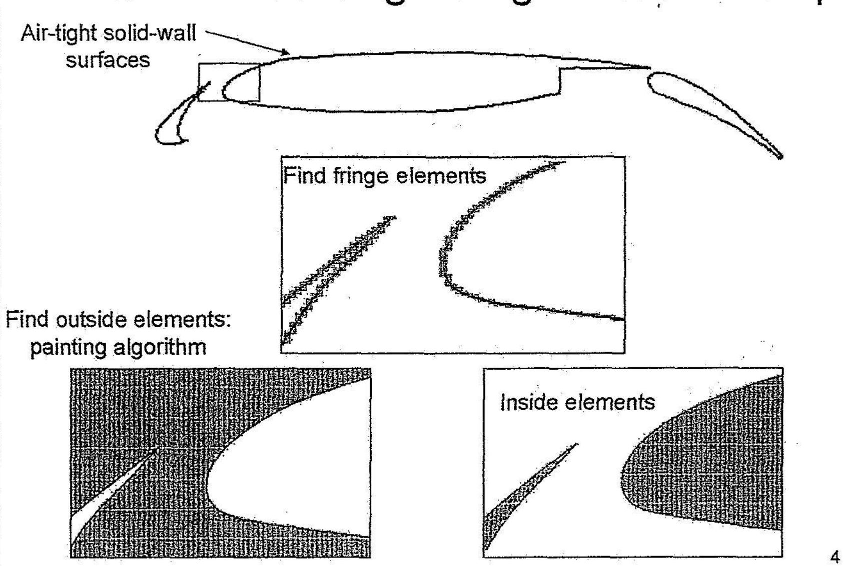
Outline

- Pegasus5 features and automation
  - Auto hole cutting
  - Interpolation and overlap optimization
  - Projection
  - Restarting
  - Parallelization
- Overview of Usage
  - Required inputs
  - Basic Usage
  - Overcoming problems

PEGASUS 5

- Fifth-generation overset software
- Primary goal: complete automation of overset process
  - Complexity of CFD problems grown
  - Hundreds of overset zones
  - Grid points in tens of millions
  - Manual control of process became intractable
- Required all-new approach to
  - Hole-cutting
  - *Overset optimization*
- Required significant improvements in ease of use
  - *Parallelization*
  - Automatic restarts
  - Projection
- Maintained backward compatibility allowing manual control where needed
- Pegasus5 is *mostly* automated, but still requires user expertise

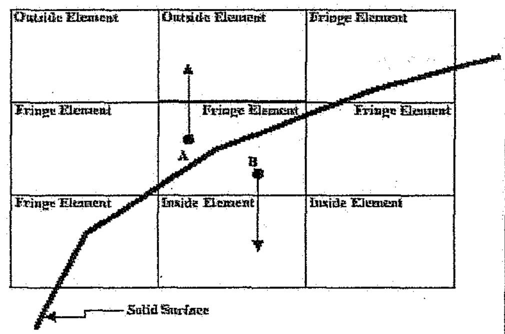
Auto Hole-Cutting Using Cartesian Map



Auto Hole Cutting

Cutting of Candidate Points

- All volume grid points considered as candidate hole points
- Points in an outside element are not hole points
- Points in an inside element are hole points
- Points in a fringe element use a line-of-sight test



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Interpolation Boundary Identification

- Outer boundary fringe points
  - All points on the boundary of a zone that do not receive a flow-solver boundary condition is assumed to be an interpolated outer boundary
  - Single or double fringes can be specified
- Hole boundary fringe points
  - Points adjacent to a hole point are interpolated hole boundary points
  - Single or double fringes can be specified

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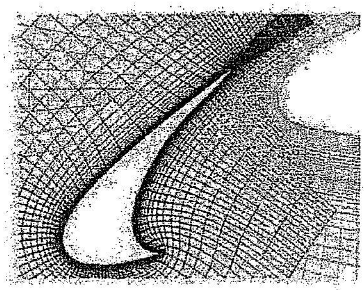
Boundary Point Interpolation

