High-fidelity multidisciplinary optimization for future aircraft design

David Zingg
University of Toronto Institute for Aerospace Studies
and
Joaquim Martins
Department of Aerospace Engineering, University of Michigan

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OBJECTIVE

- Development of high-fidelity design tools for future aircraft
- Application to
  - unconventional configurations
  - integration of new technologies, such as laminar flow control

PREMISES

- High-fidelity analysis is needed for accurate prediction of performance, fuel burn, and emissions of future aircraft
- Optimization is critical for the development and assessment of novel configurations and technologies where there exists no substantial body of design experience

EXPLORATORY OPTIMIZATION

- Gives the optimizer the freedom to make radical alterations to the geometry
- Introduces a number of challenges
  - geometry parameterization
  - complex design space - multiple local minima
  - robust tools needed, e.g. flow solver, mesh movement
- Potential to reveal hitherto undiscovered concepts

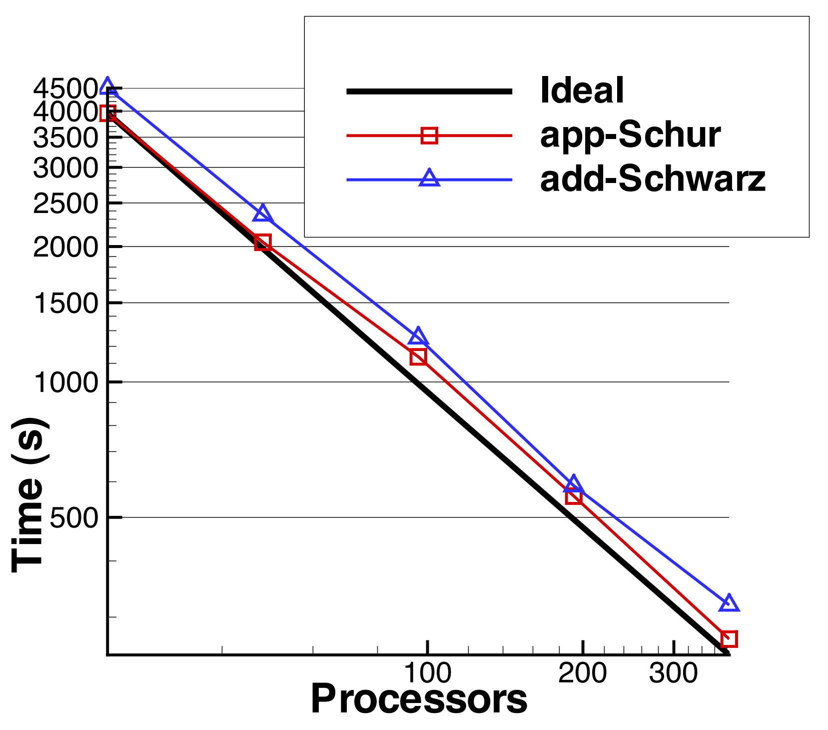
COMPONENTS OF AN AERODYNAMIC SHAPE OPTIMIZATION CAPABILITY

- Geometry parameterization
- Flow solver
- Gradient computation
- Optimizer
- Mesh movement

FLOW SOLVER

- Structured multi-block grids
- High-order finite-difference method with summation-by-parts operators and simultaneous approximation terms
- Parallel Newton-Krylov-Schur solver
  - 10-million-node mesh, 10 order residual reduction in less than six minutes on 640 processors
  - 1-million-node mesh, same convergence in 12 minutes on 24 processors

➡ Hicken, J.E., and Zingg, D.W., A parallel Newton-Krylov solver for the Euler equations discretized using simultaneous approximation terms, AIAA Journal, Vol. 46, No. 11, 2008



INTEGRATED GEOMETRY PARAMETERIZATION AND MESH MOVEMENT

- Must provide flexibility for large shape changes with a modest number of design variables
  - B-spline patches represent surfaces
  - B-spline control points are design variables

- Mesh movement must maintain quality through large shape changes
  - through tensor products, B-spline volumes map a cube to an arbitrary volume with the appropriate topology
  - can be arbitrarily discretized in the cube domain to create a mesh
  - B-spline volume control points can be manipulated to move the mesh in response to changes in the surface control points
  - efficiently generates a high quality mesh

➡ Hicken, J.E., and Zingg, D.W., Aerodynamic Optimization Algorithm with Integrated Geometry Parameterization and Mesh Movement, AIAA Journal, Vol. 48, No. 2, 2010

