



ANOPP2 Development Status

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Aeroacoustics Branch, NASA Langley Research Center

**Subsonic Fixed Wing Project
Quiet Aircraft Tech Challenge**

**Acoustics Technical Working Group
Cleveland, Ohio
April 11-12, 2012**



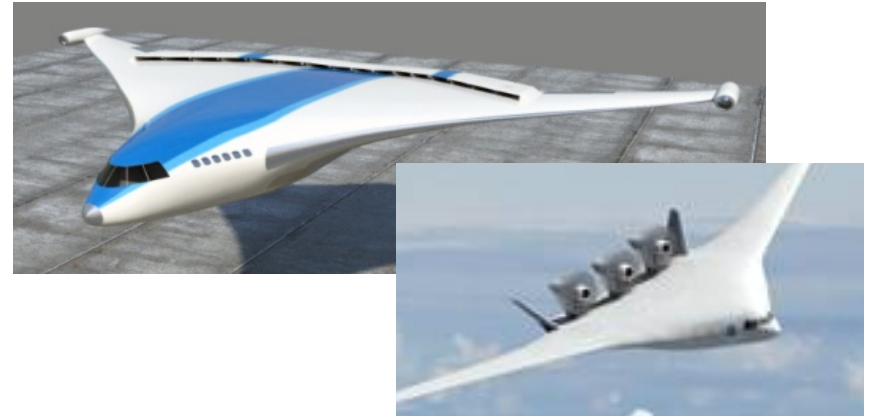
Outline

- **ANOPP2 Development**
 - Progress on current milestone: ANOPP2-beta
 - Release of ANOPP-L30
 - GECOR-update
 - ANOPP2-MDOE method for chevron effects on jet noise
 - ANOPP2-F1A solver
 - Scattering methods for ANOPP2
- **Application**
 - Contour area prediction
 - HWB/OR
- **Summary**



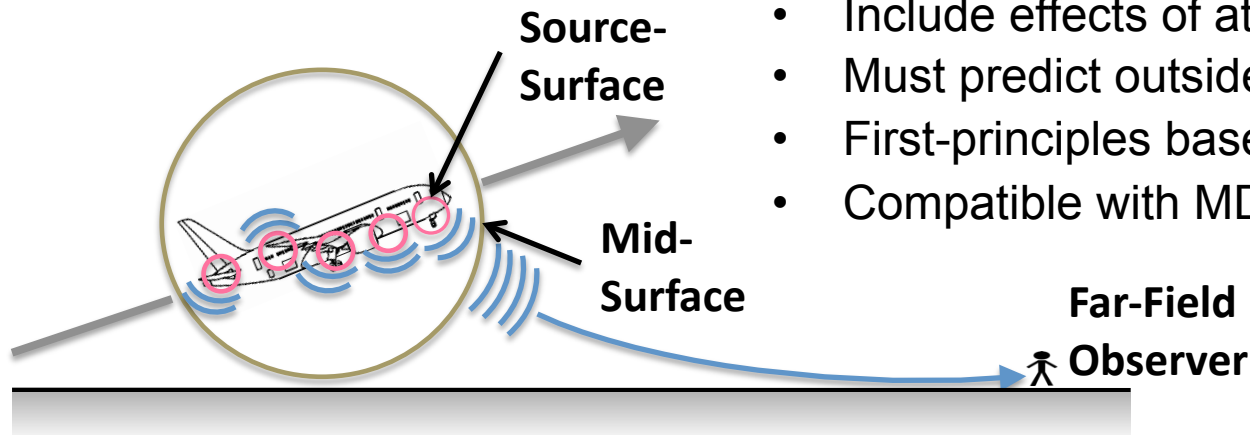
Next Generation Multi-Fidelity Aircraft Noise Prediction Capability: ANOPP2

Objective is to provide: Acoustic prediction capability of current and future aircraft designs source component noise, component interaction noise to full configuration noise.



ANOPP2 Features

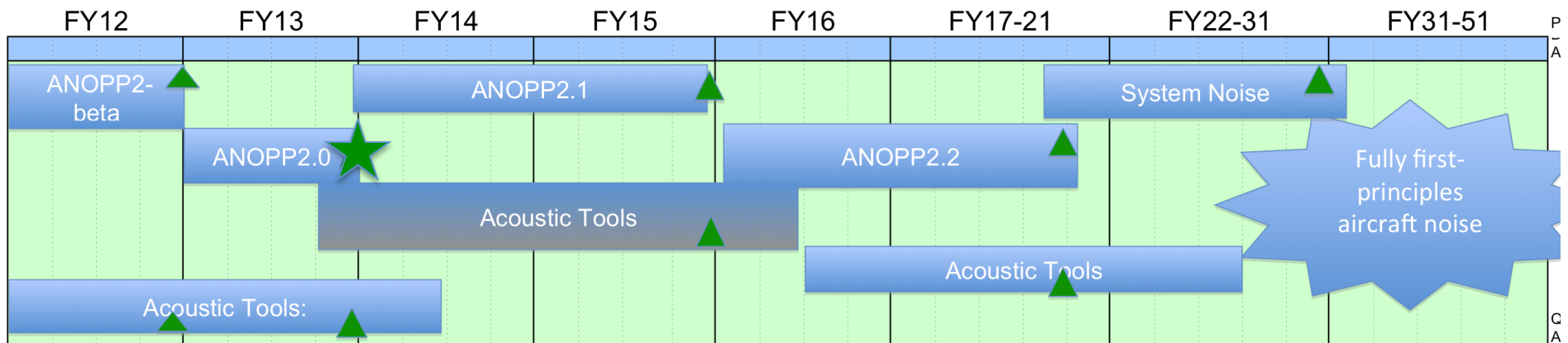
- Includes ANOPP
- Noise sources are at their true locations.
- Installation effects included
- Include effects of atmosphere and terrain
- Must predict outside of experience base
- First-principles based & multi-fidelity
- Compatible with MDAO and GEN2 framework





