SIEMENS
Ingenuity for life

Aerospace and defense

ATA Engineering

Engineering firm reduces airplane noise by using STAR-CCM+ to create digital twin of engine air brake

Product

Simcenter

Business challenges

Reduce the noise airplanes radiate to surrounding communities

Facilitate quieter landings

Design, fabricate and test a flight-weight EAB

Keys to success

Use NX to facilitate rapid generation of designs based on aerodynamic performance

Use STAR-CCM+ to quantify flow performance and operability and predict thermal operating environments

Analyze the full aerodynamic design space in simulation before identifying the final design

Results

Used STAR-CCM+ to help create a digital twin of the EAB

Demonstrated potentially quiet, steep approach glide slope in a system simulation

Used NX with assembly constraints to visualize the deployment and check for interference between parts

Siemens PLM Software solutions help ATA Engineering develop drag device to facilitate quieter landings

Taking a cleaner approach

Airplanes evoke feelings of awe and amazement for most people, but if you live uncomfortably close to a major airport, you might feel a lot more annoyed than amazed. Constant aircraft noise causes sleepless nights, stress and other health issues, reducing quality of life. Airports, airlines and aviation authorities around the world have been in an uphill battle to mitigate noise pollution in their neighboring communities. Neither the airports nor the surrounding communities are moving away from each other anytime soon, necessitating the need for urgent solutions.

The Advisory Council for Aeronautics Research in Europe (ACARE) "Flightpath 2050" document, Europe's vision for aviation, has set a goal of reducing noise at airports by 65 percent by 2050. Although mitigation strategies include flying restrictions, soundproofing homes and nighttime curfews, the real solution to meeting such goals lies at the root cause of the problem – reducing the noise airplanes generate and radiate to the surrounding communities.

The major source of airport noise comes from engine power during takeoff. During descent and approach to landing, the engines are powered down and the dominant noise is often due to the aerodynamic exposure of structures such as control surfaces, landing gear, high-lift devices and speed brakes. These structures often provide the drag needed to maintain a desired trajectory, but may also become the source of excessive noise.

One way to mitigate this noise is through drag devices that enable quieter landings through steeper, slower and/or aero-acoustically cleaner approaches. ATA Engineering has worked in collaboration with the NASA Glenn Research Center (GRC), Williams

Figure 1: The EAB nozzle configurations on the FJ44-4 engine.

International and the Massachusetts Institute of Technology (MIT) to develop a novel engine air brake (EAB) concept that will pave the way for quieter aircraft.

The EAB is a unique drag device that was conceived at MIT as a ram air-driven nacelle with a stationary set of turning vanes generating a swirling exhaust flow from the engine. With funding from the NASA Small Business Innovation Research (SBIR) program, ATA Engineering has developed and brought this technology to life in the form of a deployable swirl vane exhaust nozzle. Using STAR-CCM+® software and NX™ software, tools in the Simcenter™ portfolio from Siemens PLM Software, played a key role in the design of the EAB, accelerating the readiness of the technology by creating and validating a digital twin before building the prototype.

Using NASA's Technology Readiness Level (TRL), a measurement system to assess the maturity level of a particular technology, ATA has advanced the EAB concept to TRL level 6 – a fully functional prototype. TRL numbers run from 1 to 9 with level 1 pertaining to basic principles and conception of the idea and level 9 indicating a flight-proven system through successful mission operations.

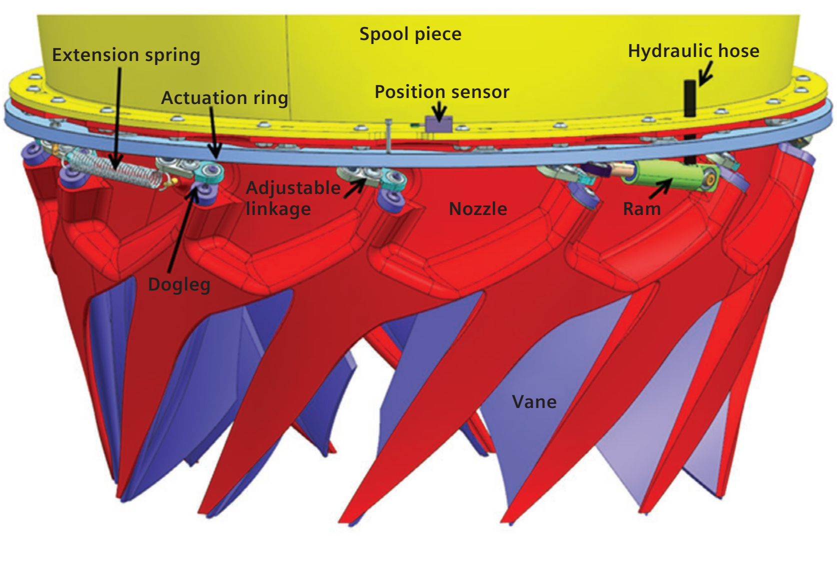


Figure 2: Key components of the EAB assembly modeled in NX.

