Rapid Fleet-wide Environmental Assessment using a Response Surface Modeling Approach

ASCENT Project 11

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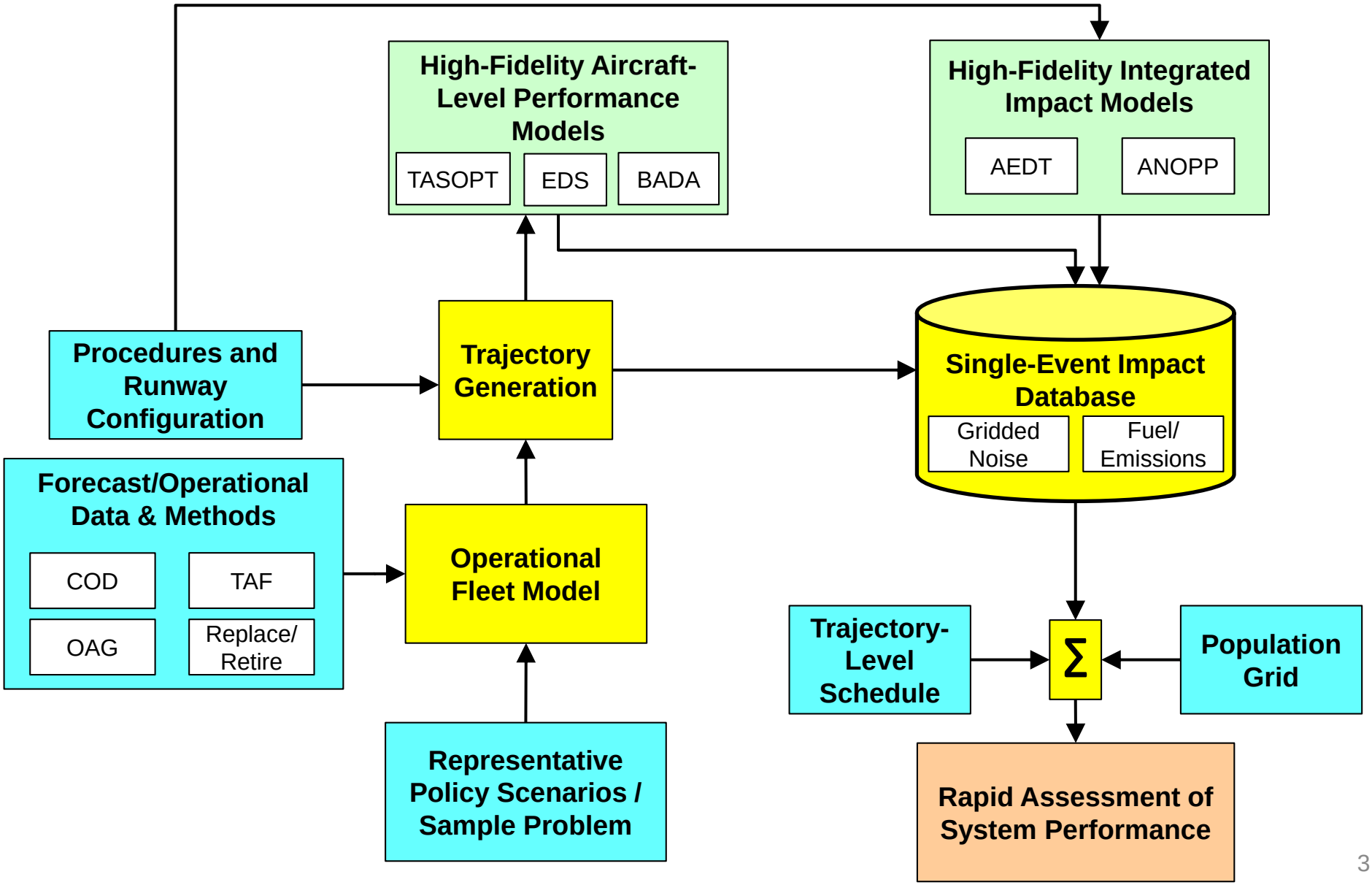
Motivation

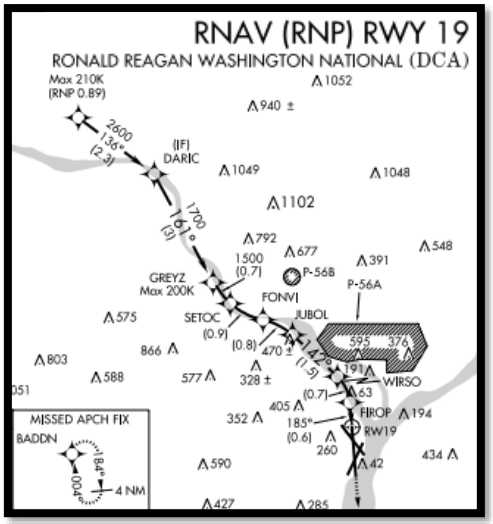
- Need for rapid environmental assessment capability to inform and support FAA for policymaking and operational evaluation
- Current analysis techniques are too slow for broad parametric analyses and do not enable analysis of future aircraft types/technologies
- Need robust and fast model to explore many potential policy scenarios
  - Allows intelligent down-selection for higher fidelity modeling

Model Framework

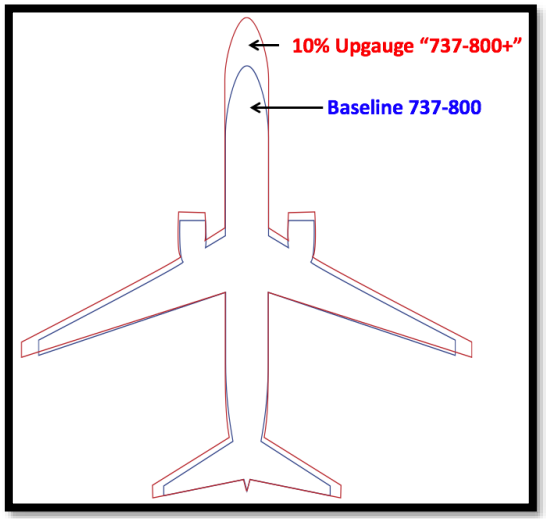


Environmental Analysis Reference Problem: Aircraft Gauge Policy at DCA

- Initial sample problem chosen based on following criteria:
  1. Generate results at airports with non-standard terminal procedures
  2. Demonstrate analysis capability for novel aircraft
- Aircraft gauge policy has potential impacts on:
  - Airport passenger capacity
  - Per-passenger environmental impact
- Rapid environmental analysis tool will be used to evaluate gauge-change scenarios
  - Noise
  - Fuel Burn
  - Emissions (e.g. CO_2, NO_X)
- DCA chosen as particularly challenging case due to nonstandard procedures
- Airport-level analysis, system-level impacts may be examined in follow-on



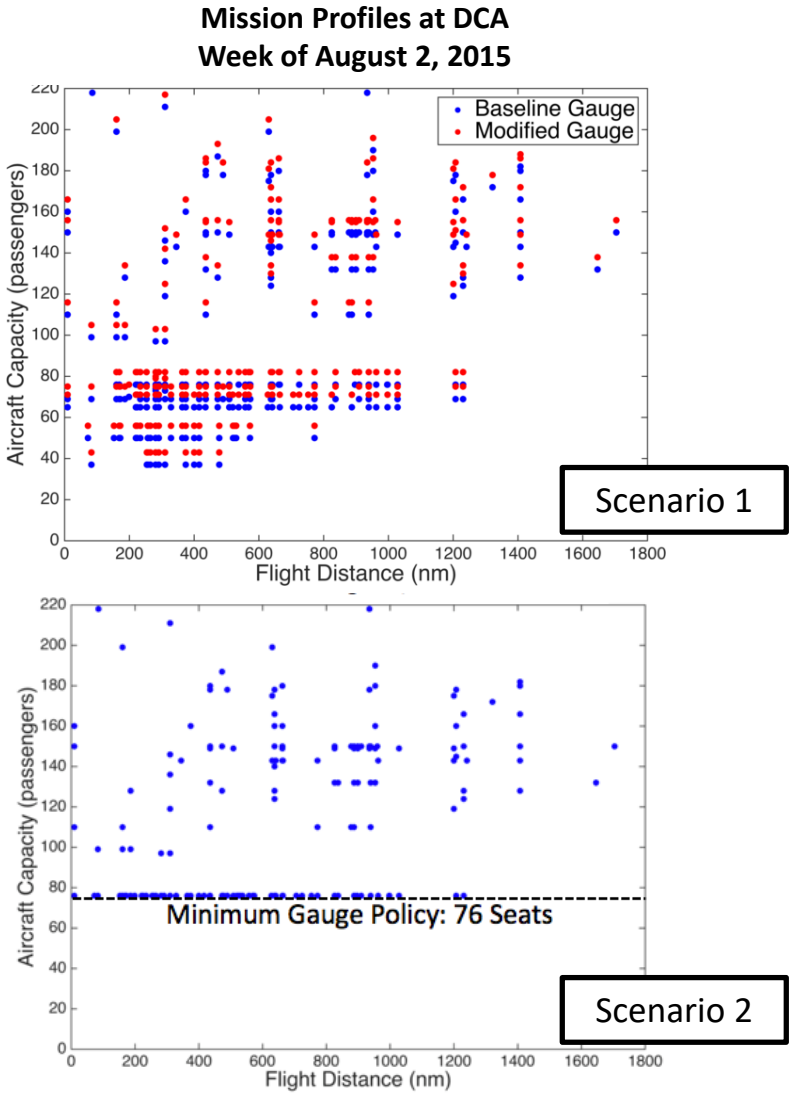
Complex, non-standard procedures at DCA



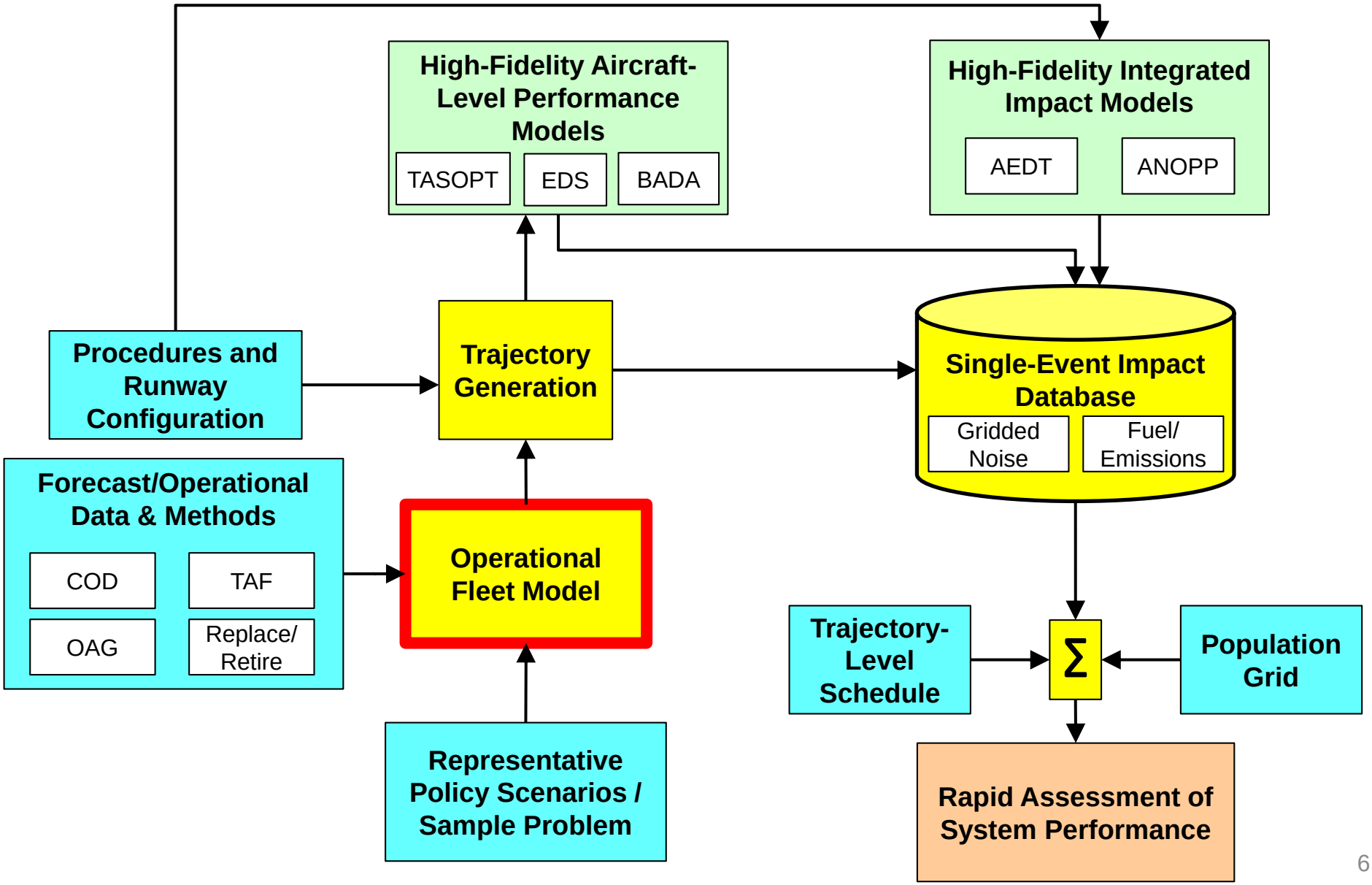
Demonstrates novel aircraft evaluation capability

