



CDISC Design Using the CATNLF Method for Application to Supersonic Configurations

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Outline



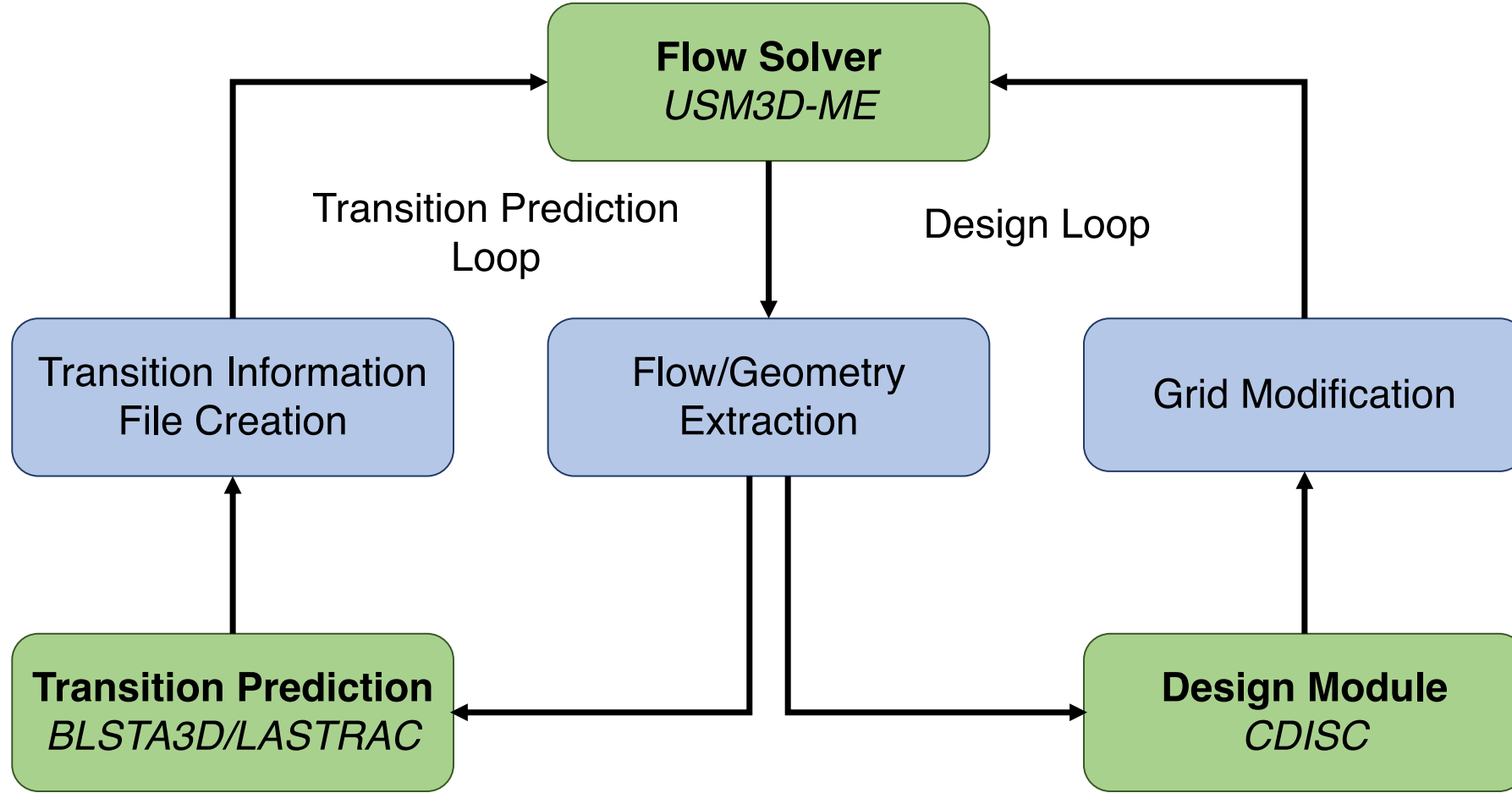
- Computational Tools
- CDISC Design Module
- CATNLF Design Method
- Supersonic Laminar Flow
- Conclusions

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Computational Tools



- **Design Module: *CDISC***
Applies knowledge-based design rules to change geometry to match target pressure distributions
- **Flow Solver: *USM3D-ME***
Solves Navier-Stokes equations on unstructured mixed-element grids
- **Boundary Layer Profile Solver: *BLSTA3D***
Calculates boundary layer velocity and temperature profiles based on chordwise pressure distribution assuming conical flow
- **Boundary Layer Stability Analysis: *LASTRAC***
Stability analysis and transition prediction using e^N Linear Stability Theory method with compressibility effects

