A Design Exploration of Natural Laminar Flow Applications for the SUSAN Electrofan Concept

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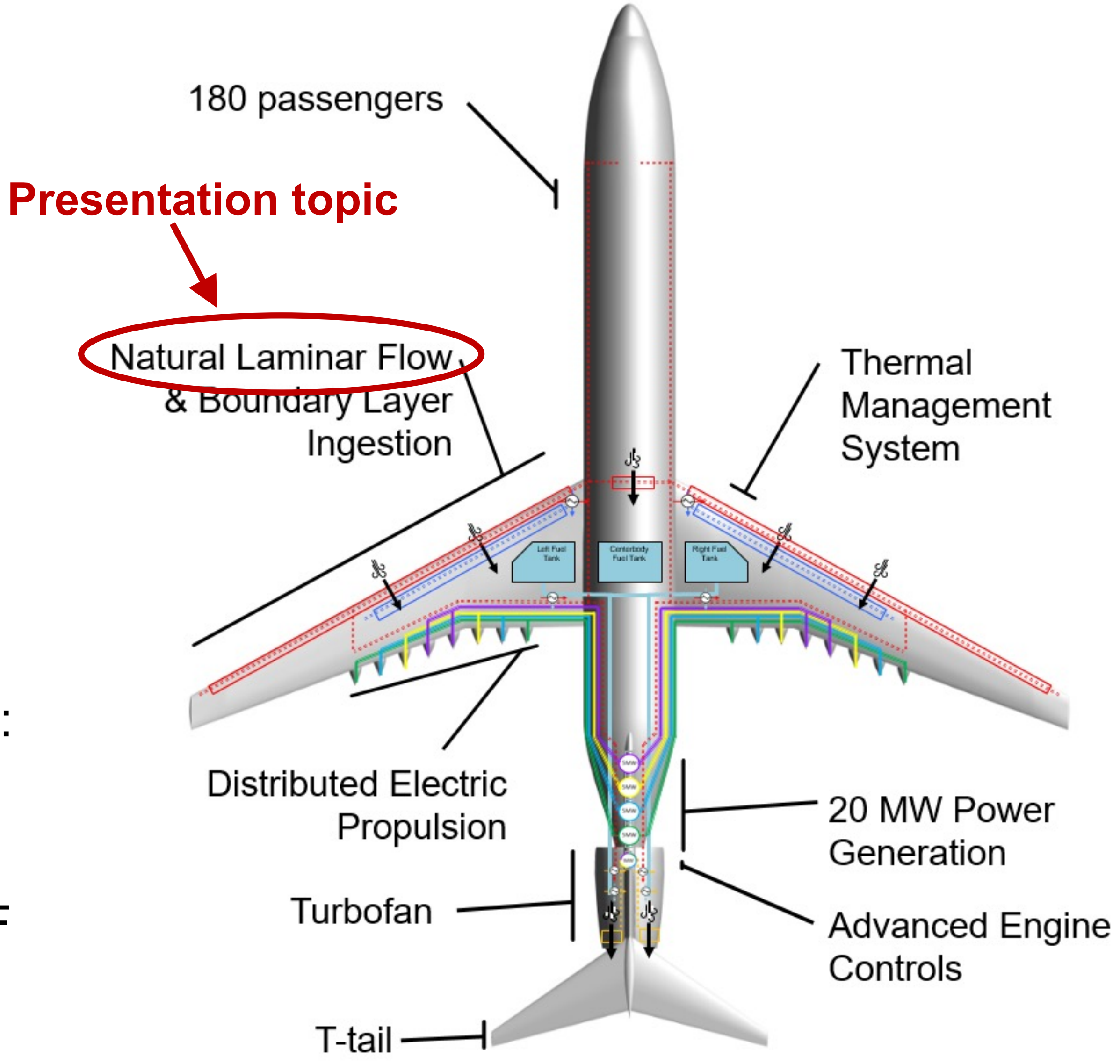
Outline