Aircraft Gauge Policy Scenarios

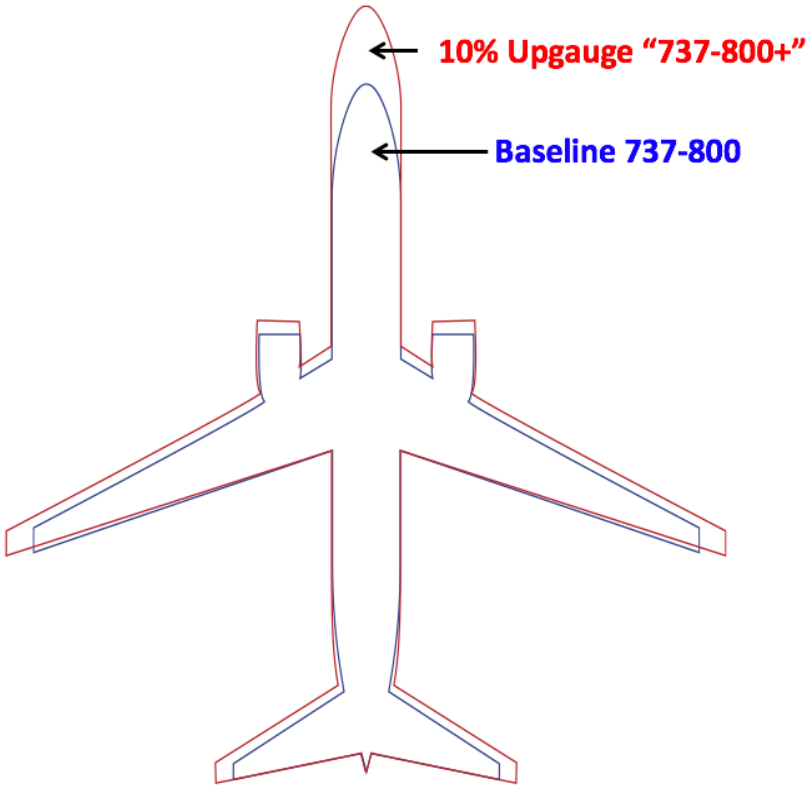
- Scenario 1: Fleet-wide Upgauge
  - Simple upgauge (by payload percentage) across all representative trajectories
  - Includes modeling of new representative upgauged aircraft types
- Scenario 2: Minimum-gauge policy
  - Substituting small aircraft with larger currently-available aircraft
  - Representative of policy to reduce regional jet use
- Scenario 3: Replace older aircraft types (e.g. MD-80)



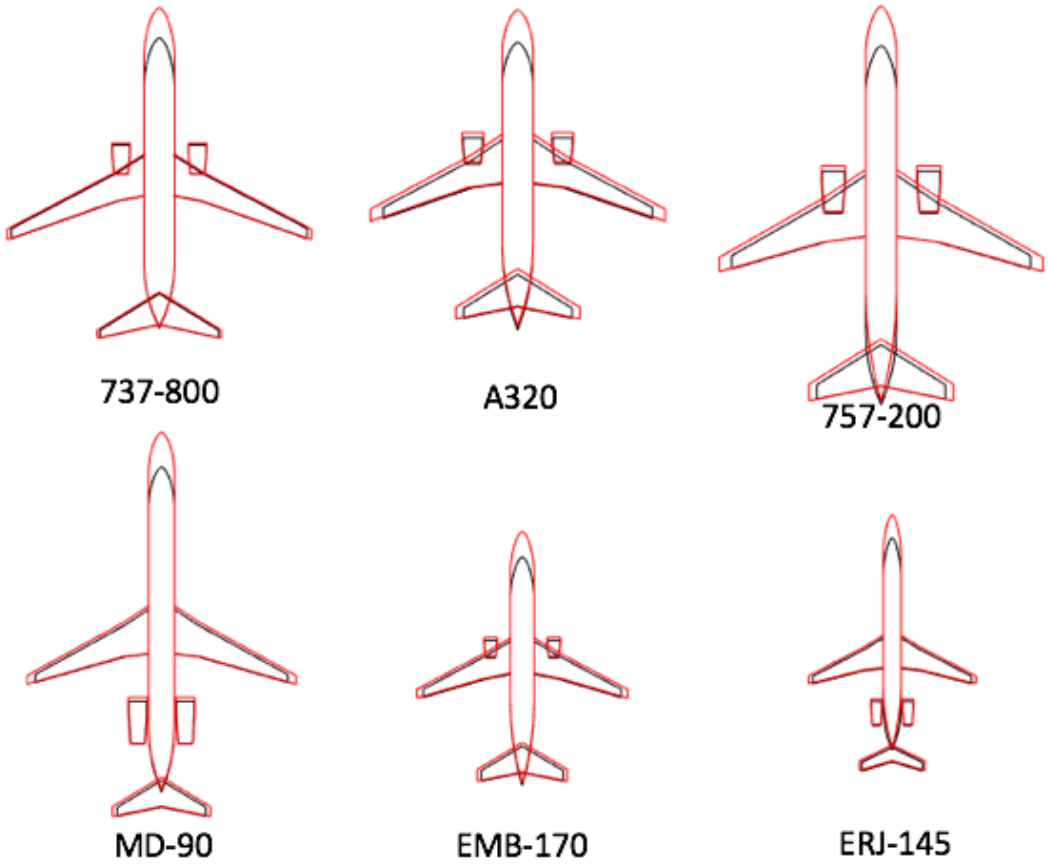
Model Framework



Fleet Modeled in TASOPT/ANOPP

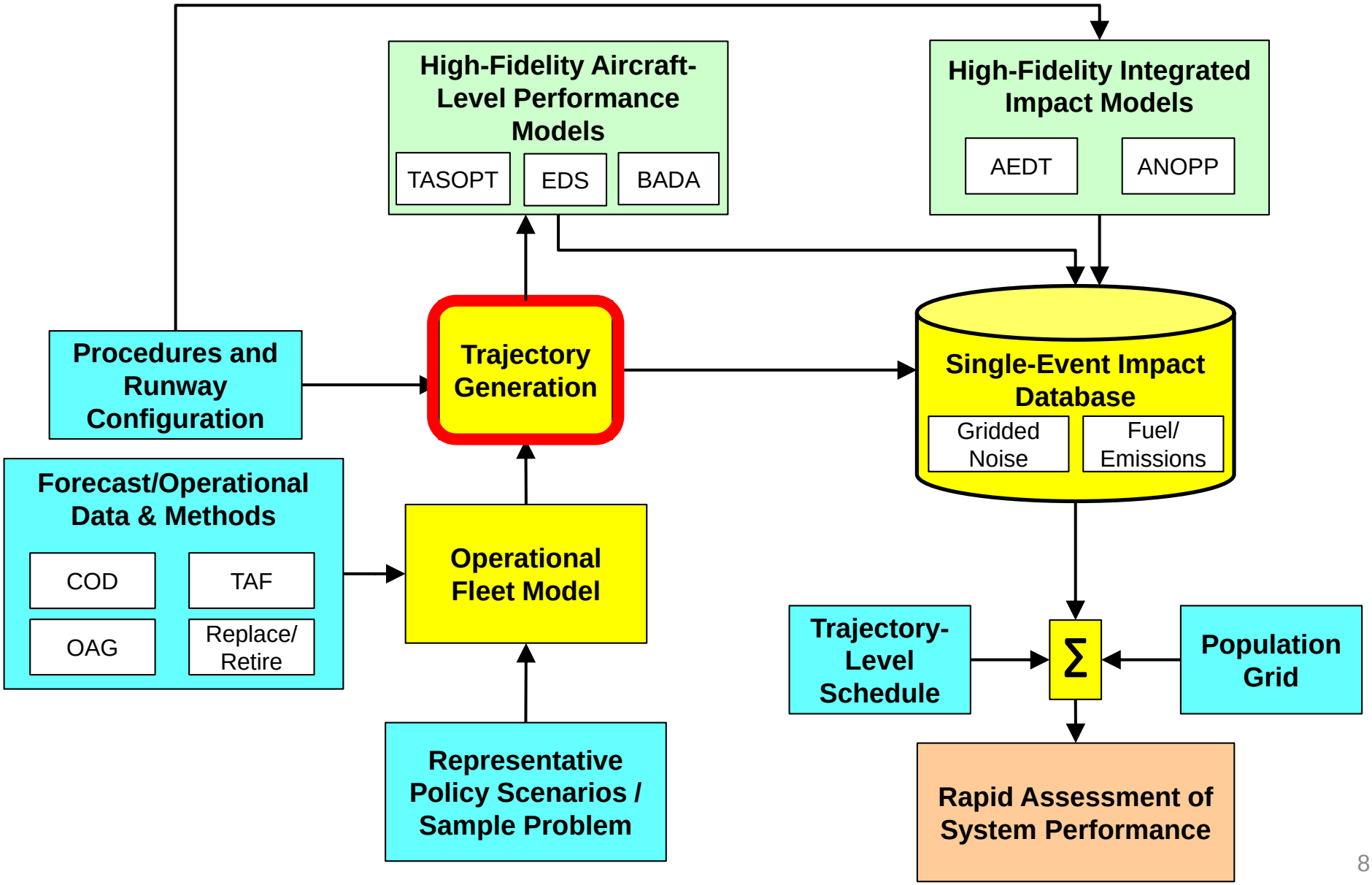


Example 737-800 10% Upgauge using TASOPT



Representative Fleet for DCA Sample Problem: Baseline and Upgauged

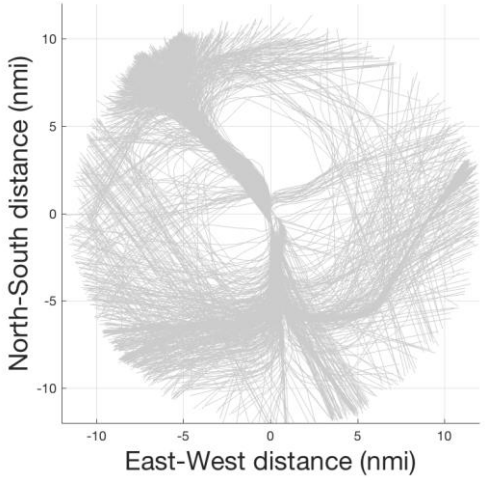
Model Framework



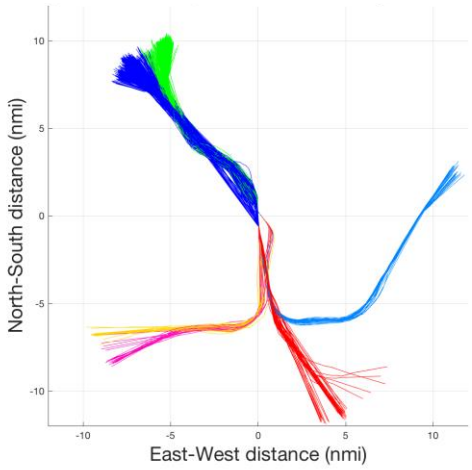
Defining Representative Trajectories

- Representative trajectories drastically reduce computation time but keep location-specific information
- Identify representative trajectories from RNAV routes
  - Filter ASDE-X historical radar track data data to find flights flying RNAV routes
  - Select flight closest to median
- Does not account for dispersion of flights
  - Noise impacts of flight track dispersion are currently under investigation

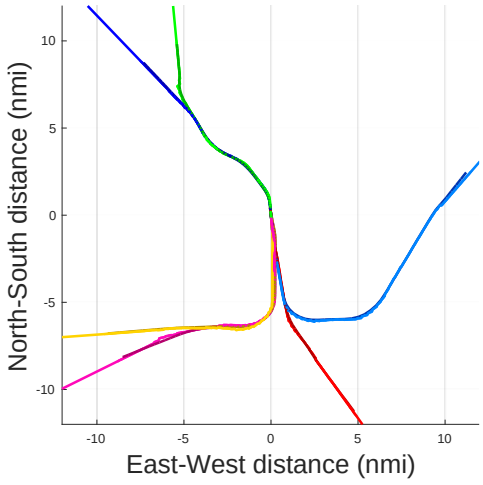
DCA Departures
(20 Days from 2015 and 2016)



RNAV Flights



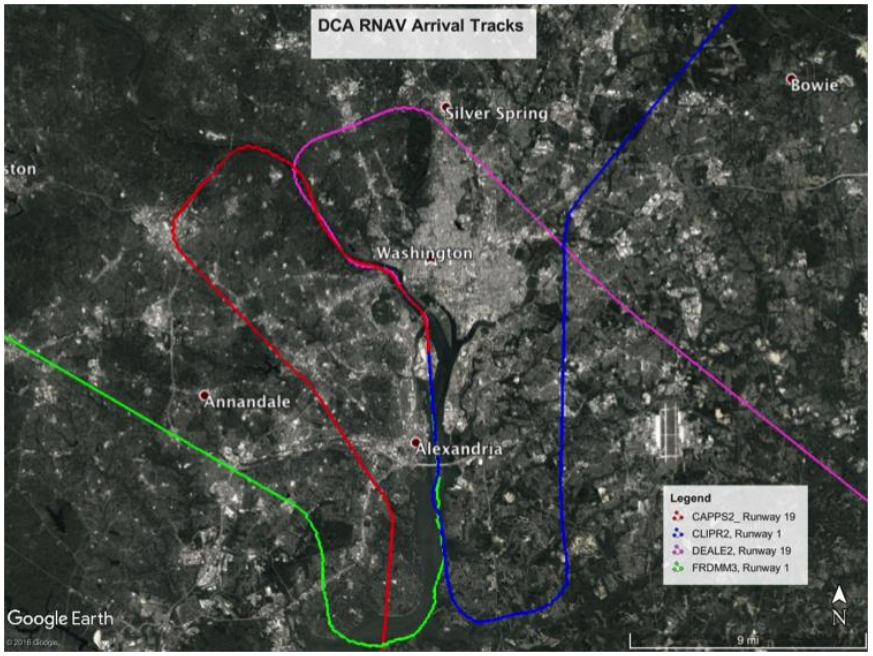
Representative Trajectories



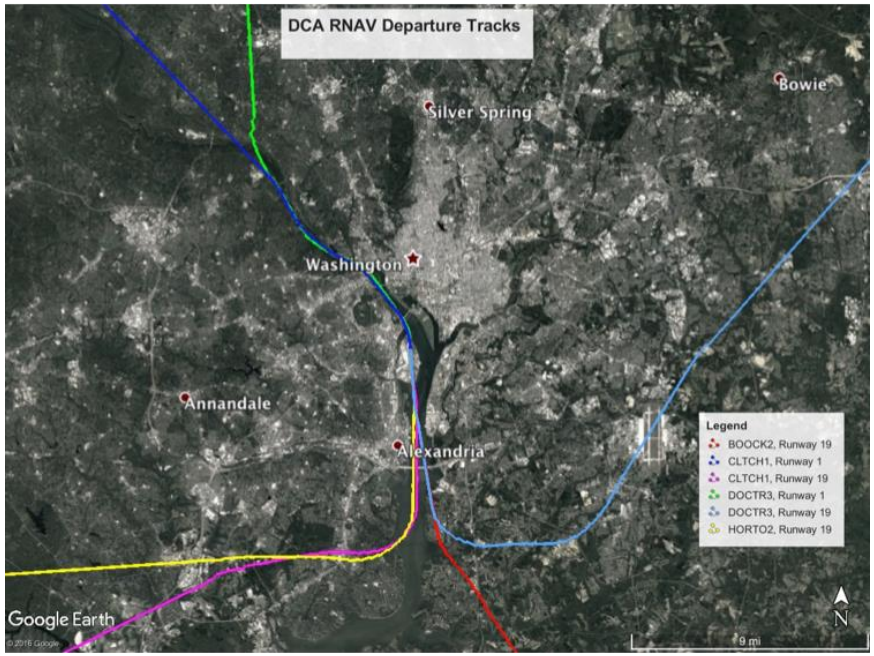
Representative Lateral Flight Tracks for DCA

