



A Perspective on Transition Modeling Needs for Subsonic Transport Aircraft

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Transition Modeling Workshop
NASA Langley Research Center
September 13, 2017

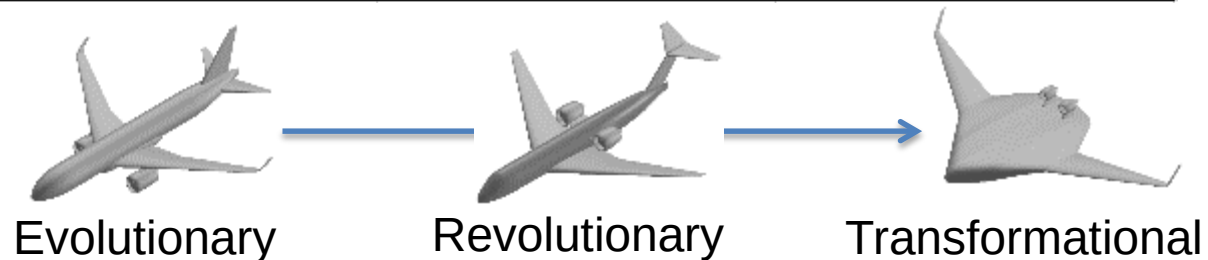
NASA Subsonic Transport System Level Measures of Success



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

v2016.1

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	Mid Term 2025-2035	Far Term beyond 2035
Noise (cum below Stage 4)	22 - 32 dB	32 - 42 dB	42 - 52 dB
LTO NOx Emissions (below CAEP 6)	70 - 75%	80%	> 80%
Cruise NOx Emissions (rel. to 2005 best in class)	65 - 70%	80%	> 80%
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	40 - 50%	50 - 60%	60 - 80%



Portfolio Development: N+3 Advanced Vehicle Concept Studies Summary



Boeing, GE,
GA Tech



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



NG, RR, Tufts,
Sensis, Spirit



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

GE, Cessna,
GA Tech



MIT, Aurora,
P&W, Aerodyne



NASA,
VA Tech, GT



NASA



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Transition Modeling / Laminar Flow Technology ‘Pull’



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



HWB Concept 1
(Tailless)



HWB Concept 2
(Tail w/OWN)



Image Credit: Lockheed Martin



TTBW-Transonic Truss-Braced Wing



D8-Double Bubble



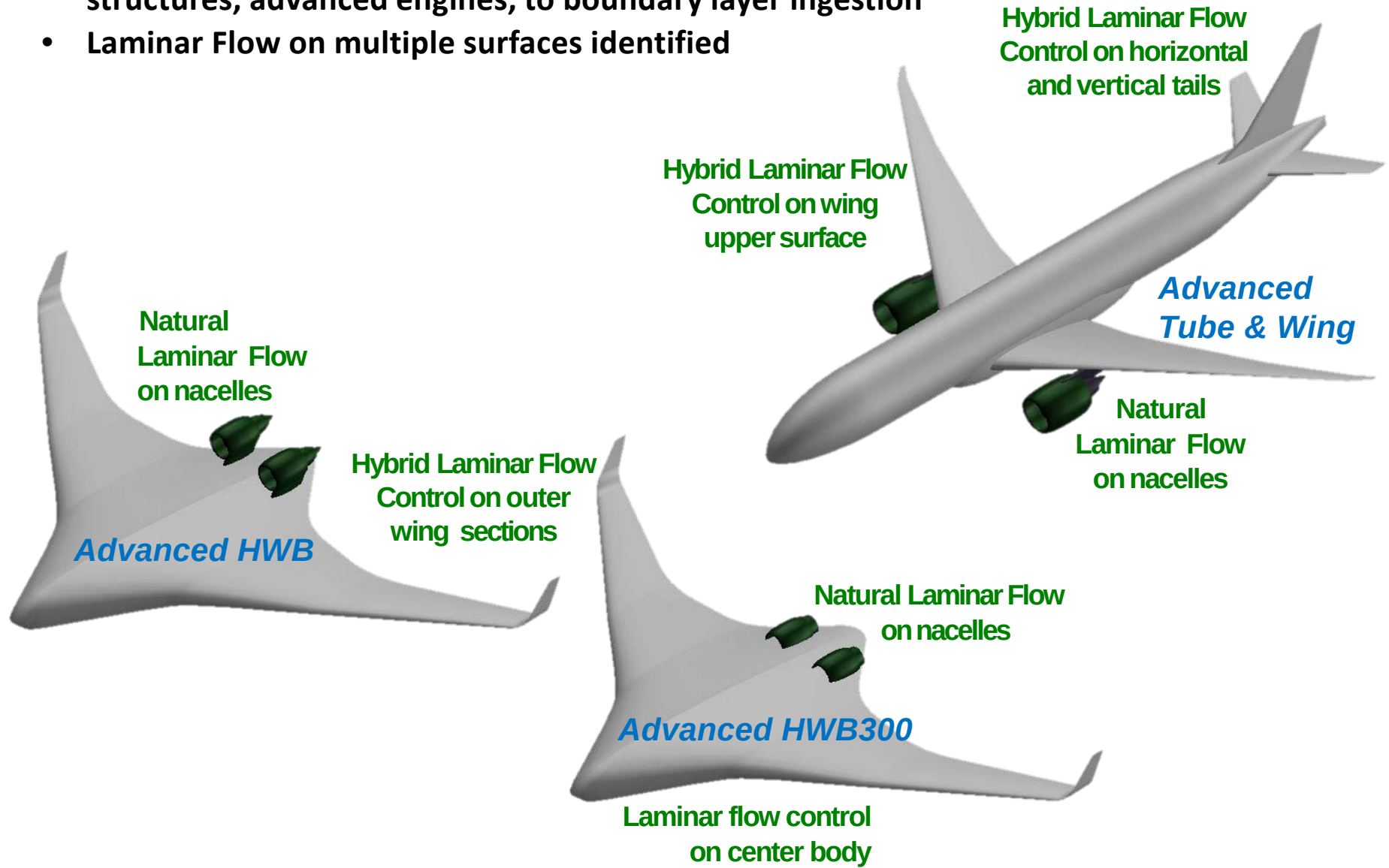
Opportunity for additional aerodynamic benefit from
laminar flow technology

