Airframe Drag/Weight Reduction Technologies

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Fuel Burn Reduction
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Airframe Components – Drag and Weight

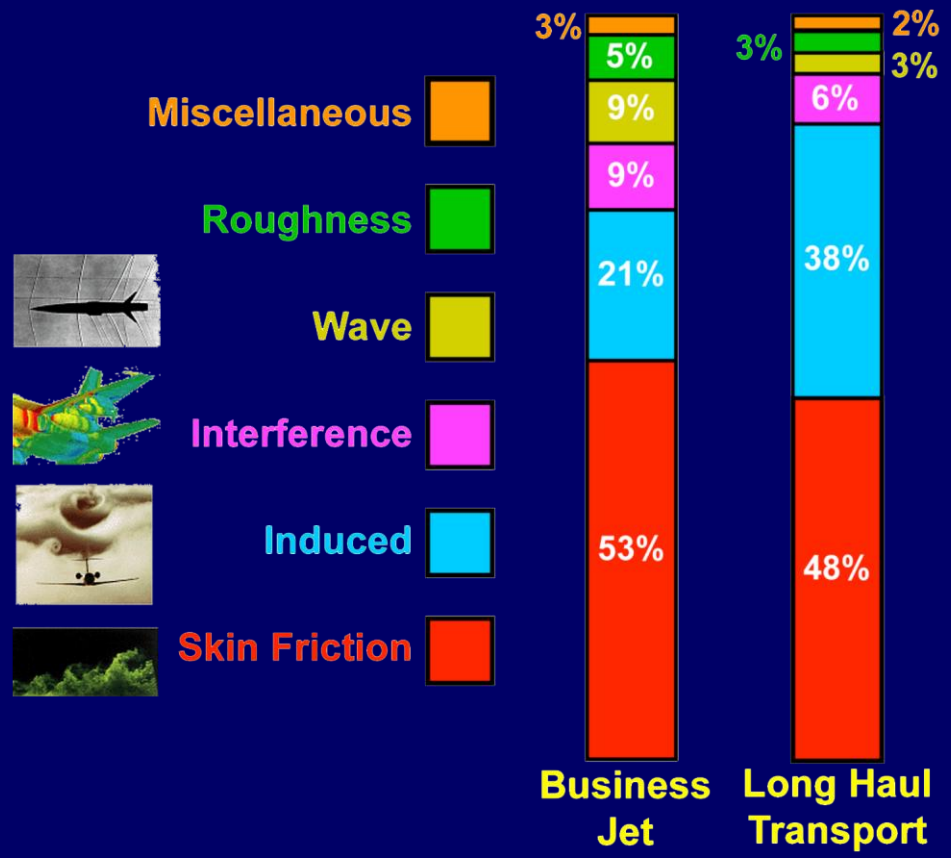
- Breguet Range Equation

$$\text{Aircraft Range} = \frac{\text{Velocity}}{\text{TSFC}}\left(\frac{\text{Lift}}{\text{Drag}}\right)\ln\left(1+\frac{W_{fuel}}{W_{PL}+W_{O}}\right)$$

Aerodynamics Empty Weight

- Technologies to reduce weight and drag are crucial regardless of selected configuration
- Often previous drag and weight reduction concepts in conflict with each other
  - e.g. – increased span at cost of increased weight…
  - NASA investing in broadly applicable technology developments
- NASA has many partners in this research

Typical Contributions to Drag - Subsonic



System Assessments

325 Passenger, 4,000 nm

	Fuel Savings
Airframe Wt (-10%)	-7%
SFC (-10%)	-14%
L/D Cruise (+10%)	-13%
Skin Friction (-10%)	-9%
Induced Drag (-10%)	-6%

Merac (ONERA, 2000) and Bushnell & Hefner (AGARD 654)

Drag Reduction Technology Approach

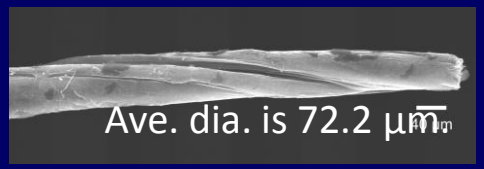
- Skin Friction Drag – Laminar Flow (LF) Technologies, Active Flow Control (AFC) for wetted area reduction, turbulent drag reduction
- Induced Drag – configuration dominated, increased aspect ratio, wing tip devices, adaptive trailing edges, active load alleviation, enabled by lightweight/multi-functional structures
- Interference Drag – configuration dominated, propulsion/airframe integration, trim characteristics
- Wave Drag – configuration dominated, shock/boundary layer interactions, adaptive trailing edges/compliant structures
- Roughness Drag – joints, fasteners, manufacturing, operations

