Aerodynamic optimization using Adjoint methods and parametric CAD models


Document Version:
Other version
Aerodynamic optimization using Adjoint methods and parametric CAD models

ECCOMAS Congress 2016

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- Motivation
- CAD parameterisation
- Gradient Calculation
- Onera Wing
- NLR 7301
- Conclusions
Outline

1. Motivation
2. Gradient Calculation
3. Onera Wing Test Case
4. NLR 7301
5. Conclusions
Motivation

- Perform high-fidelity aerodynamic optimisation
Motivation

• Perform high-fidelity aerodynamic optimisation
• Increase flexibility of Adjoint Based Optimisation
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- Perform high-fidelity aerodynamic optimisation
- Increase flexibility of Adjoint Based Optimisation
- Enable use of parametric CAD model in optimisation
Motivation

- Perform high-fidelity aerodynamic optimisation
- Increase flexibility of Adjoint Based Optimisation
- Enable use of parametric CAD model in optimisation
- Efficient calculation of parametric sensitivities for CAD based design variables
There are two main challenges to perform high-fidelity aerodynamic optimisation.
Motivation

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- Computational Cost
  - Gradient Based Optimisation
Motivation

There are two main challenges to perform high-fidelity aerodynamic optimisation

- Computational Cost
  - Gradient Based Optimisation

- Large number of parameters
  - Adjoint Methods
In CFD based optimisation, parameterisation are usual built in the software.
Motivation

The objective of this work is to integrate parameters used by CAD designers with high-fidelity analysis and optimisation.
Outline

1. Motivation
2. Gradient Calculation
3. Onera Wing Test Case
4. NLR 7301
5. Conclusions
SU² is an open-source CFD/Adjoint optimisation framework¹

- Developed at Stanford University

¹images taken from [http://su2.stanford.edu/](http://su2.stanford.edu/)
SU² is an open-source CFD/Adjoint optimisation framework\textsuperscript{1}

- Developed at Stanford University
- General purpose PDE solution methods

\textsuperscript{1}Images taken from http://su2.stanford.edu/
$SU^2$ is an open-source CFD/Adjoint optimisation framework\(^1\)

- Developed at Stanford University
- General purpose PDE solution methods
- Range of numerical schemes available (JST, ROE, MG, Euler-Implicit, . . .)

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- General purpose PDE solution methods
- Range of numerical schemes available (JST, ROE, MG, Euler-Implicit, …)
- Independent Mesh deformation/adaptation modules

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- Continuous Adjoint Solver

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- Independent Mesh deformation/adaptation modules
- Continuous Adjoint Solver
- Independent Gradient Calculation module

---

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Gradient Based Optimisation

Gradient Calculation

\[
\begin{bmatrix}
\frac{\partial f}{\partial A_1} \\
\frac{\partial f}{\partial A_2} \\
\vdots \\
\frac{\partial f}{\partial A_n}
\end{bmatrix}
= 
\begin{bmatrix}
\frac{\partial x_1}{\partial A_1} & \cdots & \frac{\partial x_m}{\partial A_1} \\
\vdots & \ddots & \vdots \\
\frac{\partial x_1}{\partial A_n} & \cdots & \frac{\partial x_m}{\partial A_n}
\end{bmatrix}
\begin{bmatrix}
\frac{\partial f}{\partial x_1} \\
\vdots \\
\frac{\partial f}{\partial x_m}
\end{bmatrix}
\]

- \( \frac{\partial f}{\partial A_i} \) - Gradient
- \( \frac{\partial x_j}{\partial A_i} \) - Design Velocities
- \( \frac{\partial f}{\partial x_j} \) - Surface Sensitivities
Gradient Based Optimisation

Gradient Calculation

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\begin{bmatrix}
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Surface Sensitivities

Flow sensitivity to surface obtained from adjoint solver ($SU^2$)
Design Velocities

**Gradient Calculation**

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\begin{bmatrix}
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- \( \frac{\partial f}{\partial x_j} \) - Surface Sensitivities
CAD parameterisation

CATIA geometry

27 CATIA Parameters
CAD parameterisation

CATIA geometry

Design Velocities Param.1

27 CATIA Parameters

Design Velocities to Param.3
Use design velocities and mesh deformation module (linear elasticity) to deform surface CFD mesh.
Outline

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Flow and Adjoint Solutions

Start the process by computing the flow and adjoint solution.
Flow and Adjoint Solutions

Start the process by computing the flow and adjoint solution

and at the same time .....
Geometric Sensitivities

CATIA geometry

Geometry Sensitivity to Param.1

27 CATIA Parameters

Geometry Sensitivity to Param.3
Gradient Validation

Compute gradient for optimiser:

Optimiser returns updated parameter values, which is used to create new CAD model and new design velocities calculated...
Transonic Test Case – Inviscid Calculation

\( M_\infty = 0.8395; \alpha = 3.06^\circ \)

\[ \min C_D \]

subject to: \( C_L > 0.283 \)
Onera Wing Drag Minimization

Transonic Test Case – Inviscid Calculation

$M_\infty = 0.8395; \alpha = 3.06^\circ$
Onera Wing Drag Minimization

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NLR 7301
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Onera Wing Drag Minimization

![Graph showing the evaluation of drag coefficients over iterations. The graph includes lines for CL, CD, CL const., CL - SU^2, and CD - SU^2. The x-axis represents evaluation numbers, ranging from 1 to 15, and the y-axis represents drag coefficients, ranging from 0.008 to 0.014. The graph indicates a decrease in drag coefficients over evaluations.]
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High-Lift Test Case – RANS Calculation (using SA)

\[ M_\infty = 0.185; \quad \alpha = 6^\circ; \quad Re = 2.51 \times 10^6; \]

Maximise \( L/D \)
High-Lift Test Case – RANS Calculation (using SA)

\[ M_\infty = 0.185; \alpha = 6^\circ; Re = 2.51 \times 10^6; \]

Maximise \( L/D \); 14 CATIA Parameters
NLR 7301 High-Lift Case

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Original

Optimised
NLR 7301 High-Lift Case

Original

Optimised
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Conclusions:

- CAD parameterisations were coupled with a CFD/Adjoint optimisation framework, SU2.
- Model deformation and geometric sensitivities are calculated outside the CFD solver.
- Alternative approach does not compromise optimisation efficiency with respect to native parameterisations.
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Thank you for your attention

Questions Welcome