Quiet Aircraft: 7. Acoustic Tools/Methods

- Elements/Tasks 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 and GEN2



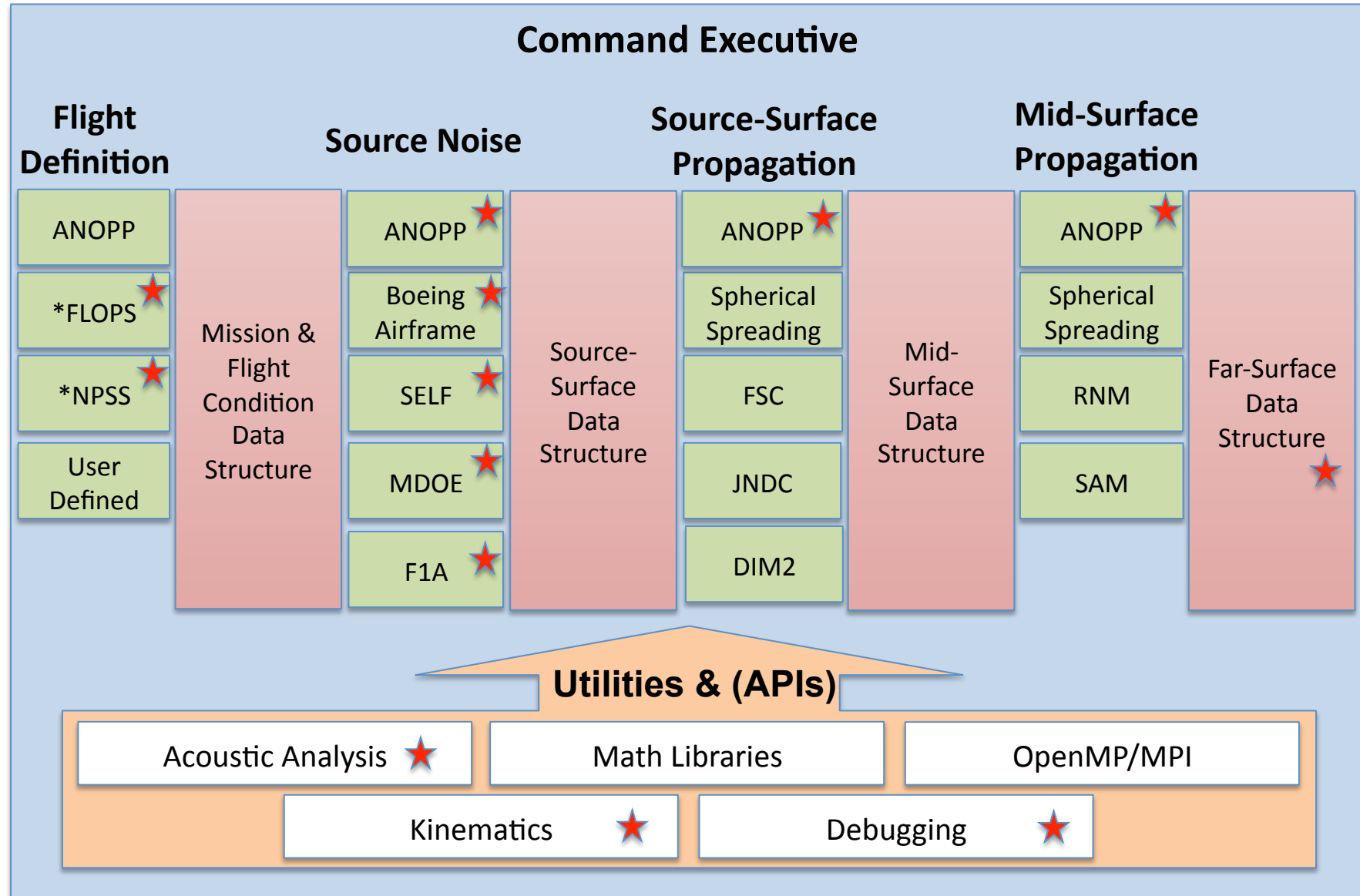
- Acknowledgements: Project support and researchers
 - SFW
 - ERA
 - SUP
 - SRW



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, system requirements/constraints, Noise Assessments (SFW/ERA)					
SFW.45.04.L.4.001: 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 output coupling, Open Rotor (CRPFAN, ASSPIN), jet, airframe(t.e.), Verification & Validation, Assessment(s)					
			ANOPP2.0 Beta		
SFW.45.04.L.4.003: Develop High-Fidelity and Reduced-Order Models for Inclusion in the Next Generation Mixed-Fidelity Aircraft Noise Prediction Capability -- Interim Assessment 3					
ANOPP2-Beta: Command Executive, Documentation, V&V suite. Scattering (FSC, DIM2, JNDC), MDOE-SUP, Far-Field Propagation, Assessment(s)				ANOPP2.0	
SFW.45.04.L.4.004: Improve and Validate Next Generation Mixed-Fidelity Component and Aircraft Noise Prediction Capability -- ANOPP2					
ANOPP2-release: Command Executive, Documentation, Scattering methods, Airframe:control surfaces & LG, Propulsion: Engine components & OR, Far-Field Propagation, V&V, Assess: N+1, N+2, N+3					



ANOPP2 “Floor Plan”



