Approach to Modeling Boundary Layer Ingestion using a Fully Coupled Propulsion-RANS Model

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openMDAO

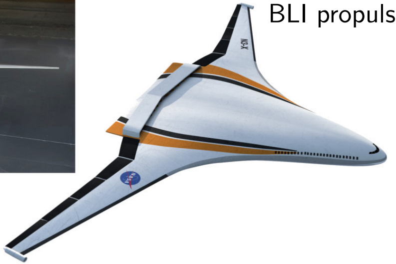
NASA

Boundary Layer Ingestion (BLI) offers between 5% and 12% fuel burn savings

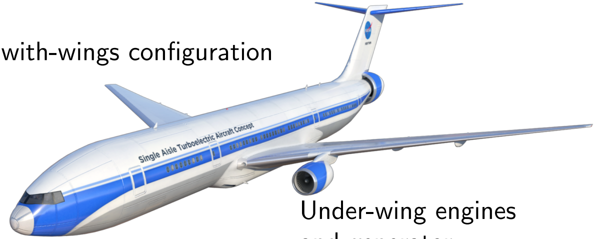
Aft-mounted
BLI propulsor

Aft-mounted BLI engines

Mail-slot inlet
BLI propulsors

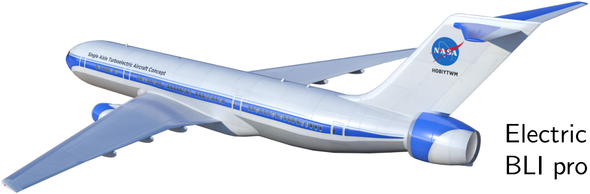


NASA's Starc-ABL configuration applies BLI to a traditional airframe



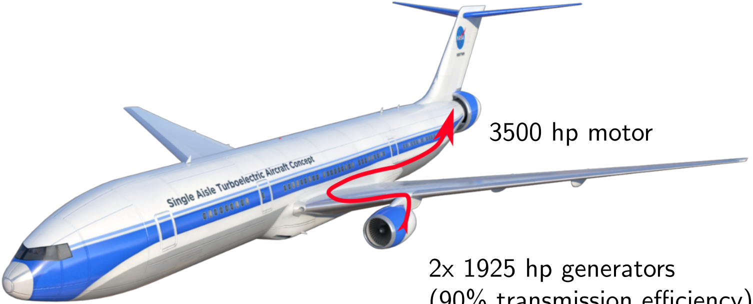
Tube-with-wings configuration

Under-wing engines
and generator



Electric
BLI propulsor

The BLI propulsor is powered by an electric motor delivering a constant 3500 hp

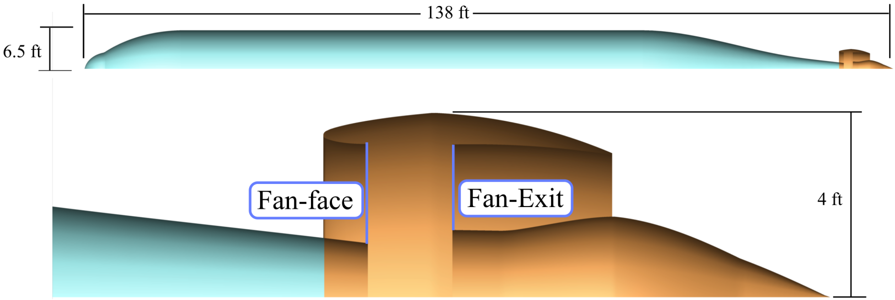


3500 hp motor

2x 1925 hp generators
(90% transmission efficiency)

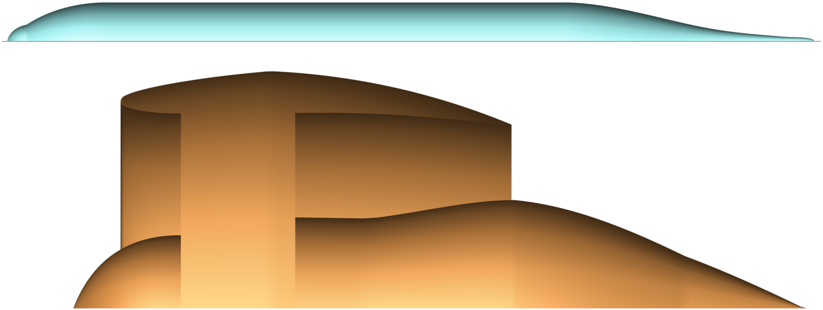
Turboelectric propulsion system has an electric BLI propulsor powered by generators mounted on the under-wing turbofans