- Pegasus searches for all possible interpolation stencil donors from all zones for **every single grid point**
  - Uses alternating-digital tree to search for a near-by cell, then a stencil-jumping approach to find exact donor cell and stencil
- Best interpolation stencil is selected for each boundary interpolation point
  - Uses a measure of the interpolation quality and the relative cell size to interpolate from a similar-sized cell

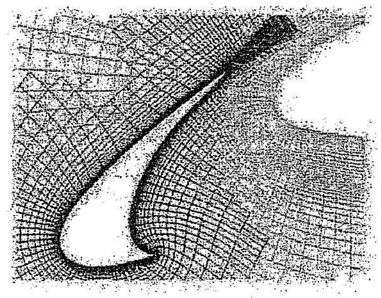
Overlap Optimization

- Begins with outer boundary and hole boundary interpolations
- Has effect of expanding the automatically-cut holes and shrinking the outer edges of overlapping zones
- Finest Mesh Points Retained
- Coarser Mesh Points are Interpolated
- Methodology is robust, requires no user inputs, and maximizes communication between overlapping zones

Optimized Overlap Example



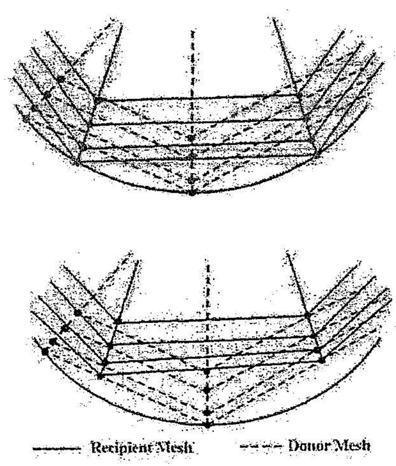
Non-Optimized Overlap



Optimized Overlap

Projection

- Corrects interpolation problems that may occur on curved viscous surfaces
  - Caused by linear discritization of curved surfaces
- Pegasus 5 projection step alters interpolation coefficients, not grids



Restarting

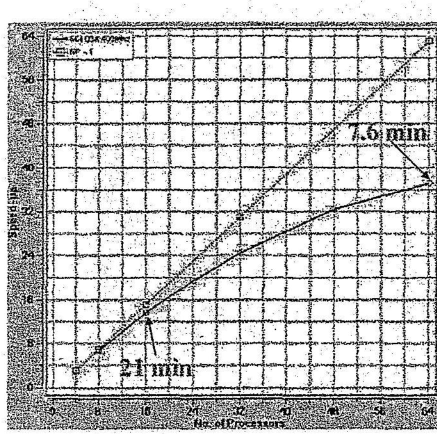
- Pegasus5 process consists a many individual sub-processes
- Each sub-process has a defined set of dependencies (inputs)
- Each sub-process results in one or more output files saved to disk
- Automatically determines which sub-processes are out of date based time-stamps of inputs and outputs
- Upon execution, pegasus5 automatically determines which sub-processes need to be run
- Can successfully restart for:
  - Modifications in user inputs or meshes
  - Addition of new meshes
  - Incomplete previous run or computer crash
- Allows incremental buildup of your CFD problem

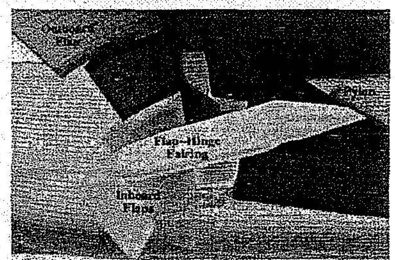
Parallelization

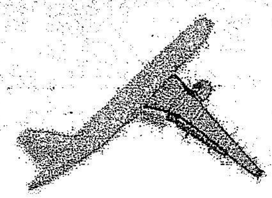
- Most sub-processes are independent of each other and can be run in parallel
- Uses Message-Passing-Interface (MPI)
  - One master process to distribute and monitor the work
  - Many worker processes, one per CPU
  - Shared or distributed memory
- Reliably reproduces results of serial execution
- The larger the problem, the better the scaling
- Requires that all CPUs have access to the same working directory

