Aircraft NOise Prediction Program 2 (ANOPP2)

Leonard V. Lopes
NASA Langley Research Center

Transformational Tools and Technologies (TTT) Project
Revolutionary Vertical Lift Technology (RVLT) Project
Commercial Supersonic Technology (CST) Project

Expanded Requirements

- Capability to predict aircraft noise for the purpose of:
  - Providing prediction methods for government (independent assessment)
  - Evaluating the potential noise reduction to be gained by noise reduction technologies
  - Assessing/evaluating noise operations and procedures which feed noise impact studies
  - ◆ Developing noise reduction technologies through understanding of noise generation of isolated and installed aircraft components
  - ◆ Providing accurate noise results that can be used to prioritize and focus aircraft noise research for NASA and other government agencies (FAA EDS efforts)
  - ◆ Providing 'noise tool' that can be used for MDAO aircraft system studies at different TRLs

Goals

- Provide a framework where methods can be developed and used to predict component and system noise
- Provide a framework where a combination of acoustic prediction methods of differing fidelity can communicate in a unified system (mixed-fidelity)
- Provide capabilities to allow comparison to flight and model-scale test data
- Include a framework where physics-based prediction of PAA and airframe interaction noise can be integrated into a unified system level environment
- Provide capabilities to aid in assessing noise reduction technologies and approaches
- Contain interoperability functionality to enable integration with system level analysis software

Generation Capability

ANOPP

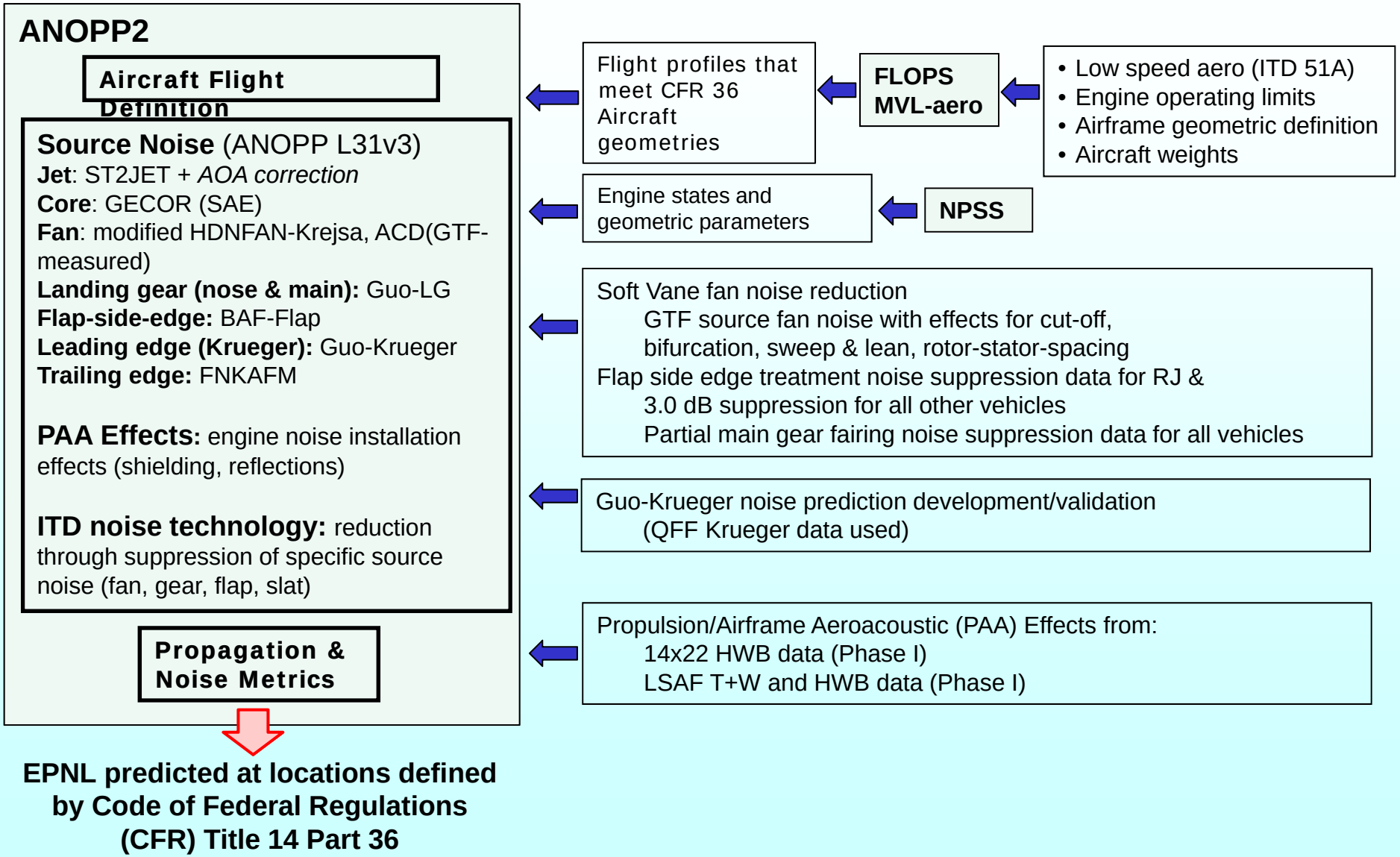
- Fast
- Semi-empirical component noise predictions
- Aircraft modeled as point: component sources at single point for propagation to receiver
- Limited noise metric options, simple ground contours
- Predominantly developed/validated for conventional tube-and-wing transport aircraft
- Useful noise tool but with ‘critical’ limitations
- Still under active development

