ASCENT Project 084

Noise Modeling of Advanced Air Mobility Flight Vehicles

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Cost Share Partner(s): Electra.aero

Objective:

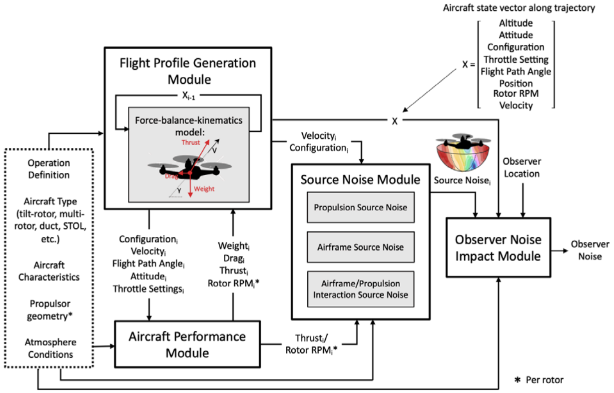
To develop first principles noise models of AAM vehicle configuration(s) to make community noise predictions of these aircraft flying at various operating states. Estimated noise levels from these models will be used to develop methods needed for a AAM-compatible AEDT to make preliminary noise estimates of these vehicles.

Project Benefits:

This project will develop noise modeling methodologies for a variety of AAM vehicles where existing noise data is currently very limited. The noise analysis models will also be applicable to study potential noise abatement methodologies through source noise modifications, procedure modifications, or both. Future developments to model AAM noise in AEDT will be directly supported by this effort.

Research Approach:

A UAM/AAM compatible noise model will be developed and used to model noise at a variety of velocities, flight path angles, and operating modes using a flight profile generator for making AAM noise estimates



Major Accomplishments (to date):

- Developed preliminary noise model framework for AAM vehicles
- Identified sample AAM aircraft for noise model case studies
- Demonstrated performance and noise modeling for sample AAM trajectories

Future Work / Schedule:

- Further define flight procedure components of AAM aircraft (Dec 2022)
- Develop source noise models for representative AAM aircraft components (March 2023)
- Demonstrate noise modeling of representative AAM aircraft for varied operating procedures (June 2023)
- Further refine framework for additional AAM aircraft and noise components (Sept 2023)
- Examine implications for AAM operations in AEDT development (Dec 2023)

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Motivation

- Various AAM configurations proposed in industry
- Noise assumed to be a critical aspect of these new AAM configurations
- Community noise impact will be a function of configuration and how vehicles are operated
- Desirable to update AEDT to enable analysis of AAM vehicles and operations

Source: SMG Consulting

Objectives and Methodology

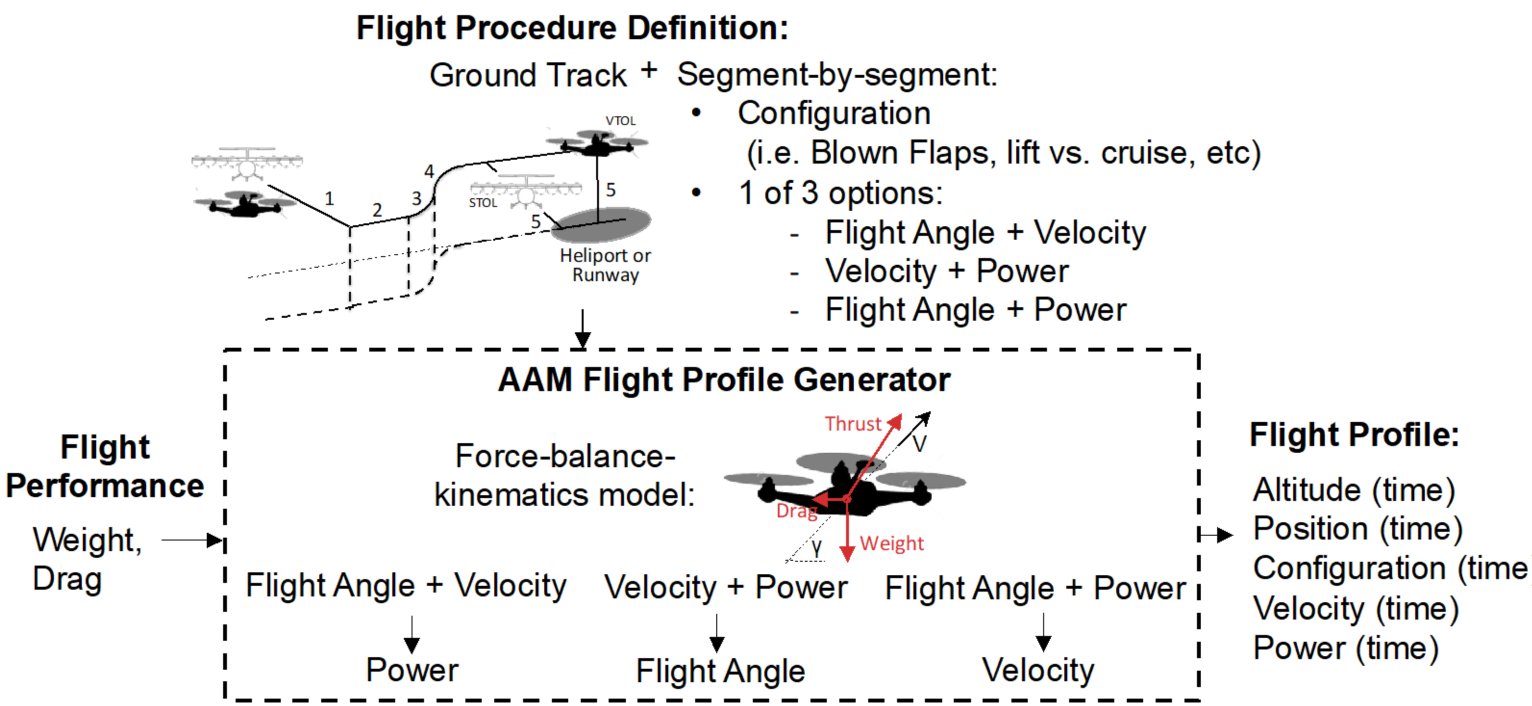
Objectives:

- Develop detailed component-based noise models for AAM vehicles
- Develop simplified noise models that can be compatible with AEDT based on detailed models
- Evaluate potential AAM arrival and departure procedures

Methodology:

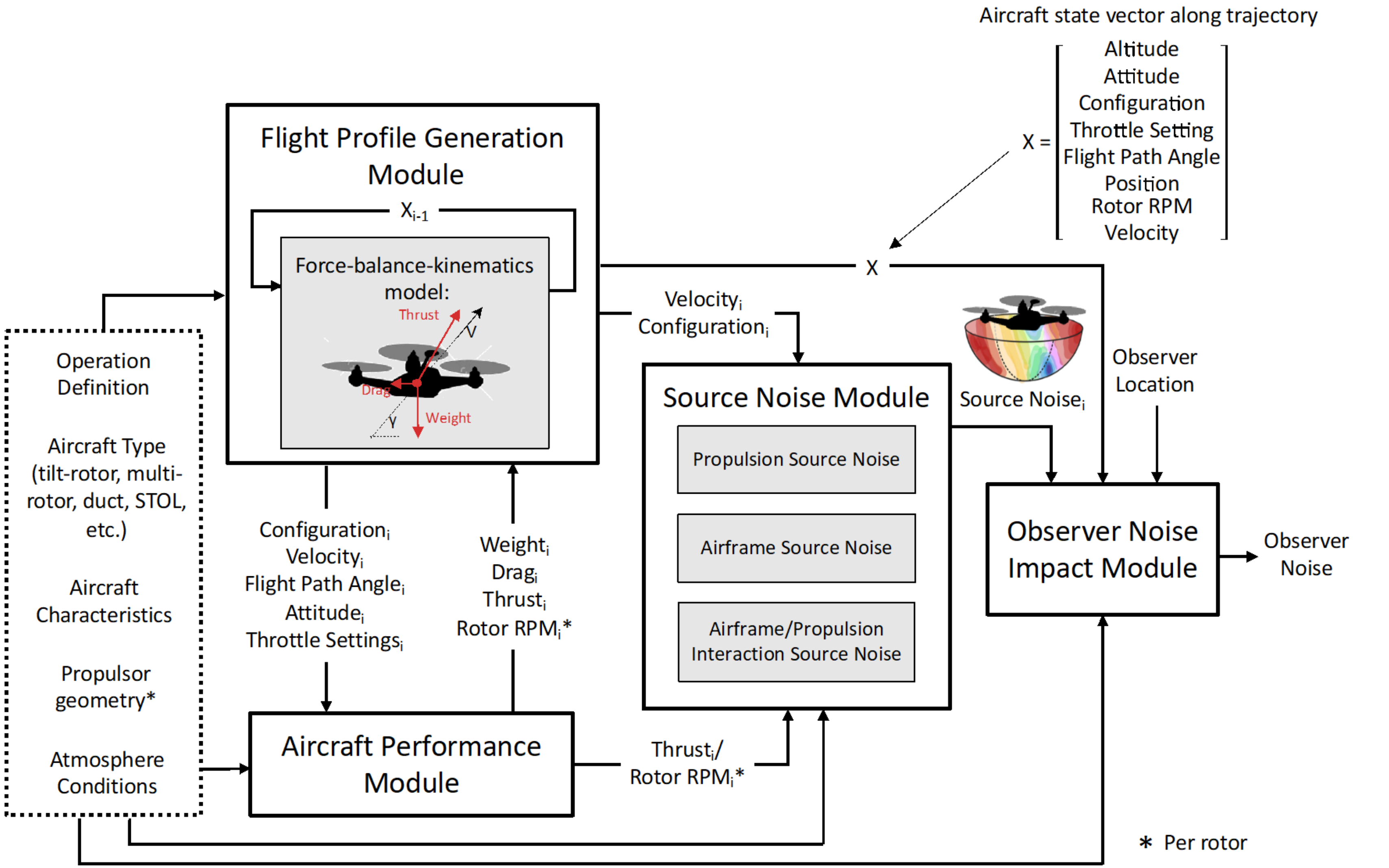
- Develop a system analysis framework for AAM to quantify the noise impacts of advanced flight procedures
  - Adapt framework developed in ASCENT 23 (analytical approach for quantifying noise of advanced operational flight procedures)
  - Utilize analysis tools such as ANOPP2, ABEAT to model the key noise sources

