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# Urban Air Mobility Operational Fleet Noise Assessment

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NASA Acoustics Technical Working Group Meeting  
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# Background

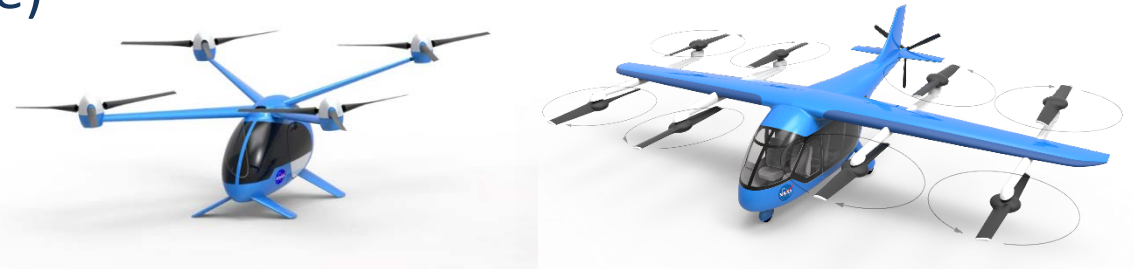
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- Unlike most commercial air traffic today, UAM vehicles will operate in communities away from conventional airports.
- It is likely that fleet routing and vehicle flight patterns will affect community noise impact.
  - Routing other than direct point-to-point will involve a mission trade-off, so it is useful to incorporate fleet noise into route planning so multiple constraints (e.g., mission time, safety, energy, and noise) can be optimized.
- It is likely that metrics used for land use planning, specifically day-night level (DNL), will not be a good indicator of annoyance to UAM vehicle noise.
- There are no known data available, specifically Noise-Power-Distance (NPD) data, for conducting community noise assessments of UAM vehicles.

# Three Track Approach

- UAM vehicle noise database generation
  - Create a database of a representative fleet mix, building on prior and current RVLТ and TTT Projects acoustic model development work, and RVLТ and ATM-X Project flight dynamics and flight control modeling work.
  - Increase the model fidelity throughout the life cycle of the work
  - Validate models through comparisons with available data (ground and flight test data, including data from UAM Grand Challenge)



|       |                                                                                            |
|-------|--------------------------------------------------------------------------------------------|
| RVLТ  | Revolutionary Vertical Lift Technology Project, Advanced Air Vehicles Program              |
| TTT   | Transformational Tools and Technology Project, Transformative Aeronautics Concepts Program |
| ATM-X | Air Traffic Management-Exploration Project, Airspace Operations and Safety Program         |

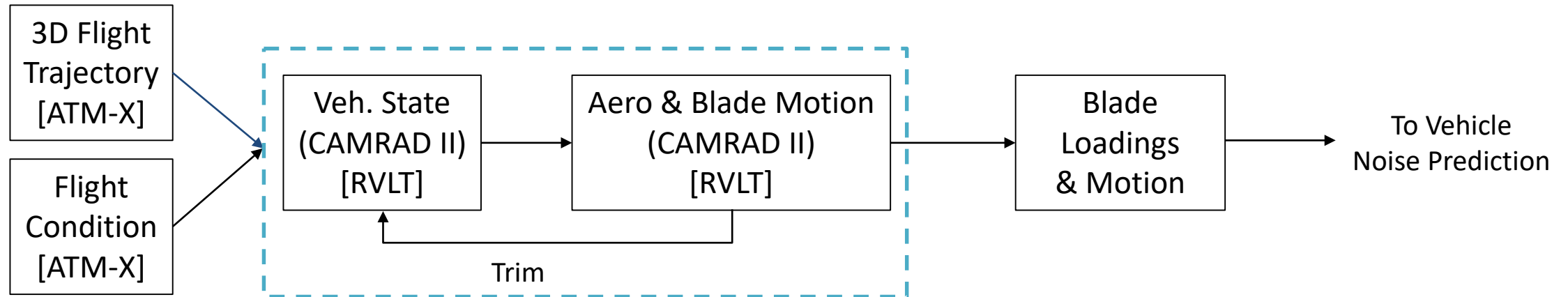


# Three Track Approach

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- Fleet noise assessments and flight operations optimization
  - Use FAA Aviation Environment Design Tool (AEDT) for fleet noise assessments with traditional metrics as constraints in optimization of flight operations
  - Use higher fidelity, time simulation for multiple event/fleet noise assessments with alternative metrics for annoyance and audibility.
  - Interact with ATM-X Project for flight trajectories and optimization of flight ops.
- Human Response
  - Perform psychoacoustic tests of single event UAM noise to lead to audibility and annoyance metrics that can be used for vehicle and operations design.
  - Explore sensitivity of route optimization to alternative metrics.

# Database Generation: Blade Loadings & Motion

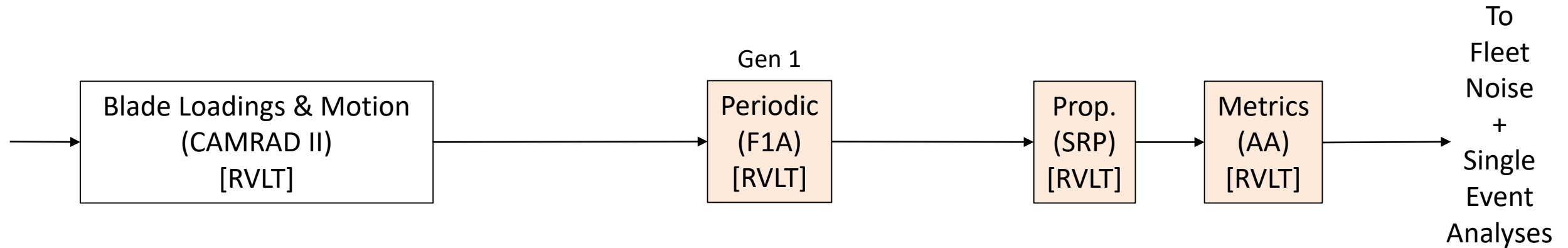


- Flight condition includes quantities like speed and descent rate (or speed and flight path angle)
- 3D flight trajectory needed here only to capture altitude effects, which are not likely significant for low flying UAMs
- Vehicle state includes vehicle and control states resulting from the flight condition, e.g., collective, cyclic, orientation, flaps, motor RPM, etc.
- Operations in the blue box are performed in a quasi-static sense

# 1<sup>st</sup> Database Generation: Vehicle Noise Prediction



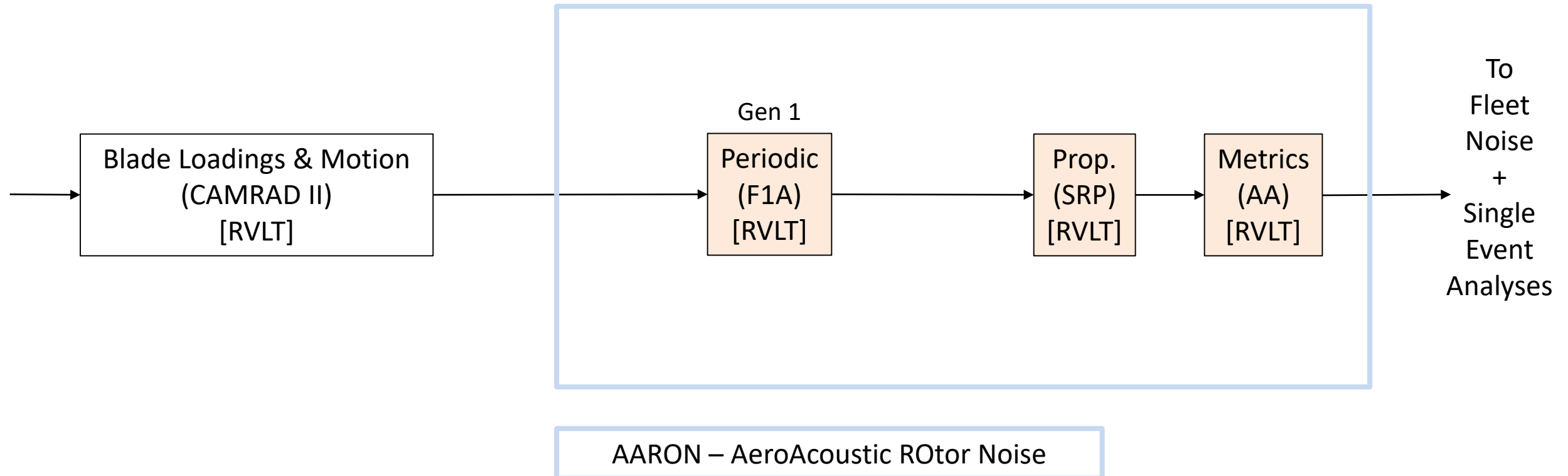
ANOPP2 – Aircraft Noise Prediction Program 2



