Supersonics/Airport Noise Plan: An Evolutionary Roadmap

- **Synopsis:** This presentation discusses the Plan for the Airport Noise Tech Challenge Area of the Supersonics Project. It is given in the context of strategic planning exercises being done in other Projects to show the strategic aspects of the Airport Noise plan rather than detailed task lists. The essence of this strategic view is the decomposition of theresearch plan by *Concept* and by *Tools*. *Tools* (computational, experimental) is the description of the plan that resources (such as researchers) most readily identify with, while *Concepts* (here noise reduction technologies or aircraft configurations) is the aspects that project management and outside reviewers most appreciate as deliverables and milestones. By carefully cross-linking these so that Concepts are addressed sequentially (roughly one after another) by researchers developing/applying their Tools simultaneously (in parallel with one another), the researchers can deliver milestones at a reasonable pace while doing the longer-term development that most Tools in the aeroacoustics science require. An example of this simultaneous application of tools was given for the Concept of High Aspect Ratio Nozzles. The presentation concluded with a few ideas on how this strategic view could be applied to the Subsonic Fixed Wing Project's Quiet Aircraft Tech Challenge Area as it works through its current roadmapping exercise.

Supersonics/Airport Noise Plan: An Evolutionary Roadmap

Presented to Acoustics Technical Working Group

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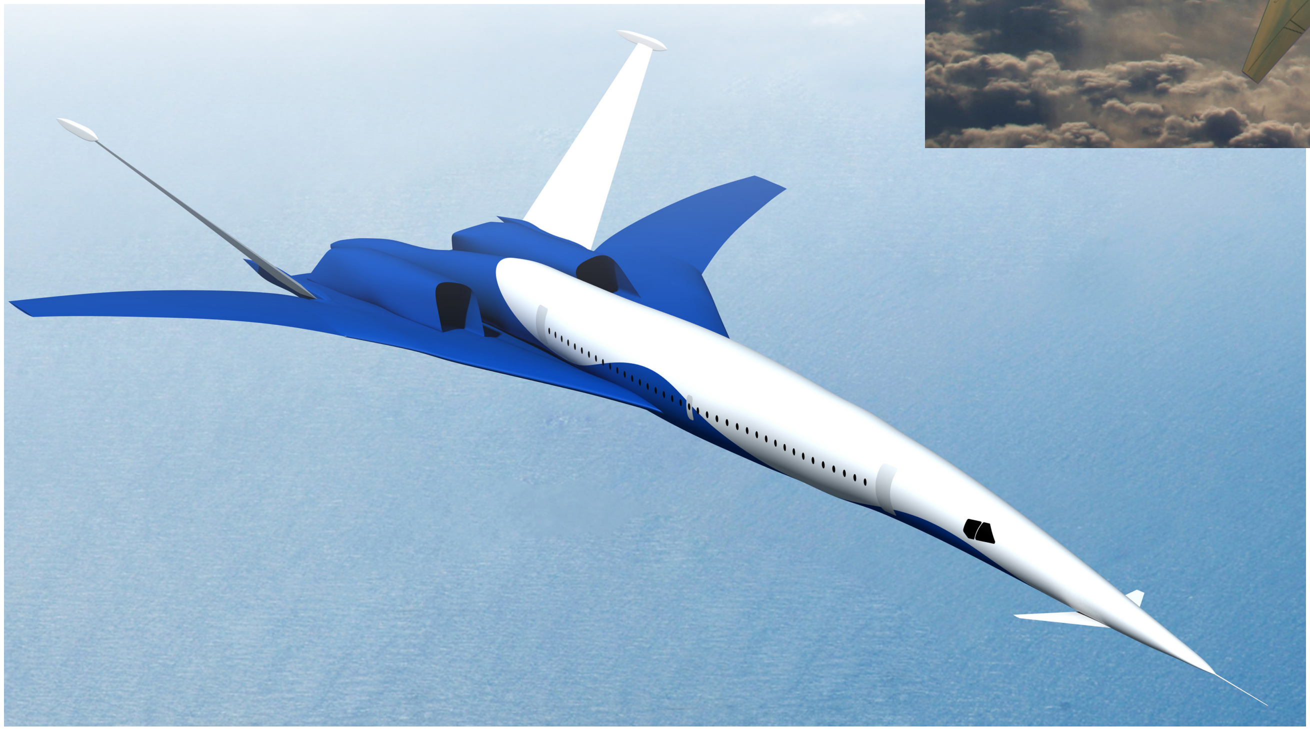
Cleveland, OH

Supersonics: N+2 Gen Aircraft

Propulsion system features minimal nacelles requiring minimal BPR, highly variable plug nozzles and inlets, highly distorted inlet flows, multiple jet interactions, staggered engines with near-by airframe structure. Airframe will require high-lift technologies.

