ANOPP2: Progress Update

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Outline

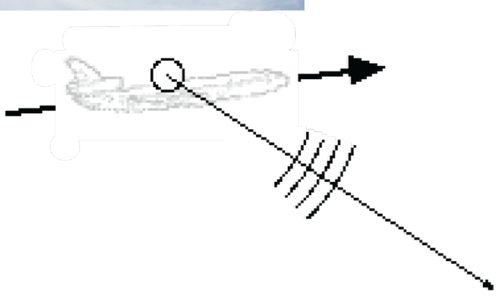
- ANOPP2
  - Objective
  - Approach & Framework
- Roadmap
  - Current plans, key deliverables/milestones
  - Future plans: direction, emphasis
- Progress
  - Scattering methods
  - Trailing Edge noise
- Summary

ANOPP2 Objective and Features

- **Objective**
  - Acoustic prediction capability of current and future aircraft designs
    - Aircraft system and aircraft components (including installation effects, i.e. Propulsion Airframe Integration (PAA))
    - Aircraft noise technologies and flight profiles
- **Features**
  - Methods for noise components with different levels of acoustic fidelity
  - Coupled prediction of flow/acoustic/propagation
  - Predict noise for multiple types of observer configurations
  - Predict noise over *long flight paths* and wind tunnel tests
  - Integration options: *observer-time-dominant* or source-time-dominant
  - Adaptable framework that accommodates current/future prediction methods, propagation algorithms, and flow solutions

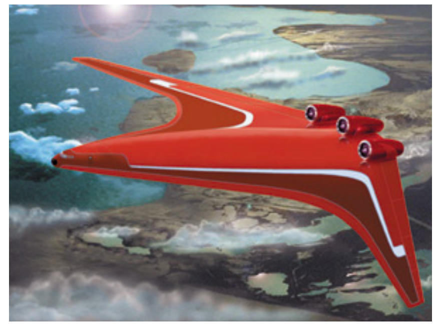
System Noise Prediction Paradigm

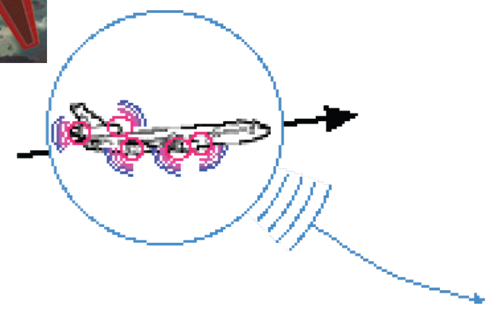
ANOPP (Current Generation)



- Noise emitted from a single point
- Installation effects are estimated
- Effects of atmosphere are primitive
- Cannot extend outside experience
- Empirical and "fixed" fidelity

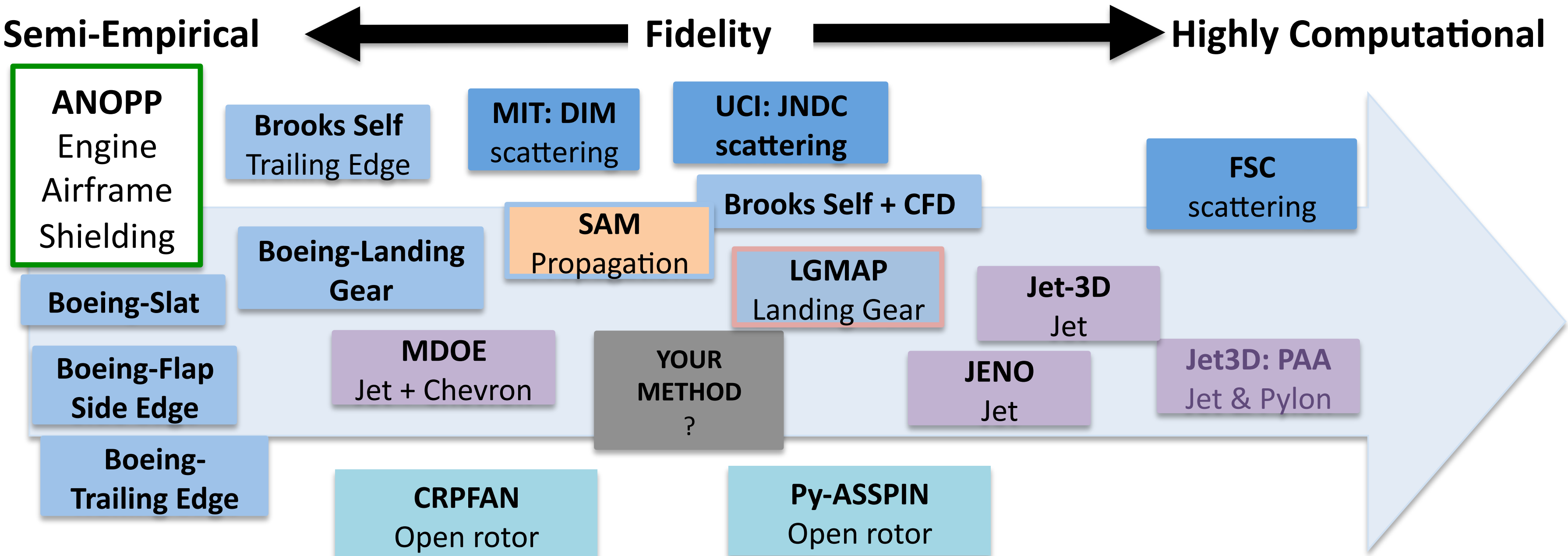
ANOPP2 ("Next Generation")





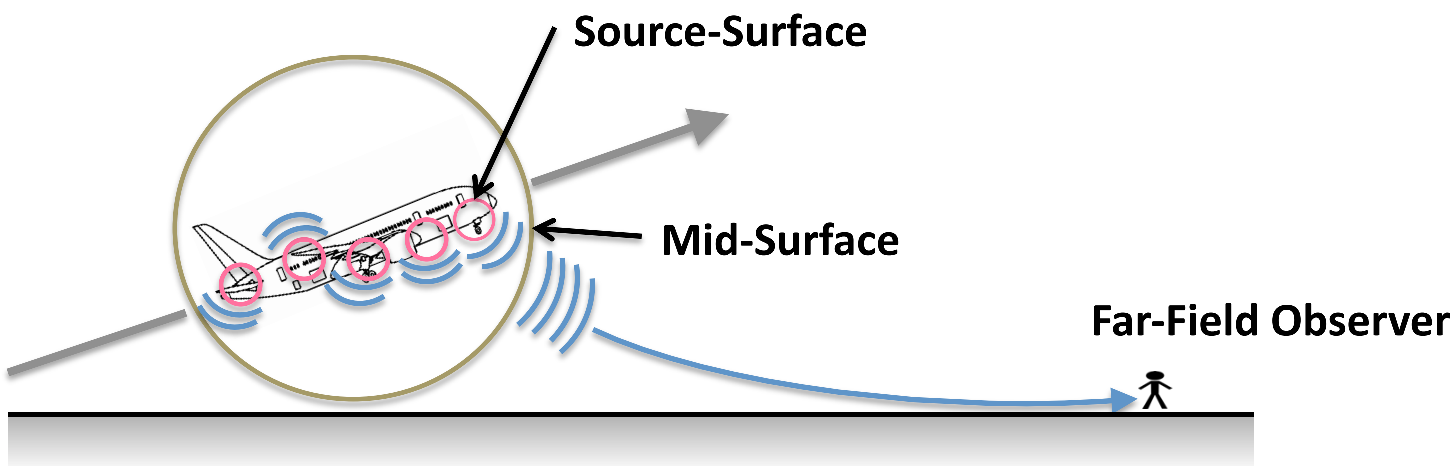
- Includes ANOPP
- Noise sources are at their true locations.
- Installation effects included
- Include effects of atmosphere and terrain
- Must predict outside of experience base
- First-principles based & multi-fidelity
- Compatible with MDAO framework