Current Focus: Modeling and Defining Reference Trajectories for AAM vehicles



- Various AAM configurations are under consideration in industry, Ex:
  - VTOL+cruise
  - Short Takeoff and Landing vehicles (STOL)
  - Tilt-duct VTOL
  - Tilt-rotor VTOL
- Methodology is expanded to generalized AAM operations for a variety of configurations

Preliminary AAM Noise Model Framework



Preliminary AAM Flight Profile Generation Module

Operation Definition →

Aircraft Type (tilt-rotor, multi-rotor, duct, STOL, etc.) →

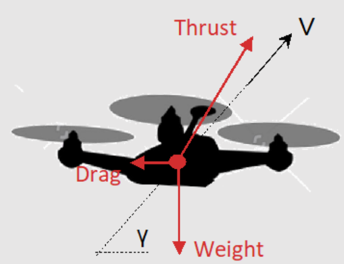
Airframe Characteristics →

Flight Profile Generation Module

X_{i-1}

Force-balance-kinematics model:

$\sum$ □= □□ → Velocity



To Observer Noise Impact Module
State Vector X_i

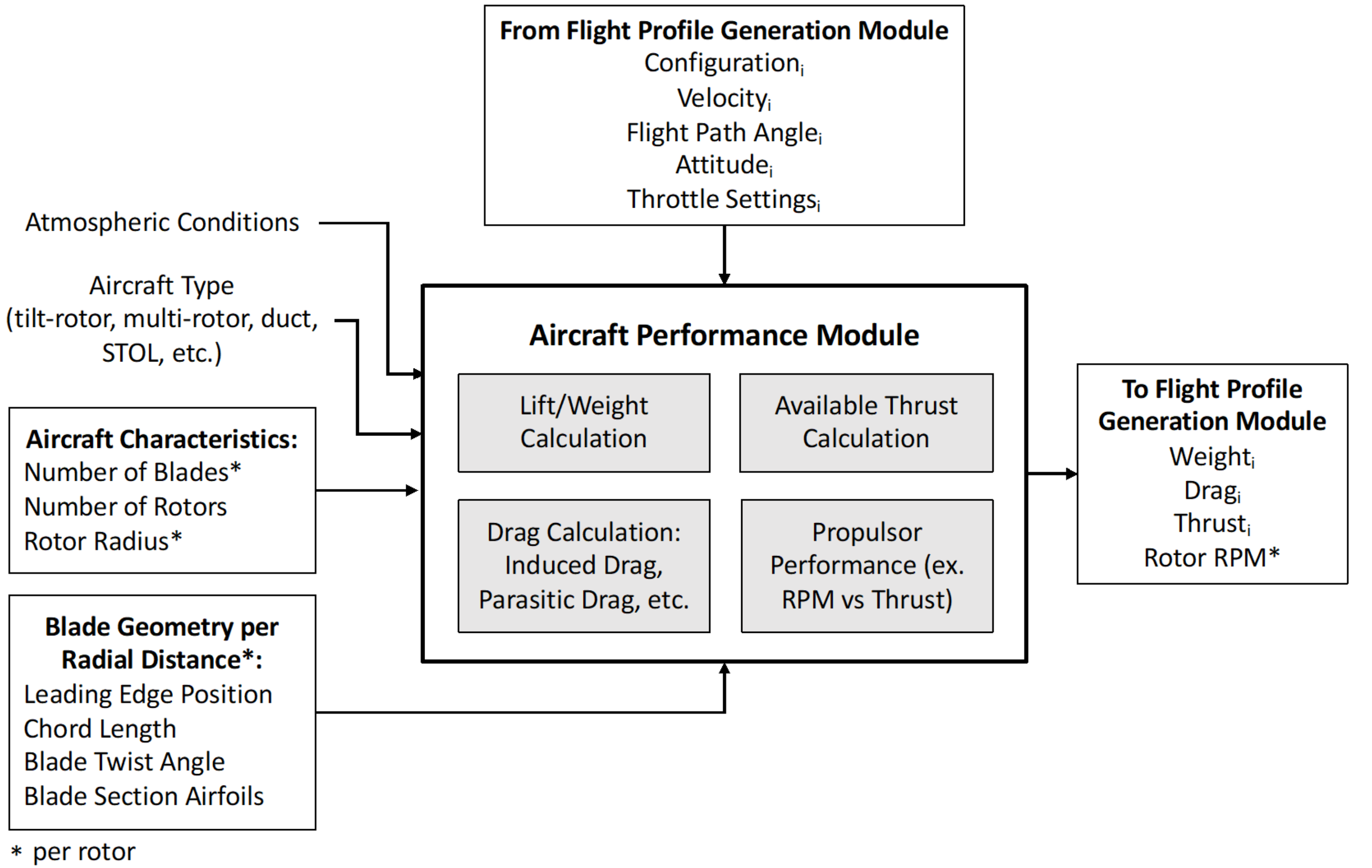
To Source Noise Model
State Vector X_i

To Aircraft Performance Module
$Configuration_i$
$Velocity_i$
$Flight\ Path\ Angle_i$
$Attitude_i$
$Throttle\ Settings_i$

From Aircraft Performance Module
$Weight_i$
$Drag_i$
$Thrust_i$
Rotor RPM*

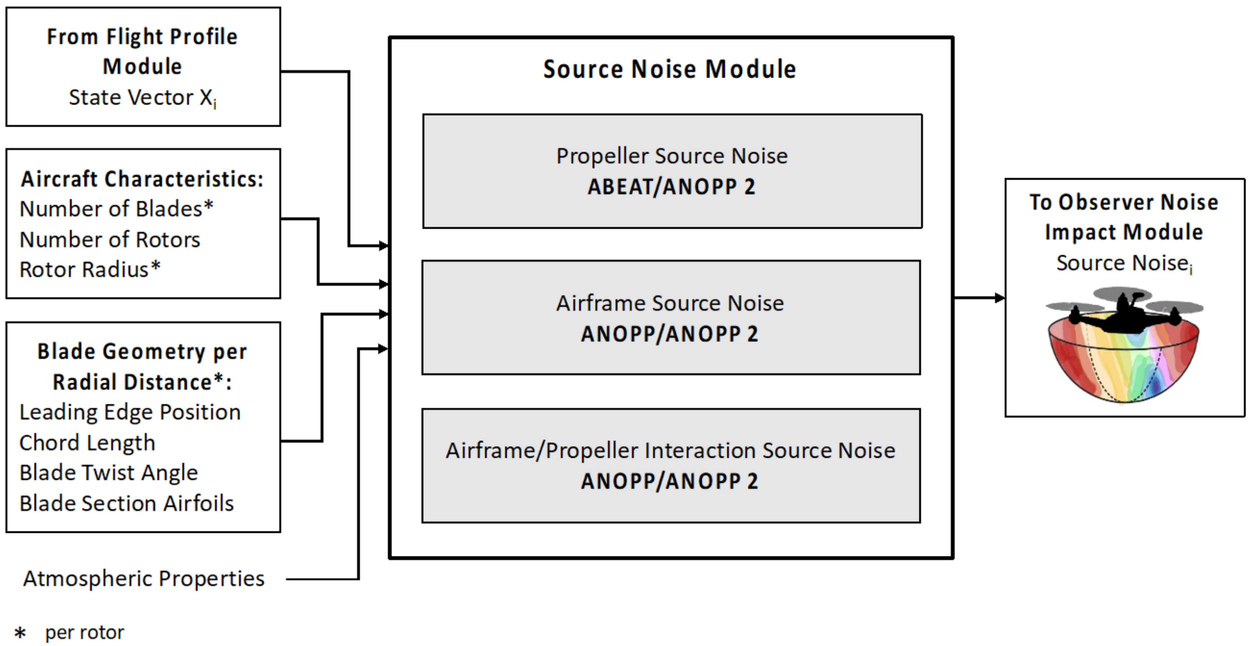
* per rotor

Preliminary AAM Aircraft Performance Module



Propulsor thrust and performance modeled using XROTOR

Preliminary AAM Source Noise Module



Source noise module to include:

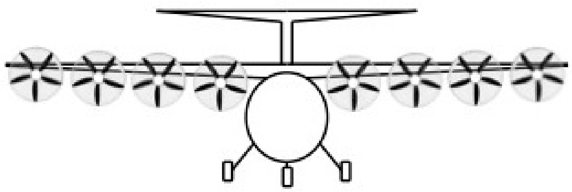
- Propeller source noise:
  - Loading tonal noise
  - Thickness tonal noise
  - Broadband Blade self noise (each rotor separately, boundary layer effect)
- Airframe source noise:
  - Gear noise, high lift configuration noise, trailing edge noise
- Interaction source noise:
  - Rotor-Airframe/Aerodynamic surface Interaction (RAI)
  - Tonal interrotor constructive destructive interference (CDI)
- Future modifications to the model to include the following, using Flightstream coupled with ANOPP2:
  - Fuselage-Wake Interaction (FWI)
  - Blade-wake interaction (BWI) from multiple rotors in proximity to one another (from interrotor and intrarotor interactions)
  - Blade-Vortex Interaction (BVI) noise

PRELIMINARY PERFORMANCE, FLIGHT PROCEDURE, AND NOISE MODELING CASE STUDIES

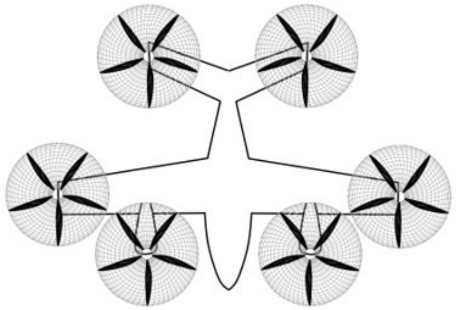
Approach

- Example AAM vehicles from industry featuring various rotor configurations and flight strategies were used as case studies to develop the preliminary performance and noise modeling approaches
- Based on published design specifications for each vehicle:
  - Conceptual flight profiles were developed using the flight performance module
  - Representative propellers were designed and modeled in off design conditions in the flight profiles to obtain propeller performance along each flight profile
- Example source noise and propagated noise contours were modeled for each case

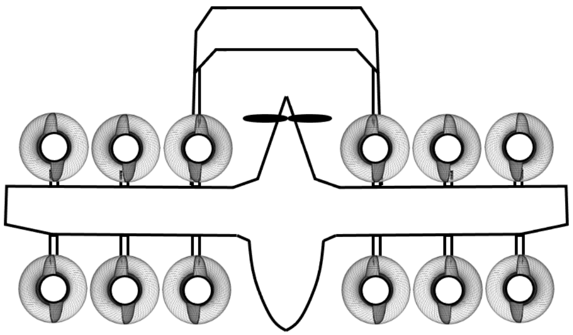
Initial Representative Aircraft Specifications



STOL



Tilt Rotor

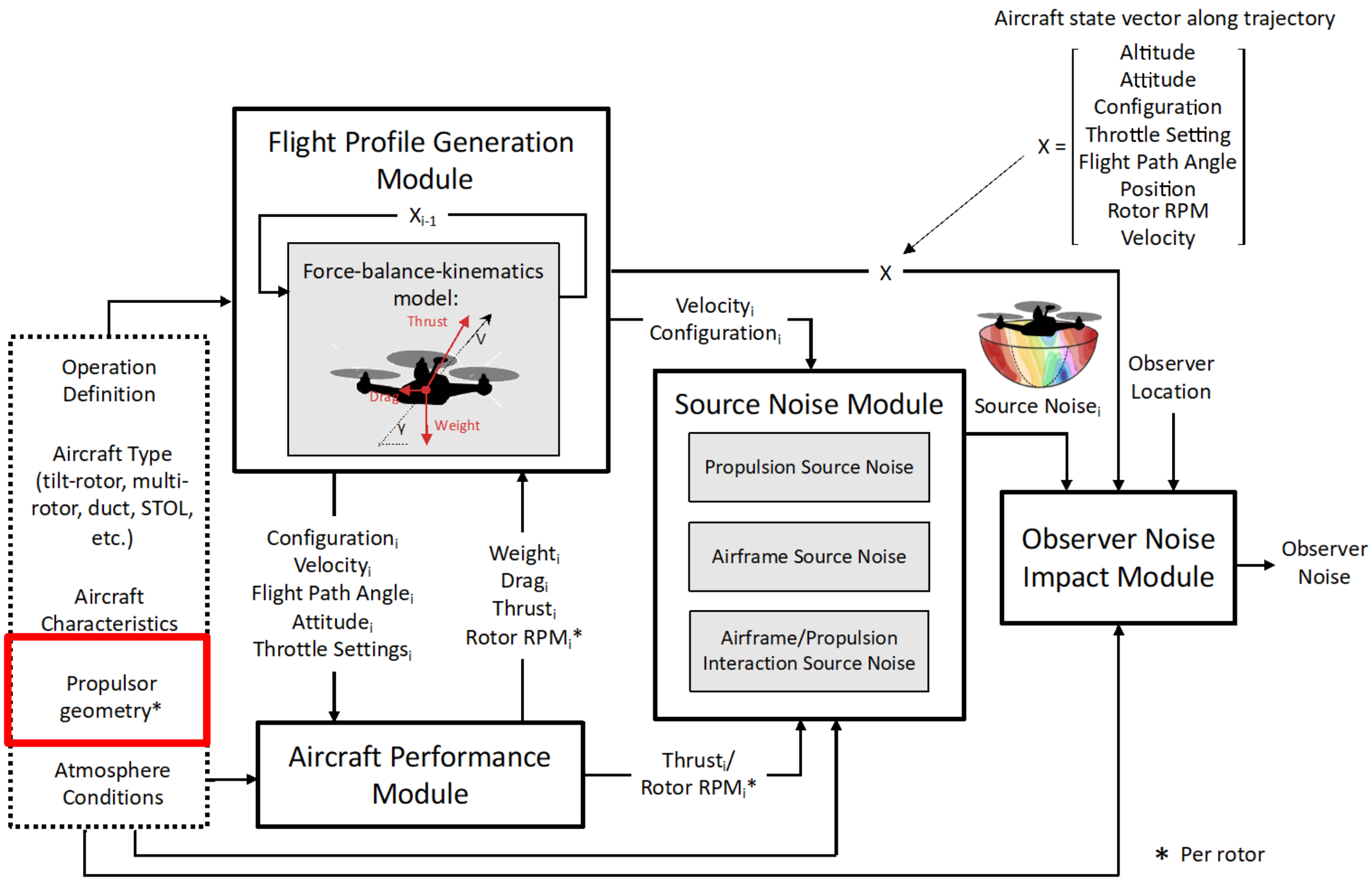


Lift + Cruise

	STOL [Ref 1]	Tilt Rotor [Ref 2]	Lift + Cruise [Ref 3]
Span [ft]	43.7	35	36
Wing Area [ft^2]	303	107	107.6
Aspect Ratio	7.9	11.4	12.4
MTOW [lb]	6000	4000	2800
Number of Lift Rotors	0	6	12
Number of Cruise Rotors	8	6	1
Blades Per Rotor	5	5	Lift Rotor: 2 Cruise Rotor: 3
Rotor Diameter [ft]	2.7**	9.5	Lift Rotor: 4.3 Cruise Rotor: 6.6
Hub Percent of Rotor Diameter [%]	25	10	Lift Rotor: 30 Cruise Rotor: 20
Range [nmi]	347.6	130.3	45.2
Take Off Distance [ft]	150	0	0
Design Takeoff Thrust per Rotor* [lb]	229	350	Lift Rotor: 303 Cruise Rotor: 0
Design Cruise Thrust per Rotor* [lb]	106	57	Lift Rotor: 0 Cruise Rotor: 111
Design Takeoff Speed* [kts]	39	39	39
Design Cruise Speed* [kts]	152	152	97
Additional Considerations	35° flaps on takeoff 60° flaps on landing	-	-