NASA “Technology Collectors”

Credit: Fay Collier UTIAS-MITAS presentation, May 27-28, 2010



- Multiple technologies identified ranging from control systems, advanced structures, advanced engines, to boundary layer ingestion
- Laminar Flow on multiple surfaces identified

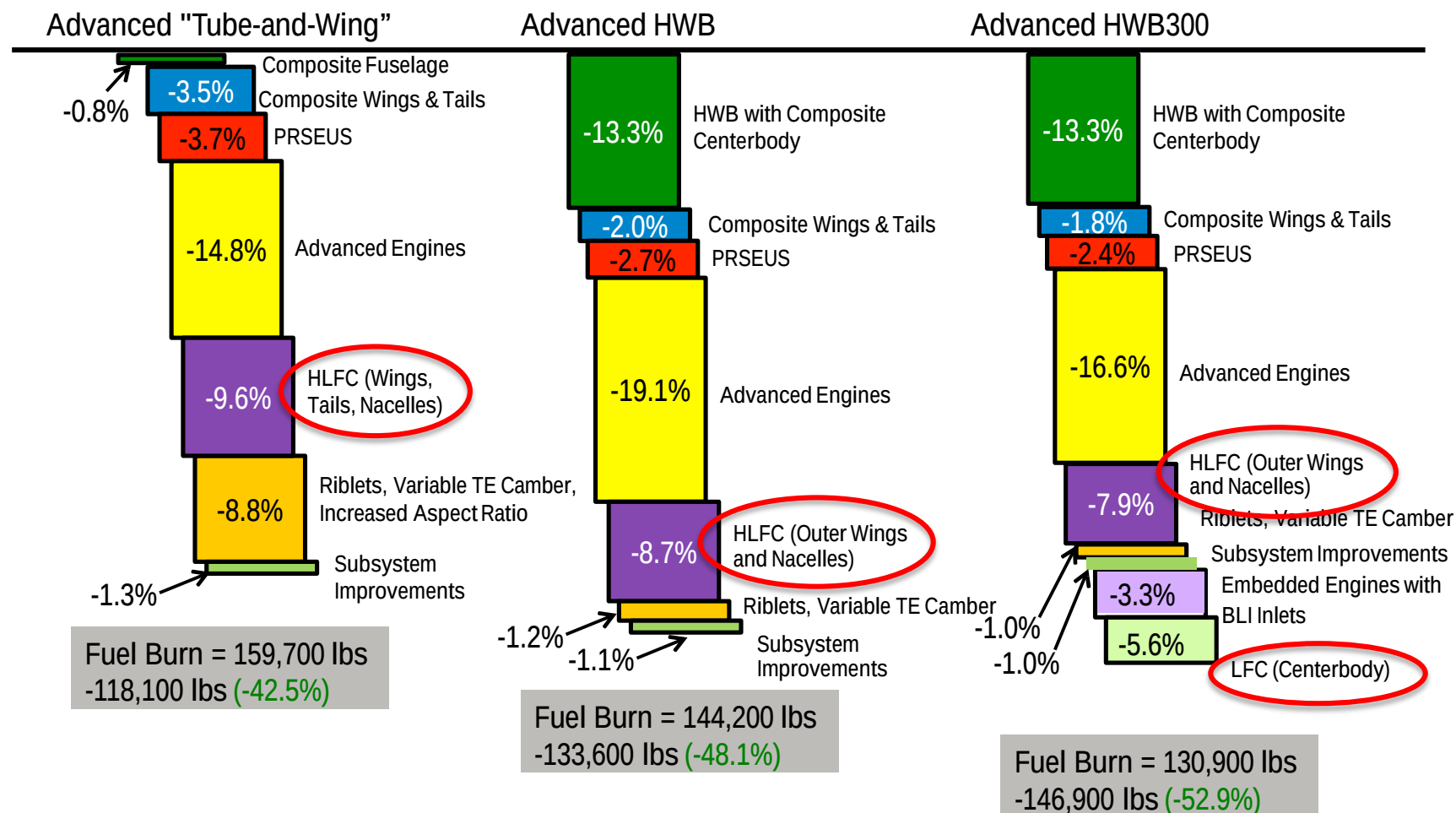


Potential for Fuel Reduction



Technology Benefits Relative to Large Twin Aisle

(Reference: 777-200LR “like” Vehicle)