ANOPP2 Mixed-Fidelity Approach



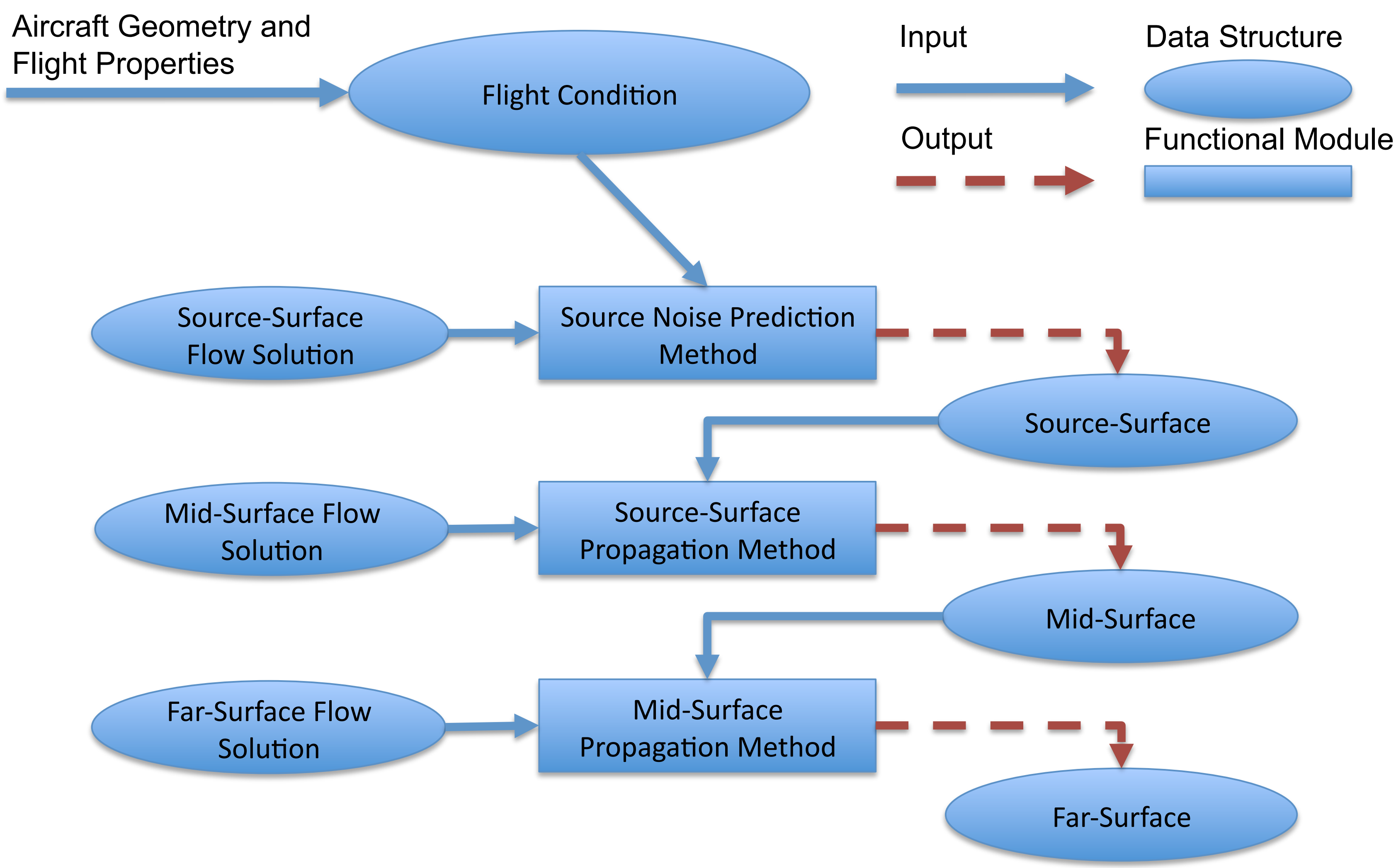
- ANOPP2 prediction modules range from semi-empirical to higher fidelity CFD based
- Pre-beta implementation of modules provides critical information required to further define ANOPP2 requirements, functionality, and guide design of initial ANOPP2 executive.

ANOPP2 Noise Prediction/Propagation Approach

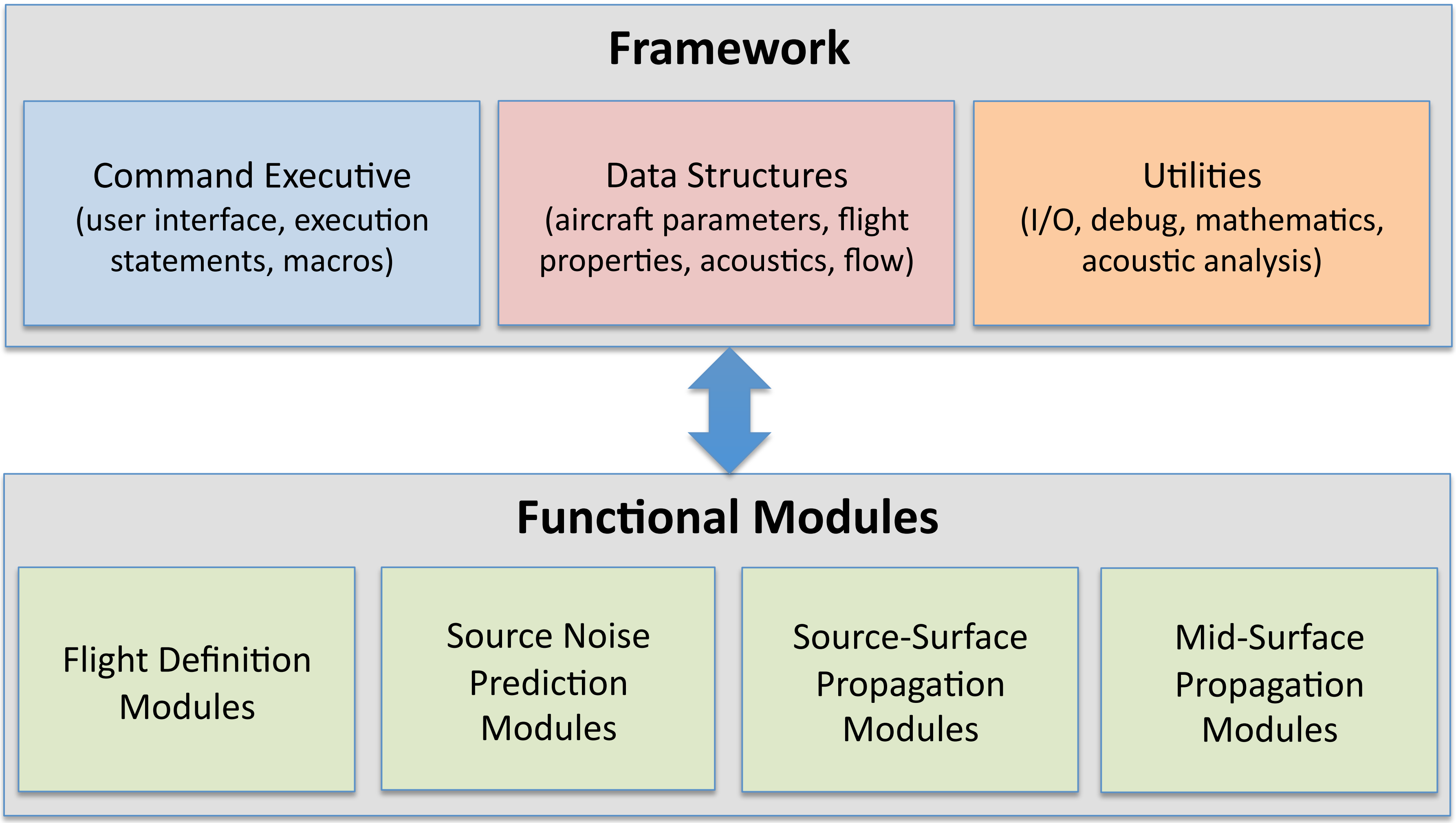


- **Source-Surface** – surrounds noise generating mechanism(s)
- **Mid-Surface** – surrounds aircraft and or sub-components, includes installation effects associated with propulsion airframe integration and noise scattering
- **Far-Field Observer** – acoustic far-field observer, includes atmosphere/ terrain effects

