Simultaneous Aerodynamic Analysis and Design Optimization (SAADO) for a 3D Wing

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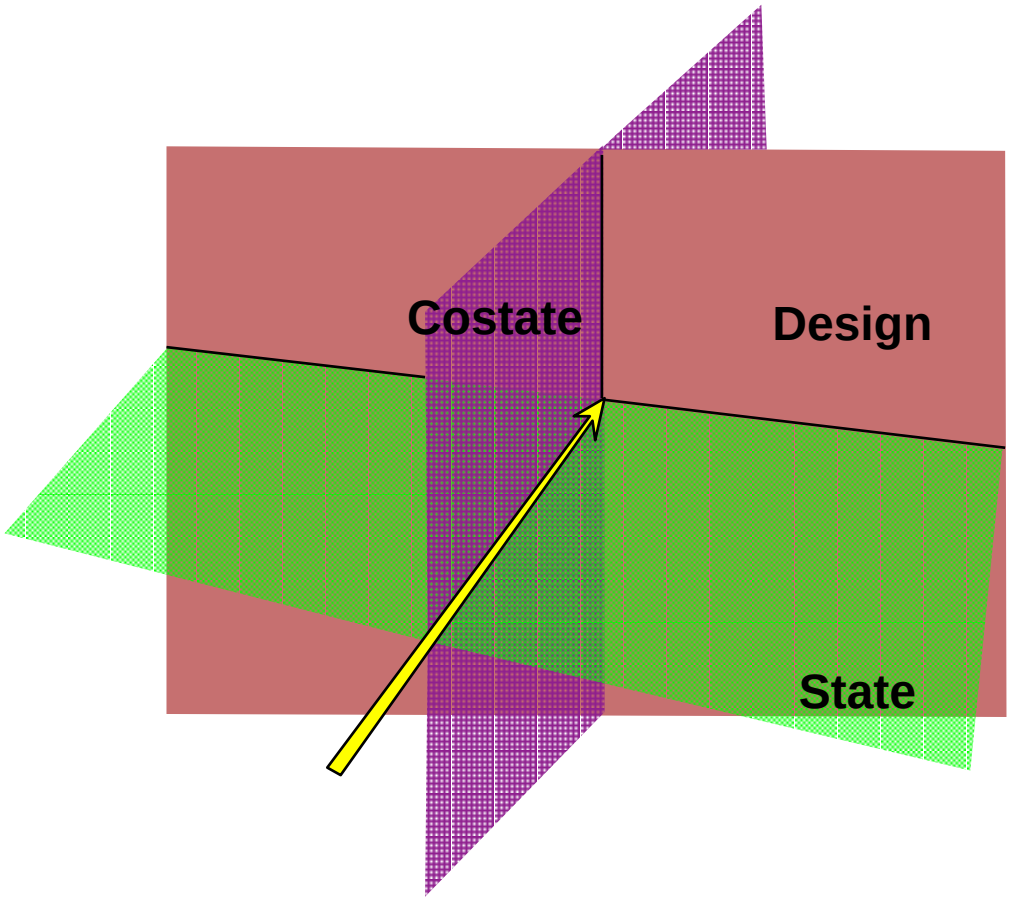
Outline

- Conventional Approach
- Optimization Challenges
- Process Implementation
- Application Problem
- Results
- Conclusions

Conventional Approach



$$\min_{\beta} F(Q(X(\beta),\beta), X(\beta), \beta)$$

subject to constraints

$$g_i(Q(X(\beta),\beta), X(\beta), \beta) \geq 0,$$

$$i=1,2,\ldots m$$

where Q is determined by

$$R(Q(X(\beta), \beta), X(\beta), \beta)=0,$$

the nonlinear aerodynamic state (flow) equations.