- Introduction
- Computational Tools
- Design Results
- Multidisciplinary Considerations
- Concluding Remarks

SUSAN Electrofan Concept

Subsonic Single Aft Engine (SUSAN) Electrofan:
Subsonic regional jet utilizing a single aft engine design with wing-mounted distributed electric propulsion

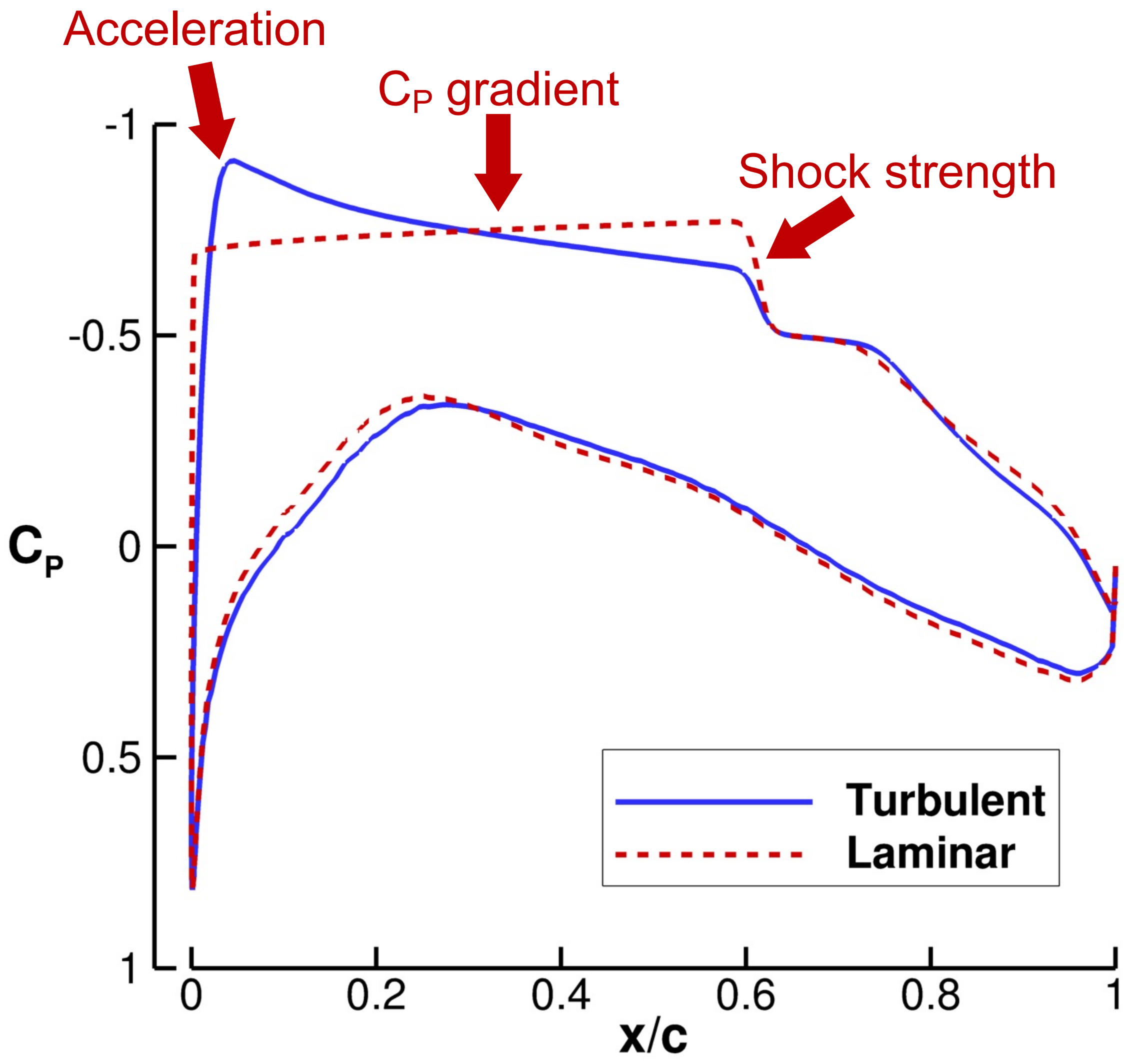
- Team exploring a variety of technologies to improve performance
- Natural laminar flow (NLF) study objectives:
  1. Quantify performance potential available from NLF wings
  2. Identify multidisciplinary impact of NLF



