National Aeronautics and Space Administration

NASA's SUSAN Electrofan Aircraft: Designing the Future of Green Aviation

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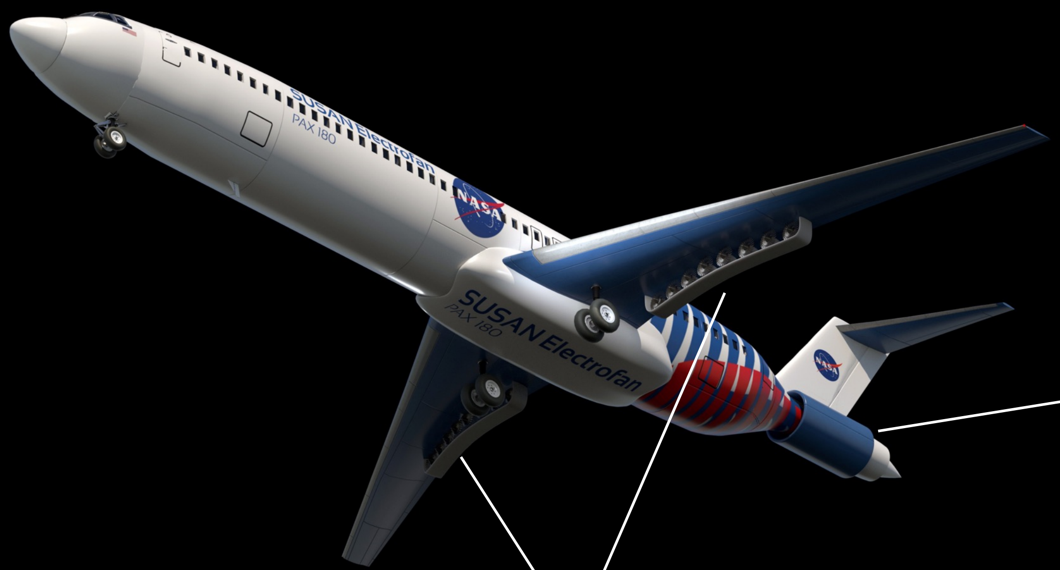
NASA's SUSAN Electrofan

- **Problem**
  - Aircraft fuel consumption and emissions have to be reduced by at least a factor of two, with a goal of zero emissions
- **Constraints**
  - Must utilize existing airport infrastructure, be flight certifiable, and be more cost effective
- **Solution**
  - Large Hybrid-Electric Aircraft
- **What is SUSAN?**
  - Transport category aircraft that uses an Electrified Aircraft Propulsion (EAP) system to enable advanced Propulsion and Airframe Integration (PAI) technologies

Artistic rendering of the SUSAN Electrofan Aircraft at takeoff

The Subsonic Single Aft eNgine (SUSAN) Electrofan

Class	Regional
Capacity	180 PAX
Design Range	2500 nmi
Economy Range	750 nmi
Mach Number	0.785



Gas Aft Fuselage Turbofan (35% Thrust)

Electric Distributed Propulsors (65% Thrust)

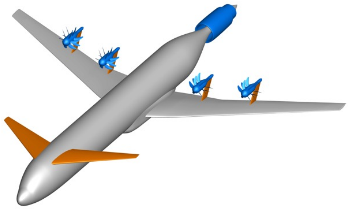
Preliminary concept <u>only</u>

Exploration of the Configuration Trade Space

SUSAN V0

17.2% Fuel savings

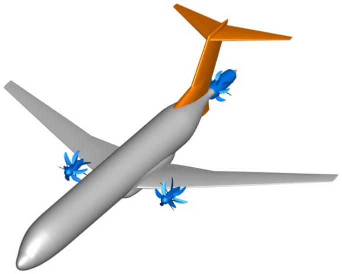
- Gas ducted turbofan
- Electric rotors
- Canard
- Control fins



SUSAN V1

23.7% Fuel savings

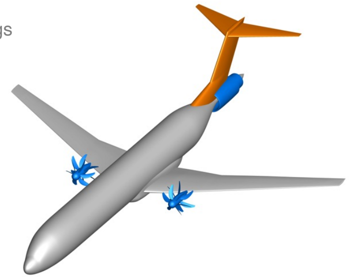
- Gas open rotor
- Electric rotors
- T-tail
- Ventral fin



SUSAN V2

20.5% Fuel savings

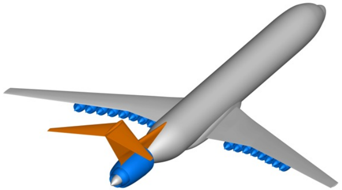
- Gas ducted turbofan
- Electric rotors
- T-tail



SUSAN V3

Fuel savings N/A

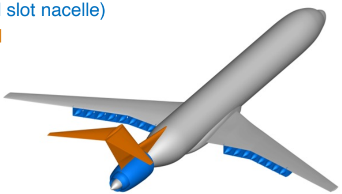
- Gas ducted turbofan (GTF)
- Electric distributed propulsors
- T-tail