Defining EAB

ATA's EAB concept[1, 2, 3] evolved from an idea that was developed at MIT. The EAB is a deployable device for drag management in aircraft. Pressure drag is generated through swirling outflows from the engine's propulsion system by reducing thrust. The EAB is stowed during flight but deploys a swirl vane mechanism (figure 1) during landing, creating a swirling vortex from the jet engine exhaust flow. The constant flow of swirling air creates additional drag by reducing thrust and is sustained by the radial pressure gradient from the swirl vanes.

The system enables a slower, steeper and acoustically cleaner approach/descent when engine thrust cannot be further reduced. The EAB ground demonstrator consisted of a spool piece, an aluminum nozzle, 12 high temperature aluminum vanes, 12 stainless steel shafts, 12 dogleg lever arms and adjustable linkages, three hydraulic rams, three extension springs, a stainless steel actuation ring and a string potentiometer (figure 2). ATA Engineering partnered with Williams International to demonstrate the EAB on a FJ44-4 engine, a 3,600-pound class, medium bypass, twin spool engine.

Challenging design requirements

As with any design, changes always result in undesired effects elsewhere and this is more pronounced in the aerospace design space. As part of the TRL program, design requirements and technical objectives for the EAB were identified first. The technical objectives were:

- Design, fabricate and test a realistic flight-weight EAB on a modern turbofan propulsion system
- Quantify the equivalent drag, effect on operability, noise, cost and weight of the system

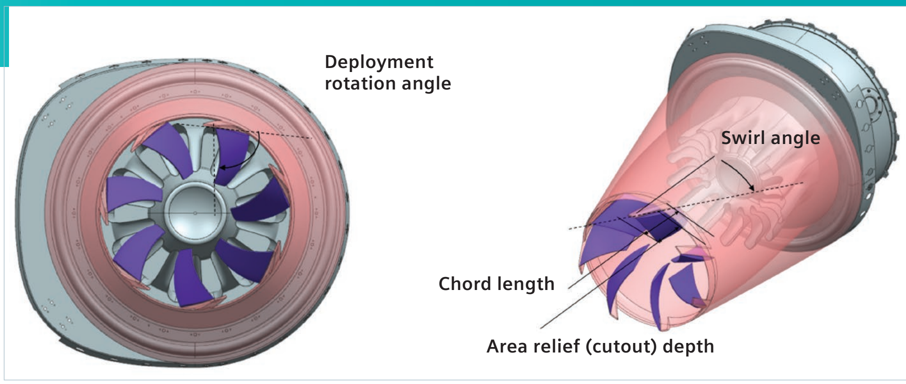
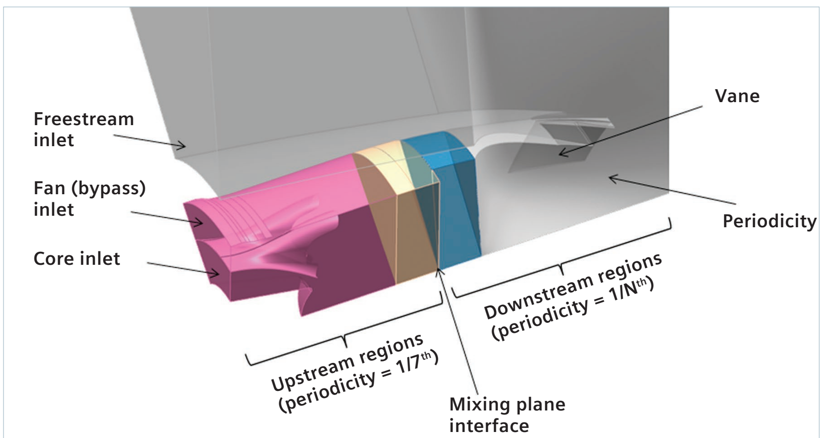


Figure 3: (Left) Design parameters studied with STAR-CCM+.



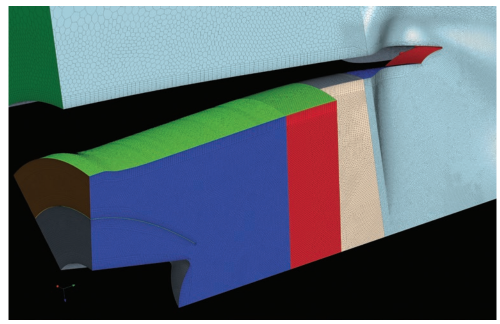


Figure 4: (Left and above) The numerical domain in STAR-CCM+ and the computational mesh.