★ ANOPP2 beta



Key Accomplishments

- **ANOPP2 Framework Development**
 - Release version of the Acoustic Analysis API with documentation
 - Beta version of the Kinematics API
 - Alpha versions of key data structures & Managers: Environment, Engine, Airframe, Observer, Flight Condition, Prediction, Mission.
 - Executables and processes for Windows, Linux and Mac operating systems
 - Documentation: draft manuals (user's, reference, and developers manuals)
 - Executive design based on ANOPP2 API (Application Programming Interface)
 - Working in Fortran, C++, Python on Windows, Linux and Mac
 - Functions for user to create and perform aircraft noise predictions using ANOPP2
- **Prediction methods – development & maturation for ANOPP2 implementation:**
 - ANOPP-L30 corrections & upgrades for ANOPP2 implementation
 - Jet noise: MDOE-based method
 - ANOPP2 FWH solver: F1A
 - Scattering: FSC, DIM2, TDBEM and JNDC/FSC



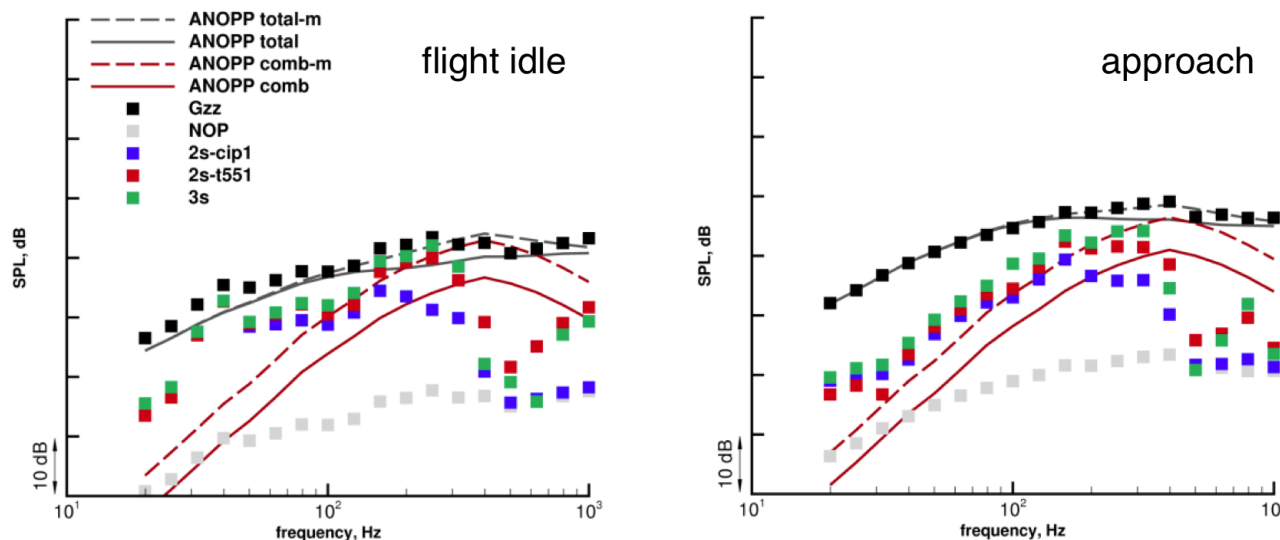
ANOPP Combustor Noise Prediction (GECOR) Turbine-Attenuation Functions

- ANOPP GECOR turbine attenuation functions

- ANOPP/GE: $|H(f)_{A/GE}|^2 = \left(\Delta T_{des}/T_{ref}\right)^4$
 - Depends on design-point temperature drop
 - Independent of operating point

- P&W: $|H(f)_{PW}|^2 = \frac{0.8\zeta}{(1+\zeta)^2}$ where impedance ratio is: $\zeta = \frac{(\rho c)_{TurbineExit}}{(\rho c)_{TurbineInlet}}$

- noise-source separation applied to NASA/Honeywell EVNERT full-scale static engine data
- Mic at $\theta = 130^\circ$ downstream: Better fit above 150Hz (more significant region)
- Hultgren: AIAA_2011-2912:





Systems Integration, Assessment, and Validation

New Engine Core Noise Prediction Method

- **New core noise prediction method to be incorporated into Aircraft Noise Prediction Code (ANOPP and ANOPP2):**

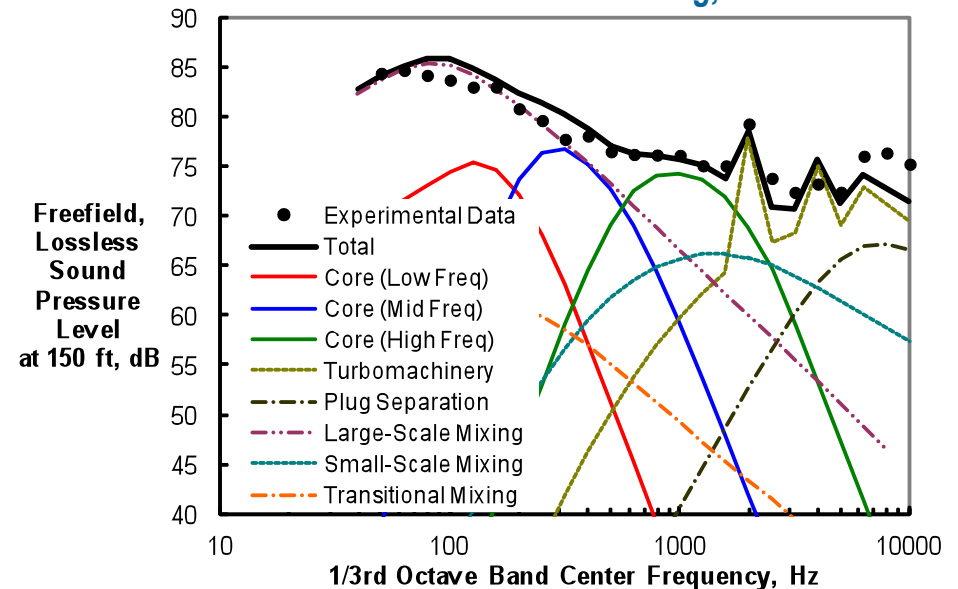
As jet and fan noise sources are reduced via cycle changes and noise reduction technologies, core noise becomes “uncovered” and problematic. Moreover, core noise continues to rise as engine makers seek ever-higher core pressures and hot-section temperatures. This will be an issue for supersonic aircraft as well as subsonic, since regulations demand that jet noise be reduced to certifiable levels.