ANOPP2

- Depends on resolution: fast to intensive (includes ANOPP)
- Mixed-fidelity prediction models enabling tailored accuracy/resolution of installed sources
- Representative aircraft configuration: component sources at true locations, enable direct computation of installed effects and accurate propagation to receiver
- Nearly unlimited noise metric options, arbitrary flight trajectories, ground contours
- Direct application for arbitrary aircraft configurations/operations
- Enables ‘design for noise’ capability to explore current and future aircraft/component designs
- Analysis of noise physics from component to system level required for noise reduction technology

Overall ERA System Noise Prediction Process

From AIAA-2016-0863



EPNL predicted at locations defined by Code of Federal Regulations (CFR) Title 14 Part 36

User Stories

- Many different ways to use ANOPP2
  1. Component noise prediction or propagation research
  2. System noise prediction and technology assessment
  3. Aircraft optimization and design

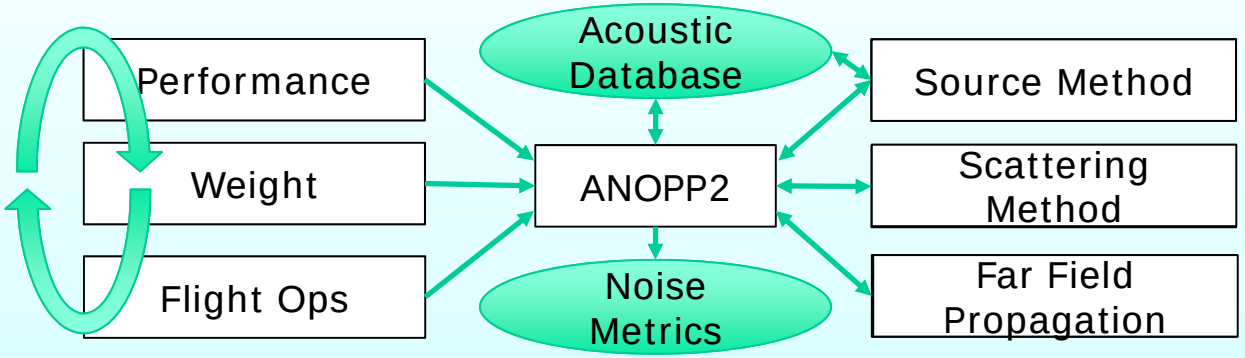
1. Component noise research

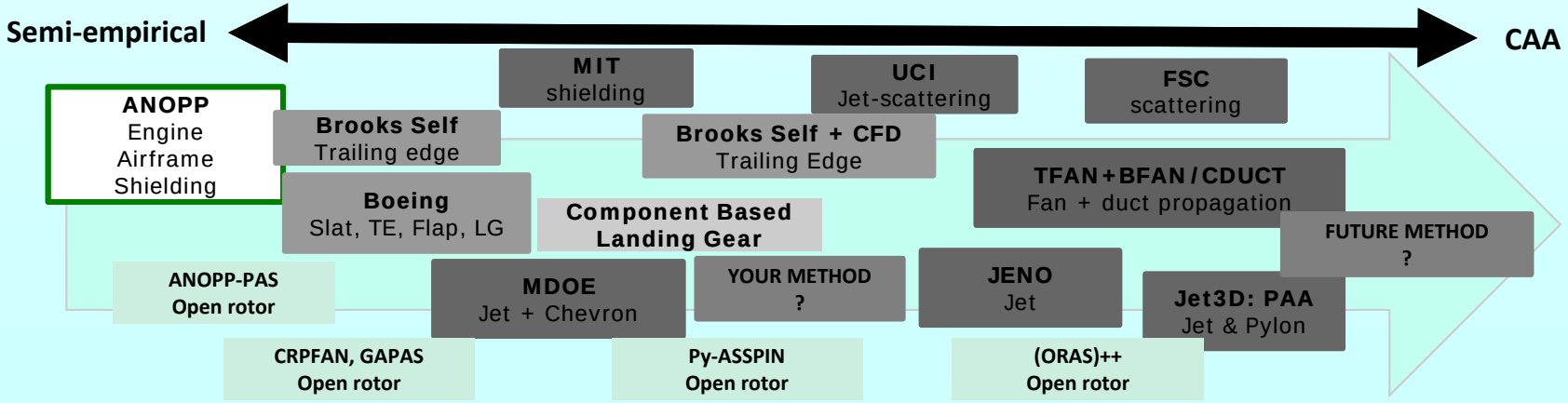
- User creates noise prediction code/measurement database and wishes to leverage capability provided by ANOPP2
- ANOPP2 provides:
  - Tools for routine acoustic calculations plus more
  - Capability to store and visualize information about the source
    - Airframe parameters, engine state information, etc.
    - Near field flow information, atmospheric properties, etc.
  - Capability to store and share noise database and compare to measurements
  - Prediction modules for comparison (to database or other fidelities)

2. System Noise Prediction

ANOPP2 provides:

- Interfaces with other software that define required information
- Capability to select method for each component (mixed-fidelity)
- Provides communication between methods
- Interfaces to measurement database and interpolation/extrapolation
- Ability to combine metrics of differing fidelity and calculate certification metrics

