Including Noise in Exhaust System Design Optimization

Making aeroacoustics an engineering science

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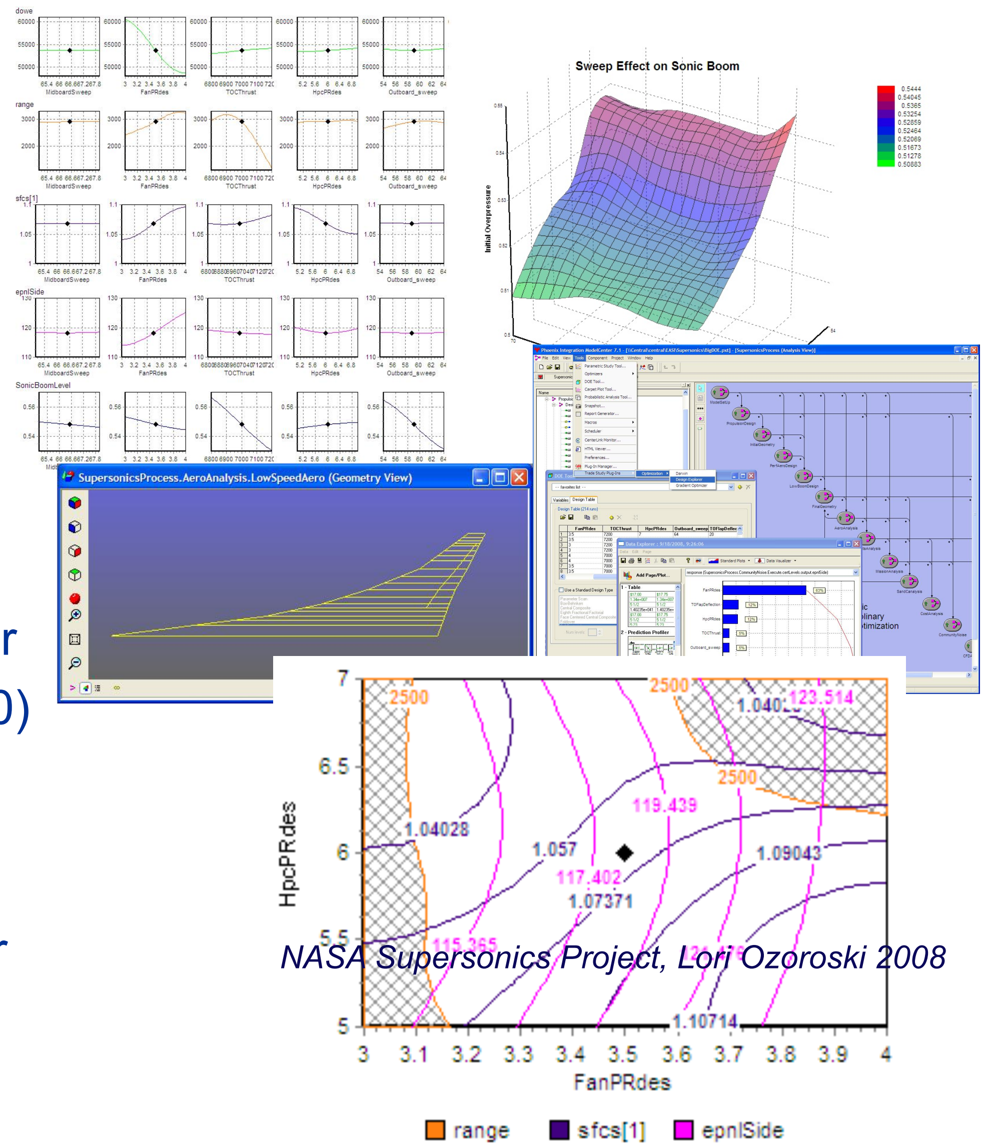
Issue being addressed

- Aircraft design make use of large numbers of design variables and surrogate models for critical performance objectives: cost/pax-mi, TOGW, etc.
- Analysis from multiple disciplines feed evaluation of thousands of design variables to find ‘optimal’ system.
- Noise is rarely one of the standard performance objectives and even more rarely an integral discipline in the process.
- **How can we make noise an equal partner in the design process?**
- NASA has been working noise prediction tools for exhaust system noise for decades, with some success.
- Time to capitalize on the success, refocus tool development.

Multi-Disciplinary Analysis and Optimization Processes

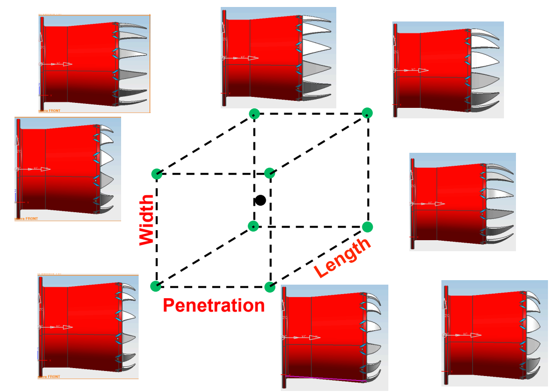
- Consists of
  - Variable database
  - Multiple objectives
  - Analysis modules
  - Framework to connect modules
  - Optimizer
- Analysis modules
  - Input from variable database
  - Output objectives to optimizer
- MDAO operations handle ~O(100) of variables, ~O(10) objectives
- When analysis modules are too time-consuming, take offline and create **surrogate models** in their place.



