



Overview of Aeroacoustic Measurements of 18% Scale Gulfstream Aircraft Model in Langley's 14x22 Wind Tunnel

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**Acoustic Technical Working Group
NASA Langley Research Center, Hampton, Virginia
April 15-16, 2014**



Objective

- Mitigate radiated airframe noise during aircraft landing
 - Develop effective noise reduction (NR) concepts for current and future generations of civil transport

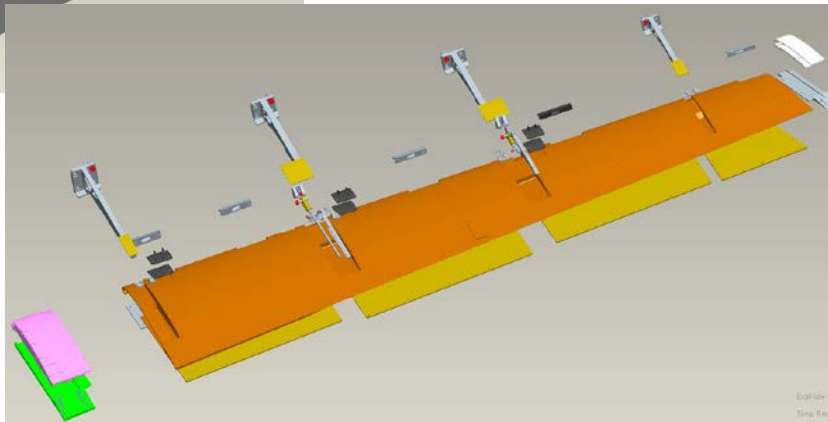
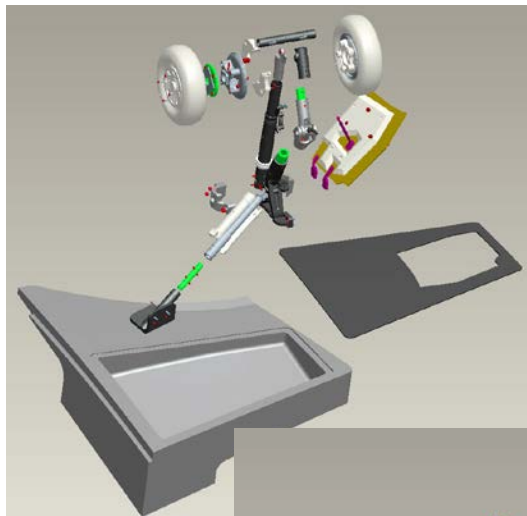
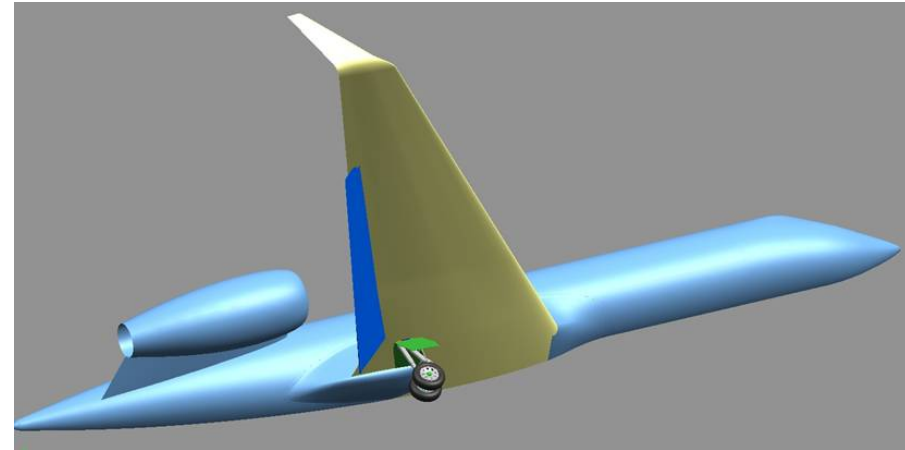
Execution Plan

- Utilize **flight tests**, **wind-tunnel experiments**, and **computational simulations** to generate a comprehensive aerodynamic and acoustic database to:
 - Better understand the principles of airframe noise generation
 - Improve airframe noise prediction tools
 - **Develop efficient noise reduction concepts**
- Evaluate the most promising noise reduction concepts in a realistic environment

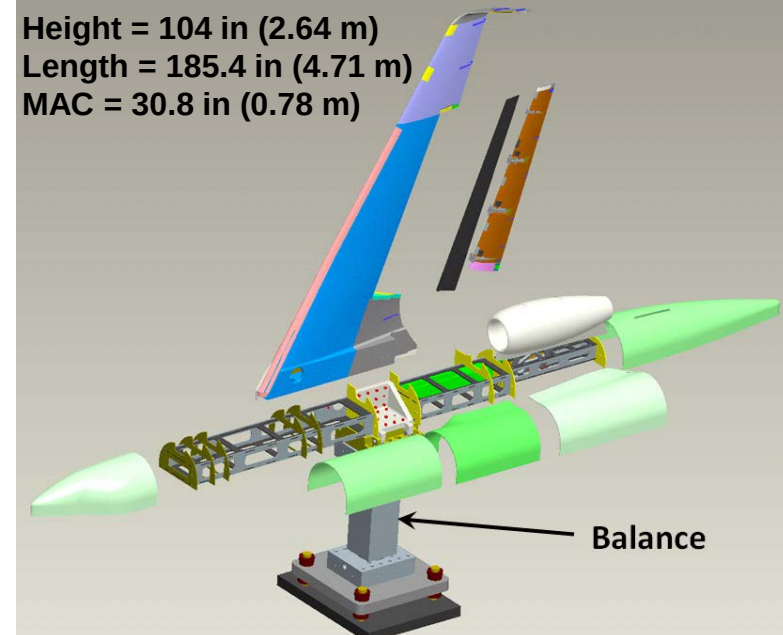
Semi-Span Gulfstream Aircraft Model



- High fidelity model
 - 18% of full-scale
 - Geometric details captured
 - Highly instrumented and fully metric
- Duplicate main gear (Goodrich model)



Height = 104 in (2.64 m)
Length = 185.4 in (4.71 m)
MAC = 30.8 in (0.78 m)



Aeroacoustic Testing of 18% Scale Aircraft Model



- **Multiple entries in NASA LaRC 14'x22' tunnel**
 - Phase1: October 2010 → Aerodynamic measurements
 - Phase2: February 2013 → Aero and acoustic measurements
- **Phase2 test campaign**
 - Limited repetition of aerodynamic measurements
 - Acoustic: Microphone array and free-field microphones
 - Off-surface flow: PIV and LV
- **Extensive evaluation of noise reduction concepts**
 - Flap side-edges
 - Main landing gear
 - Gear-flap interaction

Acoustic Configuration - 2013



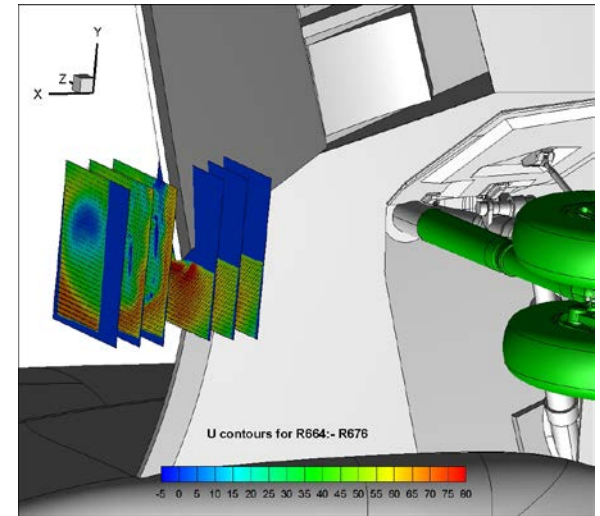
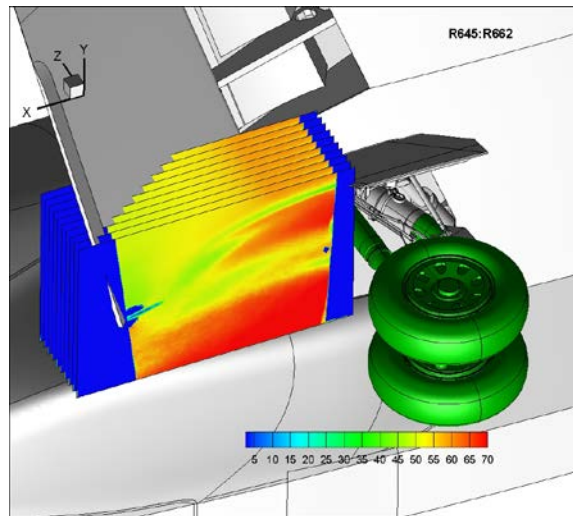
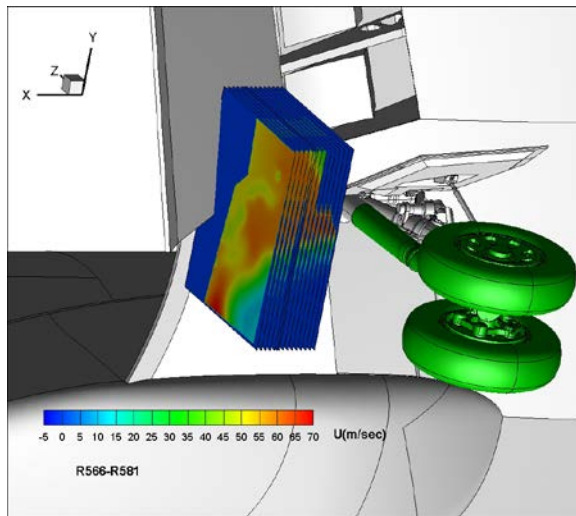
PIV Configuration - 2013