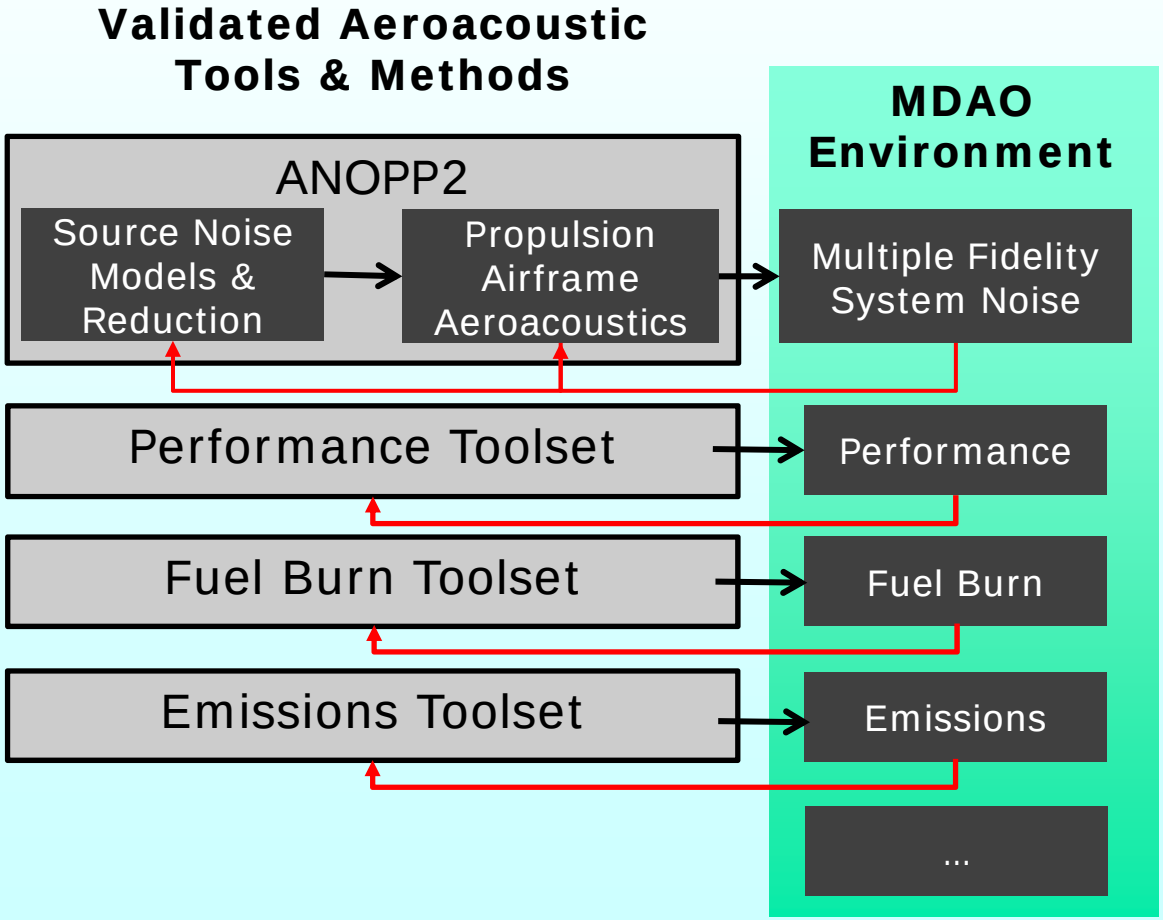




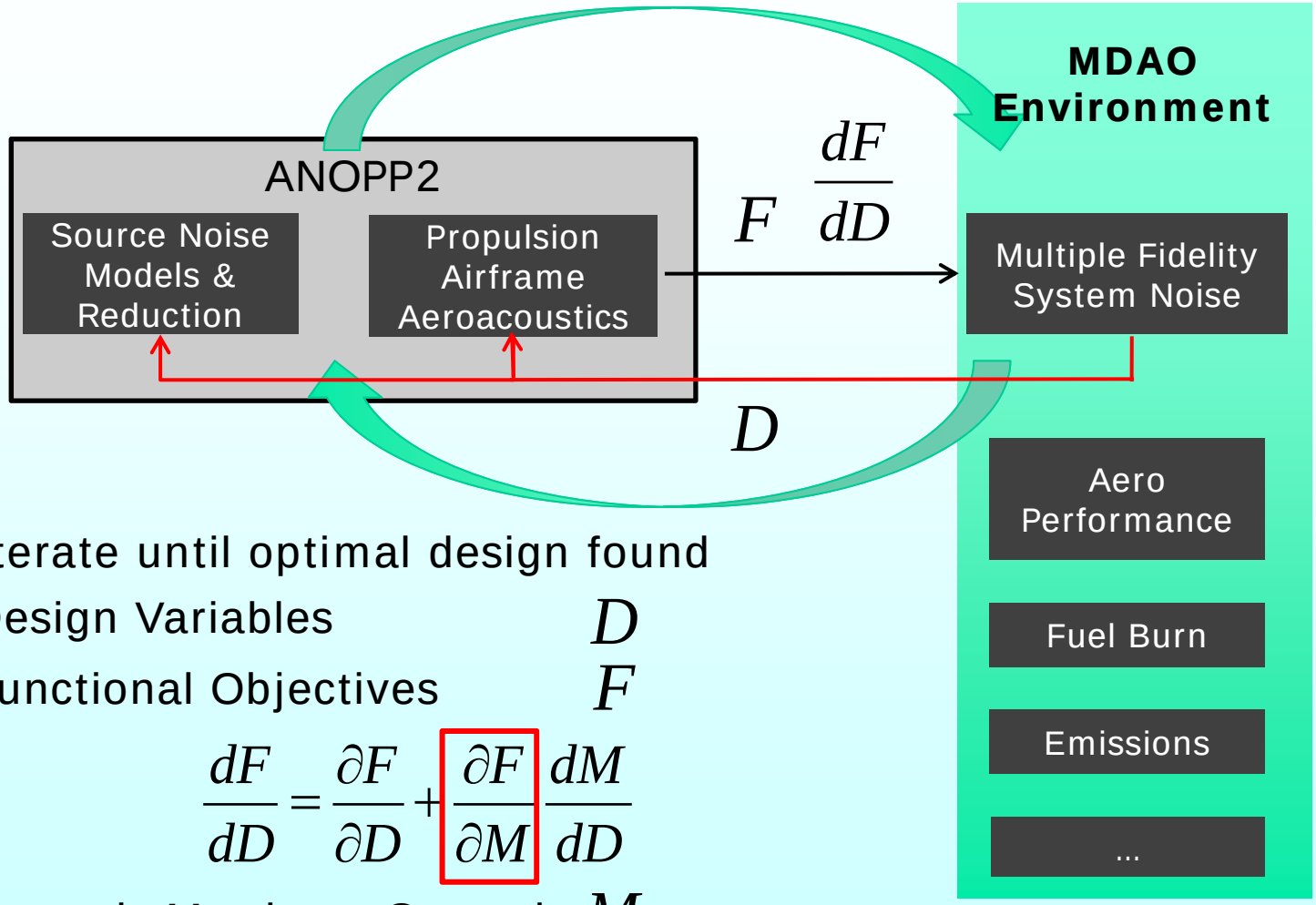
3. Aircraft Optimization and Design

ANOPP2 provides:

- Iterative improvement of aircraft design taking into account many disciplines
- Platform for acoustic toolset feeding multi-disciplinary environment



3. Aircraft Optimization and Design



Iterate until optimal design found

Design Variables D

Functional Objectives F