B-spline Volumes

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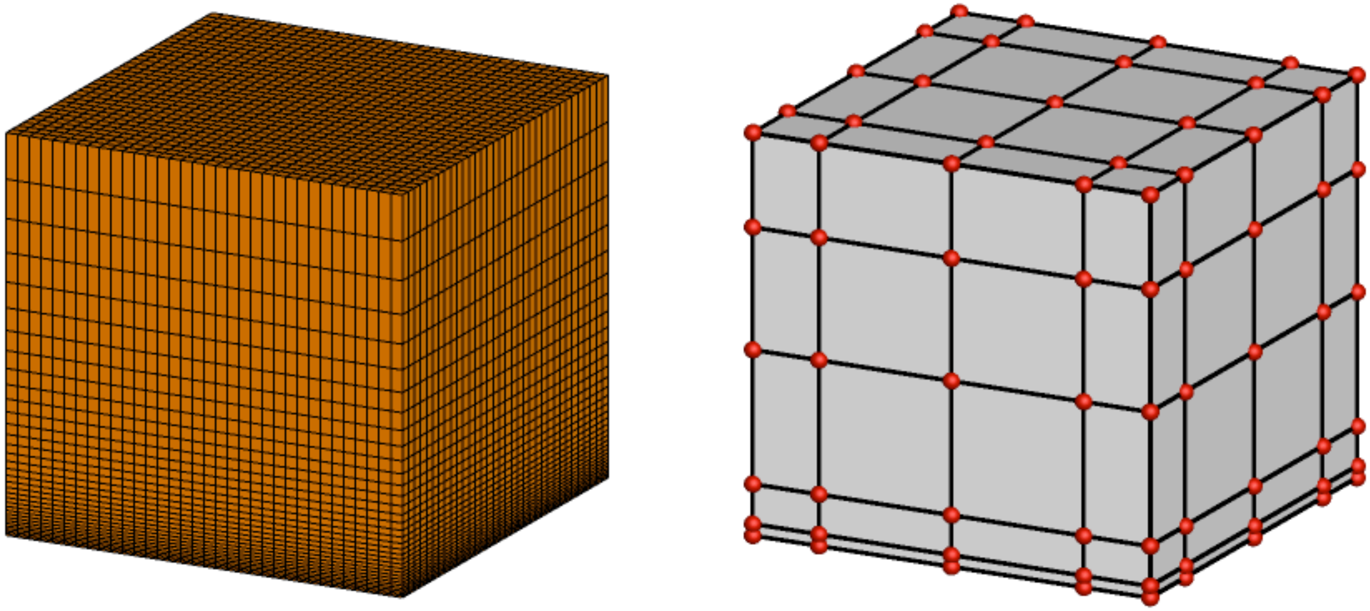
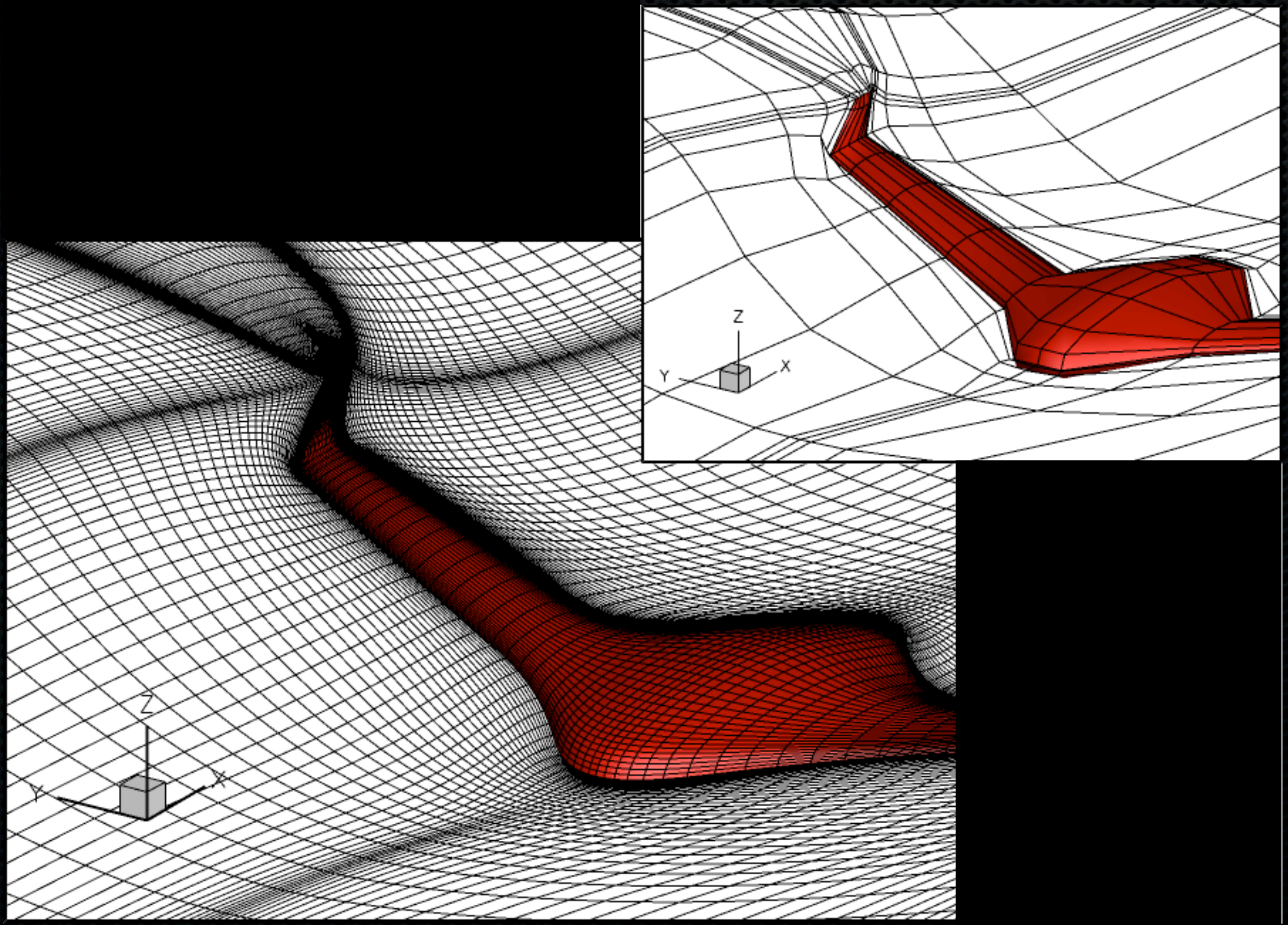