Active and Passive Concepts

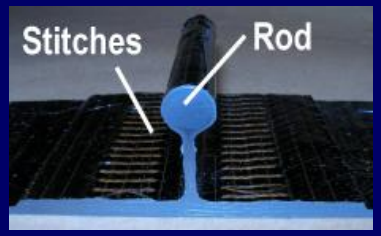
Lightweight Structures – Materials and Manufacturing

- Materials – Nanotubes, fabrics, coatings, resins
- Structures – Tailored load paths, integral curvilinear stiffeners, unitized structures, compliant structures, damage tolerance
- Manufacturing – Stitching, resin infusion , free-form fabrication, surface engineering, tooling, joints, surface quality

Carbon Nanotube (CNT) yarn.



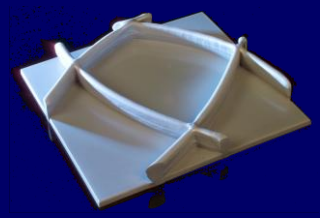
Stitched Composites



Electron Beam Free Form Fab

Large-scale CNT Sheets

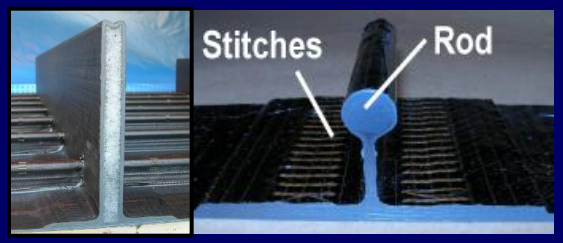
Integrated Curvilinear Stiffeners



HLFC - Insect Adhesion

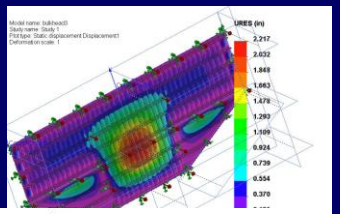
Stitched Unitized Structures

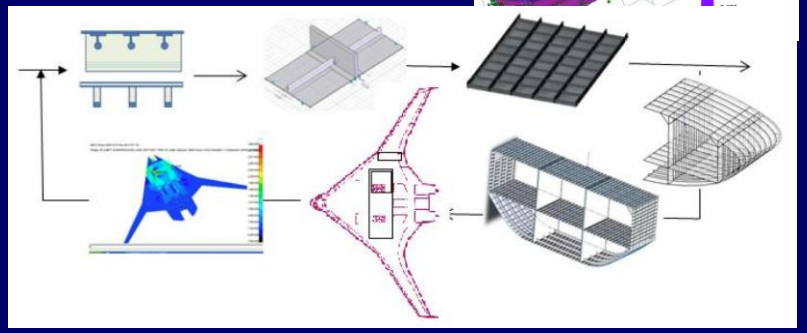
- Not “black aluminum”
- “Fail-safe” damage tolerance
- Load tailoring and weight estimation tools
  - Integrate alternate technologies (cabin noise, etc.)
- Expect 10% weight reduction compared to conventional composites
- Easier tooling

