A Perspective on Transition Modeling Needs for Subsonic Transport Aircraft

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Use industry pull to mature technology that enables aircraft products that meet near-term metrics and NASA push to mature technology that will support development of new aircraft products that meet or exceed mid- and far-term metrics.
Portfolio Development: N+3 Advanced Vehicle Concept Studies Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 Entry into Service (EIS)

Trends:
- Tailored and multifunctional structures
- High aspect ratio, laminar flow, active structural control
- Highly integrated propulsion systems
- Ultra-high bypass ratio (20+ with small cores)
- Alternative fuels and hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

Advanced Air Transport Technology Project
Advanced Air Vehicles Program

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Several of the Far Term aircraft concepts claim additional aerodynamic benefit from laminar flow technology.

- Subsonic Transports: All turbulent designs (all surfaces) until about a decade ago.
- There is a long history of pursuing laminar flow technology (for good reason).
- Industry needs tools to be able to efficiently design for laminar flow.
- Industry needs to be able to guarantee performance (extent of laminar flow, fail-safe operations, "ilities", etc.).
New Aviation Horizons - Ultra-Efficient Subsonic Transport (UEST) Demonstrators

HNB Concept 1 (Tailless)

HNB Concept 2 (Tail w/OWN)

TTBW–Transonic Truss-Braced Wing

D8–Double Bubble

Opportunity for additional aerodynamic benefit from laminar flow technology
Multiple technologies identified ranging from control systems, advanced structures, advanced engines, to boundary layer ingestion.

Laminar Flow on multiple surfaces identified.

- Natural Laminar Flow on nacelles
- Hybrid Laminar Flow Control on outer wing sections
- Hybrid Laminar Flow Control on wing upper surface
- Hybrid Laminar Flow Control on horizontal and vertical tails
- Advanced Tunnel & Wing
- Advanced HWB
- Advanced HWB300
- Laminar flow control on center body
Potential for Fuel Reduction

Technology Benefits Relative to Large Twin Aisle
(Reference: 777-200LR “like” Vehicle)

Advanced “Tube-and-Wing”
- Composite Fuselage: -3.5%
- Composite Wings & Tails: -3.7%
- PRSEUS: -0.8%
- Advanced Engines: -14.8%
- HLFC (Wings, Tails, Nacelles): -9.6%
- Riblets, Variable TE Camber, Increased Aspect Ratio: -8.8%
- Subsystem Improvements: -1.3%

Fuel Burn = 159,700 lbs
-118,100 lbs (-42.5%)

Advanced HWB
- HWB with Composite Centerbody: -13.3%
- Composite Wings & Tails: -2.0%
- PRSEUS: -2.7%
- Advanced Engines: -19.1%
- HLFC (Outer Wings and Nacelles): -8.7%
- Subsystem Improvements: -1.2%

Fuel Burn = 144,200 lbs
-133,600 lbs (-48.1%)

Advanced HWB300
- HWB with Composite Centerbody: -13.3%
- Composite Wings & Tails: -1.8%
- PRSEUS: -2.4%
- Advanced Engines: -16.6%
- HLFC (Outer Wings and Nacelles): -7.9%
- Subsystem Improvements: -1.0%
- Embedded Engines with Technology Benefits Relative to Large Twin Aisle

Fuel Burn = 130,900 lbs
-146,900 lbs (-52.9%)

Reference Fuel Burn = 277,800 lbs

Credit: Fay Collier UTIAS-MITAS presentation, May 27-28, 2010
From Hooker and Wick, AIAA 2014-1285:

“Air Force Research Laboratory (AFRL) sponsored research under the Revolutionary Configurations for Energy Efficiency (RCEE) program.” The Phase I effort identified highest fuel saving technologies. Laminar Flow is the second highest technology.