SUSAN V3 Mail-Slot

26.8% Fuel savings

- Gas ducted turbofan (GTF)
- Electric distributed propulsors (mail slot nacelle)
- T-tail

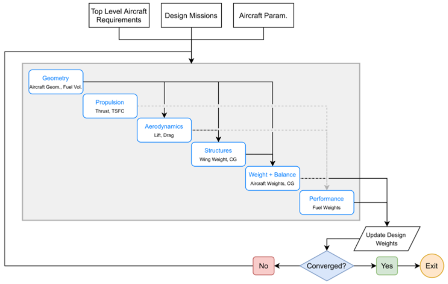


The evolution of the SUSAN aircraft configuration, with different combinations of propulsion systems (blue) and stability and control surfaces (orange). Estimates for fuel efficiency improvements only include benefit of turbo-electric propulsion system and differences in airframe configuration. Boundary-layer ingestion and other advanced technologies are not yet included.

*Fuel efficiency is measured by the block fuel over a 750 nmi economy mission relative to a Boeing 737-800-like aircraft

Concept Design Workflow

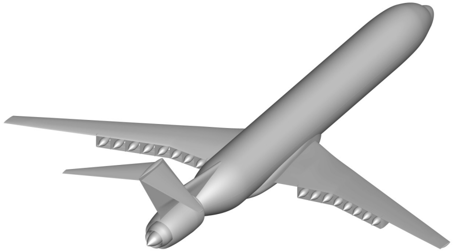
Conceptual design



Outcomes:
- Sized Aircraft
- Optimized mission

Tools:
- Faber
- FLOPS, LEAPS
- NPSS, WATE+

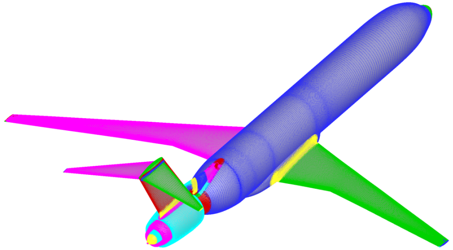
Geometry



Outcomes:
- Defined OML
- CAD file

Tools:
- Faber
- CATIA, ANSA

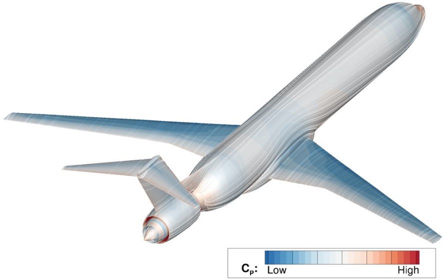
Grid generation



Outcomes:
- Computational domain

Tools:
- Pointwise
- Chimera Grid Tools (CGT)

High-fidelity Analysis

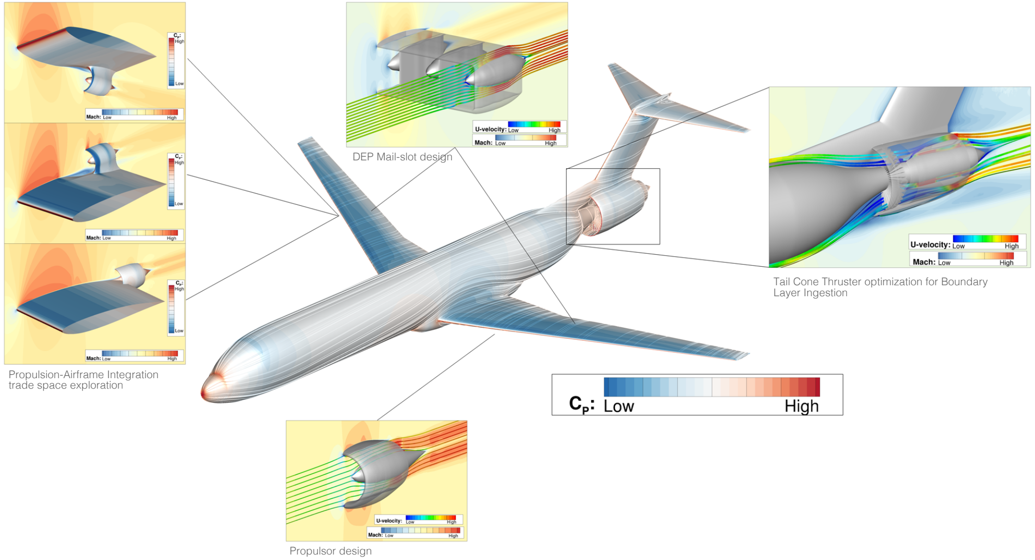


Outcomes:
- Aircraft performance metrics (lift, drag, etc.)
- Optimized airframe OML

Tools:
- LAVA

Computational Fluid Dynamics (CFD)

- **Objectives**
  - Mature design of advanced technologies considered
  - Airframe optimization
  - Quantification of overall vehicle performance
- **Advanced propulsion technologies**
  - Distributed Electric Propulsion (DEP)
  - Boundary Layer Ingestion (BLI)
  - Natural Laminar Flow (NLF)
- **Two focus areas:**
  - Wing propulsion system
  - Tail Cone Thruster (TCT)