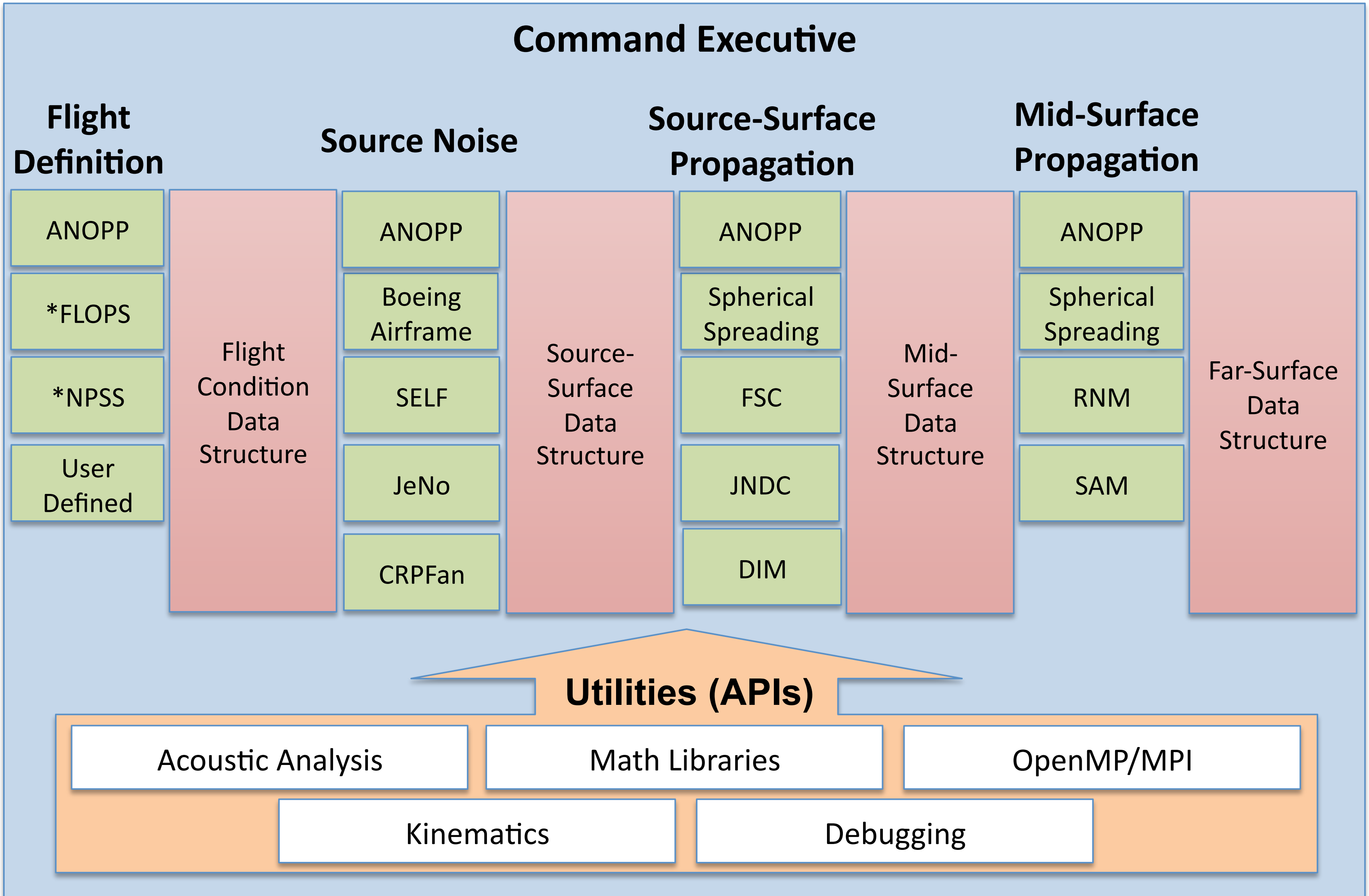
ANOPP2 Noise Prediction/Propagation Schematic



ANOPP2 System Components



ANOPP2 “Floor Plan”



Module Software Readiness Levels (SRL)

- **SRL 1: (not ready for distribution, but want to include/test as part of aircraft noise prediction system, i.e. ANOPP2)**
  - Researcher code, typically one user
  - Limited test cases for limited range of validity
  - Limited or no documentation
  - Not distributed unless requested
  - Not supported
- **SRL 2: (near ready for distribution, but needs expanded testing, validation & doc)**
  - Research code, multiple users
  - Range of validity and test cases
  - Documentation of at least theory and possible user's manual
  - Distributed with ANOPP2 with disclaimer
  - Not fully supported (installation only)
- **SRL 3: (most ready to be considered for distribution with ANOPP2)**
  - Research code, many users
  - Full range of validity for typical aircraft flight conditions, code test cases and validation cases
  - Documentation: theory and user's manual
  - Integrated part of ANOPP2 (always distributed)
  - Fully supported by ANOPP staff

Key Deliverables & Milestones

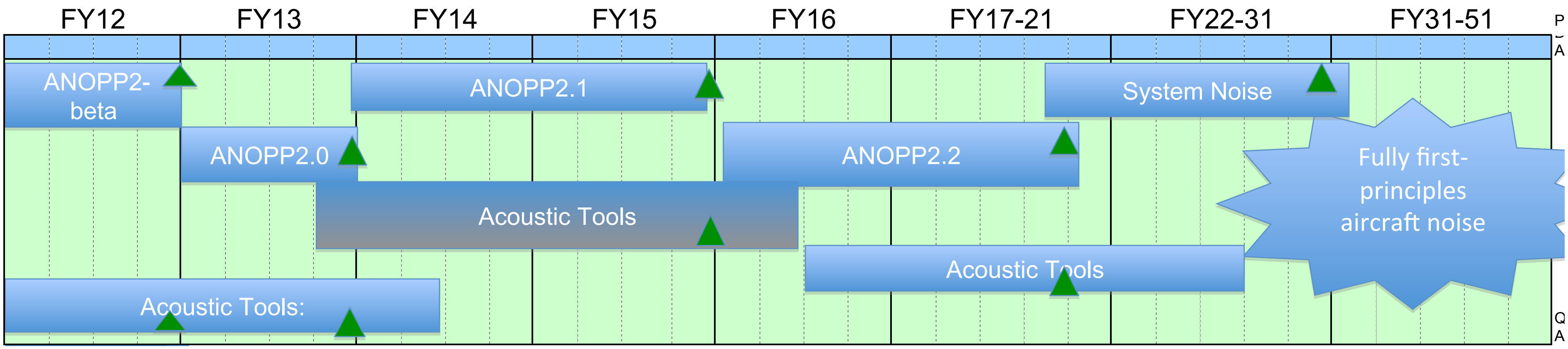
Milestones/Deliverables	FY10	FY11	FY12	FY13	FY14
SFW.08.03.012: Develop High-Fidelity and Reduced-Order Models for Inclusion in the Next Generation Mixed-Fidelity Aircraft Noise Prediction Capability -- Interim Assessment 1		ANOPP2 concept			
Mixed-Fidelity: Airframe, Jet, Propagation, Pre-beta Framework, req/constraints, Noise Assessments					
SFW.08.03.021: Develop High-Fidelity and Reduced-Order Models for Inclusion in the Next Generation Mixed-Fidelity Aircraft Noise Prediction Capability -- Interim Assessment 2		ANOPP2.0 Alpha			
Beta framework: data structures, MDAO hooks, Documentation, FLOPS & NPSS Coupling, Open Rotor (CRPFAN, ASSPIN), jet, airframe(t.e.), Liners, Verification & Validation, Assessment(s)					
SFW.08.03.022: Develop High-Fidelity and Reduced-Order Models for Inclusion in the Next Generation Mixed-Fidelity Aircraft Noise Prediction Capability -- Interim Assessment 3			ANOPP2.0 Beta		
Command Executive, Documentation, Scattering (FSC, DIM2, JNDC), Airframe & Engine, Liners, Far-Field Propagation, OpenMDAO & Gen2, V&V, Assessment(s)				**ANOPP2.0**	
SFW.08.19.001: Improve and Validate Next Generation Mixed-Fidelity Component and Aircraft Noise Prediction Capability -- ANOPP2					
Command Executive, Documentation, Scattering methods, PAA (jet installation), Airframe:control surfaces & LG, Propulsion: Engine components & OR, Far-Field Propagation, V&V, Assess: N+1, N+2, N+3					

Partners & Collaborators

- NASA
  - ANOPP2 Team
  - SFW, SUP, SRW, ERA
- External
  - Academia: MIT, GT, Ole Miss, Penn State, UCI
  - Industry: Wyle, Northrop Grumman
  - OGA: FAA, Army-AFDD, Army-CRREL)
  - NRA: Mark Dunn, Inc., Boeing(s)
- Support
  - NRA contracts
  - Lockheed, Missouri Univ, UVA, Boeing(s), GTRI, Wyle, MIT, GE, Pratt&Whitney, Belcan, ATA, APAC, SenTech, PSU

Quiet Aircraft: 7. Acoustic Tools/Methods

- Technology Areas 1-6 provide validated tools/capabilities for system noise
- Maturation of tools for system analysis and application
  - extending tools for range of parameters and conditions
  - validation within a system environment
- Noise analysis/assessment for FA in coordination with MDAO