Boeing 777 Parallel Speedup

SGI O3K 400Mhz: Total CPU Time = 283 min



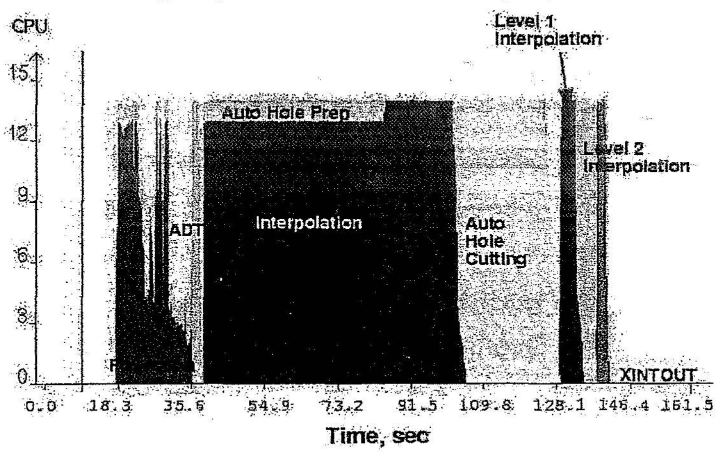




PEGASUS 5 Parallelization

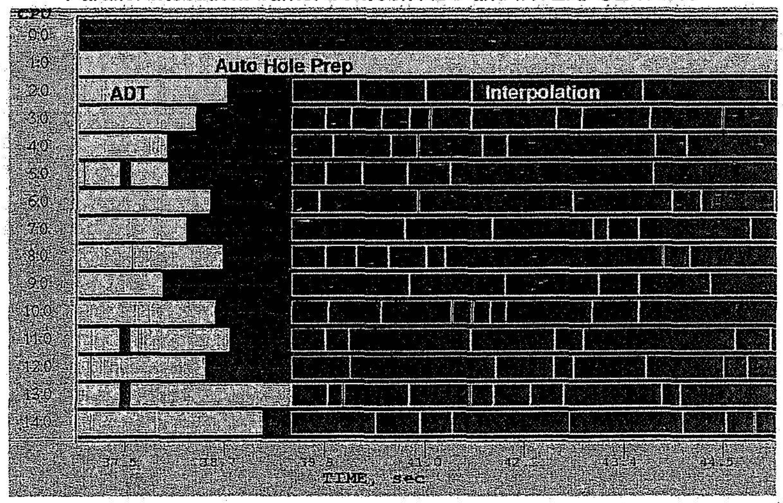
15 Processors on an SGI O2K

Harrier grid system: 52 zones, 2.5 million grid points



PEGASUS 5 Parallelization

Parallel execution: barrier between ADT and INTERPOLATION



Pegasus5 Usage

- Input requirements
  - Standard input file
  - Volume grids in individual files
    - *X_DIR/meshname1.x, X_DIR/meshname2.x*, etc
- Methods to assist in generating these inputs
  - peg_setup script
    - Requires Overflow input file and multi-zone plot3d grid file containing all the volume grids
  - Chimera Grid Tools scripts: *BuildPeg5i*

PEGASUS 5
Input Requirements (cont.)

```
$GLOBAL
  FRINGE = 2,
  OFFSET = 1,
  $END
```

[redacted]

[redacted]

```
$MESH NAME =      'body', KINCLUDE= 2, -2, LINCLUDE= 2, -1
                          OFFSET=2, $END

$MESH NAME = 'bodynose', JINCLUDE= 2, -1, LINCLUDE= 2, -1, $END

$MESH NAME =      'wing', $END

$MESH NAME =   'wingcap', $END

$MESH NAME =   'wingcol', $END
.
.
.
```


PEGASUS 5
Input Requirements (cont.)

```
$BCINP ISPARTOF =      'body',
   IBTYP =       5,   17,   17,   15,
   IBDIR =       3,    2,   -2,   -1,
   JBCS  =       1,    1,    1,   -1,
   JBCE  =      -1,   -1,   -1,   -1,
   KBCS  =       1,    1,   -1,    1,
   KBCE  =      -1,    1,   -1,   -1,
   LBCS  =       1,    1,    1,    1,
   LBCE  =       1,   -1,   -1,   -1,
   YSYM  = 1,
   $END
.
```

[redacted]

[redacted]

PEGASUS 5
Execution

- Once the `peg.i` file is available, and the volume grids (*.x) are in the `X_DIR` directory, PEGASUS 5 can be launched:
  - Serial version on a single CPU:

```
pegasus5 < peg.i >&! peg.out
```

  - MPI Parallel on $NCPUs:

```
mpirun -NP $NCPUs pegasus5mpi < peg.i > peg.out
```

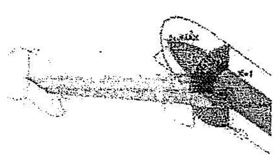

PEGASUS 5
Execution (cont.)