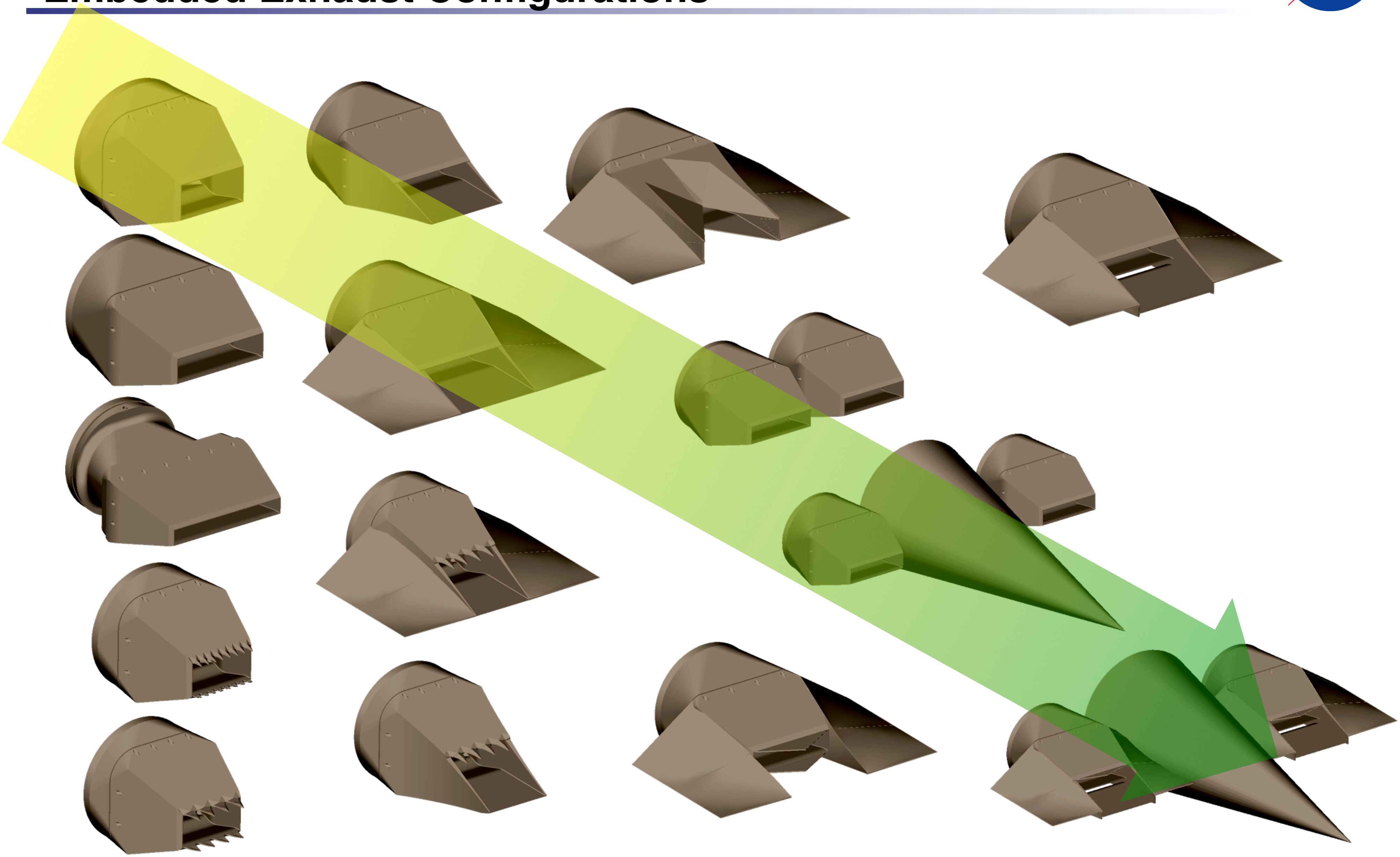


Propulsion system features highly embedded nozzles and inlets, highly distorted inlet flows, multiple jet interactions. Airframe will require high-lift technologies, with unique lifting surface interactions. Far-aft nose gear.

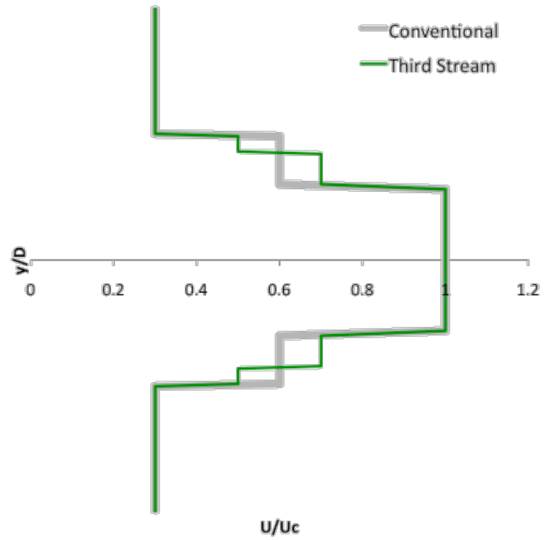
Planning Supersonics/Airport Noise Research

- Problem:
  - Noise reduction concepts that need to be explored
  - Aircraft configurations and propulsion cycles good for other disciplines
  - Need to provide Systems Analysis group with design tools for noise evaluation
- Resources:
  - Experimental facilities and instrumentation
  - Computational Tools in various states of development
- Solution:
- Plan A: Build realistic scale models of each concept, test
  - (one every 5 years)
- Plan B: Develop ultimate computational tools, apply to concepts
  - (ready in 2020)
- Plan C: Approximate as "737 on steroids" and scale noise
  - (accurate to within ±10dB)
- Plan D: Develop codes for applicable concepts, validate on canonical problems, delivering progressively sophisticated tools to Systems Analysis

Evolution of Predictive Capabilities for Supersonics N+2/N+3—Embedded Exhaust Configurations



Evolution of Predictive Capabilities for Supersonics N+2/N+3— Flow Profile Modifications