For gradient based optimization we also need

$$R'(Q',Q, X', X(\beta), \beta)=0$$

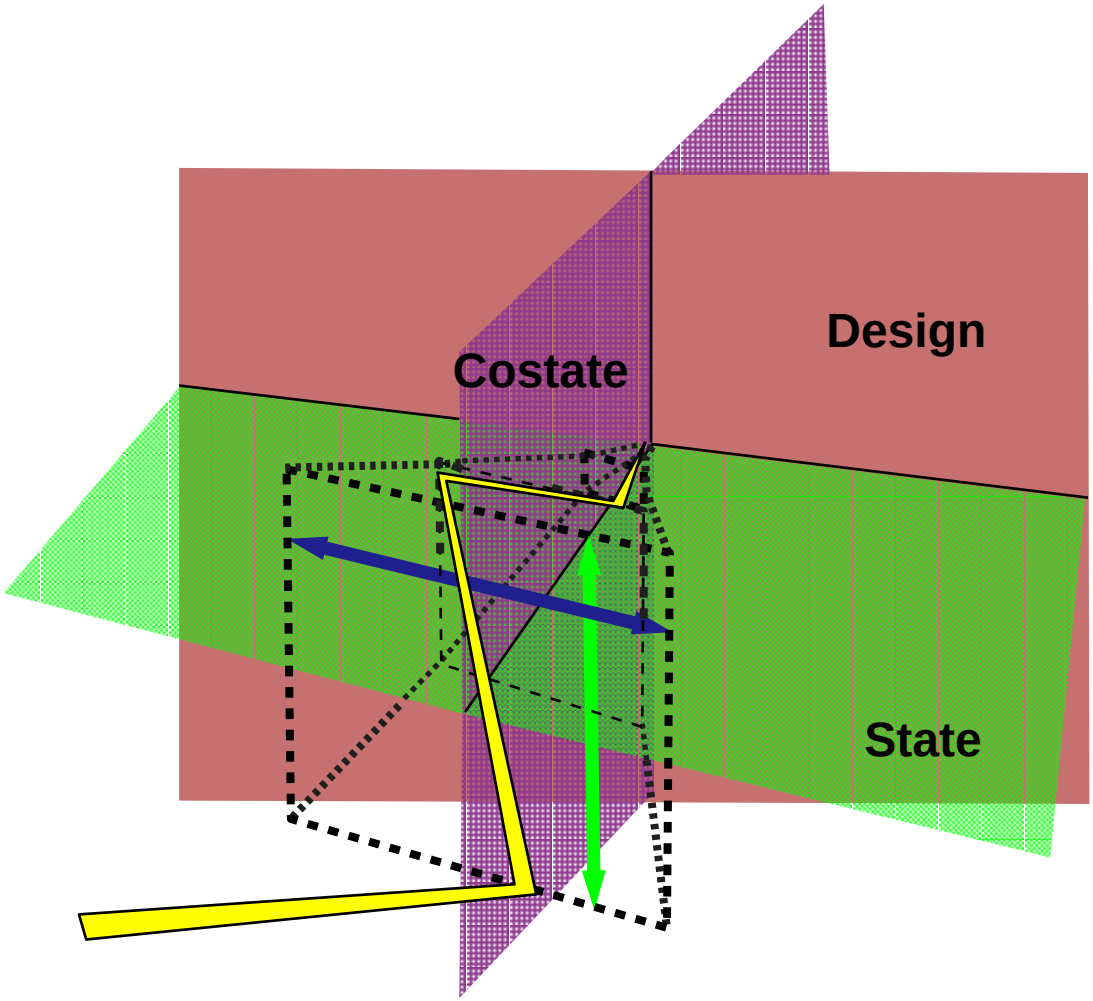
Optimization Challenges

- why SAADO?
  - To reduce the cost incurred by well−converged, iterative analyses and sensitivity analyses at non−optimal points in design space

- how SAADO?
  - Interleaf optimization updates with iterative discipline analysis
  - Require better convergence for R and R' as optimization progresses
  - Previously demonstrated for 1−D and 2−D aerodynamic applications

- 3D SAADO goals
  - Results which agree with conventional optimization
  - Computational cost less than conventional optimization
  - Minimal modifications to discipline analysis codes

Optimization Challenges
SAADO Approach



$$\min_{\beta,\, Q} F(Q, X(\beta), \beta)$$

subject to constraints

$$g_i(Q, X(\beta), \beta) \geq 0,$$
$$i=1,2,\ldots m$$

and

$$R(Q, X(\beta), \beta) = 0$$

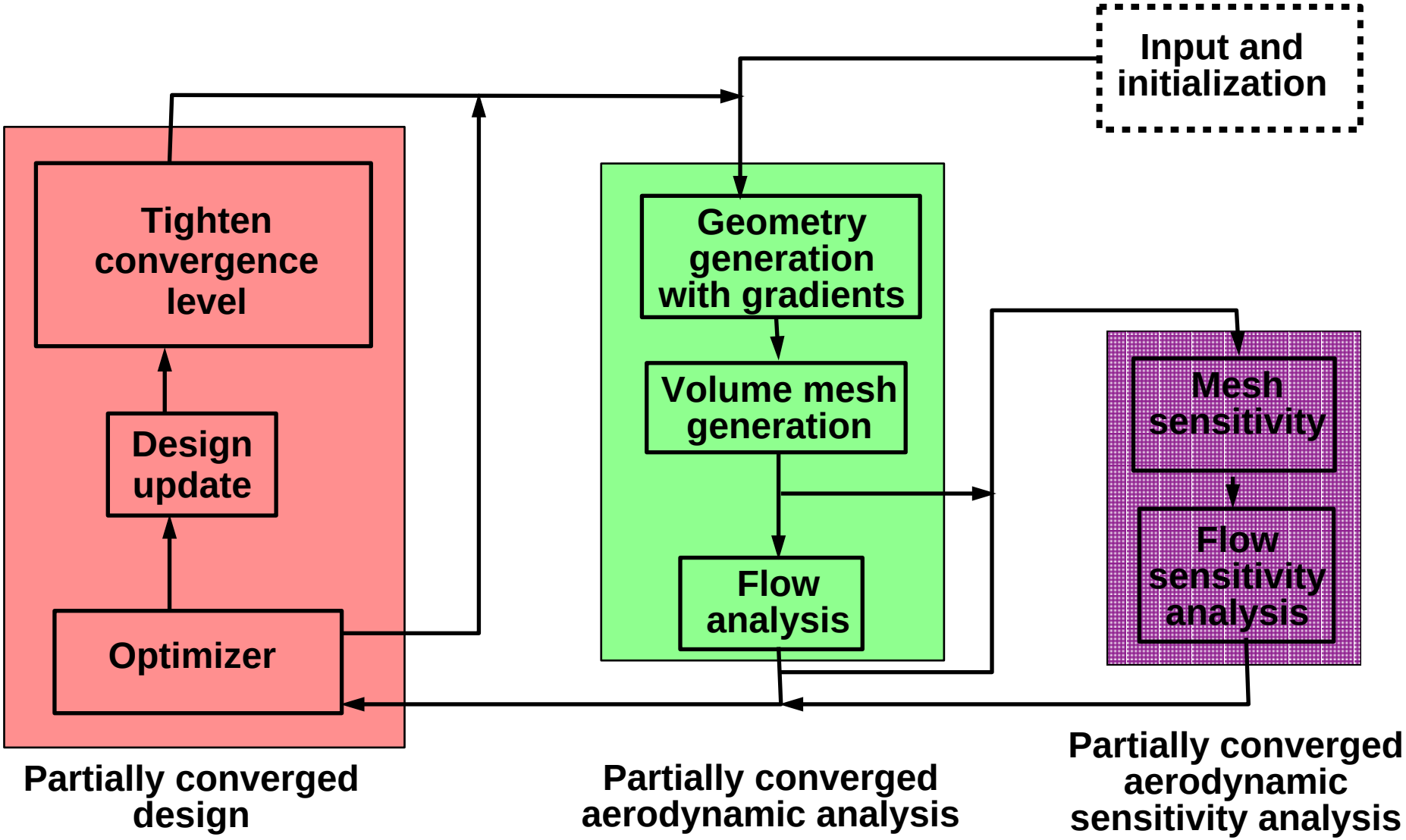
Partial convergence, implies:

- infeasibility in early design steps
- contribution to reduction of design variable domain, i.e.

$$\frac{\partial R}{\partial Q}\Delta Q + \frac{\partial R}{\partial X} X' \Delta\beta + R = 0$$