Computational Fluid Dynamics (CFD)

- **Launch, Ascent, and Vehicle Aerodynamics (LAVA) framework**
    - Steady state compressible Reynolds-Averaged Navier-Stokes (RANS) solver
    - Actuator zones to simulate propulsive effects
    - Structured curvilinear overset mesh paradigm
    - Hybrid Message Passing Interface (MPI)/OpenMP
- **Computational resources**
    - Pleiades Supercomputer at the NASA Advanced Supercomputing (NAS) facility at Ames Research Center
    - 950 Broadwell nodes per simulation
    - 2064 core-hours

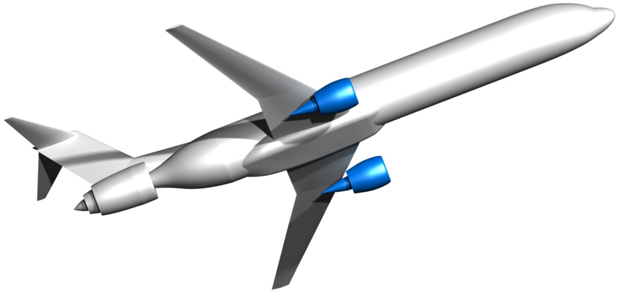
Pleiades supercomputer at the NAS facility[1]

[1]Image credit: https://www.nas.nasa.gov/supercomputing/overview.html

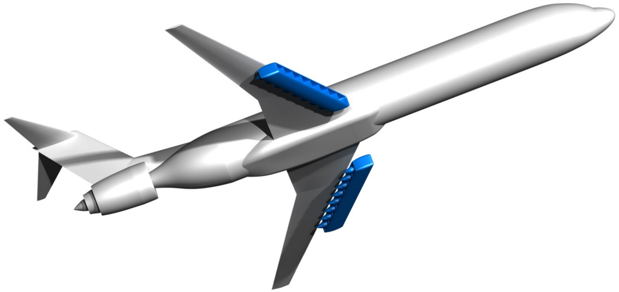
Wing propulsion system

Wing propulsion system

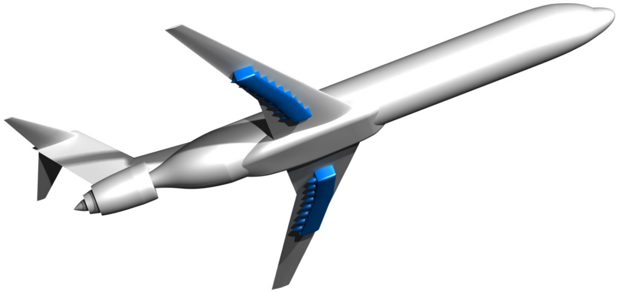
- **Wing-mounted electric propulsion system configuration trade space exploration**
- **Objectives:**
  - Accurately assess the potential benefits of DEP and BLI on an aircraft systems level
  - Further understanding the design and integration of advanced propulsion technologies
  - Investigate propulsion-aerodynamics coupling phenomena



Configuration 1
(non DEP, non BLI)



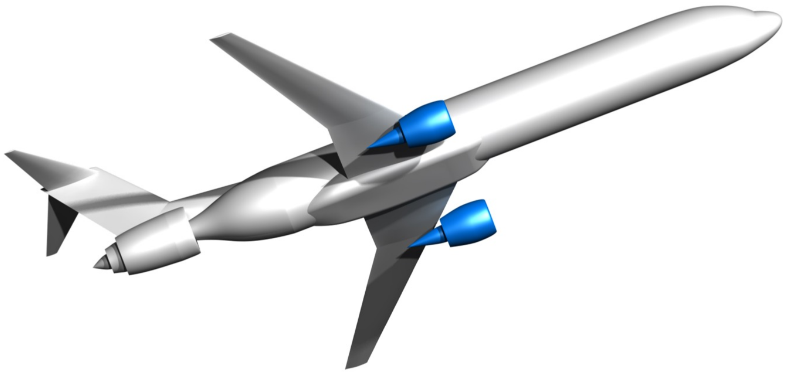
Configuration 2
(DEP, non BLI)



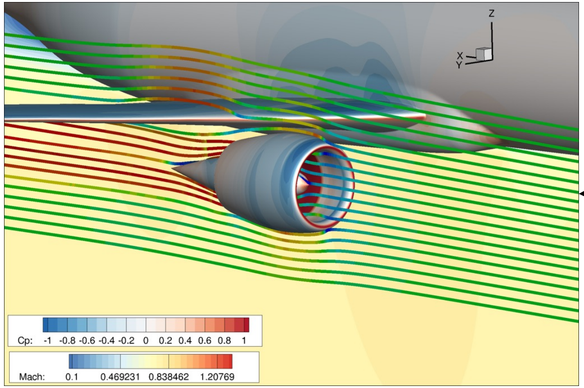
Configuration 3
(DEP, BLI)

