Large-scale Boundary Layer Ingesting Propulsor Research

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Overview

• NASA is broadly engaged in advanced subsonic commercial vehicle concepts to enable the reduction of fuel burn.

• This paper will discuss an embedded boundary layer ingestion (BLI) application which was tested in NASA GRC’s 8x6 wind tunnel at high-speed.

• The benefits and challenges with the design and test of this particular BLI system are presented.

• A vehicle-level system study is presented using the results of this test on an advanced concept aircraft.
Use industry pull to mature technology that enables aircraft products that meet near-term metrics and push to mature technology that will support development of new aircraft products that meet or exceed mid-term and far-term metrics.

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS*</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Near Term 2015-2025</td>
<td>Mid Term 2025-2035</td>
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<tr>
<td>Noise Reduction (cum below Stage 4)</td>
<td>22 – 32 dB</td>
<td>32 – 42 dB</td>
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<tr>
<td>LTO Nox Emissions Reduction (below CAEP 6)</td>
<td>70 – 75%</td>
<td>80%</td>
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<tr>
<td>Cruise Nox Emissions Reduction (rel. to 2005 best in class)</td>
<td>65 – 70%</td>
<td>80%</td>
</tr>
<tr>
<td>Fuel/Energy Consumption Reduction (rel. to 2005 best in class)</td>
<td>40 – 50%</td>
<td>50 – 60%</td>
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* Note: Reference is best commercially available or best in class in 2005.
The technology of a propulsion system with boundary layer ingestion (BLI) has been significantly advanced through a number of analytical, computational, and experimental studies.
Propulsion system is installed on the aircraft with pylons to avoid or minimize any interactions with the aircraft wake as much as possible.
**Boundary Layer Ingestion**

**Principle**
Place engine downstream of the body in order to ingest its wake *ideally* to re-energize the wake back to freestream velocity.

**Propulsor ingests and reaccelerates the airframe boundary layer**

**Less Wake & Lower Jet Kinetic Energy for the same net force**
*Means*
Less Power needs to be added to the flow by the Propulsor
*Means*
**Less Fuel Burn**

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**Boundary Layer Ingestion (180 Degree Distortion)**

- Momentum excess from jet exhaust
  - Partially Balanced
  - Momentum deficit due to a/c wake

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**Wake Ingestion (360 Degree Distortion)**

- Balanced
TRL Timeline for BLI²DTF Propulsor

- HWB Airframe Integrated Embedded BLI Propulsor System Study Complete
- Optimized BLI Inlet Aero Design Complete
- Full Wheel GTF G4 Pre-Baseline Distorted Inflow/Fan Analysis Complete
- AeroDR
- Integrated BLI²DTF Design Complete
- BLI²DTF 8x6 Test Complete
- Hardware Fab Complete
- Raised Floor Test Section Calibration Test Complete
- FY 2009
- FY 2010
- FY 2011
- FY 2012
- FY 2013
- FY 2014
- FY 2015
- FY 2016
- FY 2017
- FY 2018

Advanced Air Vehicles Program
Advanced Transport Technologies Project
WT Setup with BLI²DTF Propulsor

- Raised Test Section Floor
- Boundary Layer Bleed
- Raised Floor Roughness

Test Section Porosity

- Boundary Layer Ingesting Inlet
- Ultra High Bypass Ratio Fan Drive Rig
- Fast-Acting, Variable Area Nozzle
- Distortion-Tolerant Fan Stage
  - Rotating AIP Rake Array
  - Distortion-Tolerant Fan Stage
  - Fan Exit Rotating Rake Array
Inlet Boundary Layer Profile

Target incoming BL determined by CFD
BLI²DTF Propulsor

BLI inlet with distortion-tolerant fan stage (18 Rotors / 48 Vanes).

Mach 0.78
BL Thk = 4.80in
Advanced Air Vehicles Program
Advanced Transport Technologies Project

BLI² DTF Propulsor Instrumentation

- Aerodynamic Interface Plane Rotating Rake Array (AIPRRA)
- External Nacelle Thermocouple Probes
- Fan Stage Exit Rotating Rake Array (FERRA)
- VAFN Position, Static Taps
- Inlet Lip Static Taps
- Inlet Throat Static Taps
- Fan Intra-Stage Static Taps
- Pre-Entry Diffusion Ramp Static Taps
- BLI Inlet Static Taps
- AIPRRA Static Taps
- Distortion-Tolerant Fan Rotor Speed, Strain Gages, and Light and Capacitance Probes
- FERRA Static Taps
AEROMECHANIC RESPONSE & INLET PERFORMANCE

Campbell diagram

Inlet Performance Map

Inlet Total Pressure Recovery, $P_{t,12}/P_{t,0}$

Corrected Weight Flow, $W_{c,12}$, lb/sec

- 87.5% $x_{13}$ (Expt)
- 100% $N_c$ (Expt)

ADP (Expt)
Inlet Distortion at the AIP
Performance & Operability Maps

Fan Stage Pressure Ratio

- 87.5% x_{19} (Expt)
- 105% N_c (Expt)
- 102.5% N_c (Expt)
- 100% N_c (Expt)
- 95% N_c (Expt)
- 87.5% N_c (Expt)
- 85% N_c (Expt)
- 80% N_c (Expt)
- 70% N_c (Expt)

~24% Stability Margin (Blade Stall)
~18% Stability Margin (Blade Flutter)
~12% Stability Margin (Blade Flutter)

Corrected Flow Rate, W_{c,12}, lbm/sec

Fan Stage Adiabatic Efficiency

102.5 lbm/sec PR=1.35

Survey and Snapshot Points

Fan Speed (N_c)
- 70%
- 75%
- 80%
- 85%
- 90%
- 92.5%
- 95%
- 97.5%
- 100%
- 102.5%
Sensitivities

**Baseline ND8**

- 3.5% Fan Efficiency Loss Penalty

**Final ND8**

- 6.5% increase when BLI is turned off
- Includes fan efficiency loss

**ND8 with "BLI-off"**

- 8.5% potential reduction benefit with BLI and no fan efficiency loss

**Effect of BLI alone:**

- 6.5% increase when BLI is turned off

**BLI Benefit:**

- 5.35% reduction relative to Underwing Engines Configuration

**Sensitivity Result:**

- A 1% decrease in fan efficiency causes a 0.95% increase in block fuel if aircraft sizing effects are included.
CONCLUSION

• Type I BLI propulsor was developed & tested in the NASA GRC 8x6 wind tunnel
• New Tools/Techniques Developed for BLI:
  • Integrated Design of Inlet and Fan
  • Aeromechanics tools for Critical Modes Analysis
  • Raised floor to deliver the ‘right’ boundary layer
  • Rotating Rake Arrays to Capture Data
  • Unique Post-Processing Capabilities for non-clean inlet flow
• System study shows good fuel burn reduction potential for BLI

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