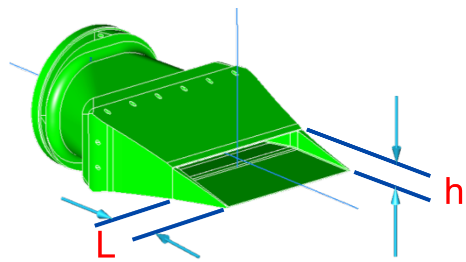
NASA Supersonics Project, Lori Ozoroski 2008

Examples of **experimentally obtained** surrogate models

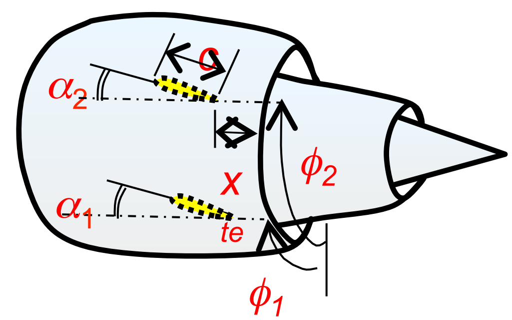
- **Chevron** designs for overexpanded military nozzles
  - Penetration
  - Width
  - Length



- **Rectangular nozzles** with aft deck extensions
  - Aspect ratio
  - Bevel length



- **Fan-Vane deflected fan flow** for low bypass ratio jets
  - Vane angles of attack
  - Vane azimuthal locations
  - Vane chords
  - Vane distances from end

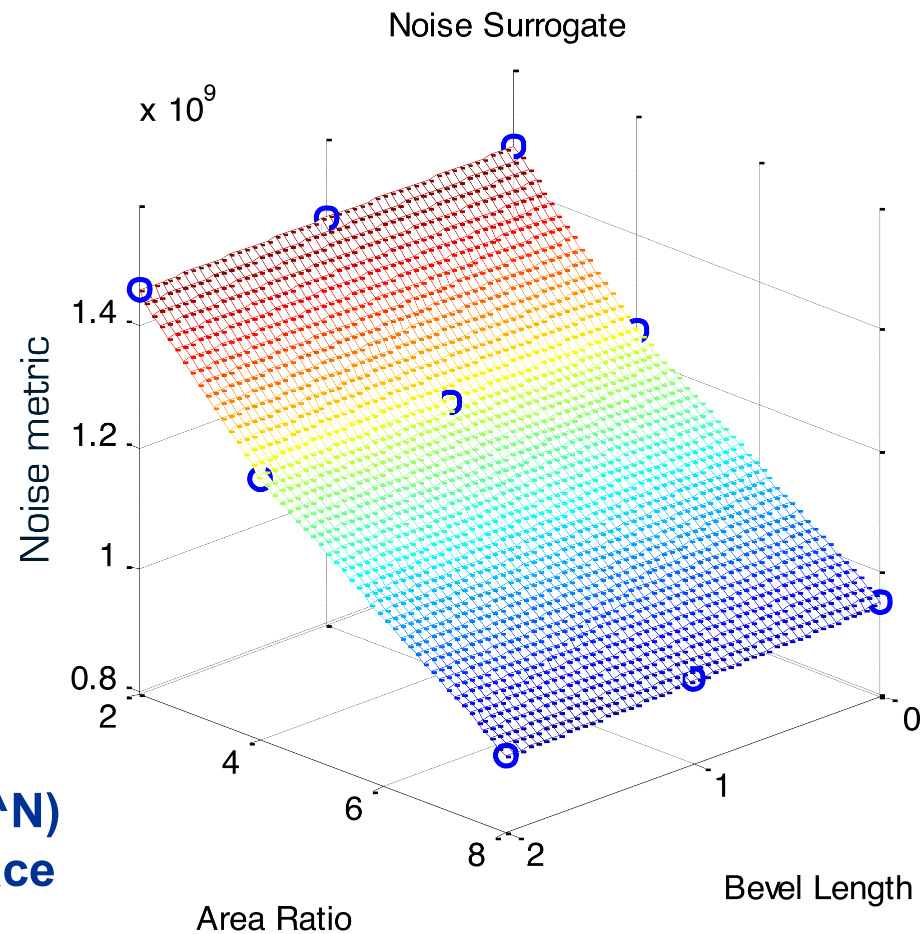


- **Common Form** (ANOPP2 MDOE module):

$$SPL(f,\theta,\phi;\alpha_i) = \alpha_0 C_0(f,\theta,\phi) + \alpha_1 C_1(f,\theta,\phi) + \alpha_2 C_2(f,\theta,\phi) + \alpha_1\alpha_2 C_{12}(f,\theta,\phi) + \ldots$$