Configuration 1

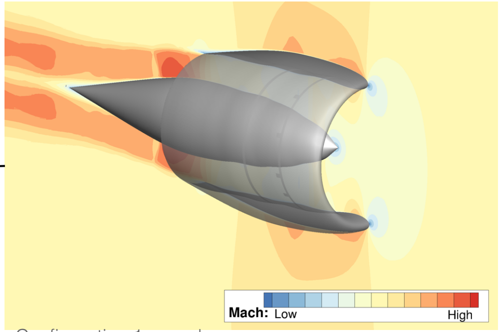
- **Conventional configuration**
  - Single engine
  - Under-wing podded propulsor installation with TCT
- **Objectives:**
  - Serve as a performance baseline
- **Design considerations**
  - Under-wing pylon-mounted podded propulsor design



Configuration 1



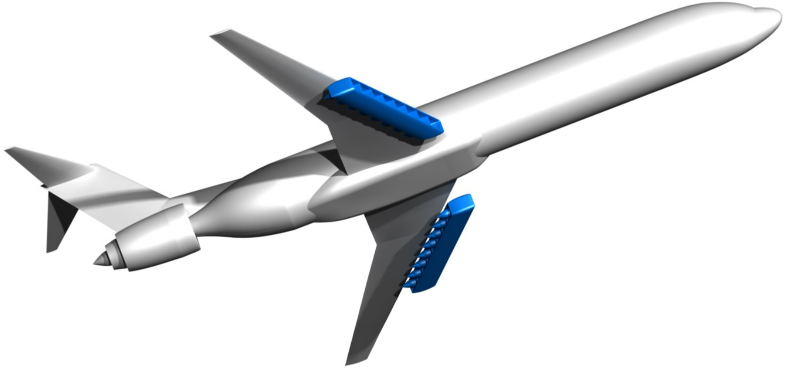
SUSAN Configuration 1



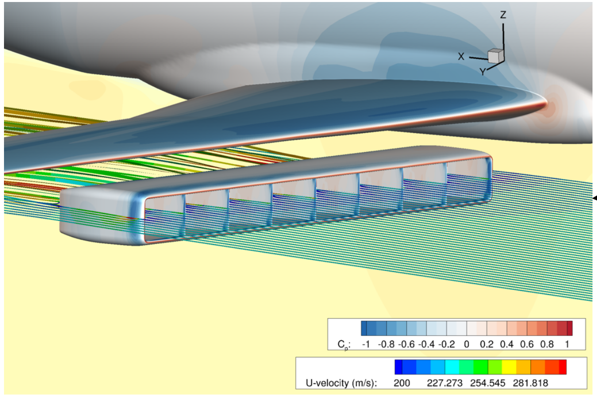
Configuration 1 propulsor

Configuration 2

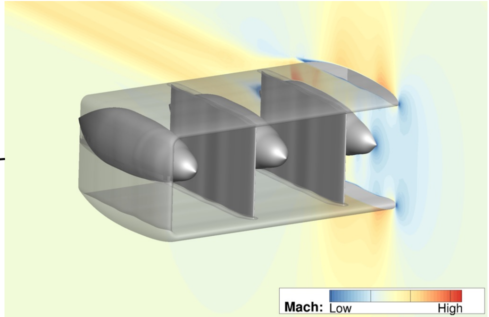
- **DEP configuration**
  - 8 under-wing podded propulsors in a mail-slot configuration
- **Objectives:**
  - Understand DEP system level benefits
  - Investigate mail-slot design challenges and performance
- **Design considerations**
  - 8 propulsor mail-slot design