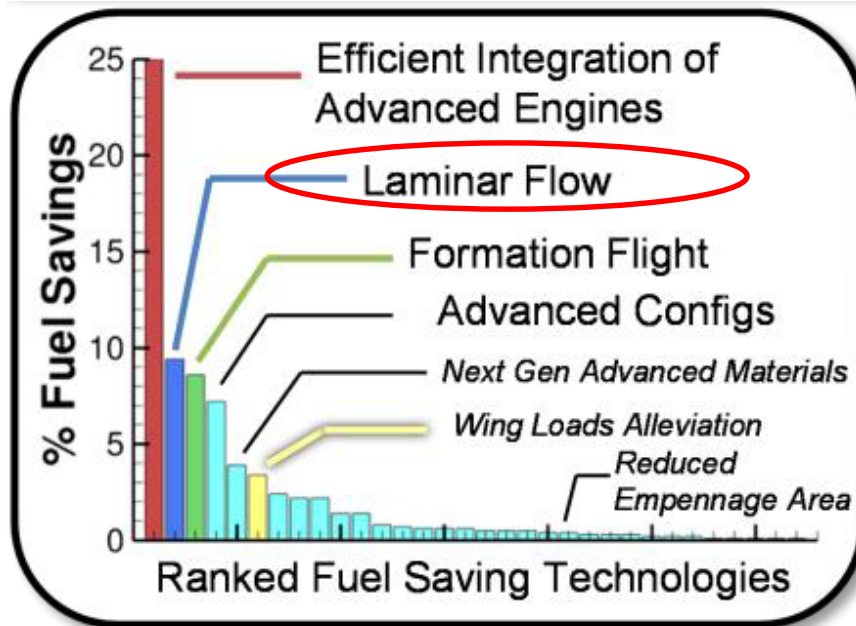
Reference Fuel Burn = 277,800 lbs

Potential for Fuel Reduction, AFRL RCEE

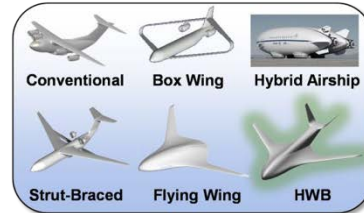


From Hooker and Wick, AIAA 2014-1285:

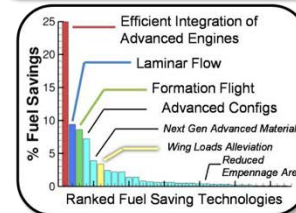
“Air Force Research Laboratory (AFRL) sponsored research under the Revolutionary Configurations for Energy Efficiency (RCEE) program.” The Phase I effort identified highest fuel saving technologies. Laminar Flow is the second highest technology.



Phase I: Develop 90% Fuel Savings Fleet & Rank Highest Pay-Off Fuel Saving Technologies

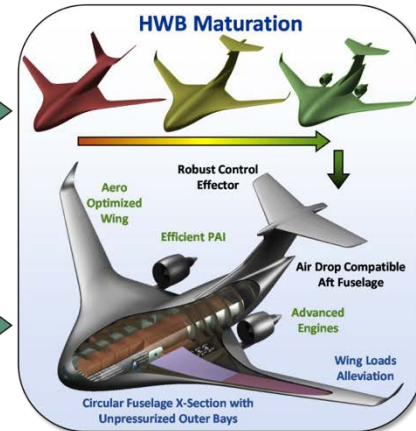


Best Performing Configuration



Highest Payoff Technologies

Phase II: Mature Technologies & Configurations



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



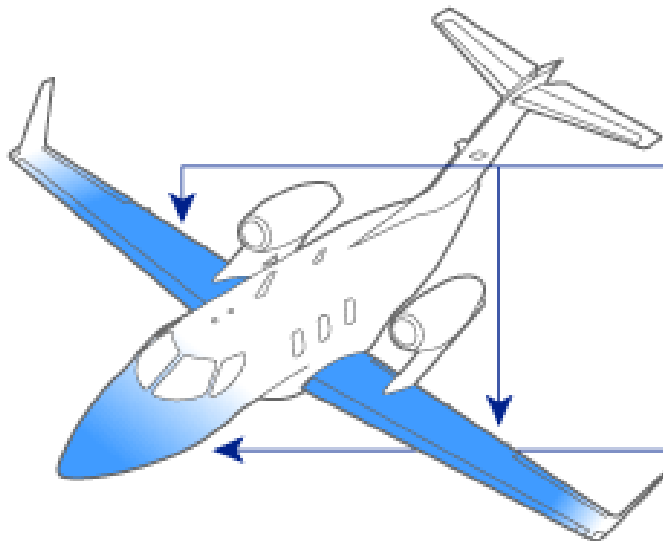
HondaJet Developed

- Natural Laminar Flow Wings
- Natural Laminar Flow Nose

Credit: From Honda website on 7/25/17
<http://world.honda.com/HondaJet/innovation/02/>



[Areas in which natural laminar flow is applied]



Natural laminar flow wing design
SHM-1



Natural laminar flow nose



HONDA

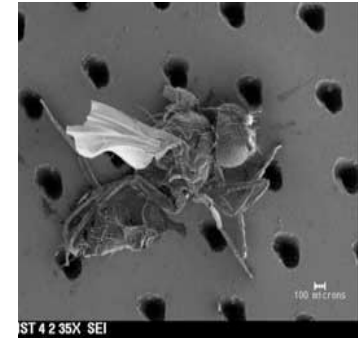
Practical Considerations for Laminar Designs