Off-surface Flow (PIV) Measurements



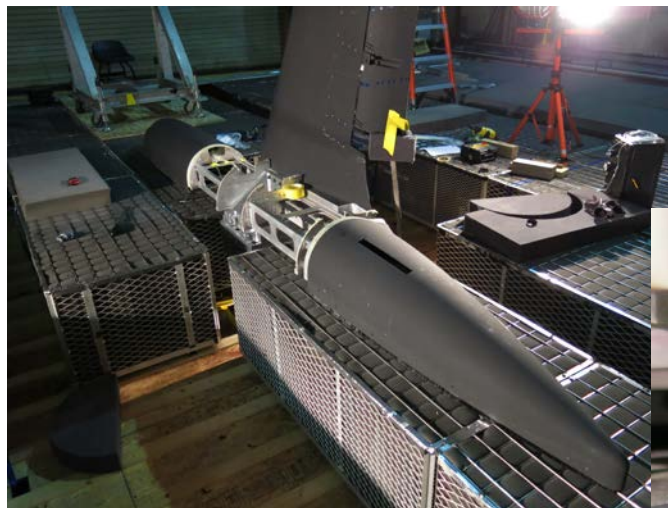
- Focused on documenting gear-flap interaction effects
- Proved to be very challenging
 - Optical access issues
 - Seeding issues
 - System calibration issues (stereo PIV)
 - Spatial resolution demands (by the PI)
- PIV team rose to the challenge and most objectives were accomplished
- 1st round of data processing and analysis just completed



14x22 Tunnel Modifications



- Design and implementation of temporary “false” floor
- Critical for allowing full functionality of turntable for:
 - o Setting AOA
 - o Determining model CL, CD vs. alpha
 - o Evaluating aero performance of noise reduction concepts



Flap Noise Reduction Concepts

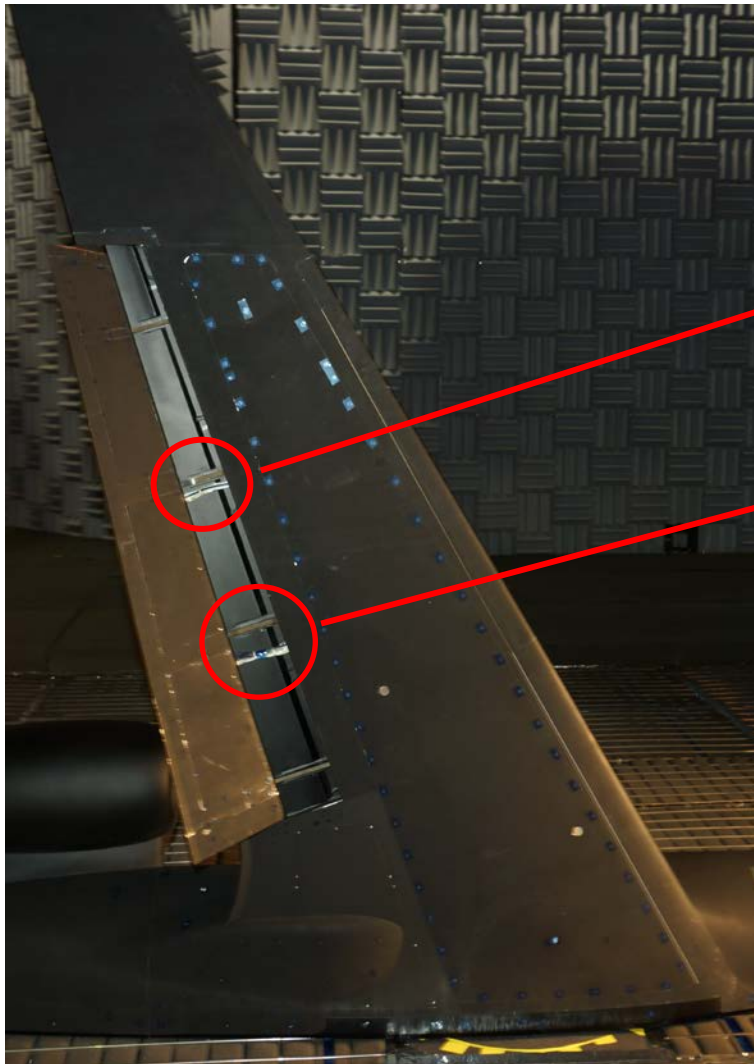


- ❑ 7 flap concepts examined
- ❑ 30 permutations fabricated
- ❑ 25 of the fabricated concepts were tested

1. Liner with serpentine chambers (holes)
2. Reactive Orthotropic Lattice Diffuser
3. Circular fins
4. Micro-airfoil (non-circular) fins
5. FLEXible Side Edge Link (FLEXSEL)
6. Porous treatment (skin)
7. Bulk liners



Flap's Secondary Noise Sources

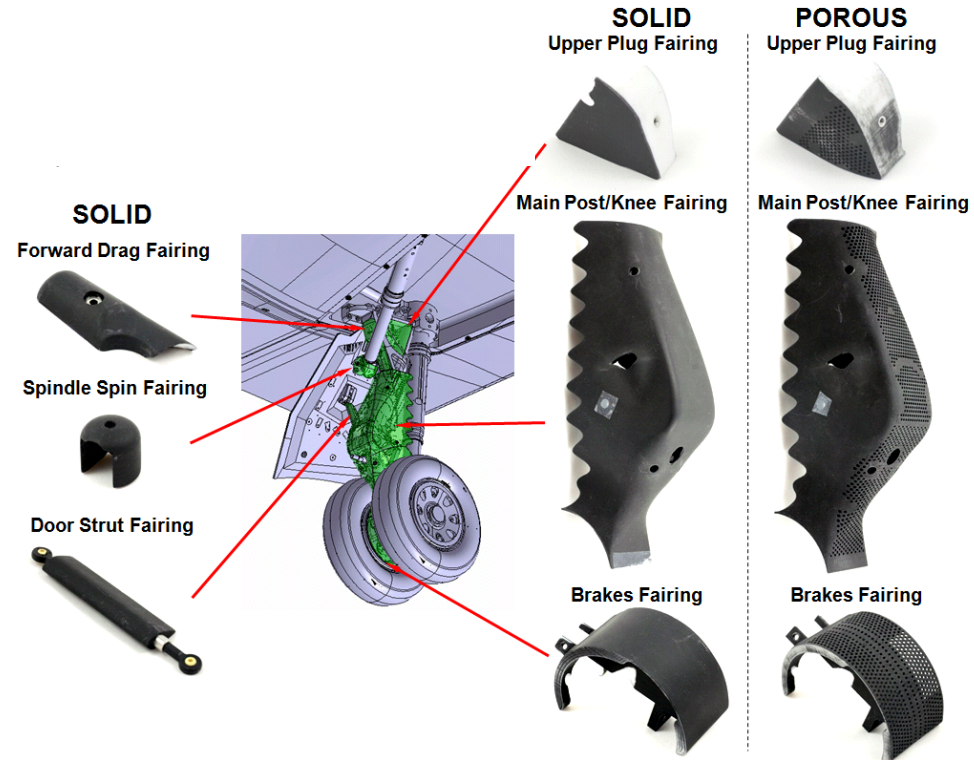
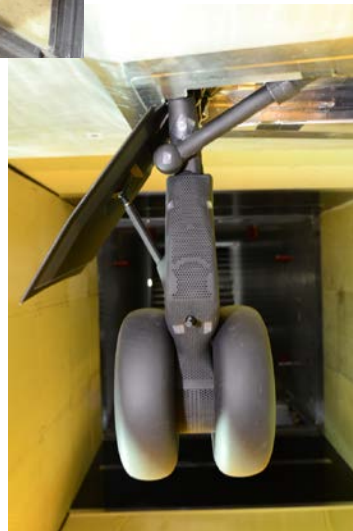
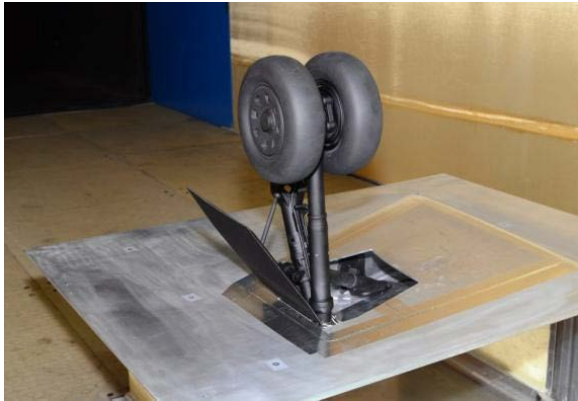


Main Landing Gear Concepts Tested (VA Tech Tunnel)