Configuration 2



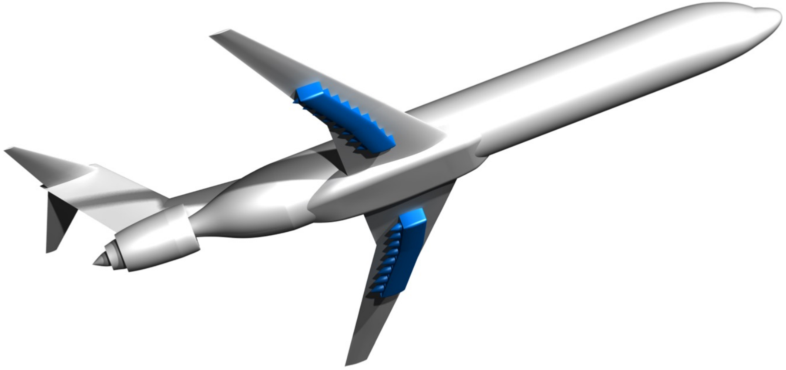
SUSAN Configuration 2



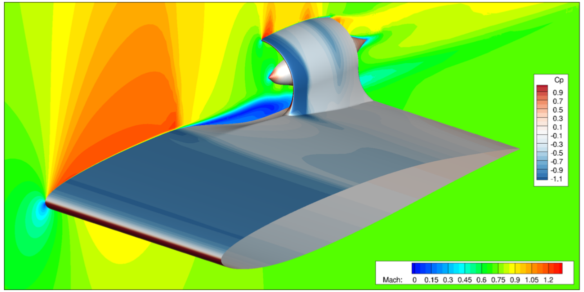
Configuration 2 propulsor

Configuration 3

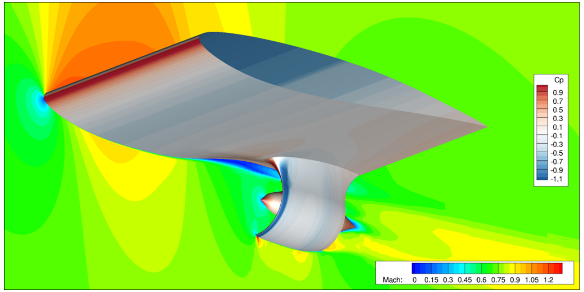
- **DEP-BLI configuration**
  - 8 propulsor mail-slot installed on wing lower surface
- **Objectives:**
  - Understand BLI system level benefits
  - Investigate under-wing installation challenges and performance
- **Design considerations**
  - 8 propulsor boundary-layer ingesting mail-slot design
  - Airframe integration



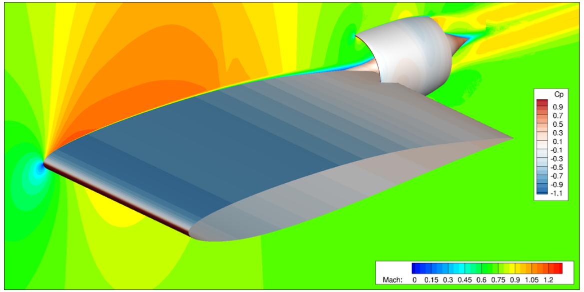
Configuration 3



Over-wing



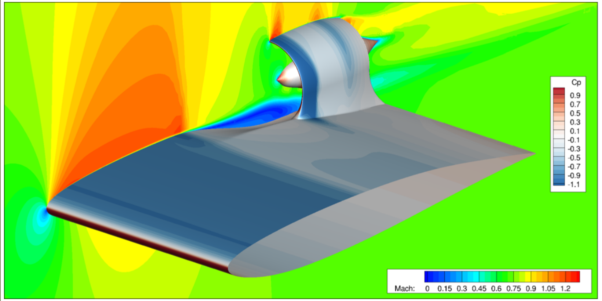
Under-wing



Trailing-edge

Propulsion Airframe Integration studies

Over-wing



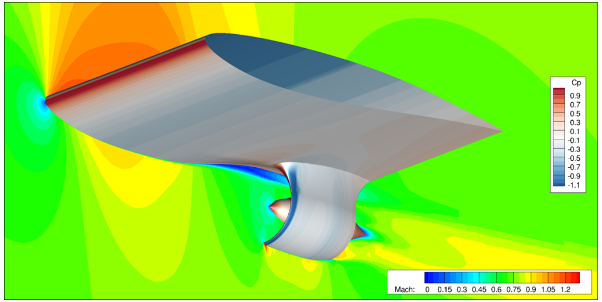
Advantages:

- Upper surface suction
- Boundary Layer Ingestion (BLI) benefit

Challenges:

- Inset design
- Upper surface shock formation

Under-wing



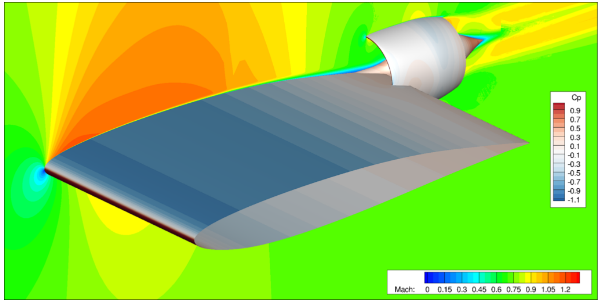
Advantages:

- More natural laminar flow
- Less integration penalties

Challenges:

- Low BLI benefit
- Lower surface suction

Trailing-edge



Advantages:

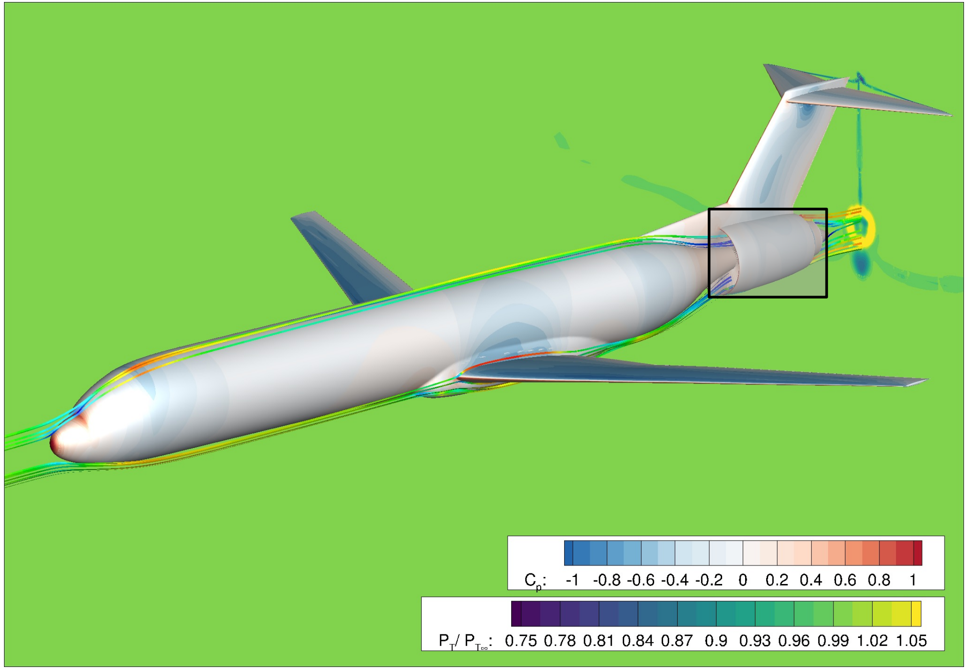
- Lowest integration penalties
- BLI benefit