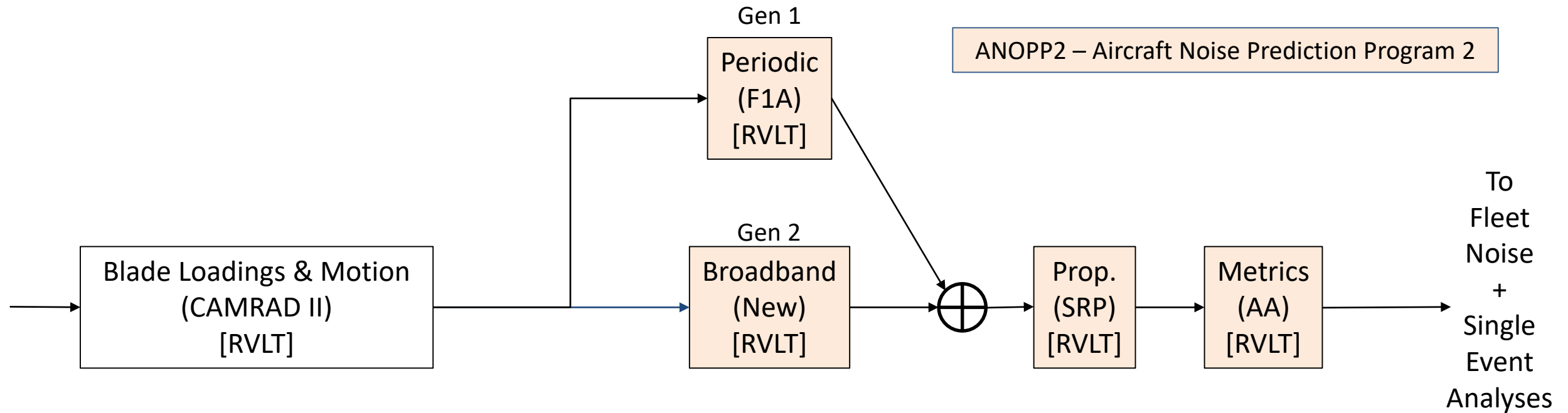
# 1<sup>st</sup> Database Generation: Vehicle Noise Prediction



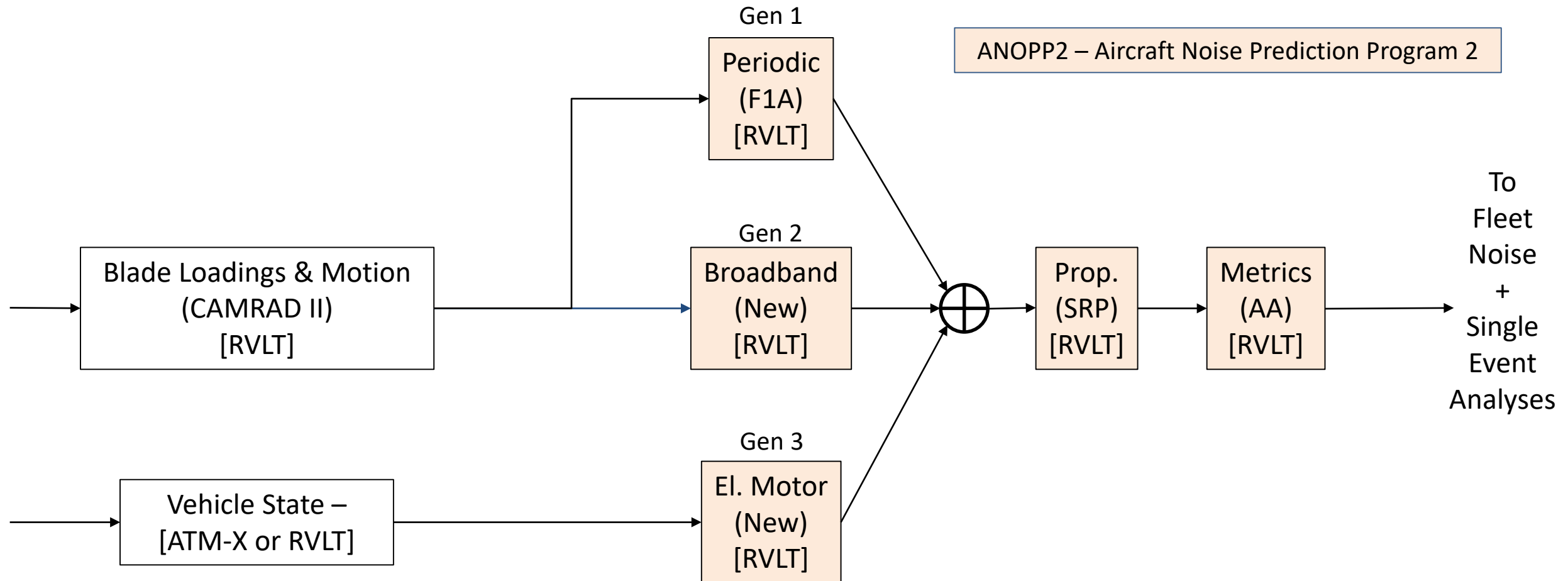
ANOPP2 – Aircraft Noise Prediction Program 2



# 2<sup>nd</sup> Database Generation: Vehicle Noise Prediction



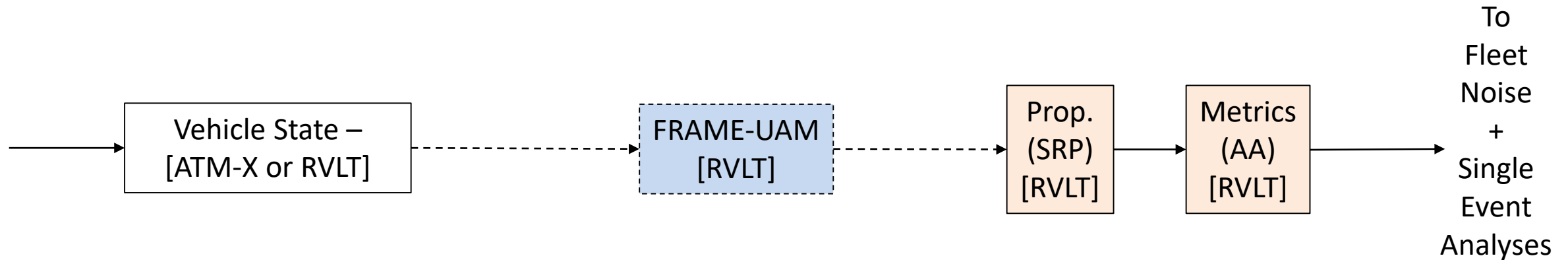
# 3<sup>rd</sup> Database Generation: Vehicle Noise Prediction



# Alt. Database Generation: Vehicle Noise Prediction



ANOPP2 – Aircraft Noise Prediction Program 2



FRAME – Fundamental Rotorcraft  
Acoustics Modeling from Experiments

# AEDT NPD Data Sets

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## Fixed Wing

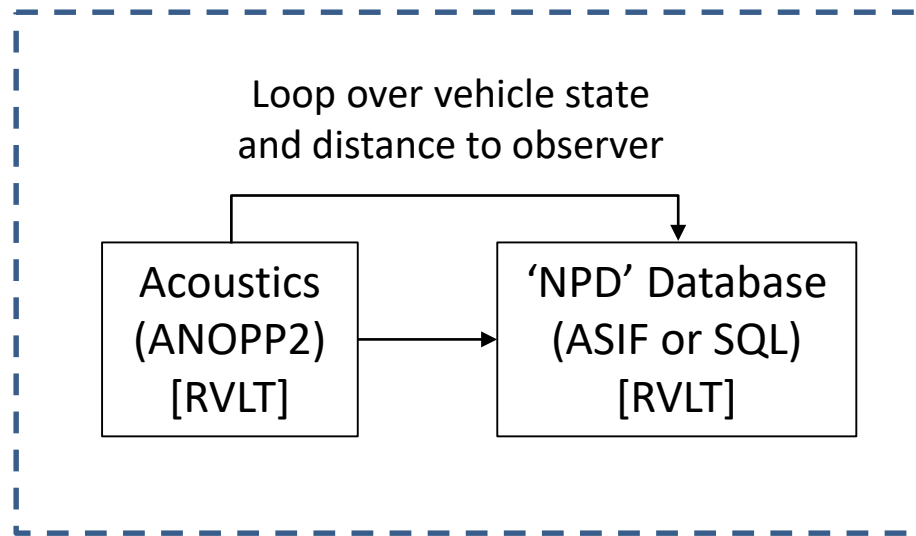
- NPD data are associated with an engine power (thrust) setting.
- NPD data consist of noise curves for each operational mode – approach, level flight, and departure.
- A performance model is used to determine the thrust setting for a specified operation.
- Source directivity applied using a dipole radiation model applied in the noise fraction adjustment for exposure metrics.