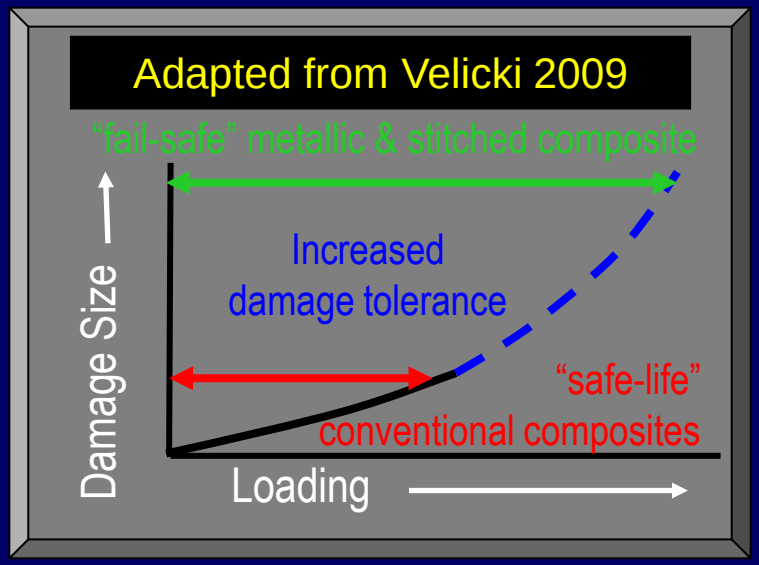


Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)