* Values calculated based on assumptions
** Diameter changed from paper to lower tip Mach number

Preliminary AAM Noise Model Framework



Need *vehicle specific propeller model* to obtain propulsor performance for flight profile and propeller geometry for noise modeling

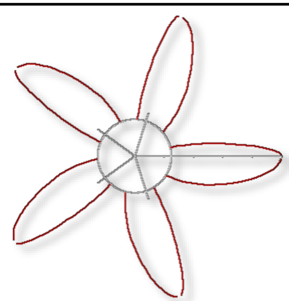
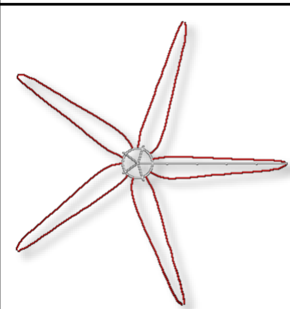
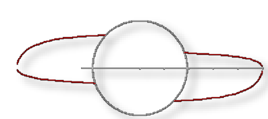
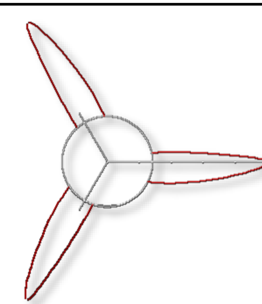
Preliminary Representative Propeller Designs

Design goals: Thrust required met at maximum power segment

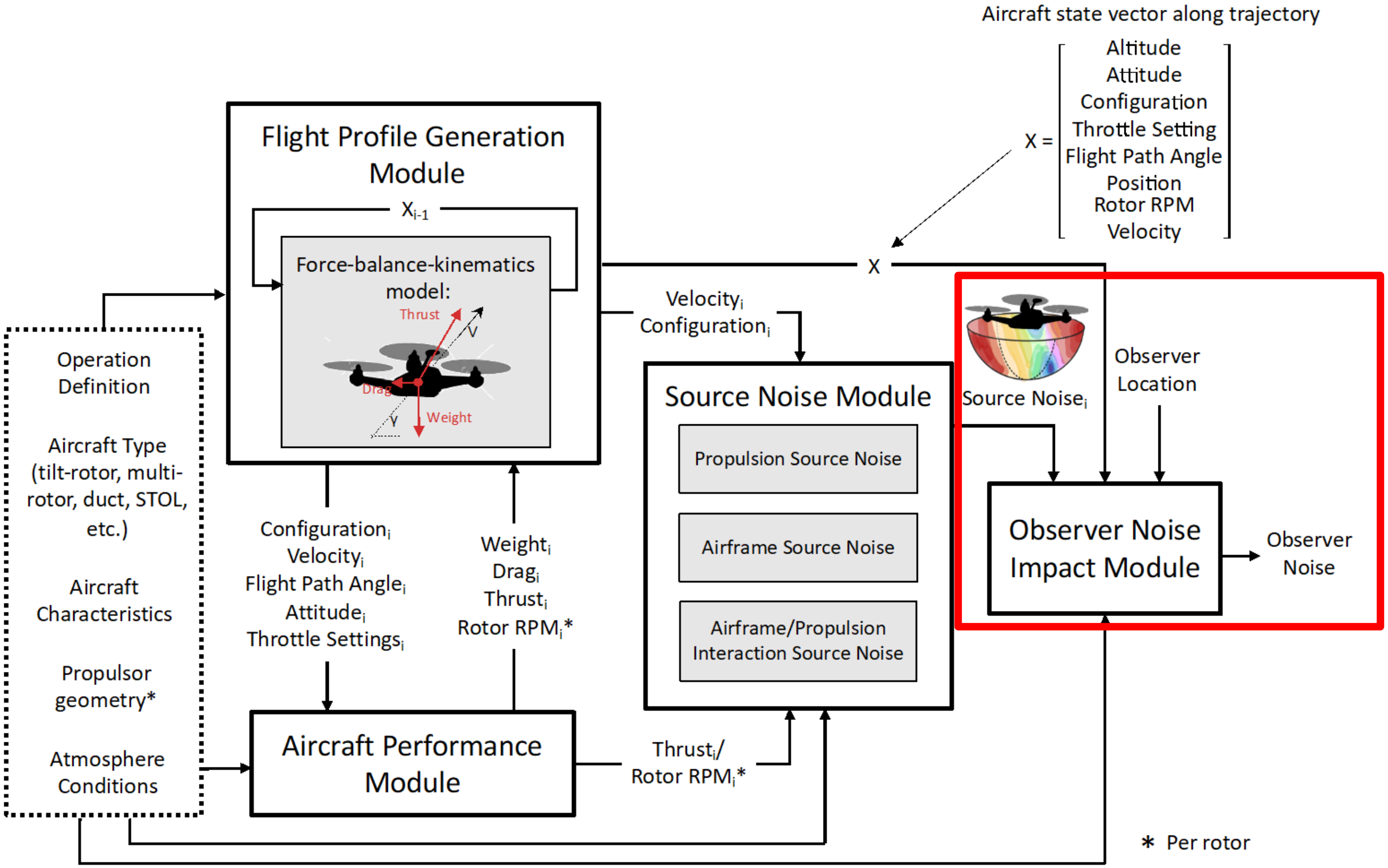
Reasonable performance for takeoff and cruise segments

Reduce M_{tip} for noise reduction

Feasible motor torque

	STOL	**Tilt-Rotor**	**Lift+Cruise (Lifting Rotor)**	**Lift+Cruise (Cruising Rotor)**
Design Condition	Slow End of Climb	Slow Transition	Takeoff	Cruise
Thrust (N)	1020	1555	1350	500
Velocity (m/s)	20	10	20	50
Power (kW)	48	28	55.4	28.2
RPM	3200	800	2900	1600
$\mathbf{M_{tip}}$	0.392	0.312	0.579	0.479
XROTOR Output Image				

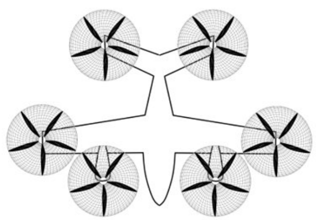
Preliminary AAM Noise Model Framework

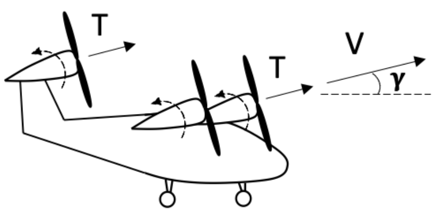


Source noise contours computed over procedure segments, and final noise footprints at observer locations then determined

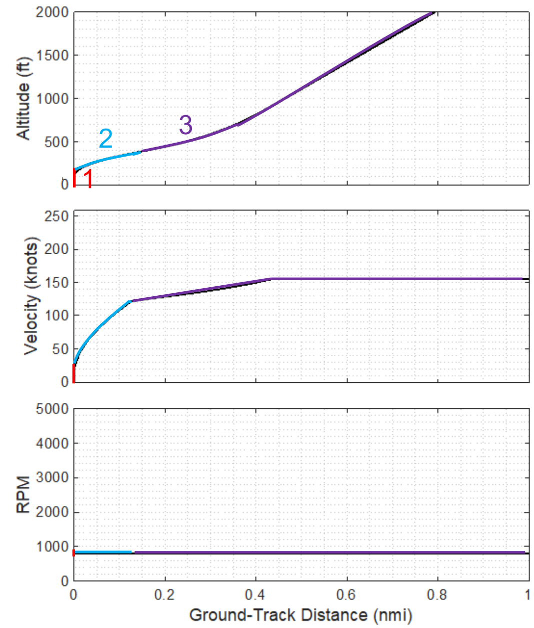
Process of Noise Modeling Along Full Flight Procedure

Rotor and vehicle performance determined



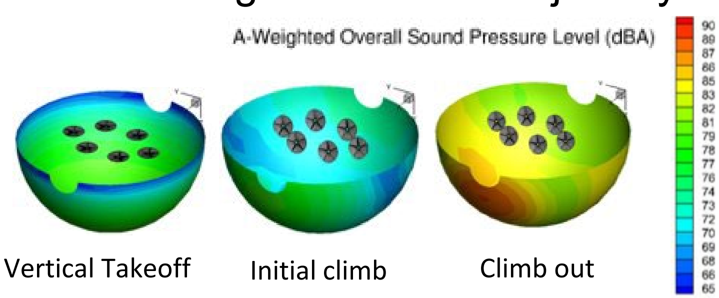


Vehicle flight trajectory modeled and points of transition of vehicle state determined

