Aerodynamic optimization using Adjoint methods and parametric CAD models


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Aerodynamic optimization using Adjoint methods and parametric CAD models

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5. Conclusions
Motivation

- Perform high-fidelity aerodynamic optimisation
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- Perform high-fidelity aerodynamic optimisation
- Increase flexibility of Adjoint Based Optimisation
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- 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

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

- **Computational Cost**
  - Gradient Based Optimisation

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Motivation

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

- Computational Cost
  - Gradient Based Optimisation

- Large number of parameters
  - Adjoint Methods
Motivation

In CFD based optimisation, parameterisations are usually built in the software.
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 framework

- Developed at Stanford University

1 images taken from http://su2.stanford.edu/
SU² is an open-source CFD/Adjoint optimisation framework¹

- Developed at Stanford University
- General purpose PDE solution methods

¹Images taken from http://su2.stanford.edu/
SU² 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, . . .)

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

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

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

¹images taken from http://su2.stanford.edu/
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

\[
\begin{bmatrix}
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\frac{\partial x_1}{\partial A_2} & \cdots & \frac{\partial x_m}{\partial A_2} \\
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Surface Sensitivities

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

**Gradient Calculation**

\[
\begin{bmatrix}
\frac{\partial f}{\partial A_1} \\
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- \(\frac{\partial f}{\partial A_i}\) - Gradient
- \(\frac{\partial x_i}{\partial A_i}\) - Design Velocities
- \(\frac{\partial f}{\partial x_j}\) - Surface Sensitivities
Motivation Gradient Calculation Onera Wing Test Case NLR 7301 Conclusions

CAD parameterisation

CATIA geometry

27 CATIA Parameters
CAD parameterisation

CATIA geometry

Design Velocities Param.1

Design Velocities to Param.3

27 CATIA Parameters
Use design velocities and mesh deformation module (linear elasticity) to deform surface CFD mesh.
Outline

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Start the process by computing the flow and adjoint solution
Start the process by computing the flow and adjoint solution

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

CATIA geometry

Geometry Sensitivity to Param.1

Geometry Sensitivity to Param.3

27 CATIA Parameters
Gradient Validation

Compute gradient for optimiser:

Optimiser returns updated parameter values, which is used to create new CAD model and new design velocities calculated ...
Onera Wing Drag Minimization

Transonic Test Case – Inviscid Calculation

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

\[
\min C_D \\
\text{subject to: } C_L > 0.283
\]
Transonic Test Case – Inviscid Calculation

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

Motivation Gradient Calculation Onera Wing Test Case NLR 7301 Conclusions

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Onera Wing Drag Minimization

![Graph showing the evaluation of different drag coefficients over evaluation steps.]

- $C_L$
- $C_D$
- $C_L$ const.
- $C_{L - SU^2}$
- $C_{D - SU^2}$

**Legend:**
- Red line for $C_L$
- Green dashed line for $C_D$
- Green dotted line for $C_L$ const.
- Red dotted line for $C_{L - SU^2}$
- Green dotted line for $C_{D - SU^2}$
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High-Lift Test Case – RANS Calculation (using SA)

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

Maximise \( L/D \)
NLR 7301 High-Lift Case

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
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NLR 7301 High-Lift Case

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 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