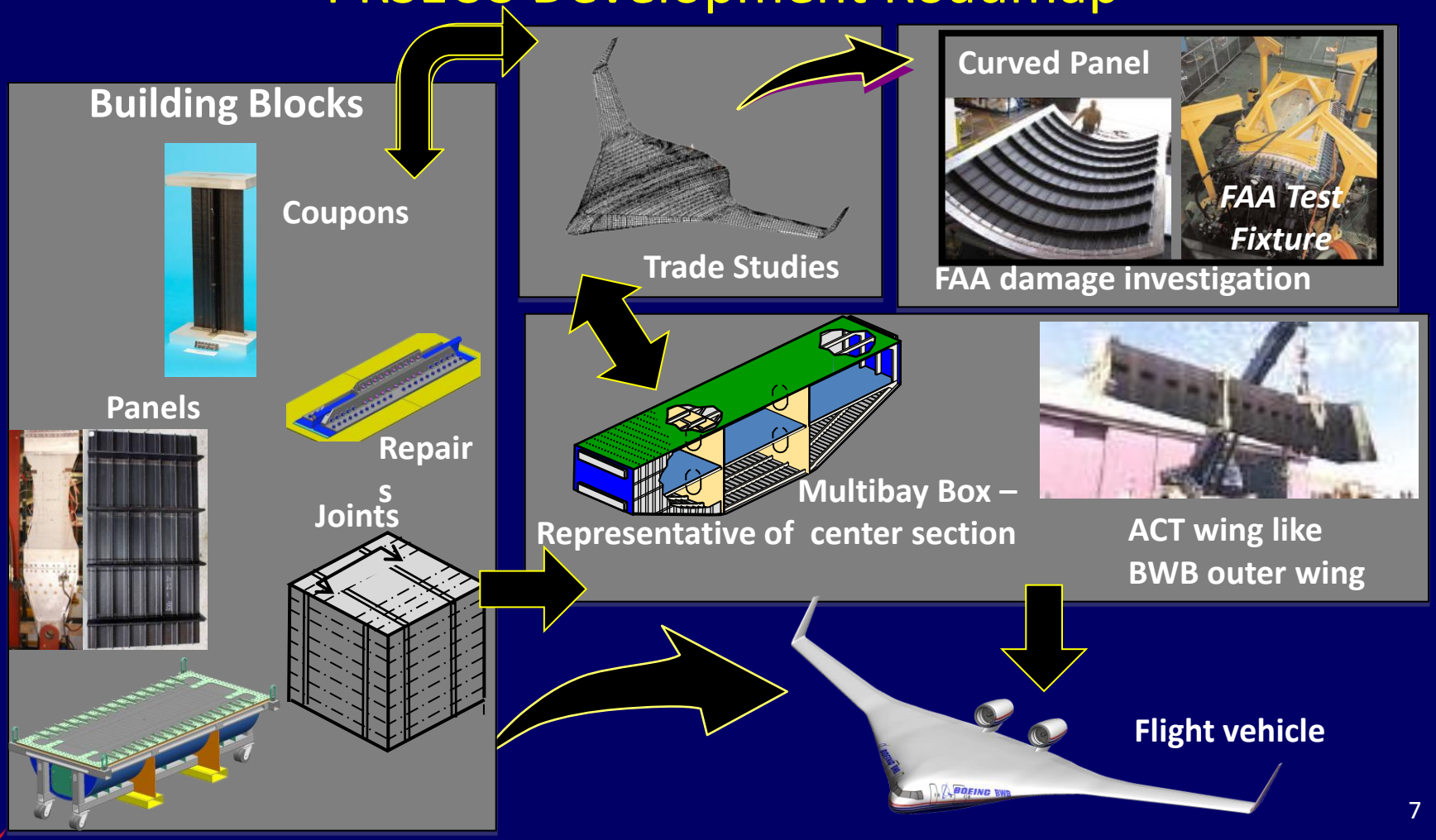
PRSEUS Multi-bay Analysis





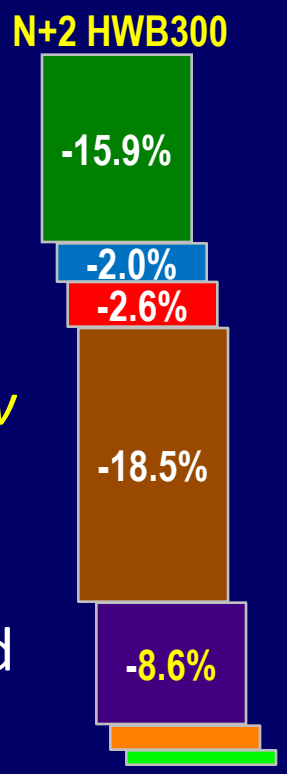


PRSEUS Development Roadmap

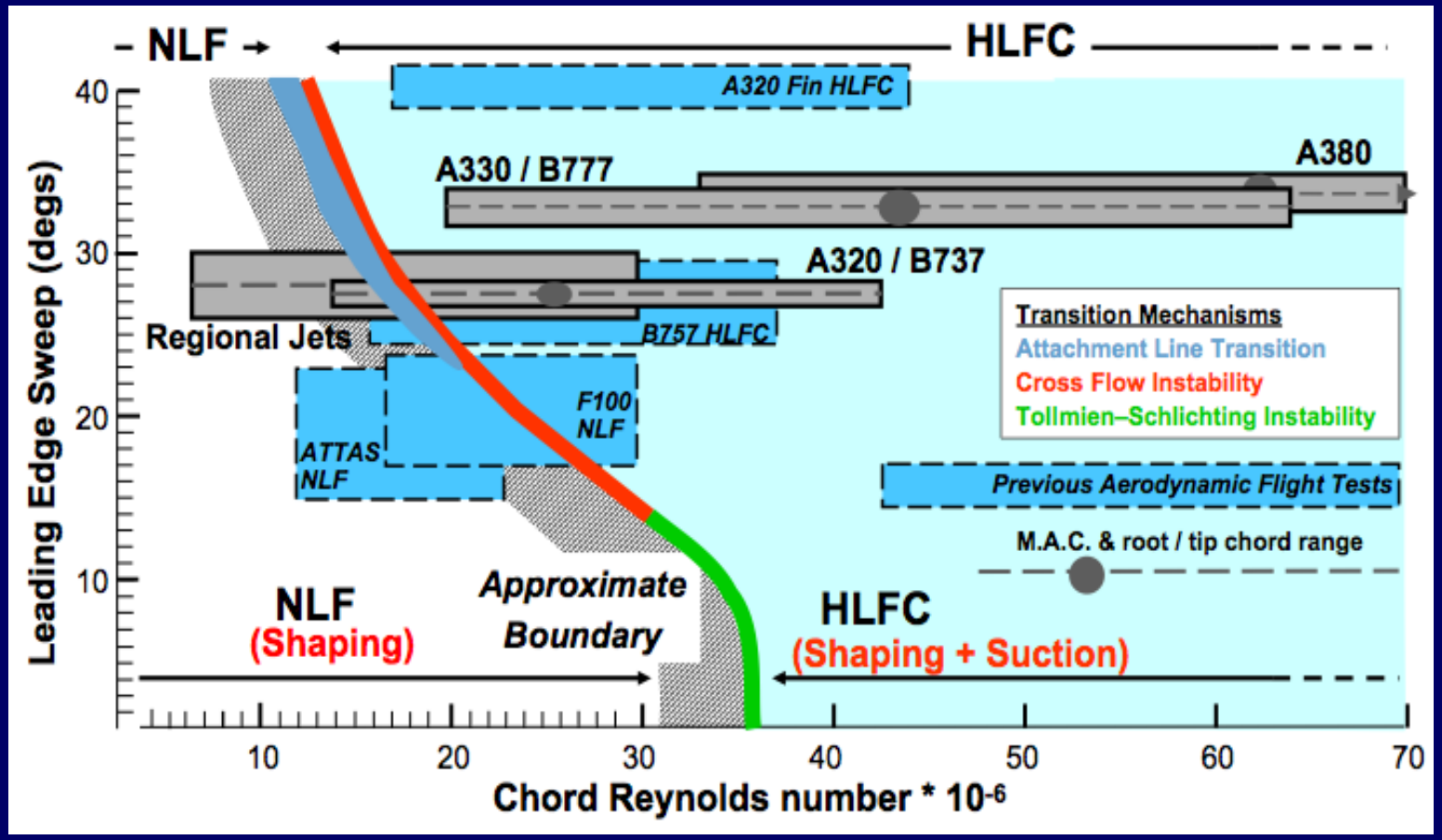


Drag Reduction by Laminar Flow Technologies

- Laminar flow aerodynamically mature, but not extensively used on transonic transport aircraft
  - Demonstrated in several aerodynamic flight experiments
  - NLF on 787 nacelles, passive HLFC on 787 stabilizers/fin
  - Receptivity to surface roughness is topic for research
- Address *critical barriers to practical laminar flow* application – surface roughness, manufacturing, contamination, energy balance
- Develop confidence to conduct highly integrated flight tests
  - Validated practical passive and active solutions



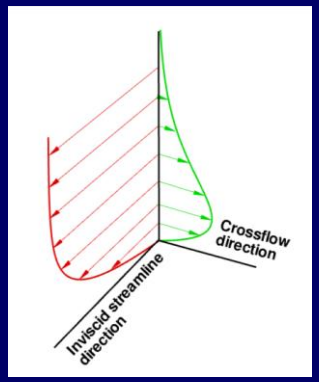
Approach for Laminar Flow is Mission Dependent



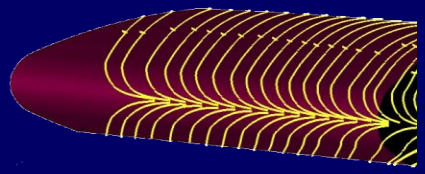
Vijgen, et al 2009 ICCAIA Paper

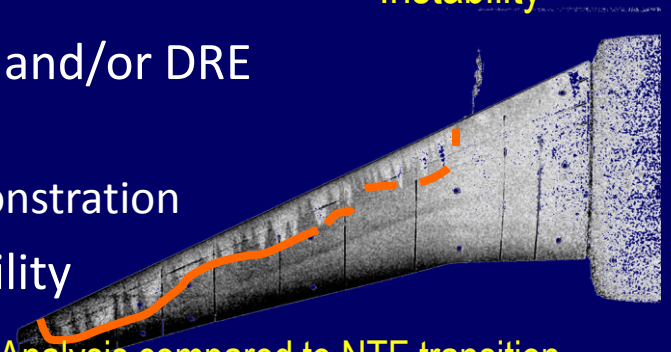
Laminar Flow Technology Maturation

- Develop and demonstrate usable and robust aero design tools for NLF, HLFC
  - Link transition prediction to high-fidelity aero design tools
- Explore limits of crossflow control through Discrete Roughness Elements (DRE)
  - Practical Mach, Re demonstration at relevant C_L
  - Relax surface quality requirements?
- Seek opportunities to integrate NLF, HLFC, and/or DRE into flight weight systems
  - Understand the system trades through demonstration
- Assess/develop high Re ground test capability



Crossflow Instability





Analysis compared to NTF transition measurements at Re = 22 M/ft

Flight Demonstration of DRE

- Previous DRE demo to Re ~8M with unit Re 1.6M
- Fly DRE on NASA G-III wing glove at B-737 equivalent Re, unit Re ~16M
- Primary Goal: DRE increase extent of laminar flow by 50%
  - Design for NLF to 15-20M Re with transition at x/c = 60%
  - Use DRE to delay transition at 22 – 30M Re to x/c = 60%
- Secondary Goal: DRE relax surface quality requirements
- Demonstrate validity at Mach, C_L, and Re before addressing *potential* need for reconfigurable actuator