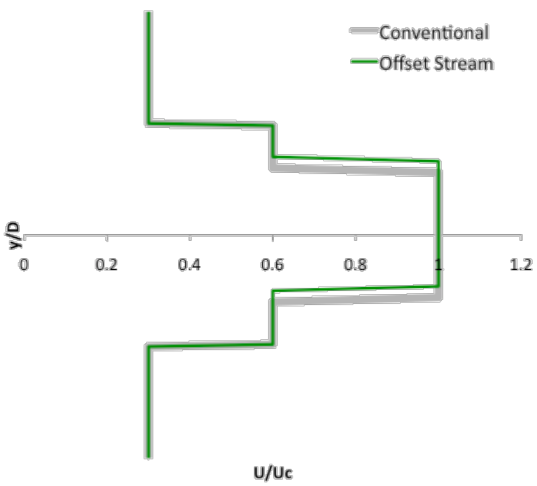


3rd stream

-Minimize outer shear

-Reduce TKE

-Highly Variable Cycle



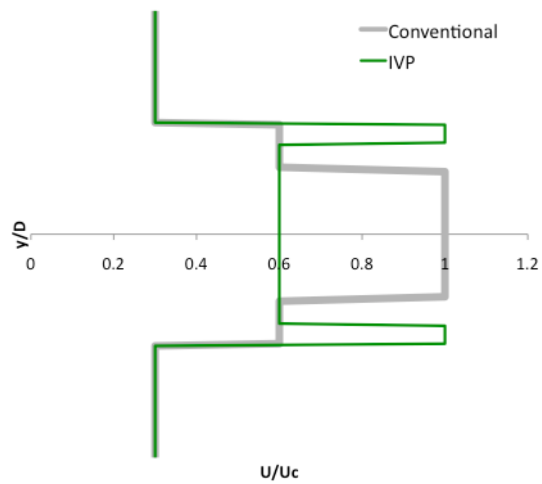
Offset Stream

-Modify TKE distribution, Mach Wave emission

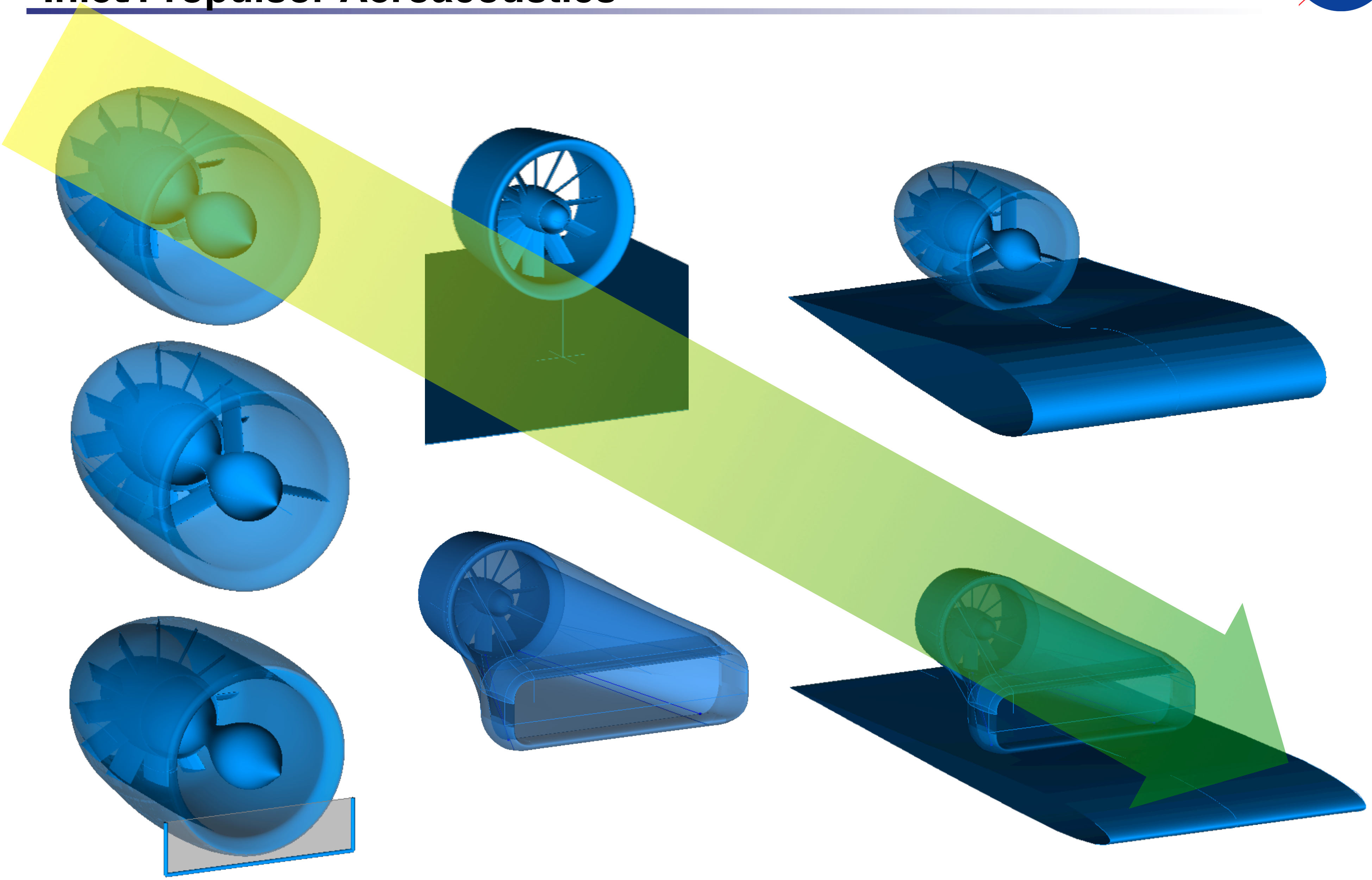
Inverted Velocity Profile

-Enhanced mixing

-Beneficial refraction



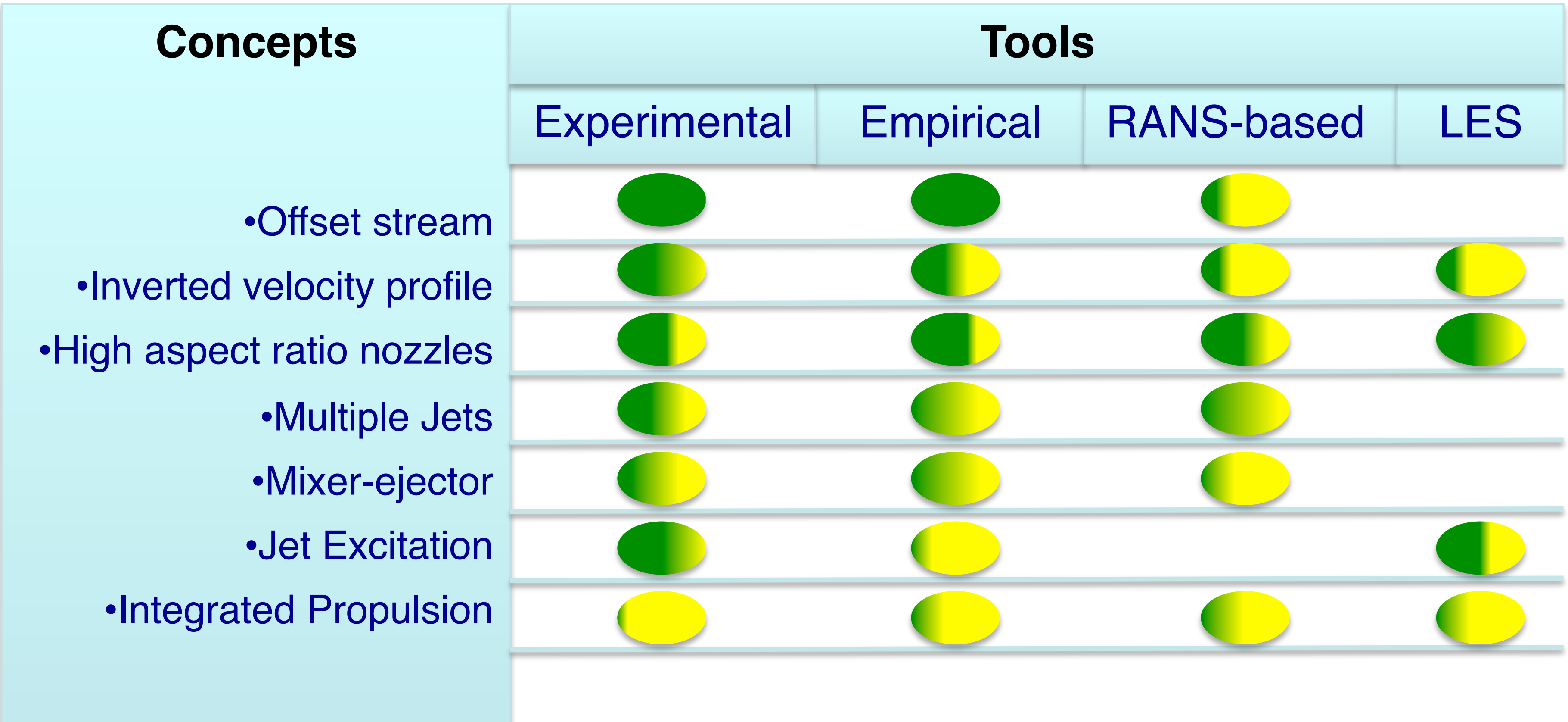
Evolution of Predictive Capabilities for Supersonics N+2/N+3—Inlet/Propulsor Aeroacoustics



Computational Aeroacoustic Tools Under Development in Supersonics Project

- Empirical/Semi-empirical
  - Design-of-experiments-based parametric modeling
  - djet (semi-empirical; *Khavaran*)
- RANS-based
  - Wind-US (v3, unstructured, turb enthalpy; *Georgiadis, Yoder, Frate*)
  - JeNo (turb enthalpy sources; *Khavaran*)
  - Leib-Goldstein (elliptic GF; *Leib*)
  - RISN (BBSN; *S.Miller*)
- LES
  - WRLES (in-house, structured; *DeBonis*)
  - BASS (in-house, structured; *Hixon,Brown*)
  - CharLES (NRA, unstructured; *Brown, DeBonis*)
- *All being interfaced to Systems Analysis frameworks via ANOPP2*