## Helicopters

- NPD data are associated with an operational mode, i.e., noise-operational mode-distance data.
- NPD data consist of noise curves for each operational mode procedural step
  - Dynamic and static operational modes
- There is no performance model. The operational mode is specified by the procedural step.
- Source directivity
  - Dynamic:  $0^\circ$ ,  $\pm 45^\circ$  azimuth
  - Static: Helicopter-specific directivity



# Database Generation: Noise-Power-Distance

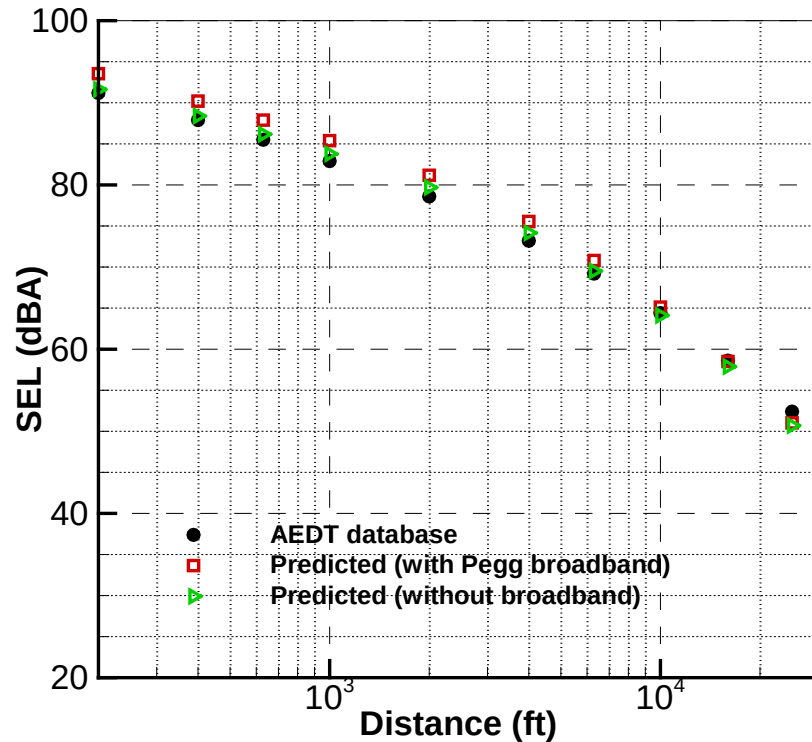


Because we have the ability to simulate the missions with higher fidelity in ANOPP2, we can assess limitations of this approach.

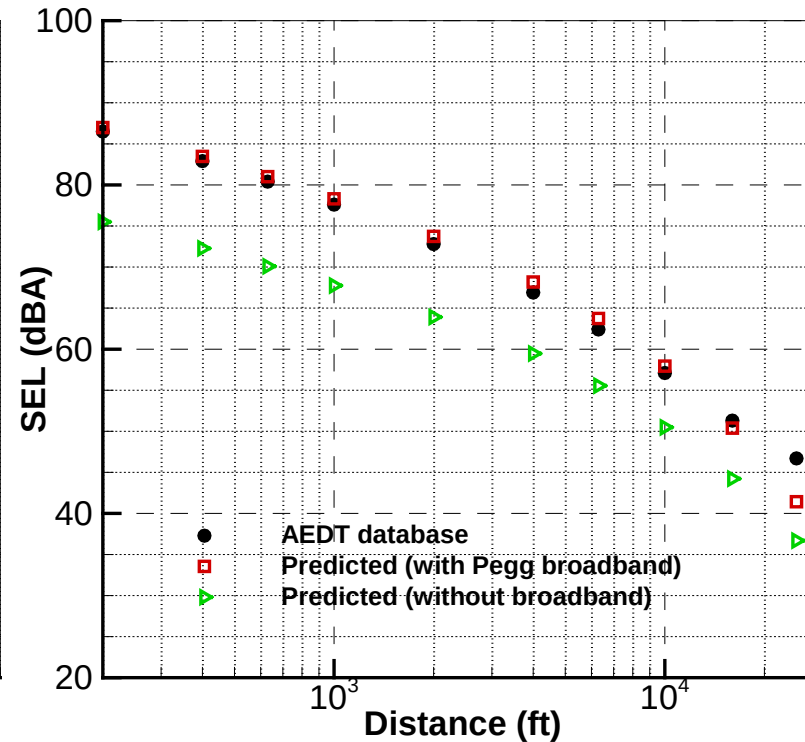
- We use a 'fixed point' profile in AEDT
  - Fixed wing NPDs that bypass AEDT perf. models
- The database links the noise ( $L_{A_{Max}}$ , SEL,  $PNLT_{Max}$ , EPNL) to the vehicle state and distance to observer
  - Vehicle state is an ID used as a surrogate for thrust and represents a particular flight condition.
  - By specifying piecewise constant flight conditions between waypoints, AEDT will interpolate noise between vehicle states (with short transitions), and distance to observer.
- In this scheme, we are hijacking the fixed wing aircraft type in AEDT.
  - NPDs generated by computing  $0^\circ$  azimuth data (normalized to reference flight speed). Directivity of fixed wing aircraft applied as part of noise fraction adjustment within AEDT.