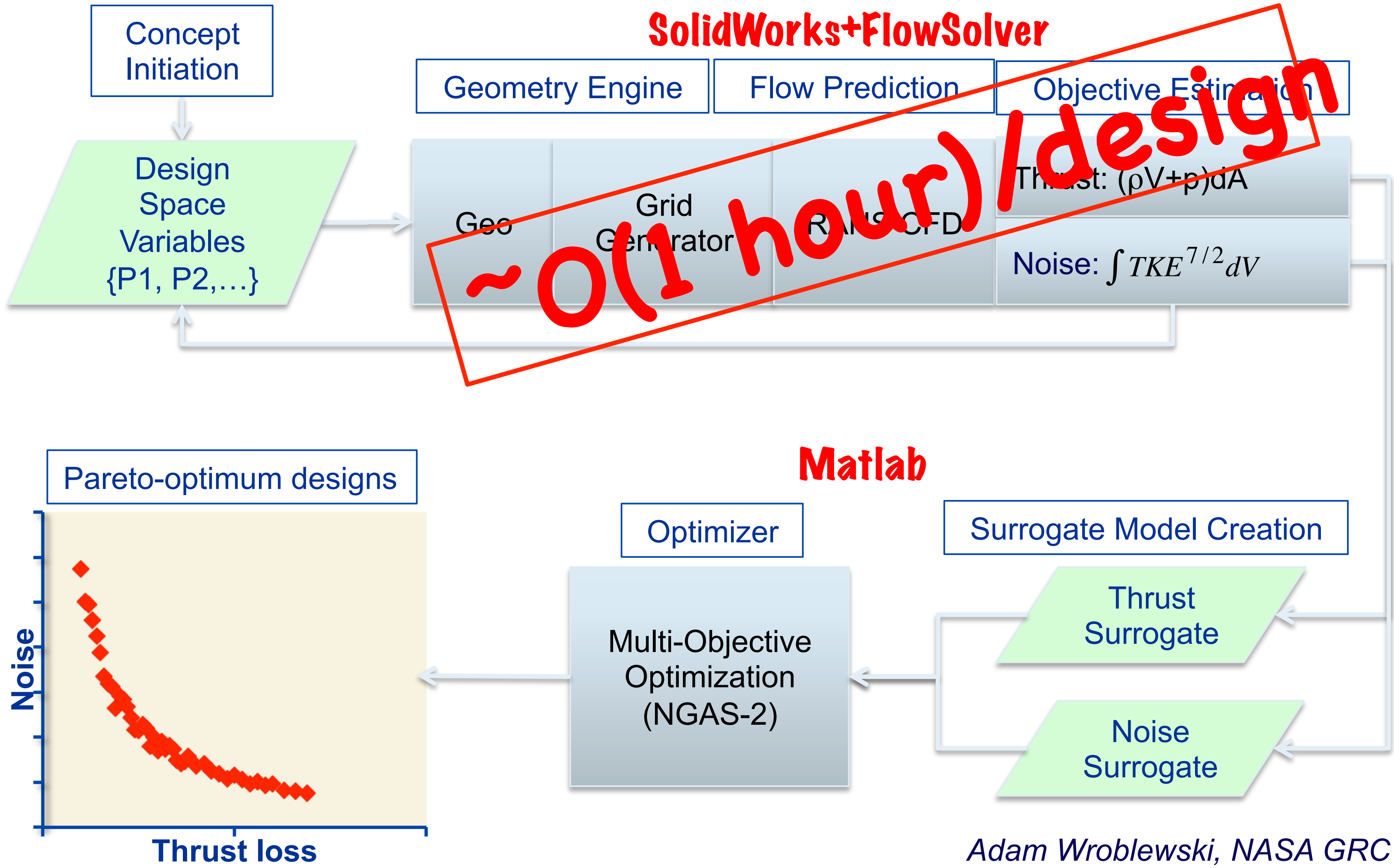
Design of Experiments-based Optimization Strategy Using CFD Instead of Experiments

- Populate variable space with CFD runs.
- Evaluate objective (noise metric) from CFD runs.
- Create surrogate model of objective over design space variables.
- Optimize system using surrogate models from many disciplines.



Even if offline surrogate model approach used, how to provide ~O(5^N) evaluations for N-variable design space in timely manner?

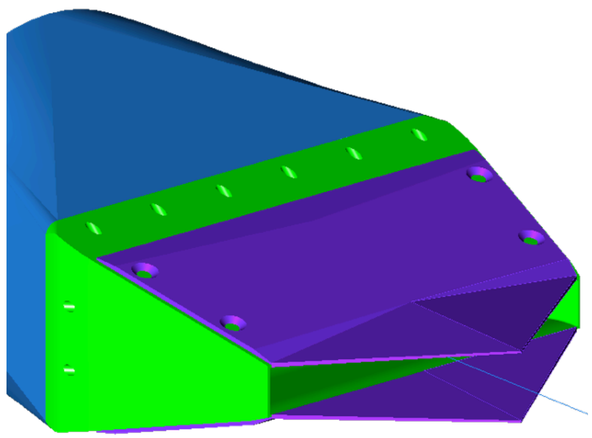
Optimization for Noise & Performance
Wroblewski's Pilot System