We simplified the configuration to focus on the coupled performance of the BLI propulsor



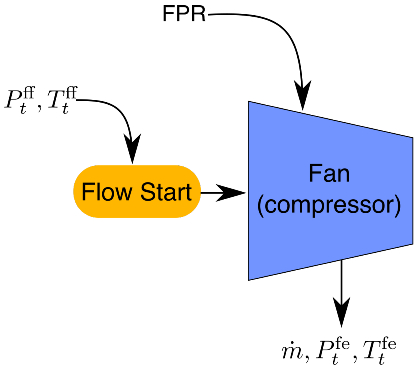
- Loosely based on 737 fuselage dimensions
- Removed wing, tail, and under-wing engines to simplify the analysis

BLI propulsor performance was compared to a podded configuration



Exact same propulsor geometry, including inlet, was used for both BLI and podded configurations

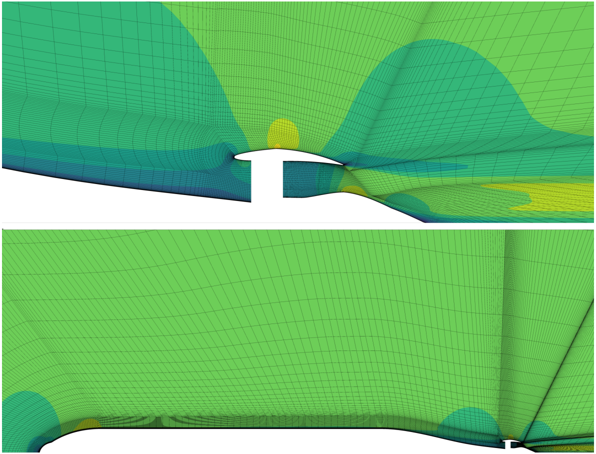
The propulsion analysis was a 1D thermodynamic cycle model



- modeled with pyCycle, a modular propulsion cycle tool built in the OpenMDAO framework

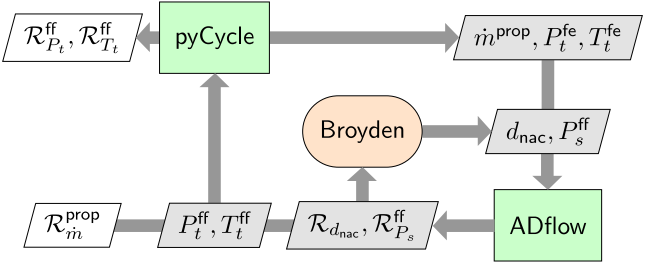
The aerodynamic analysis was a 2D axisymmetric RANS model

Mach contours



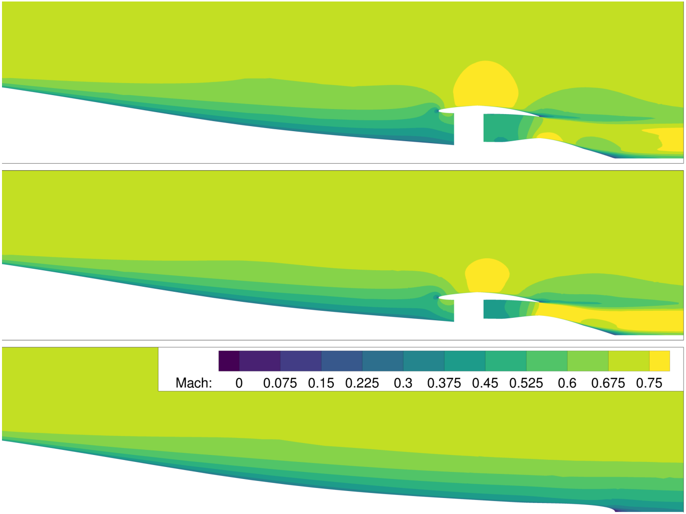
- ˜170,000 cell mesh
- a single solve takes ˜2 minutes