# Database Generation: Sample Results

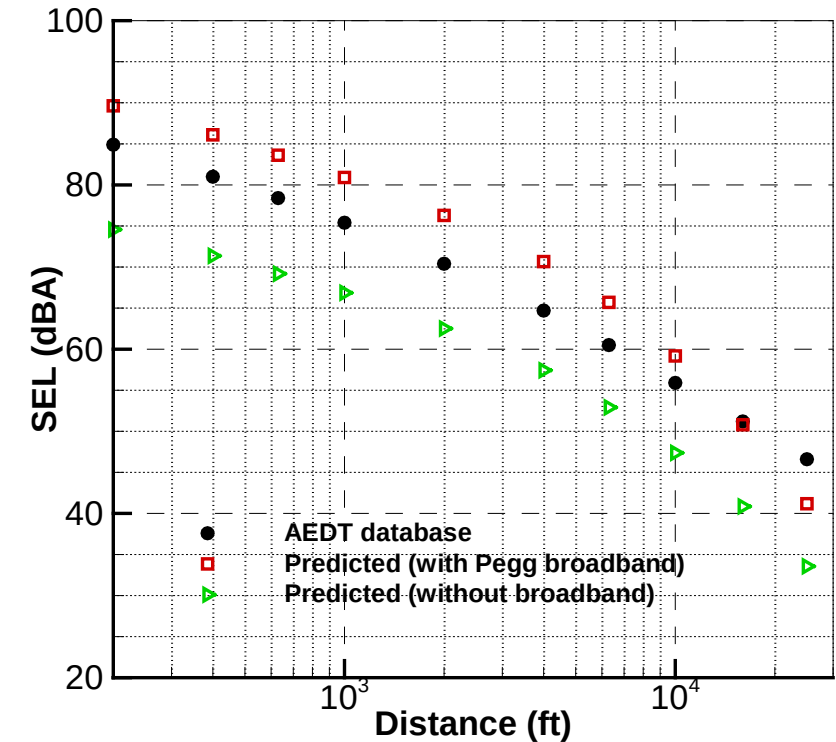
Robinson R-22 - Approach



Robinson R-22 – Level Flyover



Robinson R-22 – Departure

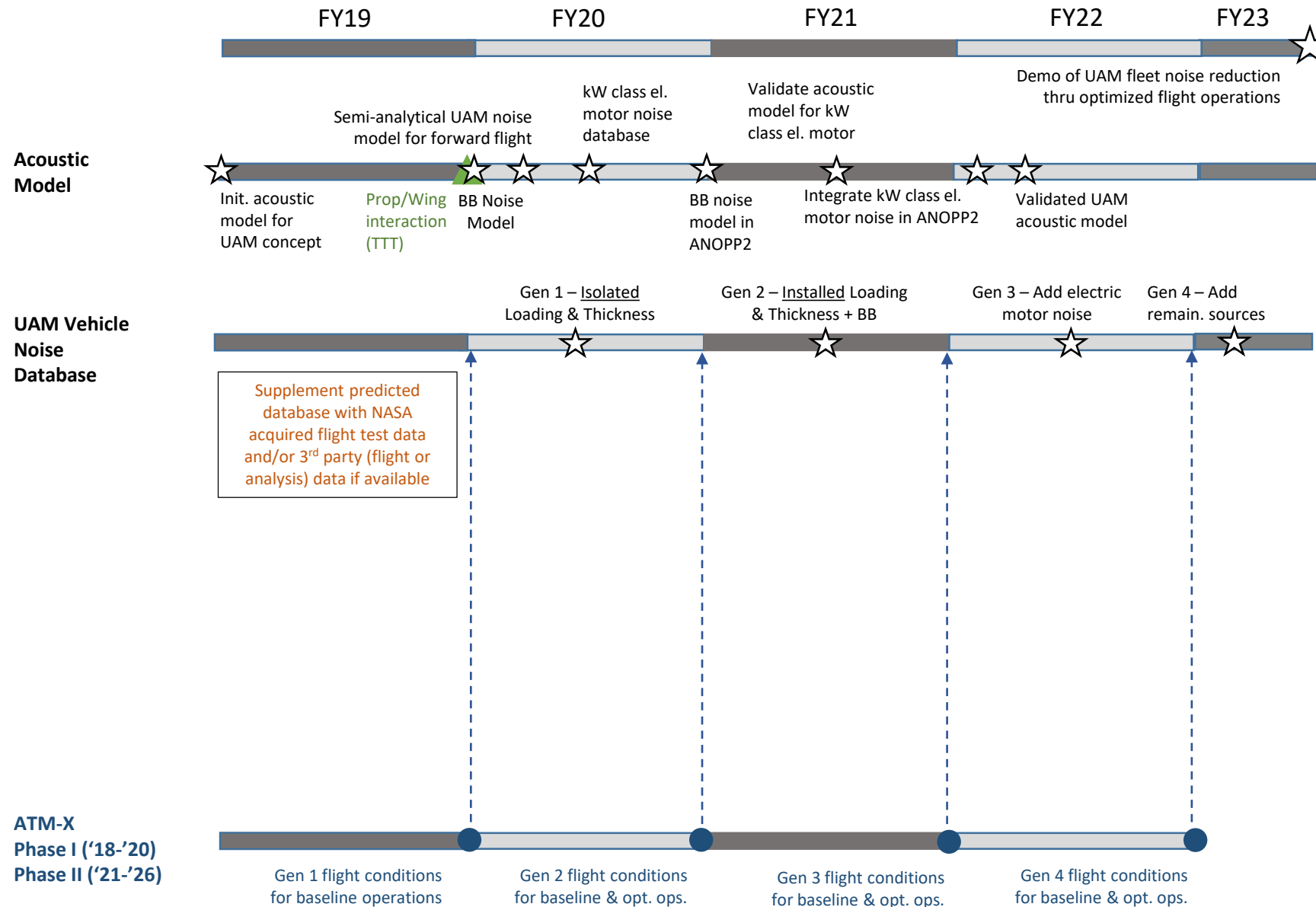


- Predicted SEL compares well with AEDT Aircraft Noise and Performance (ANP) Database
  - Contribution of broadband on approach is low because Pegg model is thrust dependent and thrust is low
  - In future, we will substitute the ANOPP2 broadband noise (ASNIFM) model for the Pegg model

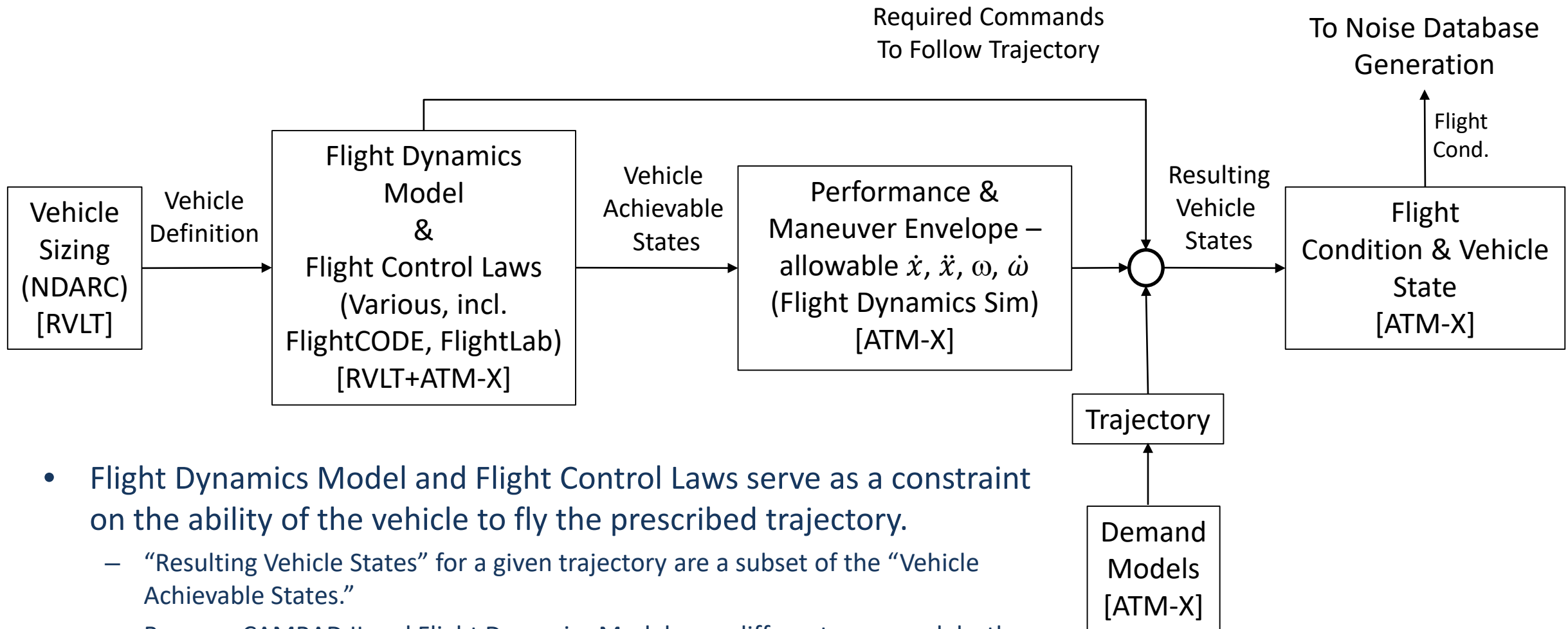


# Database Generation: Timeline

- ☆ RVL
- ▲ TTT
- ATM-X



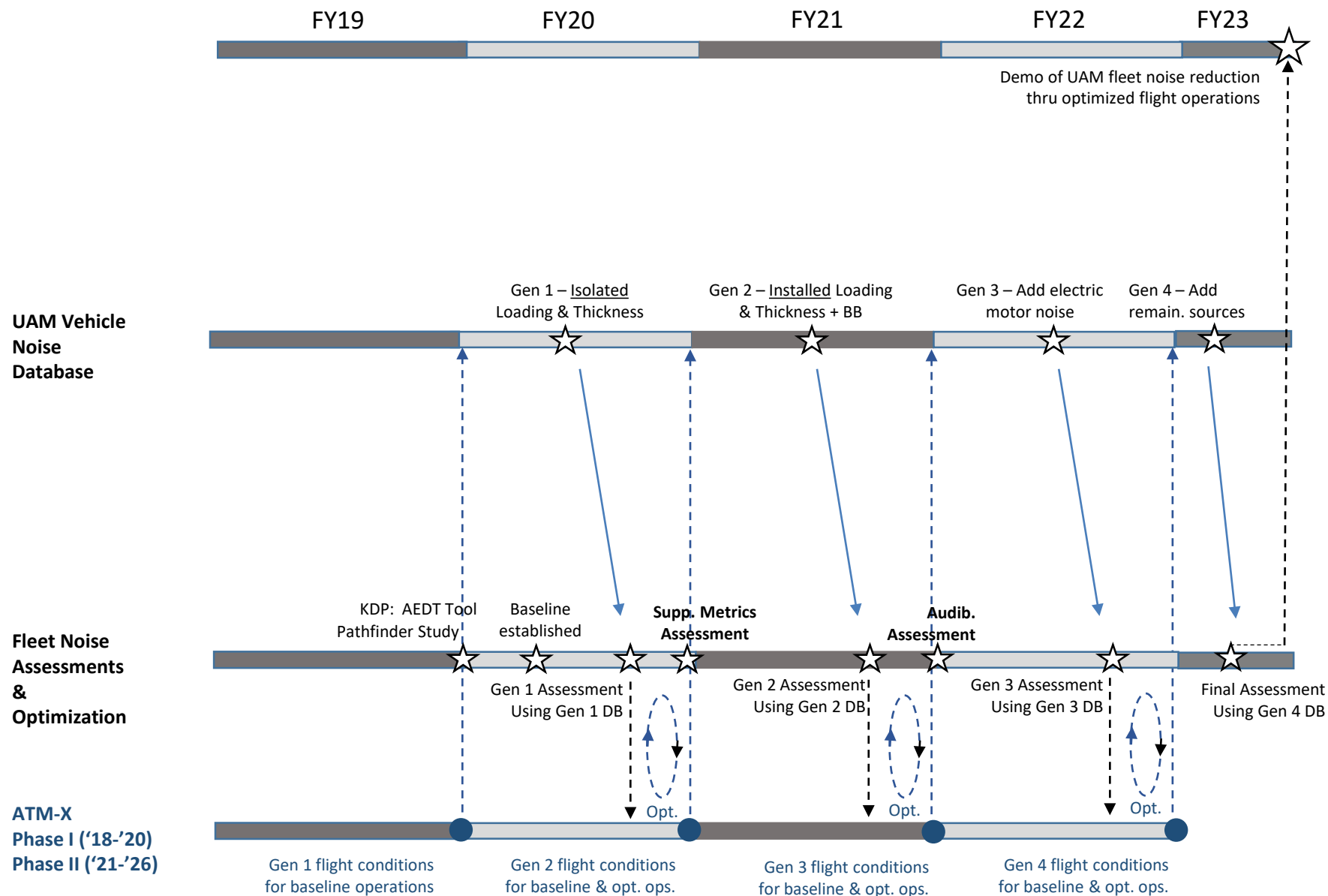
# Fleet Noise Assessments – Flight Conditions