2011 Test Campaign:

- ❑ Solid version of concepts designed solely based on modeling and simulations
 1. Multitude of smaller (upper) fairings
 2. Knee fairing
 3. Brake fairing



Main Landing Gear Concepts Tested (VA Tech Tunnel)

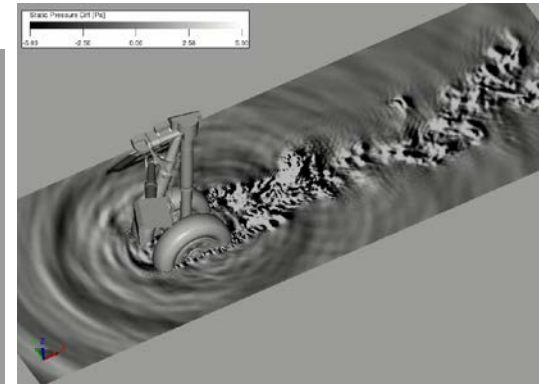
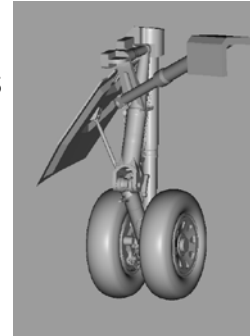


2012 Test Campaign:

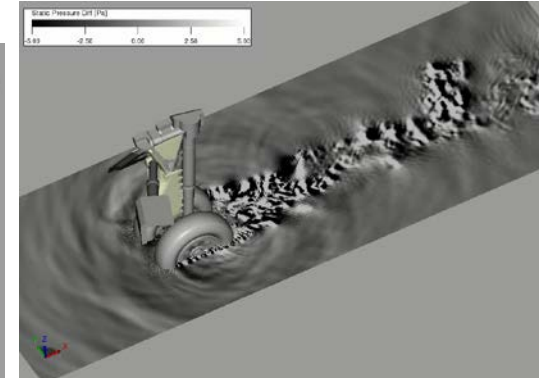
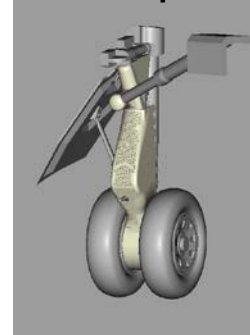
- ❑ Numerous permutations of 2011 designs plus new concepts
 1. Same upper fairings
 2. **Knee fairing (e.g., hole size, open area ratio, etc.)**
 3. Brake fairings (e.g., full or partial coverage)
 4. Wheel fairing (helmet)
 5. Hub cap
 6. Cavity treatment (e.g., LE serration, mesh, etc.)
 7. Lined door



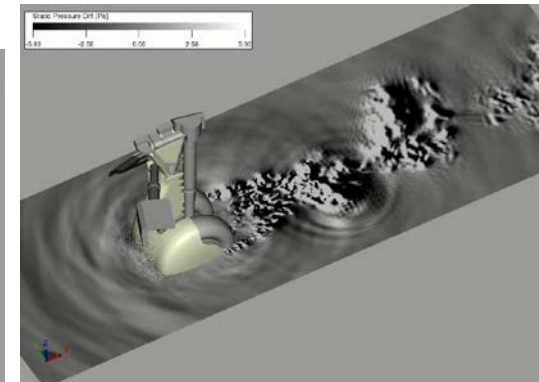
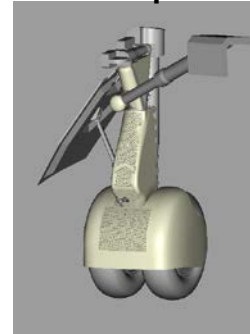
Baseline



Concept 1



Concept 2

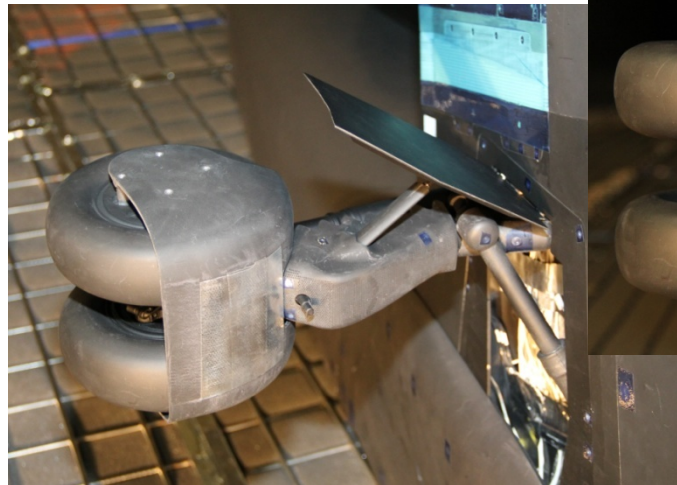
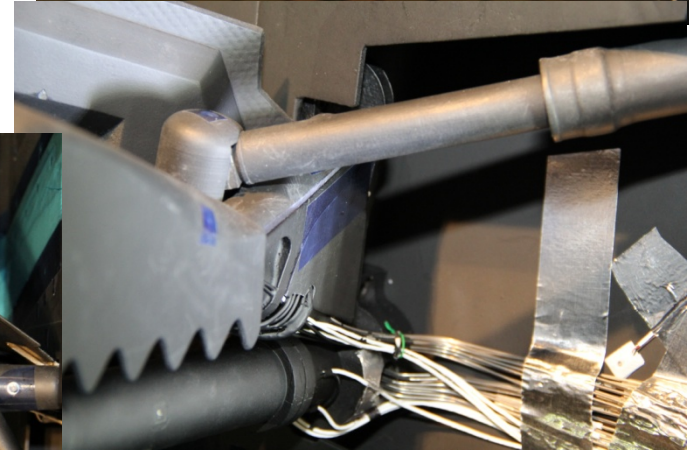
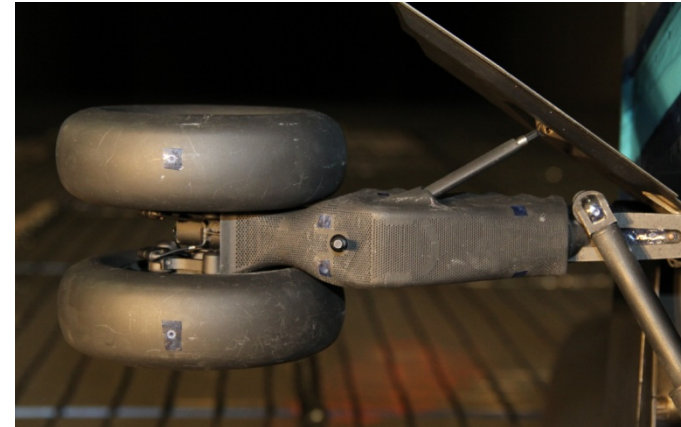


Main Landing Gear Concepts Tested (14x22 Tunnel)



2013 Test Campaign:

- ❑ The best performing concepts from 2012 with improvements
 1. Same upper fairings
 2. Knee fairing (e.g., hole size)
 3. Original brake fairing (used as benchmark)
 4. Wheel fairing (3 versions)
 5. Cavity treatment (e.g., LE serration, mesh)