FY11-15 Supersonics/Airport Noise Activities

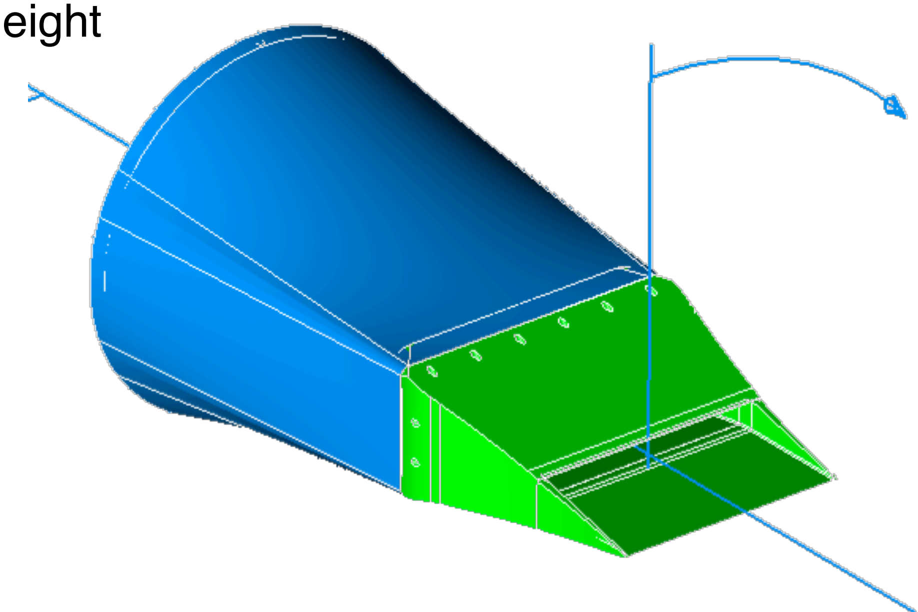


Tool Development Scale

Ready | Needs Development

Extensible Rectangular Nozzle Empirical Noise Prediction

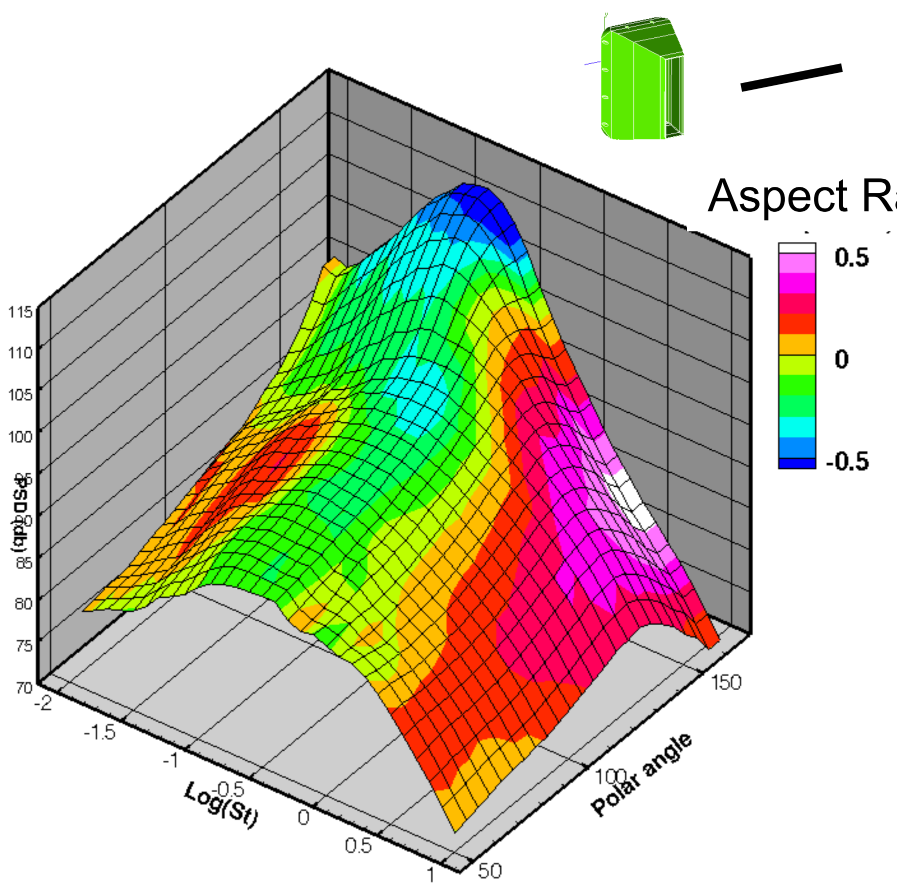
- Canonical experiments produce Empirical Tool and validation data
- Simple parametric models of the impact of various geometric features
- Aspect Ratio and Bevel Length:
  - PSD = power spectral density in dB
  - PSD0 = power spectral density of round jet
  - AR = Aspect ratio
  - L/h = bevel length relative to nozzle height

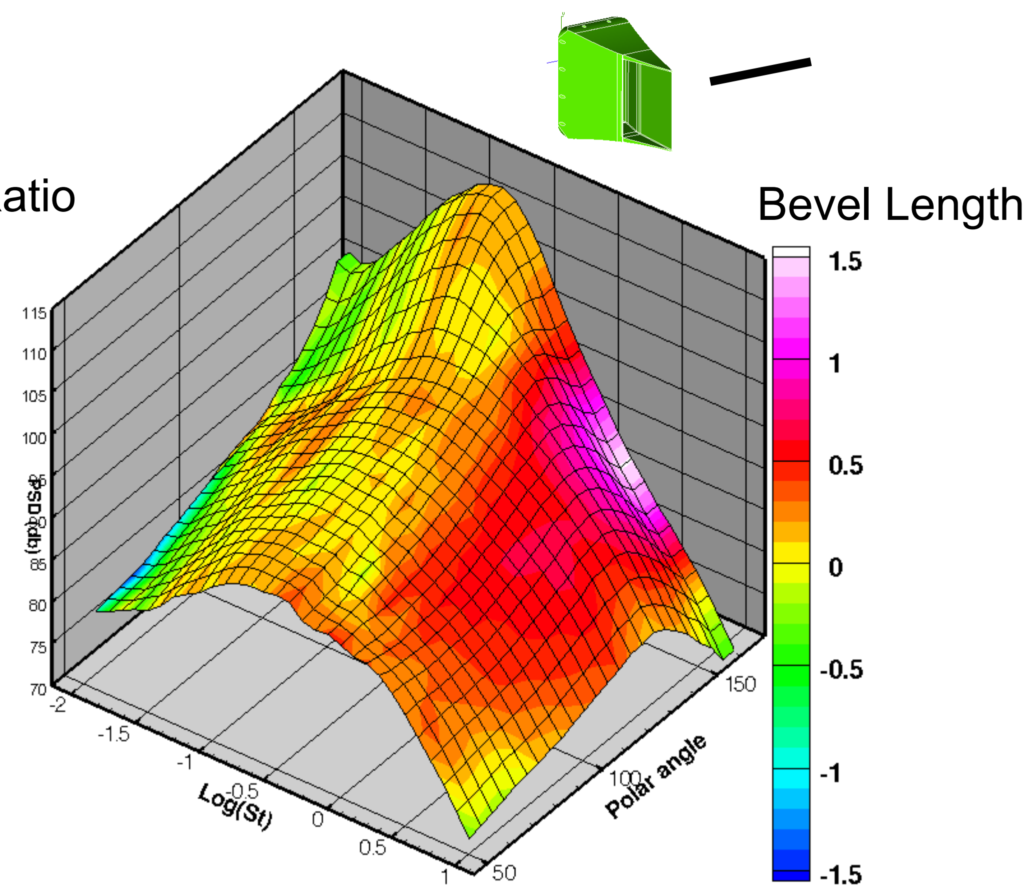


$$
\begin{aligned}
PSD(AR, L/h; f, \theta, \phi) \\
&= PSD0(f, \theta) \\
&+ AR * a(f, \theta, \phi) \\
&+ L/h * b(f, \theta, \phi) \\
&+ AR * L/h * c(f, \theta, \phi)
\end{aligned}
$$

Extensible Rectangular Nozzle Parametric Model Coefficients

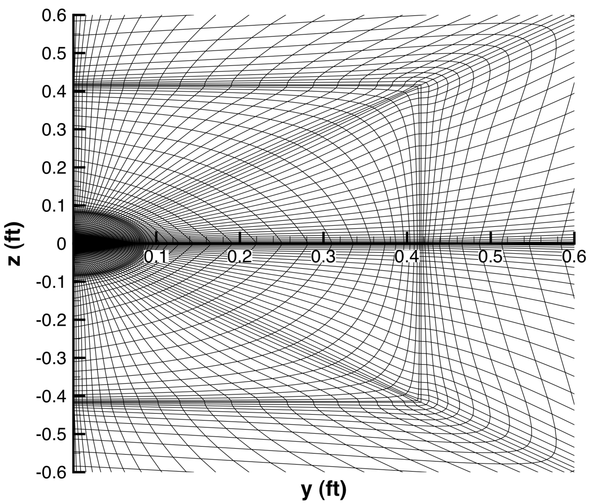
- Bilinear model fitted to 3 aspect ratios x 3 bevel lengths each.
- Linear coefficients for aspect ratio and bevel length depict basic sensitivities.
- Surface shape is spectral polar directivity, color is coefficient value.