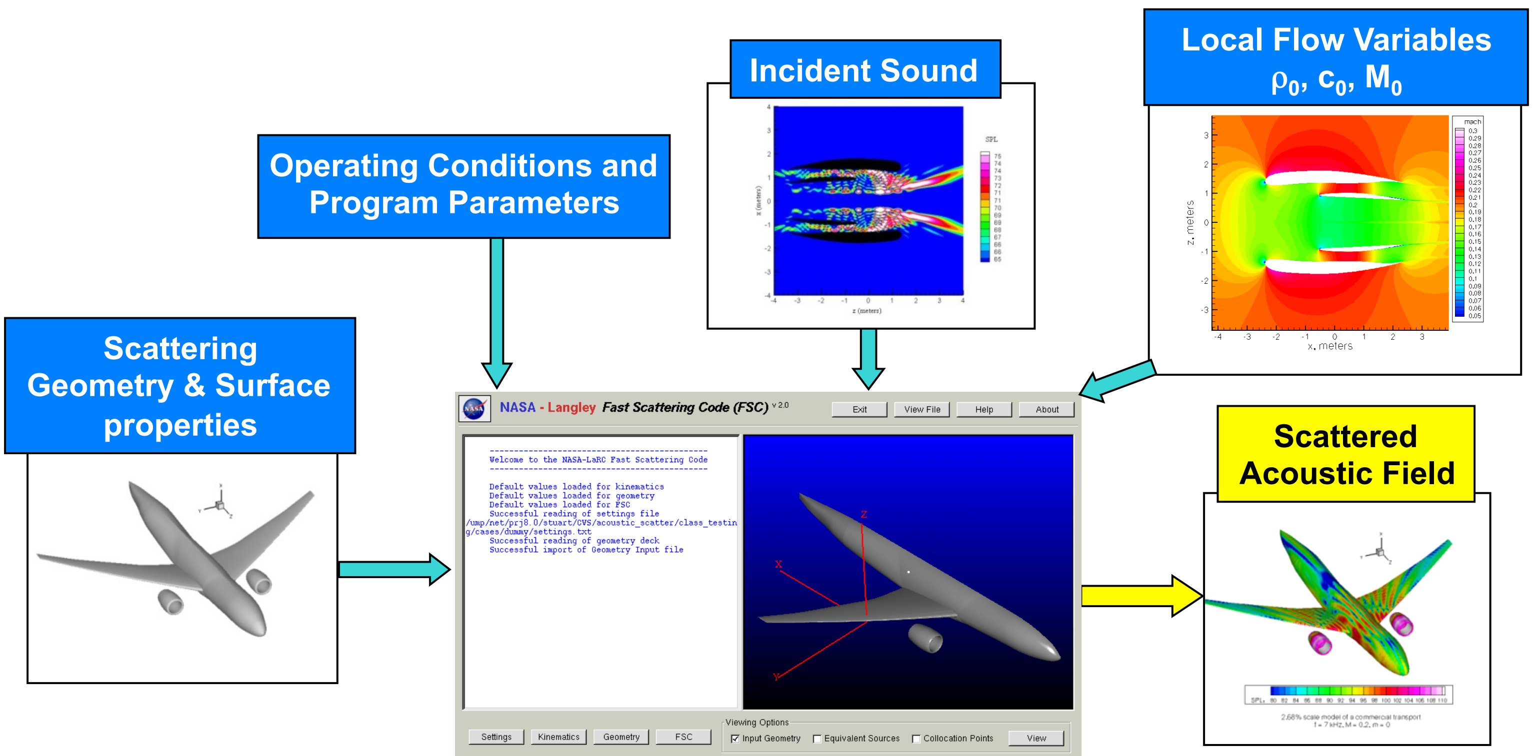
NASA SFW Element: Quiet Aircraft

Scattering Methods and Limitations

- **ANOPP-Wing**
  - Based on semi-infinite diffraction edge theory (Maekawa & Beranek)
  - Limited geometries ("wings" represented as quadrilateral)
  - No phase information retained
- **Fast Scattering Code (FSC)**
  - Can handle geometric details: i.e. edges, 'corners'
  - No frequency restrictions other than resource limitations
  - Computational parameter selection & full-scale application expertise required
- **DIM2 (based on MIT diffraction integral method**)
  - Flat geometry, edge geometry not included (sphere equivalent to thin disk)
  - Source (localized) description satisfies Helmholtz equation: spherical functions to define directional source (ex. Fan noise from Heidmann).
  - Accounts for phase and flow effects, compact source
- **JNDC/BEM (UCI: jet wave packet model coupled with BEM)**
  - Wave packet parameters definition requires 'data' for specific jet, account for distributed source
  - BEM method commercial software, plan is to replace with FSC

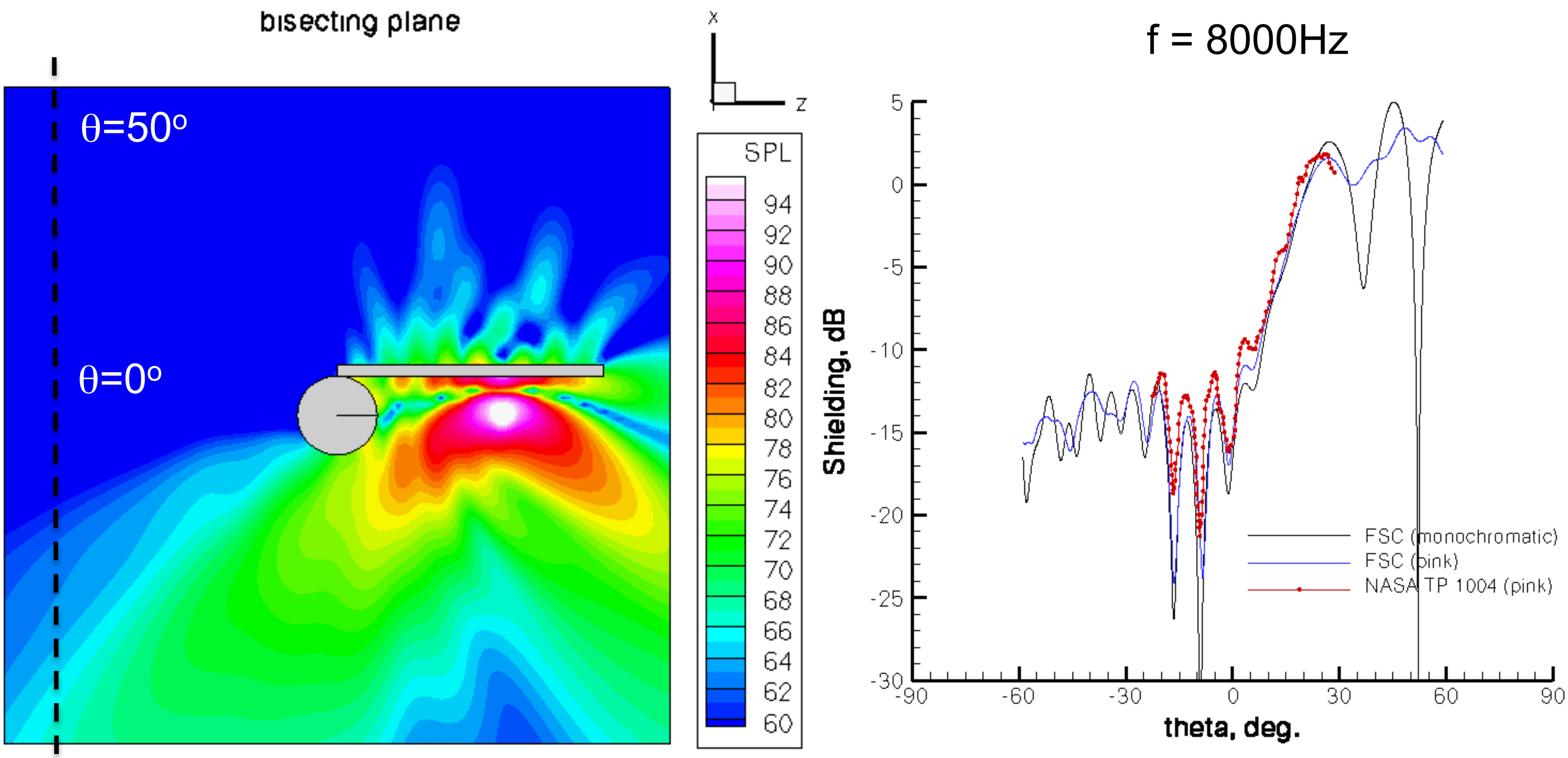
The Fast Scattering Code (FSC) Description

- SFW supported effort: Ana F. Tinetti and M. H. Dunn, Consultants, Douglas M. Nark, COTR
- Frequency domain program for predicting the scattered acoustic field produced by the interaction of known incident sound with arbitrary 3-D aerostructures in the presence of a potential background flow.
  - Methodology uses the Equivalent Source Method to solve an exterior Helmholtz Boundary Value Problem (BVP)



FSC Results for Cylinder/Plate Configuration with Point Source

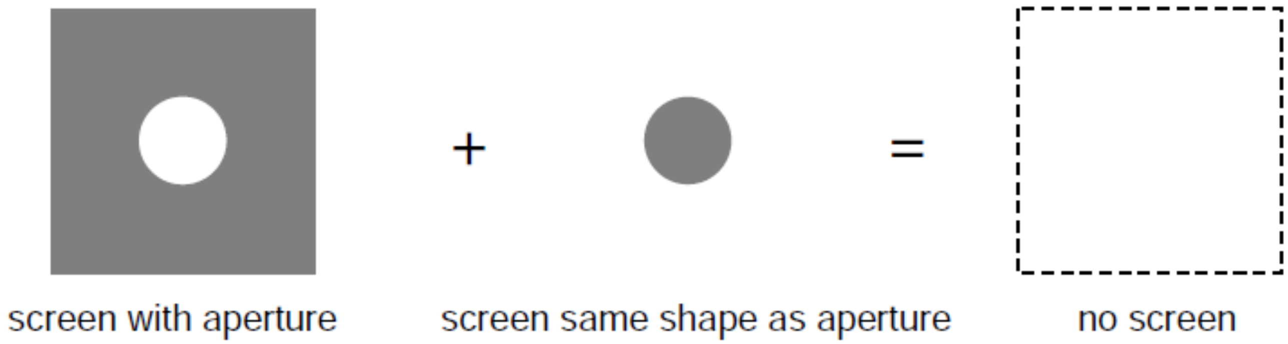
- FSC predictions by M. H. Dunn and A. Tinetti (NNL09AA17C Q2 FY11)
- flat plate: 1.6m x 0.5m x 0.07m, cylinder dia = 0.5m



- Data from: Ahtye, W. F., and McCulley, G., "Evaluation of Approximate Methods for the Prediction of Noise Shielding by Airframe Components," NASA TP 1004, January 1980.