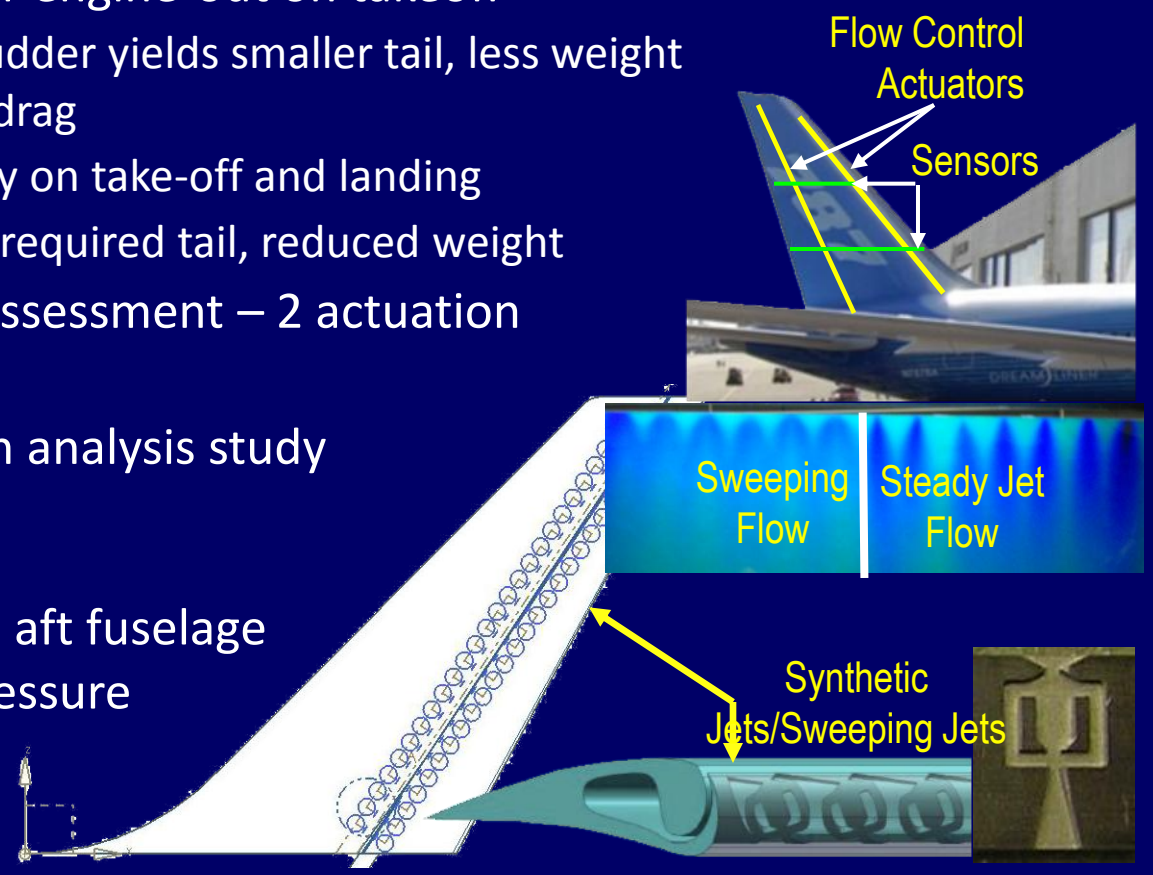
Discrete Roughness Elements

Wetted Area Reduction – Active Flow Control

Increased On-Demand Rudder Effectiveness

- Vertical tail sized for engine-out on takeoff
  - More effective rudder yields smaller tail, less weight and skin friction drag
  - AFC operates only on take-off and landing
  - Result in smaller required tail, reduced weight
- AFC effectiveness assessment – 2 actuation schemes
- Detailed integration analysis study
- Flight test in 2013?