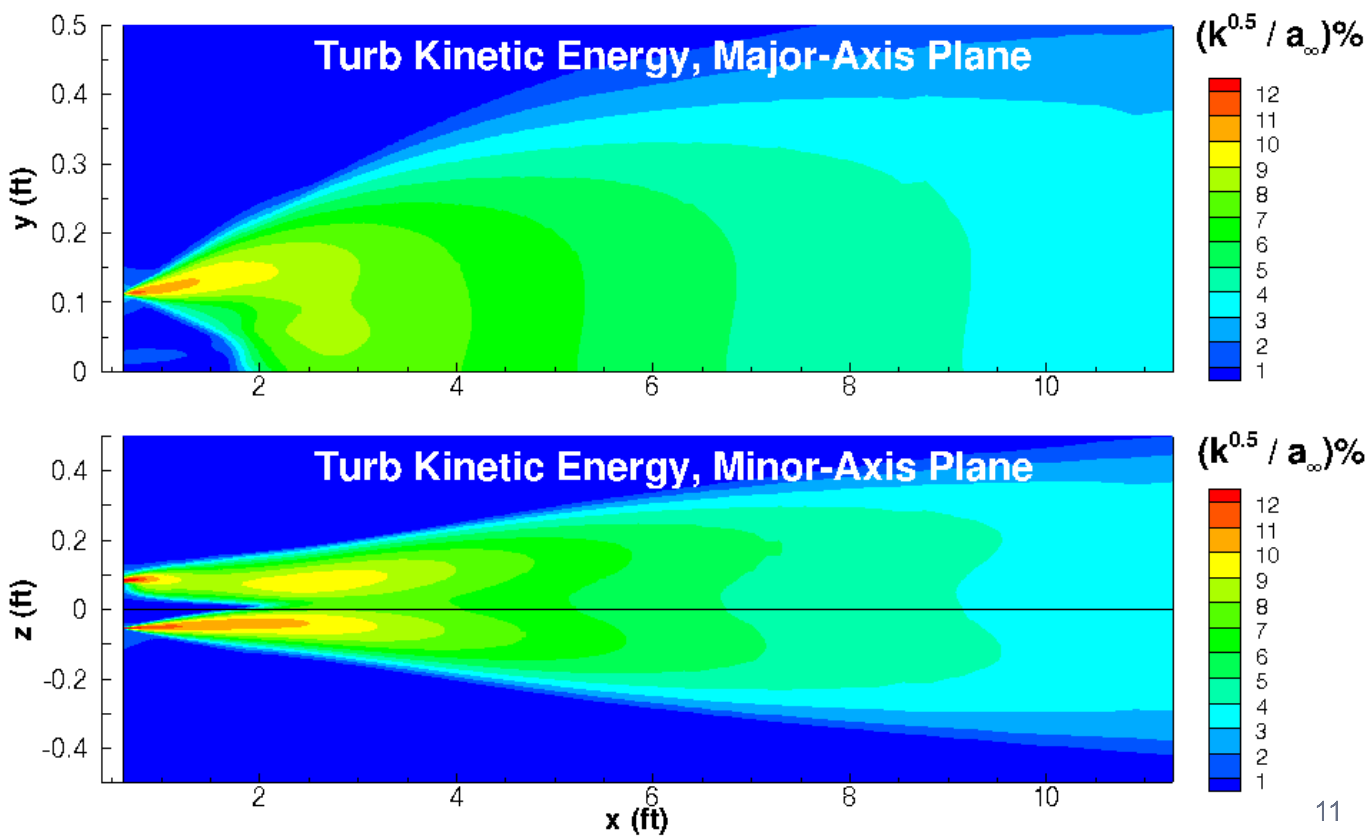




Extensible Rectangular Nozzle RANS-based noise prediction—CFD

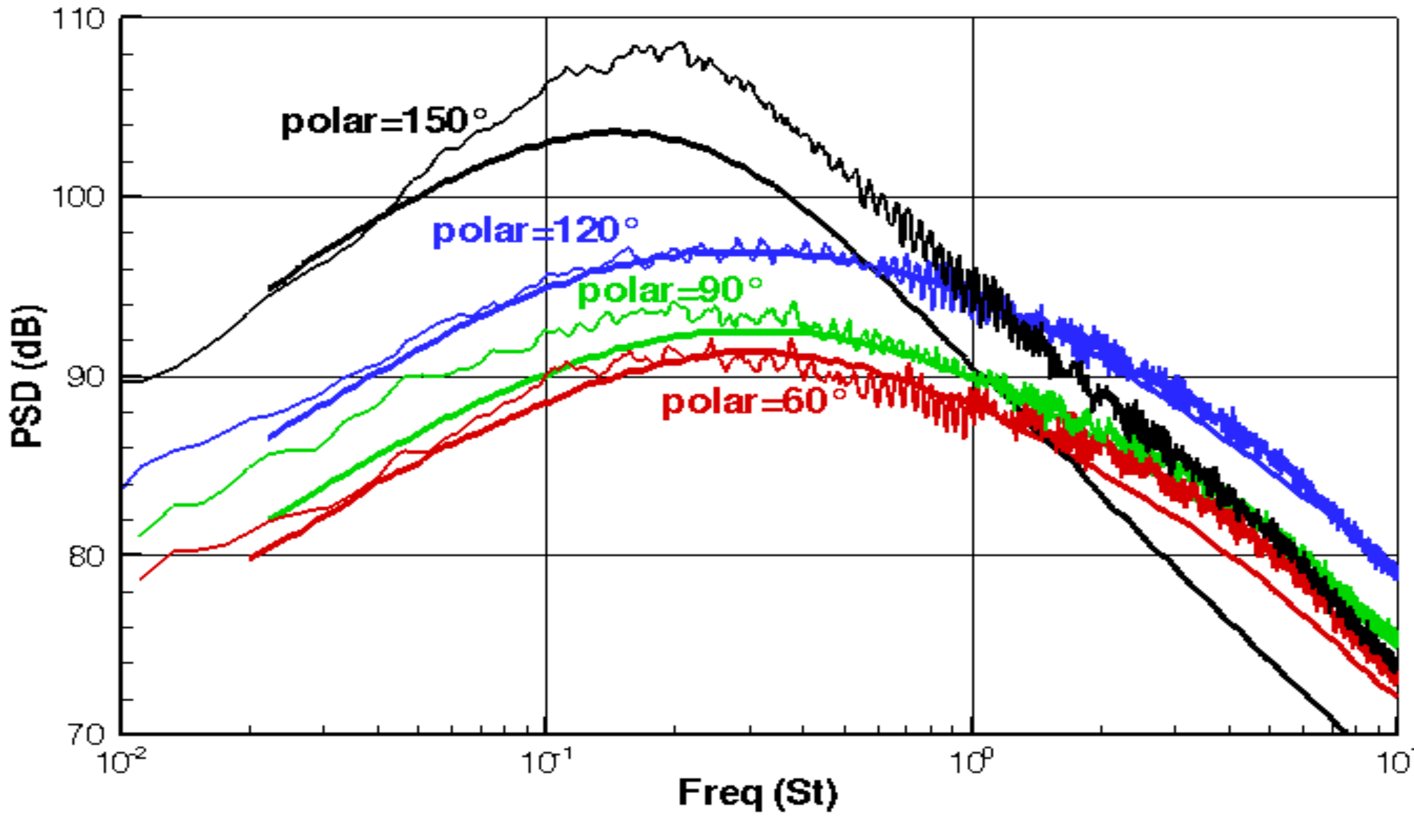
- All RANS-based noise predictions made with WindUS solutions
- Typical runs required 30M grid points on bi-symmetric fine grid
- Used SST turbulence model
- Stringent grid refinement and convergence criteria placed on TKE
- Thrust and flow angularity evaluated

