RECENT DEVELOPMENTS IN AUTOMATION OF OVERSET STRUCTURED MESH GENERATION

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OUTLINE

• Motivation, objectives, challenges
• Automation procedure
• Test cases
• Concluding remarks
MOTIVATION AND OBJECTIVES

- Structured overset viscous flow solvers – highly accurate and efficient compared to other methods

- High-fidelity overset mesh generation – significant user expertise, effort, time (weeks/months, surface grids ~80% time)

- Develop tools to reduce human effort needed

- Goal: 100% automation

- Hybrid: 90+ % automation + manual repairs => significant savings
1. Surface domain decomposition *

2. Grid point distribution *

3. Surface meshing scheme *
   - Method selection (hyperbolic/algebraic)
   - Distance estimate

4. Mesh overlap
   - Side *
   - Outer & hole boundaries **

5. Hyperbolic mesh smoothing iterations in concave regions **

** To be addressed in future work


OVERSET MESH GENERATION AUTOMATION FLOW CHART

BRep Solid Geometry (STEP, IGES, EGADS file)

Geometry Clean-Up

Original Geometry (Conceptual Design, CAD, Drawings)

Overset Surface Meshes

Face, Edge, & Node Meshes

Improved Side Overlap by Loose-Coupling

Surface Mesh Connectivity

Overset Volume Meshes

Hyperbolic Near-Body Meshes

Improved Side Overlap by Loose-Coupling

Cartesian Off-Body Meshes

Volume Mesh Domain Connectivity

Flow Solver

Current Status

Automated

Mostly Automated

Not Automated Yet
SURFACE DOMAIN DECOMPOSITION

• Input: Boundary Representation (BRep) solid
• Topological relationship: Faces (F), Edges (E), Nodes (N)
• Construct meshes based on F, E, N
• Total <= (# F + # E + # N)

GEOMETRIC COMPONENT SPECIFICATION

• List of faces on each component
• Manually constructed

Enables
• Local component grid spacing scaling
• Creation of input file for component loads integration
• Single component meshing option
OVERSET SURFACE MESH GENERATION PROCEDURE

BRep Solid Geometry (STEP, IGES, EGADS file)

↓

Face, Edge, & Node Meshes

↓

Improved Side Overlap by Loose-Coupling

↓

Surface Mesh Connectivity

40 Faces, 81 Edges, 45 Nodes

151 Surface grids

Surface grid hole points & fringe point donor stencils
FACE MESHES

- Nodes divide face into zones in J & K directions
- Construct stretched grid in each zone
- Faces cover entire surface domain
- Trimmed by directed edges

- Use cut-cells to generate iblank array (1/0 = on/outside geometry)
- Minimum hole-cut on face meshes
EDGE MESHES

Original edges

Node mesh

Outer boundary fringe layers

Retracted edges

Discretized edges

Hyperbolic/algebraic march on each side & concatenate

Variable retraction to achieve optimal overlap with end point Node meshes (created first)
NODE MESHES

• Construct initial curve to straddle Node by concatenating “best” two Edge segments

• Hyperbolic or algebraic marching: 2, 3, or 4 parts

• Algebraic march switched to TFI if iso-parameter lines of face mesh not aligned with sharp dividing Edge at Node
AUTOMATIC CONVERSION TO CAP GRID TOPOLOGY

Node meshes with acute concave corner
Wing/tail tip trailing edge region

No cap: sharp edges preserved at tip
Cap: wrap over sharp edges at tip near t. e.