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



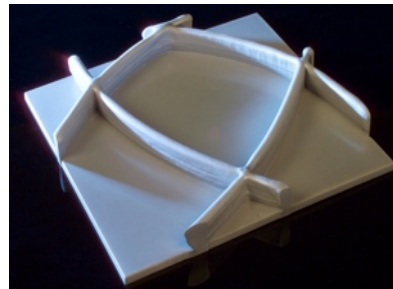
Insect Adhesion

Alleviate with Lightweight Structural Concepts Suitable for LFC Applications

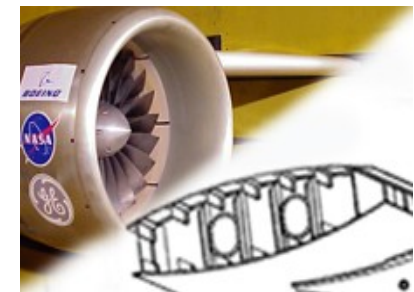
- Tailored load paths, stitching, free-form fab, integral curvilinear stiffeners, materials
- Aeroelastically tailored laminar flow wing



**Internal structure
of bird bones**



Integrated Curvilinear Stiffeners

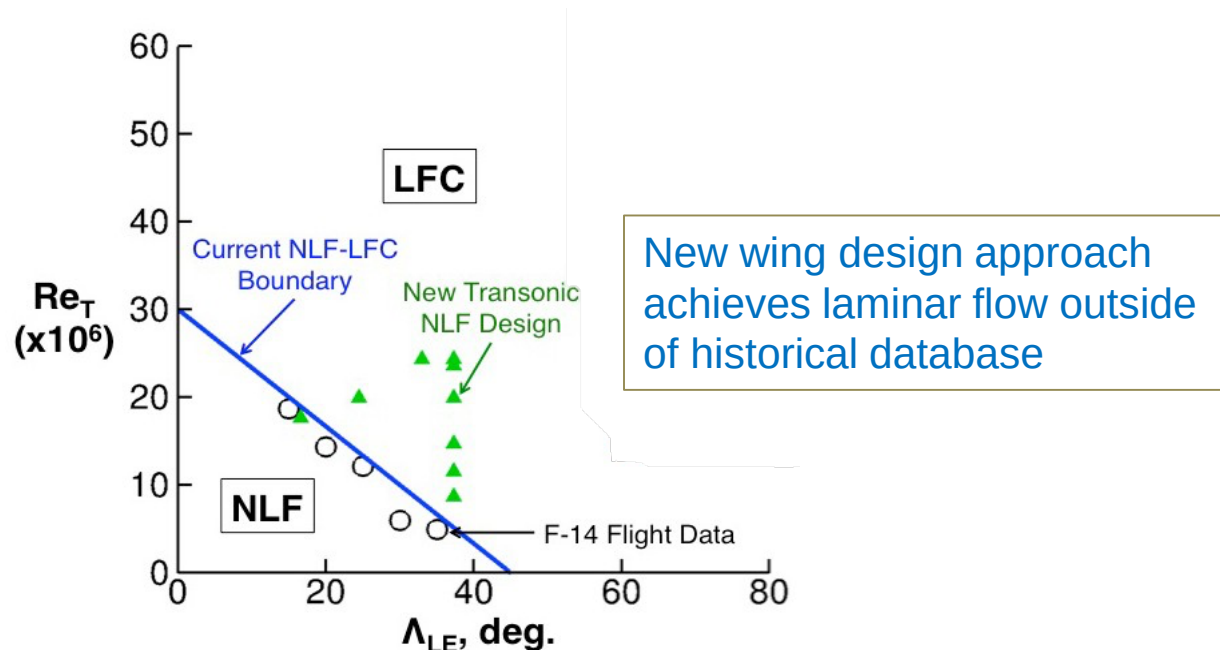


Component Integration

Natural Laminar Flow Wing Design



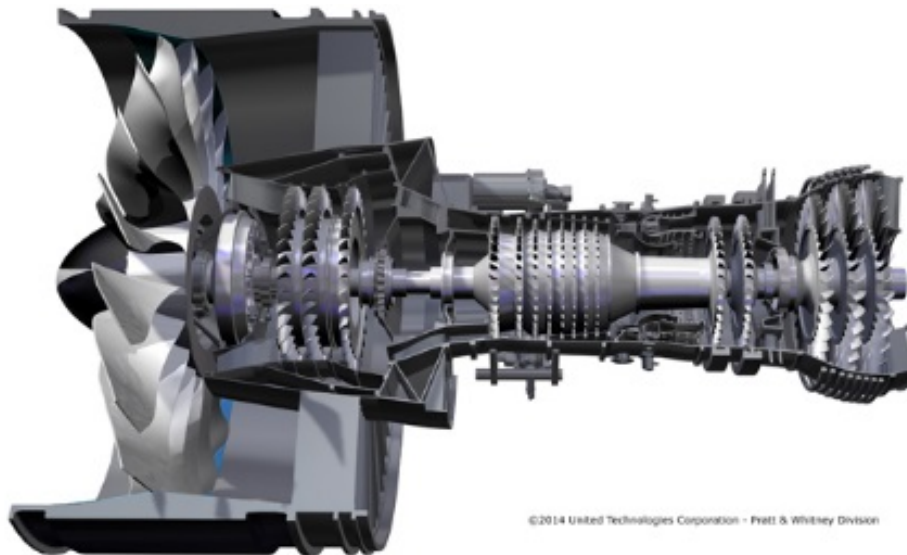
- New transonic NLF wing design approach (Lynde and Campbell)
- Laminar flow on 56% of the wing upper surface
- Transonic test in NTF (start Dec. 2017)
- Primary test goals:
 - Validate the NLF design methodology and transition prediction tools
 - Characterize NTF laminar flow testing capabilities