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 design method changes the shape of airfoils to obtain pressure distributions that delay transition by damping leading-edge crossflow instabilities

Example Design Target Pressures



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

Computational Tools

- **Design Module: *CDISC***

  Applies knowledge-based design rules to change geometry to match target pressure distributions

- **Flow Solver: *USM3D***

  Solves Navier-Stokes equations on unstructured tetrahedral grid

- **Boundary Layer Profile Solver: *BLSTA3D***

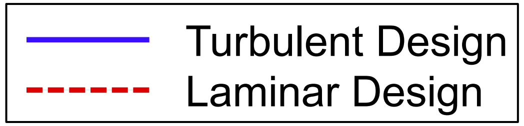
  Calculates boundary layer velocity and temperature profiles based on chordwise pressure distribution assuming conical flow

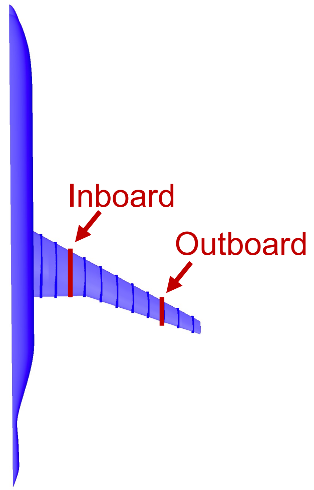
- **Boundary Layer Stability Analysis: *LASTRAC***

  Stability analysis and transition prediction using e^N Linear Stability Theory method with compressibility effects