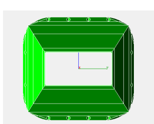




Extensible Rectangular Nozzle
RANS-based noise prediction—JeNo

- Uses axisymmetric approximation of jet mixing noise
- Until turbulent enthalpy code validated in Wind, JeNo limited to cold flows
- Predicted spectral levels within 2 dB for subsonic cold jets, most polar angles



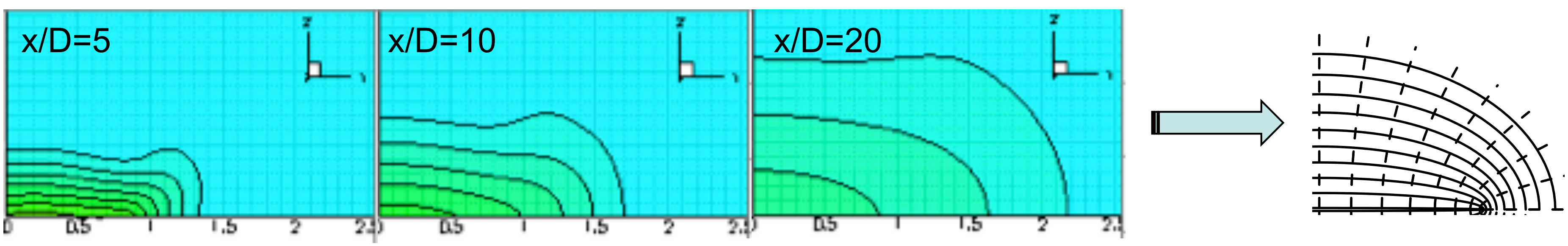


2:1

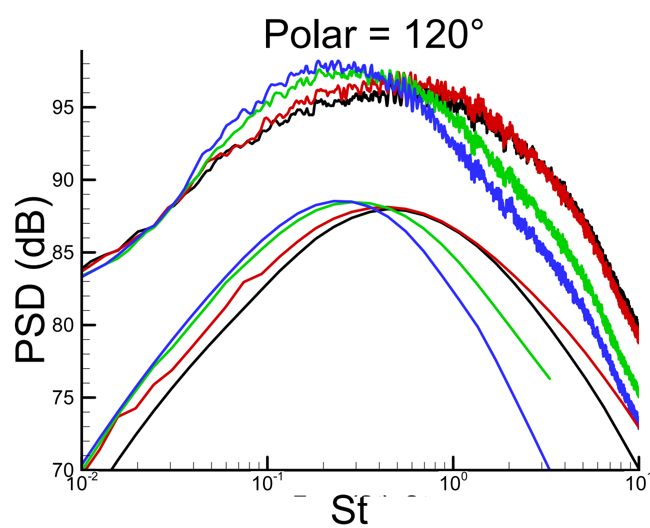
M=0.96, cold

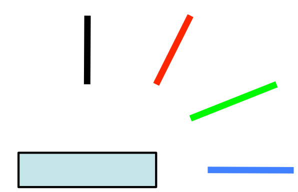
Extensible Rectangular Nozzle RANS-based noise prediction—Leib

- In acoustic analogy theory, refraction computed by Green's function
- Elliptic approximation to Green's function for prediction of nonaxisymmetric mixing noise
- Uses Goldstein-Leib formulation for mixing noise source terms
- Limited to cold flows at this time



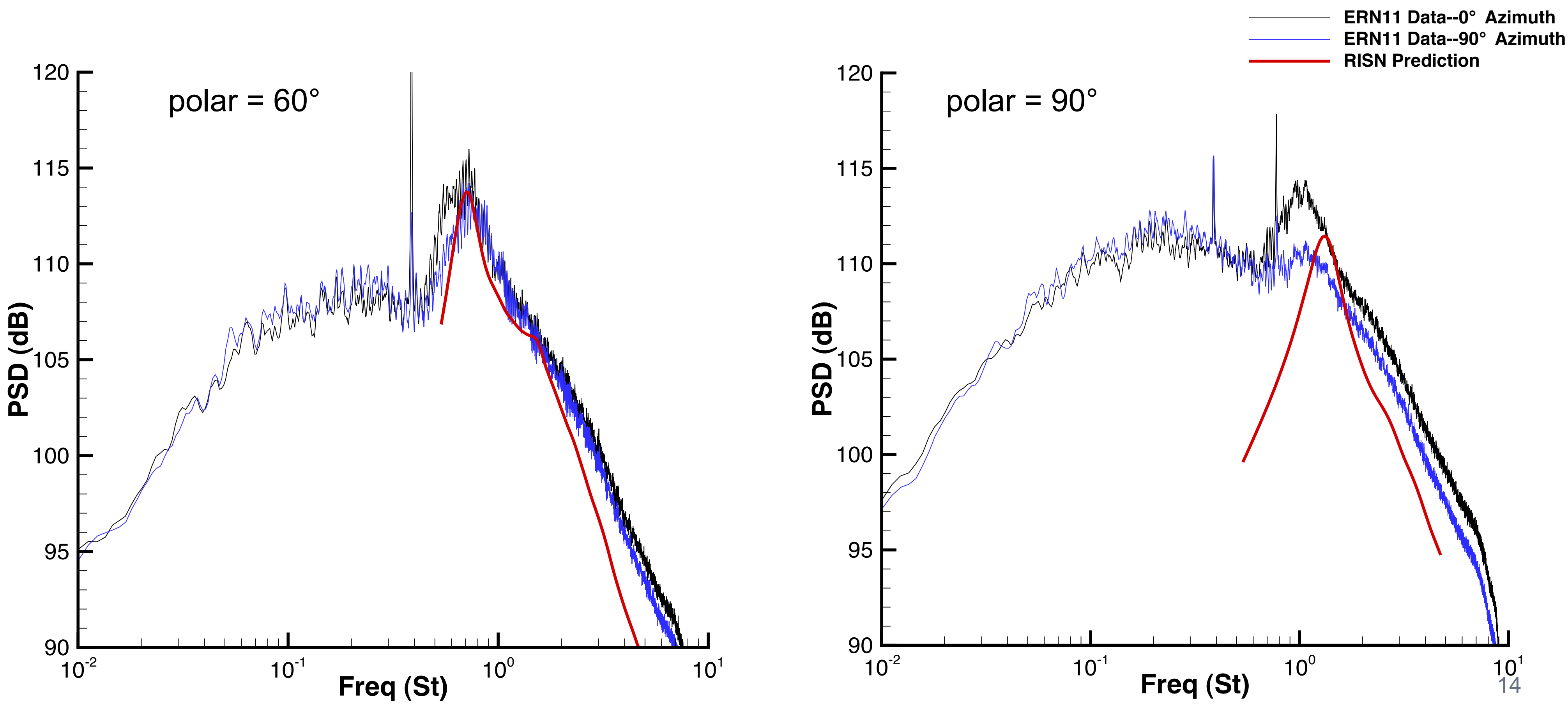
Prediction of azimuthal dependence of noise spectra for 4:1 rectangular jet at polar angle 120°—Data vs Leib