- Flight Dynamics Model and Flight Control Laws serve as a constraint on the ability of the vehicle to fly the prescribed trajectory.
  - “Resulting Vehicle States” for a given trajectory are a subset of the “Vehicle Achievable States.”
  - Because CAMRAD II and Flight Dynamics Models use different aero models, the resulting “Vehicle State” or trimmed condition will differ between the two analyses. They should hopefully be close.

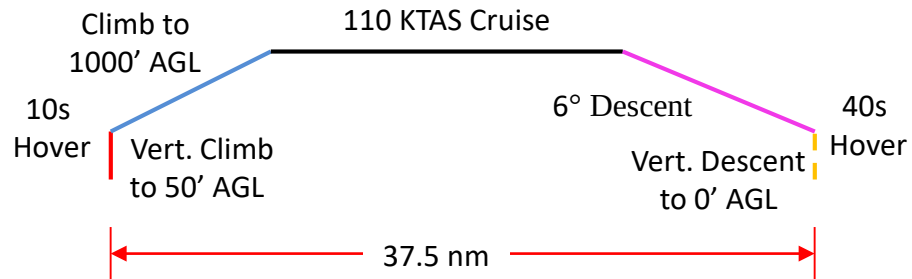
# Fleet Noise Assessments: Timeline

- ☆ RVL
- ▲ TTT
- ATM-X

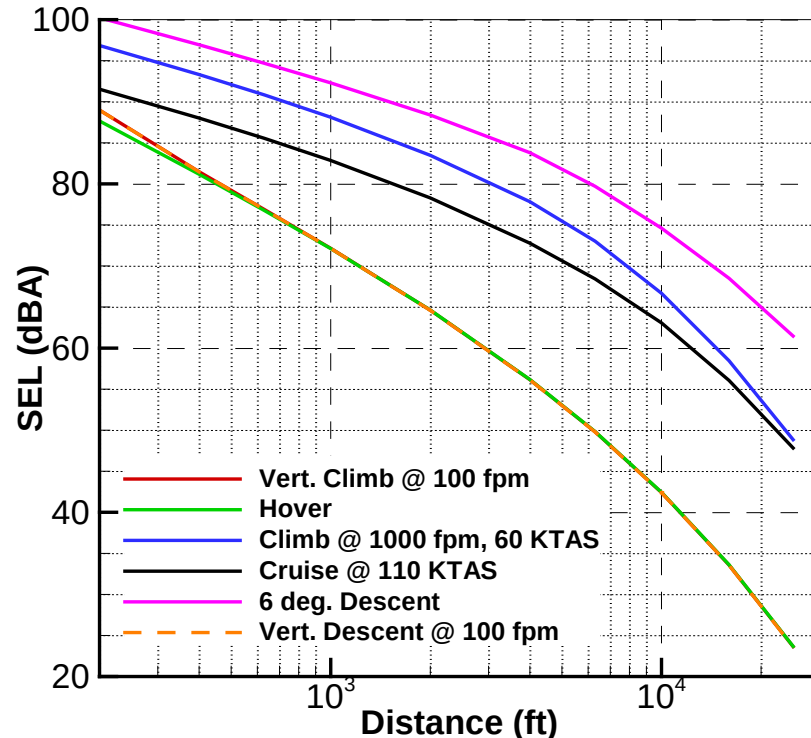


# Fleet Noise Assessments: Baseline

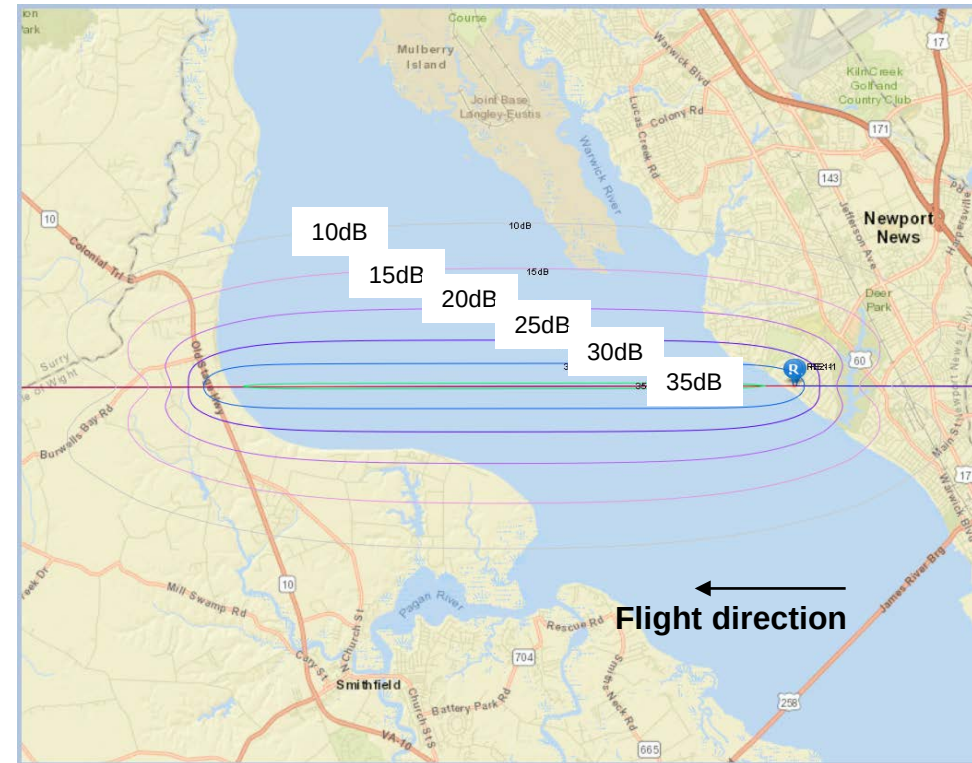