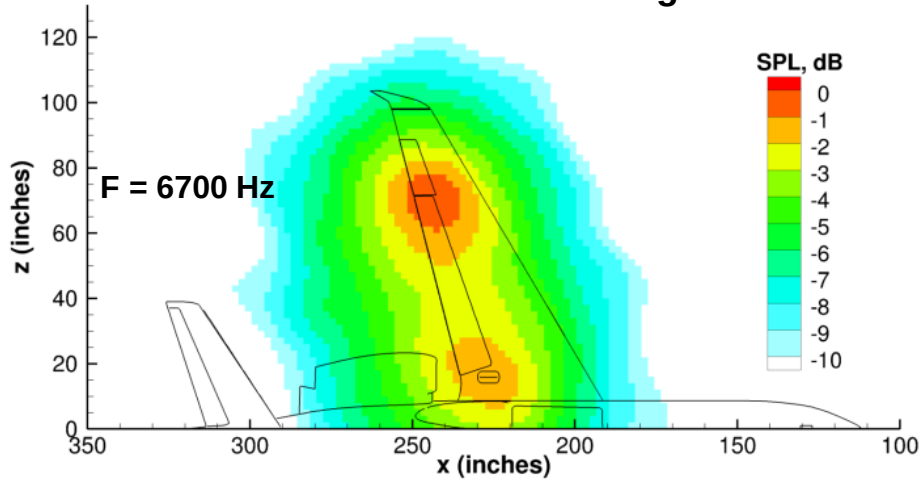


Microphone Array Data Processing and Analysis

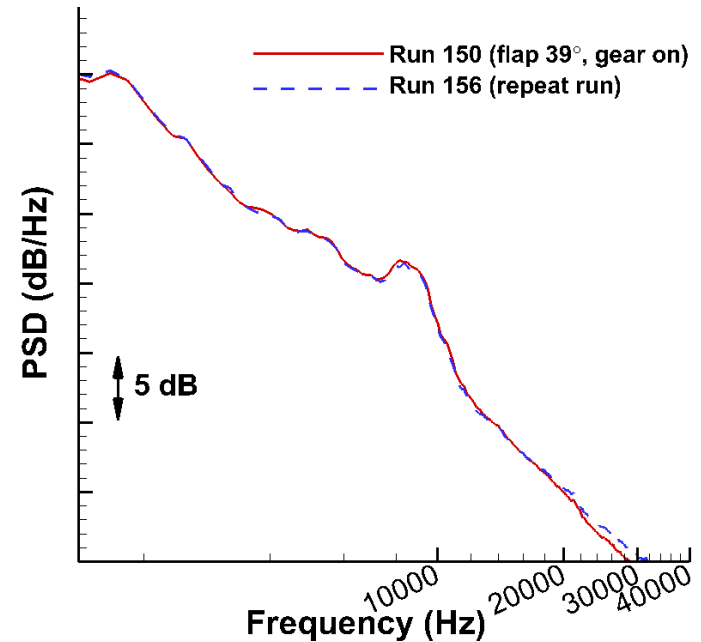
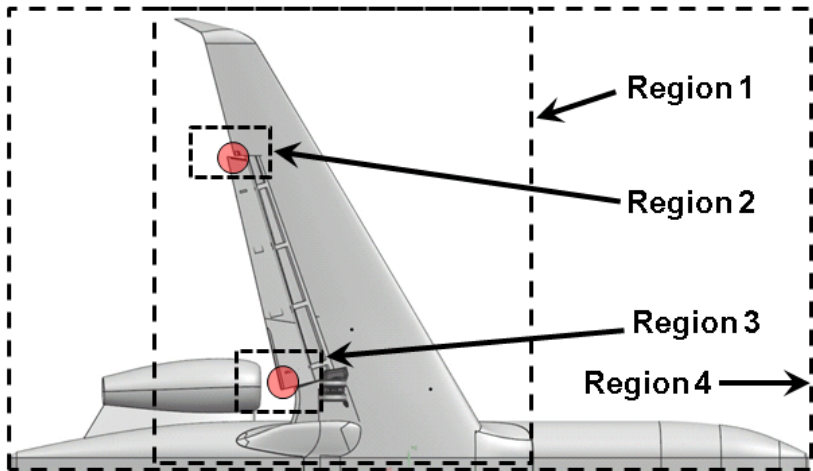
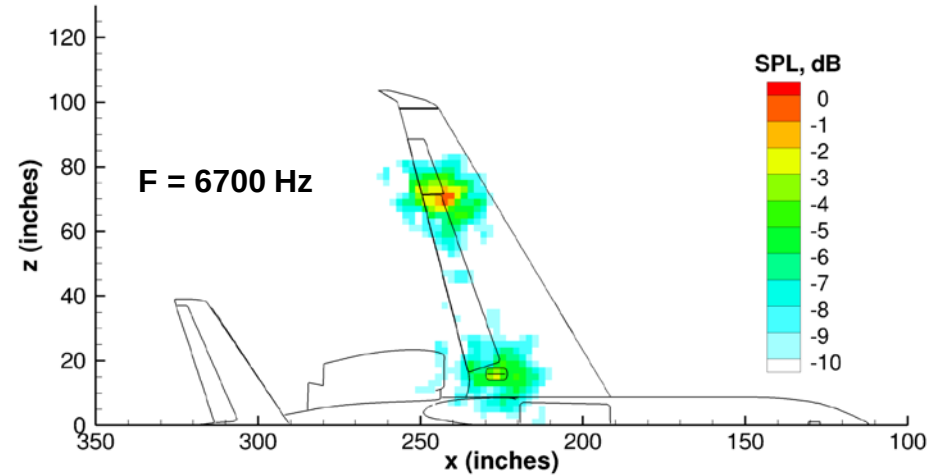


Landing Configuration at AOA of 3°

Conventional beamforming



UDAMAS



Noise Reduction Relative to Baseline (Various Flap Concepts)



UDAMAS

D-Weighted Noise Reduction Levels (dB)

0.0	3.4	3.5	3.7	4.4	3.9	3.6	3.8
Baseline (no foam), 0.0dB	ROLD - Small holes, 3.4dB	Small Circ. Fins, 3.5dB	Porous tip (570 Rayls)	NOMAX foam (20 Rayls), 4.4dB	FlexSEL with tape in gaps/TE, 3.9dB	FlexSEL full-profile, rigid, 100%, 3.6dB	FlexSEL single profile, rigid, 80%, 3.8dB

Acoustic Measurements Summary



- ❑ Extensive aeroacoustic testing of 18% scale aircraft model performed
- ❑ Over 250 test runs conducted
- ❑ 6-7 TB of acoustic data acquired and stored
- ❑ Secondary (flap's instrumentation bundles and brackets) noise sources identified and partially reduced
- ❑ Appropriate baseline configurations for evaluating noise mitigation technologies established
- ❑ Aeroacoustic performance of numerous flap and main landing gear concepts, both on a component level and in various combinations, evaluated
- ❑ No measurable aerodynamic penalty associated with any of noise reduction concepts observed
- ❑ Stall characteristics of 18% scale model remained unaffected
- ❑ Initial processing of acoustic data completed and data analysis is ongoing

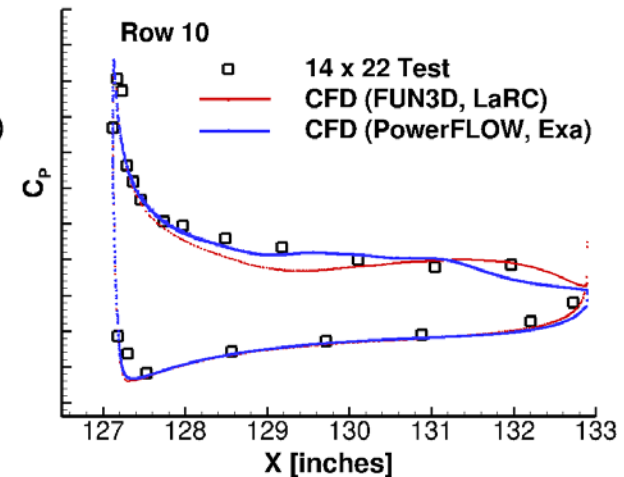
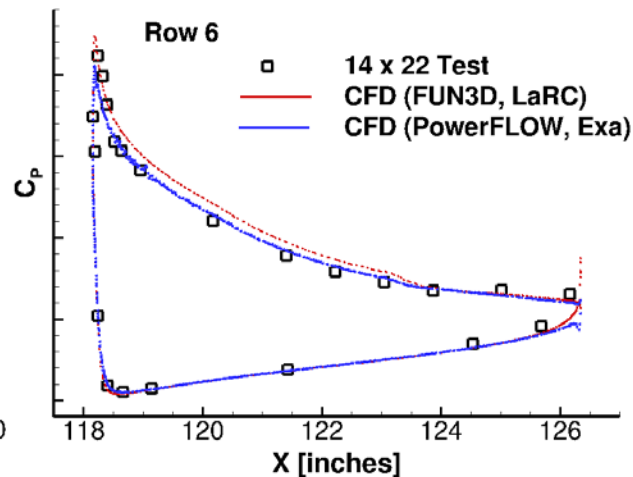
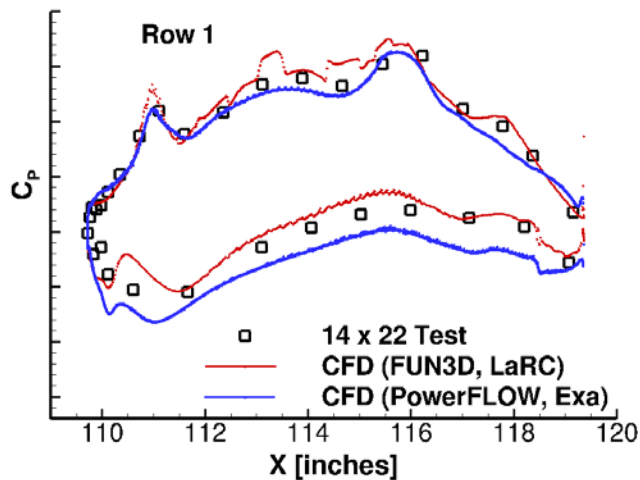
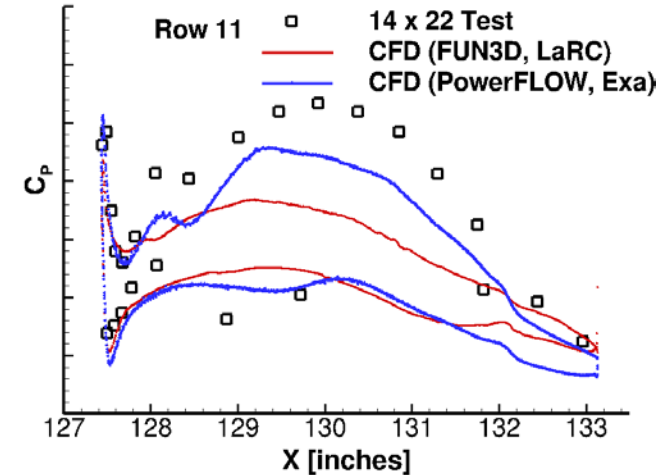
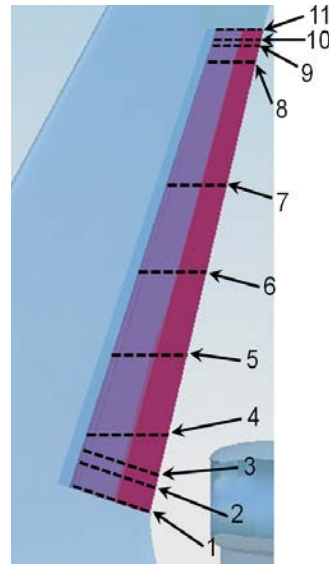
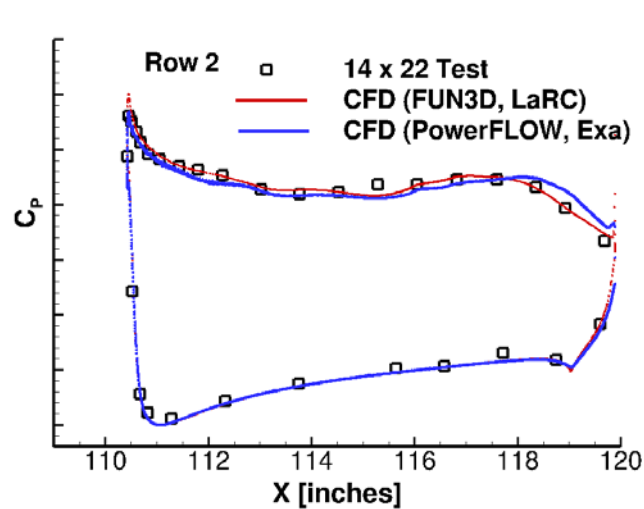
Computational Simulations