Kirchhoff Diffraction Integral Method (DIM)

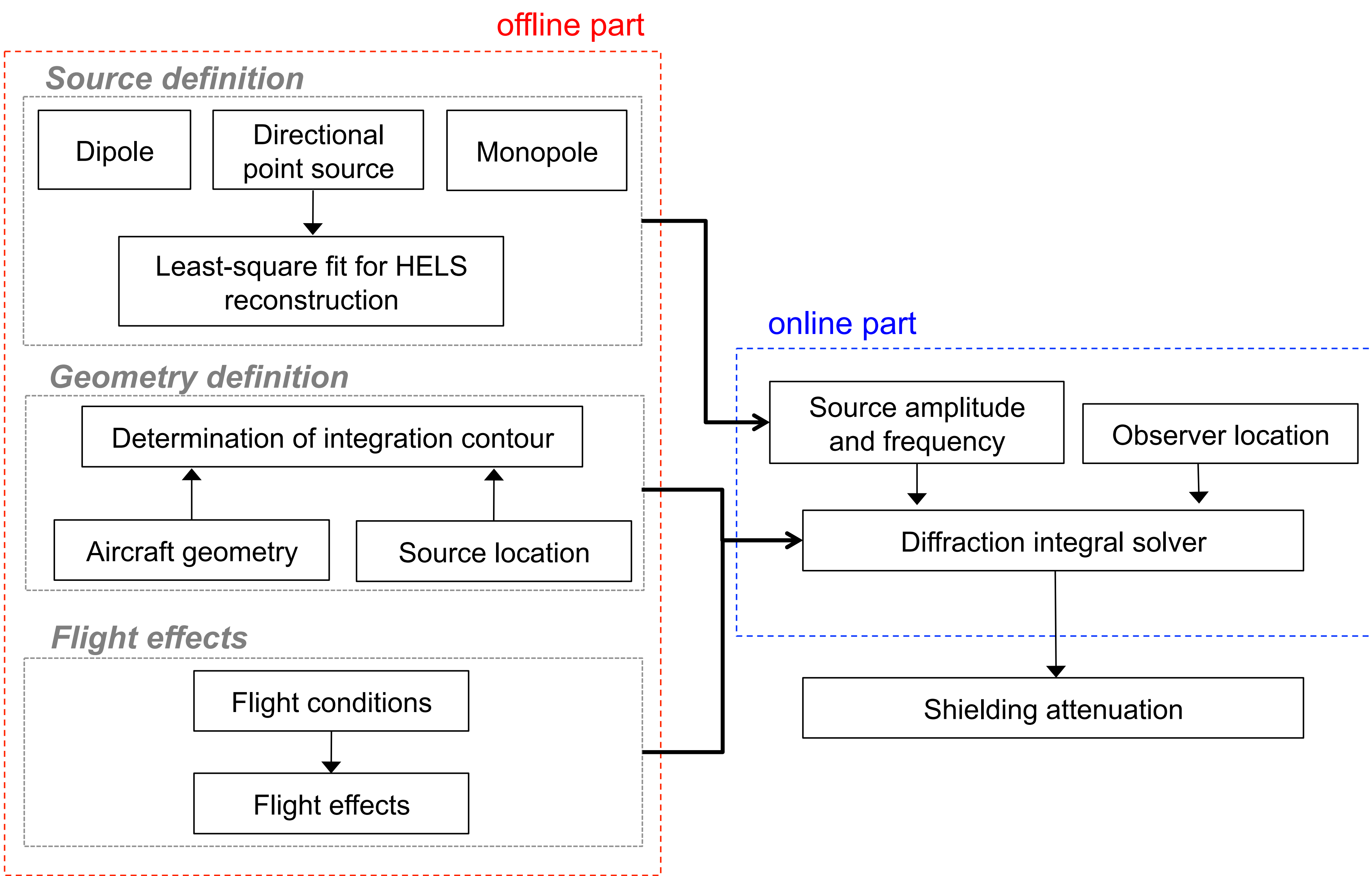
- Developed at MIT (Spakovszky) under NASA ERA contract
- A simplification of the Green's theorem solution to the Helmholtz equation for the special case of diffraction through an aperture in a screen:
- Babinet's principle: the sum of diffracted pressures due to complementary screens is equal to the undiffracted free-field pressure:



- Determine outline of shielding object based on source location
- Numerically solve the contour integral to obtain diffracted pressure through the aperture.
- Determine diffracted pressure for shielding object:

$$P_{\text{diffracted}} = P_{\text{direct}} - P_{\text{aperature-integral}}$$

Diffraction Integral Method – Overview

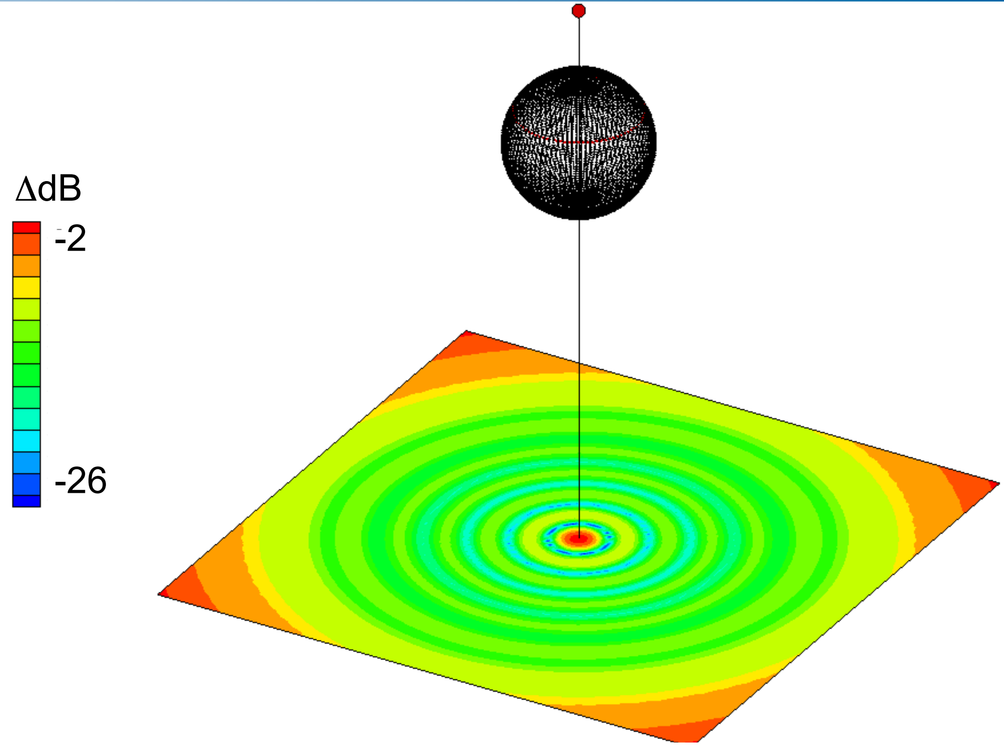


Diffraction Integral Method Developments

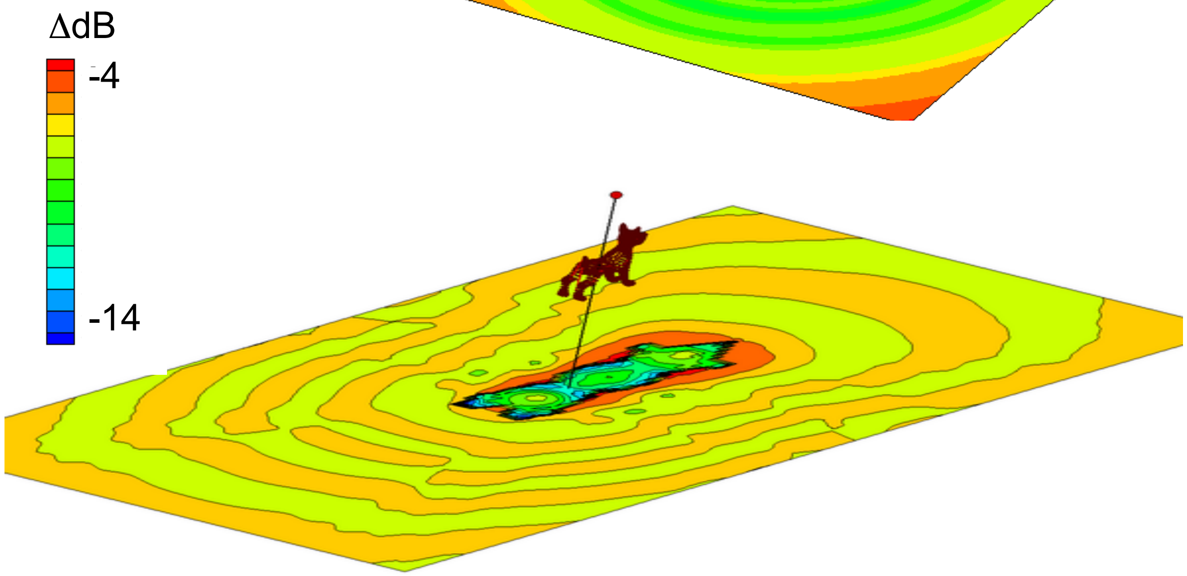
- **NASA implementation: DIM2**
  - Completely FORTRAN. No dependence on MatLab or external libraries.
  - Outline contour determination by Delaunay triangulation of diffraction object shadow rather than MIT MatLab routines (projection of object onto a parabola). (~10x faster).
  - Inclusion spherical divergence and atmospheric absorption
  - Enhanced to include source definition with full directivity ($D(\theta,\phi)$)
- **Validation**
    - Benchmark data: JNL (point source), QFF(broadband source/nacelle), UCFANS (fan tone source/nacelle)
    - Method comparison: Ahtye report (NASA TP 1004) and FSC

DIM2 Sample Results

- Simple Sphere Geometry
- f = 1080 Hz

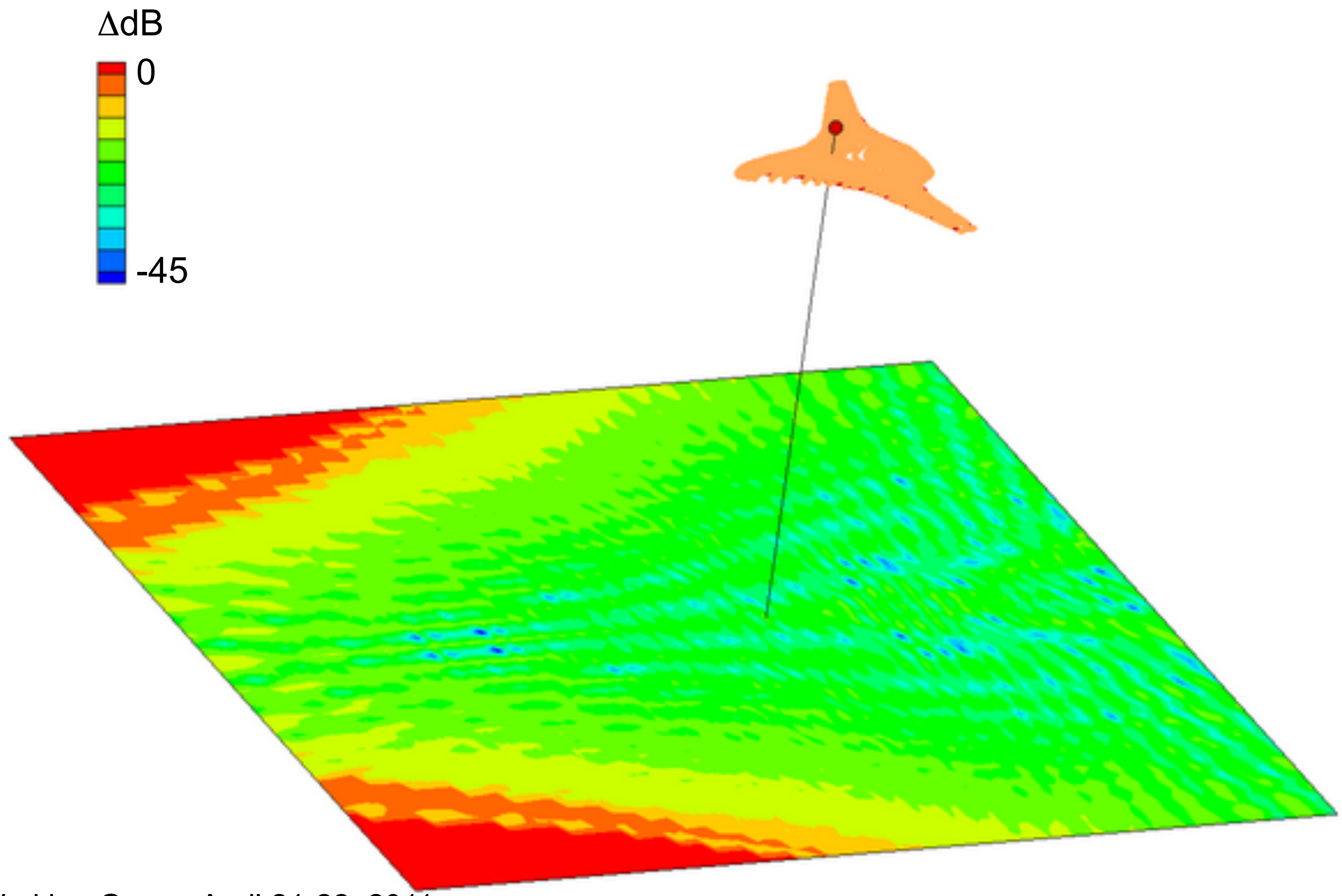


- Complex Geometry
- f = 100Hz



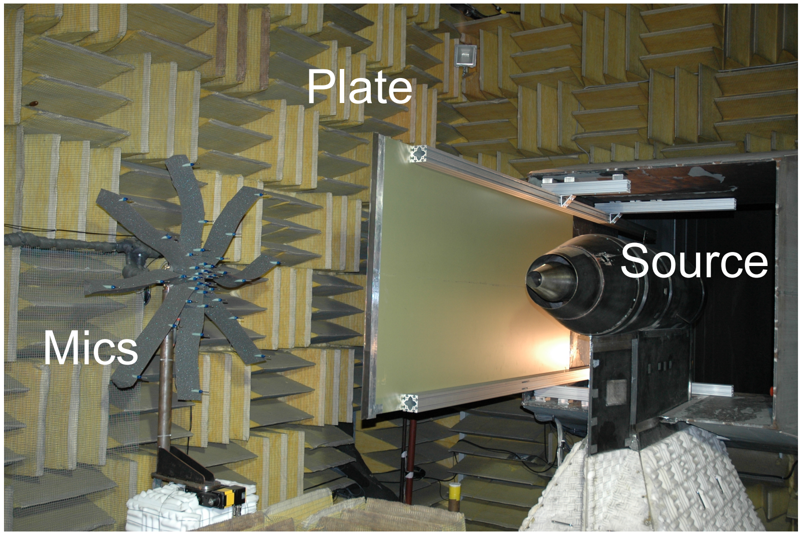
HWB Example

- Blended Wing-Body Configuration used by MIT
- f = 500 Hz
- Results match MIT results