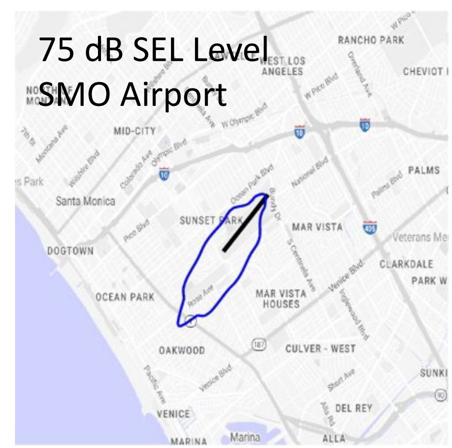


- State 1: Vertical climb
- State 2: Initial Climb
- State 3: Climb out

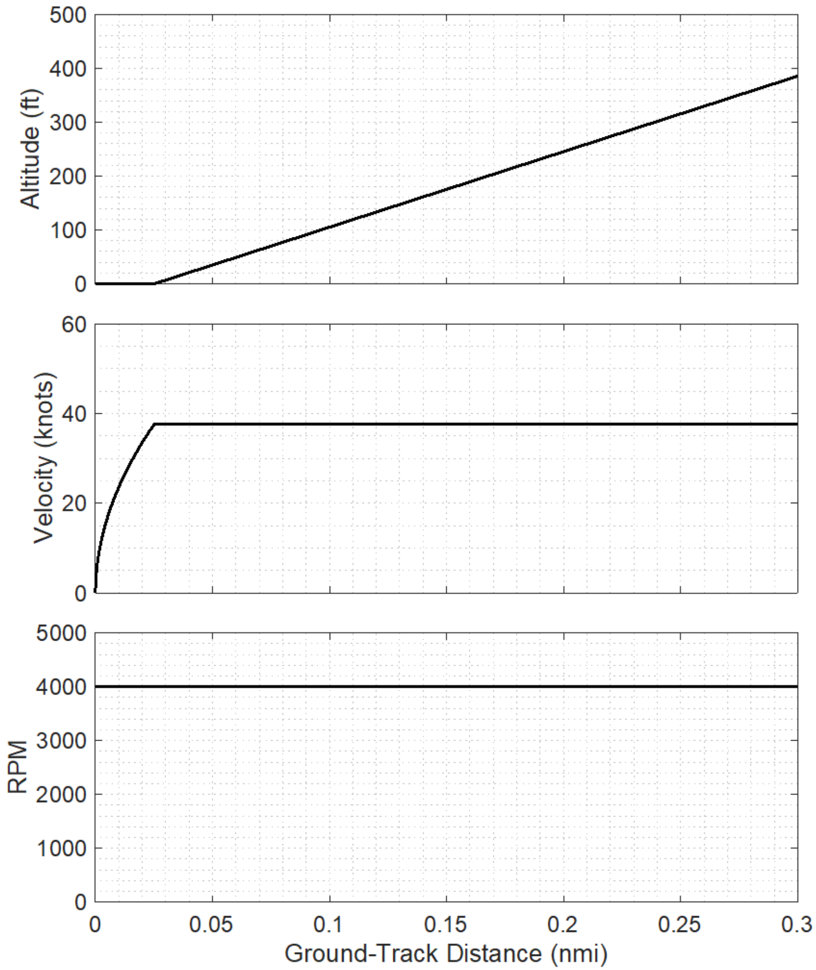
Source noise hemispheres modeled along these segments in the trajectory

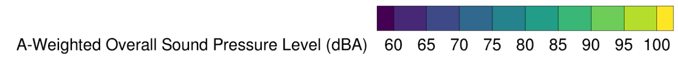


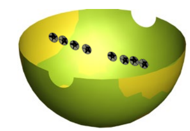
Resulting noise contour modeled from propagated hemispheres along full flight procedure



Example Demonstration of STOL Departures, High RPM Departure

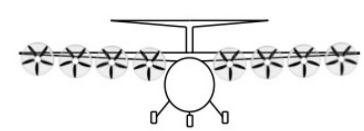




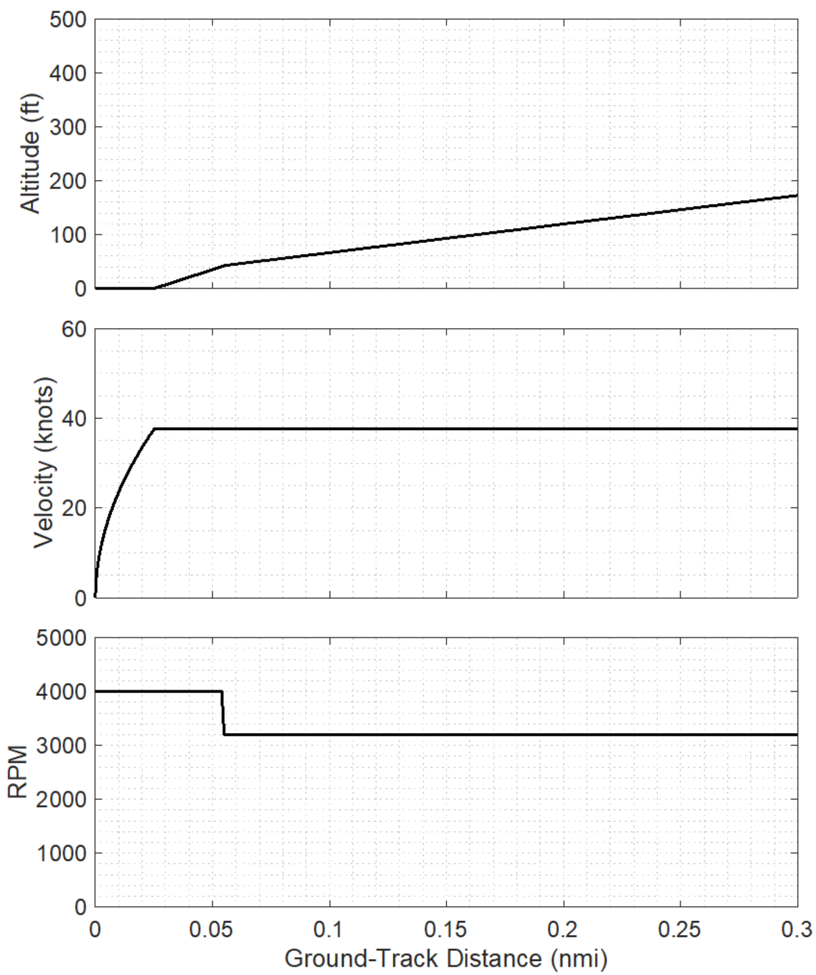


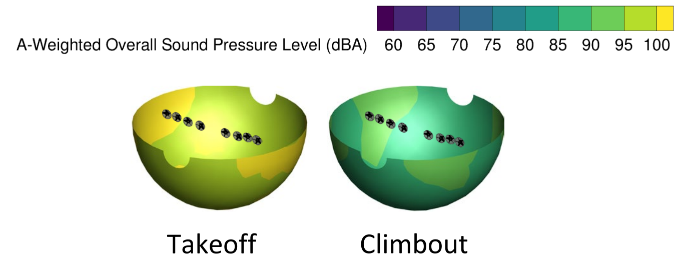
Takeoff

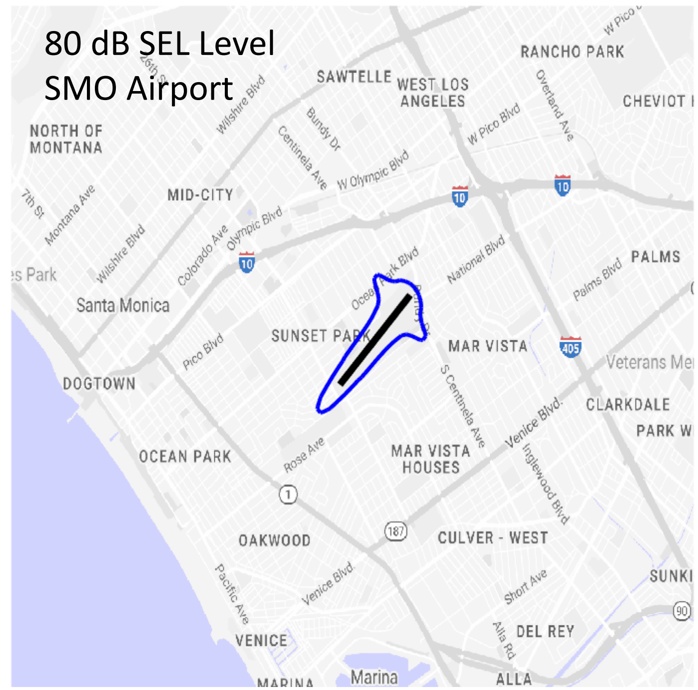
*Note, 8m radius Hemispheres

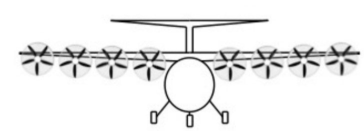


Example Demonstration of STOL Departures, Reduced RPM Departure after Max RPM Takeoff



