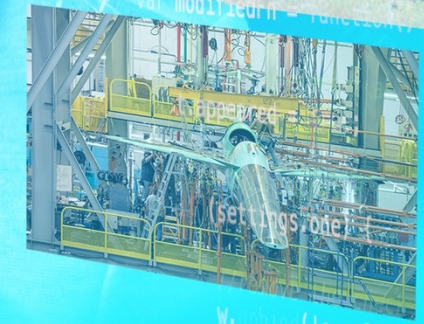
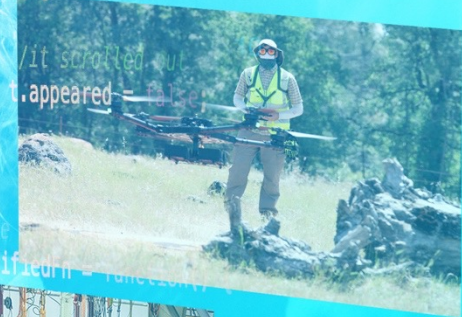


Airframe Technologies to Enable Future Efficient Transports

Dr. Sheida Hosseini, NASA
DLR Visit at Braunschweig Germany
September 29 2023



Outline

Background

Aerodynamic Technologies and Tools

- High Aspect Ratio Wings
- Natural Laminar Flow
- Cruise Slotted Wing
- Boundary Layer Ingesting Propulsor
- Active Flow Control
- Advanced Concept Studies
- Revolutionary Computational Aerosciences

Summary Remarks

Aviation is Vital to Global Economy

- 32.2 million flights globally in 2022
- 250.2 billion tons of freight transported by airlines in 2022



NASA Aeronautics Vision for the 21st Century

Global

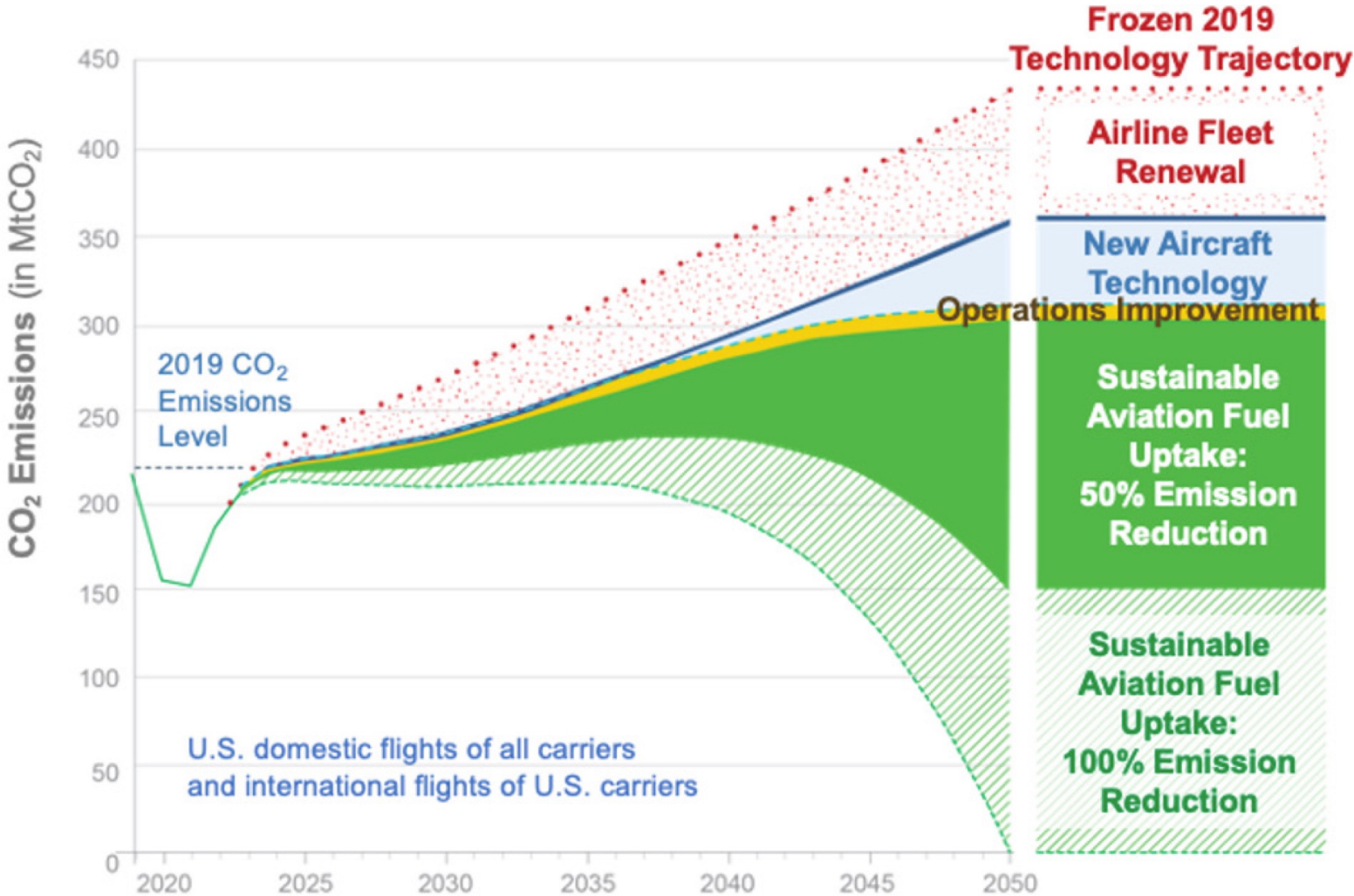


Sustainable

Transformative

U.S. Aviation Climate Action Plan

U.S. aviation goal is to achieve net-zero greenhouse gas emissions by 2050.