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- Like an inverse method, it determines the geometry that will produce a specified pressure distribution
- Like a gradient-based numerical optimization method, it uses a direct-iterative approach to minimize a flow quantity (e.g., the difference between target and analysis pressures) based on sensitivity derivatives
- Constrained Direct-Iterative Surface Curvature (CDISC) is a **knowledge-based design method** using rules to:
 - Prescribe sensitivity derivatives
 - Automatically generate target pressures from flow constraints and current analysis pressures
 - Apply geometry constraints for robustness and nonaero requirements

Example CDISC Design



Wing



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Natural Laminar Flow Wings



- Laminar flow significantly improves vehicle performance by reducing skin friction and profile drag
- NLF has been limited to aircraft components with low sweep and Reynolds number, primarily due to crossflow instabilities
- Applying NLF to transport wings requires crossflow control. Options include:
 - Reducing wing sweep
 - Adding suction system
 - Use Crossflow Attenuated Natural Laminar Flow (CATNLF) airfoils 

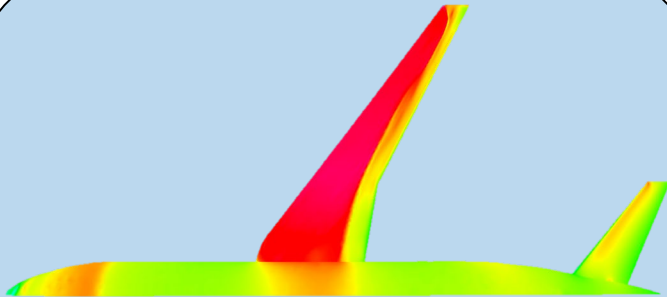
CATNLF Concept Development



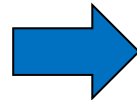
NASA Laminar Flow Design Method

Crossflow **A**tenuated **N**atural **L**aminar **F**low (**CATNLF**) design method changes the shape of airfoils to obtain pressure distributions that delay transition by damping crossflow instabilities

Computational Study



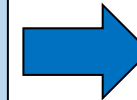
Goal: To develop technology
Reference: AIAA 2016-4326