B-spline Volumes

Mesh Movement Example

flat plate to blended-wing body: ≈ 1 million nodes



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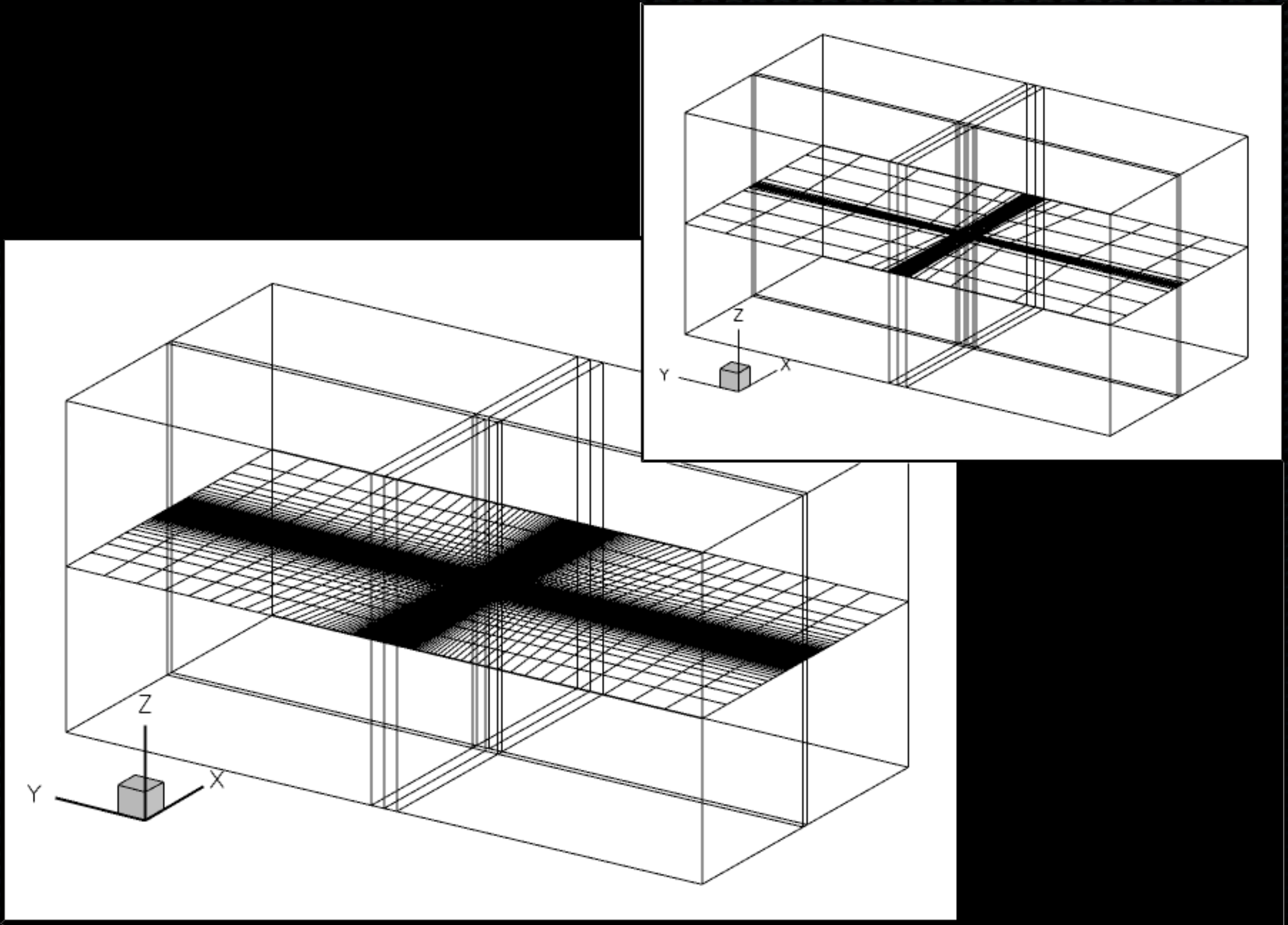