Sustainable Flight National Partnership



Small Core Gas Turbine for
5%-10% fuel burn benefit
(HyTEC Project)

Electrified Aircraft Propulsion for
~5% fuel burn and maintenance
benefit
(EPFD & AATT Projects)

Sustainable Aviation Fuels for
reduced lifecycle carbon
emissions
(AATT Project)

Transonic Truss-Braced Wing for
5%-10% fuel burn benefit
(AATT Project)

High-Rate Composites for
4-6x manufacturing rate increase
(HiCAM Project)

Integrated Trajectory Optimization for
1%-2% reduction in fuel required
and minimization of contrail
formation
(ATM-X Project)

Fuel Burn Benefit Estimates for Mach 0.80 TTBW

Subsonic Ultra Green Aircraft Research (SUGAR)

Fuel Burn Benefits Relative to Baseline*

Mission	TTBW Technology	SUGAR Technologies
3500nm	9.0%	59.0%
900nm	7.2%	55.9%

TTBW Technology:

- High aspect ratio thin wing design, strut and jury (AR=19.5)

SUGAR TTBW concept aircraft technologies:

- TTBW
- NLF/HLFC/AFC/Riblets
- Advanced Structures
- Unique Structural Joints
- Advanced Engines
- Next Gen. ATM

* **Baseline:** advanced conventional single-aisle, AR=13, same technologies



NASA/Boeing 4.5% Scale Transonic Performance Test NASA Ames Research Center Primary Plane Wind Tunnel (14 by 19-foot TWT)



NASA/Boeing 8% Scale Low-Speed Performance Test NASA Langley 14- by 22-Foot Subsonic Tunnel

Outline

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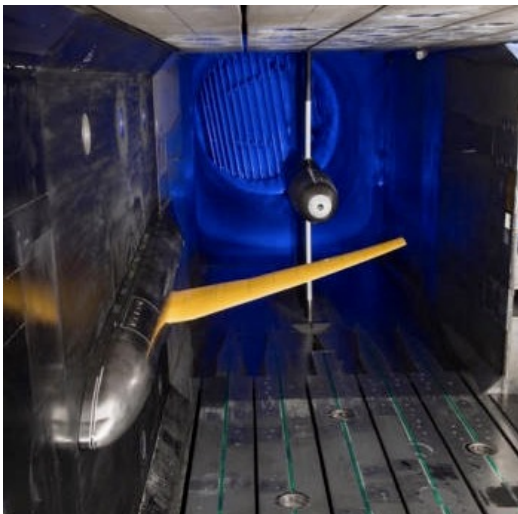
Summary Remarks

Design Method: CFD to Wind Tunnel to Flight

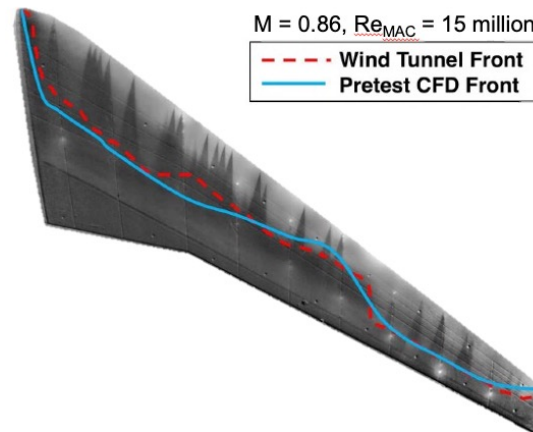
Crossflow Attenuated Natural Laminar Flow (CATNLF)

Common Research Model with Natural Laminar Flow (CRM-NLF) tested in the National Transonic Facility (NTF) in 2018

- Confirmed computational predictions
- Focus of 2020 AIAA Transition Modeling Workshop
- Limited results in wind tunnel motivated flight testing



CRM-NLF semispan model in the NTF

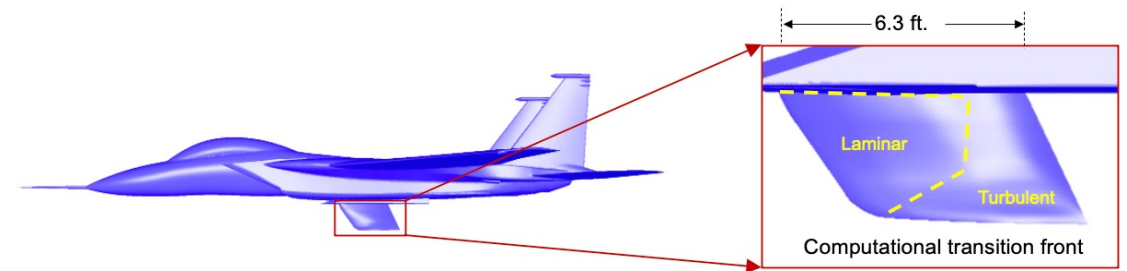


Transition images of CRM-NLF wing show regions of laminar flow on model in the NTF

(AIAA 2019-3292)

