Geometry Parameterization for Shape Optimization

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Overview

- Motivation for Geometry Parameterization
- Classification of Methods
- Criteria for Choosing a Method
- Preferred Methods and Examples
- Future Developments
Non Parametric Geometry Generation 40 Years Ago

From: D.G. Clark und A. Gibson, Concorde, Phoebus Publishing Company 1976/77
Parametric Grid/Geometry Generation 20 Years ago

- WBEP Grid Generator: From Cross-Sections to CFD-Grid
- CAGD-Functions/Subroutines (Surface/Surface Intersection) used at DLR in 1995
Parametric Grid/Geometry Generation 15 Years ago

- MegaCads Grid Generation System: From Cross-Sections to CFD-Grid
- Records Interactive Construction Steps and Replays everything in batch-mode
Non Parametric Geometry Generation 12 Years Ago

- Geometry Repair and Preparation with **CATIA V4** for CENTAUR and TAU
- Check for Non-Intersected Panels among hundreds of Panels (Faces)
Parametric Geometry Deformation 10 Years Ago

- Based on Freeform Deformation Method from Soft Object Animation
- Requires Initial Geometry to be deformed
- Changes the Coordinates of Grid Points or Supporting Points or Control Points of Spline-Curves or Spline-Surfaces
- Implemented into MegaCads for Creation of Deformation Lattices

Initial Wing

Optimized Wing

M=0.84, $C_L=0.3$
Parametric CAD-System CATIA V5
- Interactive Parametric Modeling
- Import Parameter from Design Tables
- Regeneration of Geometry in Batch Mode
- Export Geometry to neutral CAD-format
Geometry Parameterization Methods

1. No Geometry Parameterization Method
   - Design parameters identical to surface grid points

2. Manipulation / Deformation of Geometry
   - Design parameters control the deformation of geometry or grid (FFD, RBF)

3. Creation of Geometry
   - Specific black box hard coded geometry generation codes (FORTRAN, PYTHON)
   - Semi specific geometry generators (wing- and tube-type primitives)
   - Commercial parametric CAD-systems (CATIA, ProE, NX)
Preferred Methods for Geometry Parameterization (Medium Complex Problem)

1. Geometry exists → Use Manipulation/Deformation
   ![Diagram 1]
   Optimal Tail Strake-Position?

1. No Geometry exists → Use Parametric CAD
   ![Diagram 2]
   Optimal Tail Strake-Position?
Parametric Modeling with CATIA V5

Wireframe from Sectional Curves

- a) Conical Curves
- b) Ruled Curves (CST Method)
- c) Spline-Interpolation with smoothing
- d) B-Splines
Parametric Modeling with CATIA V5 cont.

- Surface Generation from Sectional Curves (Lofting)

- Surface Creation by Revolution and Extrusion
Parametric Modeling with CATIA V5 IV

- Add Blends and Fillets between Surfaces
- Make Geometry Watertight (Trailing-Edges ...)

![Image of airplane model with CATIA interface]
Example 1: Tail Strake Optimization

No Geometry exists
Tail Strake Position Optimization for Generic Transport Aircraft Configuration

- Tail strakes generate counter rotating vortices
- Best Position (+angle) of tail strake to weaken tail vortices and reduce upsweep drag?
Parameterization of the Tail Strake Problem

1. Parameter: Strake position along $u$-isocurve of tail surface
2. Parameter: Strake position along $v$-isocurve
3. Parameter: Rotation angle $\varphi$ against tangent in $u$-direction
Grid Generation for Generic Transport Aircraft

- Hybrid grids generated with CENTAURSoft®
- Prismatic layers on the surfaces and tetrahedrons in the remaining volumes
- Modular method used
- ~ 4 Mio grid points
Flow Simulation with TAU

- SAO turbulence model
- Solver + adaptation seq:
  1. 6000 time steps
  2. +10% points by adaptation (pressure difference along edges)
  3. 2000 time steps
  4. +10% points by adaptation
  5. 2000 time steps
Strake Positioning Optimization Setup

**Design Parameter:**
- $u$, $v$, $\varphi$

**Cost Function:**
- $C_L/C_D$

- **Geometry Modeling**
  - CATIA V5
  - 20 sec

- **Modular Grid Generation**
  - CENTAUR
  - 5 min

- **Flow Solver**
  - TAU + 2xAdaptions
  - 10 h
Comparison of Worst and Best Configuration of 1st Run

- Strake amplifies tail vortex
  - Ideal asymptotic convergence of objective and design variables
  - 4% improvement of lift to drag ratio due to strake
  - 28% difference between worst (No. 4) and best (No. 44) strake position

- Strake truncates tail vortex
Example 2: Engine Integration

Geometry exists
Example: Aerodynamic Optimal Engine Integration for a Business Jet Configuration

Part of common research project OPTITHECK of Rolls-Royce Germany and DLR

Evaluate installation drag savings by optimally shaped fuselage tail, pylon and nacelle of a given business jet configuration in cruise flight.
FFD Parameterization for Engine Parameterization

8 Tail Parameter

6 Pylon Parameter

6 Nacelle Parameter

- 20 Design Parameter used
- For Re-Assembly 17 Surface/Surface Intersections necessary
Aerodynamic Shape Optimization Cycle

Geometry Generation

Design Parameter → SUBPLEX Optimizer → Drag Coefficient

Simulation

MegaCads FFD → Ready to Mesh Geometry

CENTAURSoft Grid Generator → Grid → TAU Euler-Solver

CENTAURdat
Optimization Results

<table>
<thead>
<tr>
<th>Variables</th>
<th>Best</th>
<th>Δ DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 8 Tail</td>
<td>278</td>
<td>-3.1</td>
</tr>
<tr>
<td>2 14 Tail + Pylon</td>
<td>294</td>
<td>-3.7</td>
</tr>
<tr>
<td>3 20 Tail + Pylon + Nacelle</td>
<td>371</td>
<td>-4.7</td>
</tr>
</tbody>
</table>
Conclusion

- Parametric CAD and FFD showed to be applicable for complex realistic configurations
- Stable and efficient process chains with CENTAUR modular grid generation and TAU in parallel mode performing hundreds of runs
- Consistent results have been achieved in both examples
- Presented Methods and Tools for Shape Parameterization in Optimization are well established at DLR

Future Work

- Use of TAU-Adjoint
Using RBF Mesh Deformation with Radial Basis Functions

1. Generate auxiliary body-fitted surface grid and setup RBF Matrix (12635 Points)
2. Calculate deformation vectors from baseline and deformed geometry
3. Perform RBF-deformation
Current Experiences with the RBF-Mesh Deformation

- Non-Smooth Intersections observed
- Time Consuming
- Storage expensive