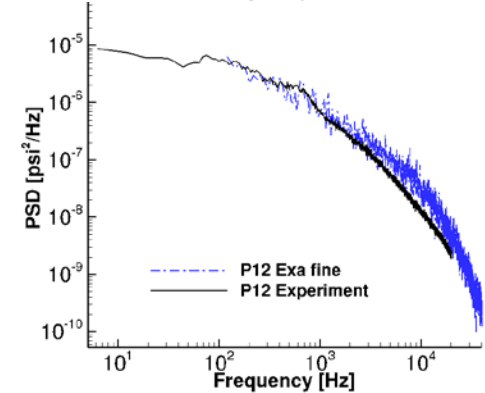
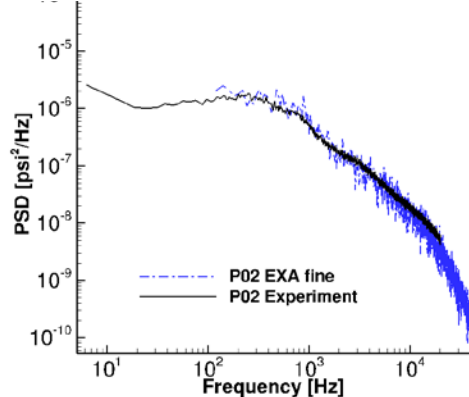
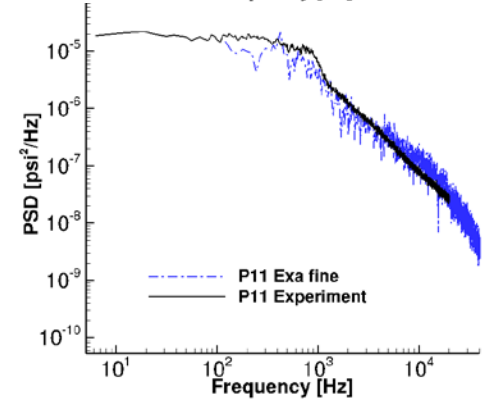
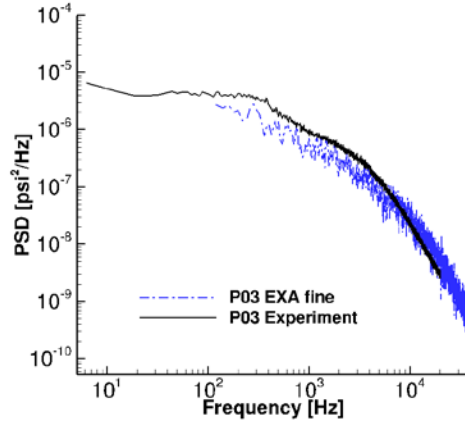
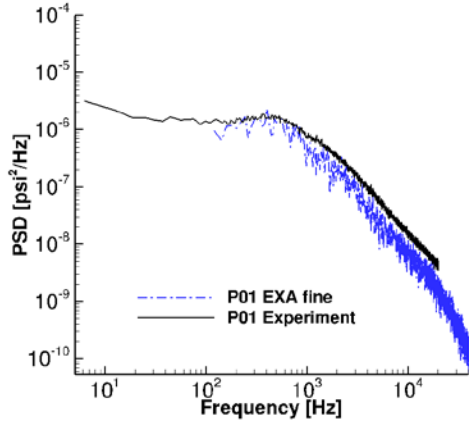
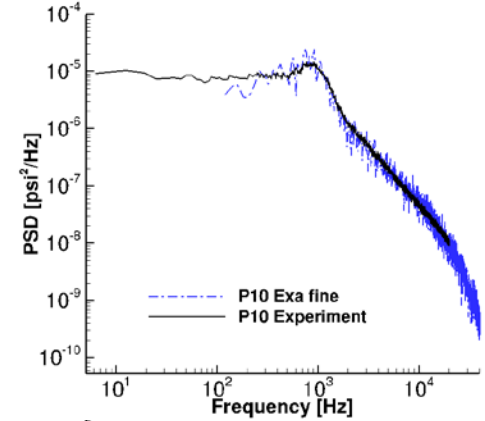
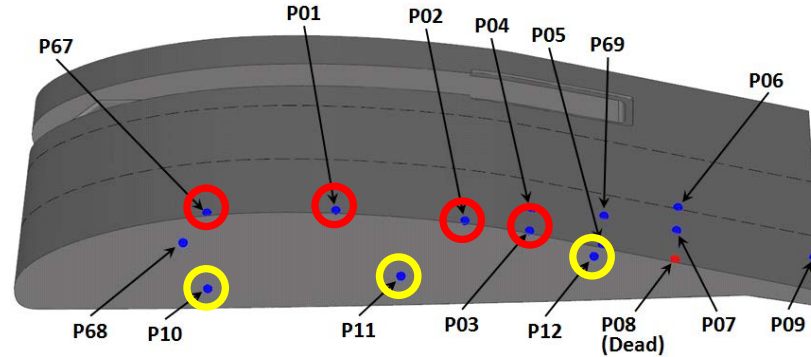
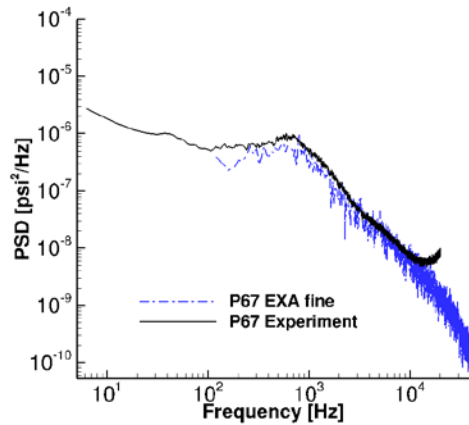
- High-fidelity large-scale unsteady simulations
- Executed on NASA Pleiades supercomputer
- Utilized both in-house and commercial software packages
 - FUN3D → NASA LaRC unstructured N-S flow solver
 - PowerFLOW → Exa Corporation Lattice-Boltzmann flow solver
- Extensive benchmarking of both codes using 18% model aero measurements
- Simulated free-field conditions that closely mimic open-wall tunnel configuration
- Simulated and analyzed many of the noise reduction concepts (PowerFLOW)
- Improved acoustic performance of several of the noise reduction technologies prior to testing (PowerFLOW)