Flight test on F-15 at Armstrong Flight Research Center

- Test article is a lifting surface representative of a transonic transport wing designed to support 52% laminar flow
- **Primary Goal:** To confirm the effectiveness of the CATNLF method to obtain laminar flow
- **Secondary Goal:** To investigate the surface requirements for laminar flow applications



Release of Flight Data for Future Workshops

Outline

Background

Aerodynamic Technologies and Tools

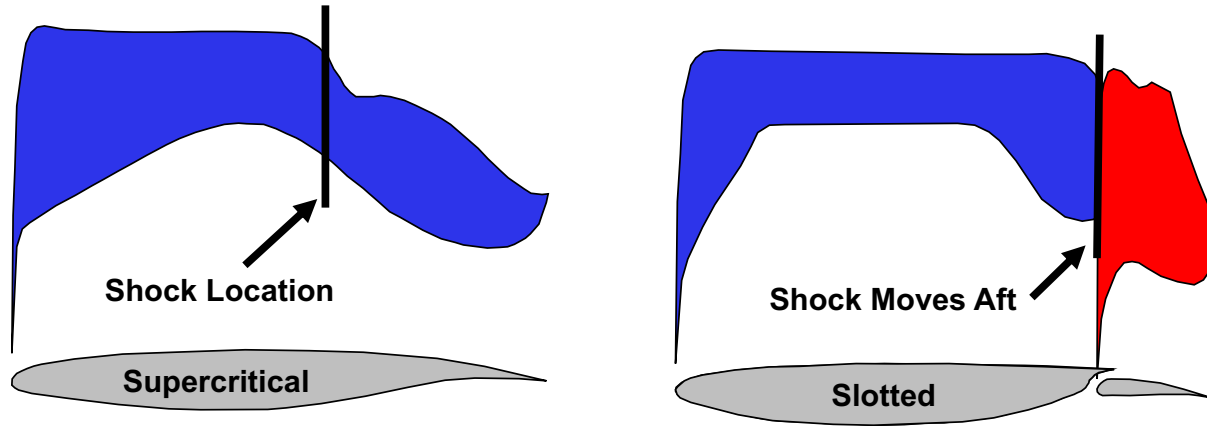
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Summary Remarks

Cruise Slotted Wing (CSW) – Expanding Wing Design Trade Space

Concept

- Flow-through slot permits stronger pressure recovery without separation
- Enables greater aft loading to weaken shock strength, reduction in wave drag








Design Challenge

Skin-friction penalty observed for slotted airfoils

- New boundary layer introduced on flap element, lower Reynolds number (Re_x) relative to supercritical airfoil

Design Tradespace

	Increase Mach Number Improved productivity, more daily city pairs
	Increase Wing Thickness Lighter wing, greater fuel volume
	Decrease Wing Sweep Lighter wing, promotes natural laminar flow
	Increase Lift Coefficient Greater payload limit or cruise altitude
	Decrease Drag Coefficient Less fuel consumption, increased range

Outline

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Summary Remarks

Propulsion Airframe Integration – Boundary Layer Ingestion

Boundary Layer Ingesting Tail-cone System (BLITS)