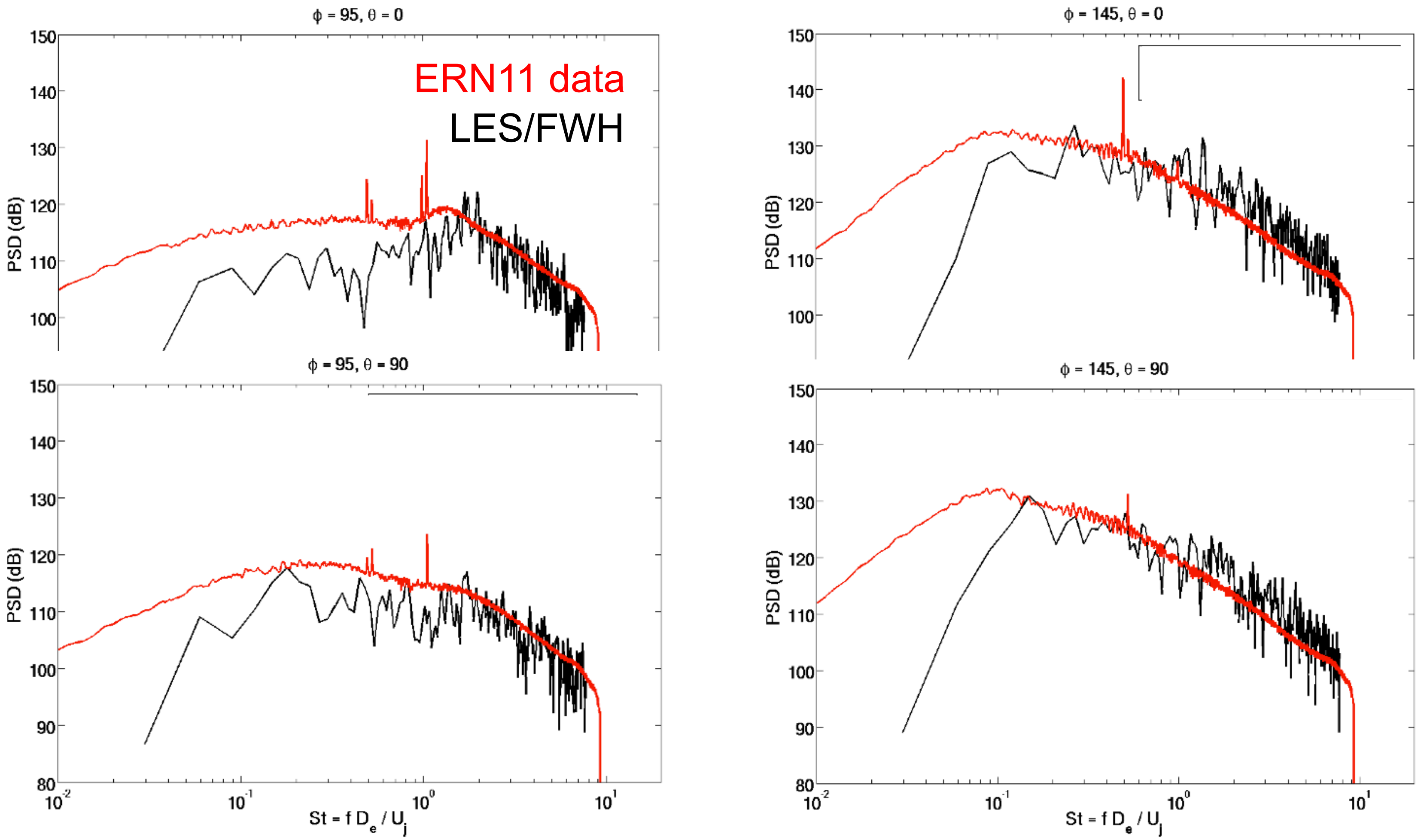
Extensible Rectangular Nozzle
RANS-based noise prediction—RISN

- Axisymmetric approximation of broadband shock noise computed from RANS CFD input
- No prediction of screech or amplification of BBSN by screech
- Blind comparison with M=1.23 hot 2:1 rectangular jet

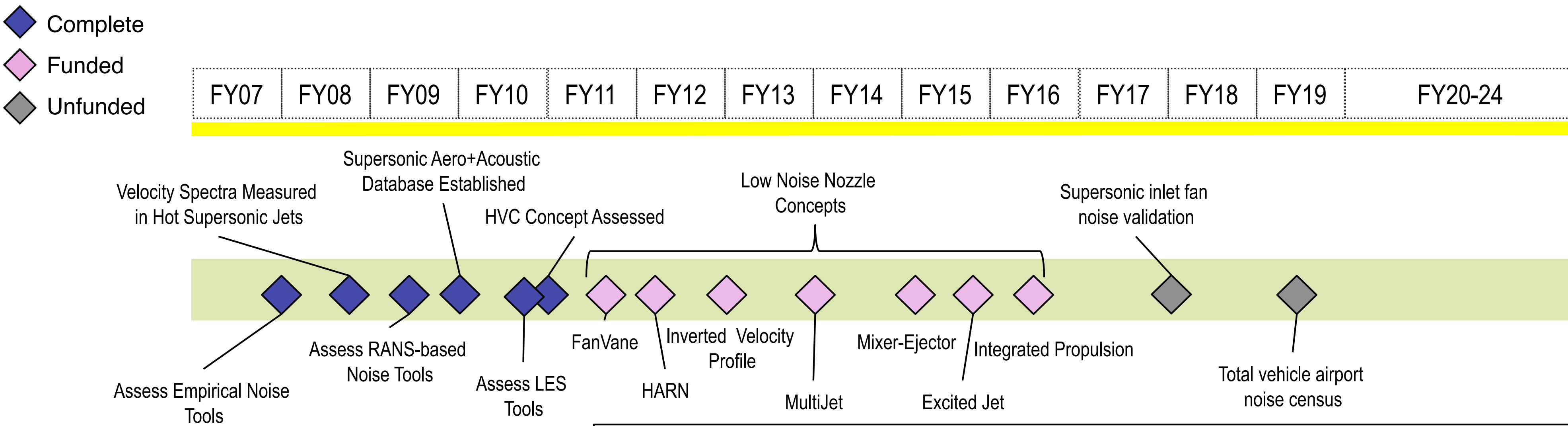


Extensible Rectangular Nozzle LES noise prediction—OASPL

- Stanford University has make LES-based predictions of far-field noise from 4:1 rectangular nozzle at hot supersonic flow condition.
- Very preliminary comparisons show remarkable agreement with data.
- More detailed comparisons underway



Measuring Progress:
Airport Noise Technical Challenge Milestones



What are the intermediate and final exams to check for success?

- Suite of noise prediction codes.
- Systems analysis tools used in cross-challenge design exercise.
- Concepts and physics-based tools demonstrated on detailed design of integrated nozzle validation test.

Recent Progress Toward Meeting Technical Challenge

- Tool Development
  - Developed RANS-based broadband shock noise code.
  - Method for creating MDOE-based empirical modules developed
- Concept Development
  - Assessed HVC mixer-ejector concept with intensive flow diagnostics.
  - FanVane concept captured in MDOE database.
  - Extensible Rectangular Nozzle models designed, tested.
  - Exploratory MultiJet experiments completed.
  - Model hardware for GE & RRLW low-noise concept validation designed.