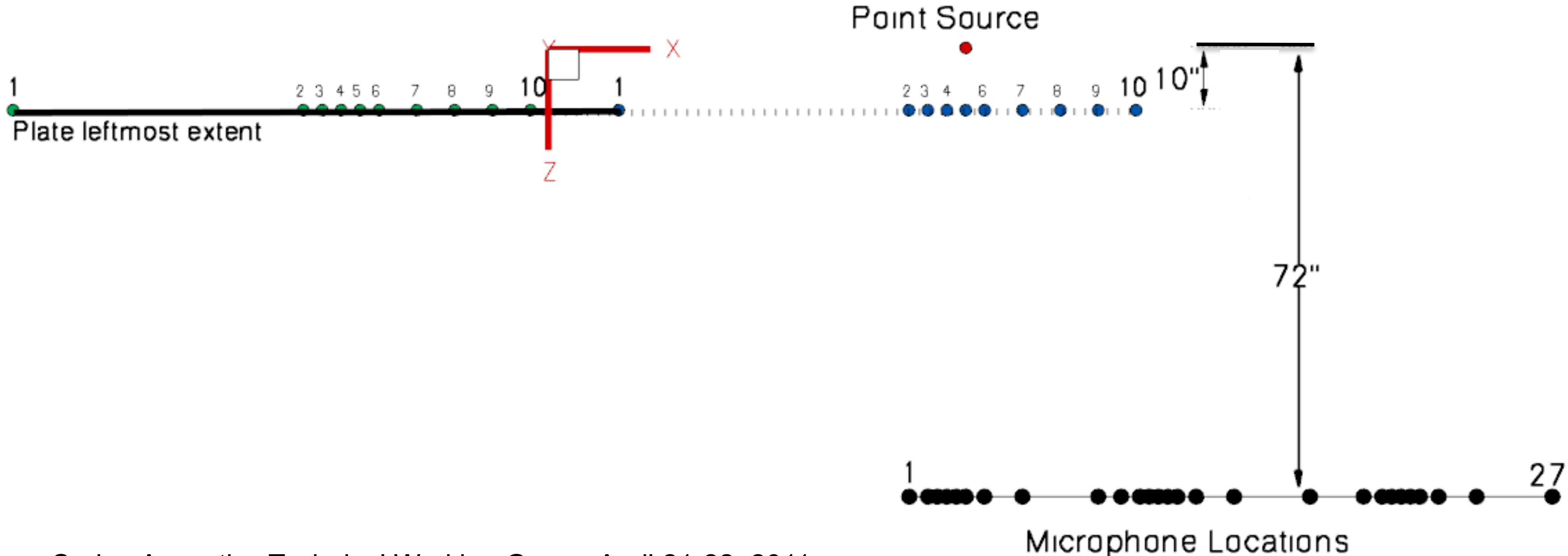


ERA Risk Reduction Test: Noise Shielding

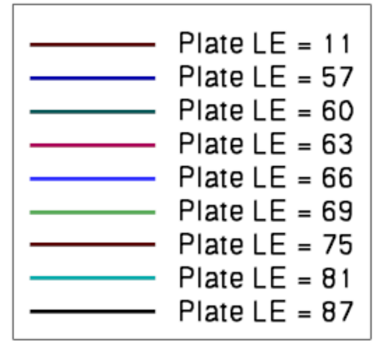
- Sources: Jet, Point Source
- Shield: Flat Plate
- Acoustic Measurements:
  Single Mic & Array



Test Schematic



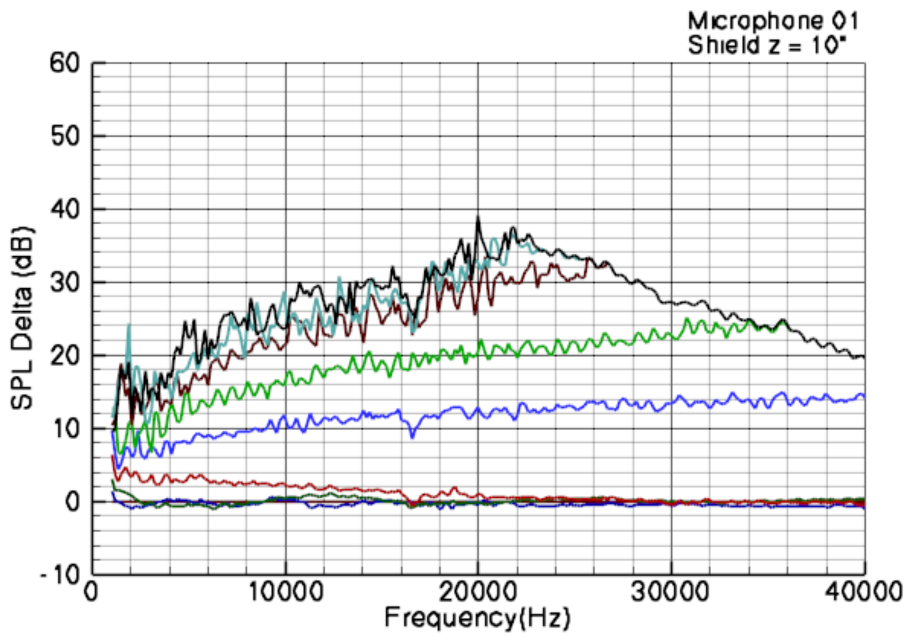
DIM2 Predictions Compared to Measured Attenuation



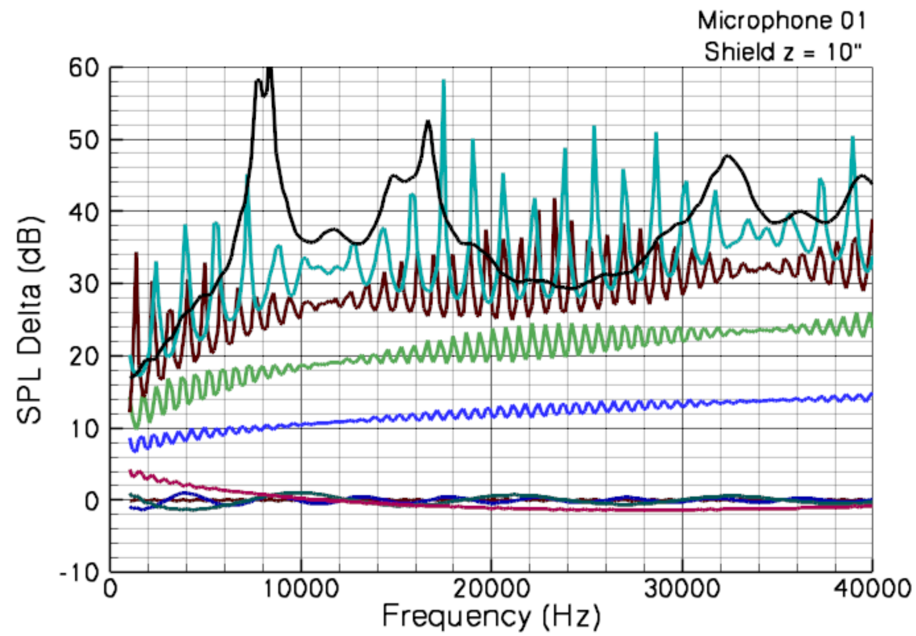
Not shielded

Shielded

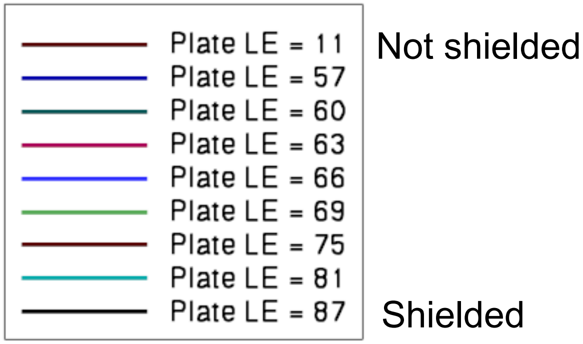
Measured Shielding (JNL)