Transitional Flow in Fan Blades



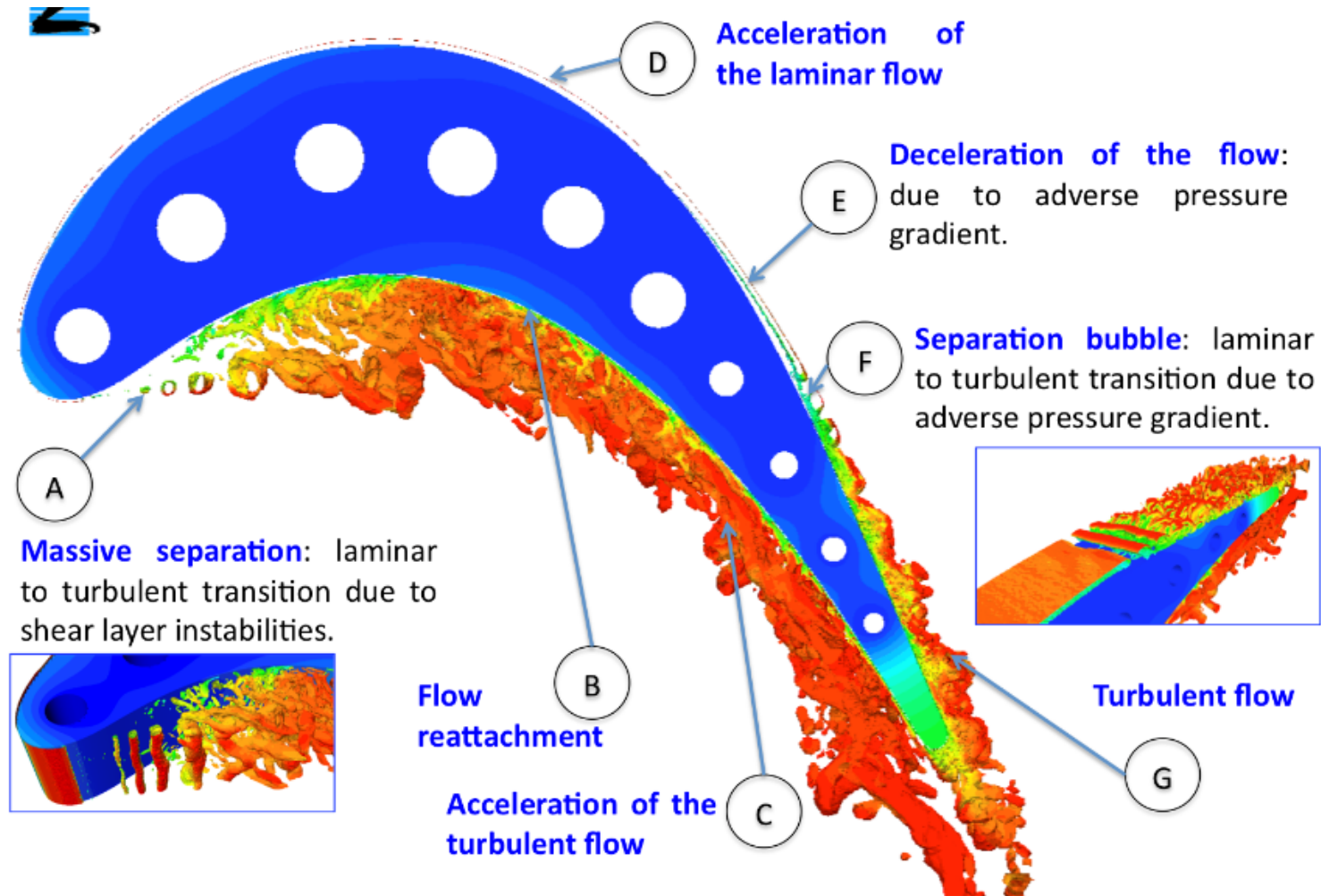
- Laminar flow presents opportunity for increased fan efficiency and reduced fuel burn
- Need to be able to predict transition reliably under range of operating conditions



Turbine Blade Transition Features



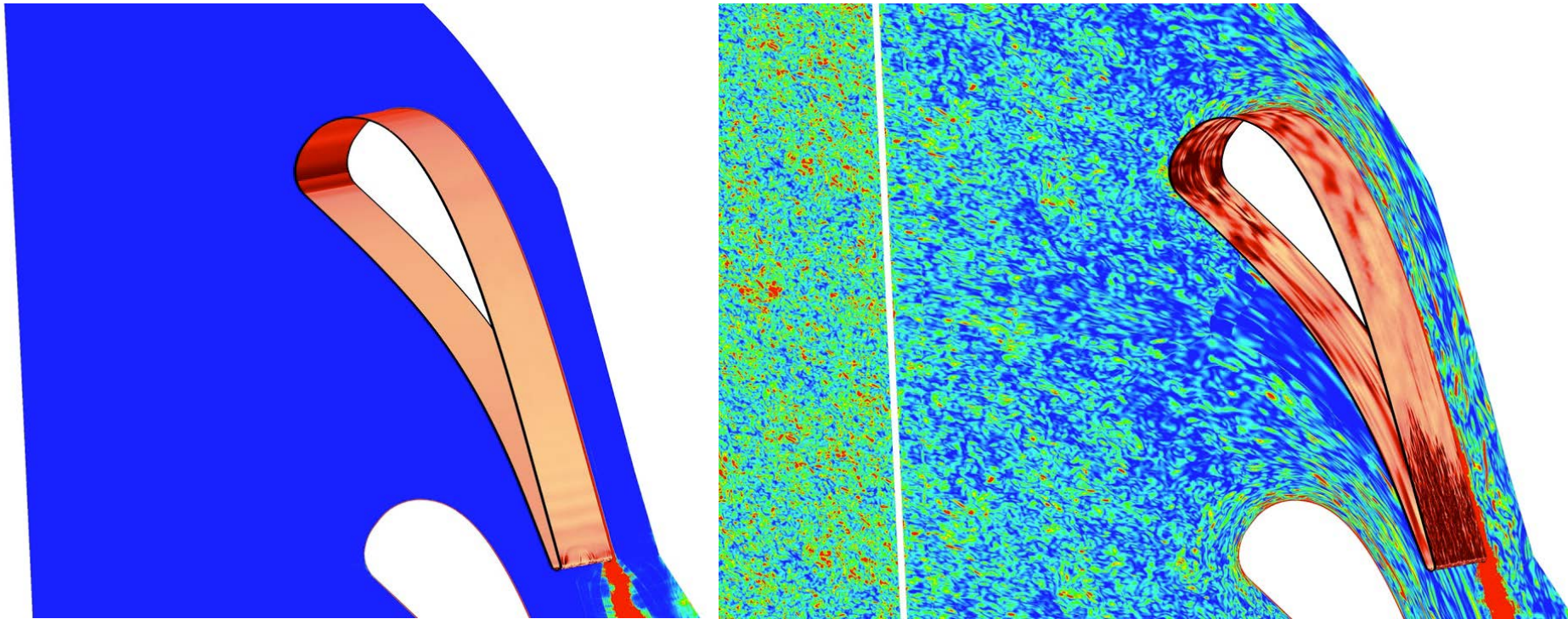
Transition prediction key to predicting heat transfer and blade durability