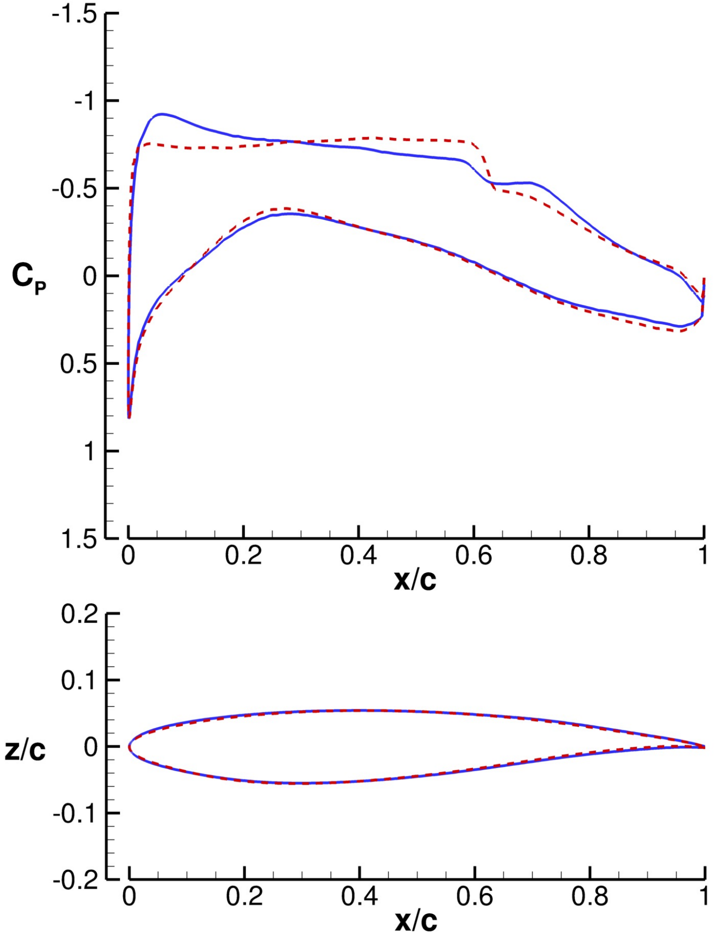
Design Results: Geometry and Airfoils

Mach = 0.785, C_L = 0.50, Altitude = 37,000 ft, Re_{MAC} = 23.1 x10^6

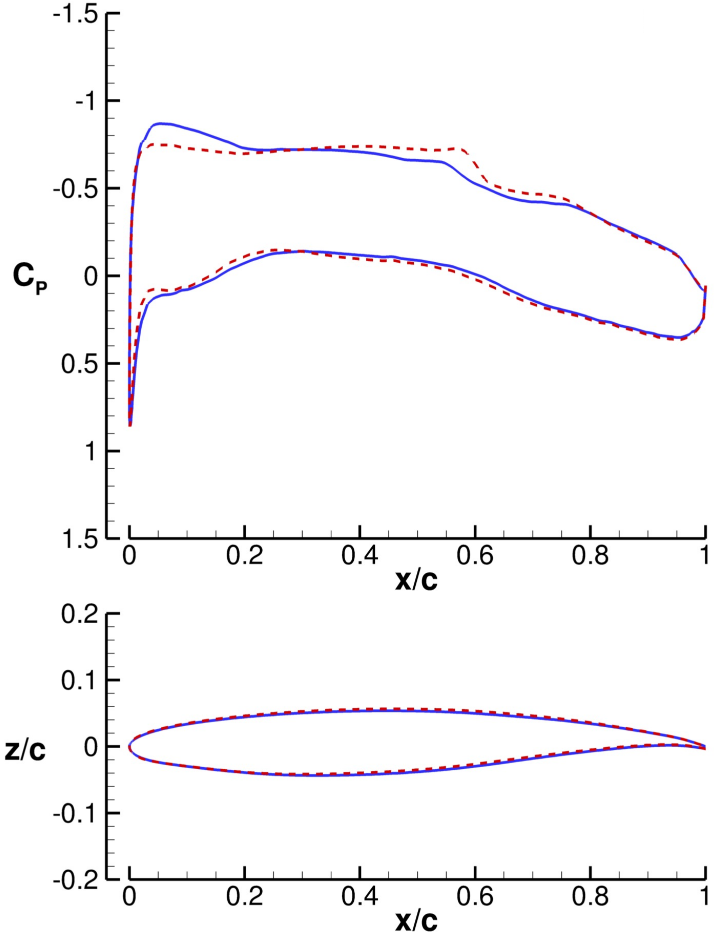




Inboard