The Stone core noise prediction methodology is a new, comprehensive method that seamlessly spans all thrust classes, from regional jets to long-haul heavies. The method will be coded and incorporated into both ANOPP and the new ANOPP2 codes.

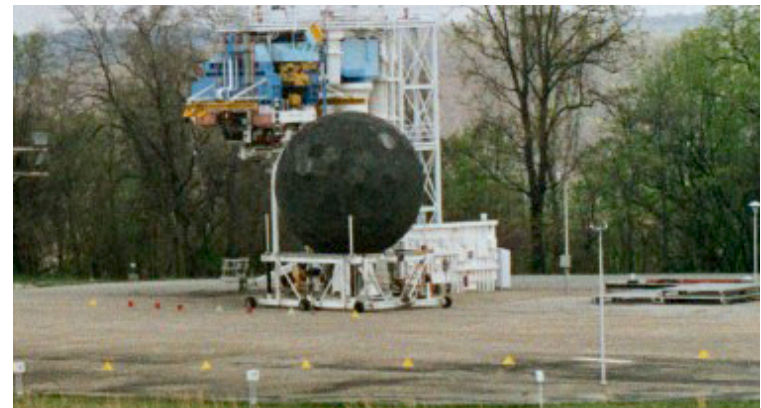
This is a cross-program task, beneficial to FAP/SUP, FAP/SFW, and ISRP/ERA.

- Analysis: Stone method per NAS3-00178, TO #15, NASA CR-2011-217026 : “Enhanced Core Noise Modeling for Turbofan Engines”
- Uses innovative Bayesian regression of acoustic data
- Database: CF34, CFM56, CF6, and GE90

Predictions for CF34-8C at 150 deg, 4400 RPM



Acoustic data collection at GE's Peebles test facility





ANOPP2 MDOE-based Prediction Method

- Introduction of chevrons on nozzle trailing edge affects the acoustic radiation of over-expanded supersonic jets.
- An MDOE approach to model the change in the acoustic radiation as function of 3 parameters: chevron penetration (p), length (L), and width (w): $\text{coeff}(f, \theta, \phi, p, L, w)$
- ANOPP2 methods:
 - MDOE-Based: Polynomial governing equation
 - Bi-cubic splines
- The ANOPP2 user specifies the parameters (e.g., a chevron penetration, length, and width), in the ANOPP2 input deck: ANOPP2.config along with an associated ANOPP2 jet prediction method
- ANOPP2 will predict the noise (ex. SPL profile) that is the sum of the baseline jet prediction plus effect of chevron based on the MDOE method.

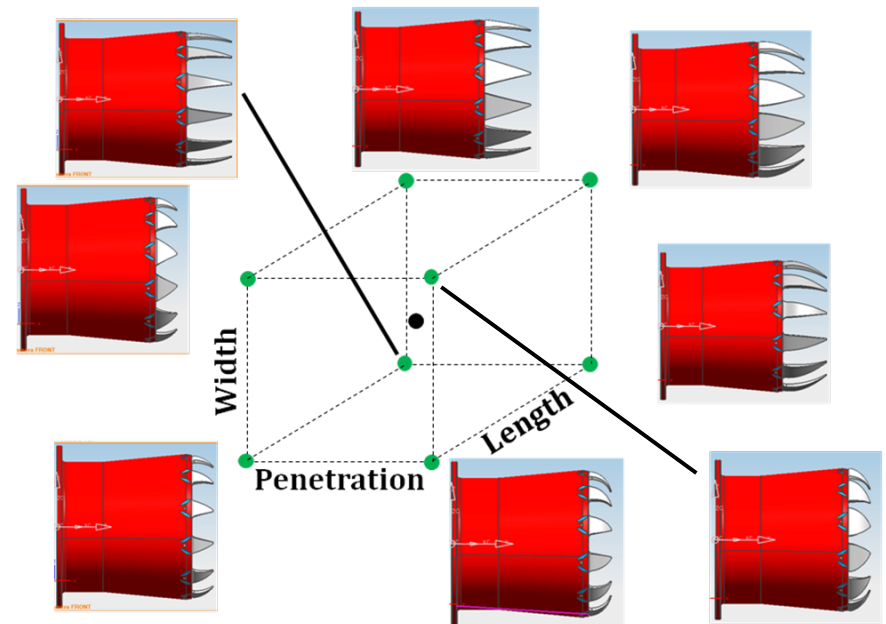


Figure 3. The chevron designs used in the MDOE





ANOPP2 Jet Noise Prediction for Jet with Chevrons ST2JET + MDOE-based Method

Jet Condition and input for ST2JET Prediction

NPR = 3.0, TTR = 3, $M_\infty = 0.3$

$M_j = 1.3578$

$M_d = 1.60$

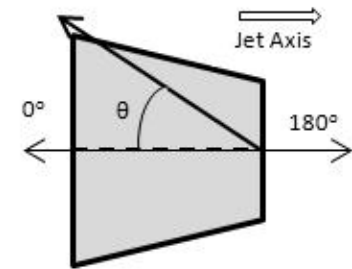
$D = 16$ in.