$$\frac{dF}{dD} = \frac{\partial F}{\partial D} + \frac{\partial F}{\partial M}\frac{dM}{dD}$$

Acoustic Metric on Ground M

- 1/3-octave band SPL spectrum
- Acoustic pressure time history

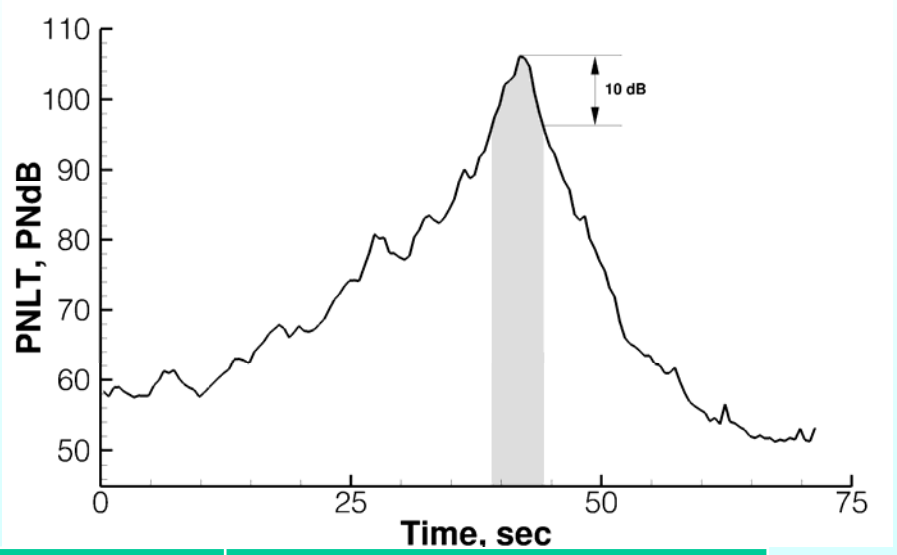
Acoustic Metric Sensitivity

$$\frac{\partial F}{\partial M} = \frac{\partial EPNL}{\partial p'} = \frac{\partial EPNL}{\partial PNLT}\frac{\partial PNLT}{\partial L_B}\frac{\partial L_B}{\partial PSD}\frac{\partial PSD}{\partial p'_s}\frac{\partial p'_s}{\partial p'}$$

- Implementation of algorithmic differentiation (AD) validated through complex differentiation (CD) and finite differencing (FD)

$$f'(x) = \frac{\mathrm{Im}\left[f(x+i\varepsilon)\right]}{\varepsilon} + O(\varepsilon^2) \qquad \varepsilon = 1e^{-10}$$

$$f'(x) = \frac{f(x+\Delta) - f(x-\Delta)}{2\Delta} + O(\Delta^2) \qquad \Delta = 1e^{-2}$$