Challenges:

- Structurally challenging
- Integration with high-lift devices

Tail Cone Thruster

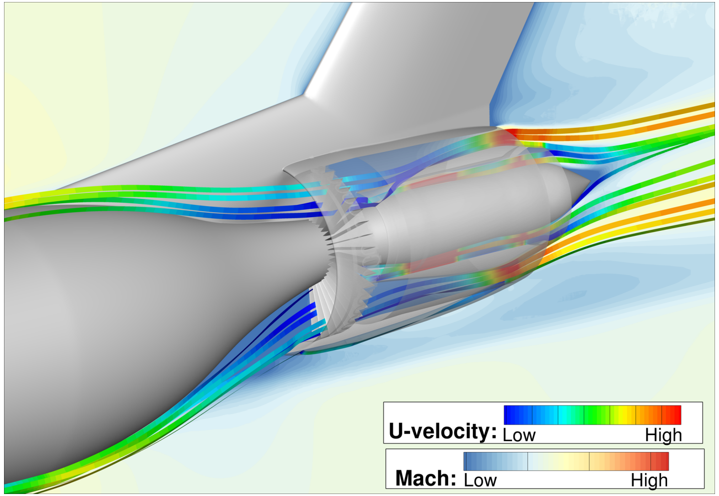
Tail Cone Thruster



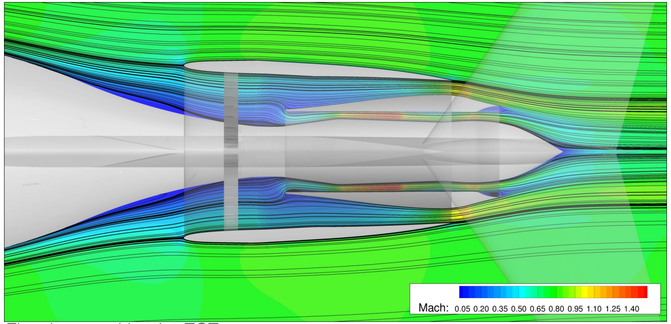
- **Engine sizing and characterization**
  - Inform design sizing
  - Quantify engine performance
  - Characterization of flow ingested by the engine
- **Fuselage diffuser optimization**
  - Reduce inlet flow distortion intensity
  - Optimize TCT performance

Engine sizing and characterization

- **Design sizing**
  - Data used to inform inlet, core, and bypass duct sizing
  - Inlet and outlet profiles informed detailed engine modeling
  - Created more accurate engine models
- **Close collaboration with propulsion team to mature TCT design**
  - Prescribed core flow inflow/outflow boundary conditions utilizing Numerical Propulsion System Simulation (NPSS) tool



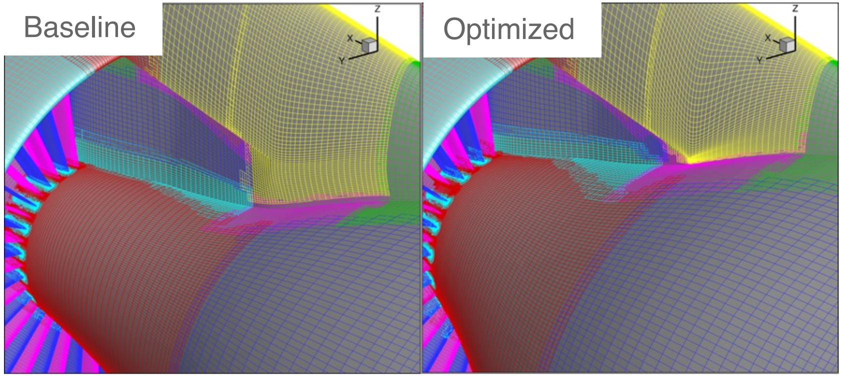
Tail Cone Thruster (TCT)