## Baseline Mission\*



## Robinson R-66 Predicted ANP Data

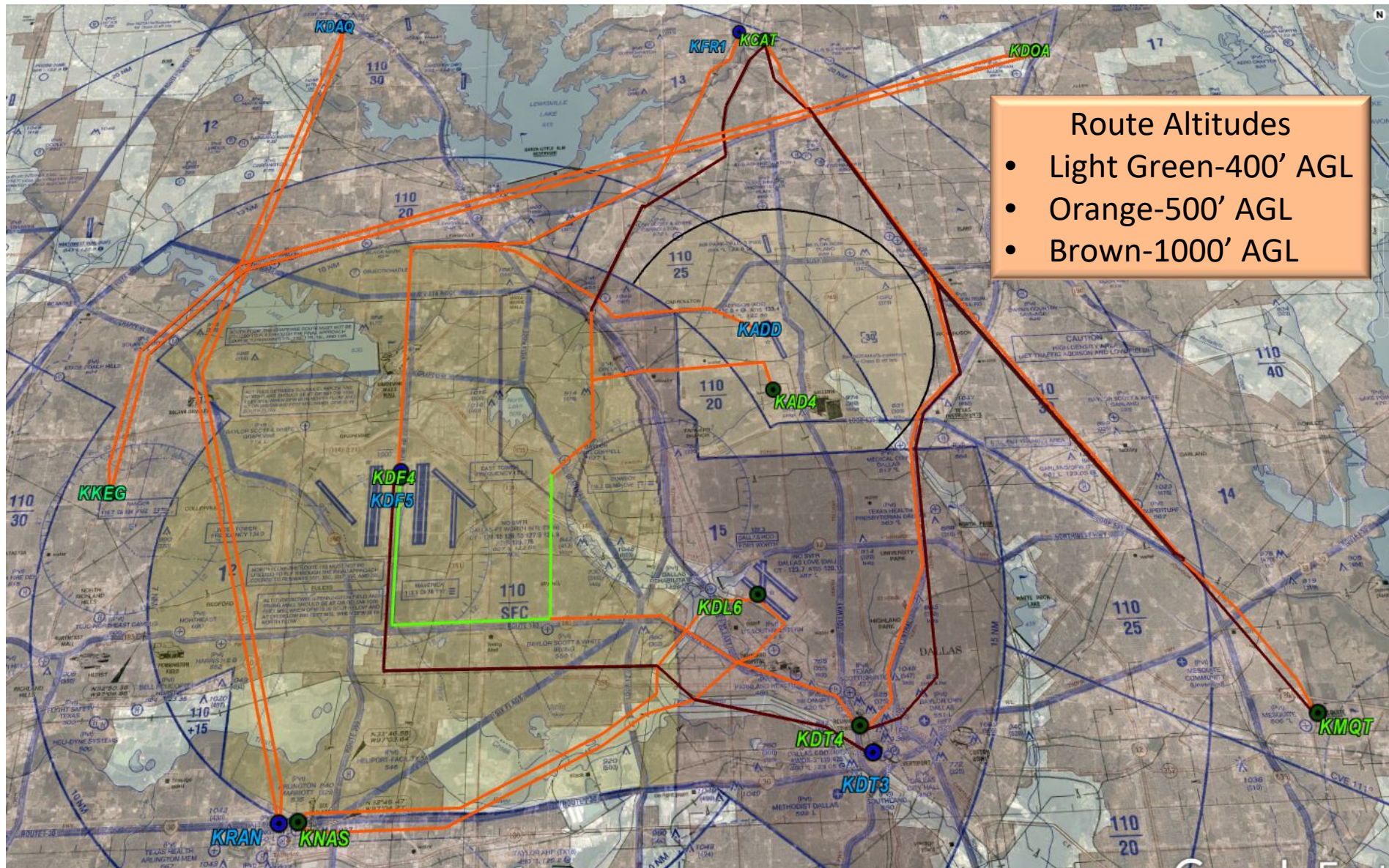


## Predicted Day-Night Level (DNL) contours for single R-66 @ 110 KTAS level cruise, 1000 ft. AGL



\* Silva, C., Johnson, W.R., Solis, E., Patterson, M.D., and Antcliff, K.R., "VTOL Urban Air Mobility Concept Vehicles for Technology Development," *AIAA Aviation*, AIAA 2018-3847, Atlanta, GA, 2018.

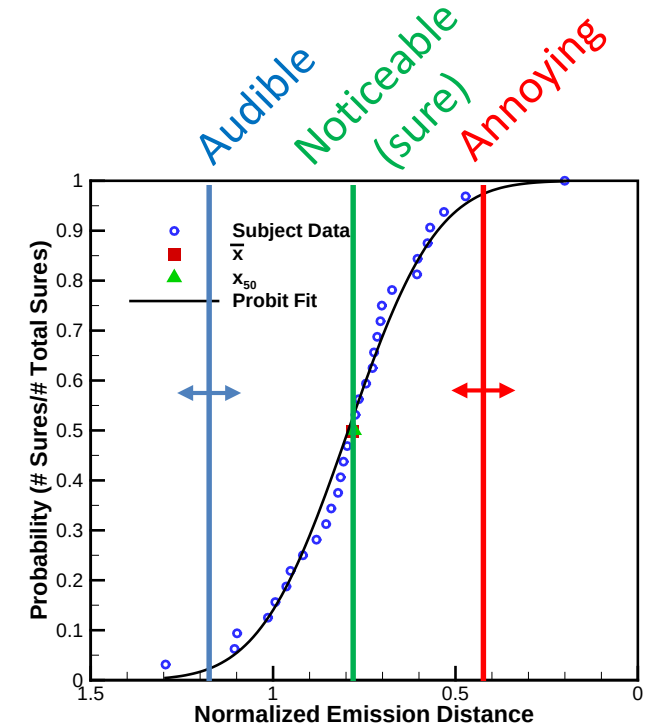
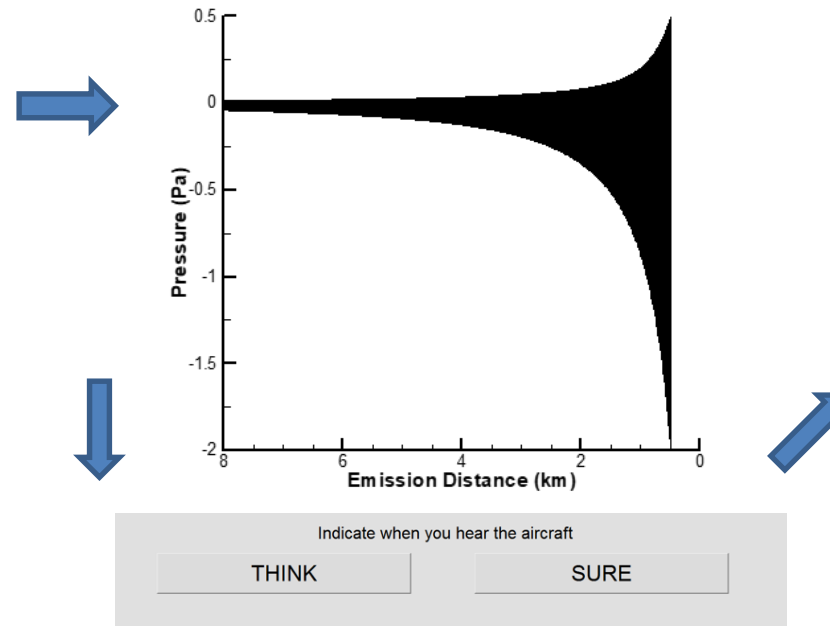
# Fleet Noise Assessments: Gen. 1 Baseline Ops†



- † Provided by ATM-X UAM X2 team
- 16 routes around DFW
- 2 vehicles
  - RVLT Quad
  - RVLT L+C

# Human Response

- Premise – DNL likely not a good indicator of annoyance to UAM vehicles
- Prior Work\*