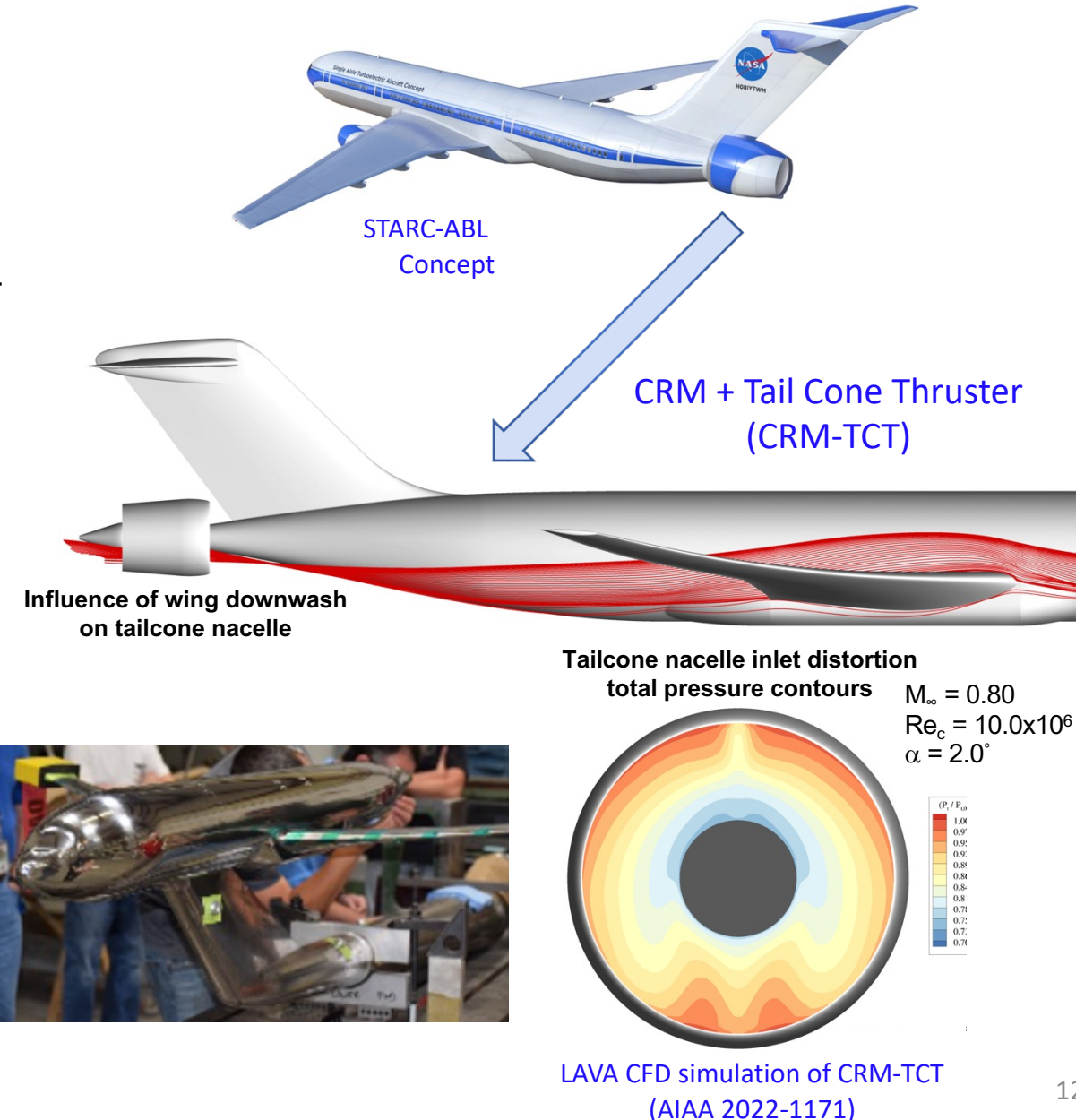
Objectives

Develop integrated CFD capabilities to enable system-level predictions for BLI configurations

- Couple NASA airframe and turbomachinery CFD tools (LAVA + TURBO)
- Wind tunnel test to develop validation data

Status

- We have shown LAVA/TURBO coupling works very well and now we are working on a test matrix looking into various configurations
- CRM-TCT wind tunnel test in NTF was completed in 2023
 - Simulate propulsor with mass flow plugs
 - WT data analysis is in progress



Outline

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Summary Remarks

Active Flow Control to Improve High-Lift System Performance

Selective Use of AFC for Enhanced Performance

Problem

Improved vehicle efficiency during high-lift conditions needed for future fuel-efficient commercial transports

Objectives

Reduce fuel consumption by reducing drag and controlling lift during take-off

Approach

- Use AFC on CRM-HL to increase maximum lift coefficient ($C_{L_{max}}$), increase lift to drag ratio (L/D), and control lift (C_L) in the linear regime of the lift curve at high-lift conditions

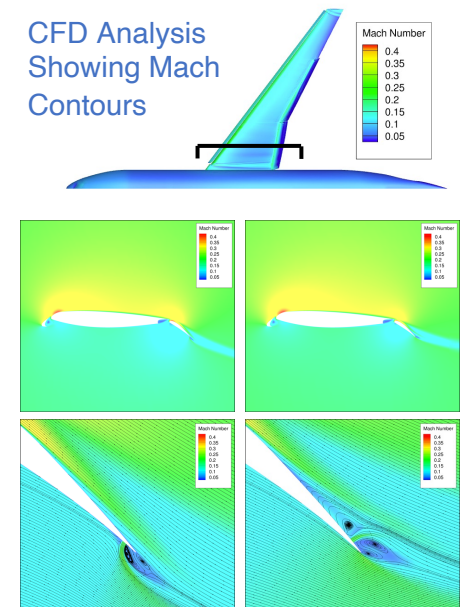
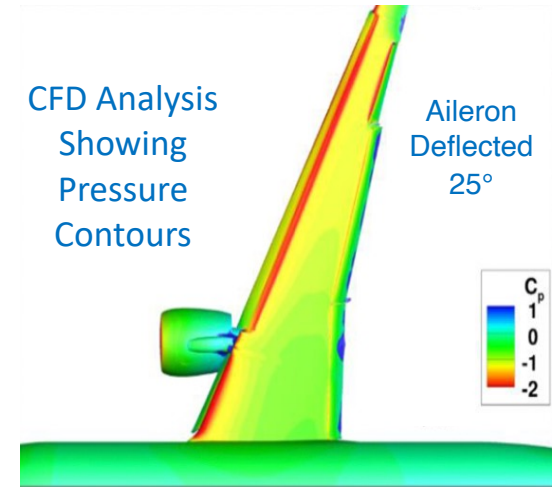
Status

- CFD on CRM-HL evaluating AFC on dropped aileron showed 5% improvement in L/D for a fixed lift coefficient and 2% improvement in $C_{L_{max}}$
- 14- by 22-Foot Subsonic Tunnel test on HL-CRM evaluating AFC on dropped aileron was completed in 2023. WT data are currently being analyzed.
- CFD on CRM-HL using TE normal blowing for lift control was completed.
 - $\Delta C_L = 0.1$ for a fixed AOA and 5% improvement in wing efficiency obtained
 - Load control capability in terms of $\Delta C_L \propto K\sqrt{C_\mu}$ demonstrated.
- 2D WT of TE normal blowing completed in 2023. WT data are currently being analyzed.