Chevron geometry and input for MDOE-based Prediction

NPR = 3.0, TTR = 3, $M_\infty = 0.3$

$L_c = 0.1143$ m

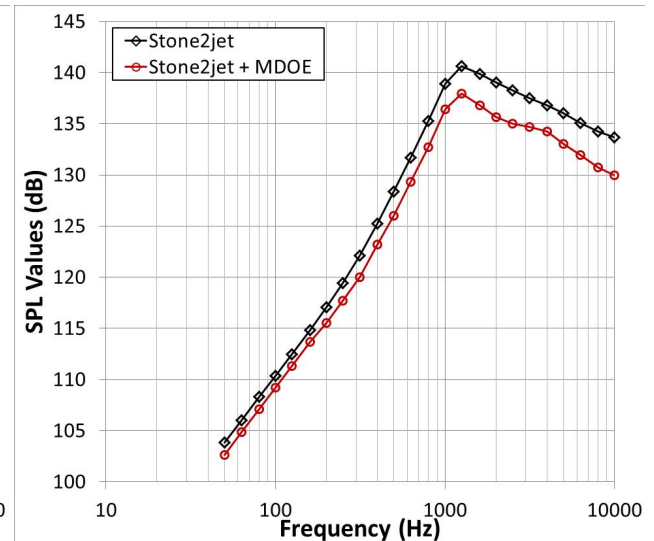
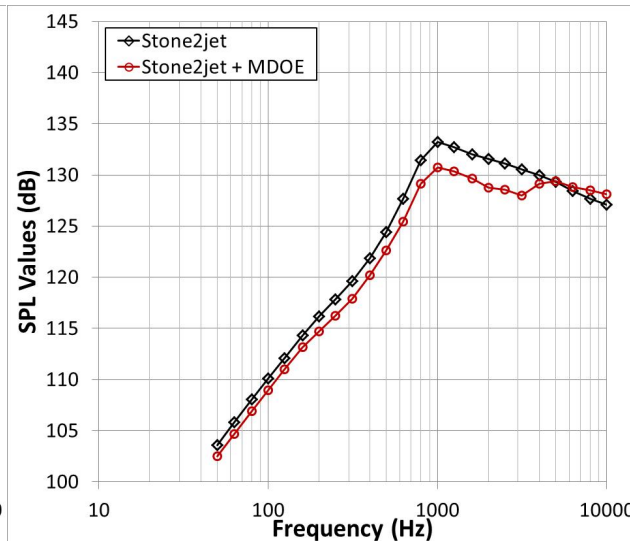
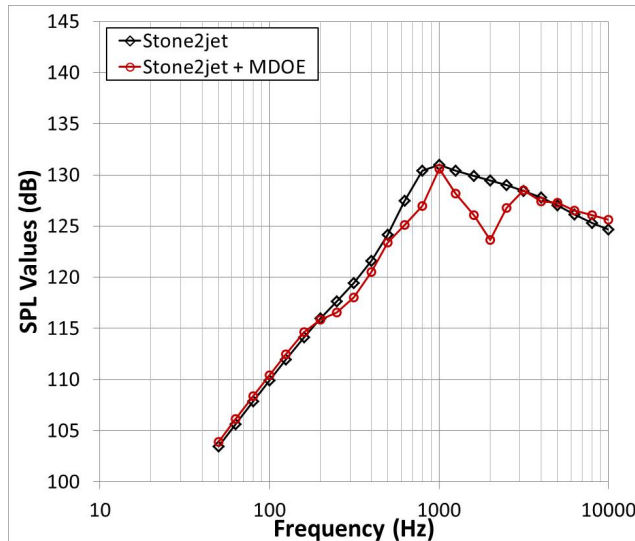
Parameters: 0.5, 0.5, 0.8 % penetration, length, width



$\theta = 50^\circ$

$\theta = 90^\circ$

$\theta = 150^\circ$





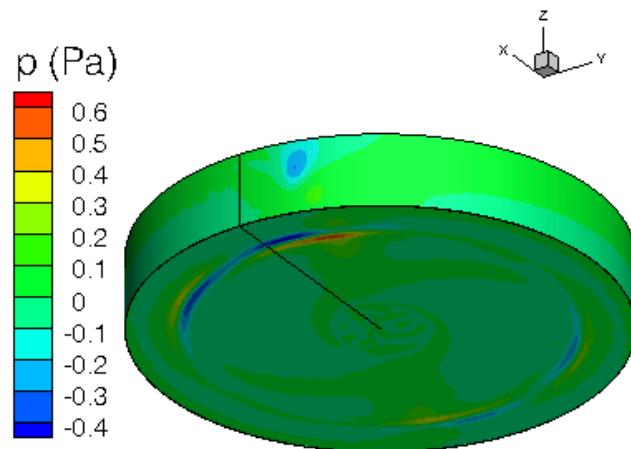
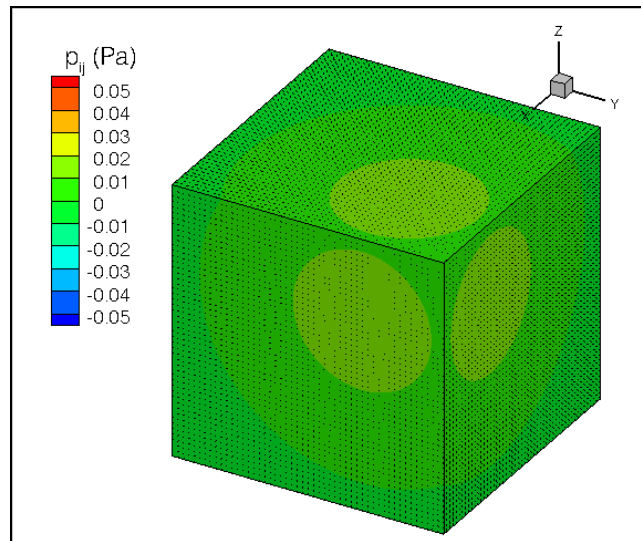
ANOPP2 Farassat's Formulation 1A Fflowcs Williams and Hawkings Solver