Lateral trajectories derived from ASDE-X radar data and applied to all aircraft types:

4 Arrival Tracks



6 Departure Tracks

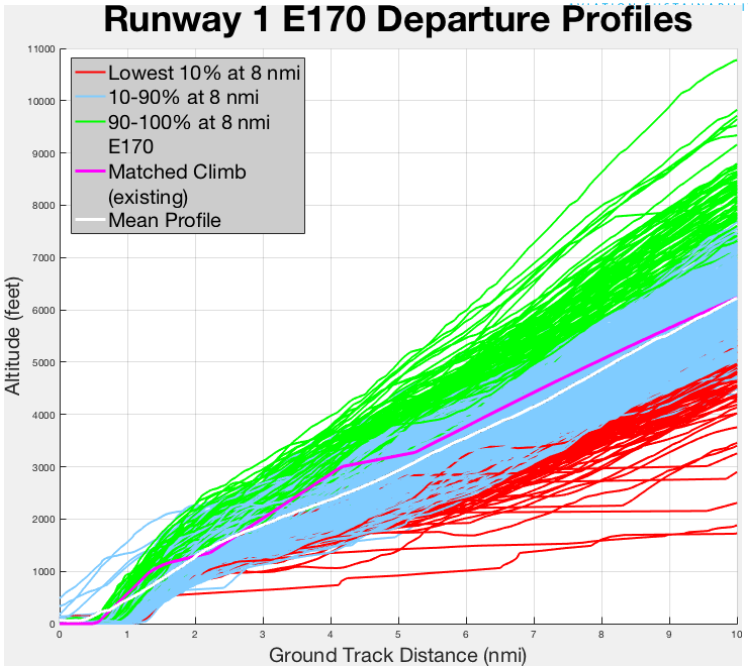


Vertical Profile Definition: Departure

Vertical profiles calculated based on radar data for each aircraft type

Departures:

- ICAO standard departure with thrust set to match median climb profile
  - Takeoff thrust and climb thrust set to match median radar-based initial climb rate
- Weight assumed to be 90% of MTOW
- Same percentage thrust and weight for upgauged aircraft



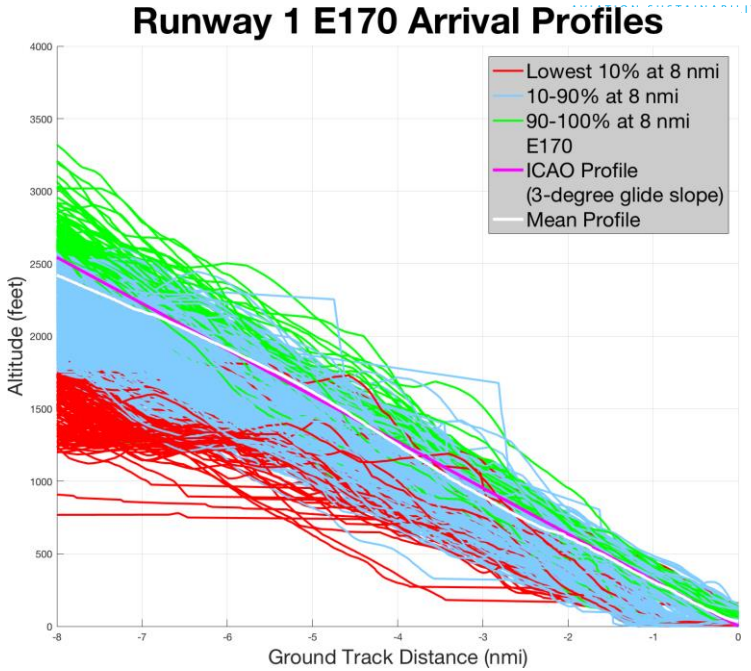
Attribute	Data Source
Drag	BADA 4
MTOW	TASOPT or BADA 4
Takeoff roll	ASDE-X data matching
Max thrust	Published data
V_2	TASOPT

Vertical Profile Definition: Arrival

Vertical profiles calculated based on radar data for each aircraft type

Arrivals:

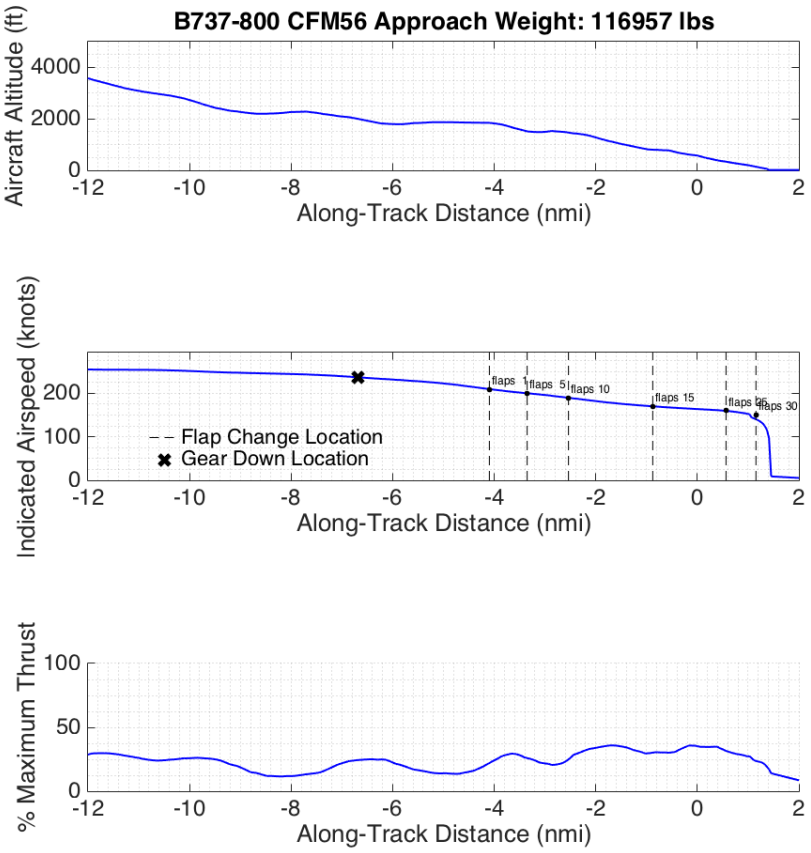
- Assume continuous 3-degree glide slope
  - Closely matches mean arrival profile
- Weight assumed to be 75% of MTOW
  - Consistent with most AEDT procedures
- Same percentage weight for upgauged aircraft



Attribute	Data Source
Drag	BADA 4
MTOW	TASOPT or BADA 4
Landing roll	ASDE-X data matching
Max thrust	Published data
$V_{approach}$	TASOPT

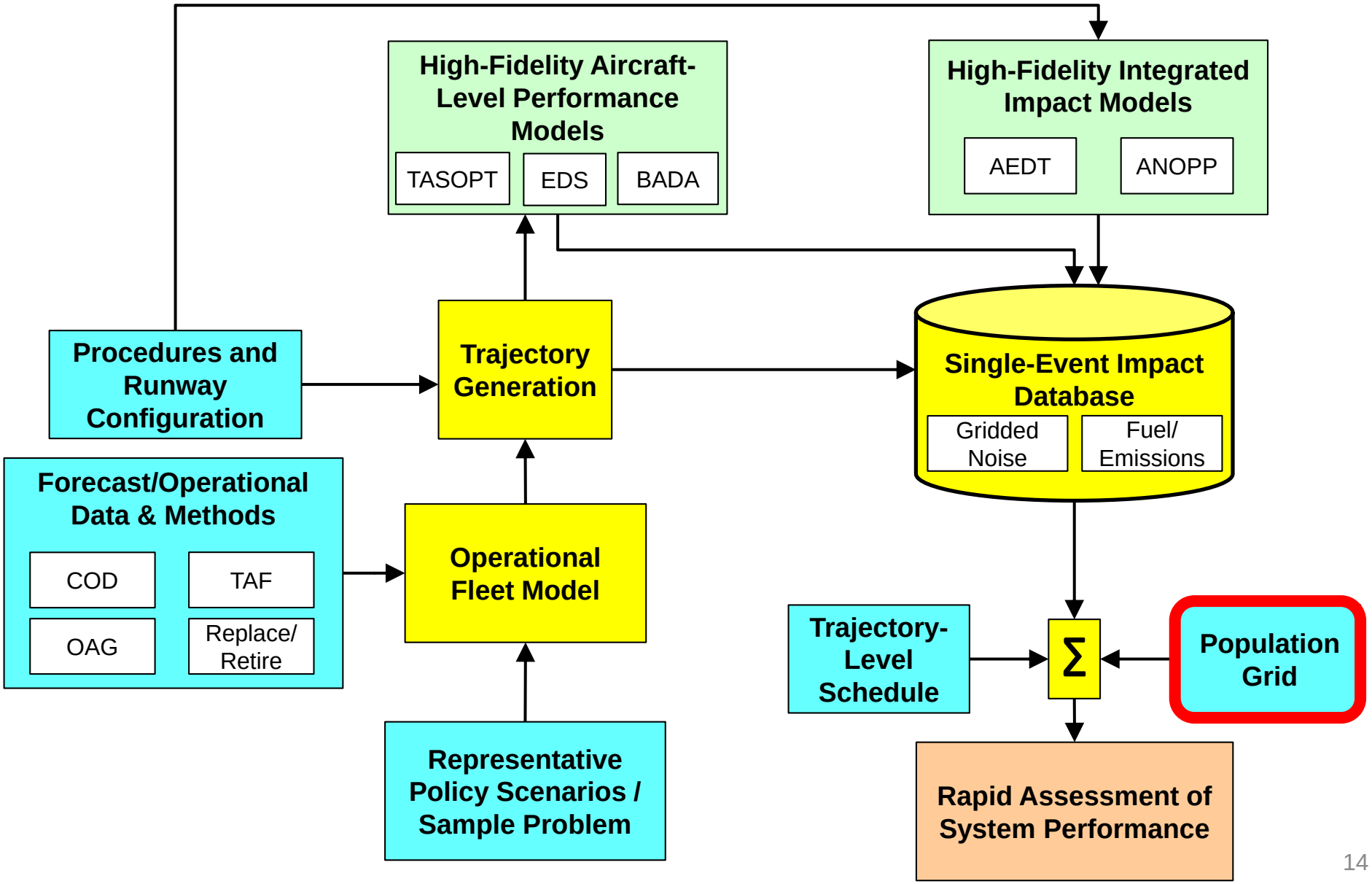
Thrust and Configuration Calculation

- Thrust and aircraft configuration required for noise and emissions analysis
- Radar records provide groundspeed only
  - Flap extension speeds obtained from BADA 4 performance files
  - Thrust calculated using kinematic approach and drag data from BADA or TASOPT
- Tool can also be used to design new trajectories and calculate thrust/performance



Example Trajectory
737-800, DCA Runway 1 RNAV Approach

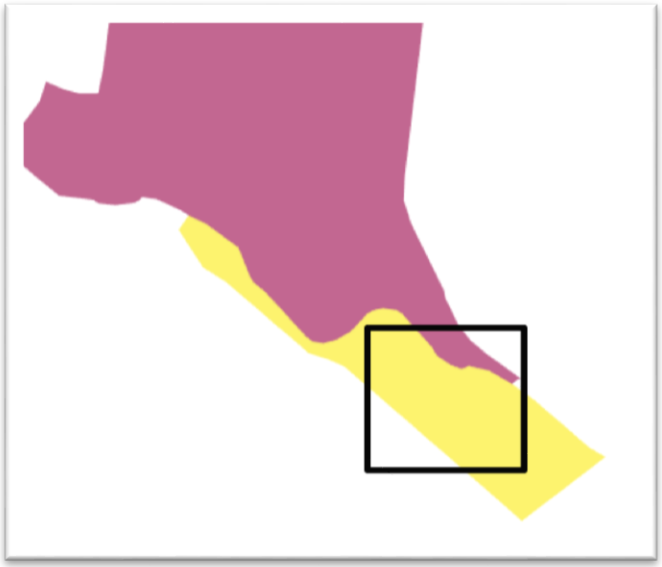
Model Framework



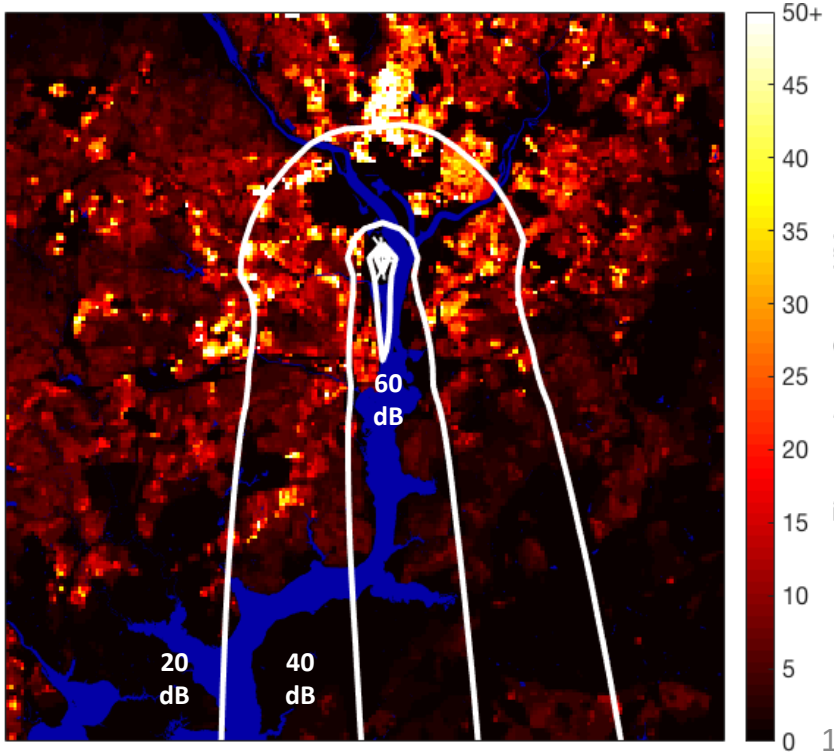
Population Impact Calculation

- Single-event noise results (SEL and L_{MAX}) calculated on a consistent grid at same resolution as population densities (2010 US Census)
- Database of single-event grids can be rotated and combined to quickly form integrated noise contours (DNL and N_{ABOVE})