Process Implementation

Flow Chart for Aerodynamic Shape Optimization



Process Implementation
Code Descriptions

Code Name	Analysis	Sensitivity Analysis
RAPID	Surface geometry generation Rapid Aircraft Parameterization in Design	ADIFOR
CSCMDO	Volume mesh generation Transfinite interpolation of deformations Single−block, 97x25x17=36864 cells	ADIC
CFL3D	General structured mesh Euler or Navier−Stokes flow analysis Euler used in this study	ADIFOR, Incremental Iterative
DOT	Optimization suite, Vanderplaats R&D, Inc. Used Sequential Quadratic Programming (SQP) and Method of Feasible Directions (MFD)	gradients provided, not computed

Application Problem

Aerodynamic Shape Optimization of a 3D Wing

- **Objective function: negative lift to drag ratio, $-L/D$**
- **Constraints:**
  - **minimum payload: $C_L \times S \geq L_{min}$**
  - **maximum root bending moment: $C_l \leq C_{l_{max}}$**
  - **maximum pitching moment: $C_m \leq C_{m_{max}}$**
  - **minimum section thickness**
  - **minimum leading edge radius**
- **Design variables: planform and section**

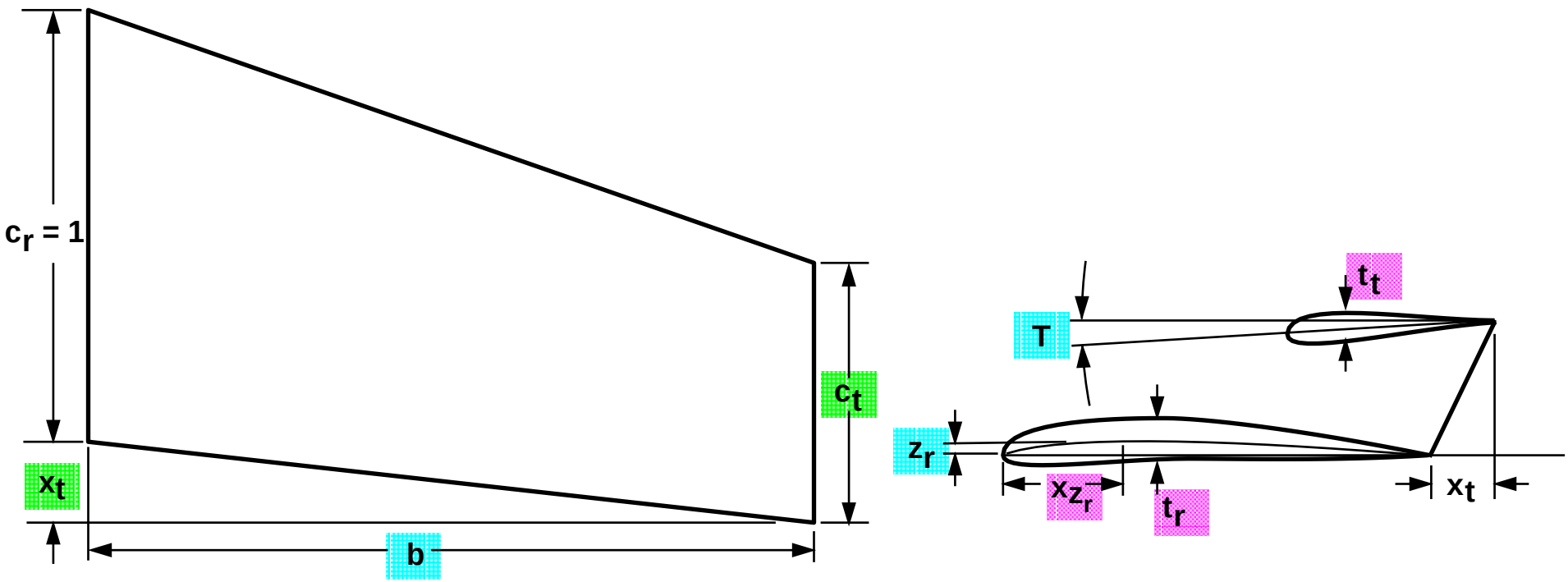
Application Problems

Wing Configuration and Parameterization

2 DV: tip chord, tip setback

5 DV: 2 DV + semispan, twist, root camber

8 DV: 5 DV + root thickness, tip thickness, location of max root camber

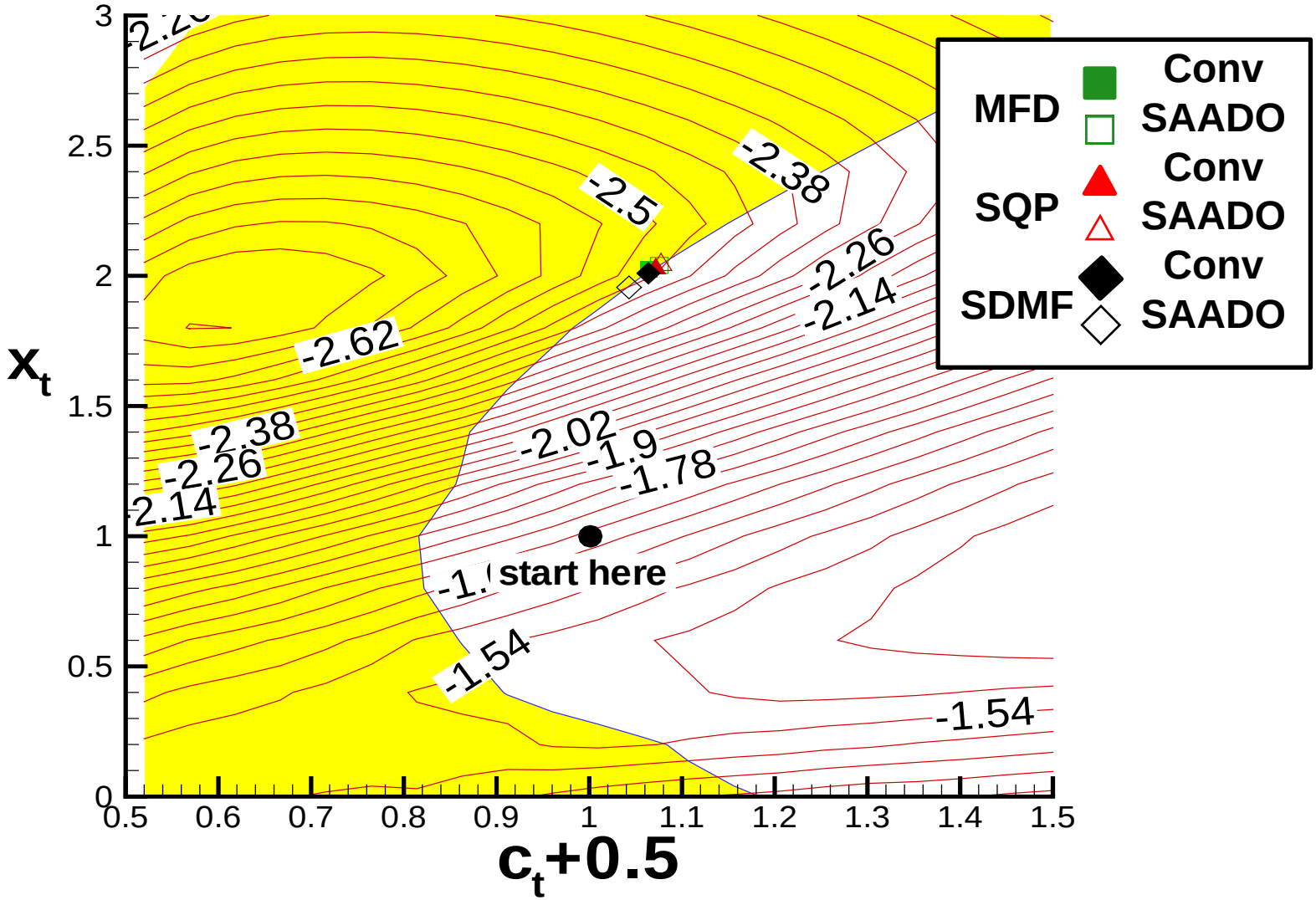


Results
SAADO vs. Conventional

- **Two planform−design variable study**
  - **tip chord, c_t, and tip setback, x_t**
  - **Subsonic, M_∞=0.5, α=3° (shown in paper)**
  - **Supercritical, M_∞=0.8, α=1°**
  - **Ensure comparable results with conventional approach**
  - **Use several optimization techniques**
  - **Readily visualizable**
- **Multiple design variable sample cases**
  - **Supercritical, M_∞=0.8, α=1°**
  - **Section variables and planform variables**

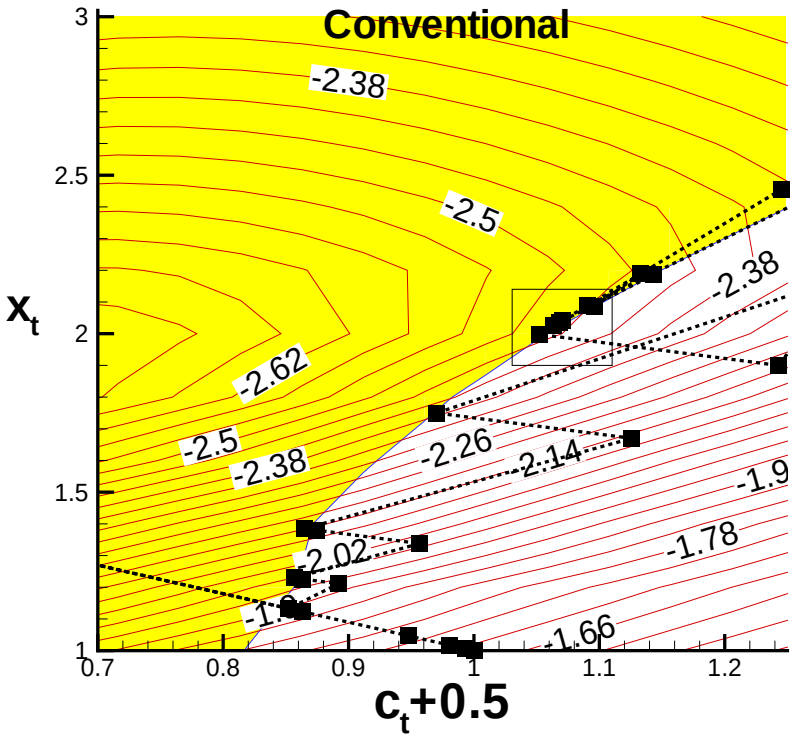
Two−Design−Variable Study

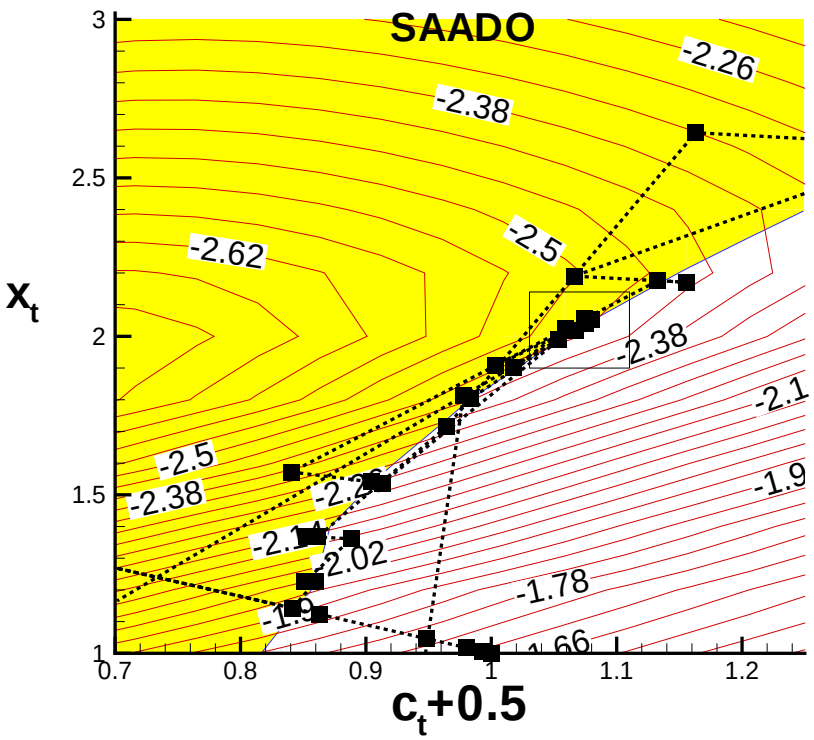
Domain, Objective Function Contours, and Endpoints



