# Unsteady adjoint optimization with grid adaptation

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The proof uses reductio ad absurdum.

#### **Theorem**

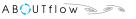
There is no largest prime number.

#### Proof.

- **1** Suppose *p* were the largest prime number.
- 2 Let q be the product of the first p numbers.
- **1** Then q + 1 is not divisible by any of them
- Thus q + 1 is also prime and greater than p.







The proof uses reductio ad absurdum.

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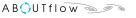
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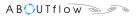
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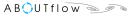
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- **3** Then q+1 is not divisible by any of them.
- **1** Thus q + 1 is also prime and greater than p.



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# Personal Information

### Background

- Born in Khulna, Bangladesh
- B.Sc. in Mechanical Engineering from Bangladesh University of Engineering & Technology
- M.Sc. in Computational Mechanics from University of Duisburg-Essen, Germany

### **Current Position**

- Joined WUT as ESR 14 on October, 2013
- Supervised by Prof. Jacek Szumbarski



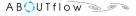




# **Objectives**

- Adjoint solver for unsteady Navier-Stokes (including check pointing)
- Usage of adjoint calculation for shape optimization and optionally for optimal control
- Optimize the performance with grid adaptation and optionally multi-gird





# Work Plan

#### **Preliminaries**

- Unsteady adjoint for a simple ODE with checkpointing
- optimal control for simple ODE

• Unsteady Euler/NS solver (Residual Distribution Scheme)

- Implementation of unsteady adjoint in the NS solver
- Implementation of moving geometry
- Gradient-based shape optimization





# Work Plan

#### **Preliminaries**

- Unsteady adjoint for a simple ODE with checkpointing
- optimal control for simple ODE

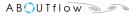
### Prerequisites

• Unsteady Euler/NS solver (Residual Distribution Scheme)

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# Prerequisites

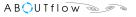
Unsteady Euler/NS solver (Residual Distribution Scheme)

### Primary Task

- Implementation of unsteady adjoint in the NS solver
- Implementation of moving geometry
- Gradient-based shape optimization







# Work Plan - continued

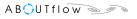
### Testing and evaluation

- Testing of the Euler/NS code on non-stationary cases
- Testing of the obtained gradients against finite difference
- Testing of a complete optimization

### Performance improvements

- Hessian-of-solution based mesh refinement
- Goal-oriented based mesh refinement





# **Progress**

### **Progress**

- Literature review
- Training on adjoint-based mesh adaptation and optimization
- Training on AD tools
- Training on Open MPI
- Development of Adjoint implementation on Euler solver is underway.





### Secondments

#### **RWTH**

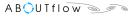
- Familiarization in parallelization of adjoint solvers
- Review of AD tools for parallel application
- Implementation of operator overloading based AD to develop Adjoint solver

#### RR

- Investigation of turbo-machinery problem using the developed adjoint solver
- Application of grid adaptation tool chain available in WUT for turbo-machinery test cases







# Duality Formulation For Adjoint Design

Primal:

$$Q^{n+1} = F(Q^n)$$

(1)

Tangent Linear:

$$\frac{\partial Q^{n+1}}{\partial \alpha} = \frac{\partial F}{\partial Q} \frac{\partial Q}{\partial \alpha} + \frac{\partial I}{\partial \alpha}$$

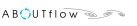
(2)

Adjoint Equation:

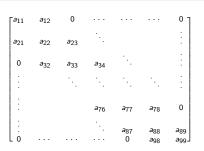
$$v^{n} = \left(\frac{\partial F}{\partial Q}\right)^{T} v^{n+1} + \frac{\partial I}{\partial Q}$$

*(* - )





# Advantage of Finite Difference to Develop Jacobian



- Developed Jacobian is a complete sparse matrix which can be calculated locally
- It is conveniently scalable
- Options to implement higher order FDM, if more accurate jacobian is required
- Tested for stationary problems with sufficient accuracy



(4)

# Acknowledgements

This work has been conducted within the **About Flow** project on "Adjoint-based optimization of industrial and unsteady flows".

http://aboutflow.sems.qmul.ac.uk

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