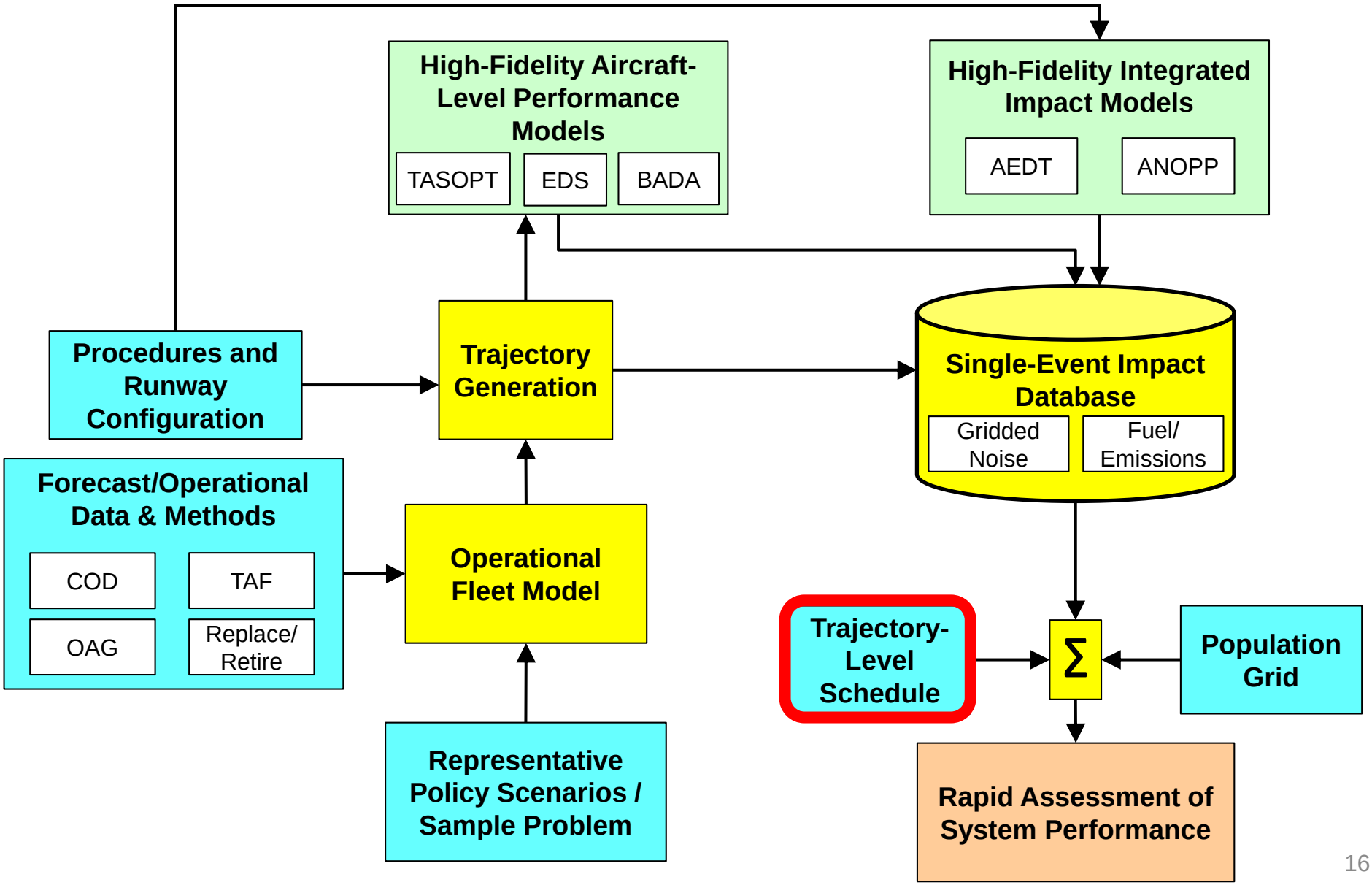
Census data re-gridded from irregular block form to regular 0.1nm square cells



Re-Gridded Population Density Map with SEL Contours



Model Framework



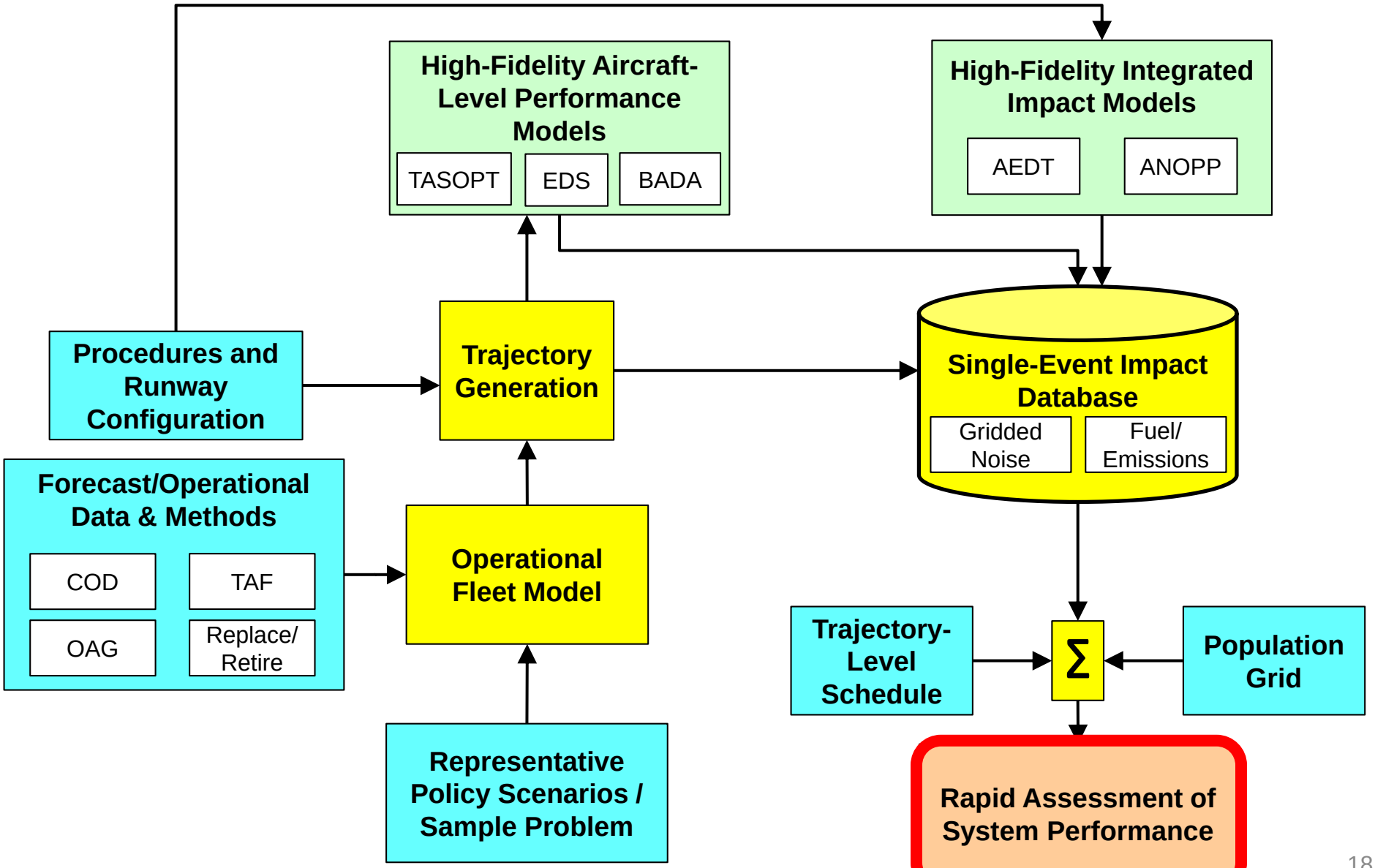
2015 Schedule and Fleet for DCA

- Aircraft types assigned to representative model families for analysis
  - Reduces number of required single-flight runs
- Schedule source: ASPM single-flight records
  - Jan 1, 2015 to Dec 31, 2015
- Flights distributed evenly across arrival and departure routes with type-specific vertical profiles

2015 DCA Average Daily Schedule and Fleet

Type Code	Annual Arrivals	Representative Type	Average Daily Arrivals
E170	28732	**E170**	**132.4**
E190	13399		
CRJ7	3734		
CRJ9	2455		
E135	222	**E145**	**94.8**
E145	2189		
E45X	1223		
CRJ2	28835		
DH8A	869		
DH8D	586		
GA T-Prop	370		
GA Turbine	290		
A319	16658	**A320**	**65.9**
A320	6419		
A321	985		
B733	193	**B738**	**83.6**
B737	15512		
B738	14684		
B739	117		
B752	814	**B752**	**2.2**
B712	378	**MD88**	**16.6**
MD82	22		
MD83	11		
MD88	2546		
MD90	3095		
Heli+Light GA	Omitted	Omitted	-
Total			**395.4**

Model Framework



Scenario 1: Fleet-wide Upgauge

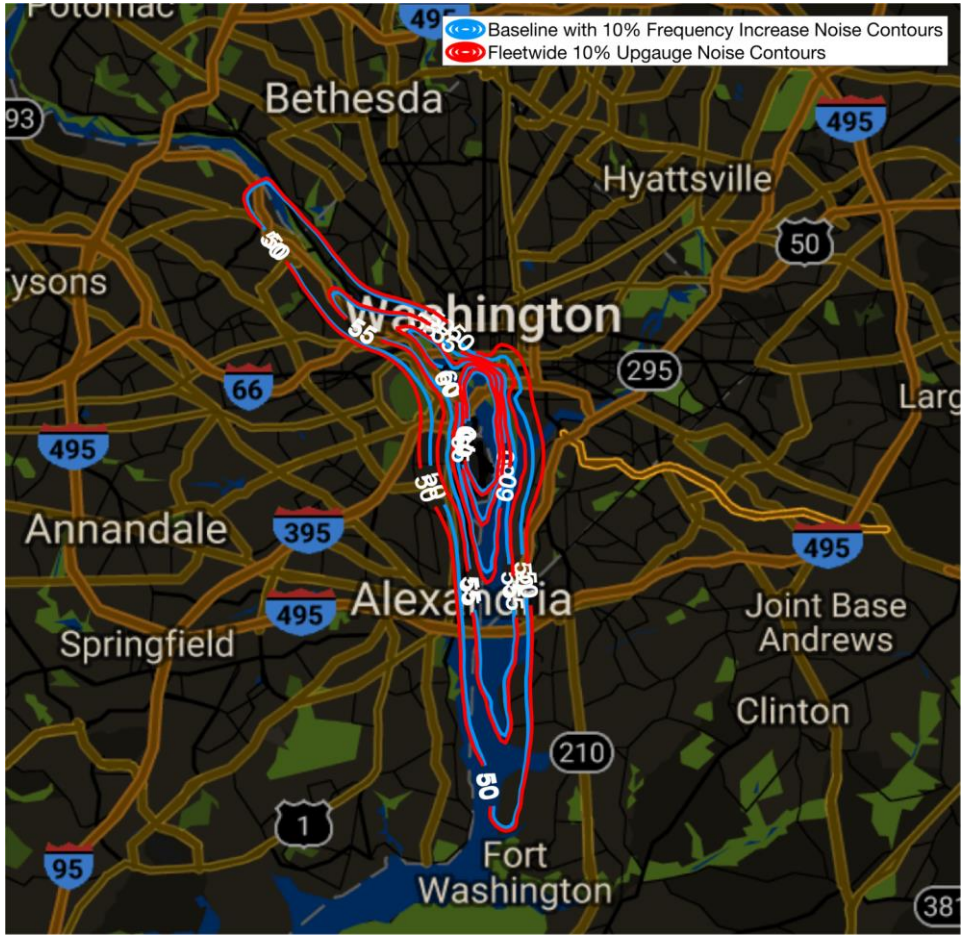
Metric	DNL
Noise Model	AEDT
Notes	Baseline Fleet with 10% Frequency Increase vs. 10% Aircraft Payload and Size Upgauge