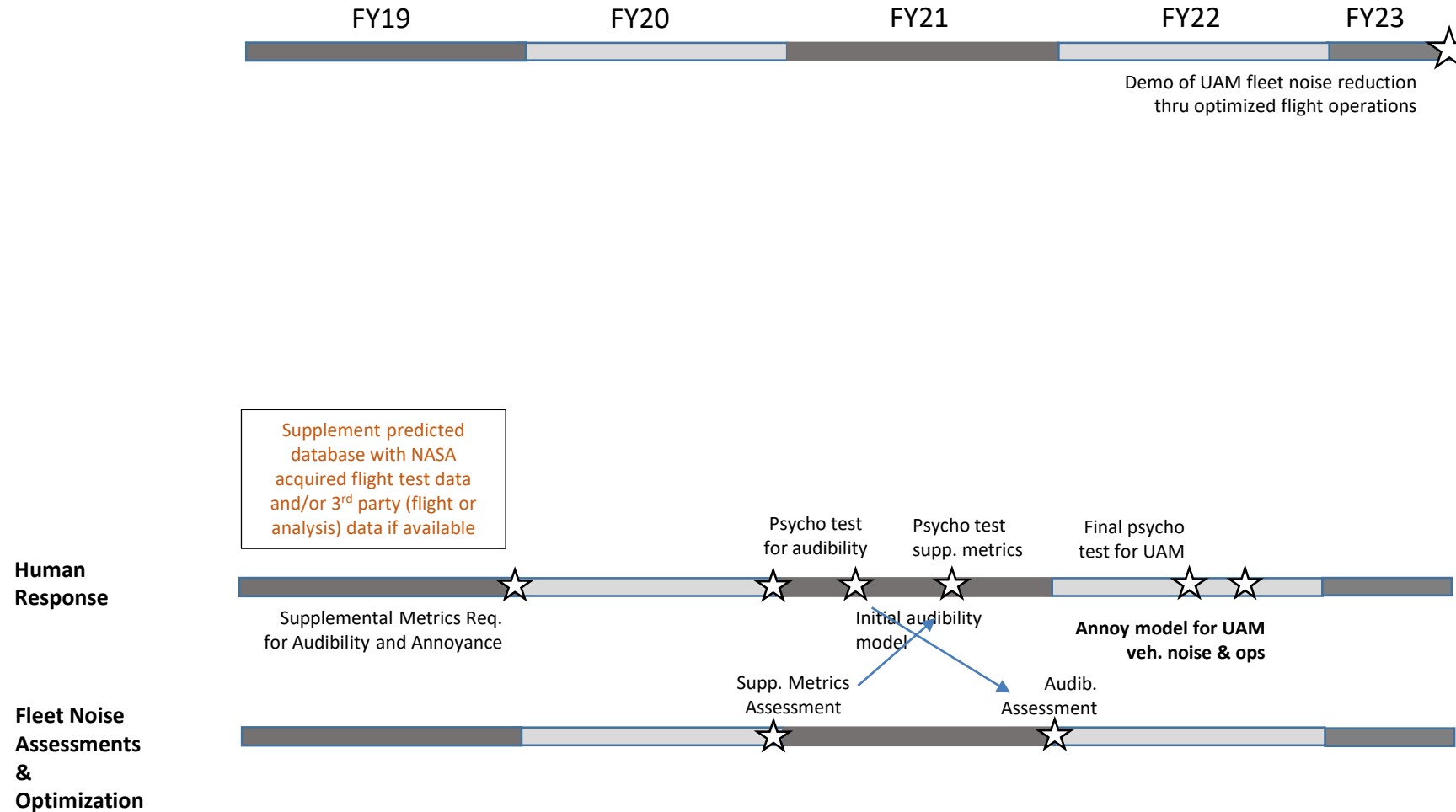


\* Rizzi, S.A., Christian, A.W., and Rafaelof, M., "A laboratory method for assessing audibility and localization of rotorcraft fly-in noise," *Journal of the American Helicopter Society*, Vol. 64, No. 1, 2019.

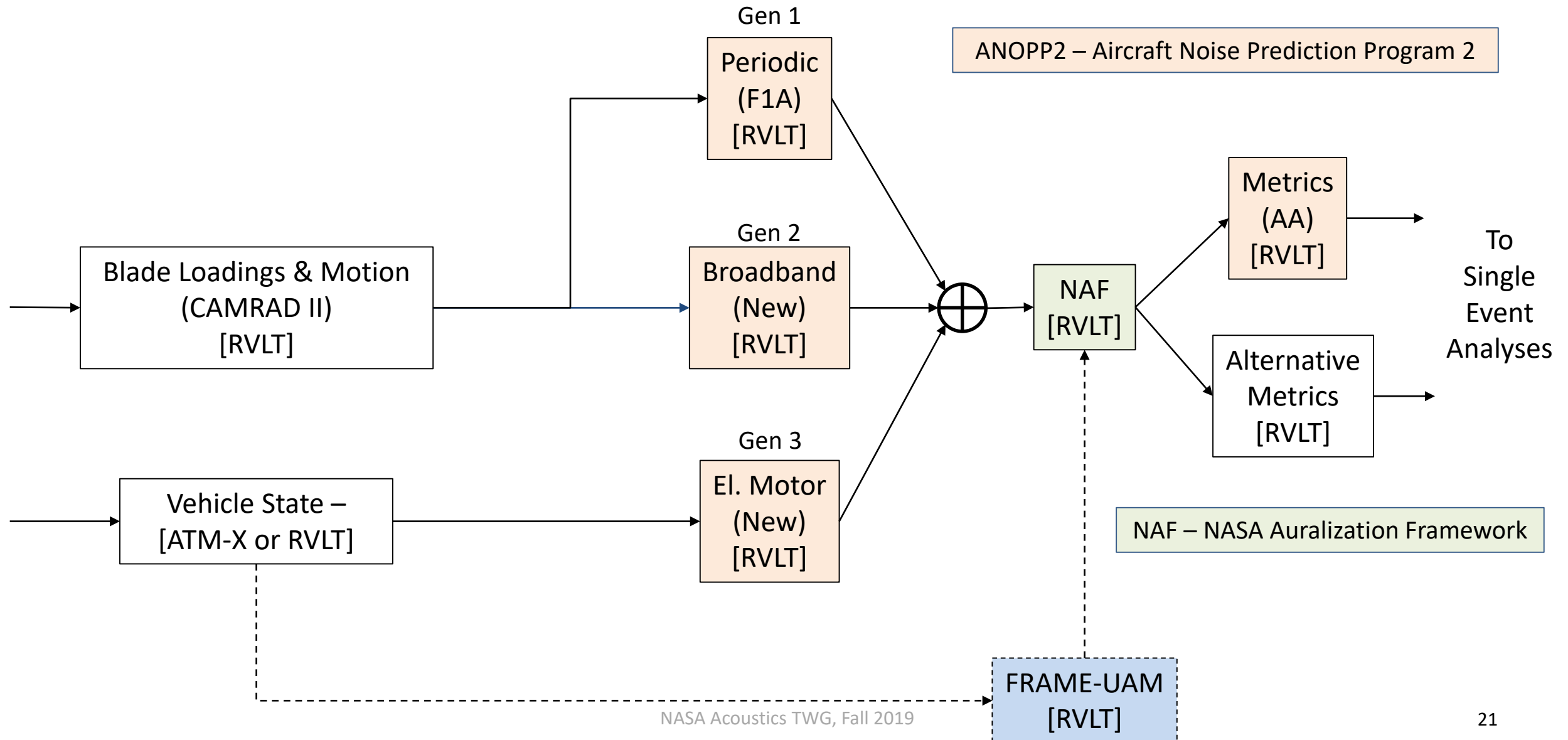


# Human Response - Timeline

- ☆ RVL
- ▲ TTT
- ATM-X



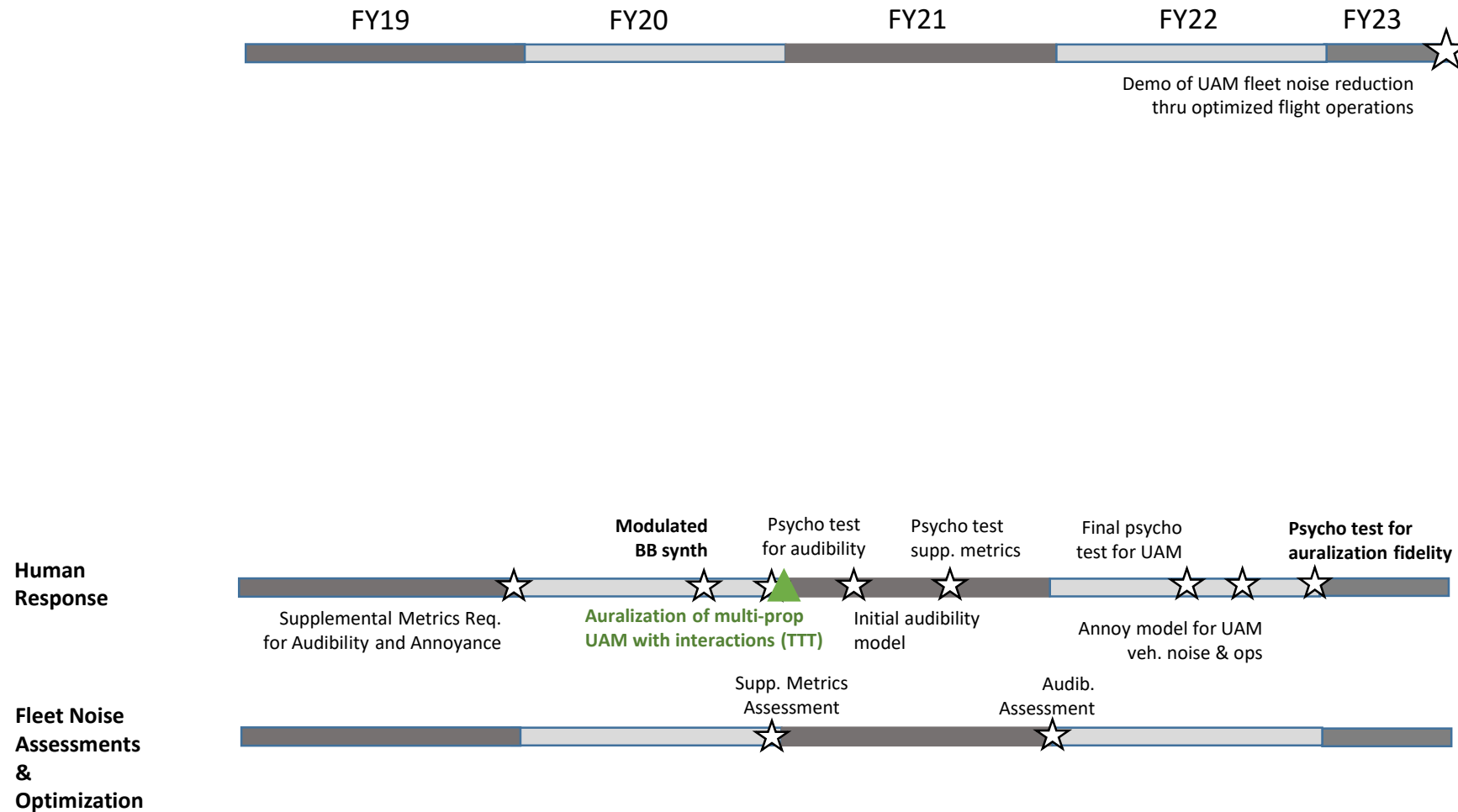
# Vehicle Noise Auralization for Supplemental Metrics