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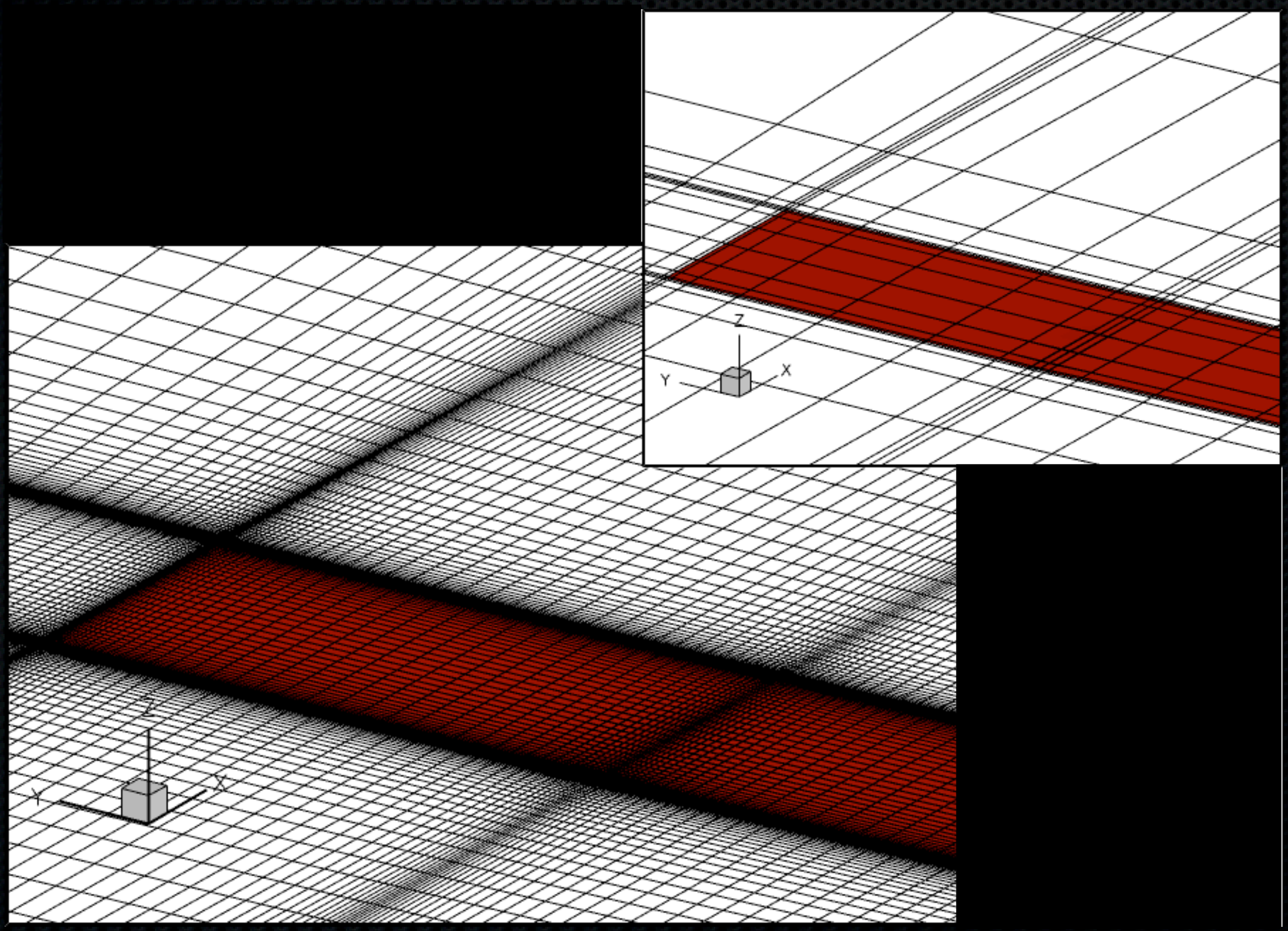