10% Frequency Increase Schedule

Type	Daily Count*
E145	104.5
E170	145.2
A320	72.6
B738	92.4
MD88	18.7
B752	2.2

10% Gauge Increase Schedule

Type	Daily Count
E145+	95
E170+	132
A320+	66
B738+	84
MD88+	17
B752+	2



*Counts represent an average annual day, resulting in fractional operations

Scenario 2: Minimum Gauge Policy DNL

E145 flights shifted to E170 flights

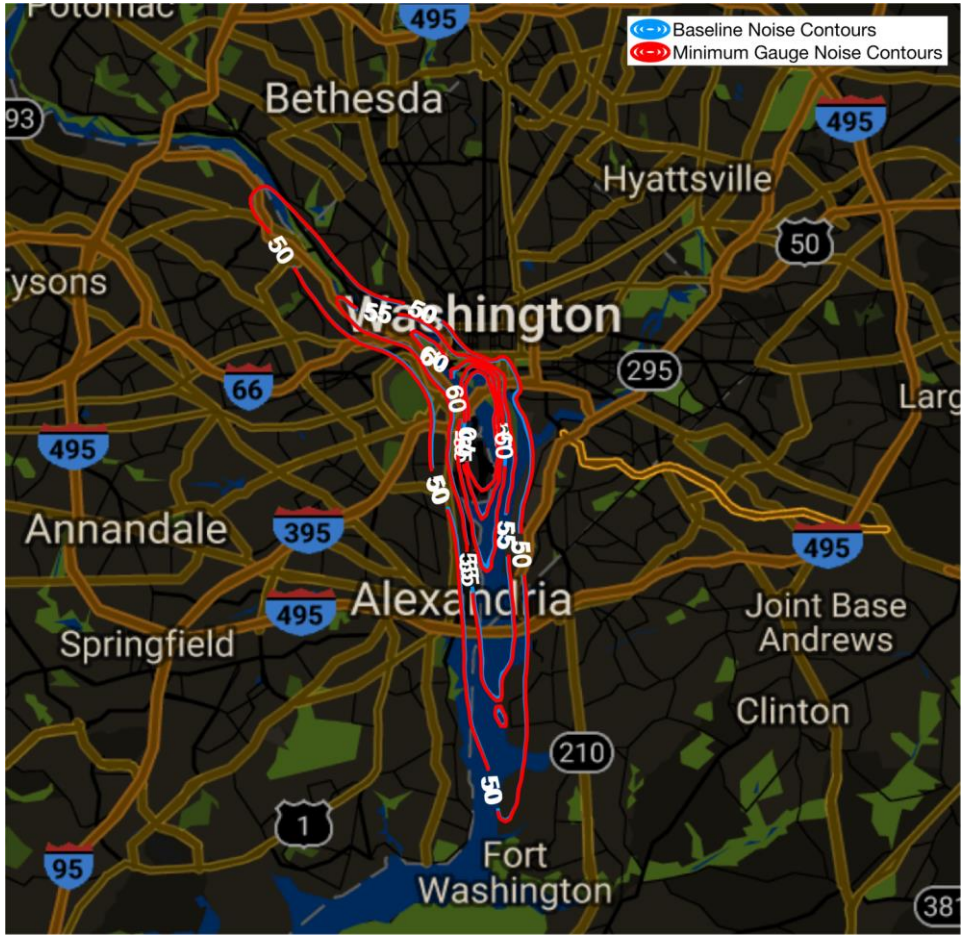
Metric	DNL
Noise Model	AEDT
Notes	Baseline Fleet vs. Minimum Gauge Policy Passenger capacity larger for non-baseline

Baseline 2015 Schedule

Type	Daily Count
E145	95
E170	132
A320	66
B738	84
MD88	17
B752	2

RJ Upgauge Schedule

Type	Daily Count
E145	**0**
E170	**227**
A320	66
B738	84
MD88	17
B752	2

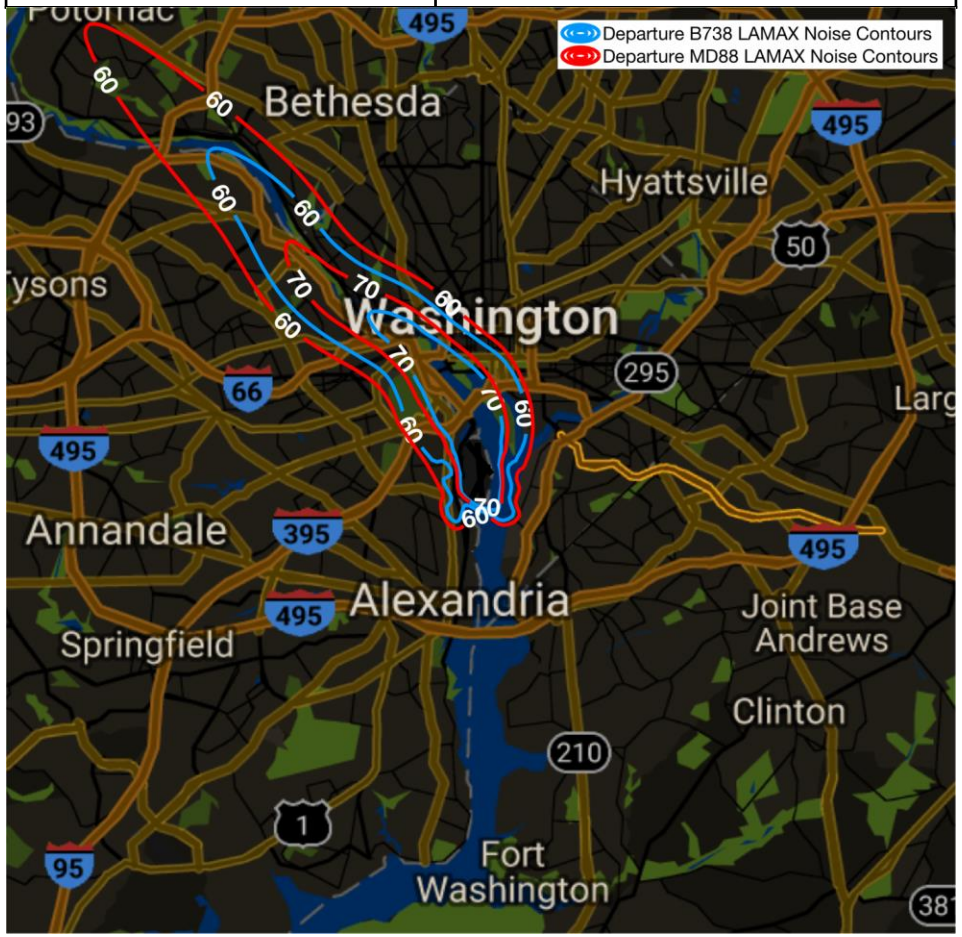


Example Single-Flight Departure: MD-80 vs. B738 L_{AMAX} Contours

Motivation for Scenario 3 (replacing older aircraft types):

- On single-flight basis, MD-80 significantly louder than B738

Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	MD-80 vs. B738



Scenario 3: Replace Older Aircraft Types DNL

MD80 flights shifted to B738 flights

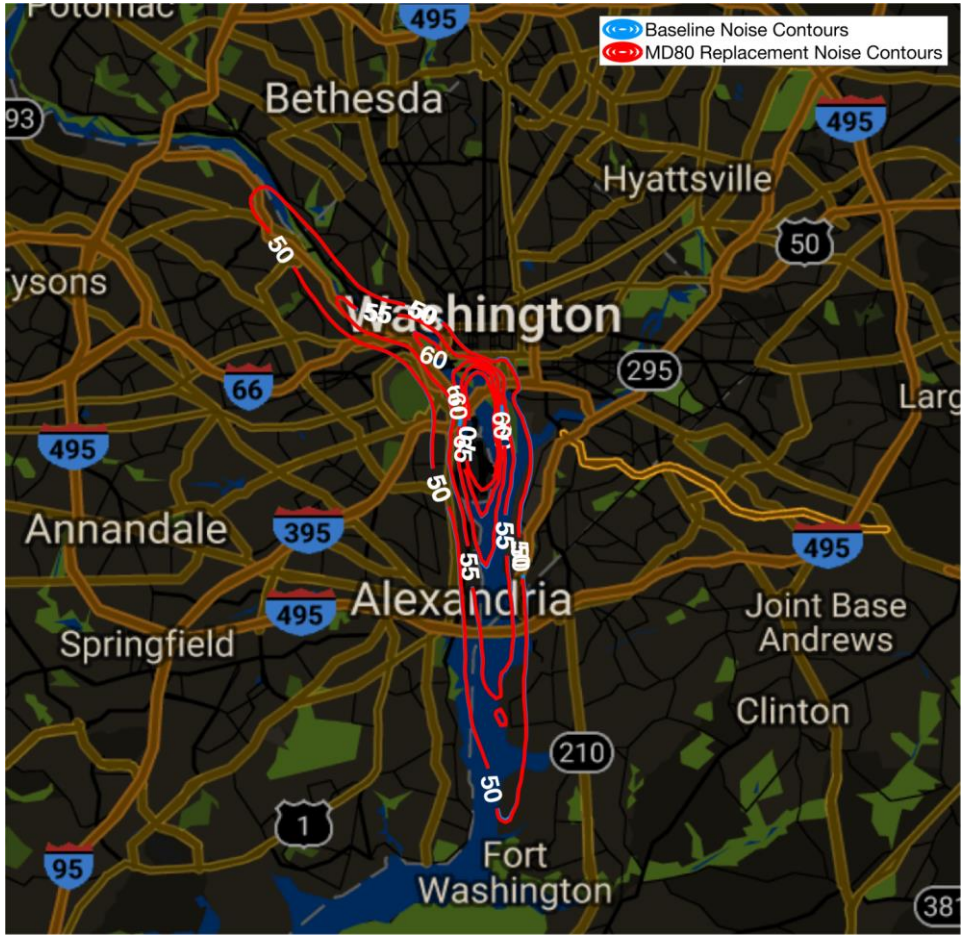
Metric	DNL
Noise Model	AEDT
Notes	Baseline Fleet vs. MD-80 Replacement Policy Passenger capacity larger for non-baseline

Baseline 2015 Schedule

Type	Daily Count
E145	95
E170	132
A320	66
B738	84
MD88	17
B752	2

MD-80 Replacement Schedule

Type	Daily Count
E145	95
E170	132
A320	66
B738	101
MD88	0
B752	2



Scenario 1: Fleet-wide Upgauge LTO Emissions

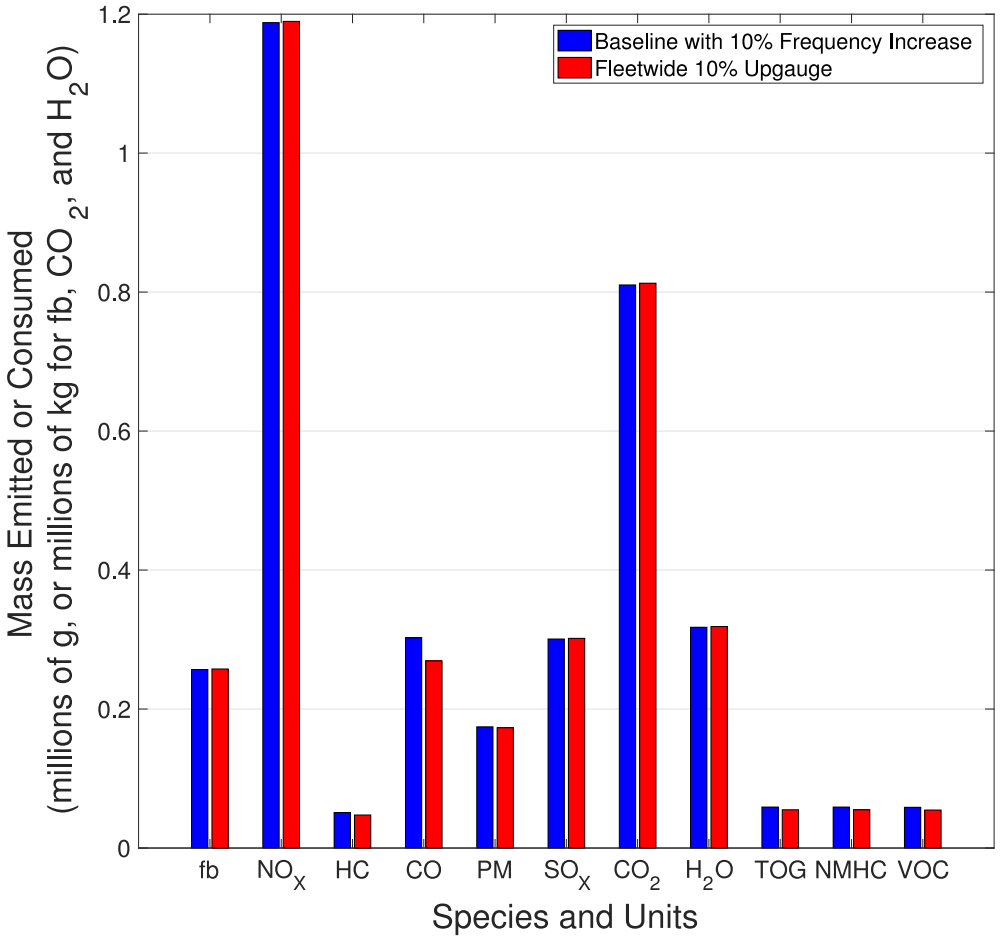
Metric	LTO Emissions, LTO <= 10,000’
Fuel Flow Model	TASOPT
Notes	Baseline Fleet with 10% Frequency Increase vs. 10% Aircraft Payload and Size Upgauge