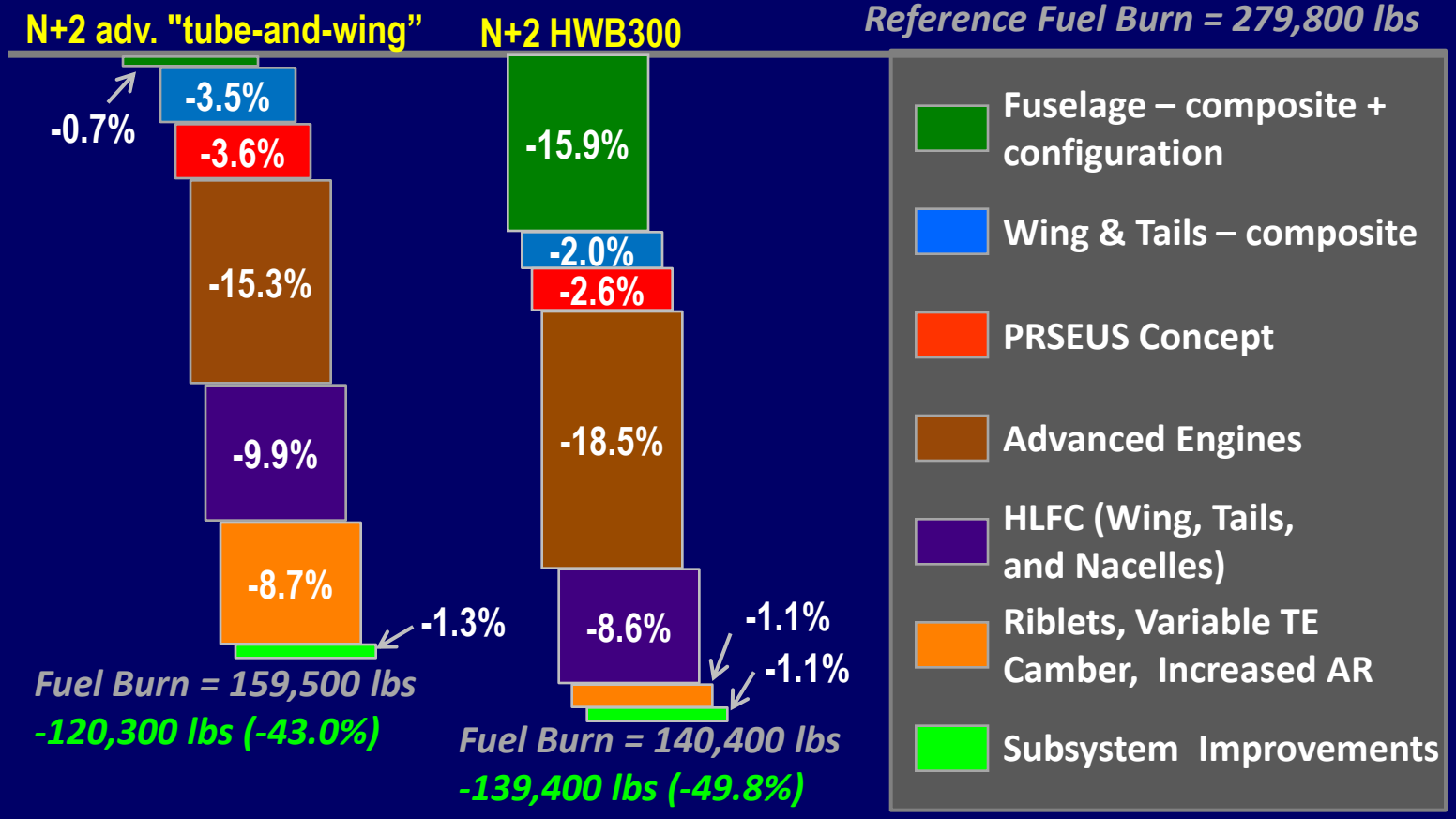
- Use flow control on aft fuselage (SRW) to reduce pressure drag……



Potential Reduction in Fuel Consumption

2025 EIS (TRL = 6 in 2020)

Benefits relative to 777-200LR "like" vehicle
Reference Fuel Burn = 279,800 lbs



Closing Remarks

- Technologies to achieve NASA subsonic fuel burn reduction goals
  - Broadly applicable technologies for drag and weight
  - Some technologies may enable new configuration
  - Additional technologies: active load alleviation, compliant flap flight test, flexible wing design, etc.
- Key Airframe System Technology Demonstrations
  - Multi-bay PRSEUS pressure/combined load test
  - High Reynolds number demonstrations of DRE, NLF, HLFC
- Partnerships are key part of portfolio