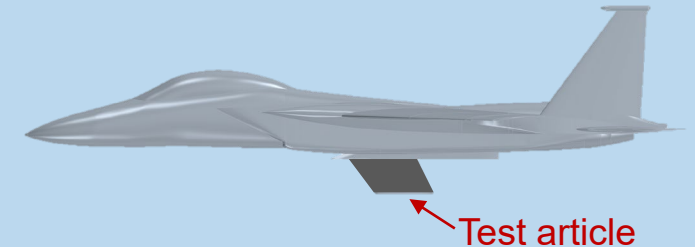
Wind Tunnel Test



Goal: To confirm computations
References: AIAA 2017-3058,
AIAA 2019-3292

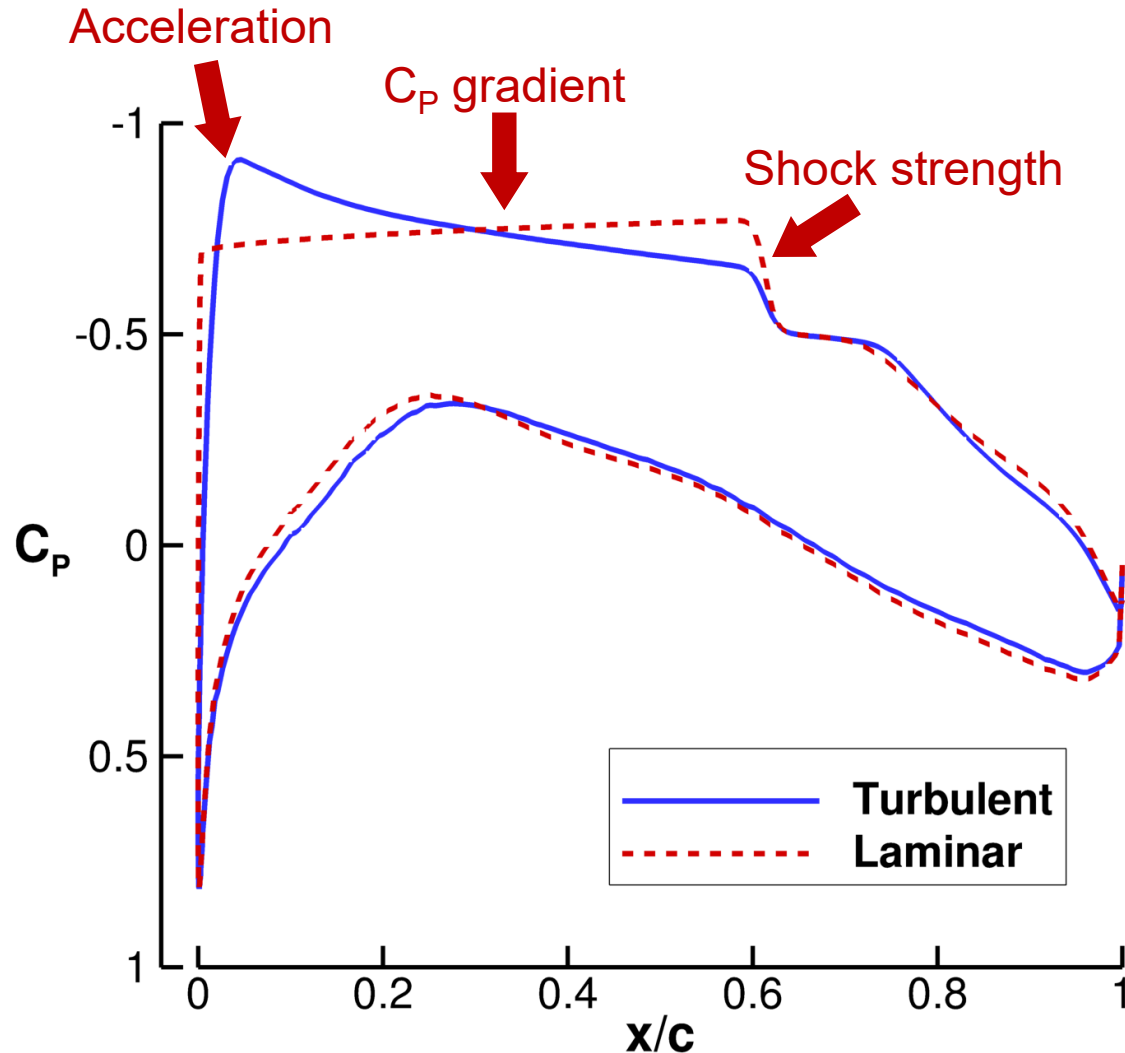


Flight Test



Goal: To advance technology
Reference: AIAA 2021-0173

Example Transonic Pressure Distributions



Notable differences:

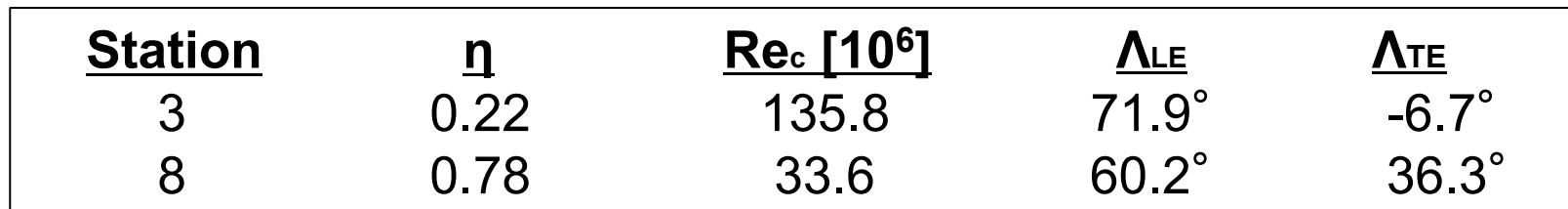
- Leading-edge acceleration
 - Laminar uses rapid acceleration for crossflow (CF) control
- Rooftop pressure gradient
 - Laminar uses mild favorable gradient for Tollmien-Schlichting (TS) control
 - Turbulent uses mild adverse gradient for shock strength reduction
- Shock strength
 - Turbulent has weaker shock