- As the code is running, PEG5 creates:
  - A directory named `/WORK` which contains all the time-stamped work files needed by different processes in the code. Delete this directory to start from a job from "scratch".
  - A log file named `log.mmdd.hhmm` which contains all the standard output from the run. Check this file for input echo, orphan count, and run times, etc.
    - NOTE: When running with MPI, `log.mmdd.hhmm.{0000,0001,…,NCPU-1}` files are created, and concatenated into one file on completion.
  - Parallel version requires that all CPUs have access to working directory and files in `/WORK`

PEGASUS 5
Output

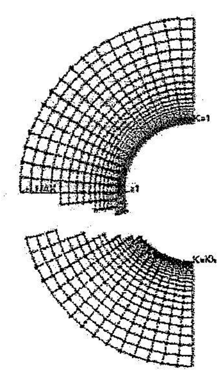
- XINTOUT contains interpolation stencils, etc. used by flow solver
- Use peg_plot to create grid.in file for flow solver:
  - Option 3 shows minimum holes (all fringe levels).
  - Option 1 (single-fringe) and option 2 (double-fringe) blank out higher level fringes, and show location where flow information will be passed within grid system.

PEGASUS 5
Output (cont.)

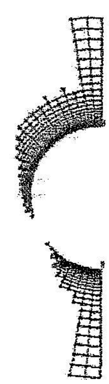


Higher level fringes are interpolated in the flow solver, but not used because code is only 2nd-order accurate.

However, they are still important because they can be used as donors by other 1st or 2nd fringe points from other grids.



Option 3
Minimum Holes



Option 2
First 2 fringe levels only

PEGASUS 5
Output (cont.)

- Option 3 shows exactly what the flow solver "sees":
  - Use to see all fringes
- Option 2 shows exact region where flow information is exchanged between grids
  - Use to see "virtual" holes

PEGASUS 5
Orphans

- **Orphans** are hole or outer boundary points that do *not* find valid interpolation stencils during the PEGASUS process.
- 2nd-level Orphans reset to field points in pegasus5
- Output from `peg_plot`:

```
Enter name for output PLOT3D grid file: Fringe Levels to show:
  1 = single fringe: blank out all level 2 and higher fringes
  2 = double fringe: blank out all level 3 and higher fringes
  3 = all fringes:   blank out only minimum and manual holes
Enter Fringe Level to plot:
Mesh No.          Name   ORPHANS: 1st-level  2nd-level Total
   1              body               0          0        0
   2         bodynose               0          0        0
   3             wing               0          0        0
   4          wingcap               0          7        0
   5          wingcol               0          0        0
   6          boxbody               0         21        0
   7          boxwing               0          3        0
   8         boxouter               0          0        0

Total                                0         21        0
```

PEGASUS 5
Execution (cont.)

- Typically, PEG5 will be iterated several times on a new configuration to eliminate all the orphans that would cause the flow solver to fail, or give erroneous results.
- Usually, a few hundred orphans remain in a grid system of >20M points.
- OVERFLOW deals with orphans by "averaging" the surrounding nodes, so orphans in areas of small gradients, etc., are okay.

PEGASUS 5
Orphans (cont.)

- Orphans in OVERFLOW
  - 2nd-level fringe orphans are reset to field points
  - 1st-level fringe orphans are "averaged" by using valid surrounding data to compute solution vector.
- Guidelines:
  - Always "fix" large groups of orphans anywhere in the grid domain. The bigger the clump, the greater the chance of bad flow interpolation/extrapolation in OVERFLOW.
  - Orphans on surfaces usually indicate serious problems with surface resolution or projection, and must be fixed.
- Plot Orphans using *Plot3d* (function 3), or *Overgrid*

PEGASUS 5
Orphans (cont.)