Significance

- AFC provides more flexibility for trade in design space
 - 5% improvement in L/D is equivalent to 14,000 lb payload increase or 750 nm range increase
 - $\Delta C_L = 0.1$ at a constant angle of attack is equivalent to shortening the landing gear height by 14 in (1,400 lb reduction)
 - AFC can enable increase in payload, range while reducing the fuel burn

CRM-HL Test of AFC on Aileron in 14x22 Tunnel, 2023



Outline

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Summary Remarks

NASA AACES 2050 Studies

Advanced Aircraft Concepts for Environmental Sustainability (AACES)



FY23 “N+4” AACES Studies - Explore 2020s, Demo 2030s, Impact 2040s

- *2040s Marketplace (payload/range/speed), 2050 Environmental Goals*
- *Alternative Energy Scenarios (LH2, LNG, Increased Electrification, 100% SAF)*
- *Advanced Airframes (clean energy compatible, shielding, adaptive, unconventional structures)*
- *Alternative Propulsion (clean energy compatible, BLI, distributed propulsion, hybrid electric)*
- *Tools & Methods for Reduced Lifecycle Cost & Environmental Impact*



Outline

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- Advanced Concept Studies
- **Revolutionary Computational
Aerosciences**

Summary Remarks

Revolutionary Computational Aerosciences (RCA)

Certification by Analysis (CbA)

Problem

While computational based modern wing design and performance predictions are accurate for well behaved flows, prediction of certification parameters such as $C_{L_{max}}$, buffet and V_{mu} primarily is done through wind tunnel and flight testing

Objectives

Develop and demonstrate computationally efficient, robust and accurate modeling tools

Approach

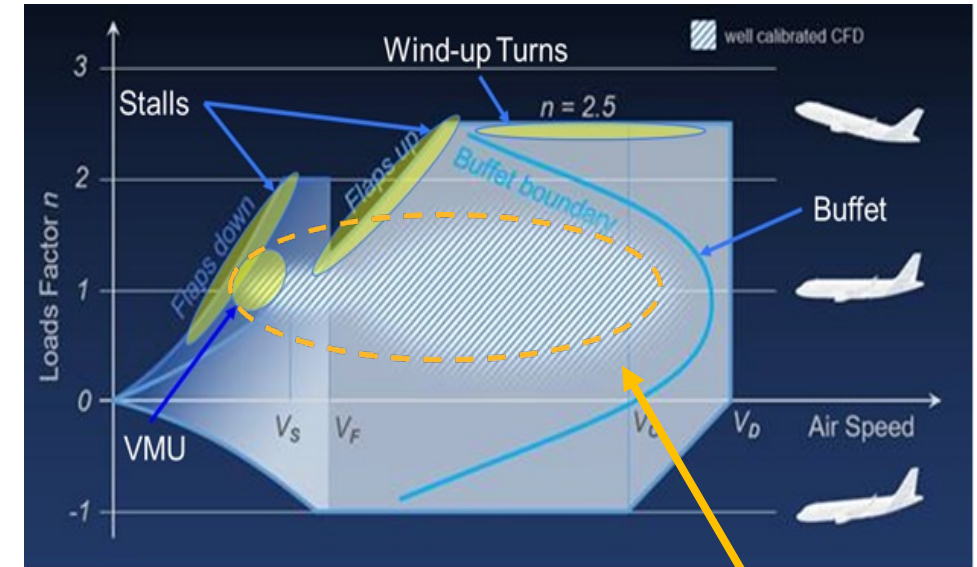
- Develop requirements for CbA, including required prediction accuracy for various maneuvers
- Develop a research roadmap to overcome technology gaps
- Demonstrate the developed models predict certification parameters with the same accuracy as certification flight tests

Status

- Accurate prediction of $C_{L_{max}}$ was deemed as a key requirement by the study
- CRM-HL ecosystem development plan is completed
- Experimental campaign has been launched partnering with US industry and international aerospace agencies to provide CFD validation data
- Code-to-code comparisons are progressing through AIAA CRM-HL workshops

Significance

If simulated results are found within required engineering accuracy compared to the experiments, then this will constitute an important step towards demonstrating CFD- based predictions capabilities. This can significantly improve airplane performance and safety while it can reduce certification cost



Limits of
current
(RANS) CFD

CRM-HL Ecosystem Development Plan

Certification by Analysis (CbA)

- NASA 10% SS (14x22/Q, 1atm / 3atm)**
 - Confirm CRM-HL design features
 - Data for reference configurations
 - NASA research (AFC, noise)
 - Tie in to NTF-derived Re # trend data
- NASA 5.2% SS cryo (NTF/ETW/others)**
 - Primary model for Re # trends
 - SS/FS model issues deemed Re # dependent
 - Wall effects
 - NASA research (Flow measurements, AM, others)
 - DLR testbed for alternate LE and nacelle
- NASA 2.7% FS cryo**
- NASA 2.7% SS cryo**
- NASA 5.2% SS (LE treatment, HBR nacelle)**
- Boeing 6.0% FS 3atm**
- Boeing 4.0% SS**
- ONERA 5.1% FS 3atm**
- KHI 3.23% FS**
- JAXA 8.0% SS**
- Boeing 6.0% SS/FS 3atm (Q/F1/others)**
 - Configuration variation data
 - SS/FS model issues
 - Tie in to NTF-derived Re # trend data
 - Mounting system effects (T&I)
 - Wall effects (collaboration with ONERA)
 - Configuration-level PIV data
- Boeing/UK 4.1% SS (Academic)**
 - Flow measurement technology development
 - Platform for UK aerodynamic research
- ONERA 5.1% FS 3.85atm (F1/Q)**
 - Wall effects (collaboration with QinetiQ)
 - Exploit unique data collection opportunities
 - Tunnel Standard Model
- KHI 3.23% FS**
 - Aerodynamic and noise research
 - Tunnel Standard Model
- JAXA 8.0% SS**
 - Acoustics
 - CFD validation
 - PIV flow field measurements
 - Tunnel Standard Model