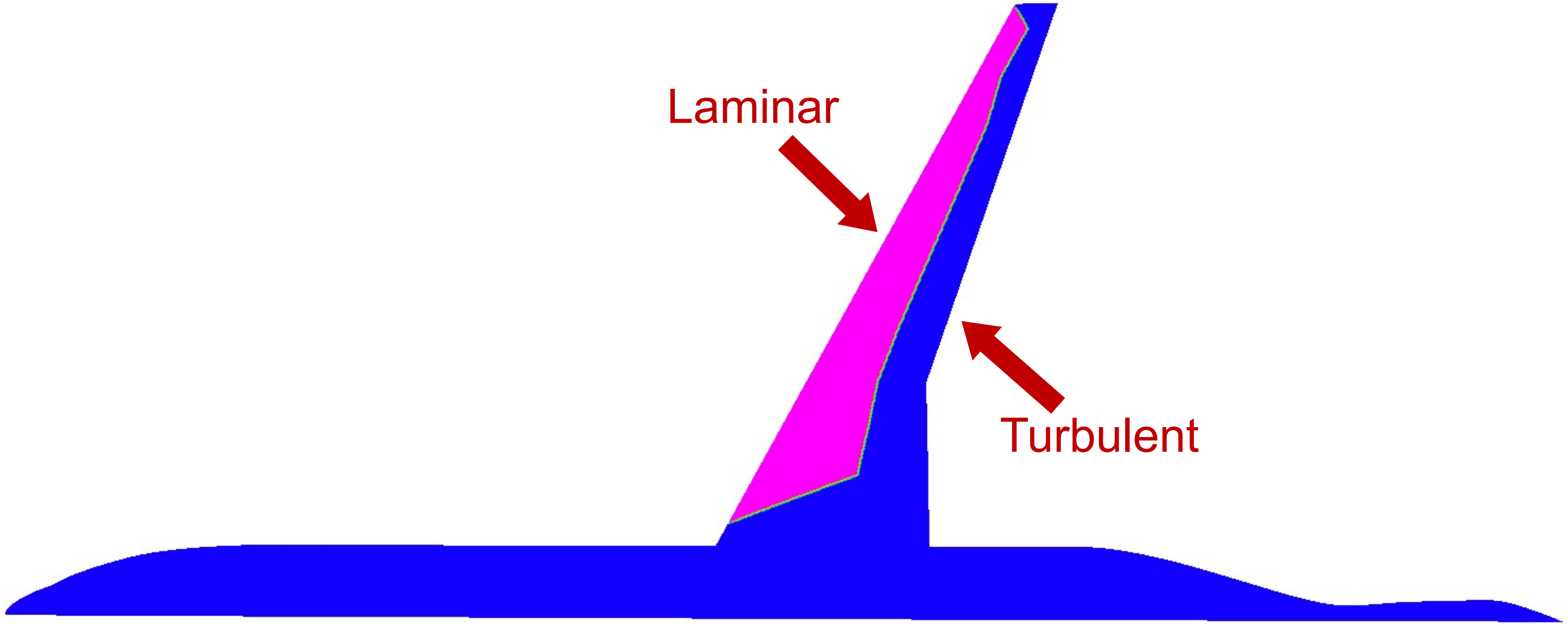


Outboard



Design Results: Laminar Flow Characteristics

Laminar Design supports laminar flow on approximately 53% of the surface area on the wing upper surface