The analyses were coupled via a Gauss-Seidel iteration



- **pyCycle** → **ADflow**: fan-exit P_t and T_t and required $\dot{m}$ for 3500 hp
- **ADflow** → **pyCycle**: mass-averaged fan-face P_t and T_t
- GS and Broyden iterations implemented with OpenMDAO solvers

For any given FPR the propulsor is resized and the mass-flow across the propulsor is balanced



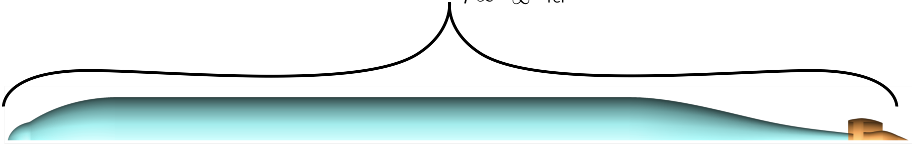
FPR = 1.2

FPR = 1.35

baseline

Performance is examined via net force coefficient

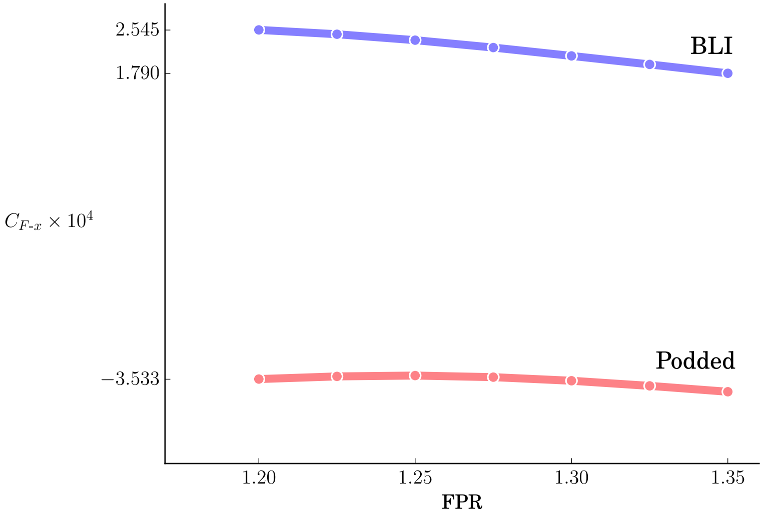
$$C_{F\text{-}x} = \frac{2f}{\rho_\infty V_\infty^2 A_{\text{ref}}}$$



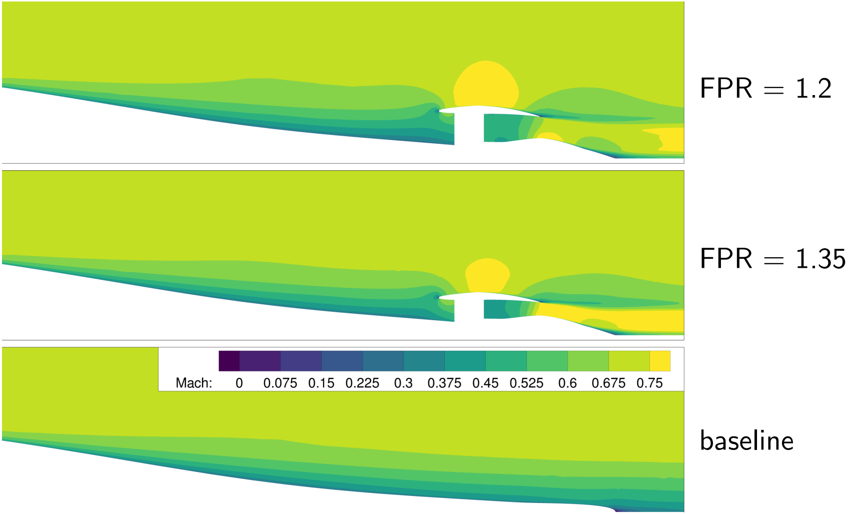
$C_{F\text{-fuse}}$ $C_{F\text{-prop}}$

- $C_{F\text{-fuse}}$ should be negative, a decelerating force (i.e. drag)
- $C_{F\text{-prop}}$ should be positive, an accelerating force (i.e. thrust)
- $C_{F\text{-}x}$ can be positive or negative

BLI offers 5 to 6 more force counts for the same 3500 hp to the propulsor



Propulsion-aerodynamic interactions cause the boundary layer height to vary with FPR