Heilmeier Questions/Responses

- What are we trying to do?
  - Validate noise prediction codes and low noise concepts envisioned for N+3 vehicles.
  - Develop ‘NASTRAN’ for aeroacoustic design.
- Why is it hard?
  - Noise is nonlinear byproduct of unsteady flow, hard to correlate with geometry and to break into independent components.
- How is it done today & what are the limits of current practice?
  - Prediction codes are predominantly empirical, limited to conventional designs with assumptions of isolated components (e.g. airframe, fan, jet, core).
  - Noise reduction concept development is largely physical cut & try testing.
  - No predictive capabilities for unconventional concepts. Very limited ability to use in systems analysis and optimization tools.
- What is new in our approach?
  - Develop and use physics-based predictive codes more and experiments less.
  - Coordinate code development to support concept development.
  - Aim at supporting system and detail design activities.
- What are the payoffs if successful?
  - Ability to relate design parameters to noise via flow physics for optimization.
  - Ability to explore innovative aircraft designs with known fidelity.
- What are the intermediate and final exams by which we show success?
  - Intermediate: Physics-based codes validated for canonical configurations.
  - Intermediate: Noise prediction modules demonstrated, appropriate for MDAO.
  - Final: Suite of noise prediction codes, demonstrated on range of low-noise concepts.

Subsonic Fixed Wing: Proposed N+3 Gen Aircraft

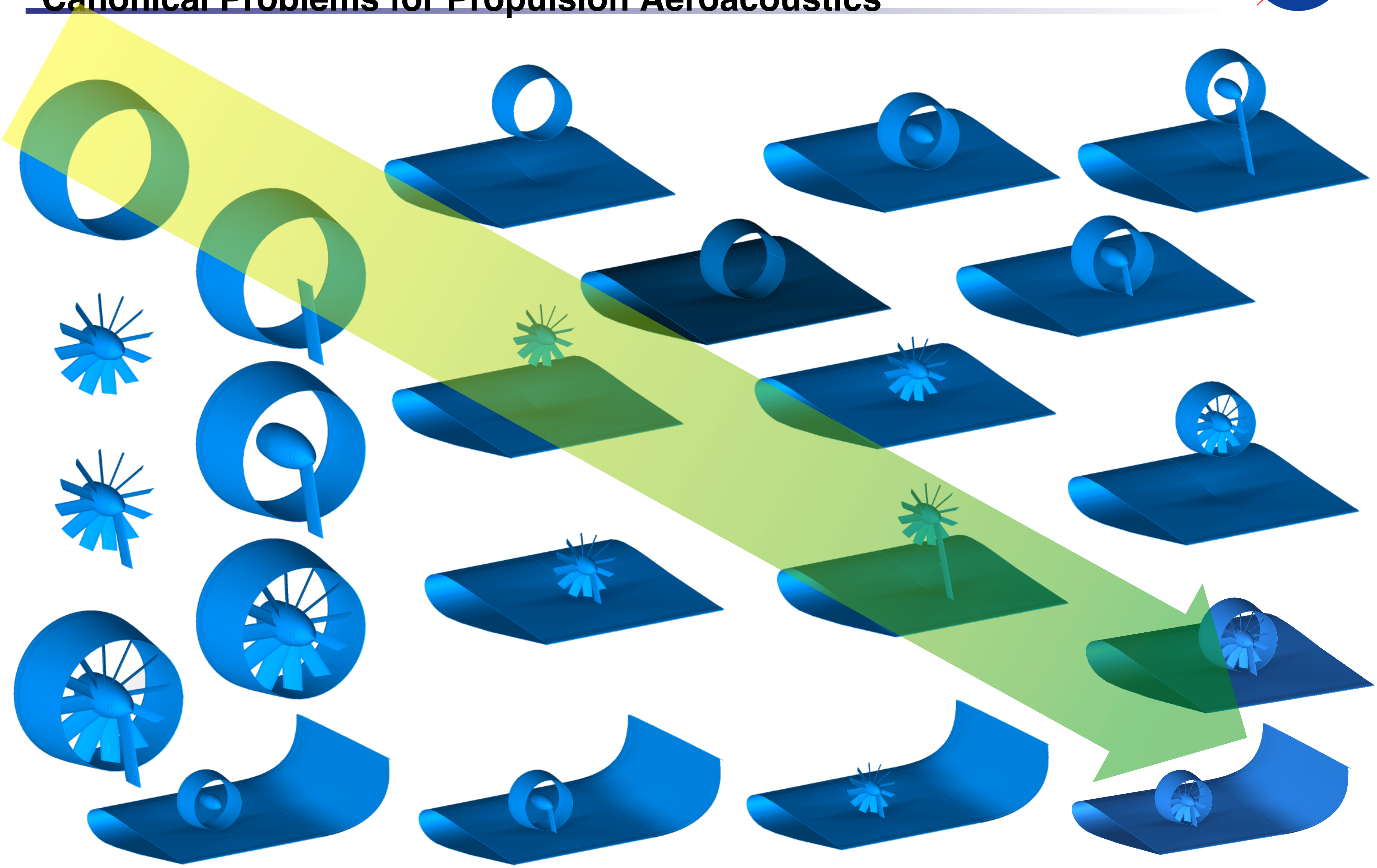
Aircraft designs involve closely coupled propulsion system(s) with the airframe. The propulsor inlets are short, operate in distorted inflow and the inlet and exhaust are in the proximity of solid surfaces acting as source and shield. Unique airframe junctures and lift distributions.

Approach to Planning Airport Noise Research

- Aerodynamic noise modeling will be embodied in a series of **code modules** that model unsteady forces and stresses, the linear and nonlinear coupling of these forces and stresses to the acoustic field, and the subsequent linear propagation of this field through inhomogeneities and solid surfaces to the far-field observer. The **flow** codes span fidelity ranges from time-average (RANS) to nearly fully resolved Navier-Stokes solvers. The **coupling codes** range from simple analytic to direct CAA, as can the linear **propagation codes**.
- To guide and validate the aeroacoustic code modules, a set of benchmark datasets are required. These datasets consist of detailed, time-resolved datasets for unsteady forces and stresses, and whole-field acoustic measurements, all **applied to canonical problems** that **embody critical features common** to the easily-recognized problems of aircraft noise.
- Recognizing that future low noise vehicles are systems of new technologies, the aeroacoustic noise modules will be **applied to concepts** as the concepts are being developed. Early application of the codes will allow creation of empirical models of the concepts, appropriate for systems analysis and optimization over a limited parametric space. In the future, the codes will support direct calculation of **adjoint solutions**, allowing high fidelity optimization of designs with minimal evaluations. Designs optimized by the numerical codes will be validated in targeted test entries with equal attention to code validation and concept validation.

Code Evolution by Increasing Complexity

Canonical Problems for Propulsion Aeroacoustics



Summary

- Vision for future aircraft given by N+2/N+3 studies in Subsonic Fixed Wing and Supersonics Projects
- Aeroacoustics challenged to explore noise of concepts and create new concepts.
- Designing advanced concepts requires
  - prediction of noise from unconventional configurations
  - prediction of sensitivities of noise to design parameters
- Supersonics/Airport Noise Tech Challenge plan (2010) combines
  - exploration of low noise concepts and
  - development of design tools.
- Plan involves evolutionary series of canonical problems which simultaneously validates concepts and design capabilities.
- Similar philosophy being explored for SFW roadmap.

NASA