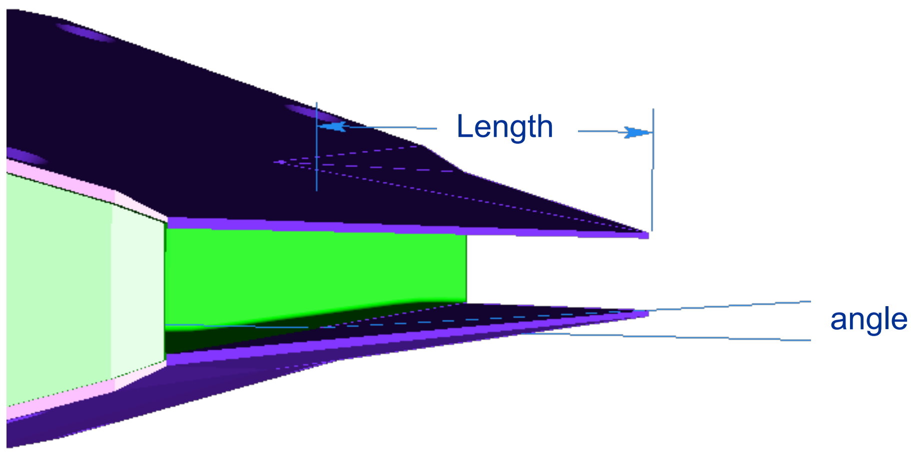


Adam Wroblewski, NASA GRC

Initial Design Space

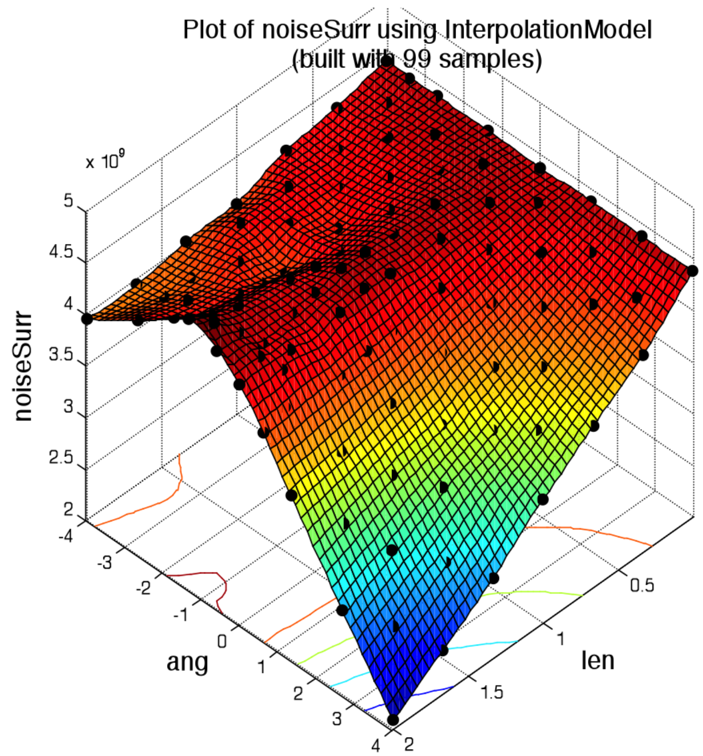
- Geometry variables: chevron length and penetration angle on 8:1 rectangular nozzle.
  - Positive angle is penetrating inward.
  - Create parametric study to find smallest sample space using low-order model. (Here, a uniform sampling was used.)
  - Populate space with simple CFD runs.