- Perform system-level analysis of the proposed impact in terms of steep approach for noise reduction

For the aerodynamic design of the EAB, the following requirements were identified:

- No measurable thrust or thrust-specific fuel consumption (TSFC) penalty when stowed
- A 15 percent net thrust reduction at dirty approach fan speed when deployed, measured as a percentage of the stowed nozzle's gross thrust at same condition
- No measurable fuel consumption penalty or flow reduction when fully deployed
- Adequate surge margin during all operation, including dynamic deployment and stowing
- Meet stow/deploy time requirements (.5 seconds and 3 to 5 seconds, respectively)

Other design requirements included structural and packaging constraints that ensured that the EAB could be integrated into a typical aircraft installation, such as the Cessna CJ4, without impeding performance while providing the noise reduction benefits. The design activity involved performance assessment of various systems, including aerodynamic, mechanical, acoustics and structures.

Using STAR-CCM+ for aerodynamic design

Parametric solid modeling with NX for design from Siemens PLM Software was used to create the 3D computer-aided design (CAD) geometry of the EAB. This facilitated rapid generation of designs with varying parameters based on aerodynamic performance. The various design parameters (figure 3) for the numerical simulation were: vane count (N), swirl angle (S), deployment rotation angle (R), chord length (L) and cutout (area relief) depth (C).

EAB technology has advanced due to an analysis-driven design approach using STAR-CCM+ to quantify flow performance and operability, and predict the thermal operating environments of the design.

EAB technology has advanced due to an analysis-driven design approach using STAR-CCM+ to quantify flow performance and operability, and predict the thermal operating environments of the design.

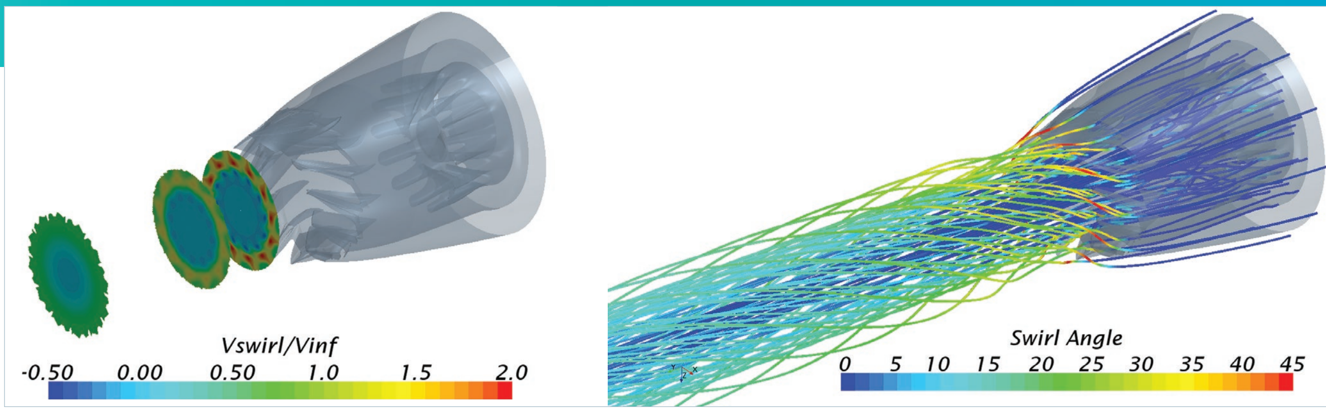


Figure 5: Mixing-plane results for final design in deployed configuration showing (a) circumferential-to-freestream velocity ratio at downstream exhaust planes and (b) streamlines colored by swirl angle.

The swirl velocity shows the flow becomes axisymmetric about two nozzle diameters downstream of the vanes. The aerodynamic performance results from STAR-CCM+ were used to update the design parameters and iterate on the NX design.

Using the power of computational fluid dynamics (CFD), design optimization and powerful computing hardware, ATA Engineering was able to analyze the full aerodynamic design space before identifying the final design that met all the aerodynamic requirements in simulation. The aerodynamic domain is shown in figure 4. The domain was discretized with polyhedral cells. Prism layers were used to capture the boundary layer flow. The final designs had a mesh count of 3 to 5 million cells. Total pressure and temperature were specified as boundary conditions at the fan, core and freestream inlet. Steady Reynolds-Averaged Navier-Stokes (RANS) simulations with ideal gas and k-ω SST turbulence model were carried out.