10% Frequency Increase Schedule

Type	Daily Count*
E145	104.5
E170	145.2
A320	72.6
B738	92.4
MD88	18.7
B752	2.2

10% Gauge Increase Schedule

Type	Daily Count
E145+	95
E170+	132
A320+	66
B738+	84
MD88+	17
B752+	2



Scenario 2: Minimum Gauge Policy LTO Emissions

E145 flights shifted to E170 flights

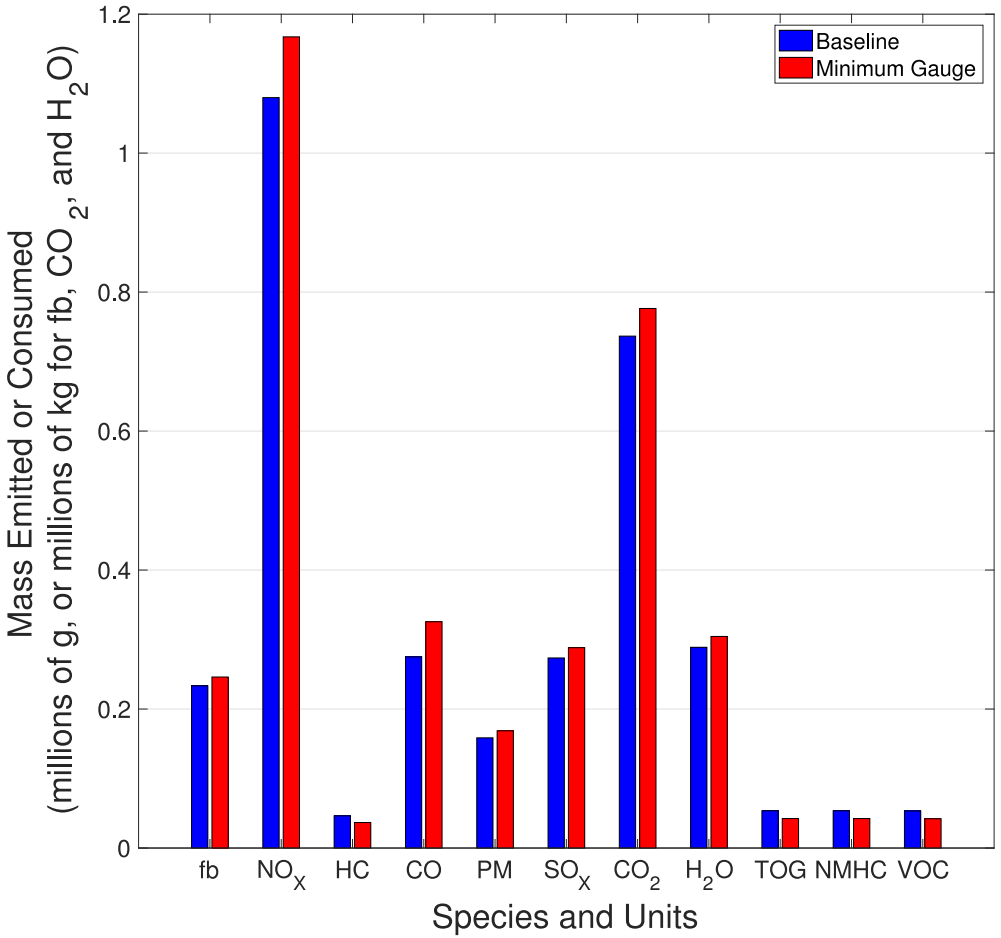
Metric	LTO Emissions, LTO <= 10,000’
Fuel Flow Model	TASOPT
Notes	Baseline Fleet vs. Minimum Gauge Policy Passenger capacity larger for non-baseline

Baseline 2015 Schedule

Type	Daily Count
E145	95
E170	132
A320	66
B738	84
MD88	17
B752	2

RJ Upgauge Schedule

Type	Daily Count
E145	**0**
E170	**227**
A320	66
B738	84
MD88	17
B752	2



Scenario 3: Replace Older Aircraft Types LTO Emissions

MD80 flights shifted to B738 flights

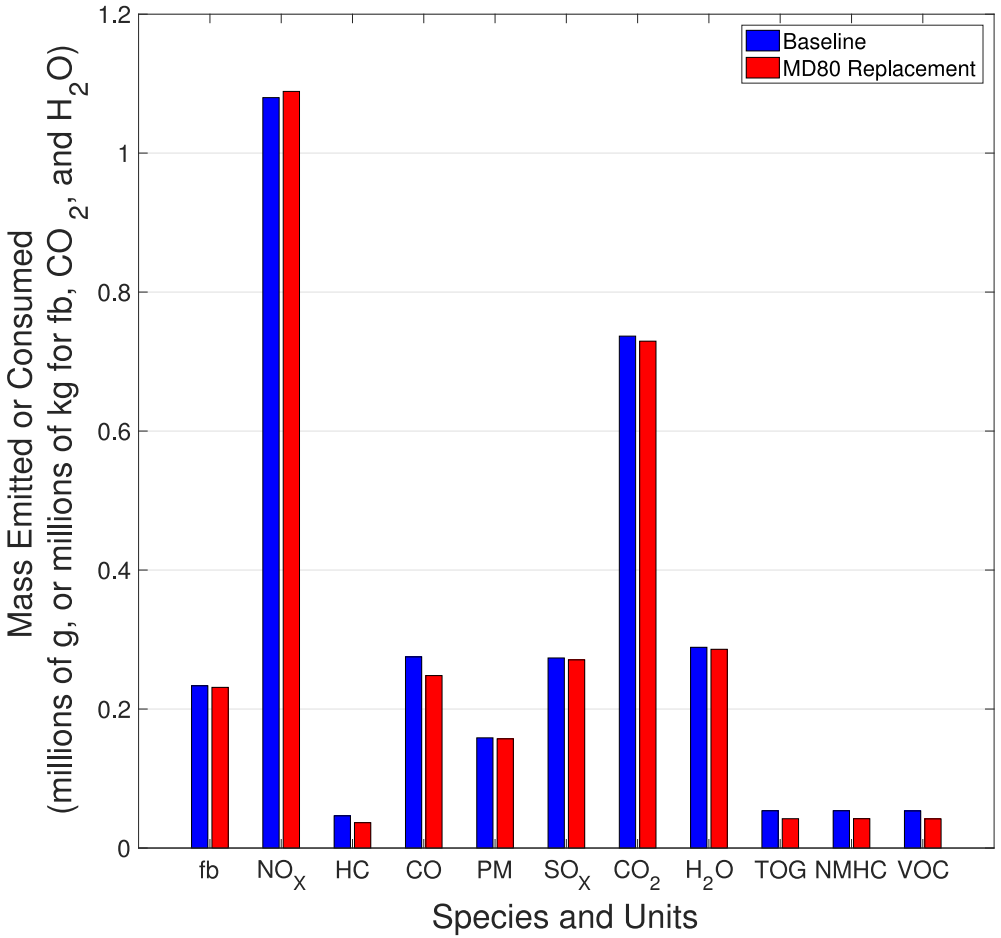
Metric	LTO Emissions, LTO <= 10,000’
Fuel Flow Model	TASOPT
Notes	Baseline Fleet vs. MD-80 Replacement Policy Passenger capacity larger for non-baseline

Baseline 2015 Schedule

Type	Daily Count
E145	95
E170	132
A320	66
B738	84
MD88	17
B752	2

MD-80 Replacement Schedule

Type	Daily Count
E145	95
E170	132
A320	66
B738	86
MD88	17
B752	0

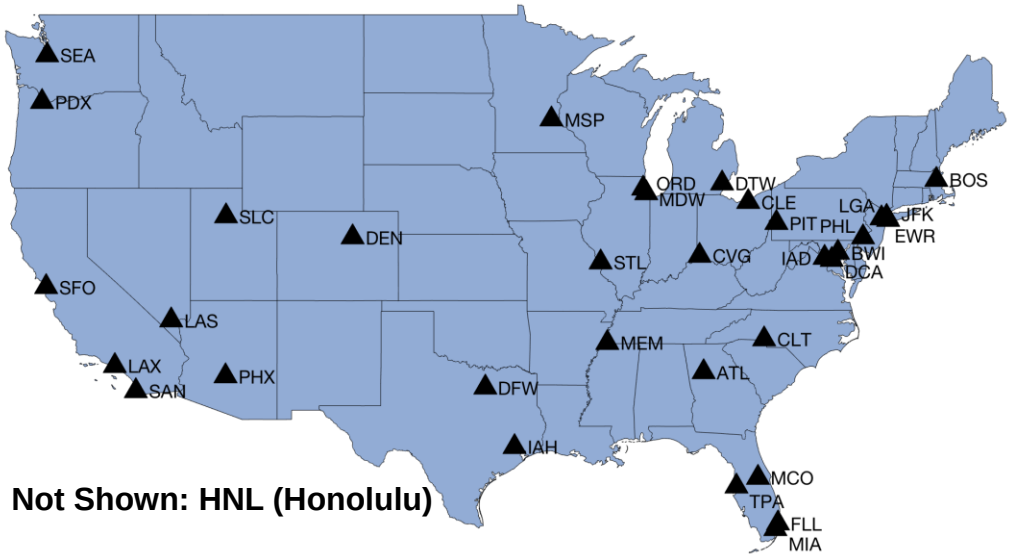


SYSTEM-LEVEL ANALYSIS

Extension to System Level Analysis

- Objective: rapidly calculate nationwide population noise impact
  - Simplifying assumptions for computational efficiency
- Applications for system-level procedure or policy evaluation
- Analysis developed initially using OEP35 airports

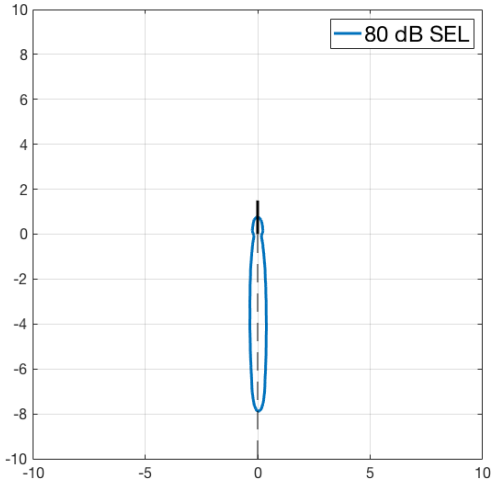
Operational Evolution Plan (OEP 35) airports



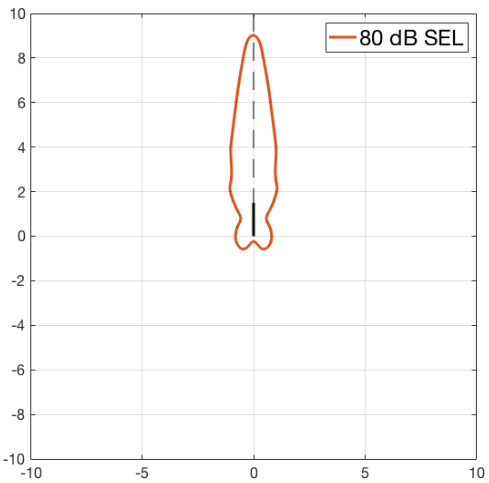
Not Shown: HNL (Honolulu)

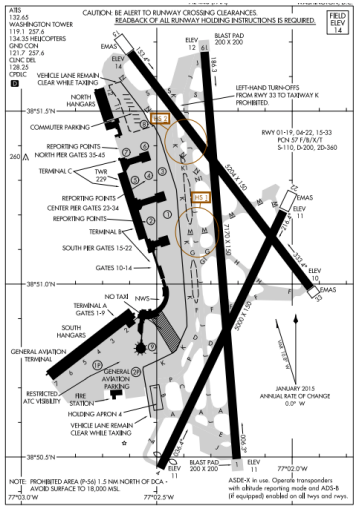
Generic Noise Contour Rotation

Straight-In B738 Arrival SEL



Straight-Out B738 Departure SEL

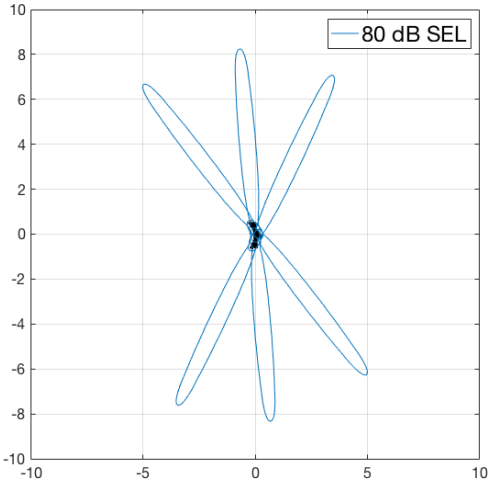




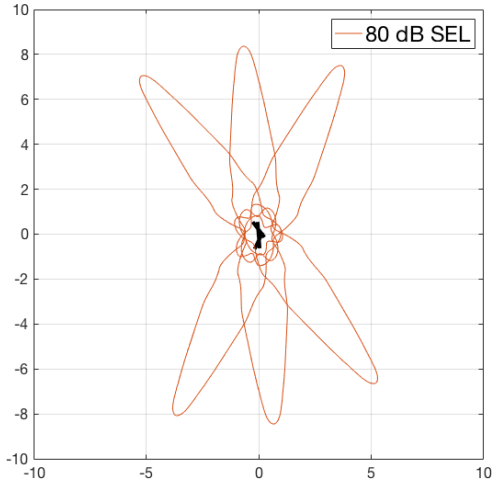
DCA

1. Pre-calculate generic straight-in arrival and straight-out departure noise (SEL and/or L_{MAX}) for each aircraft type
2. Rotate and translate noise data to align with every runway end on a common grid (0.1nm resolution)