Initial curve for hyperbolic/algebraic march
IMPROVED SURFACE GRID OVERLAP USING LOOSELY-COUPLED BOUNDARY CONDITIONS (LCBC)

Before LCBC Iterations

After LCBC Iterations

OVERSET VOLUME MESH GENERATION PROCEDURE

- Overset Surface Meshes
- Hyperbolic Near-Body Meshes
  - Same wall spacing, marching distance, stretching ratio
  - Auto selection: smoothing parameters, splay boundary conditions with concave region detection
- Improved Side Overlap by Loose-Coupling
- Cartesian Off-Body Meshes
- Overset Volume Meshes

Removal of negative cell volumes (work in progress)

Volume mesh LCBC more complex due to presence of hole boundaries and collar grids
OVERSET VOLUME MESH DOMAIN CONNECTIVITY  
(work in progress)

- Inherit surface holes from surface grids
- Near-body grids minimum hole
  - Grid index directions: J, K tangential, L normal
  - Check L line segments intersection with surface grid and blank all points in L after intersection
  - Check for minimum distance clearance from surface grid cells
- Off-body grid minimum hole – X-ray method using z-constant lines on Cartesian mesh
- Minimum hole expansion
- Donor stencils identification (partially completed from volume mesh LCBC)

15.8 M volume grid pts
1863 orphan pts
OVERSET MESH GENERATION AUTOMATION SOFTWARE

- EGADS2SRF
- POGS (Pre-processor for Overset Grid Simulations)

Current Automation Level
95 - 100% Surface Mesh Generation
85 - 100% Volume Mesh Generation
0% Domain Connectivity

Manual Grid Repairs (if needed)
Manual Domain Connectivity

Flow Solution Computation (OVERFLOW, LAVA)
AUTOMATION SOFTWARE FLOW CHART

BRep Solid Geometry (STEP, IGES, EGADS file)

- Engineering Sketch Pad (ESP) from MIT

- Global parameters
  - max turning angle
  - max grid spacing
  - max stretching ratio
  - min # pts on edge

- EGADS2SRF

- Volume Mesh Domain Connectivity
  - Currently manually performed
  - Work in progress in POGS

- Flow Solver

- Face meshes
- Surface triangulation
- Discretized edges
- Edge-face topology
- POGS input file
  - # fringe pt layers
  - volume mesh wall spacing
  - donor stencil quality

- POGS – Pre-processor for Overset Grid Simulations

- Edge & node surface meshes
- Surface domain connectivity
- Near & off-body volume meshes
- Flow solver input file (OVERFLOW, LAVA b.c.)
- Component aero-loads comp. input file (FOMOCO)
OPEN GEOMETRIES & SINGLE COMPONENT MESHING

Open Geometries
- User-specified list of faces to remove
- Auto-update of face/edge/node topology

Truncated-Body
- Removed Face(s)

Internal Flow with Entrance & Exit

Single Component Meshing
- E.g., mesh one or more slat brackets + connected faces
TEST CASES

All cases ran on 2018 Mac BookPro laptop, 2.9 GHz Intel Core i9, 16GB memory

- Surface meshes – mostly single processor
- Volume meshes – 6 OpenMP threads

Mesh quality (% acceptable)

- % surface meshes with no negative cell areas
- % volume meshes with no negative Jacobians or self-intersections
# JUNCTURE FLOW EXPERIMENT WING-BODY
## DLR-F6 and NACA-0015

<table>
<thead>
<tr>
<th>Model</th>
<th># Meshes</th>
<th># Volume mesh pts</th>
<th>% Acceptable meshes</th>
<th>Wall clock time</th>
<th>Manual meshing time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Surface Volume</td>
<td>surface+volume</td>
<td>~ days</td>
</tr>
<tr>
<td>DLR-F6</td>
<td>171</td>
<td>15.8 M</td>
<td>100% 98%</td>
<td>1 min 19 sec</td>
<td></td>
</tr>
<tr>
<td>NACA-0015</td>
<td>145</td>
<td>14.1 M</td>
<td>100% 97%</td>
<td>0 min 58 sec</td>
<td></td>
</tr>
</tbody>
</table>

Volume mesh repair + connectivity ~ 2 hrs.