Sample Comparison - Experiment vs. Simulation

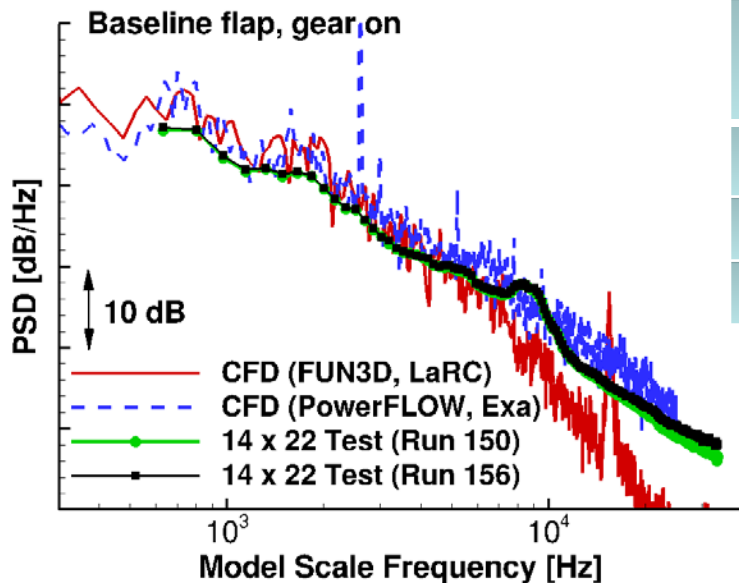
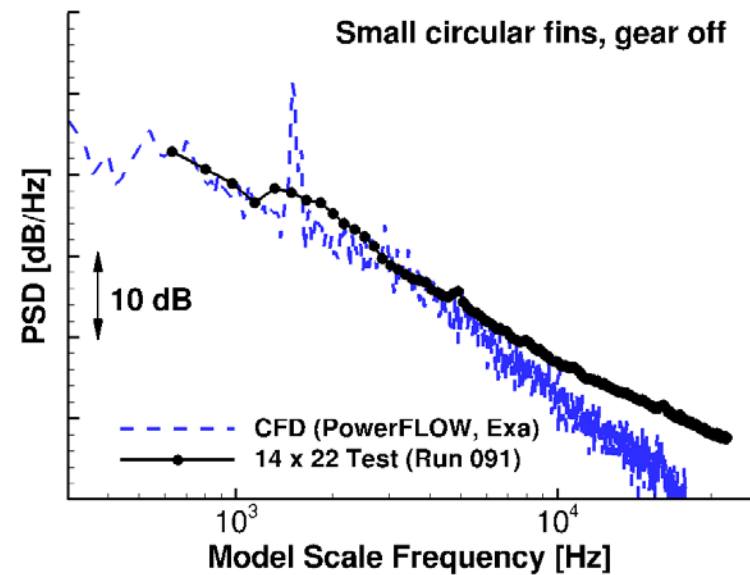
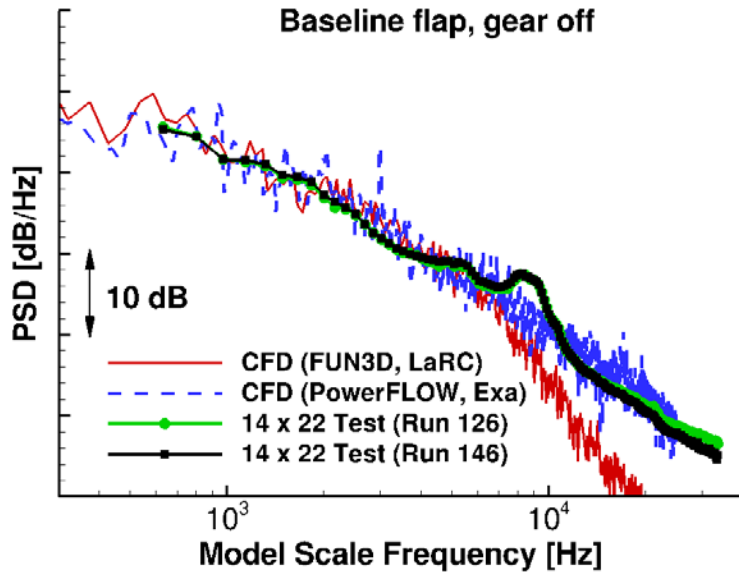
Surface Pressure at Flap Tips (Main Gear off)



Unsteady Surface Pressures at Flap Inboard Edge Power Spectral Density (Main Gear off)



Far Field Noise - Experiment vs. Simulation

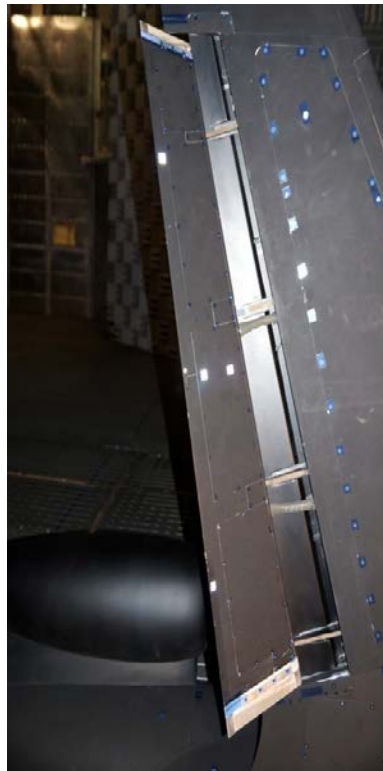


	Small Circular Fins D-Weighted Noise Reduction Levels (dB)							
Dir. Angle	50°	60°	70°	80°	90°	100°	110°	120°
Simulations	3.9	4.4	4.4	4.1	4.1	3.5	3.6	3.8
14x22 Test		2.88	3.15		3.46		2.85	

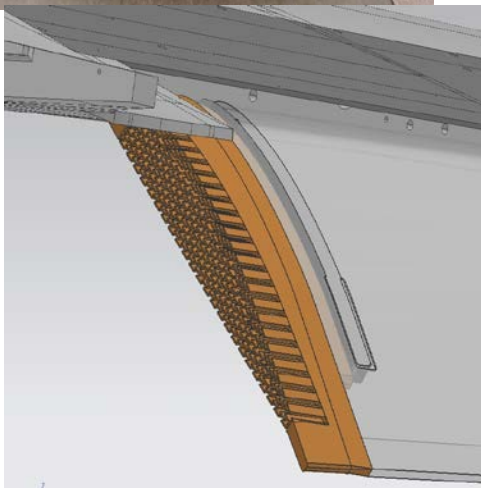
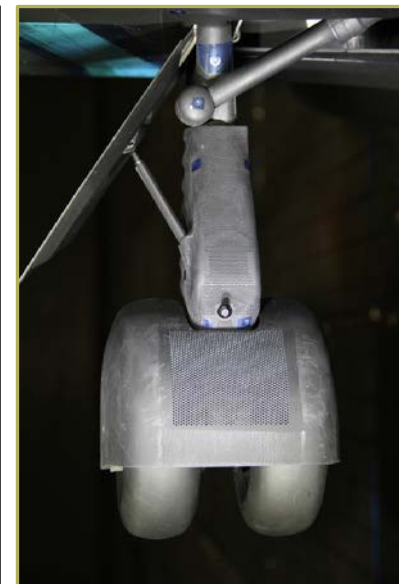
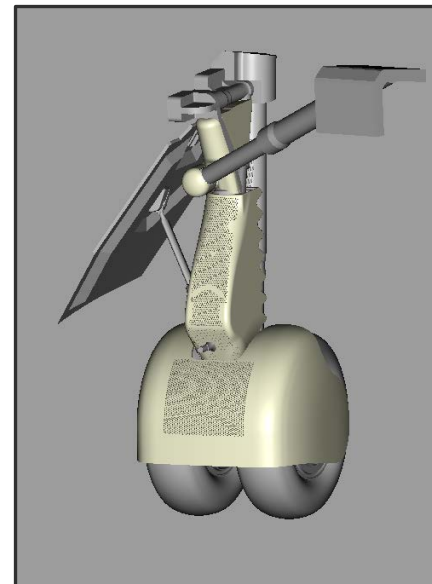
Low Noise Flap: Flap Edge Noise Reduction Fins (FENoRFins)



- Targets noise generated at aircraft flap tips
- Circular and non-circular metallic fins
- Effectiveness of concept was validated/evaluated via simulations and testing