- **ANOPP2-F1A Module: Integral part of ANOPP2 (NASA Owned)**
 - Documented, commented, unit tests, verified, validated code
 - Distributed with ANOPP2/Supported by ANOPP2 Team
 - Contains several different options for efficiency and accuracy
- **Features**
 - Permeable and Impermeable surfaces
 - Deforming and Non-Deforming surfaces
 - Structured and Unstructured surfaces
 - Flow quantities (p , u , ρ) on surface: Node or Cell Centered
 - Single and Double Precision
 - Parallelized by observer position (MPI) and Node (MPI, OpenMP)
 - Group surface nodes into node grouping
 - Metadata Files for Analysis and Debugging
 - Perform derivatives as needed (not stored, reduces memory but adds overhead)
 - Read surface information as needed (not stored, reduces memory but adds overhead)

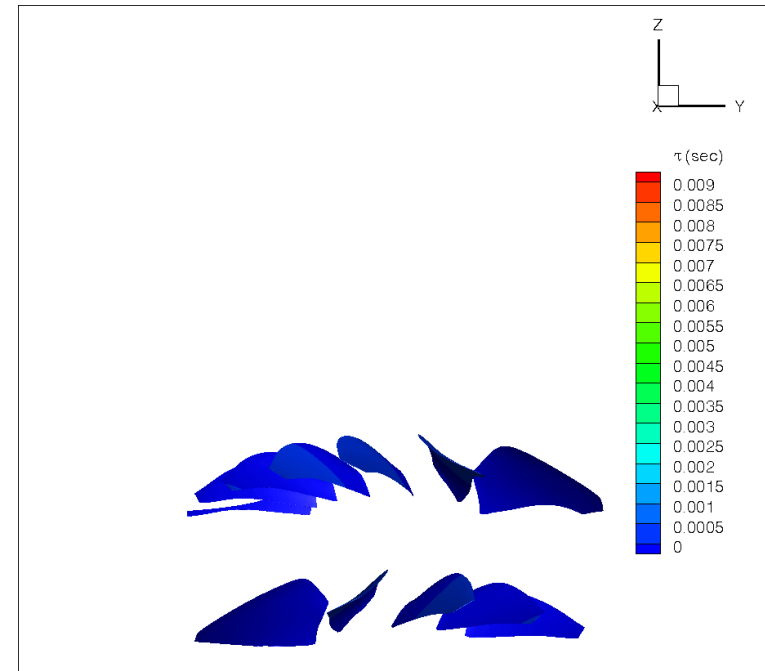


ANOPP2-F1A Examples

Monopole in a Cube



Open Rotor Received Times



Pressures on permeable surface for "Rotor in Tuna Can"



ANOPP2-F1A Plans

- **Further Development of Features**
 - Continued improvements for speed and memory
- **Create Suite of Formulations**
 - 1, G1, 1A (subsonic-tau), G1A (gradient), 2 (collapsing sphere), 2B (broadband & vel. potential), 3 (supersonics-sigma surface)
 - Study and use
 - Platform for future Formulations
- **L. V. Lopes, D. M. Nark, and D. D. Boyd, Jr, "Identification of Spurious Signals from Permeable Flowcs Williams and Hawkings Surfaces," 18th AIAA/CEAS Aeroacoustics Conference (33rd AIAA Aeroacoustics Conference), June 4-6 2012.**



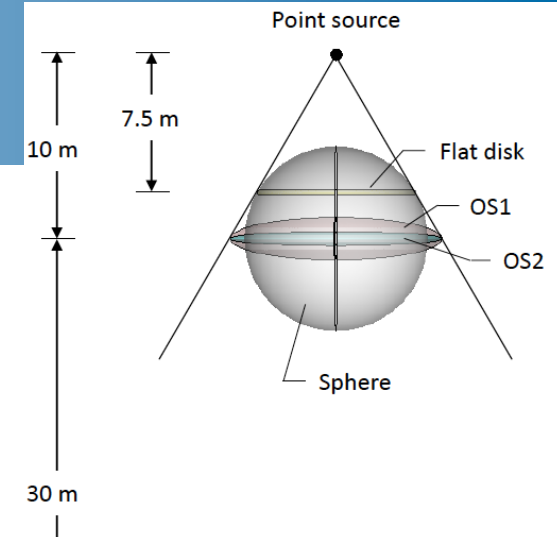
Scattering Methods for ANOPP2

- **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)** (SFW NRA (end 2012): Dunn, poc D. Nark)
 - Can handle geometric details: i.e. edges, ‘corners’
 - No frequency restrictions other than resource limitations
 - Application/validation on HWB: Broadband Engine Simulator (BENS) predictions
- **Time Domain BEM : TDBEM** (SFW NRA (end 2014): Fang Hu, ODU, poc D. Nark)
 - Scattering solutions at all frequencies are obtained within one single computation
 - Broadband noise sources and time dependent transient signals
- **DIM2 (based on MIT diffraction integral method)** (ERA funded, poc Burley)
 - Flat geometry, creeping ray effect modeled using Geometrical Theory of Diffraction for deep shadow region & wedge diffraction potential (transition region) (April 2012)
 - Source (localized) description satisfies Helmholtz equation: spherical functions to define directional source (ex. Fan noise from Heidmann).
- **JNDC/BEM (UCI: jet wave packet model coupled with BEM)** (ERA funded, poc Burley)
 - Packet parameters definition requires ‘data’ for specific jet, account for distributed source
 - JNDC is modified to couple with FSC (replace BEM) to determine jet/airframe noise field.