---

### Manual meshing time

<table>
<thead>
<tr>
<th>Method</th>
<th># Pts</th>
<th>$C_L$</th>
<th>$C_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual (OVERFLOW)</td>
<td>50.9 M</td>
<td>1.7157</td>
<td>0.1383</td>
</tr>
<tr>
<td>Manual (LAVA)</td>
<td>56.8 M</td>
<td>1.7159</td>
<td>0.1380</td>
</tr>
<tr>
<td>Automatic</td>
<td>60.5 M</td>
<td>1.7176</td>
<td>0.1394</td>
</tr>
</tbody>
</table>
## Rotorcraft Concept Vehicles

### Manual meshing time ~ weeks per vehicle

<table>
<thead>
<tr>
<th>Concept Vehicle</th>
<th># Meshes</th>
<th># Volume mesh pts</th>
<th>% Acceptable Surface</th>
<th>Wall clock time surface+volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-Pax Quadrotor</td>
<td>227</td>
<td>21.7 M</td>
<td>100</td>
<td>5 min 15 sec</td>
</tr>
<tr>
<td>Quiet Single Main Rotor</td>
<td>179</td>
<td>15.2 M</td>
<td>99</td>
<td>3 min 1 sec</td>
</tr>
<tr>
<td>Side-By-Side</td>
<td>162</td>
<td>14.8 M</td>
<td>100</td>
<td>4 min 3 sec</td>
</tr>
<tr>
<td>Lift+Cruise (no pylons, no gears)</td>
<td>87</td>
<td>35.6 M</td>
<td>100</td>
<td>7 min 1 sec</td>
</tr>
<tr>
<td>Lift+Cruise (with pylons &amp; gears)</td>
<td>365</td>
<td>43.7 M</td>
<td>99</td>
<td>4 min 9 sec</td>
</tr>
<tr>
<td>Tiltwing Cruise</td>
<td>307</td>
<td>38.6 M</td>
<td>100</td>
<td>4 min 47 sec</td>
</tr>
</tbody>
</table>

**Notes:**
- Manual meshing time estimated to be several weeks per vehicle.
- Percentages indicate the percentage of acceptable surface and volume.
- Wall clock time refers to the time taken to create the mesh.

**Images:**
- 6-Pax Quadrotor
- Quiet Single Main Rotor
- Lift+Cruise (no pylons, no gears)
- Lift+Cruise (with pylons & gears)
- Side-By-Side Hybrid
- Tiltwing Cruise Mode
<table>
<thead>
<tr>
<th>Case</th>
<th># Meshes</th>
<th># Volume mesh pts</th>
<th>% Acceptable Surface</th>
<th>% Acceptable Volume</th>
<th>Wall clock time surface+volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Hub</td>
<td>142</td>
<td>4.9 M</td>
<td>99</td>
<td>99</td>
<td>0 min 35 sec</td>
</tr>
<tr>
<td>Multi-Rotor Testbed</td>
<td>258</td>
<td>35.6 M</td>
<td>100</td>
<td>100</td>
<td>1 min 35 sec</td>
</tr>
</tbody>
</table>
### Side-by-Side Rotor Wind Tunnel Hardware

**Case** | # Meshes | # Volume mesh pts | % Acceptable Surface | Volume | Wall clock time surface+volume
---|---|---|---|---|---
Complex | 883 | 41 M | 99.8 | 96 | 4 min 14 sec
Simplified | 251 | 11 M | 100 | 99 | 1 min 27 sec
HIGH-LIFT COMMON RESEARCH MODEL (HLCRM)
High-Lift Prediction Workshop 4
Half-body geometry: 414 Faces, 1108 Edges, 698 Nodes

Wing
Outboard Slat
Outboard Flap
Flap Track Fairings (x3)
Middle Flap Gap
Inboard Flap
Inboard Flap Gap
Fuselage

Outboard Slat Brackets (x12)
Pylon
Nacelle
Chine
Inboard Slat
Inboard Slat Brackets (x3)
## HLCRM AUTO SURFACE MESH STATISTICS