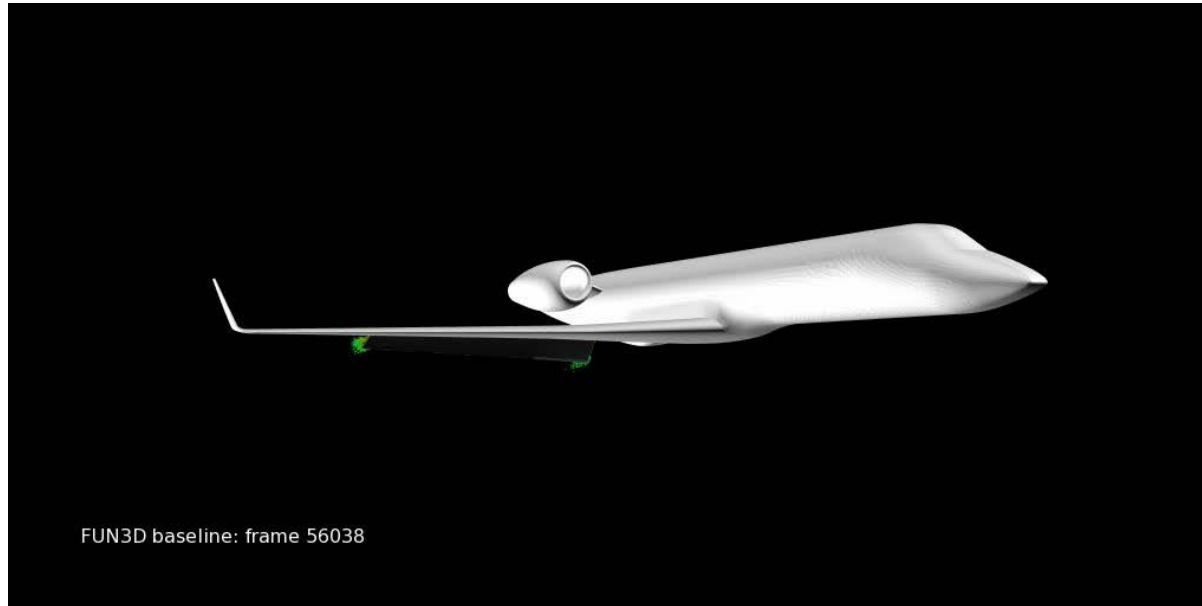
Low Noise Configuration



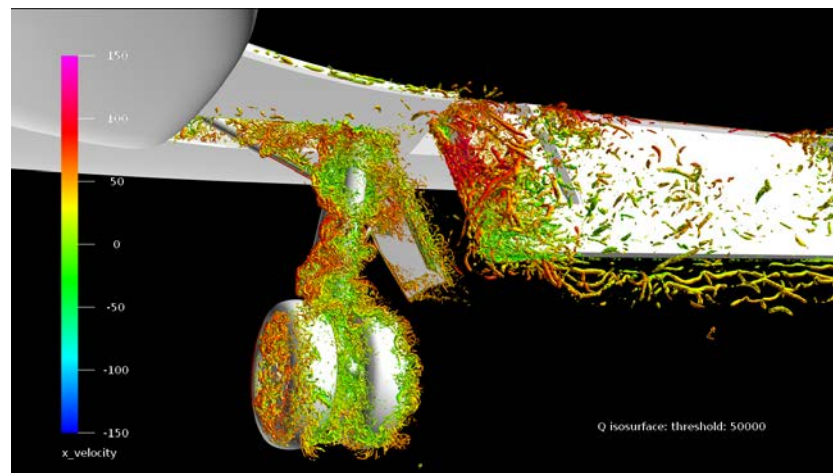
Sources of Flap Noise



Flap only Configuration



Flap and Main Landing Gear

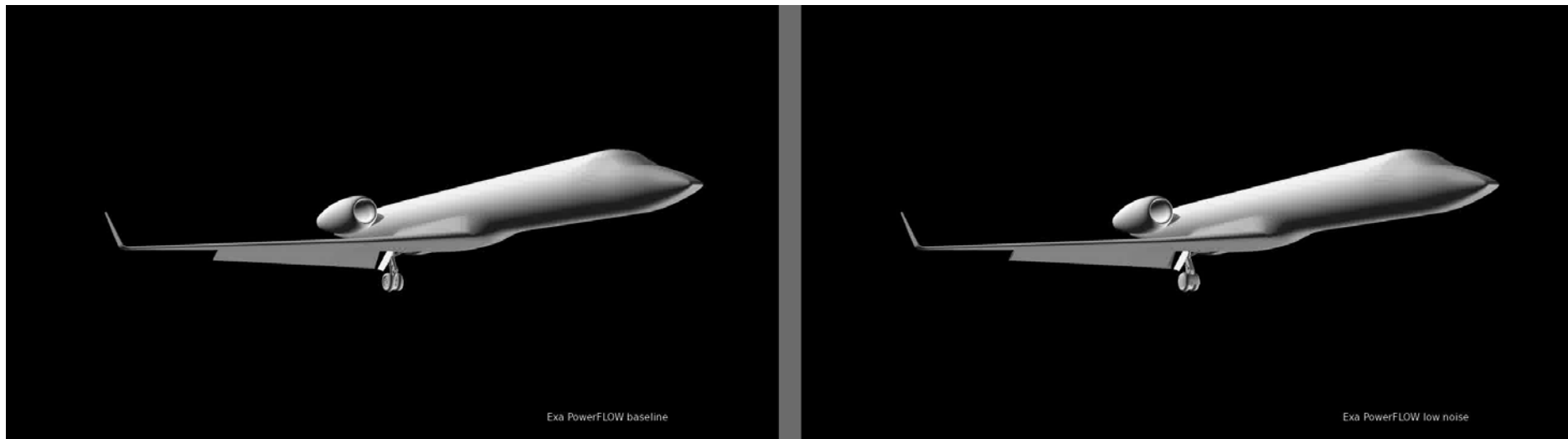


Baseline Comparison with Low Noise Case (Surface Pressure Fluctuations)

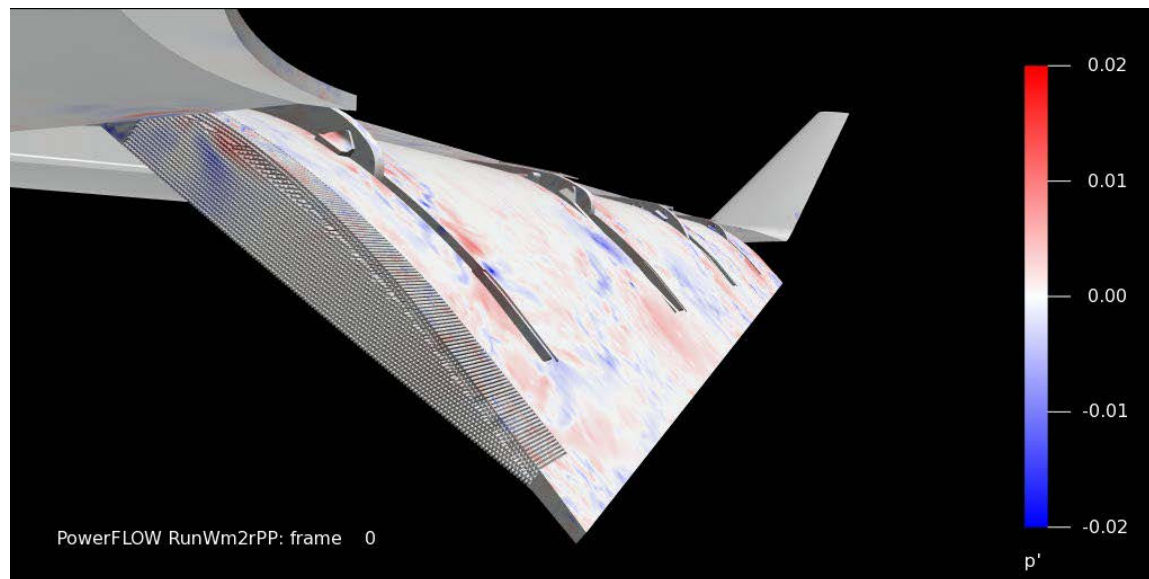
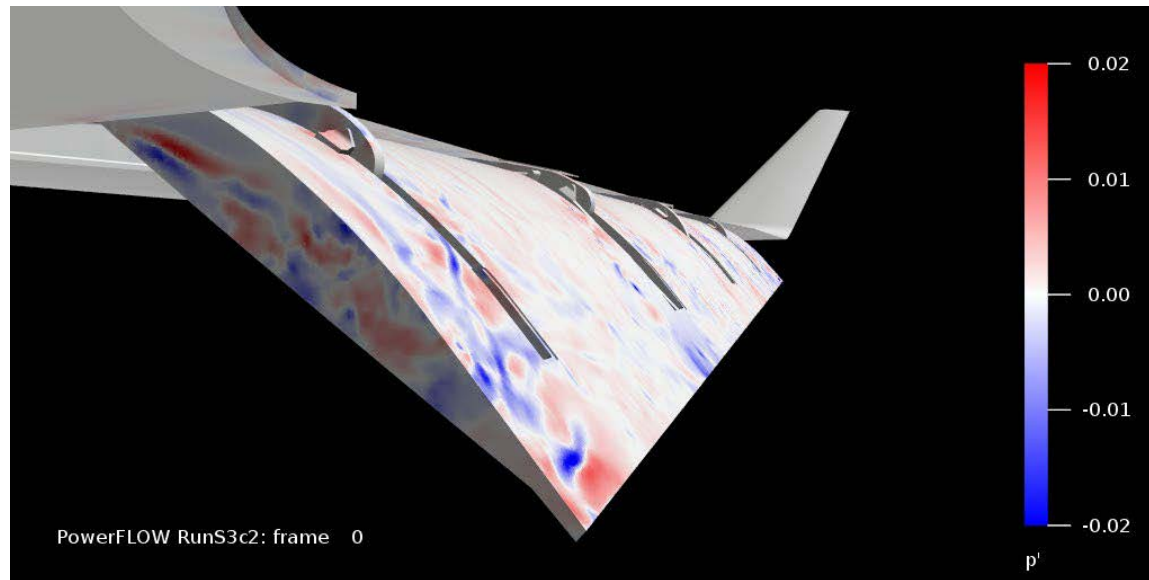


Baseline Configuration

Low Noise Configuration



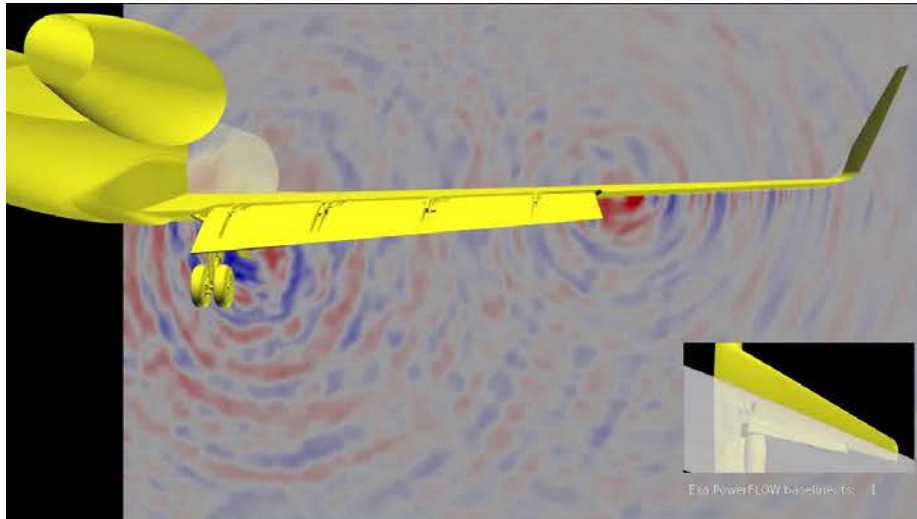
Baseline Comparison with FENoRFins (Surface Pressure Fluctuations)