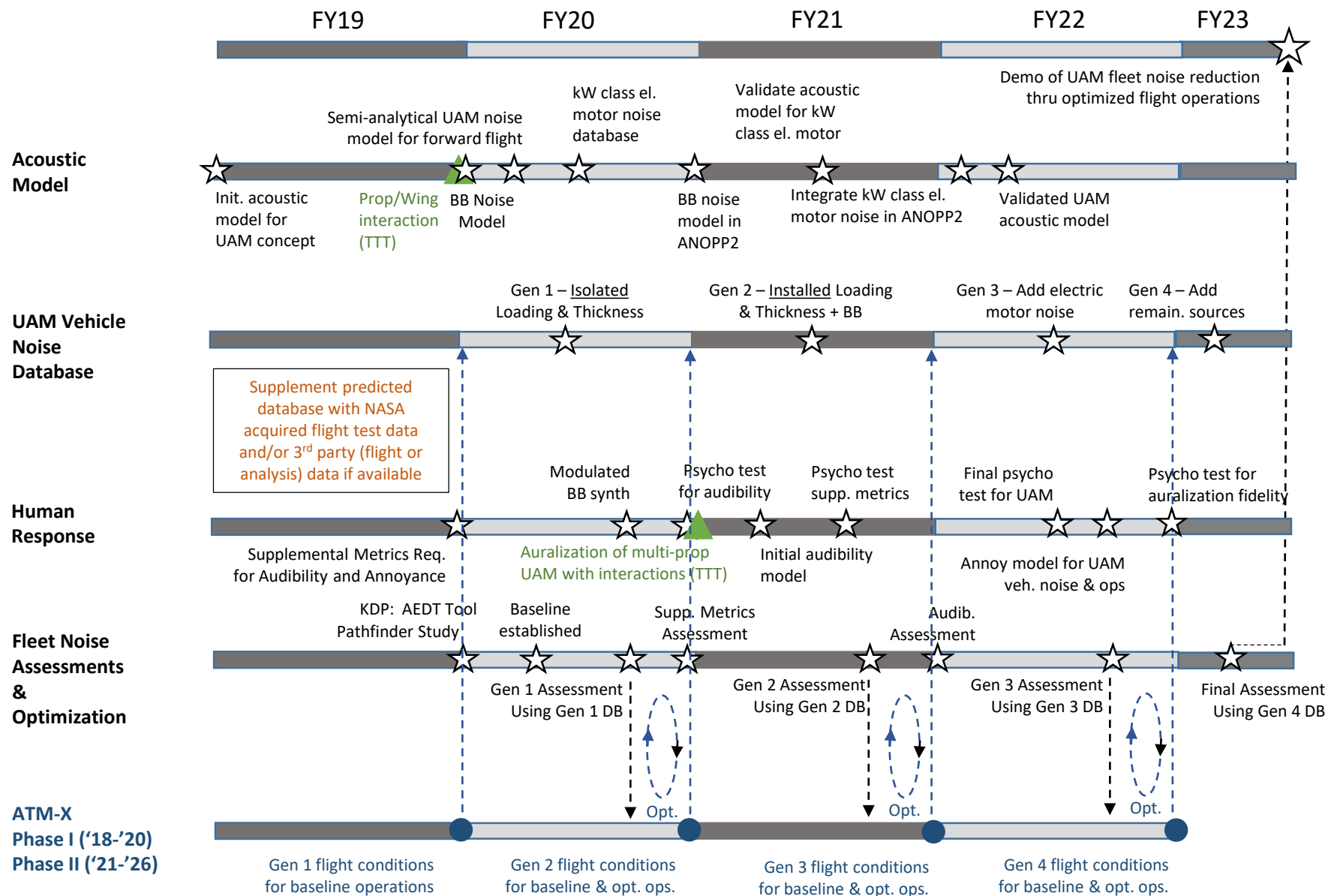
# Human Response - Timeline

- ☆ RVL
- ▲ TTT
- ATM-X



# Putting it all together

- ☆ RVLt
- ▲ TTT
- ATM-X



# RVLT Team

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## NASA Ames

Durand Begault

## National Institute of Aerospace

Rui Cheng & Menachem Rafaelof

## SAIC

Aric Aumann

## Analytical Mechanics Associates, Inc.

Brian Tuttle

# Backup Slides

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# AEDT Noise Metrics



| Metric Type                                   | AEDT Name | Standard Name | Definition/Full Name                                                          |
|-----------------------------------------------|-----------|---------------|-------------------------------------------------------------------------------|
| <b>A-Weighted Noise Metrics</b>               |           |               |                                                                               |
| Exposure                                      | SEL       | $L_{AE}$      | A-Weighted Sound Exposure Level                                               |
|                                               | DNL       | $L_{dn}$      | Day Night Average Sound Level                                                 |
|                                               | CNEL      | $L_{den}$     | Community Noise Equivalent Level                                              |
|                                               | LAEQ      | $L_{AeqT}$    | Equivalent Sound Level                                                        |
|                                               | LAEQD     | $L_d$         | Day-average noise level                                                       |
|                                               | LAEQN     | $L_n$         | Night-average noise level                                                     |
| Maximum Level                                 | LAMAX     | $L_{Amax}$    | A-Weighted Maximum Sound Level                                                |
| Time-Above                                    | TALA      | $T_{ALA}$     | Time-Above A-Weighted Level                                                   |
| Time-Audible                                  | TAUD      | $T_{Au}$      | Time-Audible                                                                  |
|                                               | TAUDSC    | $T_{AudSC}$   | Time-Audible with Overlapping Events Method (Statistical Compression)         |
|                                               | TAUDP     | $T_{AudP}$    | Time-Audible Percent                                                          |
|                                               | TAUDPSC   | $T_{AudPSC}$  | Time-Audible Percent with Overlapping Events Method (Statistical Compression) |
| <b>C-Weighted Noise Metrics</b>               |           |               |                                                                               |
| Exposure                                      | CEXP      | $L_{CE}$      | C-Weighted Sound Exposure Level                                               |
|                                               | CDNL      | $L_{cdn}$     | C-Weighted Day Night Average Sound Level                                      |
| Maximum Level                                 | LCMAX     | $L_{Cmax}$    | C-Weighted Maximum Sound Level                                                |
| Time-Above                                    | TALC      | $T_{ALC}$     | Time-Above C-Weighted Level                                                   |
| <b>Tone-Corrected Perceived Noise Metrics</b> |           |               |                                                                               |
| Exposure                                      | EPNL      | $L_{EPN}$     | Effective Perceived Noise Level                                               |
|                                               | NEF       | $L_{NEL}$     | Noise Exposure Forecast                                                       |
|                                               | WECPNL    | $L_{WECPN}$   | Weighted Equivalent Continuous Perceived Noise Level                          |
| Maximum Level                                 | PNLTM     | $L_{PNTSMx}$  | Tone-Corrected Maximum Perceived Noise Level                                  |
| Time-Above                                    | TAPNL     | $T_{APNL}$    | Time-Above Perceived Noise Level                                              |
| <b>Number Above Noise Level Metric</b>        |           |               |                                                                               |
| Number Above Noise Level                      | NANL      | NANL          | Number Above Noise Level                                                      |

# AEDT Helicopter Operational Mode Procedure Steps



| Operational Mode | Description                           | State   |
|------------------|---------------------------------------|---------|
| A                | Approach at constant speed            | Dynamic |
| D                | Departure at constant speed           | Dynamic |
| L                | Level flyover at constant speed       | Dynamic |
| G                | Ground idle                           | Static  |
| H                | Flight idle                           | Static  |
| I                | Hover in ground effect                | Static  |
| J                | Hover out of ground effect            | Static  |
| V                | Vertical ascent in ground effect      | Static  |
| W                | Vertical ascent out of ground effect  | Static  |
| Y                | Vertical descent in ground effect     | Static  |
| Z                | Vertical descent out of ground effect | Static  |
| B                | Approach with horizontal deceleration | Dynamic |
| C                | Approach with descending deceleration | Dynamic |
| E                | Depart with horizontal acceleration   | Dynamic |
| F                | Depart with climbing acceleration     | Dynamic |
| T                | Taxi at constant speed                | Dynamic |