Large-Eddy Simulation and Conjugate Heat Transfer Around a Low-Mach Turbine Blade, Duchaine et al., J. Turbomach 136(5), 051015 (Oct 23, 2013)

Physics-based approach for freestream turbulence

8th-order

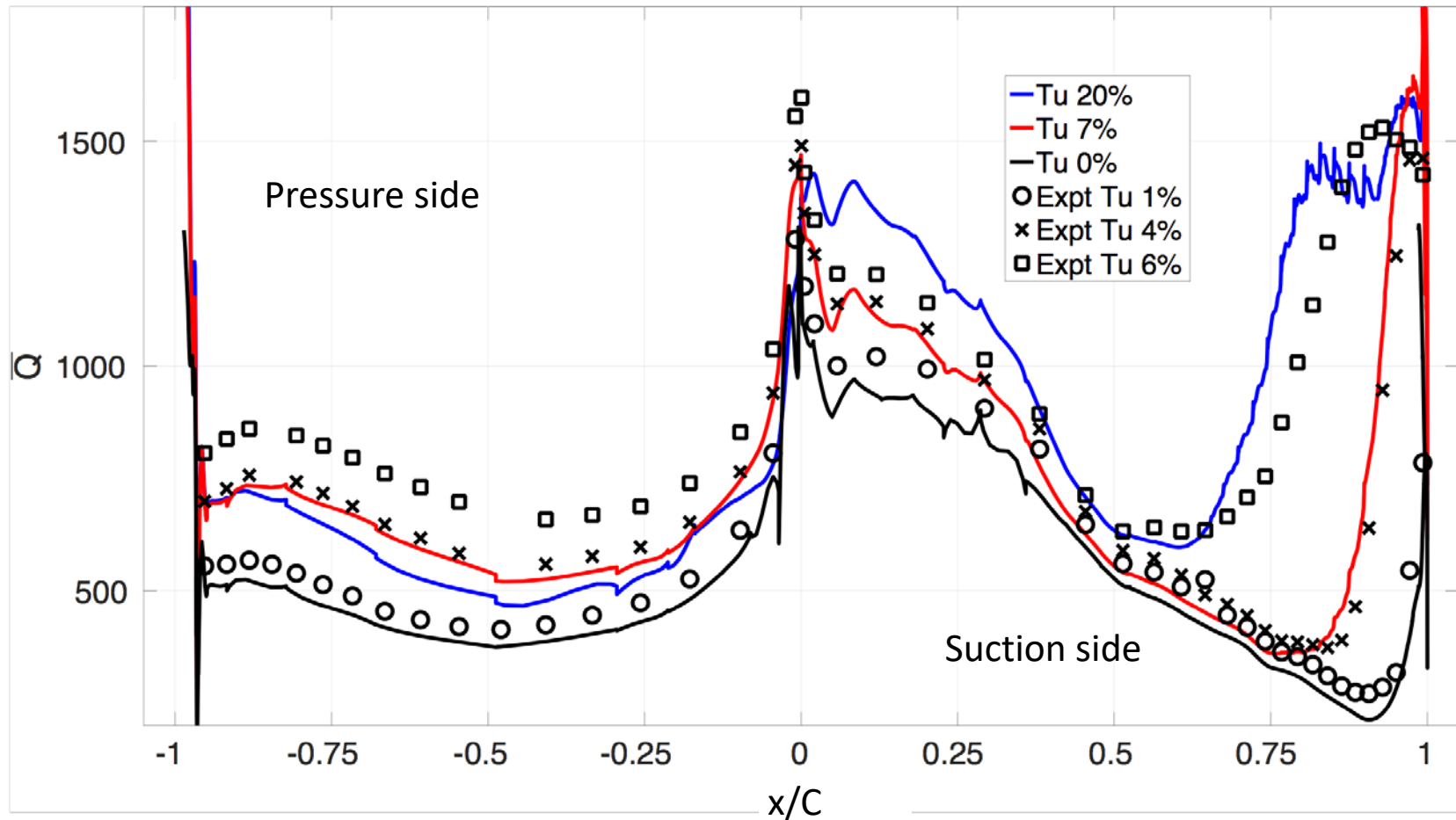


0% Tu_{in}

7% Tu_{in}

Spanwise Vorticity

Predicted Mean Heat Flux