Two−Design−Variable Study

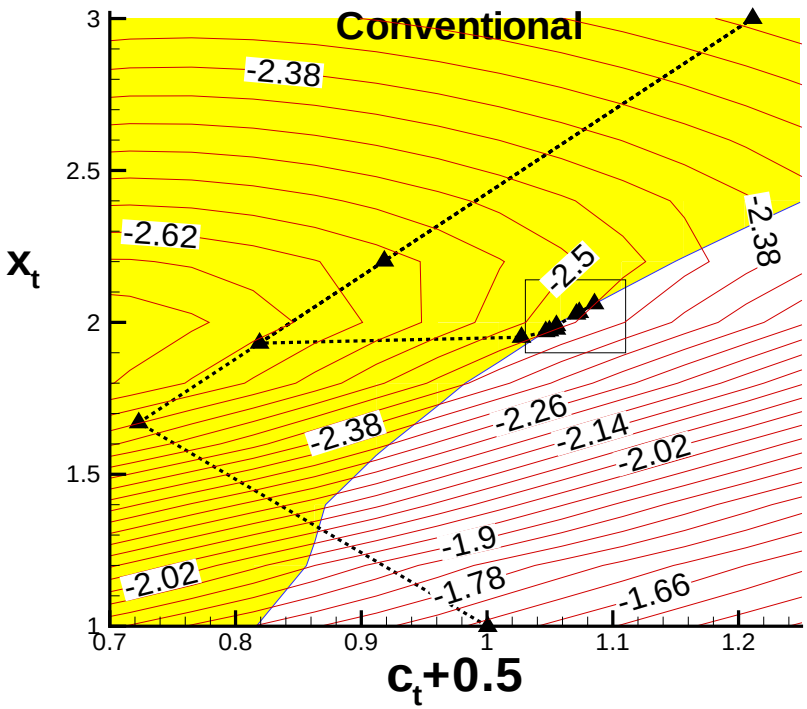
MFD Optimization Paths

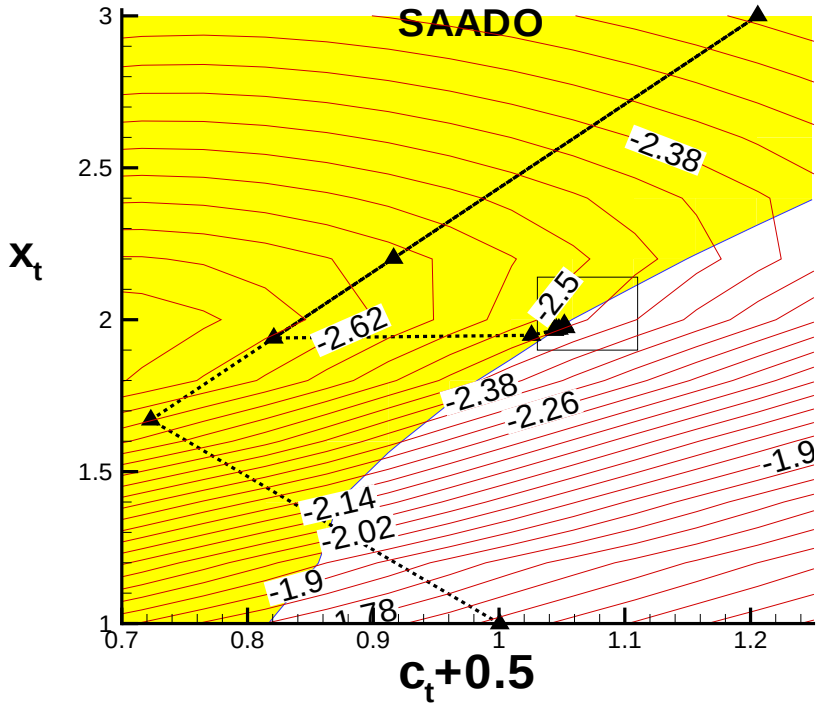




Two−Design−Variable Study

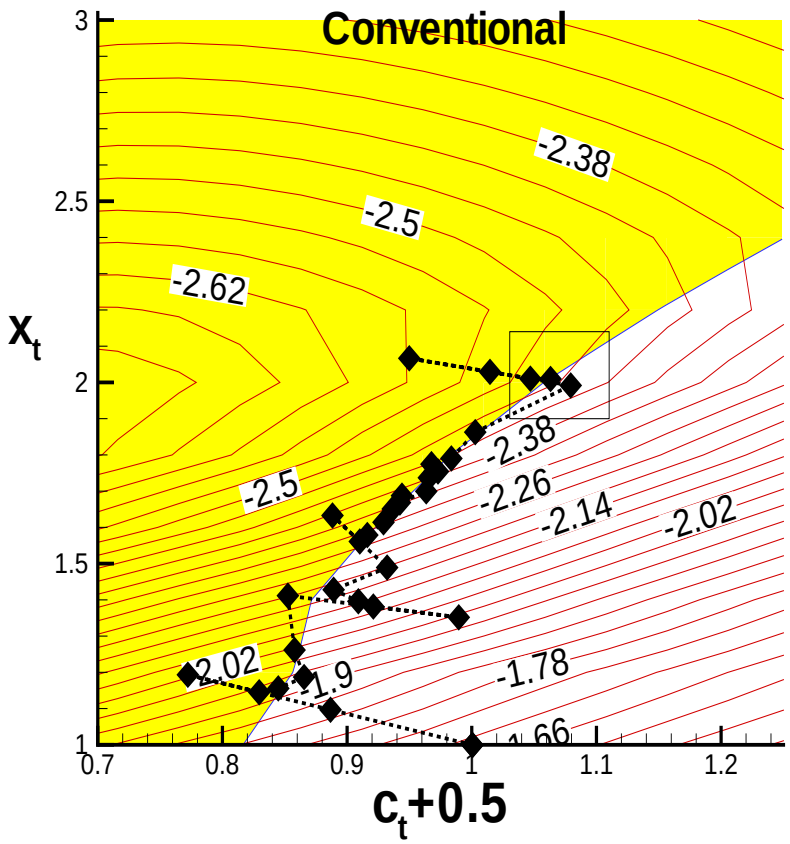
SQP Optimization Paths

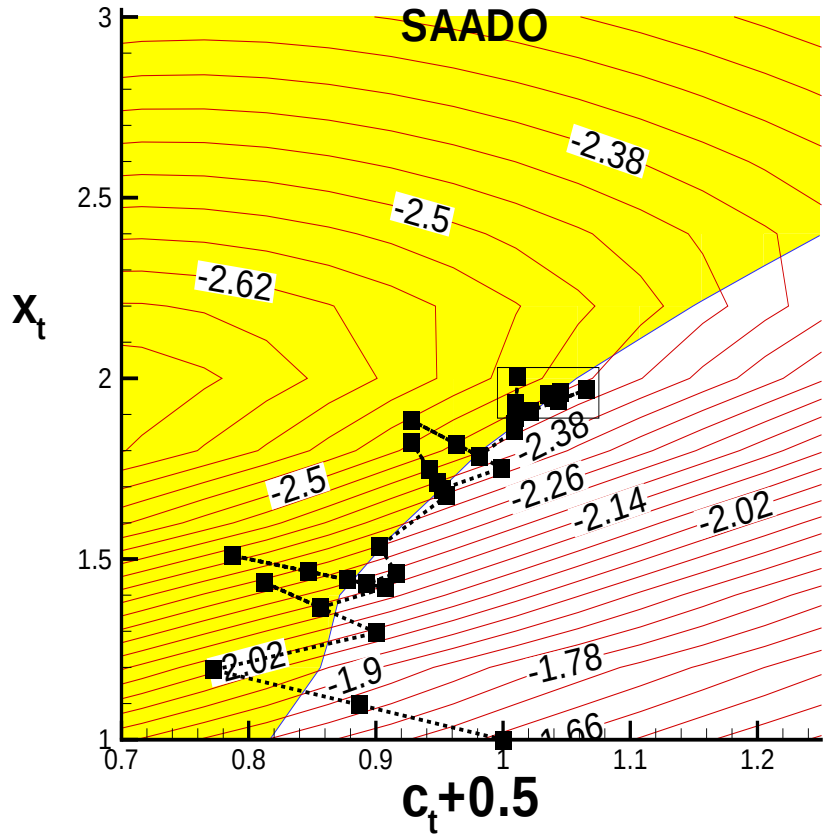




Two−Design−Variable Study

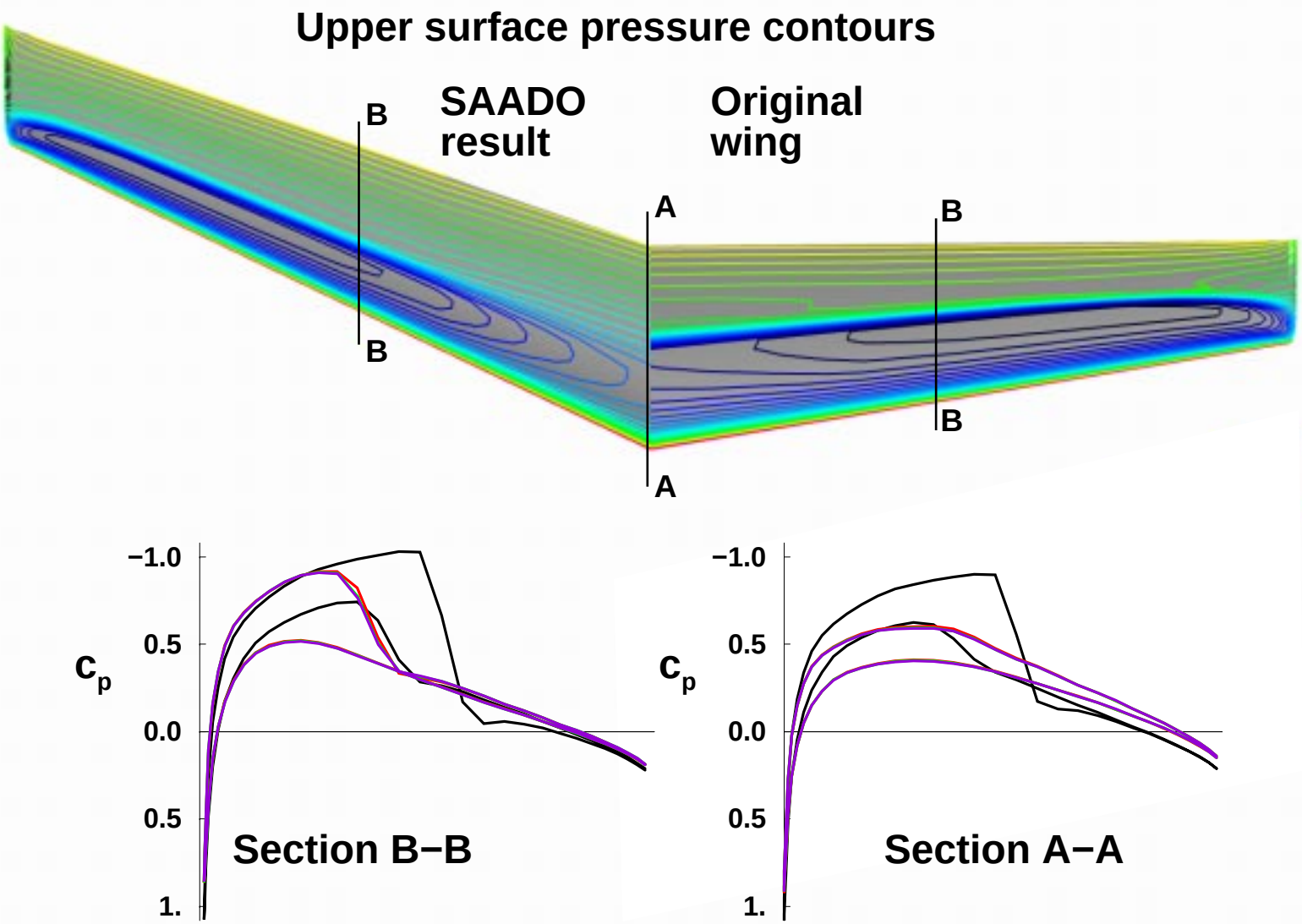