Circumferentially periodic boundary conditions were used, enabling modeling of 1/7th of the upstream region. A mixing plane interface was used to cope with the lack of uniformity in the flow emanating from the 14-lobe mixer. Reducing the computational domain in this way enabled faster exploration of the design space. Full annulus simulations were carried out on final designs to verify consistency and the performance prediction. Contours of dimensionless swirl velocity (normalized to approach flight velocity) and streamline patterns for the stowed and deployed final design are shown in figure 5. The swirl velocity shows the flow becomes axisymmetric about two nozzle diameters downstream of the vanes. The aerodynamic performance results from STAR-CCM+ were used to update the design parameters and iterate on the NX design. Exactly 150 different designs were evaluated and the best performing design was identified, the parameters of which are shown in figure 6.

Providing an analysis-driven design

Aside from the aerodynamic analysis detailed above, ATA Engineering used Siemens PLM Software tools throughout this analysis-driven design process to define the final configuration. The multi-physics capabilities of STAR-CCM+ enabled performance and gap leakage analysis with RANS CFD, thermal analysis with conjugate heat transfer (CHT) modeling, unsteady loads calculation with large eddy simulation (LES) capability and flutter assessment. Thus a digital twin of the EAB was created that validated the aerodynamic performance of the final design. Structurally, NX Nastran® software from Siemens PLM Software was used for finite element analysis (FEA), fatigue analysis and predicting thermal/structural

Thus a digital twin of the EAB was created that validated the aerodynamic performance of the final design.

deformation. Figure 7 shows sample results from various simulations used to create the complete digital twin. The deployment mechanism was challenging to design due to limited space and syncing the operation of the 12 vanes. Performing solid modeling in NX with assembly constraints facilitated visualizing the deployment and checking for interference between parts. The physical EAB prototype was manufactured with a combination of a 5-axis mill and hand work to bring the nozzle up to specifications.

Reaching Technology Readiness Level 6

Full-scale ground testing of the final EAB design was conducted at Outdoor Test Facility #2 (OTF2) at Williams International's complex in Walled Lake, Michigan. The testing confirmed the performance of the EAB prototype. Here are the results from the test:

- Met drag and flow/operability targets
- Noise was favorable compared to analysis
- Demonstrated dynamic deployment (<5s) and stow (.5s)
- Reduced fuel burn on deployment
- Mechanism fit in a notional cowl
- Predicted thermal performance was matched and no structural dynamic concerns were found
- Demonstrated potential quiet steep approach glide slope in a system simulation

Testing confirmed the performance of the EAB as a function of the vane rotation angle, which had been predicted with the digital twin. Figure 8 shows dimension-less flow capacity on the X axis and drag generated on the Y axis for stowed and other stages in the deployment cycle. The predictions generated by using STAR-CCM+ were in sync with test results for all configurations, reinforcing the use of STAR-CCM+ as a valuable design tool to bring this new technology to life. A steep approach flyover analysis predicted a 1- to 3-decibel (dB) reduction in noise on the ground, successfully confirming the performance of the EAB as a noise-reducing device.

Figure 6: Using STAR-CCM+ to identify the final design from among 150 designs.