MODEL

NASA 10% SS

NASA 5.2% SS cryo

NASA 2.7% FS cryo

NASA 2.7% SS cryo

NASA 5.2% SS (LE treatment, HBR nacelle)

Boeing 6.0% FS 3atm

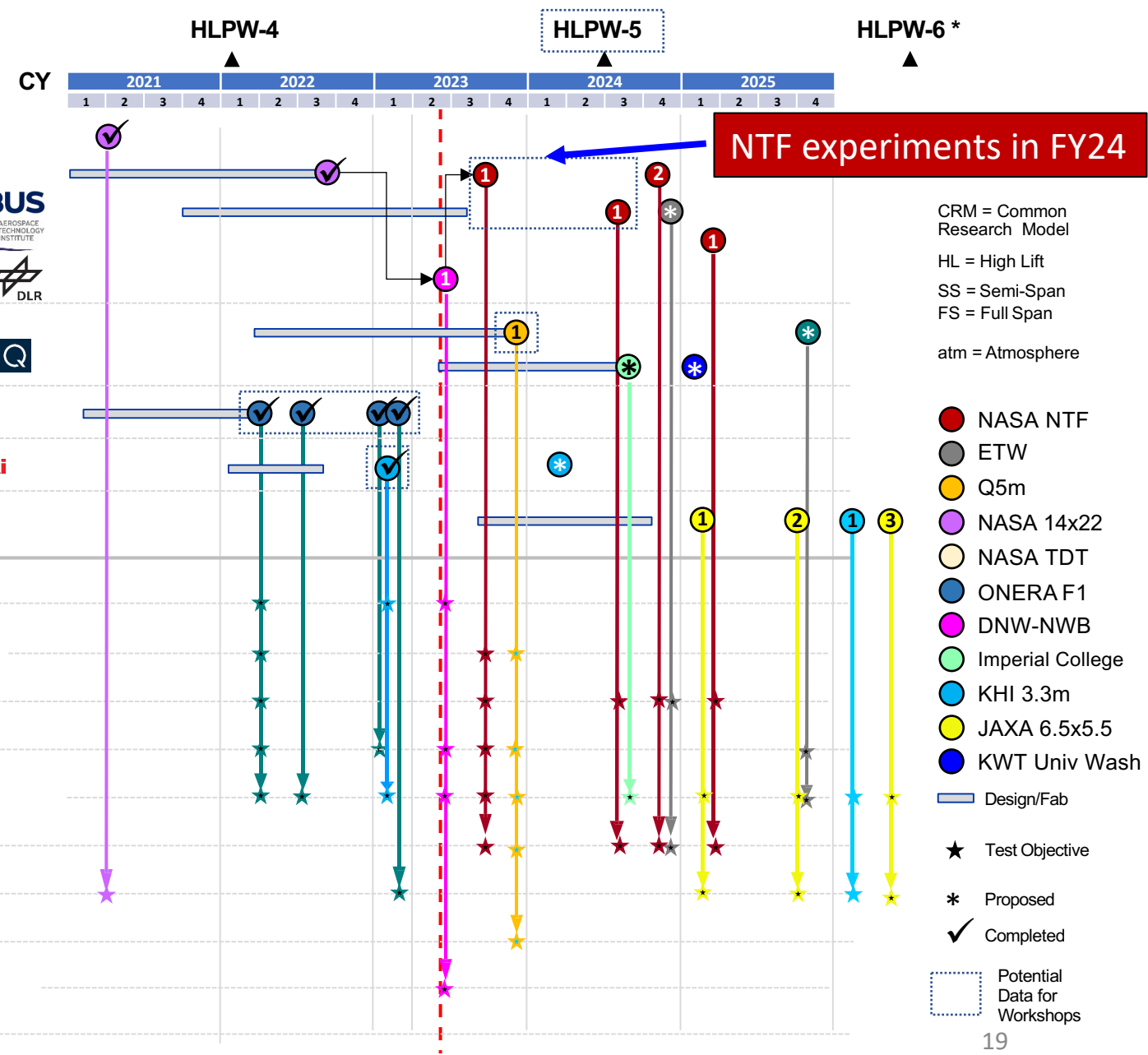
Boeing 4.0% SS

ONERA 5.1% FS 3atm

KHI 3.23% FS

JAXA 8.0% SS

- Reference Configuration
- Optimization/Sensitivity Data
- Reynolds Number Effects
- WT Modeling Effects
- Flow Physics CFD Validation Data
- Ice Effects
- Acoustics
- Trailing Wake
- Propulsion / Airframe Integration
- Active Flow Control



Blind code-to-code Comparison for 5.2% Scale CRM-HL

Certification by Analysis (CbA)

Approach

- WMLES using LAVA , FUN3D and CharLES codes are completed at Reynolds numbers of 5.49 million and 16 million in free air

Status

- For both Reynolds numbers, maximum-lift from these simulations is within about 2 percent of the average of the four solutions. The drag and moment distributions from the simulations are also in reasonable agreement.
- This is remarkable given that the three codes use different numerical schemes and employ very different grid topologies