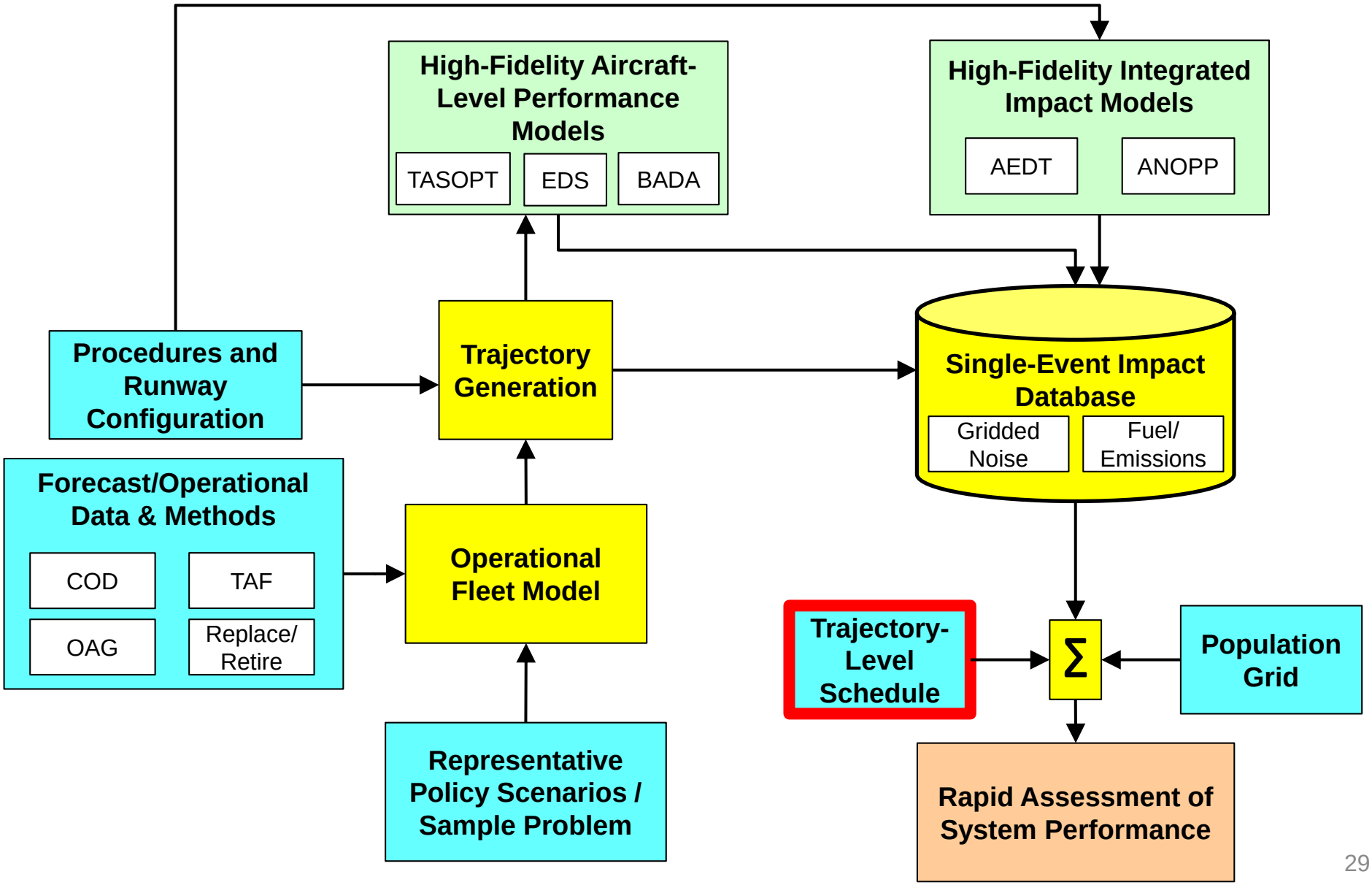
DCA B738 Arrivals



DCA B738 Departures



Model Framework



Trajectory-Level Schedule Development

ASPM : Individual Flights

Departure From 3/31/2017 To 3/31/2017 | Departure=DCA

Departure	Arrival	ACID	ETMS Equipment Code	Actual Wheels Off
DCA	CMH	RPA4687	E75S	0:52
DCA	DFW	AAL93	B738	5:44
DCA	CLT	JIA5497	CRJ7	5:50
DCA	IAH	UAL551	B738	5:55
DCA	BOS	JBU1790	E190	6:03
DCA	FLL	JBU1279	E190	6:04
DCA	MCO	SWA20	B737	6:05
DCA	LGA	RPA6132	E75S	6:06
DCA	DTW	DAL2854	A320	6:07
DCA	MIA	AAL913	B738	6:08
DCA	LGA	RPA4707	E75S	6:10
DCA	DAL	SWA9	B737	6:11
DCA	ORD	SKW5177	E75L	6:13
DCA	ATL	DAL872	B738	6:18
DCA	JFK	EDV3738	CRJ9	6:20
DCA	ATL	SWA141	B737	6:25
DCA	BNA	SWA1456	B737	6:26
DCA	ATL	RPA4713	E75L	6:30
DCA	MSP	DAL1368	MD90	6:32
DCA	CVG	DAL303	B712	6:38
DCA	PHL	AAL1645	E190	6:40
DCA	BOS	AAL2160	A319	6:41
DCA	CLE	ASQ4004	E45X	6:42
DCA	HPN	LOF4322	E145	6:43
DCA	RDU	LOF4379	E145	6:45
DCA	IAH	ASH6291	E75L	6:57
DCA	FLL	SWA6291	B737	7:00

- Schedule derived from flight-level ASPM data from a one-year period binned by:
  - Operational hour
  - Aircraft type
- 12 aircraft types modeled in current implementation
  - Each operation assigned to most-similar type
  - Light general aviation operations omitted

A320	B744	B788	E145
B77W	B752	CRJ2	E170
B738	B763	DH8D	MD88

Trajectory-Level Schedule Development

Airport	Scheduled Departure Date	Local Hour	Actual Departures	Actual Arrivals	Runway Configuration (Arr|Dep)
DCA	03/31/2017	0	2	5	19 | 19
DCA	03/31/2017	1	0	0	19 | 19
DCA	03/31/2017	2	0	1	19 | 19
DCA	03/31/2017	3	0	0	19 | 19
DCA	03/31/2017	4	0	0	19 | 19
DCA	03/31/2017	5	3	0	1 | 1
DCA	03/31/2017	6	22	7	1 | 1
DCA	03/31/2017	7	23	25	1 | 1
DCA	03/31/2017	8	25	22	1 | 1
DCA	03/31/2017	9	29	24	1 | 1
DCA	03/31/2017	10	31	23	1 | 1
DCA	03/31/2017	11	25	22	1 | 1
DCA	03/31/2017	12	26	24	1 | 1
DCA	03/31/2017	13	21	24	1 | 1
DCA	03/31/2017	14	21	31	1 | 1
DCA	03/31/2017	15	25	22	1 | 1
DCA	03/31/2017	16	25	25	1 | 1
DCA	03/31/2017	17	22	27	1 | 1
DCA	03/31/2017	18	29	24	1 | 1
DCA	03/31/2017	19	22	27	1 | 1
DCA	03/31/2017	20	25	32	1 | 1
DCA	03/31/2017	21	27	30	1 | 1
DCA	03/31/2017	22	23	17	1 | 1
DCA	03/31/2017	23	2	15	1 | 1
Total			**428**	**427**	

- Operations assigned to runways based on hourly ASPM configuration records
  - For multi-runway configurations, operations distributed equally across active runways

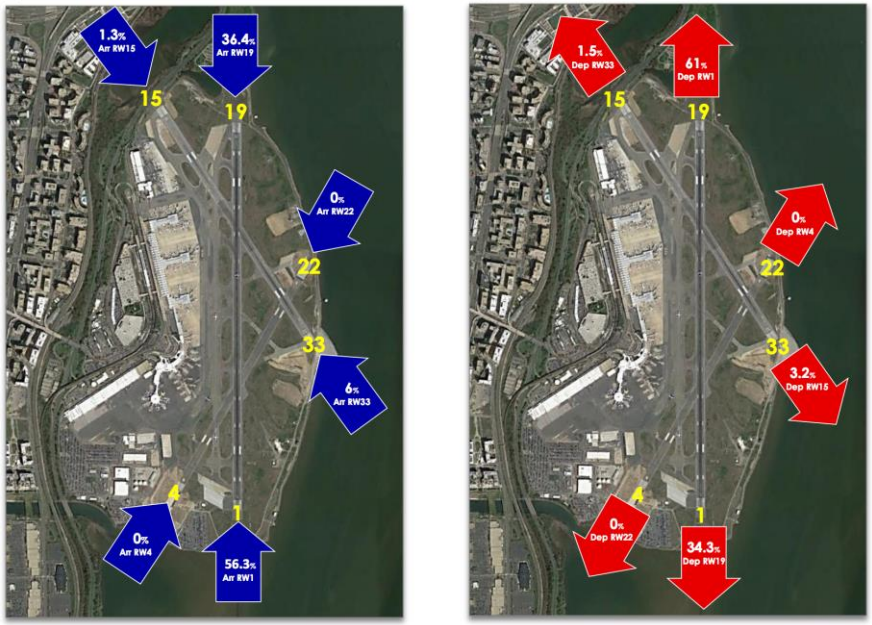
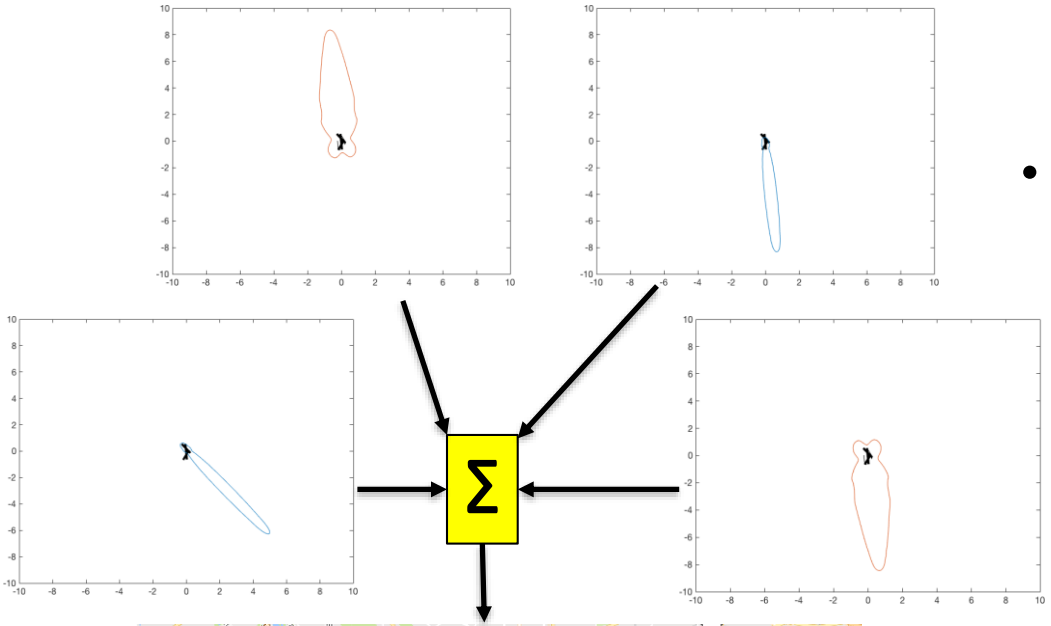
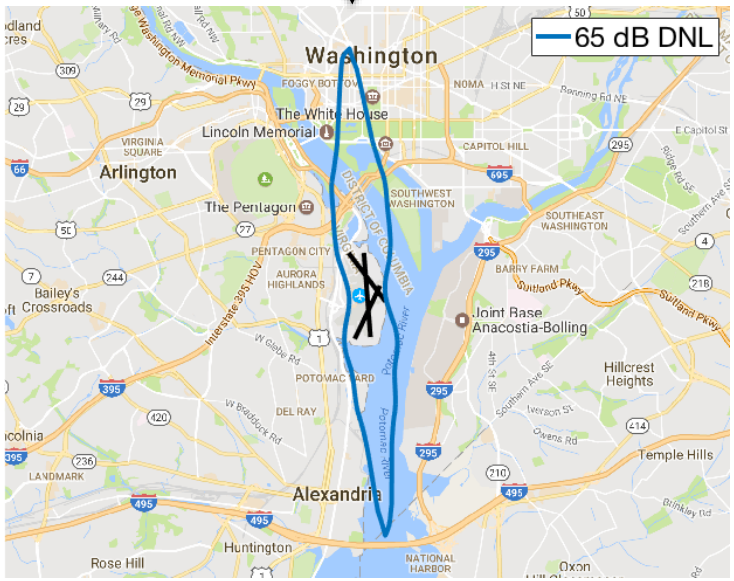