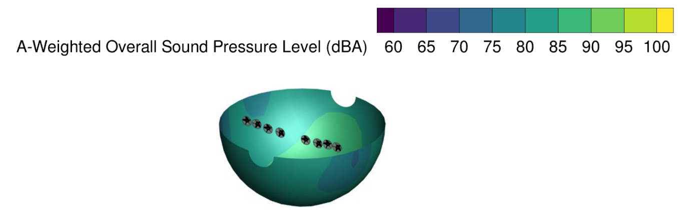




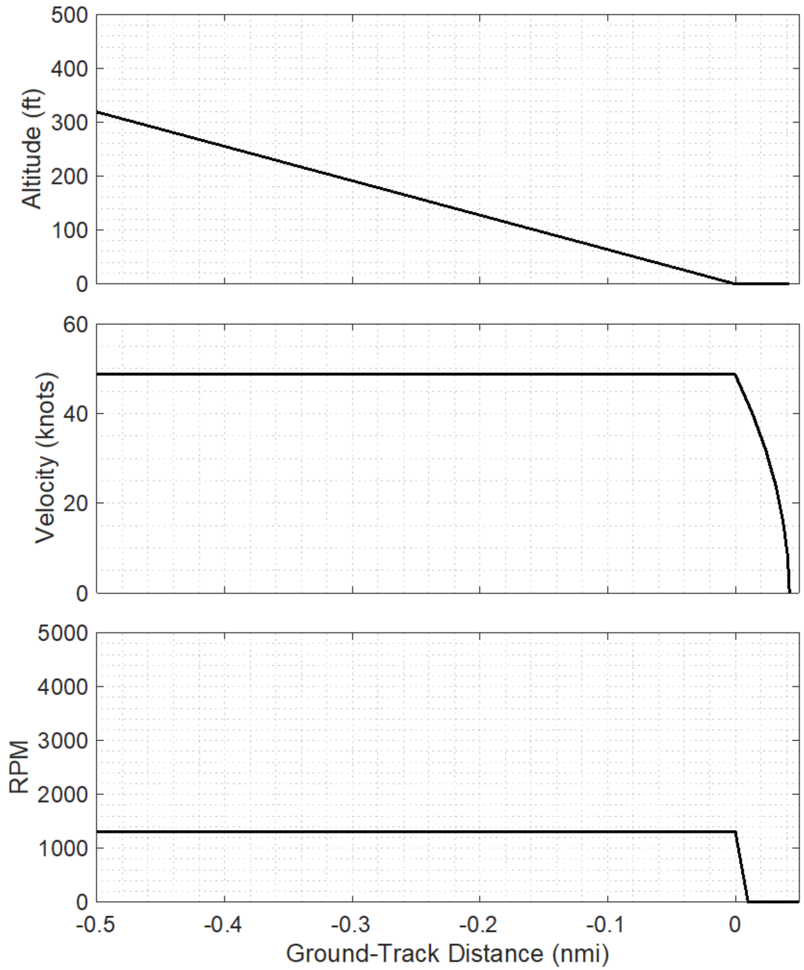


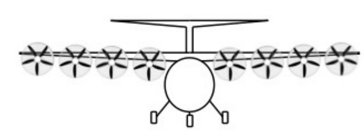
Preliminary

Example Demonstration of STOL Arrivals, Constant 6 degree Descent at 48 knots

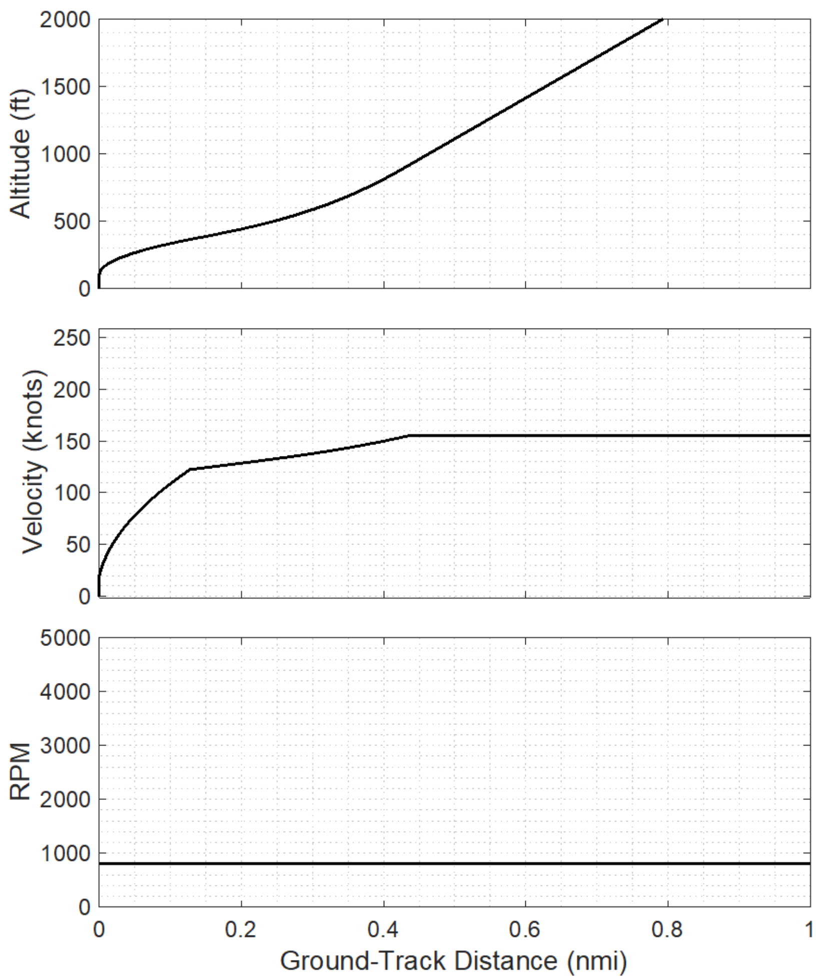


Descent

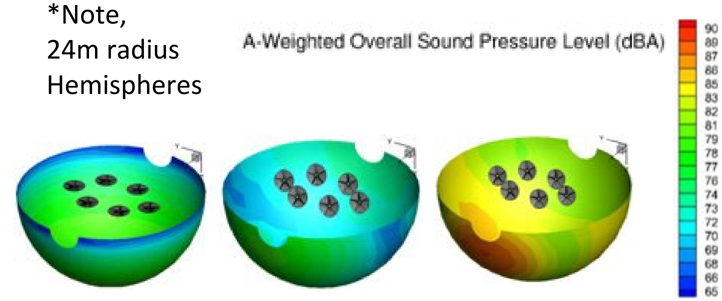




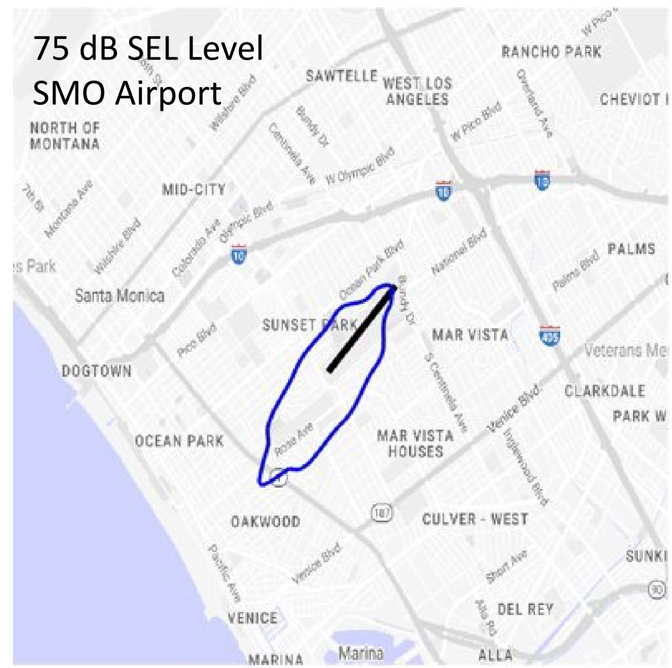
Example Demonstration of Tilt Rotor Departure, 100 ft Vertical Liftoff, Transition and Climb at Max Power