Significance

This is an important step because in previous attempts (e.g., High-Lift Prediction Workshop – 4), experimental data was available upfront essentially providing the target answer

Next Steps

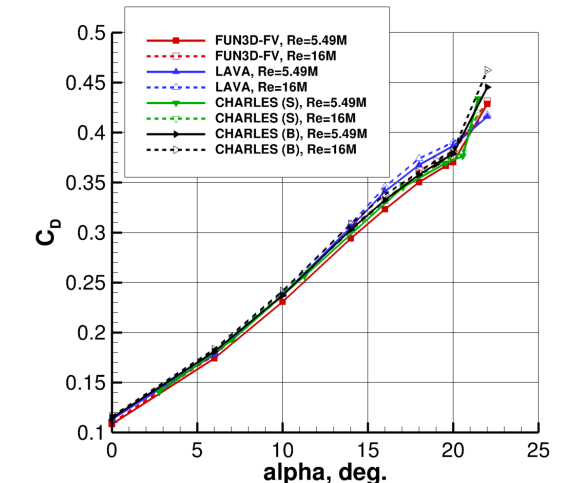
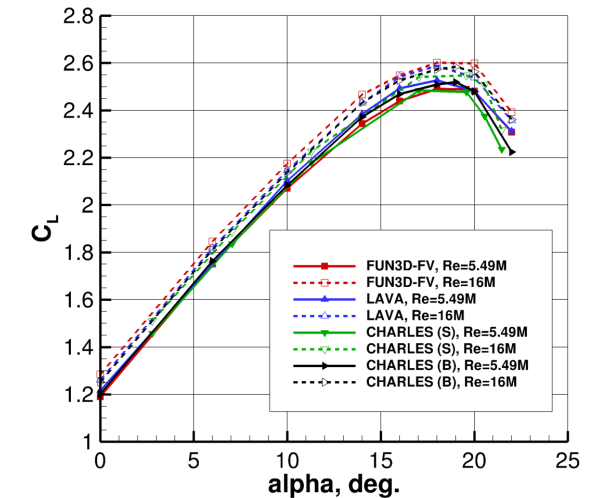
AIAA HLPW-5 to be held in summer 2024 with five technology focused groups:

- Fixed-grid Reynolds-averaged Navier-Stokes (**RANS**)
- Automated mesh adaptation (**ADAPT**)
- High-order methods (**HO**)
- Wall-modeled large-eddy simulation (**WMLES**)
- Hybrid RANS/LES (**HRLES**).

HLPW-5 partners:

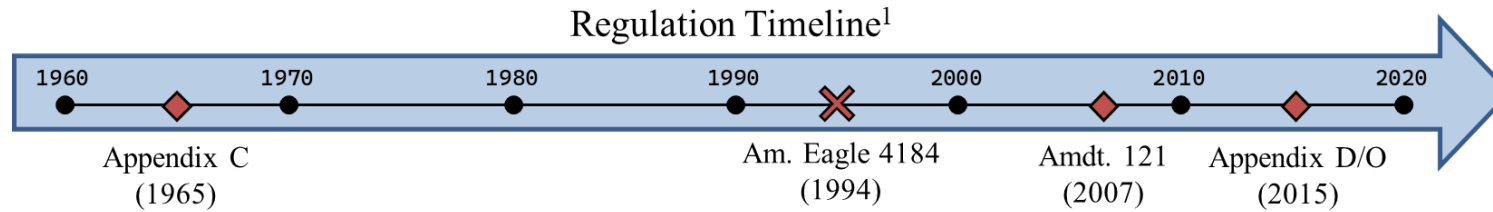
NASA, Boeing, MIT, University of Wyoming, NIA, ORNL, JAXA, DLR, KHI, ONERA, Gulfstream, Textron, Volcano Platforms, Luminary Cloud, and Amazon Web Services.

HLPW is also partnering with several commercial mesh-generation companies, including Cadence, Helden Aero, and BETA-CAE.



Icing Prediction

Certification by Analysis (CbA)



Problem

Current practices require use of wind tunnels to assess performance degradation of iced vehicles. For novel large commercial transports and engines with no flight history, this poses an unknown safety risk, and by extension a certification risk

Approach

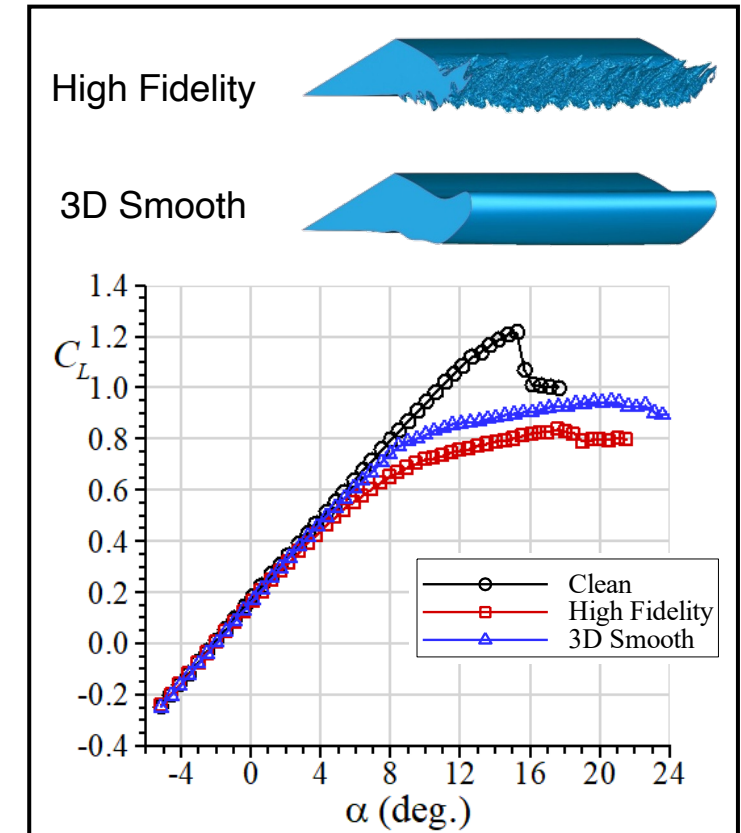
Develop computational capabilities to specially provide insight into the first order fundamental physics that dominates icing challenges