DISCRETE-ADJOINT GRADIENT COMPUTATION

- Cost independent of the number of design variables
- Efficient if the number of design variables exceeds the number of constraints
- Hand linearization complemented by judicious use of the complex step method for difficult terms
- Adjoint equation solved by parallel Schur-preconditioned modified Krylov method GCROT(m,k)

➡ Hicken, J.E., and Zingg, D.W., A Simplified and Flexible Variant of GCROT for Solving Nonsymmetric Linear Systems, SIAM Journal on Scientific Computing, accepted March 2010

Application to Wing Design

Lift-constrained induced-drag minimization

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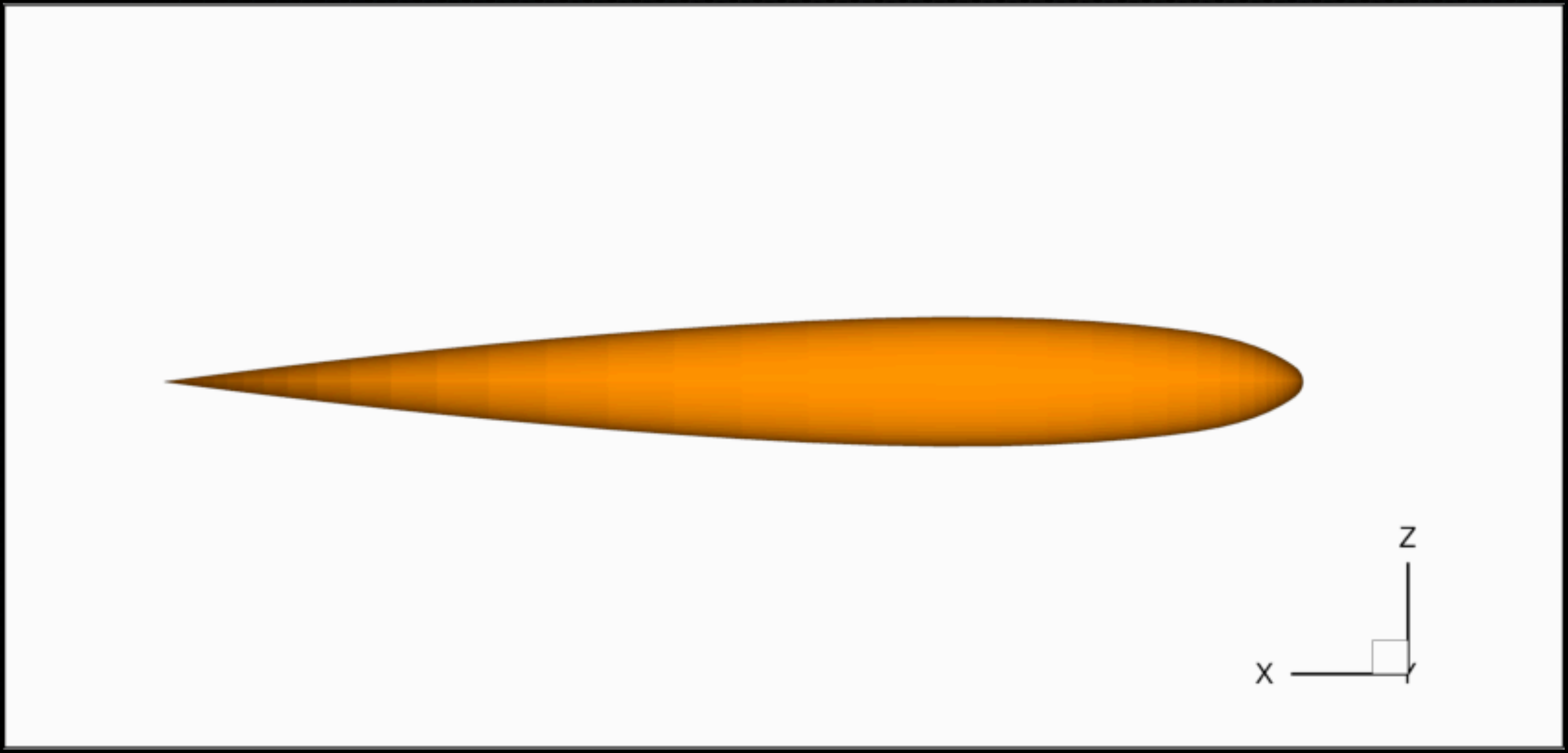