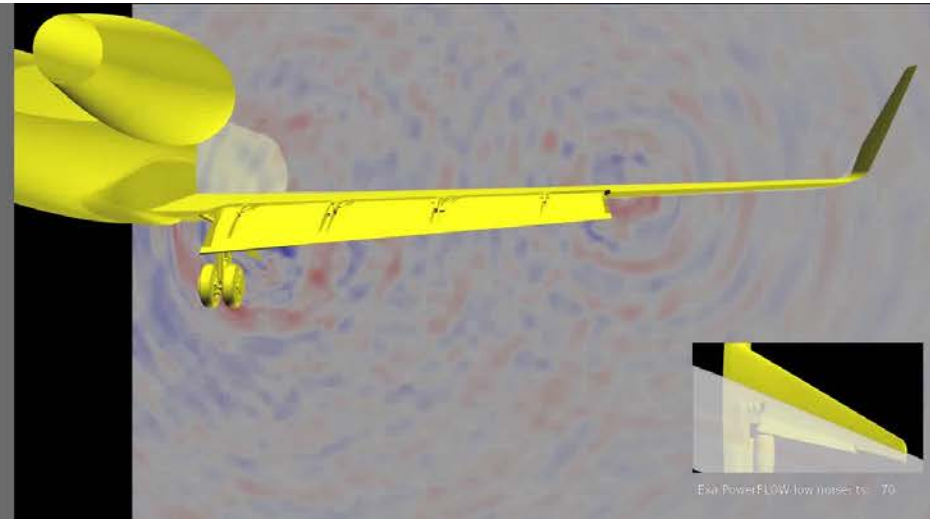
Baseline Comparison with Low Noise Case (Far View of Pressure Field)



Baseline Configuration



Low Noise Configuration



Summary



- An ambitious partnership program focused on airframe noise research has been established and is being executed systematically
- The aim of the partnership is to develop and evaluate effective noise reduction technologies and advance simulation based airframe noise prediction tools
- Aeroacoustic testing and high-fidelity simulations of several novel flap and landing gear noise reduction concepts constitute the critical steps toward achieving these goals

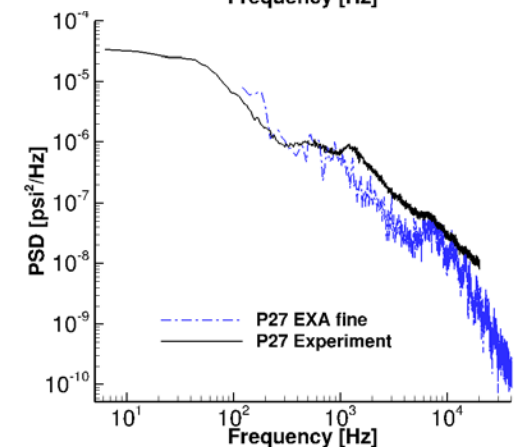
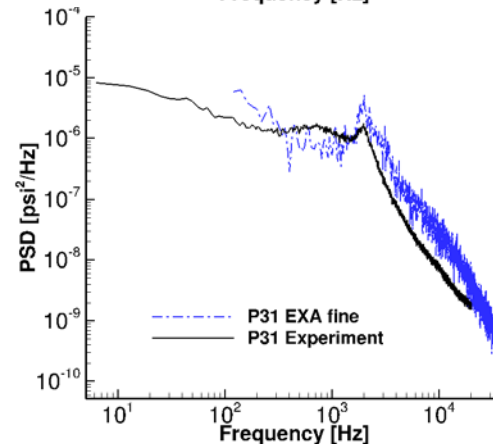
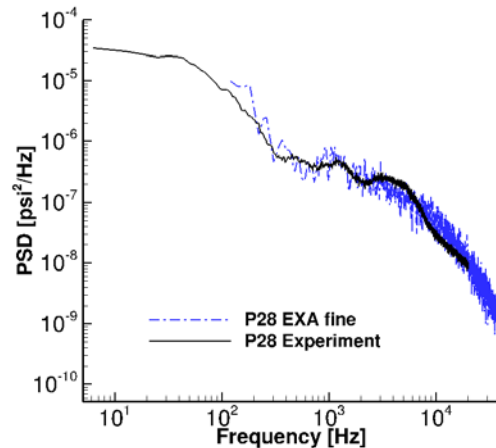
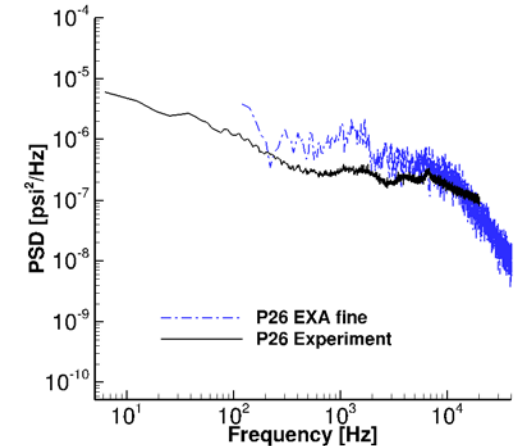
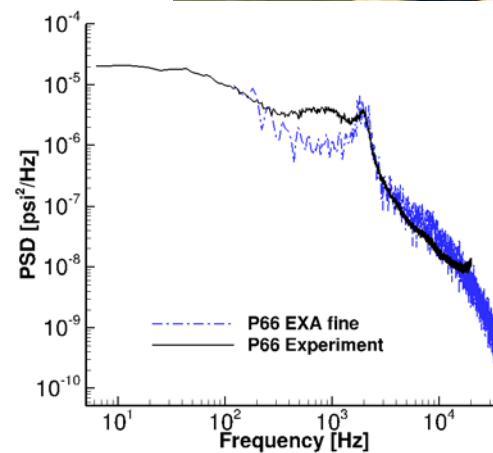
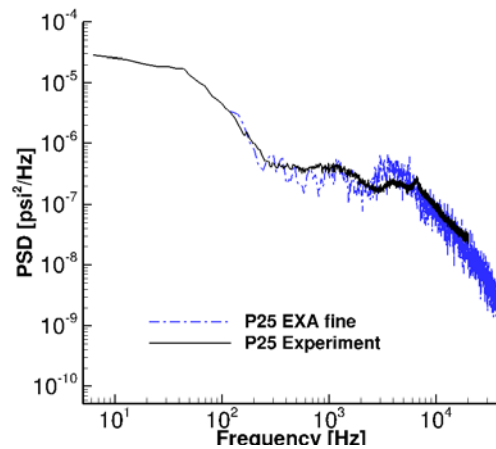
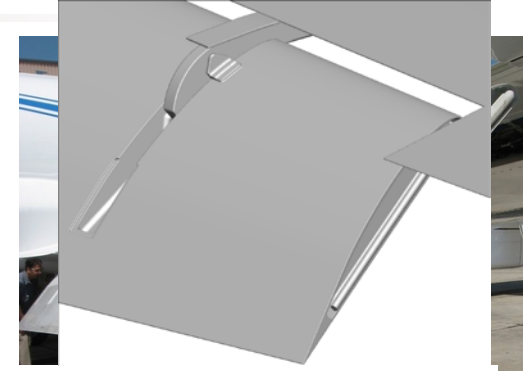
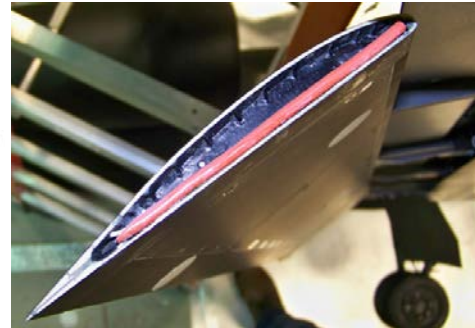
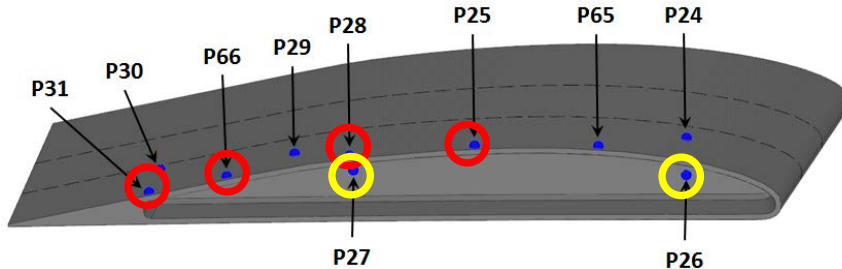
**Please join us for the special session on
NASA-Gulfstream airframe noise research at
the 2014 AIAA Aeroacoustics Conference
16-20 June, 2014 Atlanta, GA**



Backup Slides



Unsteady Surface Pressures at Flap outboard Edge Power Spectral Density (Main Gear off)



NASA-Gulfstream Airframe Noise Flight Test (2006)



Main Gear and Flaps only



Flaps only



Main Gear only