SDMF Optimization Paths





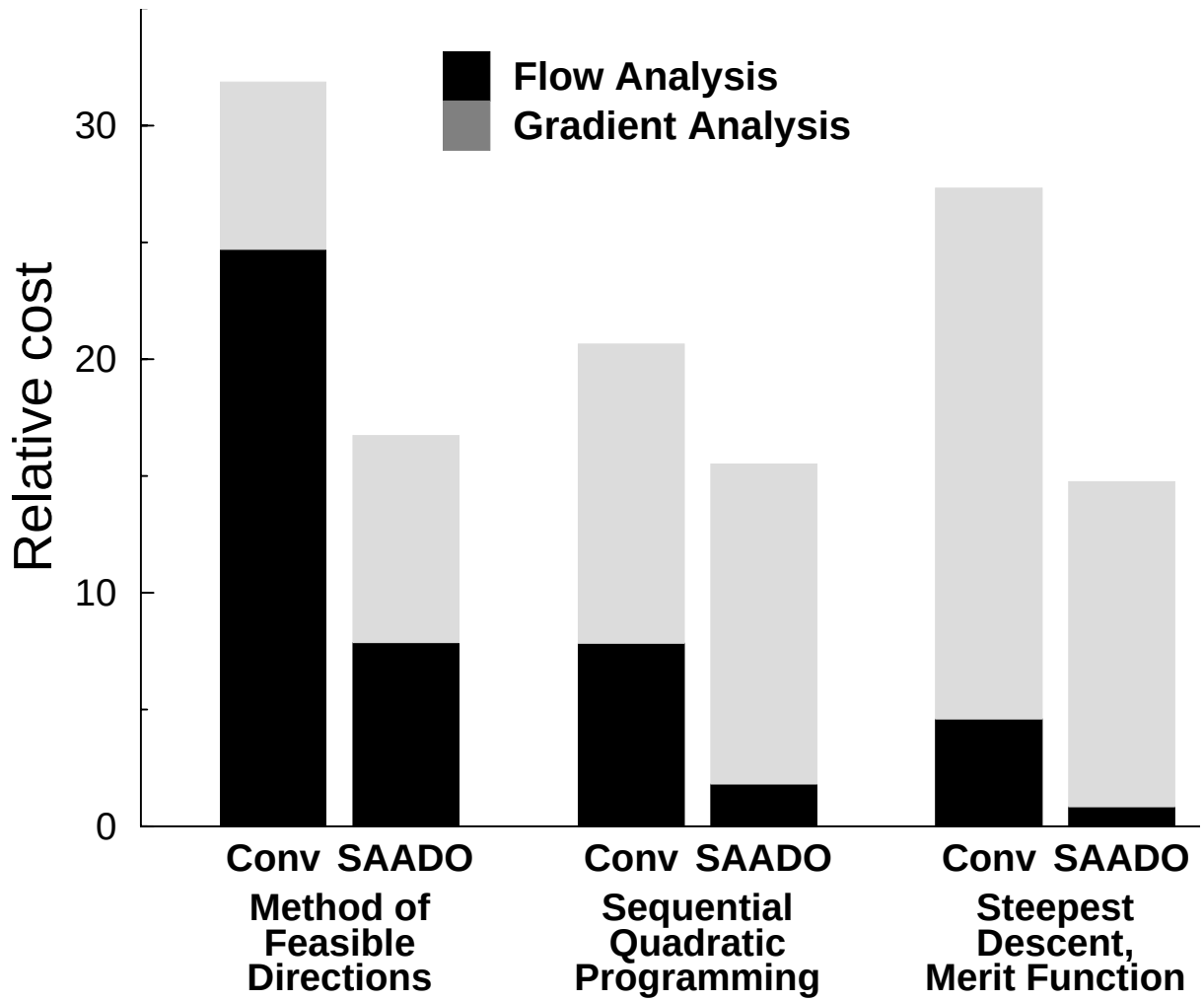
Two−Design−Variable Study

Final Design



Two−Design−Variable Study

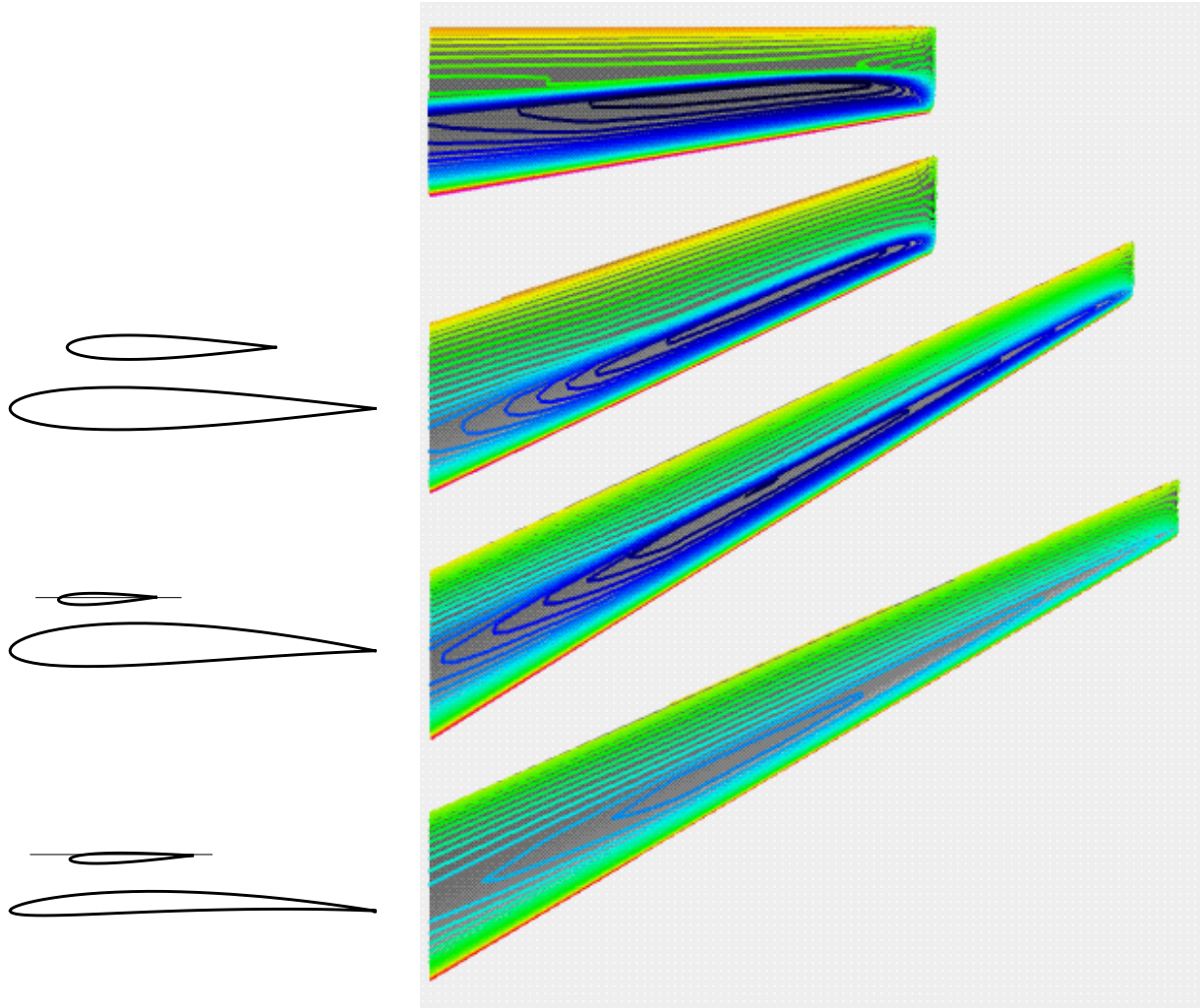
Relative Computational Cost



Multiple−Design−Variable Cases

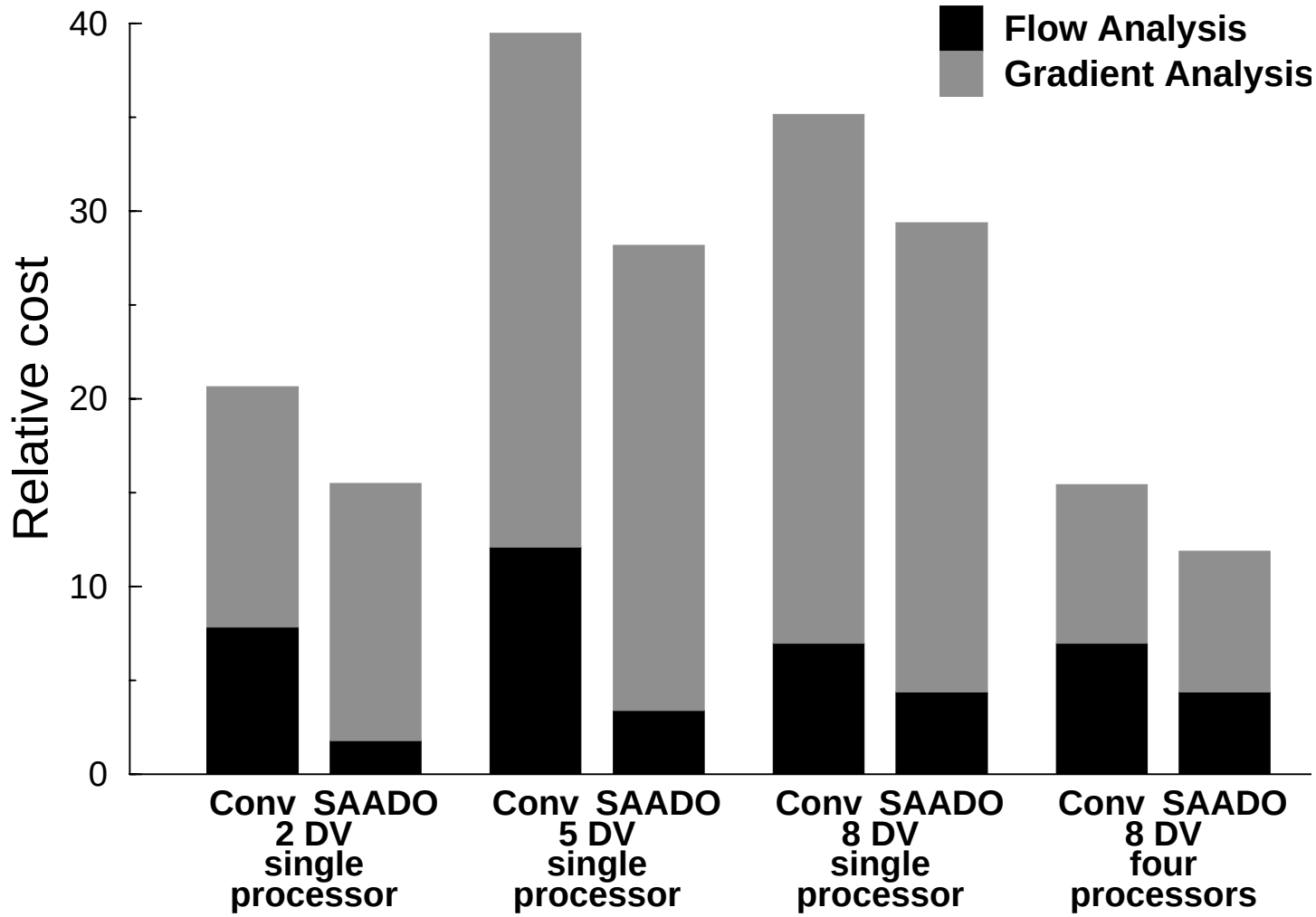
Design Comparisons

L/D	
8.4	Original
12.4	2 DV
27.6	5 DV
29.3	8 DV



Multiple−Design−Variable Cases

Relative Computational Cost



Conclusions

- Initial 3D wing SAADO results obtained.
- SAADO finds essentially the same local minimum as conventional optimization techniques.
- SAADO is computationally more efficient than conventional techniques.
- Gradient computation times dominate SAADO.
- SAADO requires few modifications to the analysis and senstitivity analysis codes.

Current and Future Development

- Adjoint formulation to address gradient cost
- Simultaneous multidisciplinary design optimization
  - Aerodynamic design of flexible wing
  - Simultaneous aerodynamic and structural design optimization
- Application to other problems/configurations