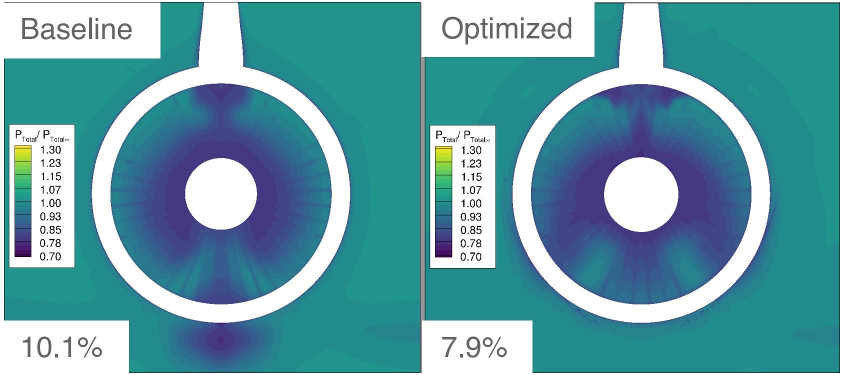
Flow ingested by the TCT

Aerodynamic shape optimization

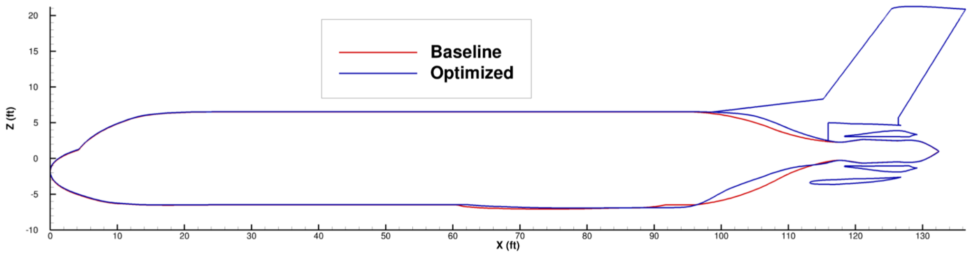
- **Aerodynamic shape optimization to minimize fan distortion**
  - Eliminate flow separation at aft fuselage diffuser
  - Alter flow behavior at aft fuselage contributing to distortion
- **Optimization reduced distortion intensity from 10.1% to 7.9%**
  - Eliminated low momentum flow spillage
  - Eliminated flow separation at diffuser section



Aft fuselage contours for baseline (left), and optimized (right)



Distortion profile at fan face for baseline (left), and optimized (right)



Fuselage contours comparing baseline (red), and optimized (blue) geometries

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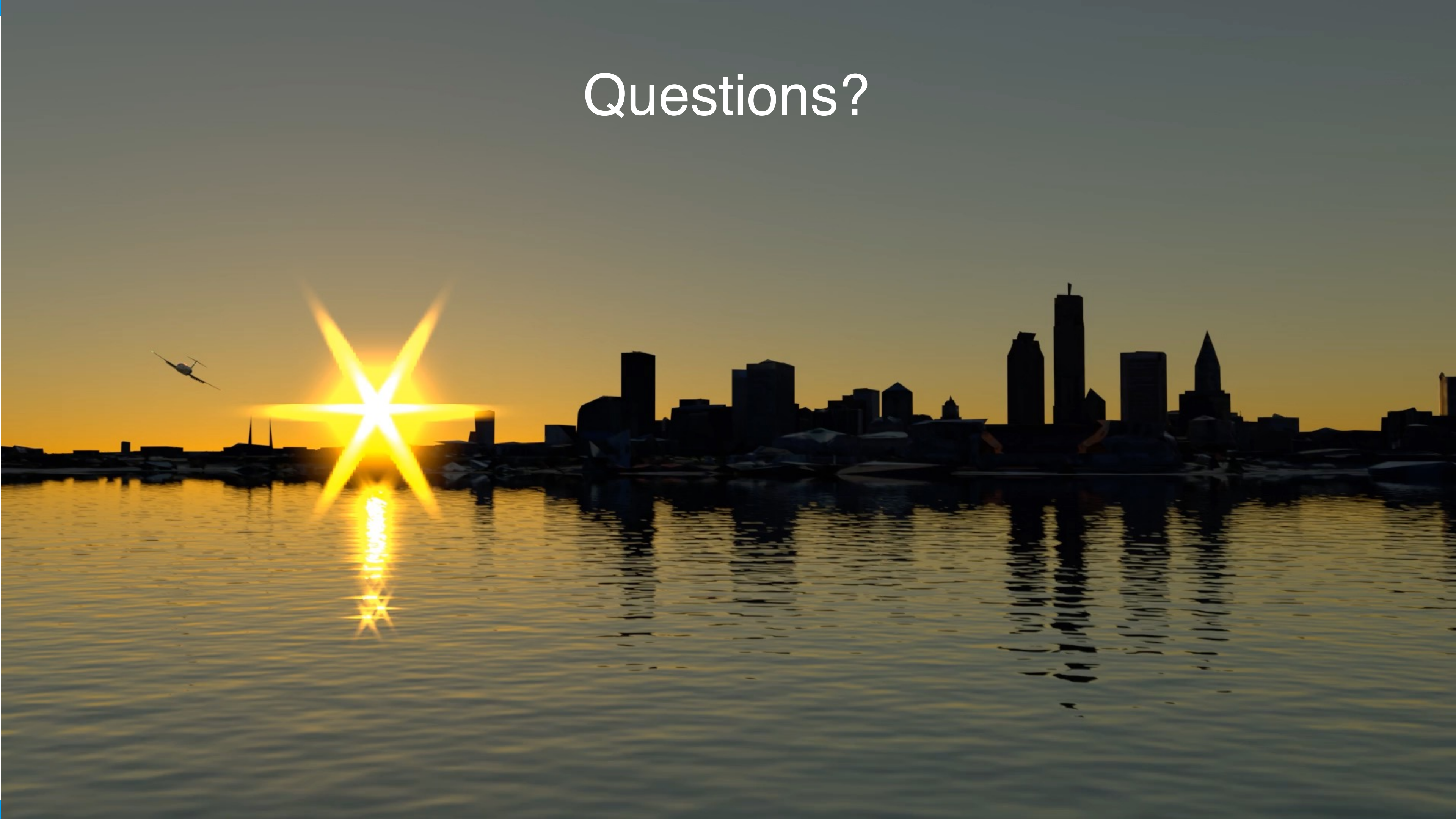
- Special thanks to Michelle Lynde, Ralph Jansen and the rest of the SUSAN Electrofan team for valuable discussions.
- Computational resources provided by NASA Advanced Supercomputing (NAS) division at NASA Ames Research Center.