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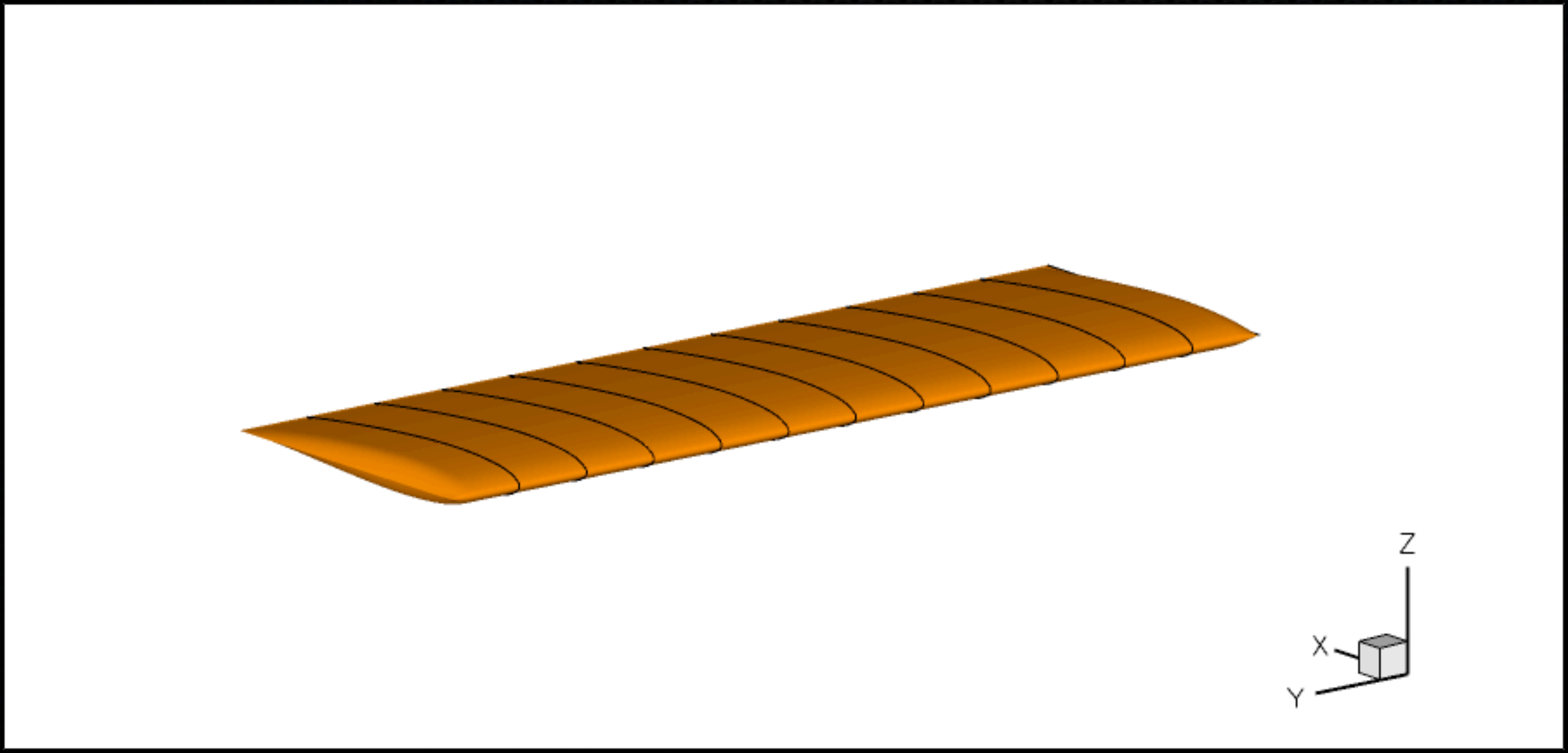
Lift-constrained induced-drag minimization