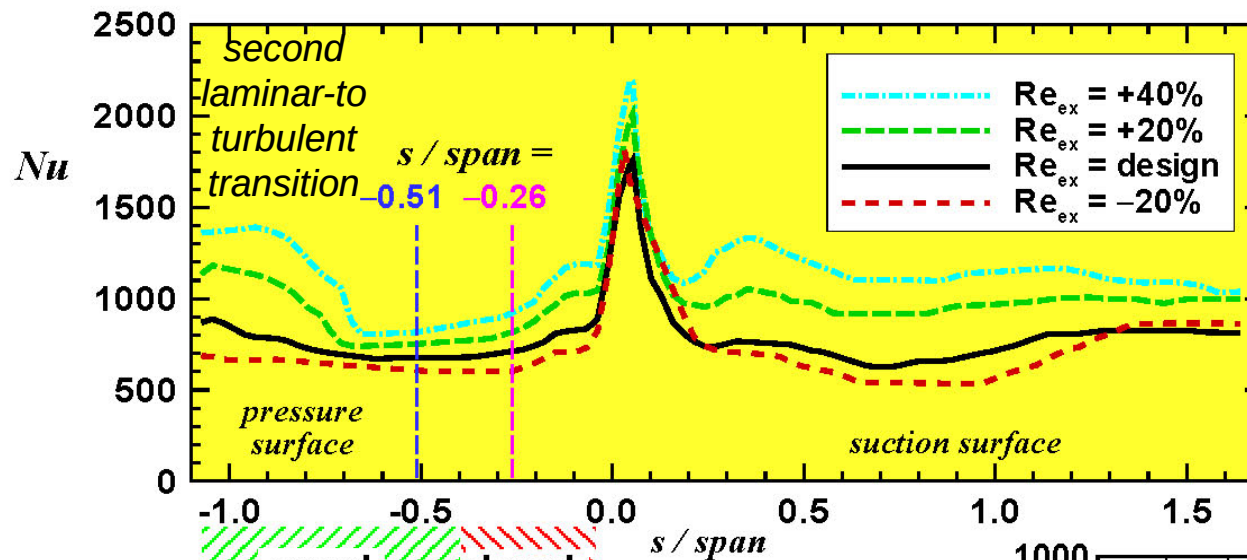
- Heat flux peaks at the leading edge and in the suction side turbulent flow
- First time scale-resolving CFD has replicated experimental transition location

Transonic Turbine Blade Cascade

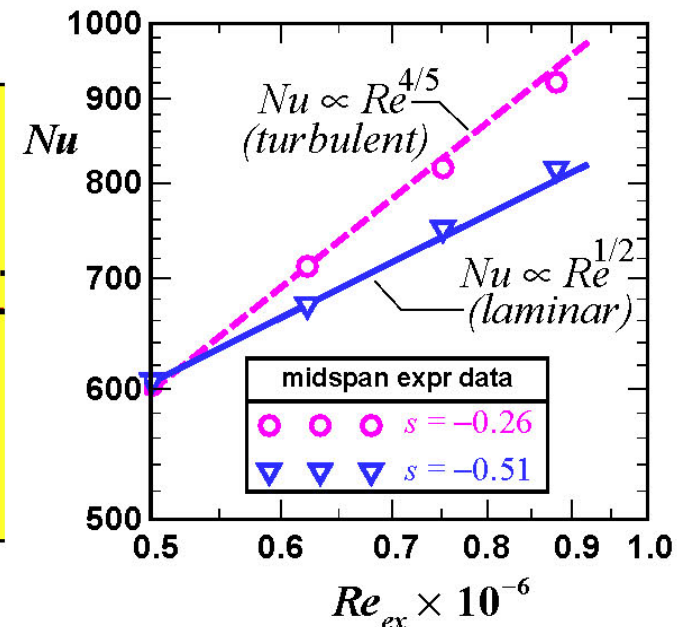
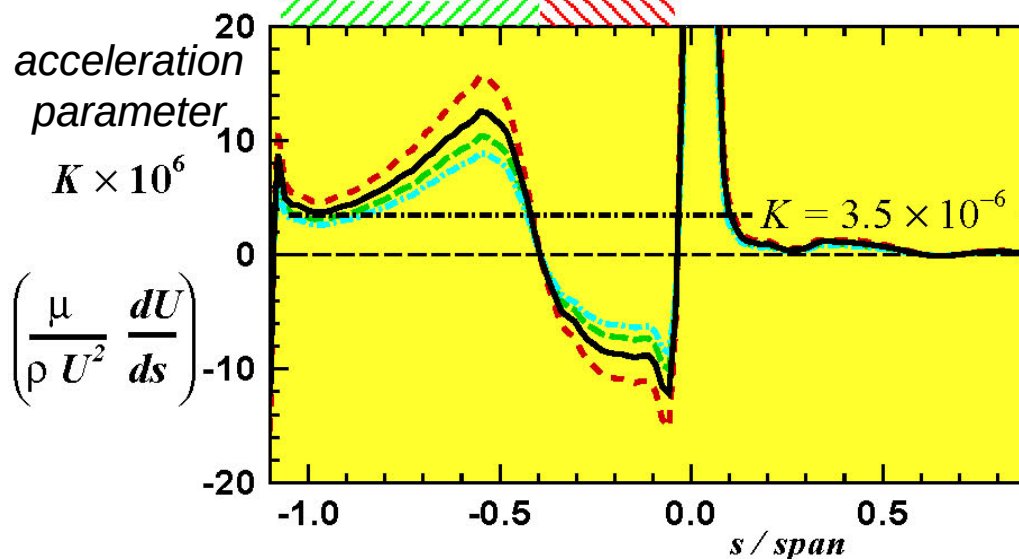
Reynolds number effects