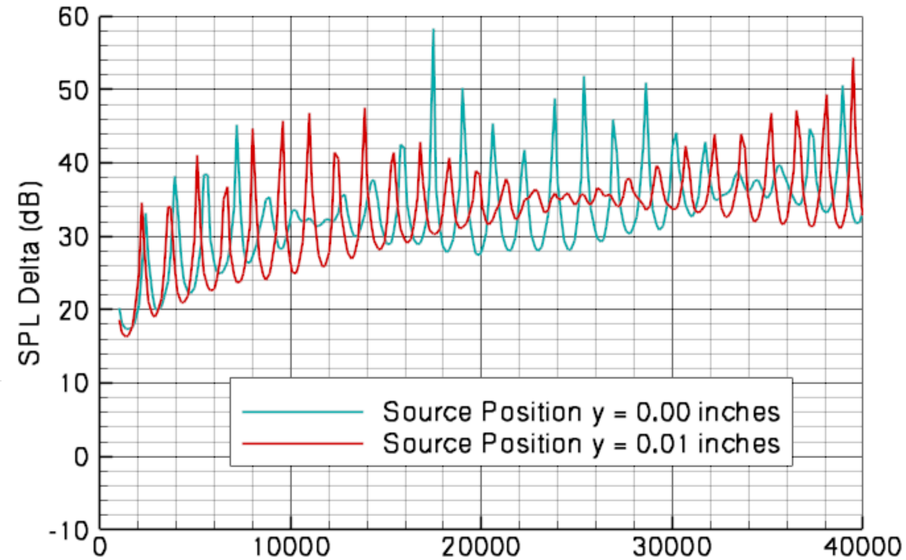
DIM2 Predictions



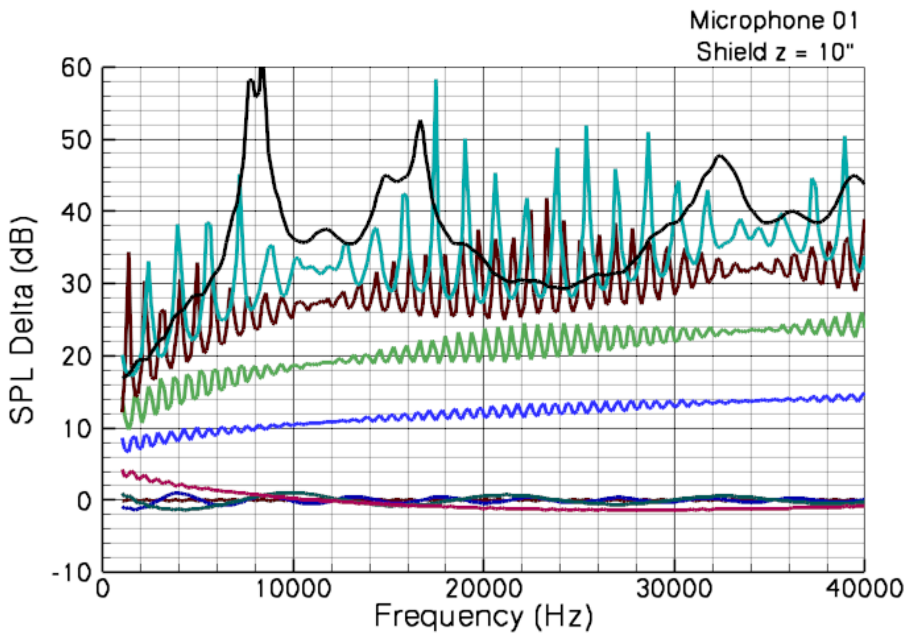
DIM2 Predictions
Effect of Source Position and Plate Size

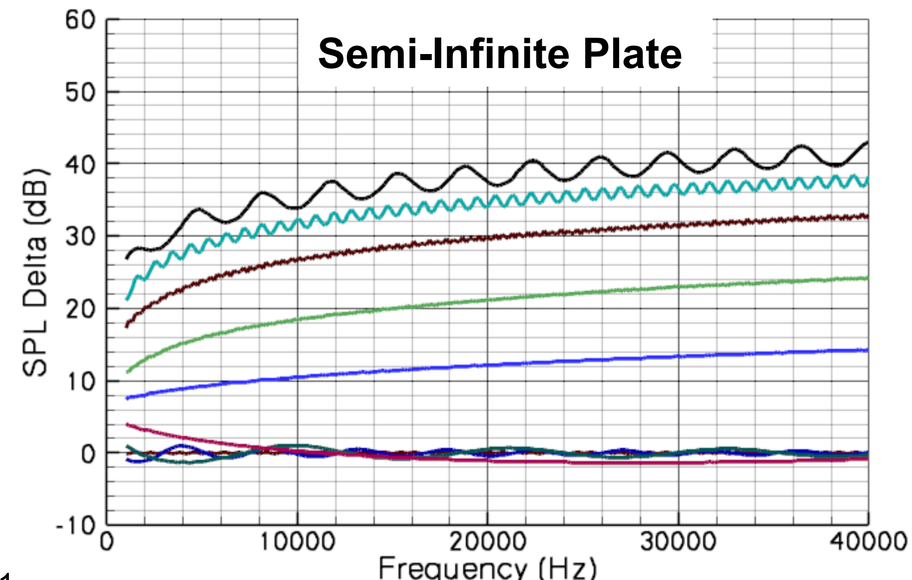


Source Position Increment



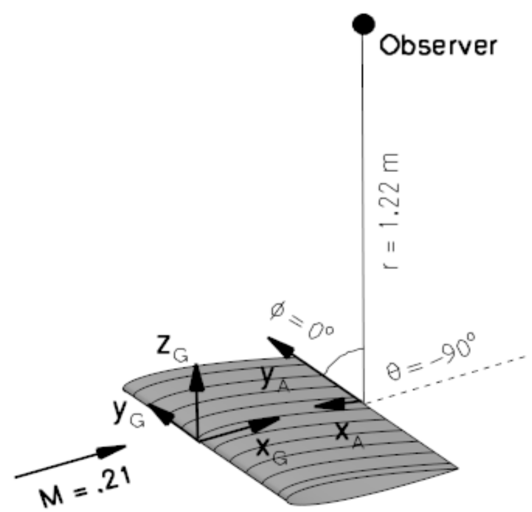
Correct Source Position and Plate Size





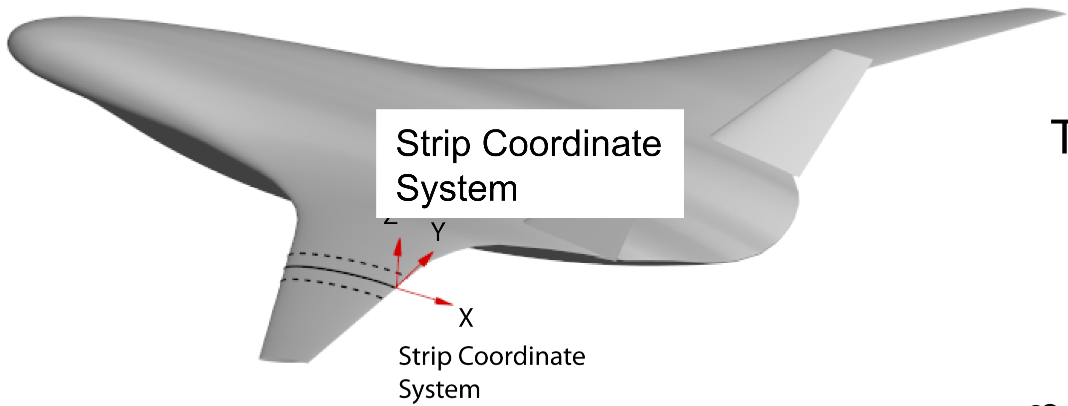
Trailing Edge Noise Prediction

- **Based on method of Brooks, et al (NASA RP1218)**
  - Four sources: turbulent boundary layer, laminar boundary layer, trailing edge bluntness, tip vortex edge
  - Validated for 0012, with successful rotorcraft application
- **Application for aircraft prediction**
  - Divide trailing edge surfaces into discrete strips
  - Locate with respect to aircraft coordinate system
  - Determine inputs for each strip: such as geometric parameters detailing edge, boundary layer thickness at edge, local flow velocity
  - Inputs from CFD solution or input by user.
    - requires data mining tools
- **ANOPP2 implementation**
  - Development of data structures to accommodate CFD input
  - Coordinate system definitions and transformations
  - Module integration

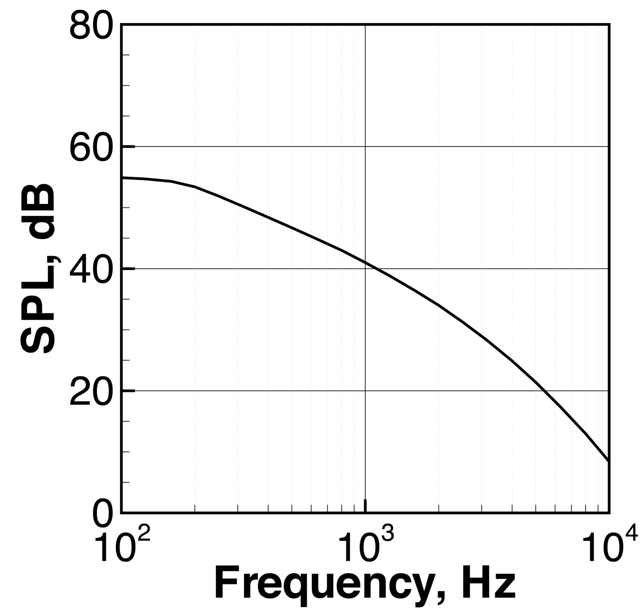


Example HWB Trailing Edge Noise Prediction

- Trailing edge noise prediction using method based on Brooks
- Inputs: CFD grid used for geometric inputs, boundary layer computed empirical analysis
- Observer: R = 4*span, $\theta = 90$ deg, $\phi = 0$ deg
- Mach = 0.21



Turbulent boundary layer noise



Summary

- **ANOPP2 Development Progressing**
  - 'Floor Plan' and Approach finalized
    - Observer definitions & data structures, command executive
    - Source, Mid- and Far-surface interfaces (developer templates)
  - Documentation (user's manual, theoretical manual, developer's manual, etc)
  - Installation and distribution upgrades
  - Release of ANOPP2 Pre-Beta (September 2011)
- **Prediction Modules**
  - Further integration of ANOPP with ANOPP2
  - Upgrades and additions to current jet methods (documentation, demos, etc)
  - Landing Gear Method: component based method for landing gear noise
  - CRPFAN, ASSPIN, LINPROP
  - Near- and far-field propagation methods
    - Ray method, Gauss Beam, GFPE & FSC for near-field
  - Scattering Models: Diffraction Integral Method2, FSC, Jet Noise Diffraction Code