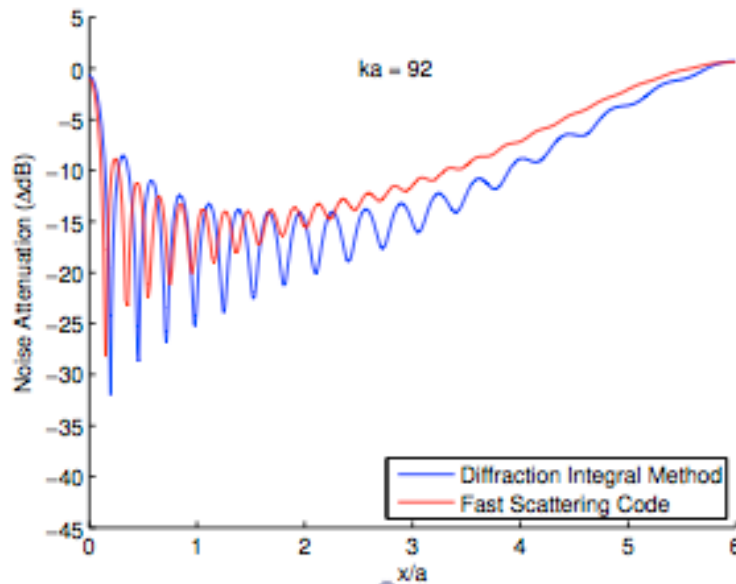


DIM predictions: with & without edge effect

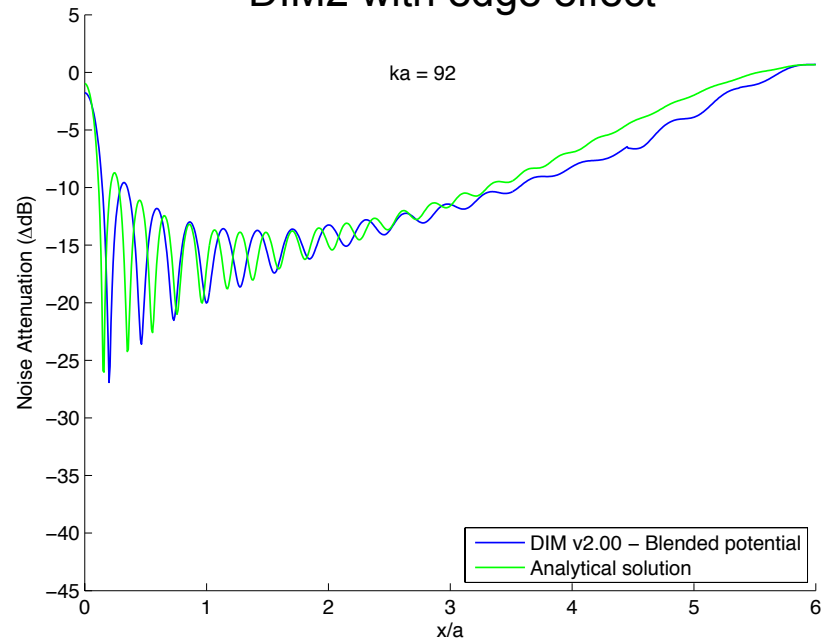
- MIT Diffraction Integral Method: DIM (Spakovszky)
- Modeling to include effect of noise scattering due edge geometry
- Sphere radius: $a = 5$ m
- $ka=92$



DIM without edge effect



DIM2 with edge effect





NASA Noise Goals

NASA Subsonic Transport System Level Noise Goals

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
cum below Stage 3	-42 dB	-52 dB	-81 dB

- **Stage 4 is derived from Stage 3**

1. Stage 4 cum is 10dB below Stage 3
2. Stage 4 cannot exceed any of the Stage 3 limits – no trading
3. Sum of any 2 must be 2 EPNdB below corresponding sum of Stage 3 limits

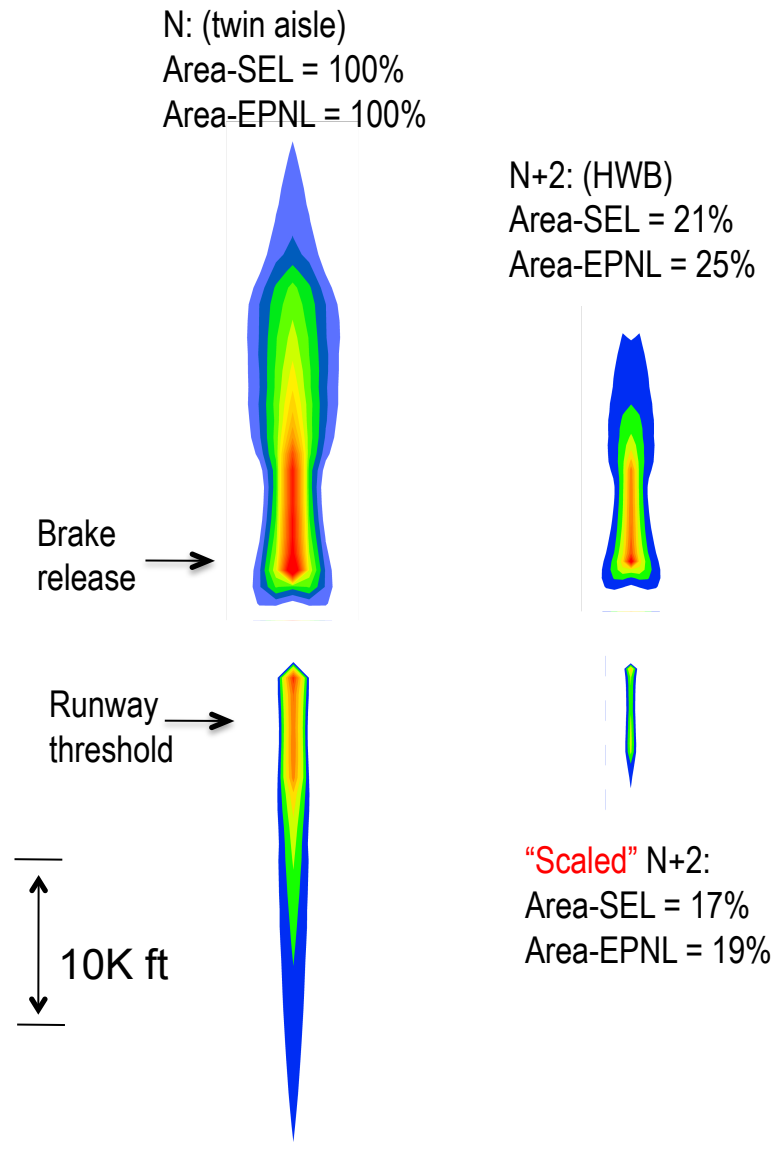
- **N to N+3 technology benefit noise goals**