Status

GlennICE is currently being developed and is used by some of our U.S. government and industry partners

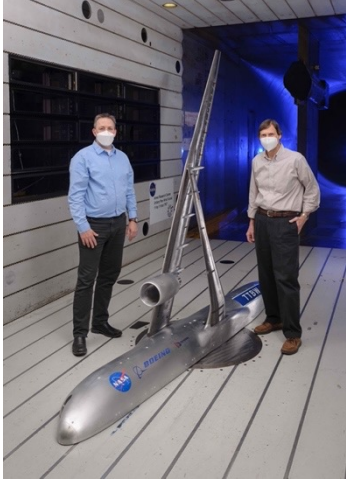
Significance

- Icing related challenges bear a significant economic burden. Advancements in tools as well as understanding the dominant physics has historically been the path to reduce this economic burden



CRM65 performance data collected on a cruise cantilevered wing. CRM-HL effort consists of a high lift wing-body geometry at high Re.

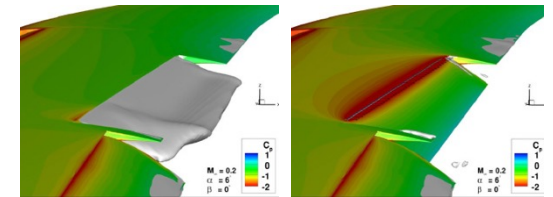
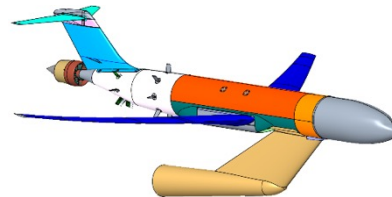
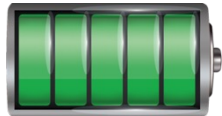
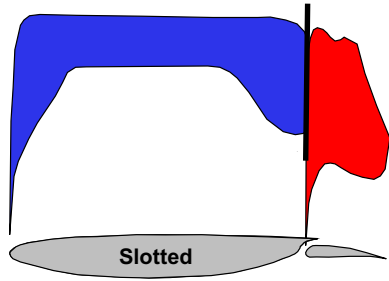
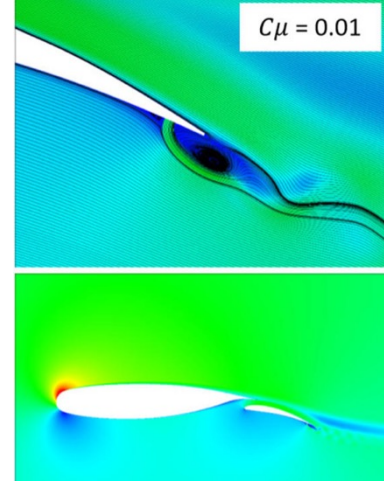
Summary Remarks

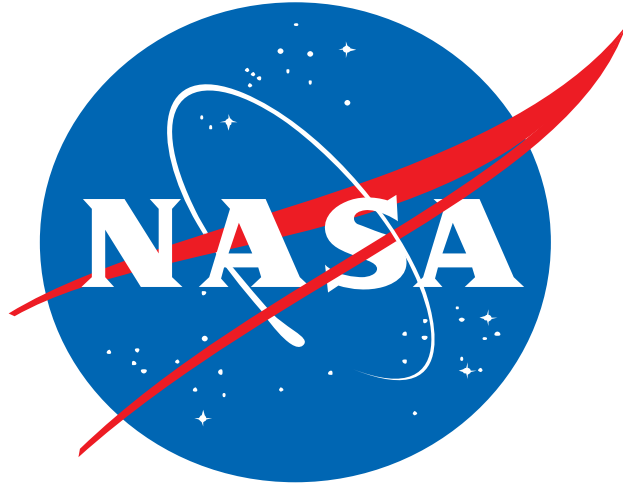


NASA is committed to dramatically improve the energy efficiency of subsonic commercial transport aircraft through focused research efforts supporting the goals of the Sustainable Flight National Partnership.

The aerodynamic technologies presented today highlighted a broad range of research efforts that can realistically enable the development of ultra-efficient commercial transports in the 2030 timeframe and help meet the 2050 environmental.

What was presented today is the work of many individuals and teams within NASA and is funded by NASA's Advanced Air Transport Technology (AATT) and Transformational Tools and Technologies (TTT) projects.





Thank You for Your Time!