Glenn Research Center



**midspan
experimental
data
showing
pressure surface
relaminarization**

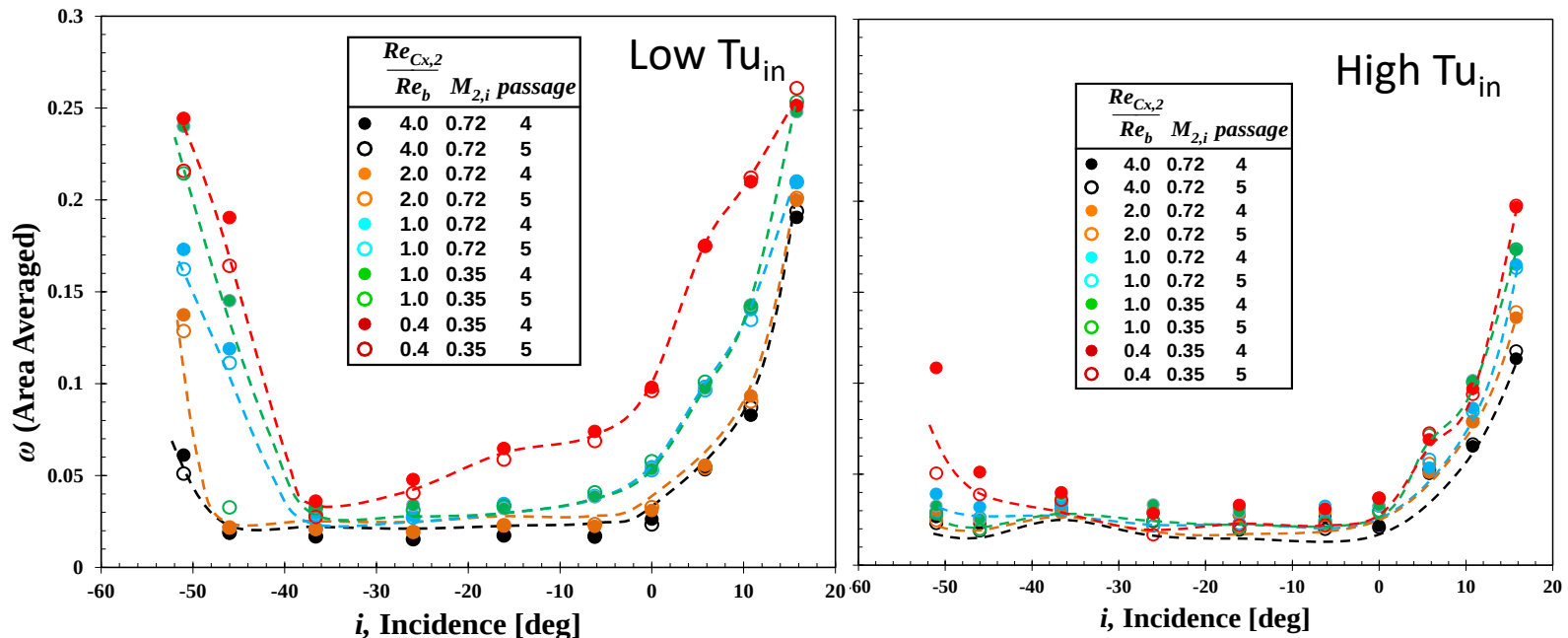
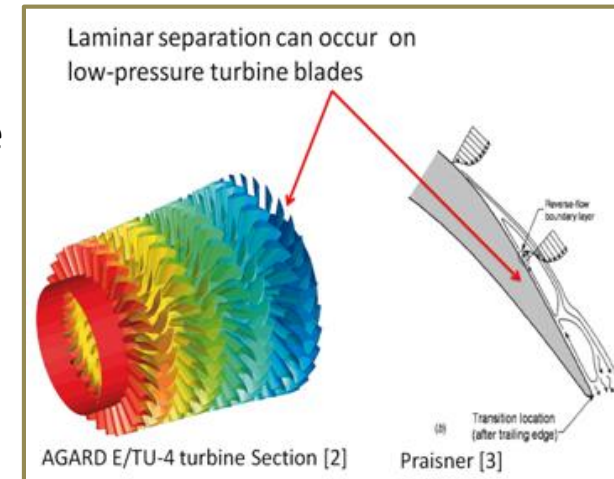


Laminar Separation in Low Pressure Turbine



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**
 - NASA N+3 studies, far term concepts & demonstrators
 - AFRL RCEE studies
 - NASA technology collector studies
 - Laminar Flow on current commercial aircraft but room for larger gains
- **NASA Working New Laminar Flow Design Method**
 - Presented later today (Michelle Lynde)
- **Transition Important in Propulsion Systems**
 - Impacts fan performance
 - Impacts HPT heat transfer and durability
 - Impacts LPT flow separation and performance
- **Transition Modeling Important for Reliable Prediction of Benefit**
 - Impacts design phase
 - Impacts industry performance estimate guarantees
 - Impacts fail-safe approaches
 - Impacts “ilities”