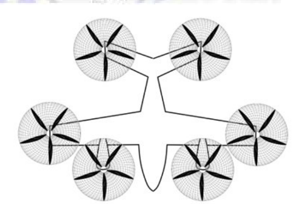


*Note,
24m radius
Hemispheres



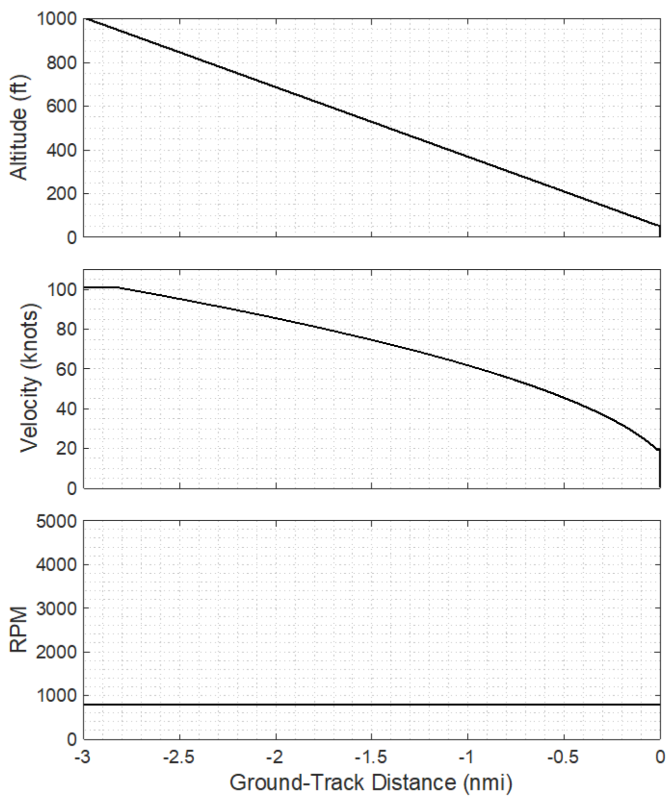
Vertical Takeoff | Initial climb | Climb out

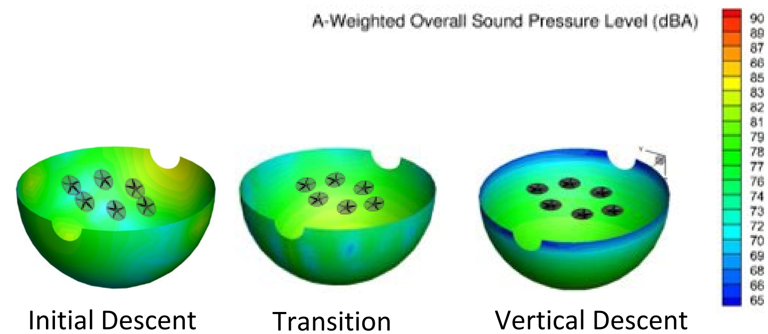


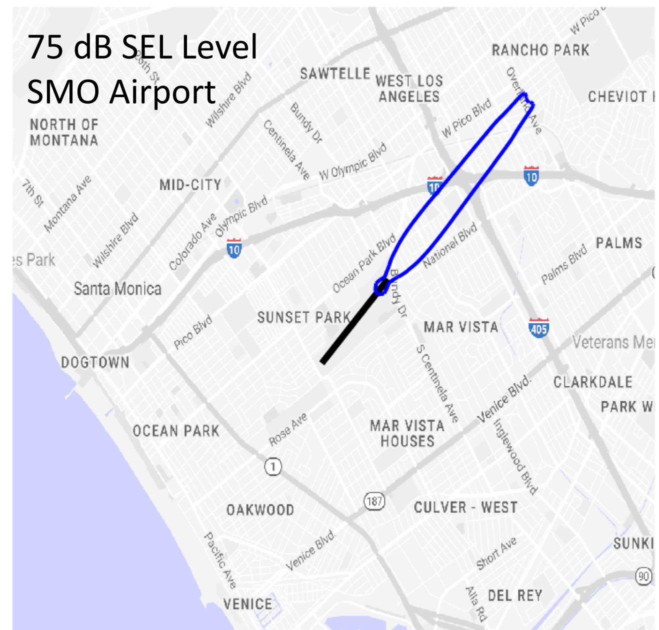


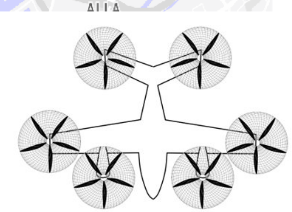
Example Demonstration of a Tilt Rotor Arrival, Transition from Cruise to Vertical Position Rotors

- Constant power during transition, variations in thrust achieved with variable pitch

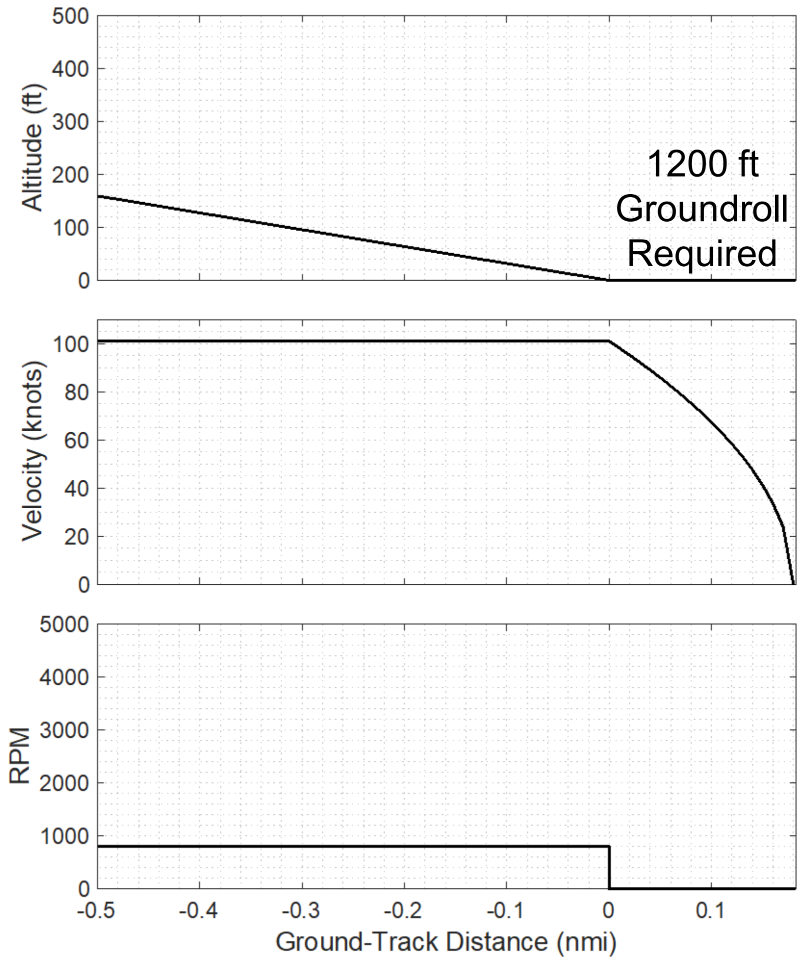


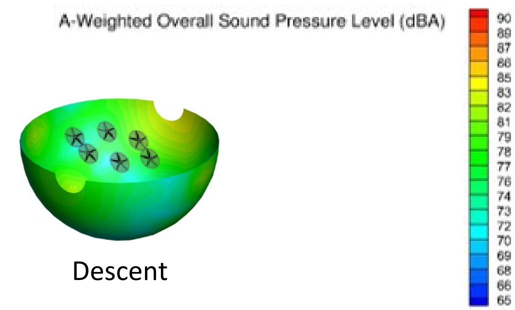


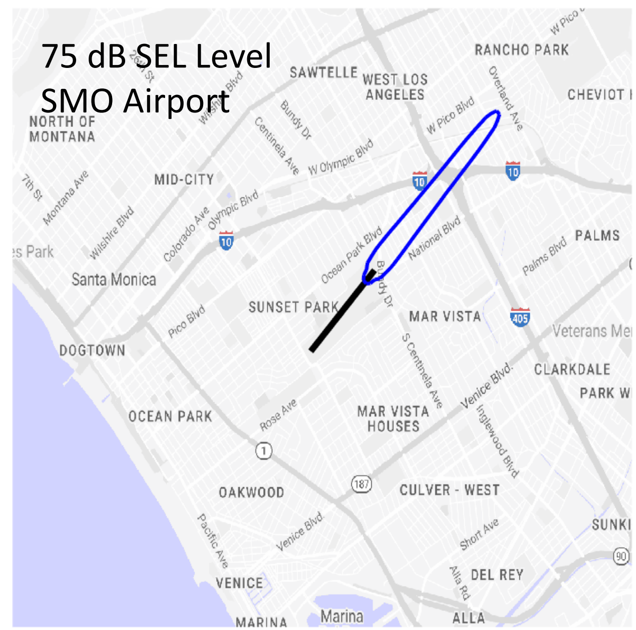


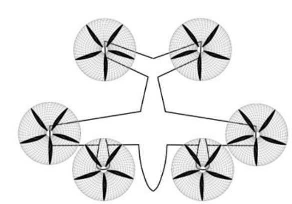


Example Demonstration of a Tilt Rotor Arrival, Conventional descent at 3 degrees to touchdown