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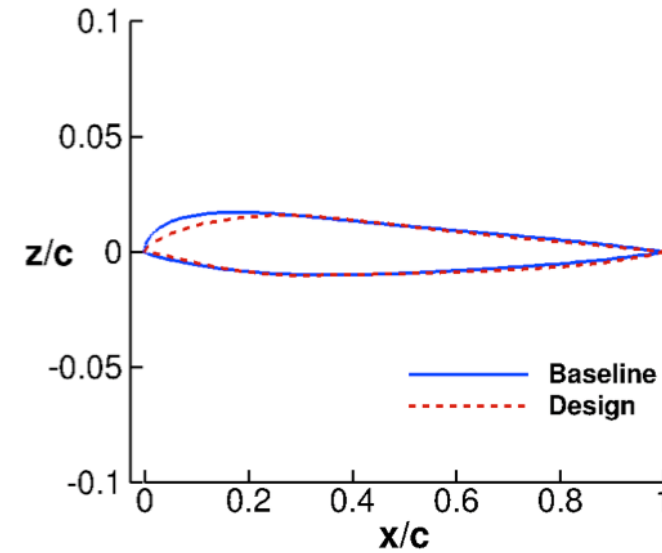
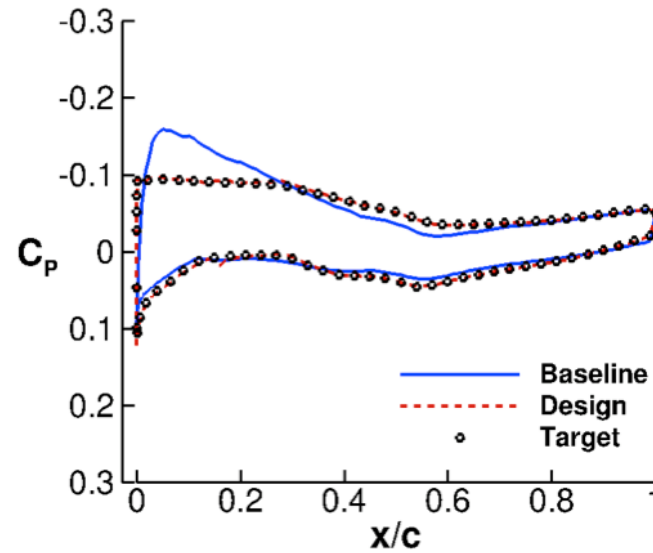
- Low-boom compatible configuration initially optimized for turbulent performance
- Design conditions: Mach = 1.6, $C_L = 0.1$, $Re_{MAC} = 118$ million
- Critical N-factor = 13 for all boundary-layer transition types (TS/FB/CF)



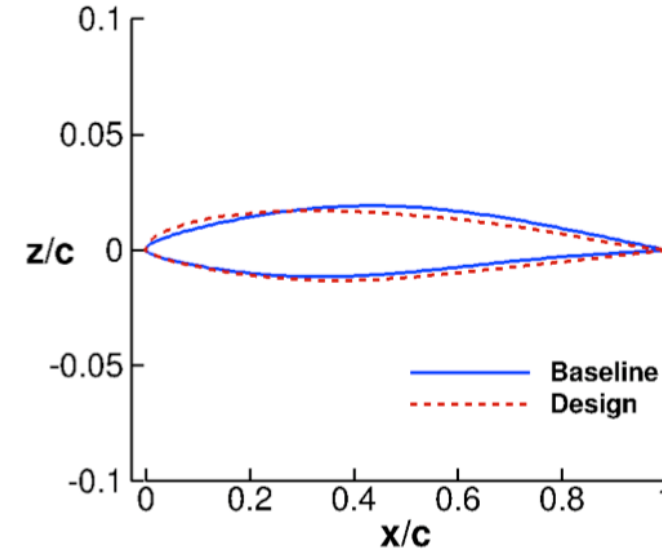
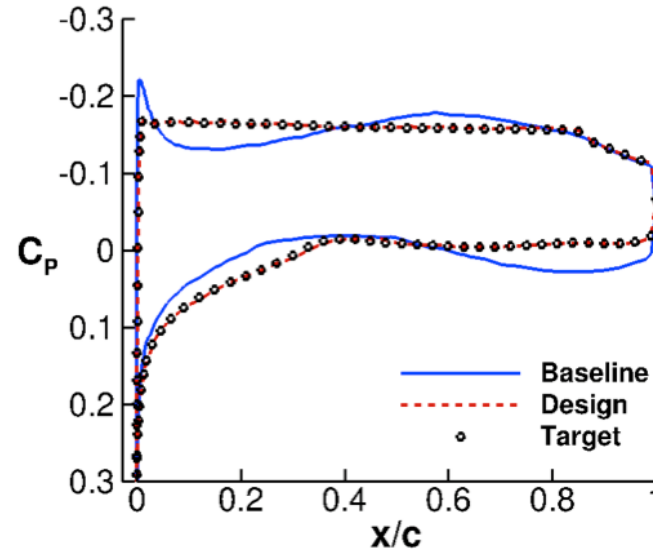
NJWB Design Results: Pressures and Geometry