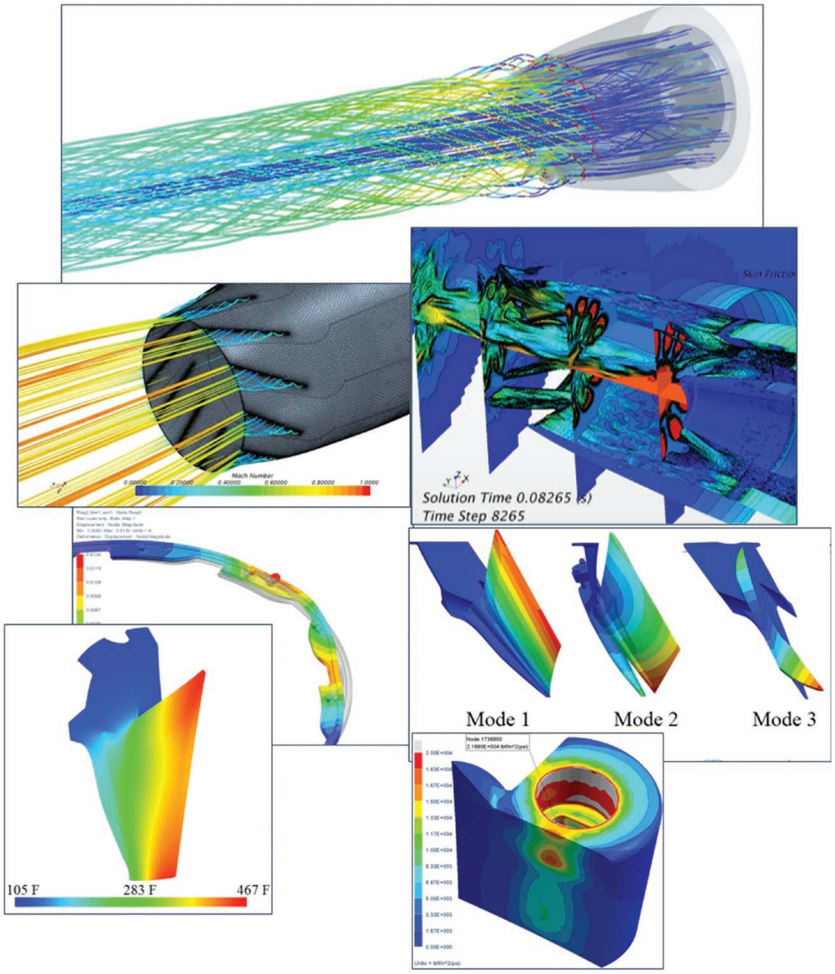


Figure 7: Results from various Siemens PLM Software tools creating the digital twin for the EAB.

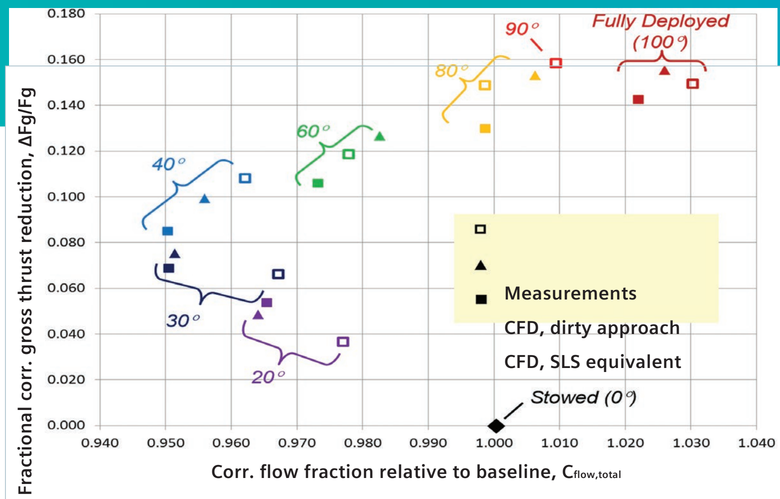


Figure 8: Thrust reduction comparison between ground testing and digital twin predictions (STAR-CCM+).

Solutions/Services

Simcenter
www.siemens.com/simcenter

STAR-CCM+
www.siemens.com/star-ccm-plus

NX
www.siemens.com/nx

Customer's primary business

ATA Engineering provides analysis and test-driven design solutions focusing on the needs of major manufacturers in addressing their cost, quality and time-to-market engineering challenges for mechanical and aerospace systems. ATA uses advanced computer-aided engineering software to solve problems for customers in the aerospace, biomedical, automotive, entertainment, and consumer products industries.
www.ata-engineering.com/

Customer location

San Diego, California
United States

Next steps

The next steps are ground testing the reliability and durability of the system and a flight test demonstration. ATA Engineering hopes that future aircraft designs will incorporate the EAB, and the device might also be retrofitted to existing aircraft. There may yet be a day in the future when the general population is lining up to live in close proximity to airports. Sound crazy? Maybe not. Now that airplanes and airports can be quieter, very few other balcony views can match the sheer splendor of watching our fantastic flying machines take off and land all day.

References

1) Shah, P.N., et al. "Engine Air-Brakes for Quiet Air Transport." AIAA-2007-1033, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, January 8–11, 2007

2) Shah, P.N., et al. "A Novel Turbomachinery Air-Brake Concept for Quiet Aircraft," Journal of Turbomachinery 132, October 2010

3) Shah, P.N. et al. "Aeroacoustics of Drag Generating Swirling Exhaust Flows." AIAA Journal 48, no. 4, April 2010: 719–737

The predictions generated by using STAR-CCM+ were in sync with test results for all configurations, reinforcing the use of STAR-CCM+ as a valuable design tool to bring this new technology to life.

Siemens PLM Software

Americas +1 314 264 8499
Europe +44 (0) 1276 413200
Asia-Pacific +852 2230 3308

www.siemens.com/plm

66628-A7 9/17 B