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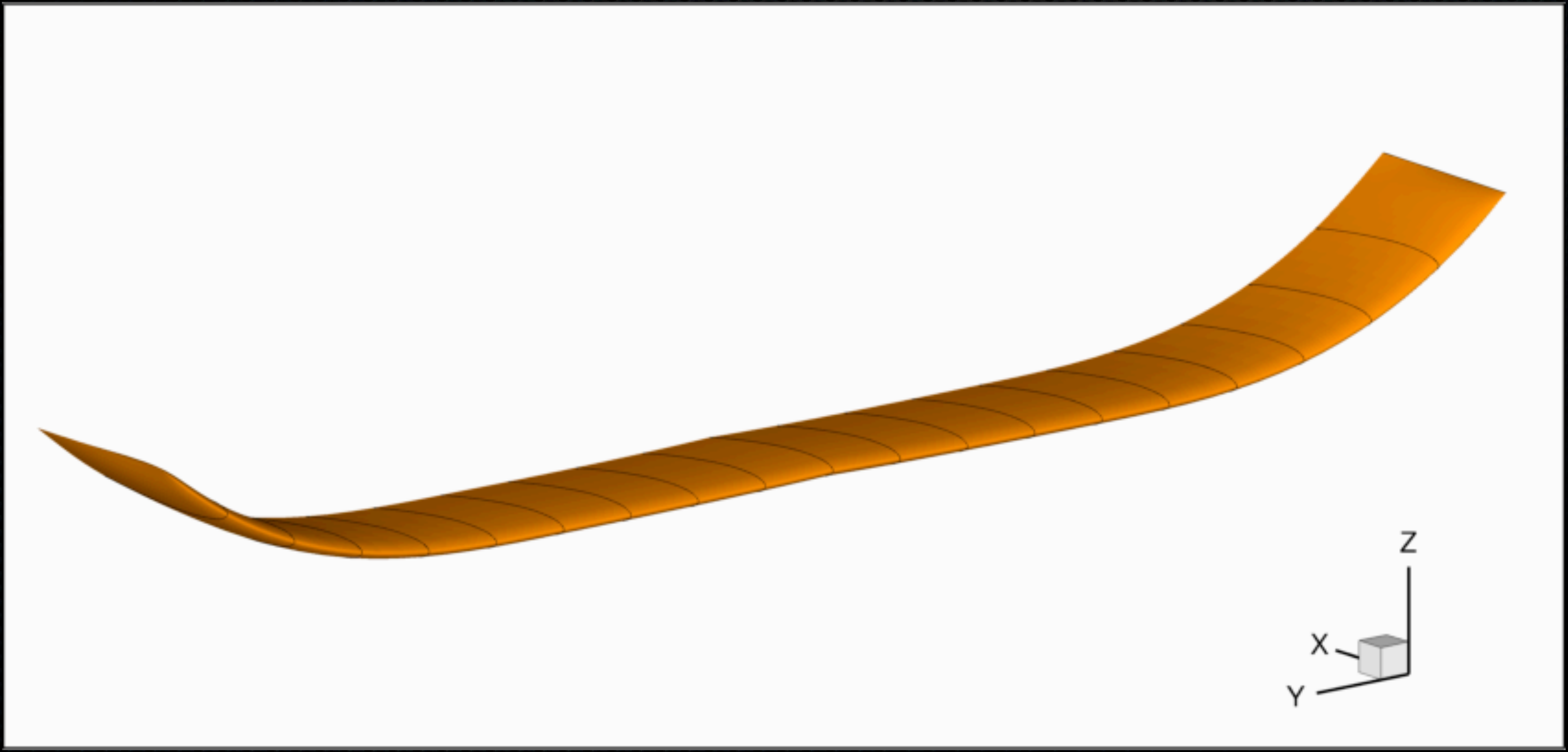
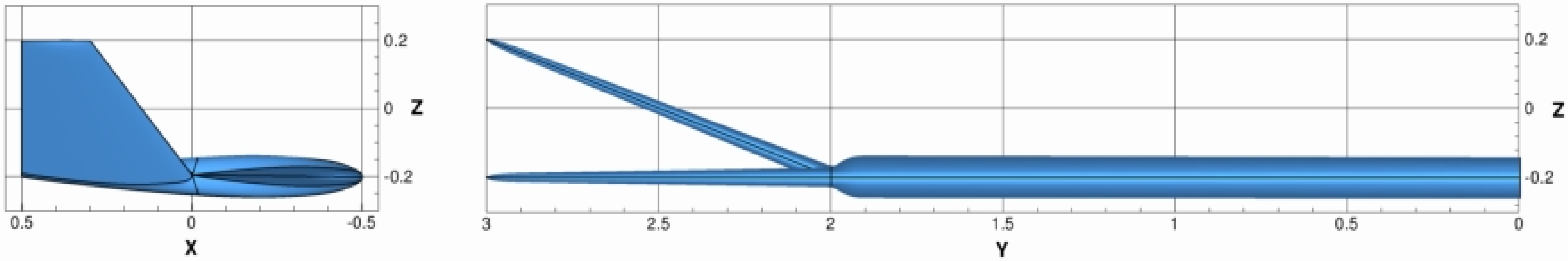
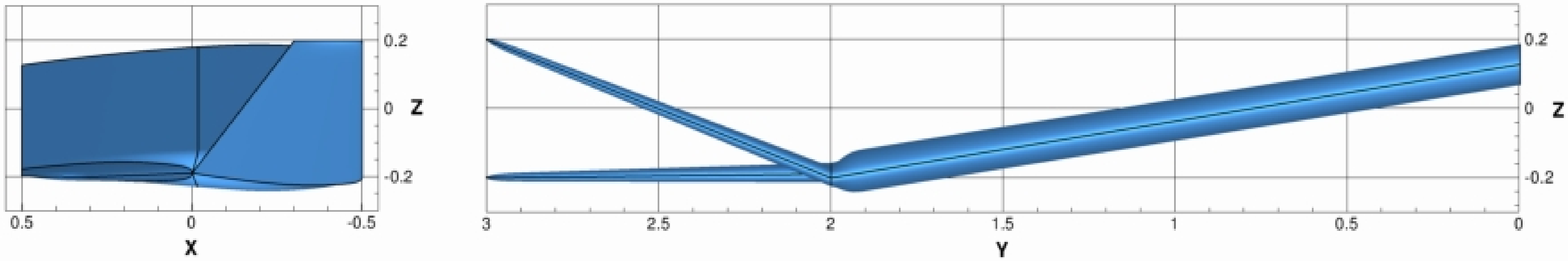