- For Example: EPNL

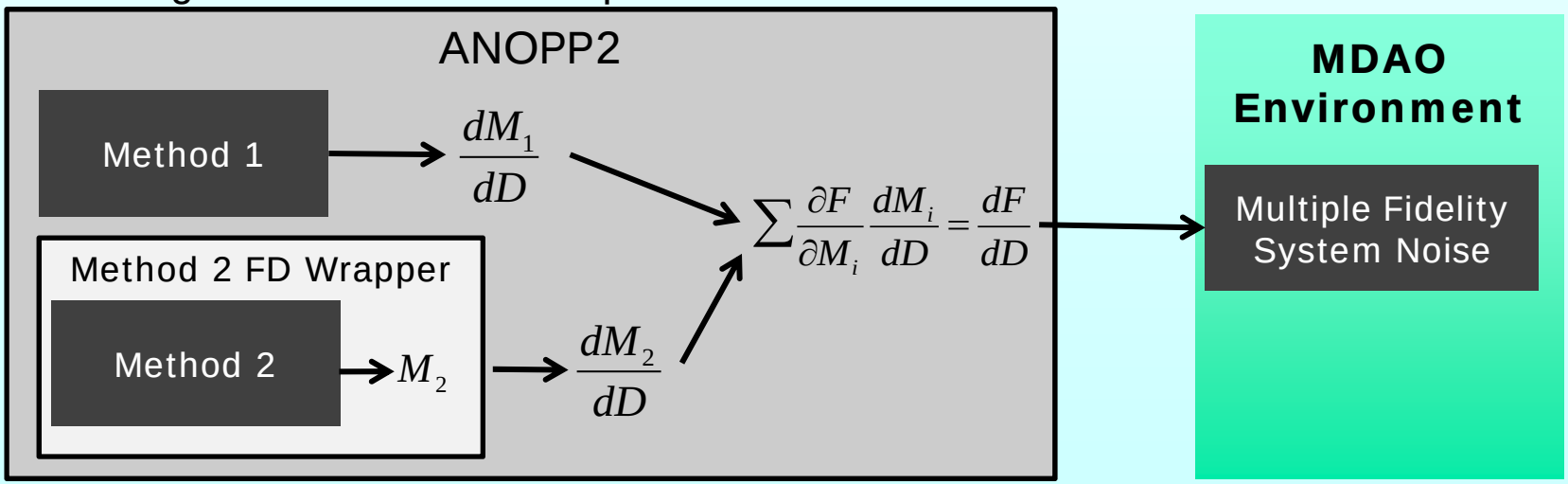
	EPNL	dEPNL / dPNLT$_{max}$
Complex Differentiation	96.03973	0.1586321
Finite Differencing	96.03973	0.1590729
Algorithmic Differentiation	96.03973	0.1586321