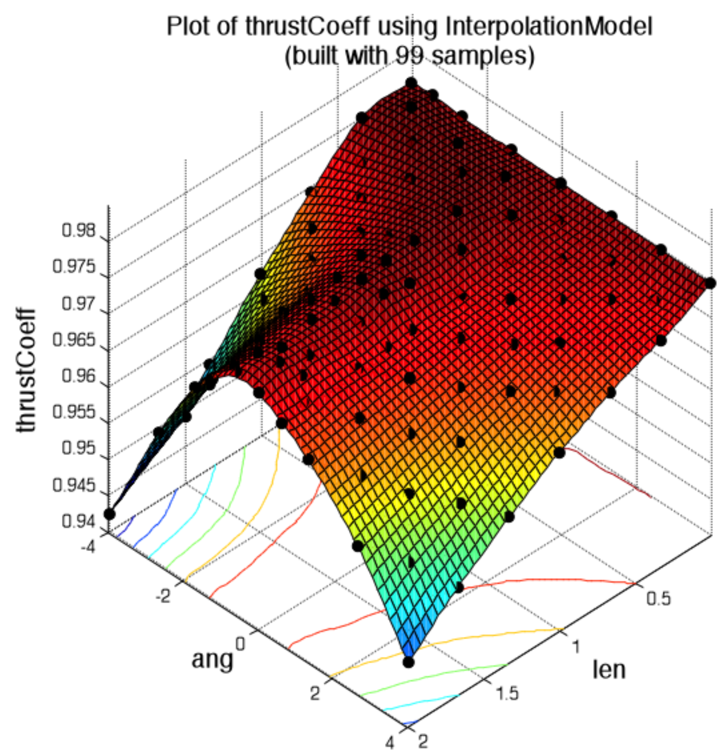




Surrogate Model

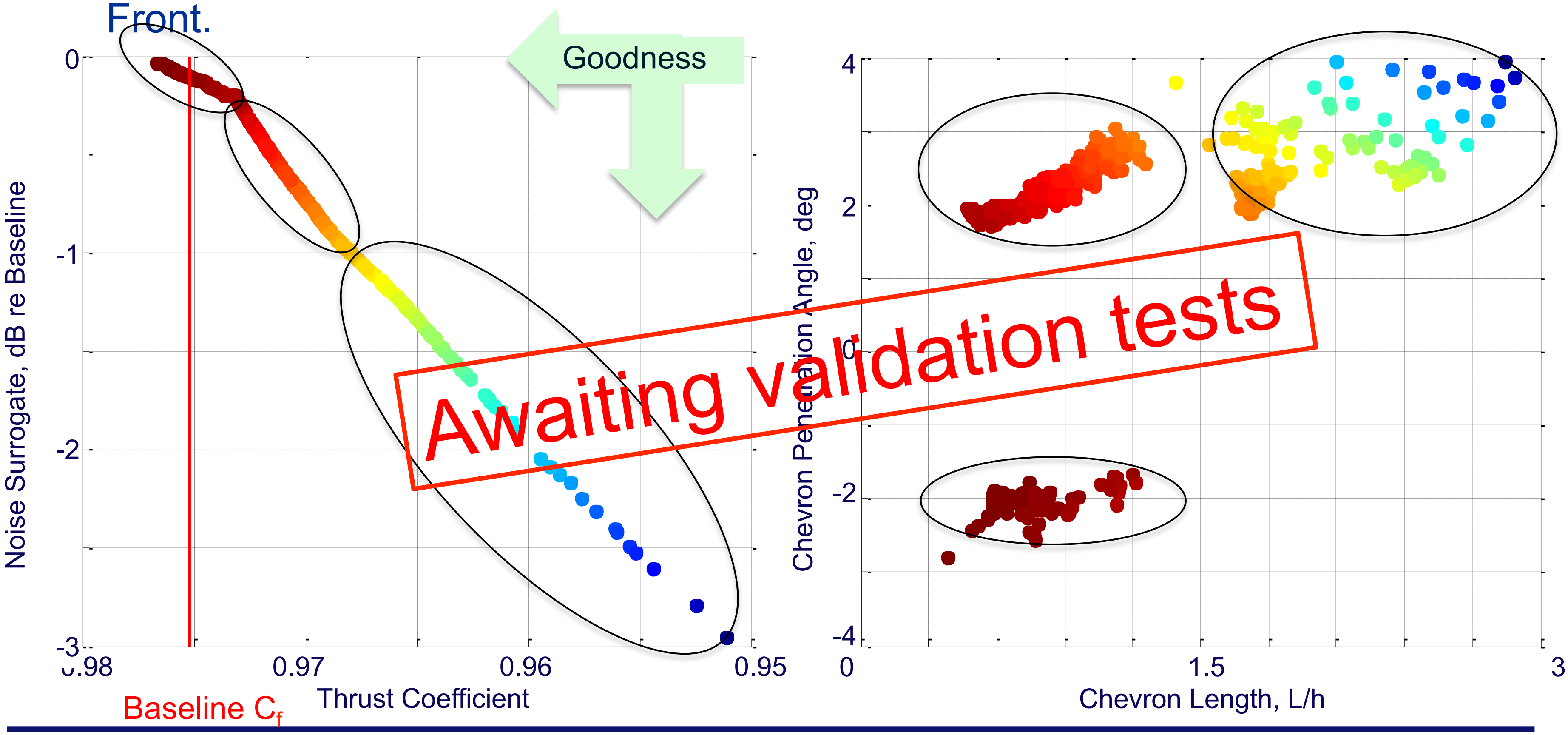
- Automated geometry/adaptive grid/RANS process using SolidWorks FlowSolver (COSMOS) with k-ε turbulence model.
- 55 initial runs accomplished on single workstation over weekend. 100 runs in surrogates.
- Post process for thrust coefficient and integral noise estimate.





Pareto Optimization

- The MATLAB multi-objective optimization routine (NSGA-II) applied to 2000 surrogate candidates with 500 generations to determine the Pareto front. Top 25% candidates shown.
- Note breaks in variable space as thrust is traded for lower noise along Pareto Front.



Issues to be addressed in optimization for exhaust noise

- Validate CFD accuracy for aeroacoustics predictions
- Create and validate low-cost approximations to objectives (noise, thrust, etc)
- Use more flexible geometry scheme for design space (flexible body descriptors)
- Work out programming details integrating into MDAO framework (ANOPP/ ANOPP2)
- Demonstrate machinery by exercising on sample problem (High Speed Project Milestone)

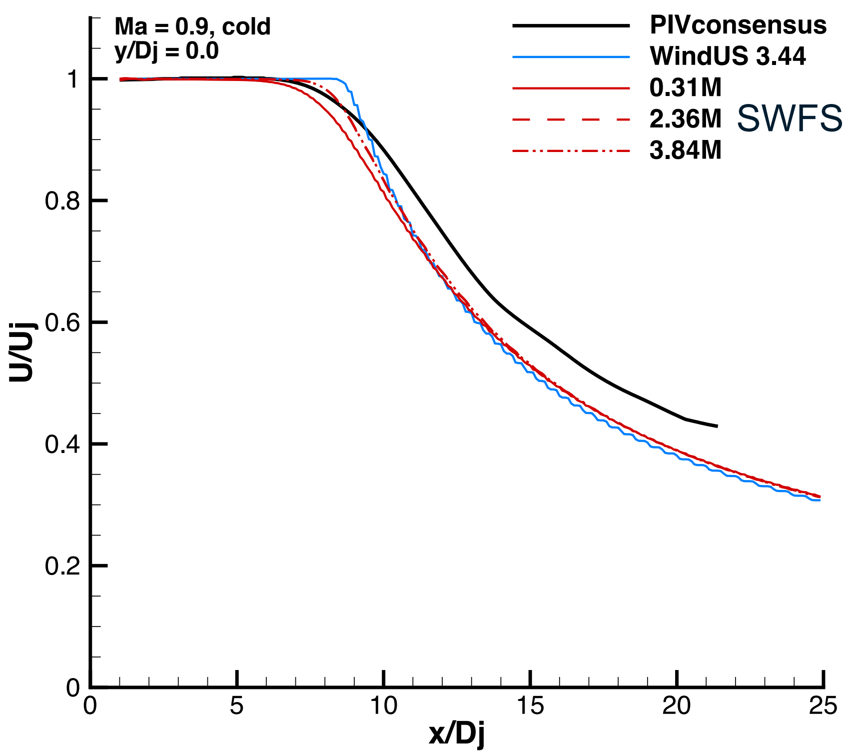
Flow Solver Validation

- Flow solver requirements
  - U, density, temperature, TKE, epsilon
  - Robust, quick turnaround from design variables to flow solution
- Codes currently being evaluated
  - WindUS (GRC/Inlet&Nozzle Branch)
  - FUN3D (Steve Miller)
  - SolidWorks (Adam Wroblewski/James Bridges)
  - OpenFOAM(?)
- Quantities to be validated
  - U, TKE on centerline, lipline (PC length, peak TKE level & location)
- Datasets for validation
  - Single-stream subsonic, hot jets (GRC PIV consensus dataset)
  - Rectangular subsonic jets (ERN12)
  - Supersonic (GRC PIV)
- Measure of robustness? Speed? Support? Licensing?