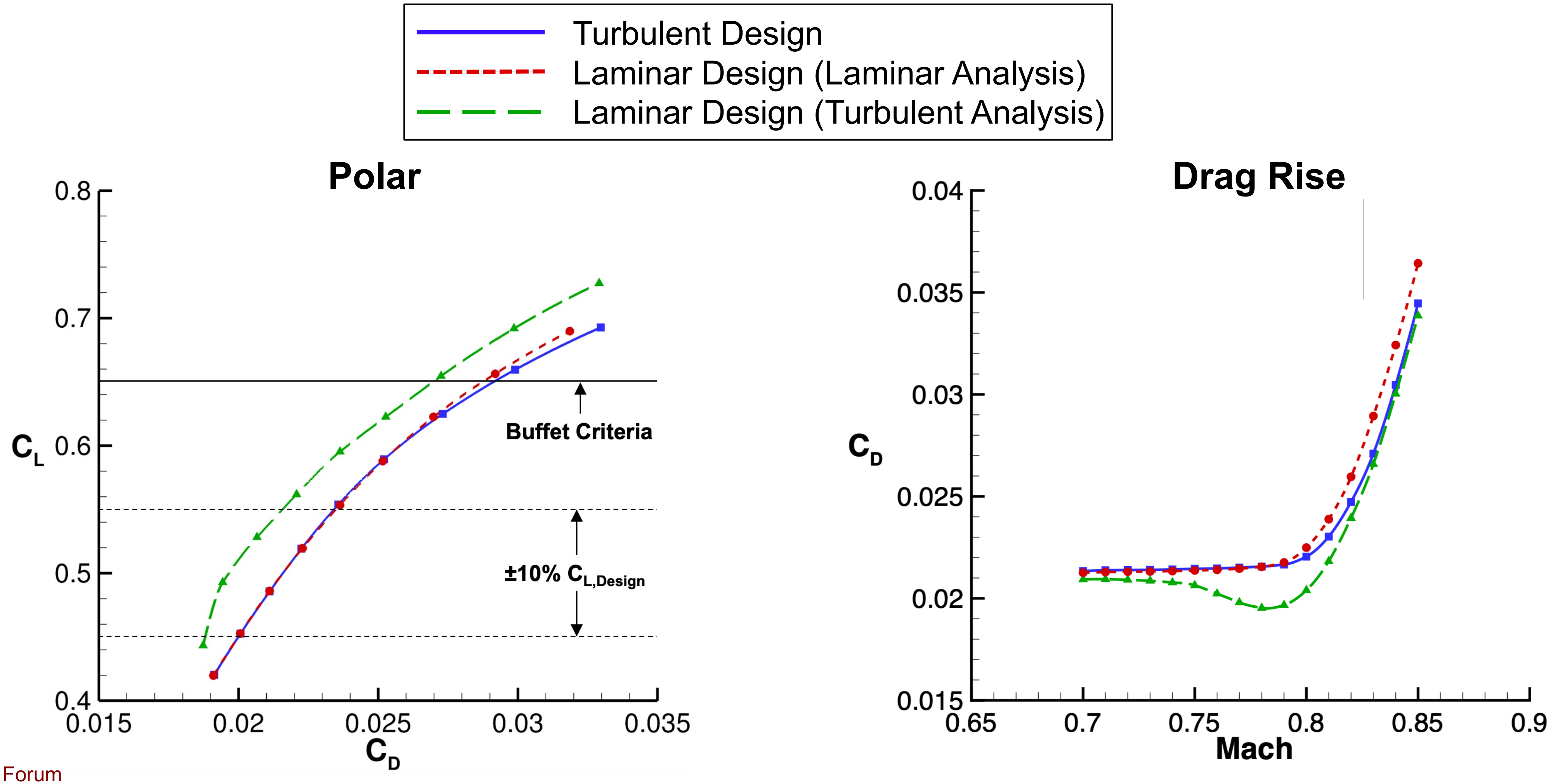
Design Results: Performance Improvement

Configuration	C_L	C_D	C_m	ML/D
Turbulent Design	0.500	0.0216	-0.281	18.17
Laminar Design (Laminar Analysis)	0.500	0.0197	-0.309	19.92
Laminar Design (Turbulent Analysis)	0.500	0.0216	-0.291	18.17

- Laminar Design reduced drag by 19 counts (8.8%) from Turbulent Design
- Total loss of laminar flow on Laminar Design would results in:
  - No performance change from Turbulent Design
  - Drag increase of 19 counts (8.8%) from Laminar Design

Design Results: Off-Design Characteristics

Laminar Design shows sustained performance improvement across near-cruise off-design range



Multidisciplinary Considerations of NLF

- **General NLF considerations:**
  - Surface finish requirements ➔ additional manufacturing and maintenance costs
  - Smooth surface requirements ➔ wing upper surface must be free of all steps and gaps

- **SUSAN Electrofan considerations:**
  - Impact of wing-mounted engines on NLF:
    - Engines can cause forward shock movement ➔ limit possible NLF extent
    - Engines may increase turbulence/noise in boundary layer ➔ reduced NLF extent
  - Impact of NLF on wing-mounted engines:
    - NLF thins boundary layer ➔ reduced boundary layer ingestion benefit
    - Possible boundary layer thickness changes ➔ engine performance with range of thicknesses

Concluding Remarks

- CATNLF design process applied to the SUSAN Electrofan regional jet configuration
- NLF study objectives:
  1. Quantify performance potential available from NLF wings
  2. Identify multidisciplinary impact of NLF on SUSAN Electrofan
- Laminar Design supports 53% laminar flow on the wing upper surface providing an 8.8% decrease in drag for the wing-fuselage configuration
- Off-design characteristics show robust design with sustained laminar flow benefit
- Next steps:
  - Design wing with wing-mounted engines
  - Explore NLF on other surfaces such as nacelles, tail, nose, etc.

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