- Sensitivity via AD of 13+ acoustic metrics implemented and validated

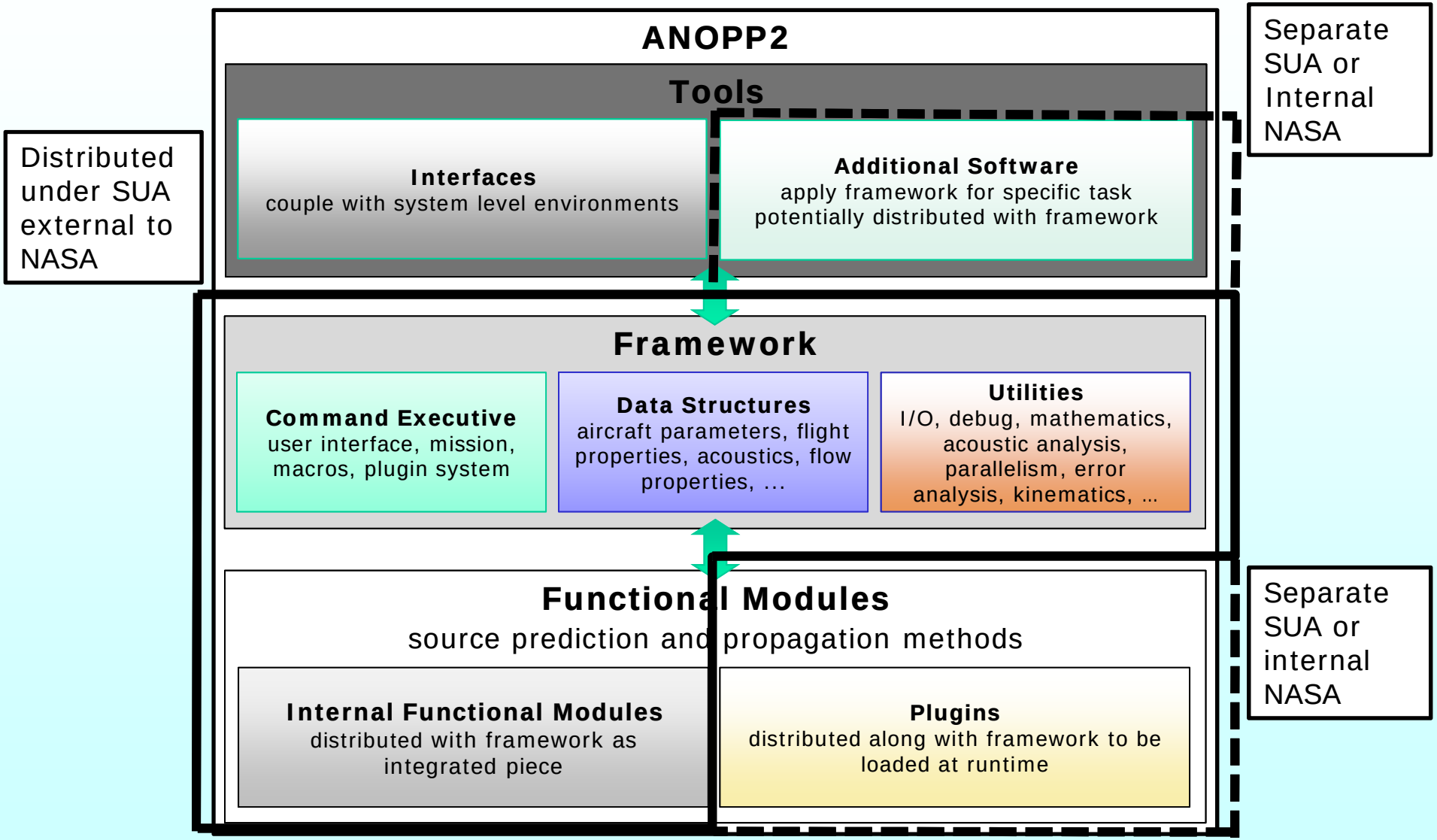
Acoustic Method Sensitivity

$$\frac{dF}{dD} = \frac{\partial F}{\partial D} + \frac{\partial F}{\partial M}\frac{dM}{dD}$$

- Gradient-based design optimization requires derivatives
- ANOPP2 contains many methods, different levels of software development
  - Algorithmic differentiation not available to all (development time)
- ANOPP2's platform provides:
  - Platform where methods can be 'wrapped' for FD when AD not implemented
  - Platform where methods can be improved with AD as needed
  - Common interface for MDAO environment
- Leverage frameworks like OpenMDAO