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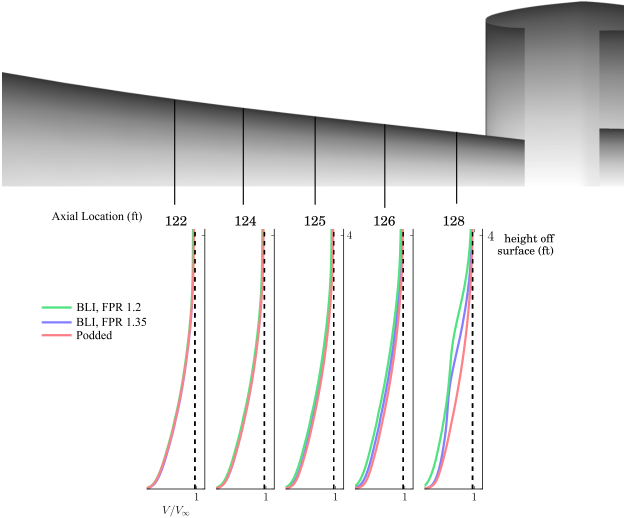
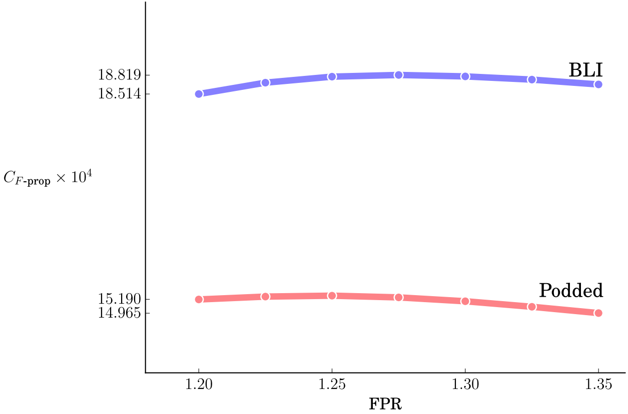


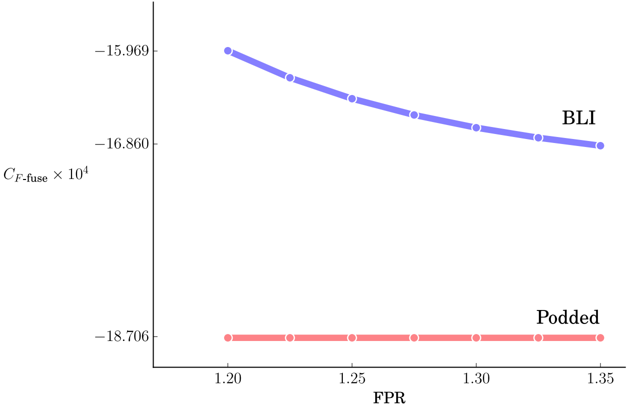
Improved propulsor performance accounts for 50-60% of the BLI performance gain

- Of the 5 to 6 total counts of improvement $C_{F\text{-}x}$, 3 counts come from increased $C_{F\text{-prop}}$

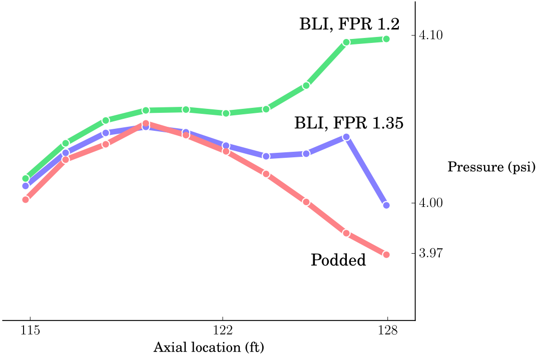


Fuselage drag reduction contributed 40-50% of the BLI performance gain

- Of the 5 to 6 total counts of improvement $C_{F\text{-}x}$, 2 to 3 counts come from smaller $C_{F\text{-fuse}}$



Reduction in $C_{F\text{-fuse}}$ comes from an increased surface static pressure on the aft-fuselage



- the change in surface static pressure profile is a strong function of FPR

The performance gains from BLI come from a combination of propulsion and aerodynamic effects

- Capturing BLI effects requires a coupled simulation
- Aerodynamic effects are strongly influenced by inlet design and throttle setting

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Next step is to perform optimization of this configuration with propulsion and shape design variables

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