### Single Component Runs

<table>
<thead>
<tr>
<th>Component</th>
<th># Meshes</th>
<th># Mesh pts (x 10^6)</th>
<th>% Acceptable meshes</th>
<th>Wall clock time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage</td>
<td>123</td>
<td>0.63</td>
<td>99%</td>
<td>25 min 29 sec</td>
</tr>
<tr>
<td>Inboard Slat</td>
<td>59</td>
<td>0.18</td>
<td>85%</td>
<td>10 min 13 sec</td>
</tr>
<tr>
<td>Outboard Slat</td>
<td>147</td>
<td>0.91</td>
<td>87%</td>
<td>18 min 5 sec</td>
</tr>
<tr>
<td>Flaps + gaps</td>
<td>99</td>
<td>0.30</td>
<td>75%</td>
<td>12 min 14 sec</td>
</tr>
<tr>
<td>Pylon+Nacelle+Chine</td>
<td>74</td>
<td>0.61</td>
<td>89%</td>
<td>17 min 43 sec</td>
</tr>
<tr>
<td>Inboard Slat Bracs (x3)</td>
<td>95</td>
<td>0.17</td>
<td>85%</td>
<td>10 min 49 sec</td>
</tr>
<tr>
<td>Outboard Slat Bracs (x12)</td>
<td>426</td>
<td>0.51</td>
<td>84%</td>
<td>16 min 13 sec</td>
</tr>
<tr>
<td>Inboard Flap Track Fair.</td>
<td>176</td>
<td>0.25</td>
<td>94%</td>
<td>12 min 35 sec</td>
</tr>
<tr>
<td>Middle Flap Track Fair.</td>
<td>182</td>
<td>0.30</td>
<td>93%</td>
<td>12 min 44 sec</td>
</tr>
<tr>
<td>Outboard Flap Track Fair.</td>
<td>183</td>
<td>0.33</td>
<td>92%</td>
<td>14 min 26 sec</td>
</tr>
<tr>
<td>FTF Connectors (x3)</td>
<td>124</td>
<td>0.30</td>
<td>75%</td>
<td>10 min 6 sec</td>
</tr>
<tr>
<td>Wing</td>
<td>451</td>
<td>1.70</td>
<td>85%</td>
<td>59 min 20 sec</td>
</tr>
<tr>
<td><strong>Complete HLCRM</strong></td>
<td>413</td>
<td>2.70</td>
<td>100%</td>
<td>44 min 16 sec</td>
</tr>
</tbody>
</table>

*Face meshes only, Edge + Node meshes in progress*

Manual meshing time ~ 4 months
HLCRM: FUSELAGE AND WING

Fuselage

Wing underside
HLCRM: PYLON/NACELLE/CHINE

- Pylon
- Nacelle
- Chine
  - Auto surface hole cut on nacelle mesh
HLCRM: OUTBOARD SLAT BRACKETS

Auto mesh clustering on slat mesh

Auto surface hole cut on slat mesh
HLCRM: FLAPS & FLAP TRACK FAIRINGS

- Top view
- Middle Flap Track Fairing
- Flap track fairing intersection
- Bottom view near outboard tip

Auto mesh clustering
Auto hole cut
CONCLUDING REMARKS

• Automation scheme on BRep solids
  • Surface domain decomposition into face, edge, node meshes
  • Near and off-body volume mesh generation
  • Domain connectivity (surface: automatic, volume: manual)
  • Input files: flow solver, component loads computation

• Low to medium complexity cases (Juncture Flow, RVLT concept vehicles, wind tunnel hardware)
  • 99 - 100% acceptable surface meshes
  • 94 - 100% acceptable volume meshes

• Preliminary flow solutions on Juncture Flow F6 and Lift+Cruise concept vehicle cases show comparable convergence behavior and converged aerodynamic loads as manual meshes

• Significant reduction in effort and time: hybrid auto & manual meshes
  • Weeks/months -> days
  • Days -> hours
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