- Cum numbers are defined
- Determine associated noise contour areas – allow insight into effect of noise directivity and noise impact over an area



Determination of Noise Areas: Comments

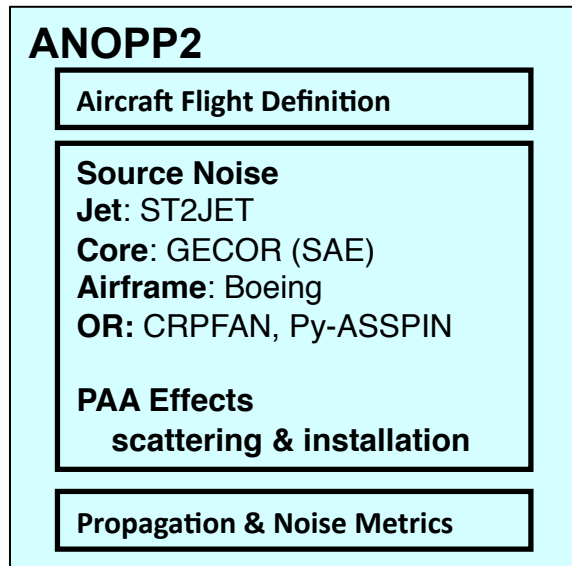
Change in noise “footprint” area (within 85 dB contour) for a landing and takeoff



- Areas include takeoff ground roll but not approach ground operation.
- N and N+2 areas are ANOPP2 predictions (N is tube & wing, N+2 is HWB)
- “Scaled” noise area reduction assumed to be evenly distributed between the three certification points
 - N+2 → 95.6 dB contour area of N
- Effects of source component directivity and aircraft configuration are included.
- “Scaled” noise area approx. 20% smaller than predicted area
- “Scaled” noise area does not directly account for duration or change in directivity due to configuration



HWB/OR Noise Assessment– Status



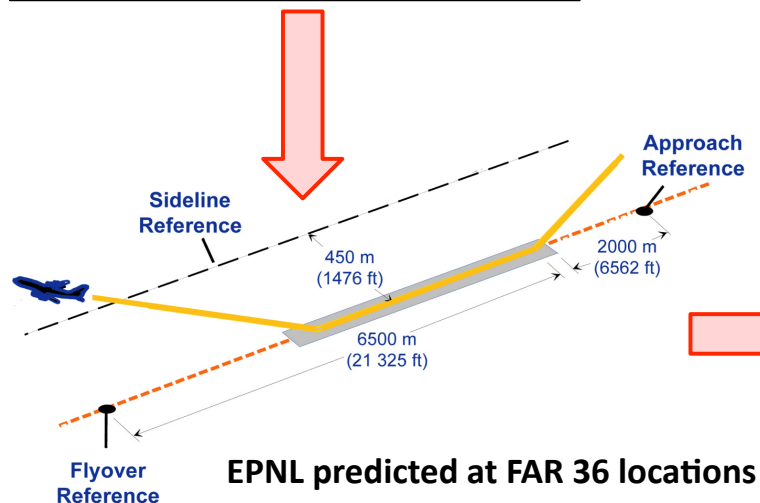
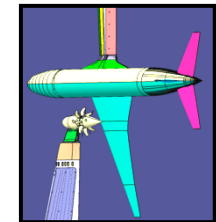
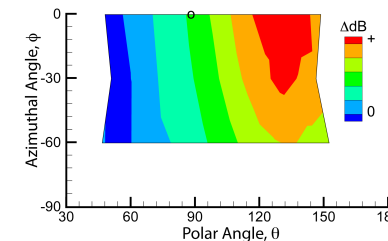
FLOPS



*ERA Study (2011):
Open Rotor Engine
Integration On HWB
(Boeing)

Numerical Propulsion System Simulation (NPSS)

Measurement
Data and/or
Scattering
prediction



- ANOPP2 validation of system with emphasis on scattering methods
- ERA noise assessment
- SFW N+3 prediction



Summary

- **ANOPP2 Development Progress**

- Release of ANOPP2-Beta (October 1, 2012)
 - Observer & flight condition data structures, command executive
 - Component and flight vehicle examples
- Documentation (user's manual, theoretical manual, developer's manual)
- Installation and distribution upgrades

- **Prediction Module Progress**

- Further and continued integration of ANOPP with ANOPP2
- Upgrades and additions to current jet methods with MDOE-based models (documentation, demos, etc) for supersonic application
- Scattering Models: Diffraction Integral Method2 (DIM2), FSC, Jet Noise Diffraction Code (JNDC/FSC), TDBEM
- Near- and far-field propagation methods
 - Atmosphere/terrain: ray methods (curved and straight), GFPE, FFP
- Open Rotor methods: CRPFAN, ASSPIN, F1A implementation within ANOPP2 framework

- **Noise Assessments and Capabilities**

- Contour area and cum noise levels
- HWB/Open Rotor Noise Assessment