Split Tip Wing for Reduced Induced Drag

- down-up configuration: span efficiency = 1.159

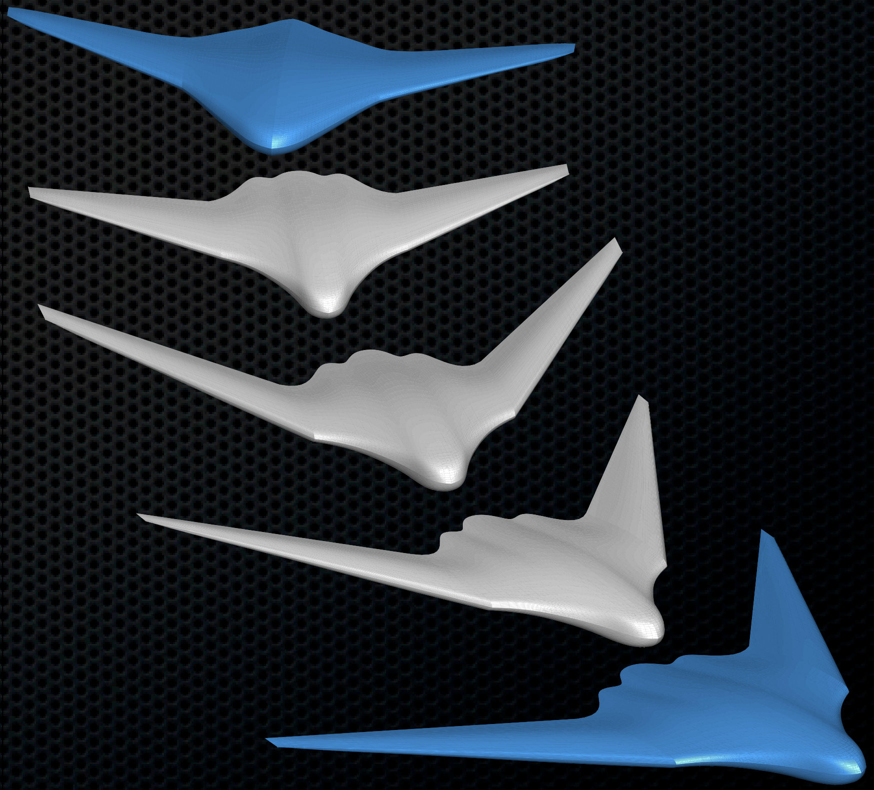


- up-down configuration: span efficiency = 1.167



Blended Wing Body Optimization

- single-point lift-constrained drag minimization
- inviscid flow - wave and induced drag only
- limited geometric flexibility
- aerodynamics only
- ten passengers
- Mach number = 0.85



CONCLUSIONS

- Exploratory aerodynamic shape optimization capability developed
  - efficient and robust flow solver based on higher-order SBP-SAT discretization and parallel Newton-Krylov-Schur algorithm
  - integrated geometry parameterization with mesh movement permitting large shape changes
  - discrete-adjoint gradient computation based on improved variant of linear solver GCROT
  - multi-point optimization - a strategy for optimizing over an entire flight envelope
- Application to
  - non-planar geometries: winglets, split-tip wing
  - blended wing-body

Future Work

Future Work

- viscous effects: turbulence model and transition prediction
- efficient techniques for multi-modal design spaces
- adaptive geometry parameterization
- integration with multi-disciplinary design optimization
- application to the design and evaluation of unconventional aircraft concepts