Bottom Line:

Laminar Flow is consistently rated as very high value – across RCEE, N+3 studies, Far Term Concepts
Examples of Laminar Flow in Current Boeing Aircraft

**Boeing 737 MAX Winglet**
Detailed design, surface materials and coatings enable natural laminar flow on the winglet

**Boeing 787-9 Tail**
Leading edge of vertical and horizontal stabilizers utilize hybrid laminar flow control

**Boeing 777X Tail and Nacelles**
Hybrid laminar flow control vertical tail and natural laminar flow nacelles

Credit: From Boeing website articles
Example: HondaJet Wings and Forebody

HondaJet Developed

- Natural Laminar Flow Wings
- Natural Laminar Flow Nose

Credit: From Honda website on 7/25/17
http://world.honda.com/HondaJet/innovation/02/
Practical Considerations for Laminar Designs

Need transition prediction capabilities that include “real-world” considerations (waviness, roughness, imperfections, etc.)

Alleviate with Low-Surface Energy Coating/Finishes

- Self-cleaning surfaces, insect/ice protection
- Develop adhesives with very low surface energy

Alleviate with Lightweight Structural Concepts Suitable for LFC Applications

- Tailored load paths, stitching, free-form fab, integral curvilinear stiffeners, materials
- Aeroelastically tailored laminar flow wing

Credit: Fay Collier UTIAS-MITAS presentation, May 27-28, 2010
Natural Laminar Flow Wing Design

- New transonic NLF wing design approach (Lynde and Campbell)
- Laminar flow on 56% of the wing upper surface
- Transonic test in NTF (start Dec. 2017)
- Primary test goals:
  - Validate the NLF design methodology and transition prediction tools
  - Characterize NTF laminar flow testing capabilities

New wing design approach achieves laminar flow outside of historical database

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Transitional Flow in Fan Blades

- Laminar flow presents opportunity for increased fan efficiency and reduced fuel burn
- Need to be able to predict transition reliably under range of operating conditions
Turbine Blade Transition Features

Transition prediction key to predicting heat transfer and blade durability

Massive separation: laminar to turbulent transition due to shear layer instabilities.

Acceleration of the laminar flow

Deceleration of the flow: due to adverse pressure gradient.

Separation bubble: laminar to turbulent transition due to adverse pressure gradient.

Flow reattachment

Acceleration of the turbulent flow

Turbulent flow

High Pressure Turbine Vane Simulation,

Physics-based approach for freestream turbulence

Spanwise Vorticity

8th-order

O% $Tu_{in}$

7% $Tu_{in}$
Predicted Mean Heat Flux

- Heat flux peaks at the leading edge and in the suction side turbulent flow
- First time scale-resolving CFD has replicated experimental transition location
Transonic Turbine Blade Cascade Reynolds number effects

midspan experimental data showing pressure surface relaminarization

Second laminar-to turbulent transition

accelerating parameter

\[ K \times 10^6 \]

\[ \left( \frac{\mu}{p U^2} \frac{dU}{ds} \right) \]

accel. decel.

\[ s / \text{span} = 0.51 \]

\[ s / \text{span} = 0.26 \]

\[ s / \text{span} = 0.51 \]

\[ s / \text{span} = -0.26 \]

\[ Nu \propto Re^{4/5} \]

\[ Nu \propto Re^{1/2} \]

midspan expr data

\( Re_{ex} \times 10^{-6} \)

\( Nu \times (turbulent) \)

\( Nu \times (laminar) \)
Laminar Separation in Low Pressure Turbine

Low Pressure Turbine Design and Performance

- Transition prediction is key to predicting performance
- Low Pressure Turbine component is heavy therefore there is a drive to fewer stages which results in higher stage loading
- Low Reynolds Number environment favorable to laminar flow and separation

Loss buckets for VSPT blading at low and high cascade inlet turbulence intensity
Concluding Remarks

• Recognition and Pursuit of Laminar Flow Continues
  o NASA N+3 studies, far term concepts & demonstrators
  o AFRL RCEE studies
  o NASA technology collector studies
  o Laminar Flow on current commercial aircraft but room for larger gains

• NASA Working New Laminar Flow Design Method
  o Presented later today (Michelle Lynde)

• Transition Important in Propulsion Systems
  o Impacts fan performance
  o Impacts HPT heat transfer and durability
  o Impacts LPT flow separation and performance

• Transition Modeling Important for Reliable Prediction of Benefit
  o Impacts design phase
  o Impacts industry performance estimate guarantees
  o Impacts fail-safe approaches
  o Impacts “ilities”