- Usual causes:
  - Insufficient overlap
  - Poorly resolved geometry (overlapping surfaces that are not projected properly)
  - Inappropriate or missing BCs
  - Failure in holecutting algorithm

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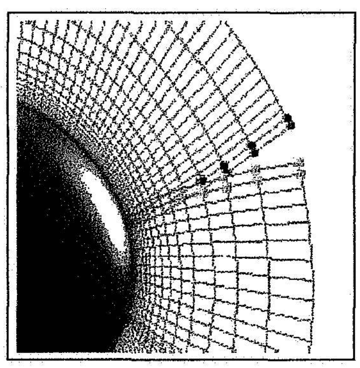
PEGASUS 5
Orphans (cont.)

- Insufficient overlap



To fix:

1. Increase surface overlap, or
2. Use "splaying" in HYPGEN or LEGRID, or
3. Add field box grid to resolve open space

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Custom Hole Cutting

- $HCUT namelists are used to define separate hole-cutters. The default is to include ALL solid wall surfaces in one hole-cutter
- Adding an $HCUT entry eliminates the default hole-cutter, and you must provide all of the hole-cutting inputs
- Adding multiple $HCUT entries increases parallel efficiency

Solid walls of these meshes must form a fully enclosed volume

```
$HCUT NAME = 'hcutter1',
    MEMBER  = 'body1', 'body2',
    INCLUDE = 'bodynose', 'wing', 'wingcol',
    CNX = 512, CNY = 512, CNZ = 512,
    CARTX = -100.0, 100.0,
    CARTY = -50.0, 50.0,
    CARTZ = 0.0, 100.0,
    $END
```

List of meshes which are cut

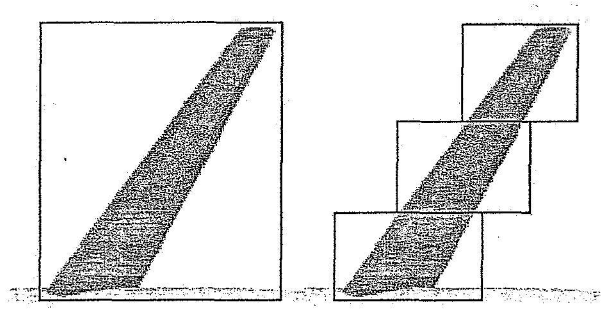
Number of Cartesian cells

Bounding box of hole-cutter

Custom Hole Cutting

- Multiple $HCUT definitions can be used to better resolve and focus the Cartesian hole-cutter:

Single $HCUT



Three $HCUT namelists:
•Created by specifying CARTX,CARTY, CARTZ
•Focuses Cartesian cells in volume of interest

Hole-Cutting Issues

- Holes too small near thin bodies (i.e. trailing edge of a thin wing)
  - Use `OFFSET` to enlarge holes
  - Increase `CNX`, `CNY`, `CNZ` to increase resolution
- Hole points not cut out properly near collar grids
  - Use `OFFSET` to enlarge holes
- Holes cut at zone boundaries on surface when no holes should be made
  - Occurs on curved surfaces with poor resolution
  - Can be undone by "unblanking" with $REGION and $VOLUME names lists

PEGASUS 5
Some Useful Utilities

- `peg_setup` is a menu-driven script which initializes the PEG5 problem, given a single, multi-zone PLOT3D file that contains all the volumes grids, and an OVERFLOW input file.
- `peg_plot` creates the iblanked PLOT3D grid file used in OVERFLOW.
- `peg_hole_surf` creates a multi-zone PLOT3D file of all the solid wall subsets in each defined holecutter. Used to visually examine the hole-cutting surfaces.
- `peg_diag` creates a diagnostic file for plotting quality and cell difference values.
- `peg_orph` is a script to list orphans by zone, etc.

Summary

- PEGASUS 5 successfully automates most of the overset process
  - Dramatic reduction in user input over previous generations of overset software
  - Order of magnitude reduction in both turn-around time and in user-expertise requirements
- Not a "black-box" procedure: care must be taken to examine the resulting grid system
- Additional documentation and examples available online:
  http://people.nas.nasa.gov/~rogers/pegasus/status.html