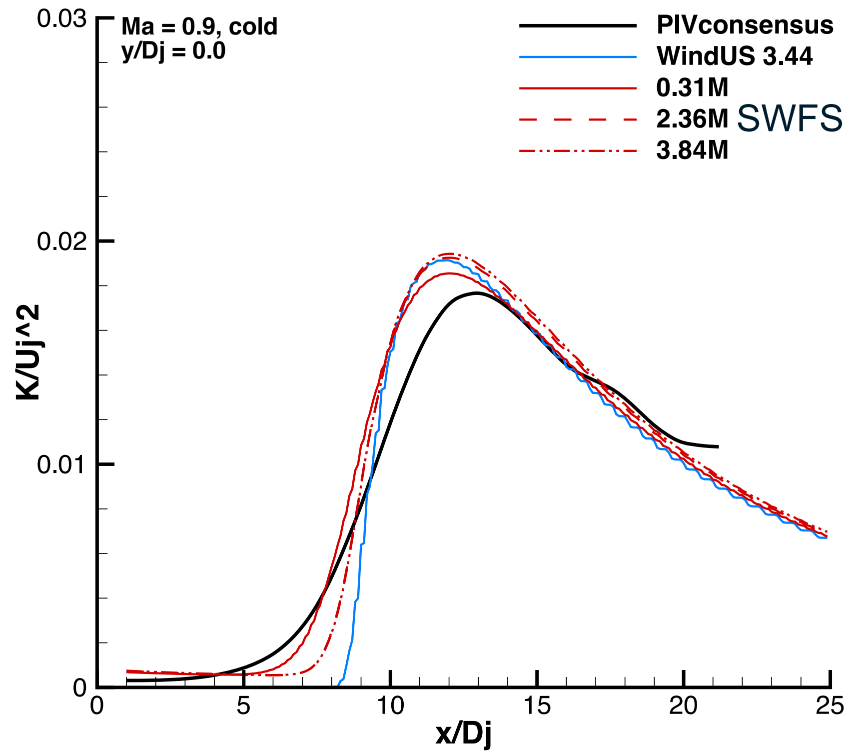
Validate Flow Solver Accuracy for Aeroacoustics

- Compare SolidWorks plume results with WindUS for round jet
- Results similar (uses same turbulence model, auto gridding good)

Centerline Mean Velocity



Centerline TKE



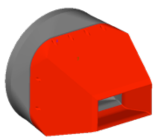
SolidWorks Flow Solver applied to Rectangular Jets

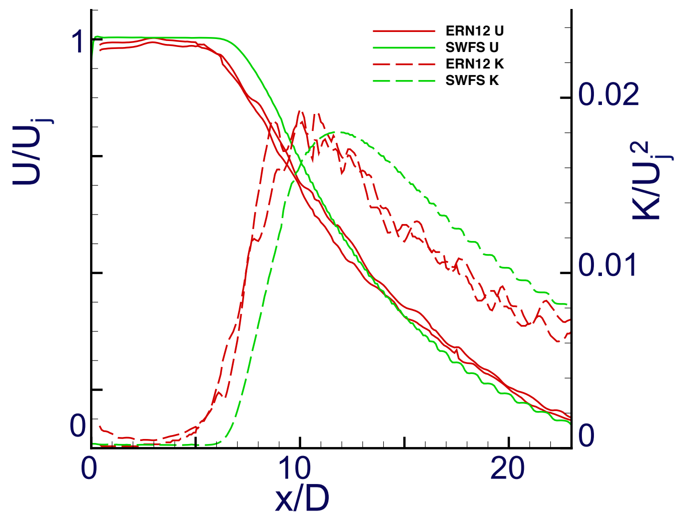
Examples:

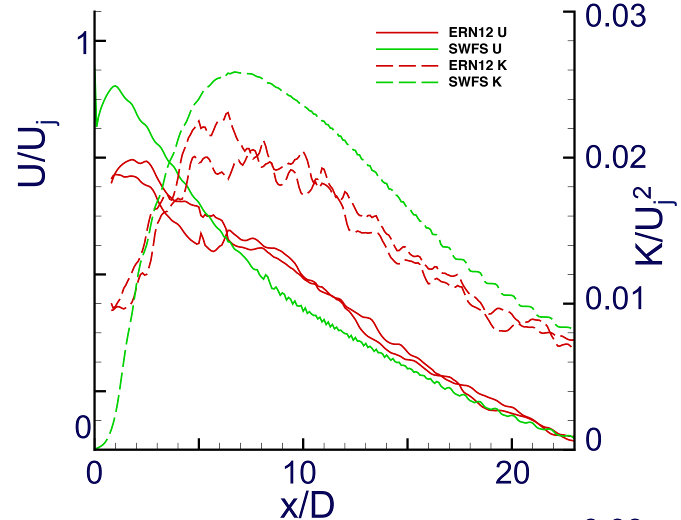
Centerline

Lipline

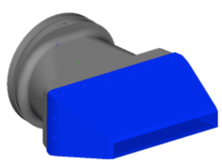
2:1 baseline

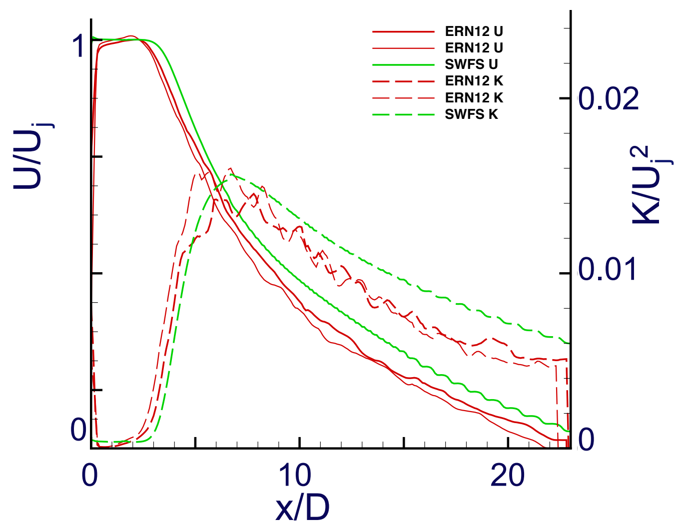


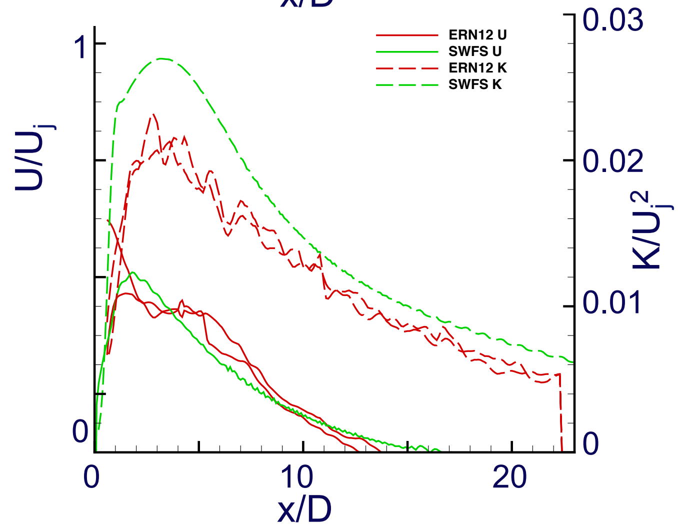




8:1 baseline







Validate Flow Solver Accuracy for Aeroacoustics

Good enough for acoustics?

Computing Noise from RANS

- Spectrum of acoustic source/coupling models for noise estimation:

	Ad hoc		Acoustic Analogies (AA)
Sources:	Int (TKE^n)	Reynolds Stress	+Enthalpy
Coupling:		Axisymmetric	General Geometry
Cost:	O(10^{-1})	O(10^2)	O(10^3)

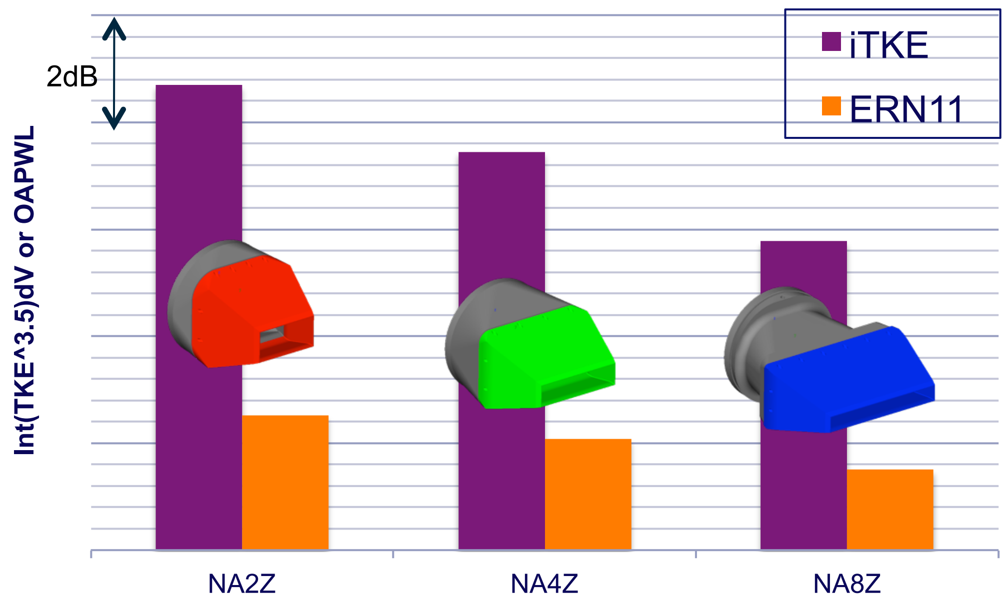
- Range of noise metrics

	OAPWL	OASPL	EPNL
Fidelity:	0-D	3-D	3-D, freq

- Match cost, accuracy of acoustic calculation and flow sol'n
- **Aim for accurate trends at fidelity matching other disciplines.**