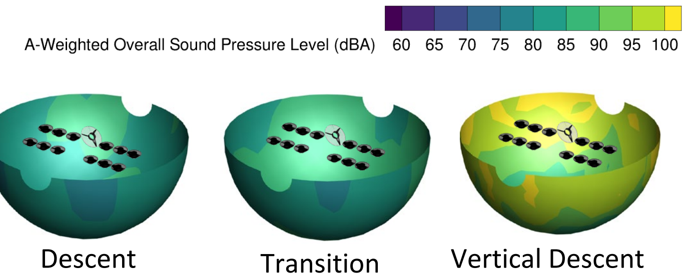


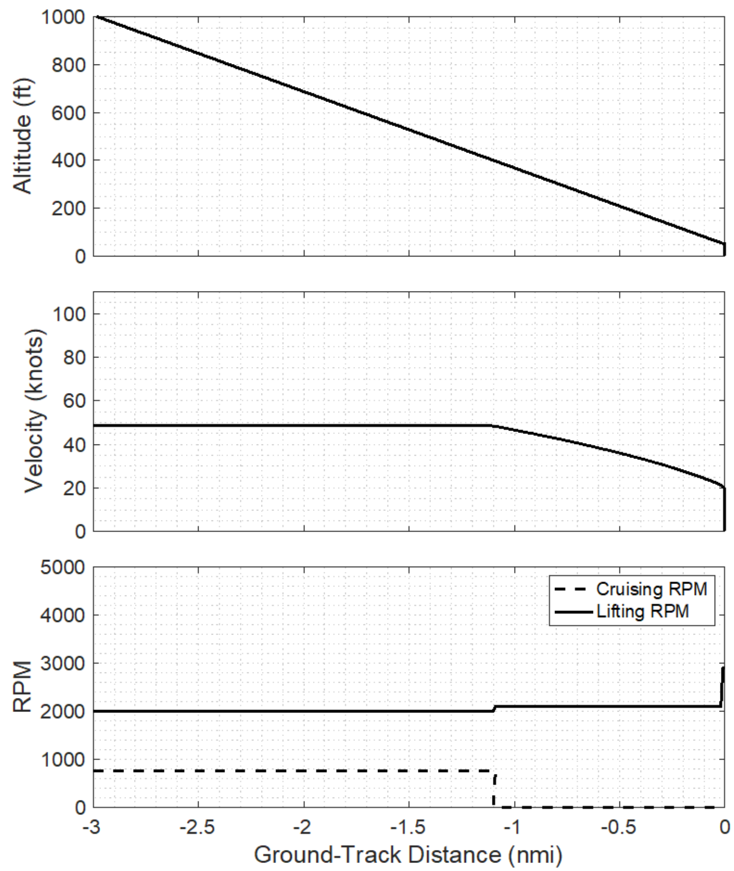


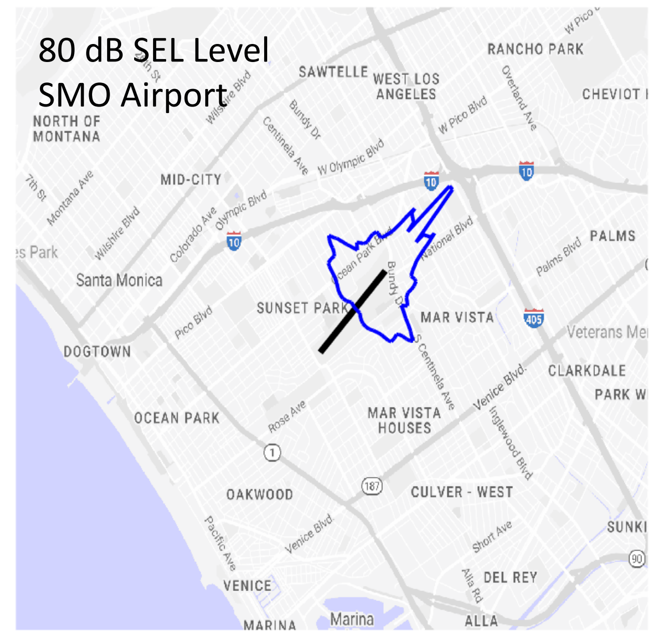


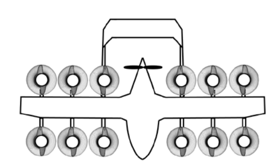


Example Demonstration of Lift+Cruise Arrival, Transition from Cruise to Deceleration with Lifting Rotors, Vertical Final Descent



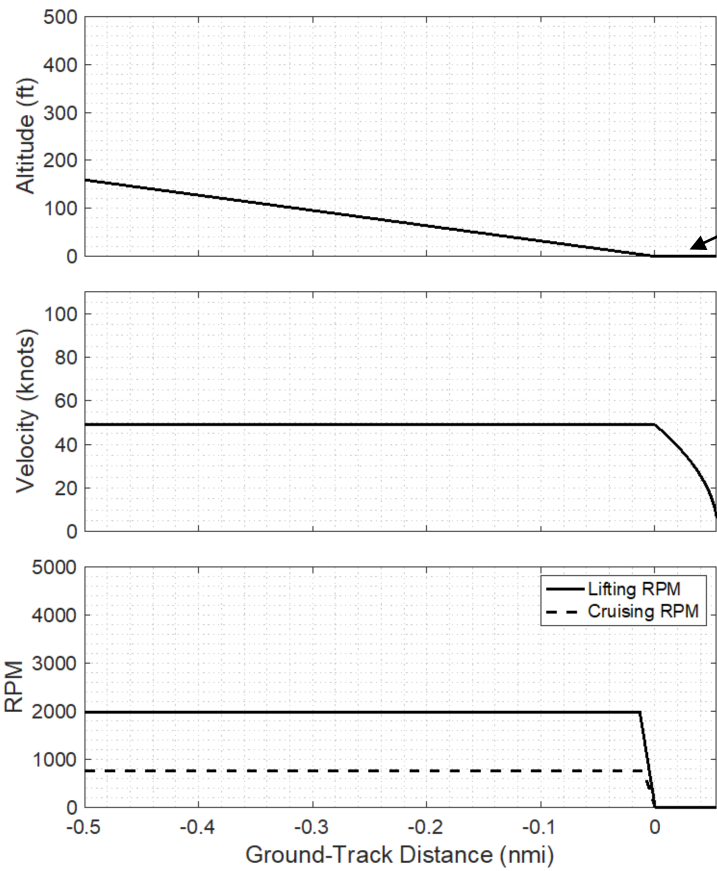




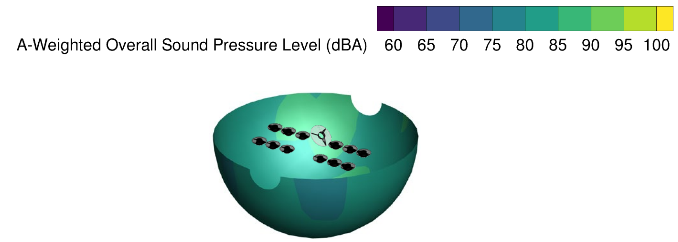


Example Demonstration of Lift+Cruise Arrival, 3 Degree Continuous Descent

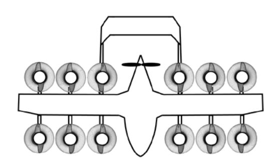
- Conventional descent at 3 degrees to touchdown



300 ft Groundroll Required



Descent



Future steps:

- Evaluate noise impact of different flight procedures
  - AAM noise levels observed to be highly sensitive to propeller geometry design and flight profile operations
- Further refine framework for additional AAM aircraft and noise components
- Explore AEDT integration approaches
- Determine potential industry collaboration opportunities to verify predictions

Source: SMG Consulting

References

[1] Courtin, C., and et al, “A Performance Comparison of eSTOL and eVTOL Aircraft,” AIAA 2021-3220, AIAA Aviation 2021 Forum, 2021.

[2] Pascioni, K., and et al, ”Acoustic Flight Test of the Joby Aviation Advanced Air Mobility Prototype Vehicle,” Aeroacoustics 2022.

[3] Bacchini, Alessandro & Cestino, E.. (2019). Electric VTOL Configurations Comparison. Aerospace. 6. 26. 10.3390/aerospace6030026.