Questions?



Extra slides

Why Boundary-Layer Ingestion (BLI) Propulsion?

Consider the simplified thrust equation for a ducted fan propulsor:

[Thrust] = [Change in Momentum] × [Change in Time]

= [Mass Flow Rate] × [Change in Velocity]

BLI increases propulsive efficiency:

The boundary layer provides a lower [V1], which, for the same [Thrust] and [Mass Flow Rate] …

- Lower [V2] for the same [Change in Velocity]
- Less work done by fan blades
- Less shaft power required to drive the fan!

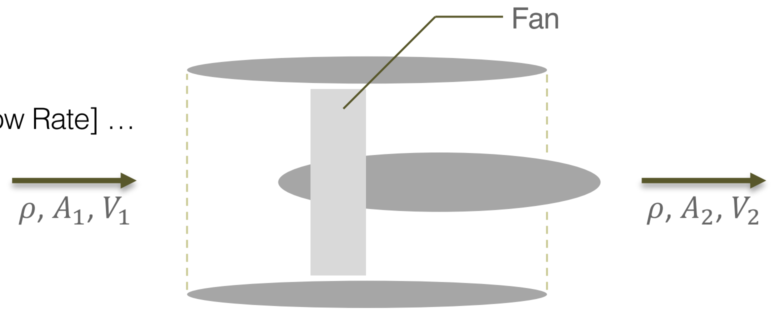


Figure. Ducted fan propulsor.

Challenges:

- Inlet distortion reduces fan blade stability and performance

Why Distributed Propulsion?

Again, consider the simplified thrust equation for a ducted fan propulsor:

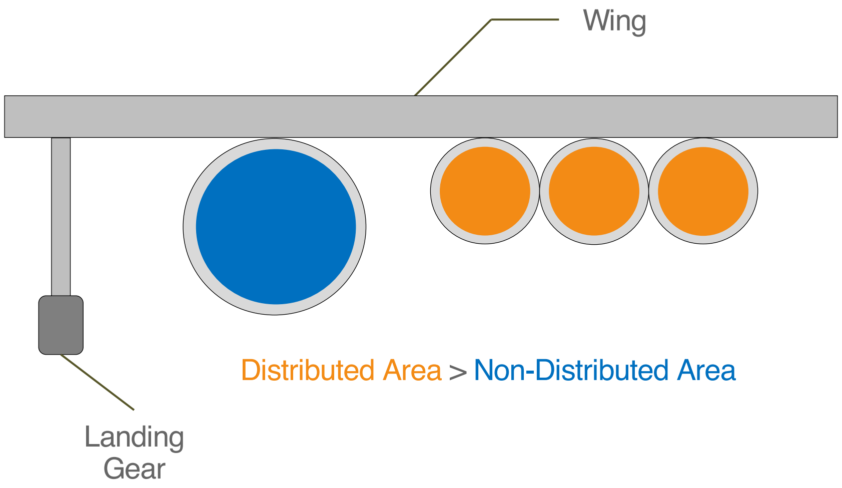
[Thrust] = [Mass Flow Rate] × [Change in Velocity]

[Mass Flow Rate] = [Density] × [Area] × [Velocity]

Distributed propulsion increases propulsive efficiency:

Distributed propulsion allows for a greater inlet capture area [A1], which, for the same [V1] and [Thrust] …

- Higher [Mass Flow Rate] means lower [Change in Velocity]
- Less work done by fan blades
- Less shaft power required to drive the fan!



Challenges:

- More airframe drag (i.e. from more wetted area)
- More weight (i.e. more albeit smaller separate fans, motors, nacelles, pylons, etc.)