Baseline rectangular nozzles: iTKE vs OAPWL

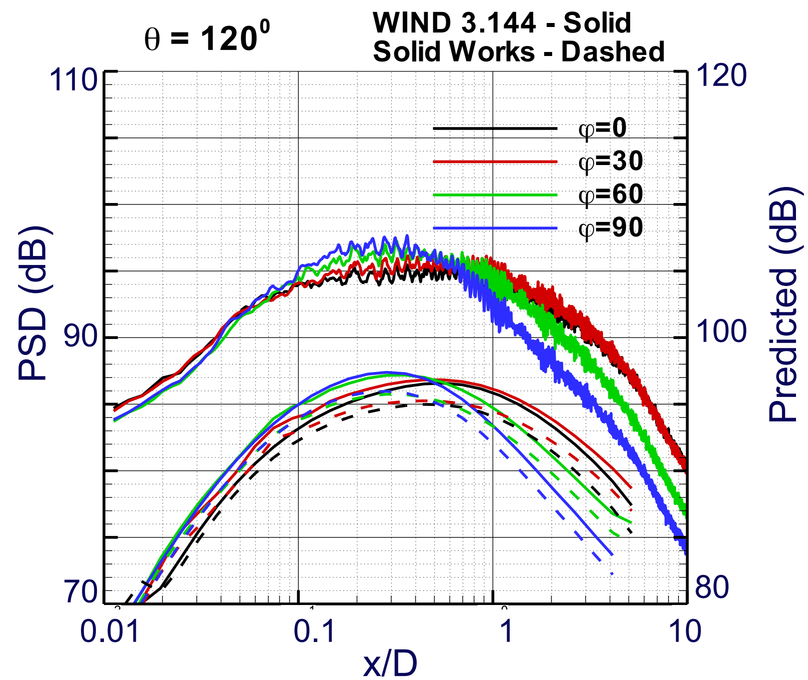
- Note that OAPWL integrates over all azimuth and polar angles, and frequencies.
  - ERN11 experimental data integrated over 0.1 < St < 1.0
  - iTKE=TKE^3.5 integrated over plume volume.
- iTKE approximation overpredicts impact of aspect ratio on OAPWL.
- Error in CFD or in acoustic approximation?



Baseline rectangular nozzles: High-End AA

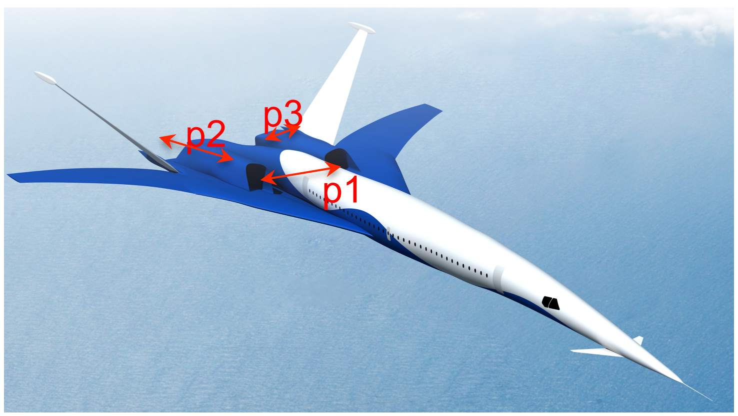
- Leib's AA code applied to WindUS and SolidWorks RANS solutions
  - Non-axisymmetry addressed by Conformal Mapping
  - Cold, Ma = 0.9 flow only
- Same trends predicted with both CFD solutions
- High-end AA code works on cheap CFD.
- Fault lies with oversimple acoustic approximation.

- **Bigger Picture:**
  - **'Cheap' CFD good enough!**
  - **Still need cheap acoustic calculation.**

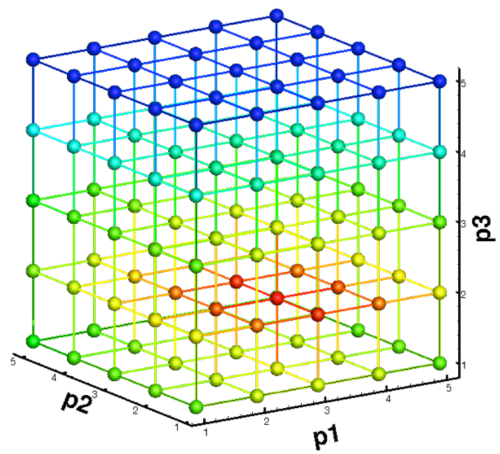


2016 High Speed Project Level 1 Milestone

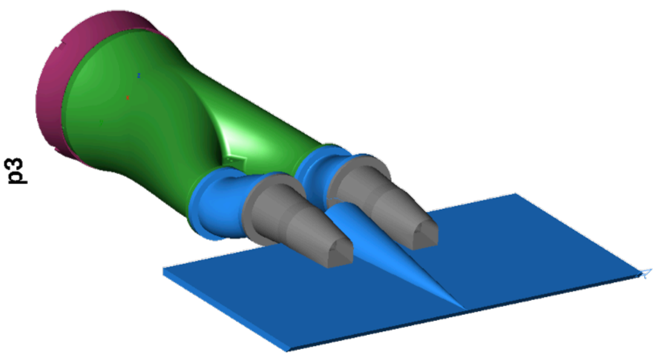
"Validate predicted sensitivities of boom, thrust, and noise of propulsion system to design variables for an N+2 aircraft design which meets FAP goals."



Concept



Sensitivities



Validated

Questions, Comments, Criticisms?

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