An Open Source Computational Geometry Library for Parametric Aircraft Design

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Outline

Introduction
• Aircraft design optimization
• TiGL Software overview

TiGL methods
• Applications and uses
  • Architecture
  • Curve and surface interpolation algorithms

Results
• Comparison Gordon surfaces vs. Coons patches
• Complete aircraft geometries
Motivation
Aircraft design optimization overview

• Explore the **aircraft of tomorrow**
• Evaluate **new designs**

• **Geometry generation** has **essential** role
• All codes in the process chain must be **robust**
The TiGL software package

- **C++ Library** for parametric modelling of aircraft and helicopter based on parametric CPACS* (XML) files

- Used at DLR and international universities / research institutes for aircraft design and analysis

- **TiGL Viewer** to visualize CPACS-based aircraft geometries and other CAD files

- **Cross platform:** Linux, macOS, Windows, Android

- Open Source, developers from [AIRBUS DEFENCE & SPACE](https://www.airbus.com), [RISC Software GmbH](https://www.risc-software.com), DLR

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*B. Nagel et. al., Communication in Aircraft Design: Can we establish a Common Language?, 28th ICAS, Brisbane, Australia, 2012*
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Parametric geometry
Features and Applications

• Custom geometric modeling algorithms

• Geometry export to common file formats, e.g. IGES, STEP, STL, VTK, Collada

• NURBS-based modelling of the main parts, e.g.
  • Wings
  • Fuselages
  • Engine covers
  • Wing structure
  • Flaps
  • Fuselage structure (at work)

• API to query
  • Points on surfaces
  • Intersections
  • Projections

• Mesh generation (at work)
  • Volume meshes for fluid dynamics simulations
  • Surface meshes for structural analysis, radar signatures
Architecture

- **TiXI** ([https://github.com/dlr-sc/tixi](https://github.com/dlr-sc/tixi))
  - Library to parse XML (CPACS) files

- **OpenCASCADE** ([https://www.opencascade.com/](https://www.opencascade.com/))
  - Geometry (NURBS-based)
  - Topology (Boundary Representation)
  - CAD Exports, Visualization

- **Language Bindings**
  - Can access all C++ Data structures

- **TiGL Viewer**
  - 3D Visualization
  - Scripting
  - Debugging
Under the hood
B-splines / NURBS

• B-spline curve:
\[ c(u) = \sum_{i=0}^{n} P_i \cdot N_i^d(u, t) \]

with:
• Control points \( \{P_i^c\} \)
• B-spline basis functions \( N_i^d(u, t) \)
• Knot vector \( t, t_i \leq t_{i+1} \)

• B-spline surface:
\[ s(u, v) = \sum_{i=0}^{n} \sum_{j=0}^{m} P_{ij} \cdot N_i^{du}(u, t_u) \cdot N_j^{dv}(v, t_v) \]
Under the hood
B-spline curve interpolation

• Solve control points $P_i$, given data points $D_j$, such that:

$$\sum_{i=0}^{n} P_i \cdot N_i^d(u_j, t) = D_j$$

$$\Rightarrow Np \equiv d$$

i.e. the curve passes though the data points
Under the hood
B-spline surface skinning

- Interpolates set of B-spline curves \( c_i(u) \) by B-spline surface \( s(u, v) \)

- First: knot insertion to create same knot vector for all curves
- Then: Interpolate each row of control points with a curve → Control points of surface
Gordon Surfaces
Curve network interpolation

• Given network of profile and guide curves: Find surface that interpolates these curves

• Problem: No free library available for curve network interpolation!

• Custom development from OpenCASCADE for DLR based on Coons-patches showed poor results

• “Gordon Surfaces” interpolate curve networks, but require the curves to be compatible

  Compatibility condition
  ➢ All profile curves $f_i(u)$ must intersect with a guide curve $g_j(v)$ at exactly the same parameter value $u_j$ and vice versa:
  
  $$f_i(u_j) = g_j(v_i), \forall i, j$$

• Practically never the case → Reparametrization of the curves (tricky)
Gordon Surfaces
Algorithm overview

→ Gordon Surface is superposition of three surfaces:

\[ G(u, v) = S_u(u, v) + S_v(u, v) - T(u, v) \]

- \( S_u(u, v) \): Skinning surface interpolating all profiles
- \( S_v(u, v) \): Skinning surface interpolating all guides
- \( T(u, v) \): Tensor product surface interpolating the intersection points of the curve network

→ Convert Gordon surface to B-Spline / NURBS for further use in TiGL (degree elevation, knot insertion)
Gordon Surfaces
Robustness

- In theory: Profiles and guides must intersect each other!
- In practice: Allow for user defined tolerances
- Allow curve imperfections
- Reorder and reverse curves if necessary
- Try to handle ALL special cases!
- Provide Coons-based fallback solution
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Surface Quality Analysis

- Surface quality analysis with zebra stripe plot
- Implemented in TiGL Viewer using OpenGL fragment shader code
Gordon Surface
Results: Wing

Old – Coons Style 😞  New – Gordon Style 😊
Gordon Surface
Results: Belly Fairing

Old – Coons Style 😞

New – Gordon Style 😊
Gordon Surface
Results: Engine Cover

Old – Coons Style 😞
New – Gordon Style 😊
Gordon Surface

Results: Engine Cover

Old – Coons Style 😞

New – Gordon Style 😊
Gordon Surface
Results: Helicopter Body

Old – Coons Style 😞
New – Gordon Style 😊
Full aircraft model
Possible aircraft designs
TiGL on GitHub

- Open Source, Apache-2.0 License
- ~120 kLOC
- ~43 kLOC auto-generated from CPACS XML schema
- [https://github.com/DLR-SC/tigl](https://github.com/DLR-SC/tigl)
Conclusion

Summary

• TiGL is a library for geometric modeling of aircraft
• TiGL can be used for general purpose geometry modeling too
• Gordon Surfaces are a major building block for surfaces with high surface quality

Outlook

• Fuselage structure will come soon
• TiGL 3 Release probably in Q3 / 2018 (when CPACS 3 is finished)
• More aircraft specific geometries

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Thank you for your attention!