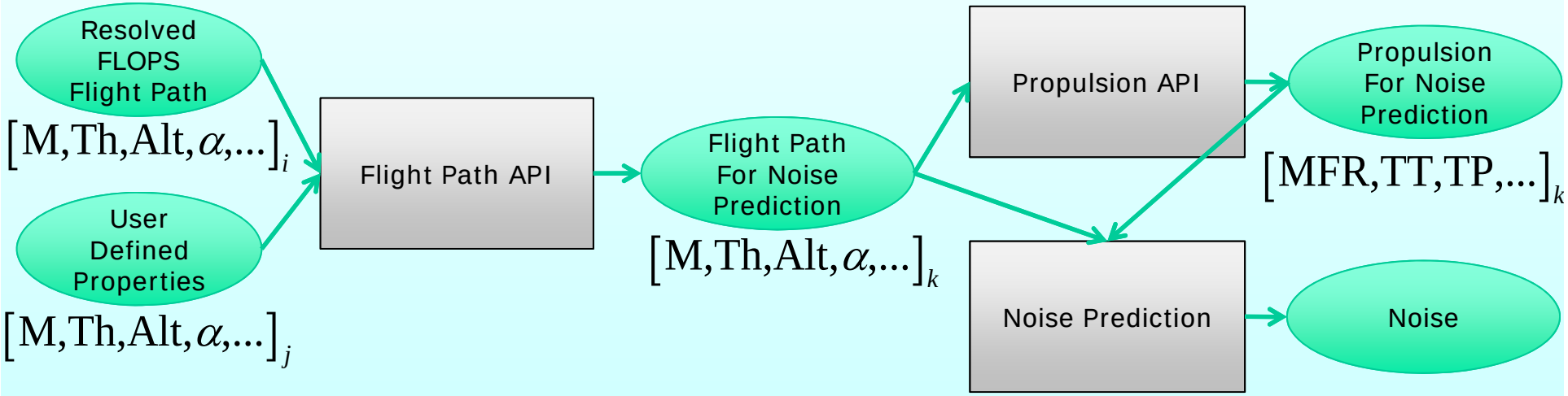


Architecture and Distribution



Collaboration Driving Framework Development

- CST cooperation (Langley/Glenn) required propulsion parameters not currently included
  - Third stream parameters, could hardcode but prefer flexible system
  - Previously time-independent parameters now a function of flight condition
- Propulsion API parameters function of flight condition $[\mathrm{MFR},\mathrm{TT},\mathrm{TP},\ldots]=F([\mathrm{M},\mathrm{Th},\mathrm{Alt},\ldots])$
  - Collectively called variant Propulsion API properties: default, user defined
- Flight Path API define flight condition as function of time $[\mathrm{M},\mathrm{Th},\mathrm{Alt},\alpha,\ldots]=F(\tau)$
  - Source time determined via tolerances and FLOPS flight path and/or user defined



- ✧ Flight Path and Propulsion API's work together to provide flexibility
- ✧ Successful and ongoing cooperation between project/center and ANOPP2 development team

ANOPP2's Quality Assurance System

- ANOPP2 is very flexible in what things it can do
- Also very flexible in where it can do those things
  - Windows/Linux/Mac, Fortran/C++/Python/C#
  - Single/Double Precision, With/Without Complex Differentiation, 32-/64-bit
  - Internal NASA/U.S. General/General Purpose (International)
- Under active development (>4 active developers)
- Quality assurance is key!
- Utilize agile programming techniques and continuous integration
  - Many computers working synchronously to validate via regression testing
  - Allows for immediate identification of problems

Usage Since Initial Release (2015)

Internal NASA
TTT
AATT
CST
RVLT

Other Government Agency
John A. Volpe National Transportation Systems Center

Academia
Massachusetts Institute of Technology
Georgia Institute of Technology
Pennsylvania State University
Old Dominion University
University of Mississippi
University of São Paulo (Brazil)

Industry
Techsburg Inc.
Gulfstream
Boeing Defense Systems
Boom Technology
Ohio Aerospace Institute
GLSV Inc.
National Institute of Aerospace
Lockheed Martin Aeronautics Co.
Cornerstone Research Group
Northrop Grumman Aerospace Systems
Honeywell Aerospace
AVEC Inc.
ATA Engineering
General Atomics Aeronautical Systems, Inc.
Google
United Technologies Research Center

Future Development Efforts

- New functional modules
  - New Tri-Stream Suppression (TSS) and Jet-Surface Interaction (JSI) plugins
  - Several scattering methods in pipeline for inclusion into ANOPP2
  - Looking to expand far field propagation capabilities
  - Improved ANOPP's Acoustic Data (ACD) type database interpolation
  - Flexibility to meet demand of new configurations
- Framework improvements
  - Currently developing Propulsion API v2
  - Designing Airframe API that can couple with geometric tools
  - Adding MATLAB interfaces (much requested feature)
  - Uncertainty calculation and propagation
- Additional/Improved tools
  - ANOPP2 Model Center Interface Code (AMCIC)
  - ANOPP2 OpenMDAO Interface Code (AOIC)
  - Rotorcraft prediction tool
- Expansion of algorithmic differentiation
  - Formulation 1A (Formulation S1A)
  - ANOPP (several different functional modules)

Questions