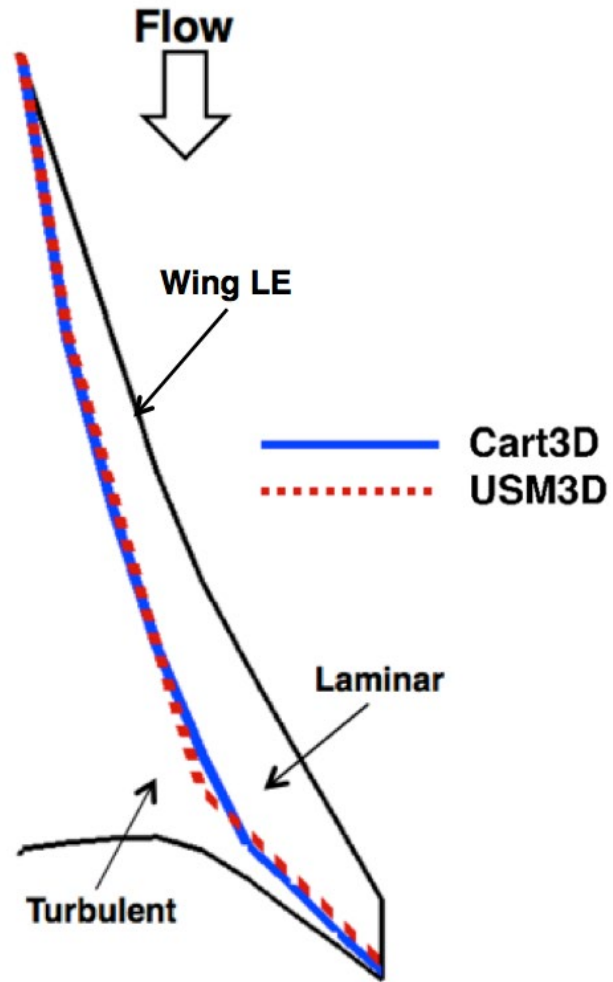
Station 3



Station 8



NJWB Design Results: Laminar Flow Extent



Transition front on wing planform
showing 44% laminar flow

Configuration	C_D [counts]
NJWB Baseline	82.6
NLF Design	78.4

**4.2 drag counts (5%)
savings from baseline**

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Conclusions



- Design method uses NASA computational tools
 - Available for US Citizens: USM3D, LSTRAC
 - Pending release for US Citizens: CDISC (includes CATNLF method)
 - Not available: BLSTA3D
- CATNLF method uses CDISC design module to reshape wing airfoils to obtain large extents of laminar flow
- CATNLF has been applied to supersonic configurations
 - 2016 work to develop concept, applied to NJWB
 - Current work by Bozeman to evaluate compatibility with low boom, applied to LBFD

Relevant References



- USM3D:
 - Pandya, M.J., Jespersen, D.C., Diskin B., Thomas, J.L., and Frink, N.T., “Efficiency of Mixed-Element USM3D for Benchmark Three-Dimensional Flows,” AIAA Journal (2021), 59(8), pp. 2997-3011; DOI: [10.2514/1.J059720](https://doi.org/10.2514/1.J059720).
- LASTRAC:
 - Chang, C.L., “The Langley Stability and Transition Analysis Code (LASTRAC): LST, Linear and Nonlinear PSE for 2-D, Axisymmetric, and Infinite Swept Wing Boundary Layers,” AIAA 2003-0974, 2003.
- CDISC:
 - Campbell, R.L., Banchy, M.N., and Hiller, B.R., “History and Status of the CDISC Aerodynamic Design Method,” AIAA SciTech Forum 2024, January 2024.
- CATNLF:
 - Lynde, M.N. and Campbell, R.L., “Computational Design and Analysis of a Transonic Natural Laminar Flow Wing for a Wind Tunnel Model,” AIAA 2017-3058, June 2017.
- Supersonic NLF:
 - Lynde, M.N. and Campbell, R.L., “Expanding the Natural Laminar Flow Boundary for Supersonic Transports,” AIAA 2016-4327, June 2016.
 - Bozeman, M.B., Campbell, R. L., and Banchy, M. N., “Progress Towards the Design of a Natural Laminar Flow Wing for a Low-Boom Concept using CDISC,” AIAA Paper 2024-0675, January 2024.