Figure Source: MWAA

DNL Calculation



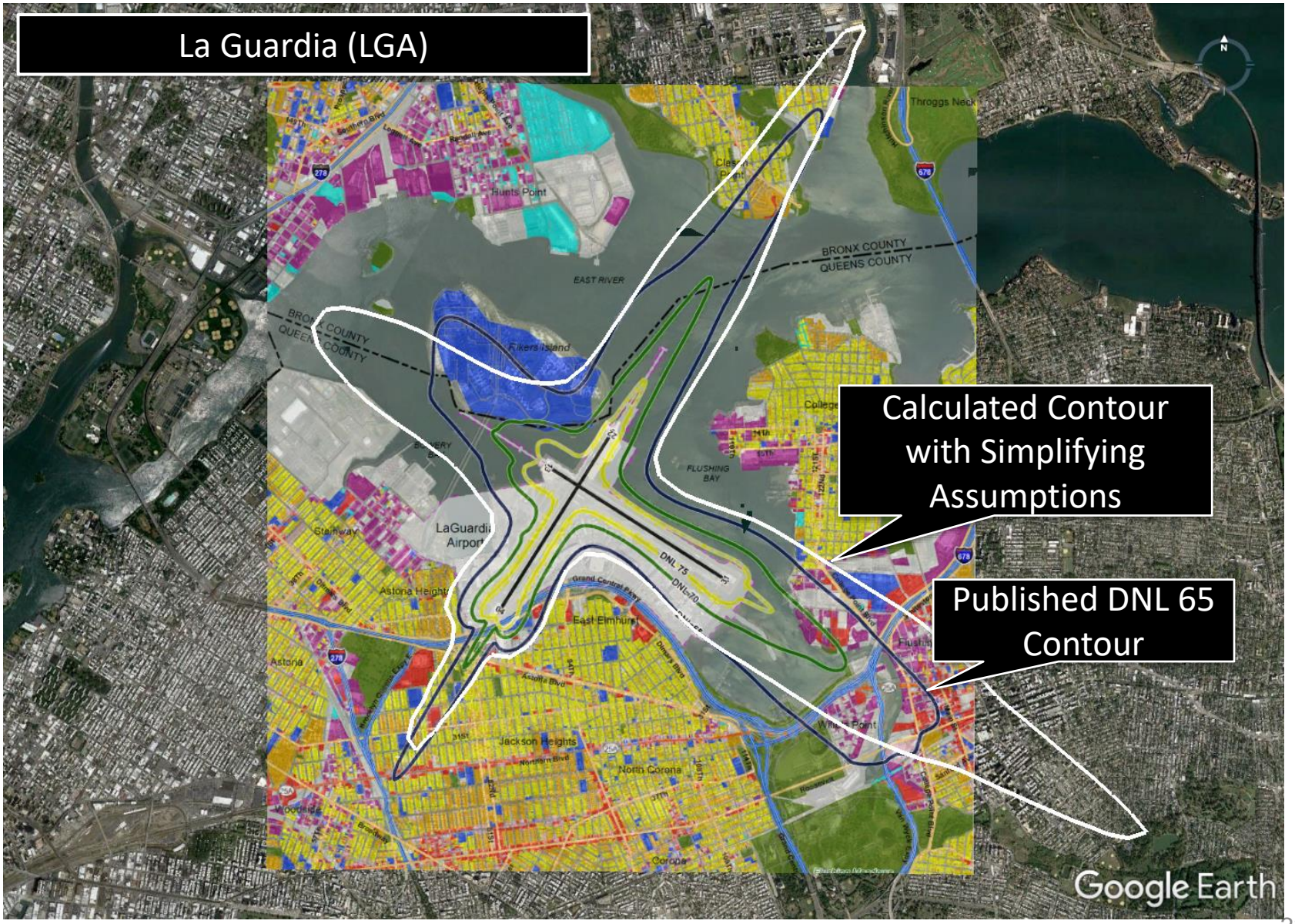


- **DNL**: Single-event Sound Exposure Level (SEL) summed and normalized across a year of operations
  - 10 dB penalty applied to night operations (10pm-7am)

N_{ABOVE}: L_{MAX} events above a set level counted across a year of operations and normalized to a daily average

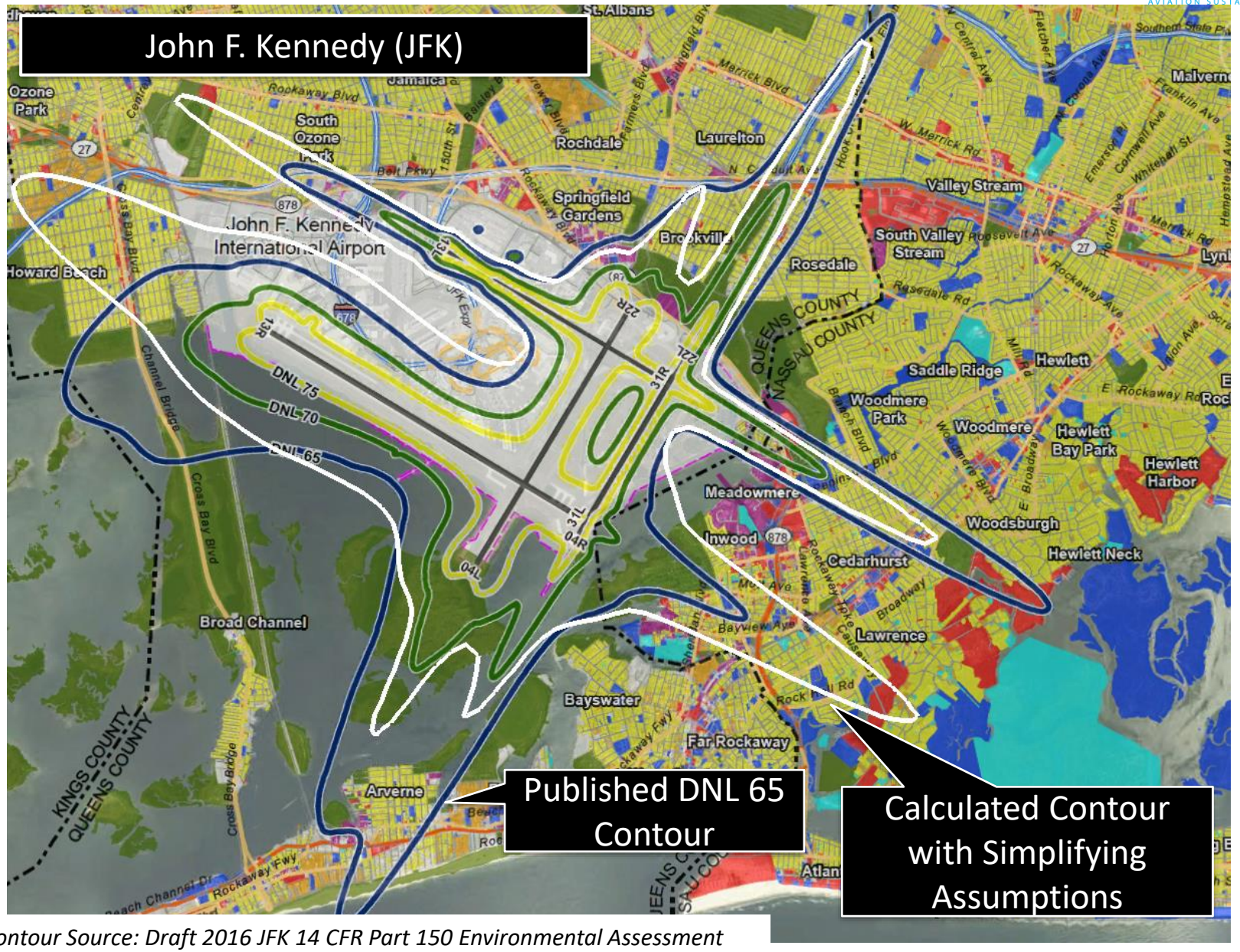
- Resulting contours capture all runway configurations weighted by actual utilization frequency
- Fast computation time due to consistent grid definition

Comparison with Published 65 DNL Contours



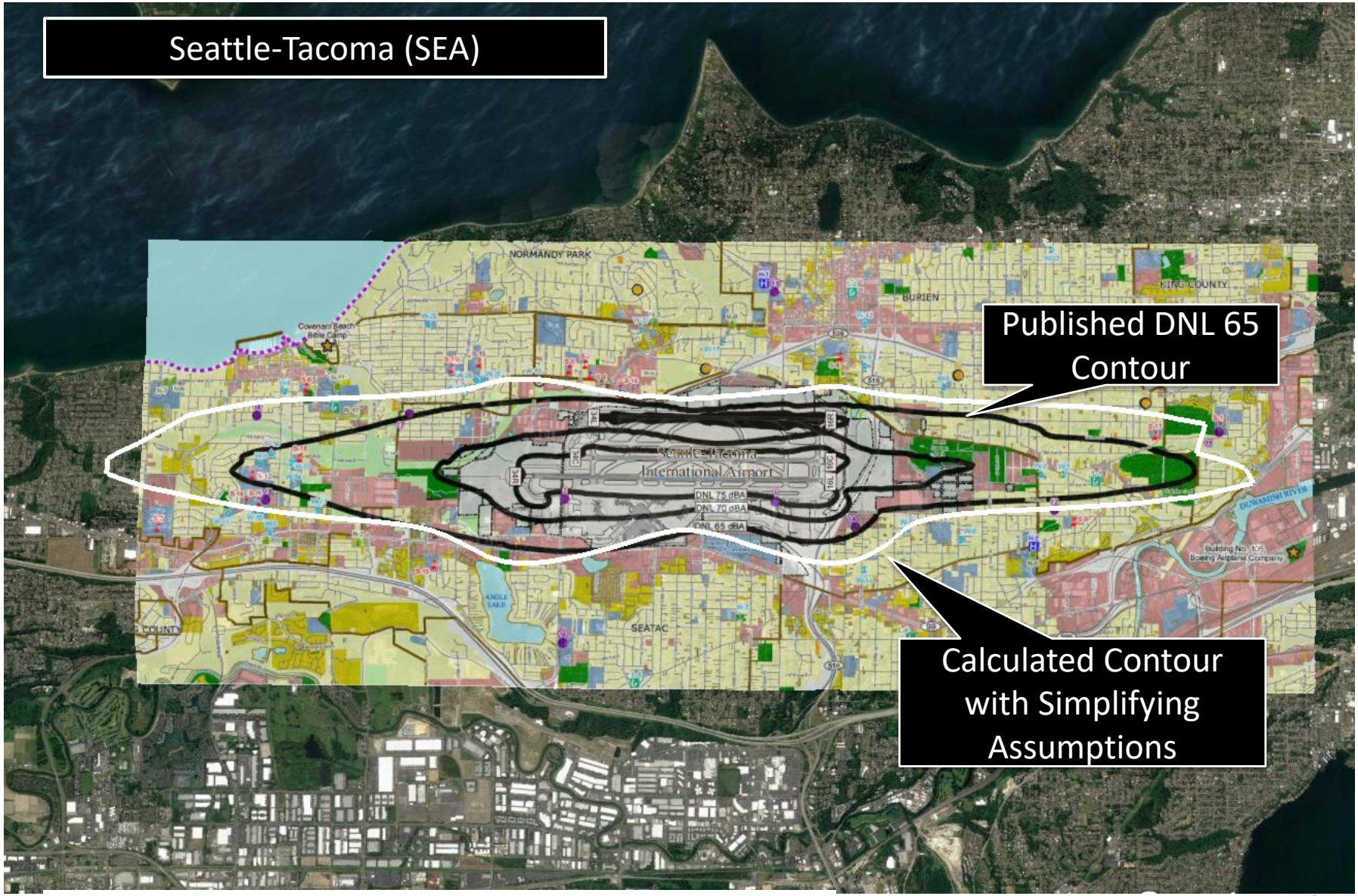
Contour Source: Draft 2016 LGA 14 CFR Part 150 Environmental Assessment

Comparison with Published 65 DNL Contours



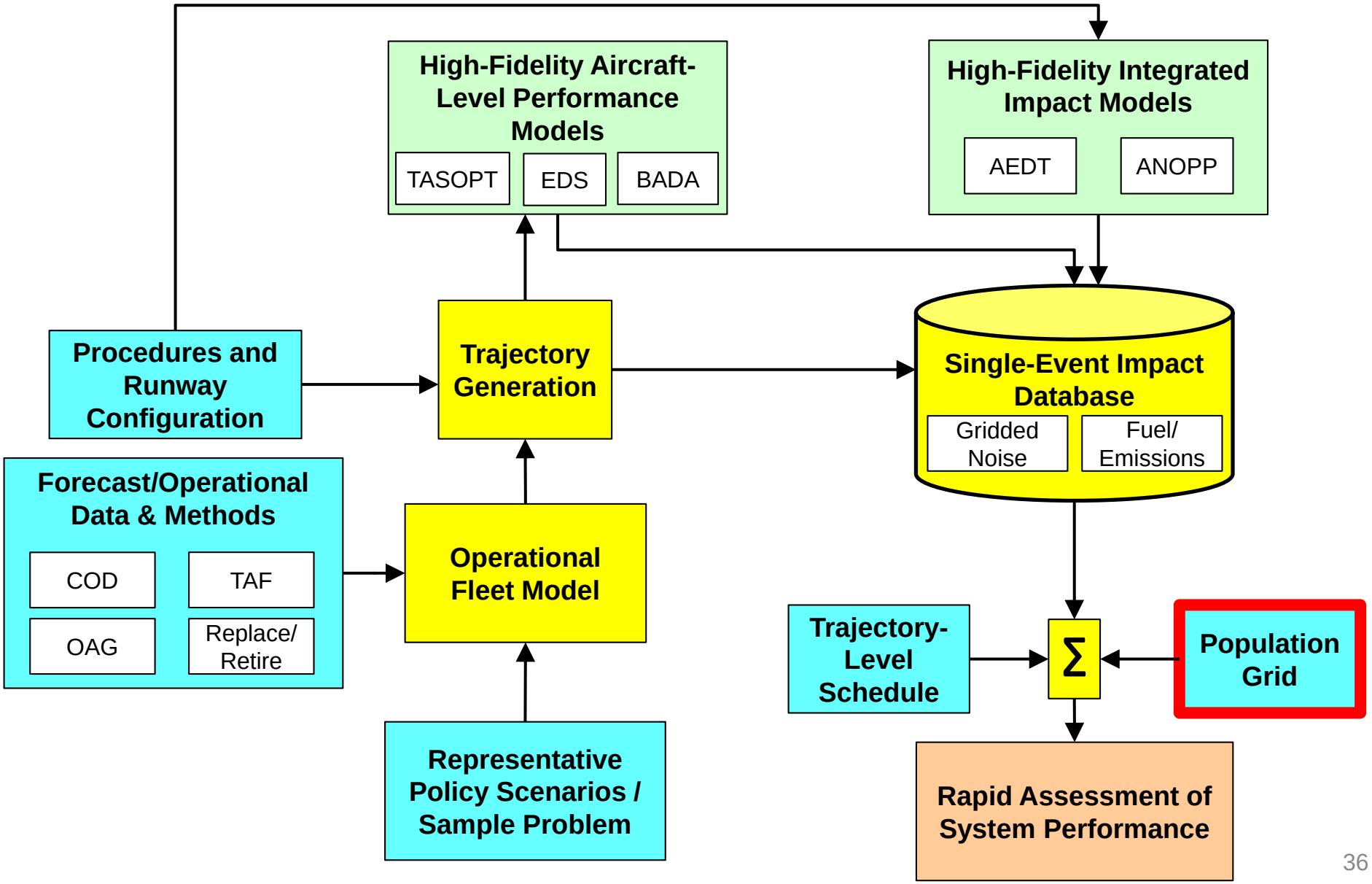
Contour Source: Draft 2016 JFK 14 CFR Part 150 Environmental Assessment

Comparison with Published 65 DNL Contours



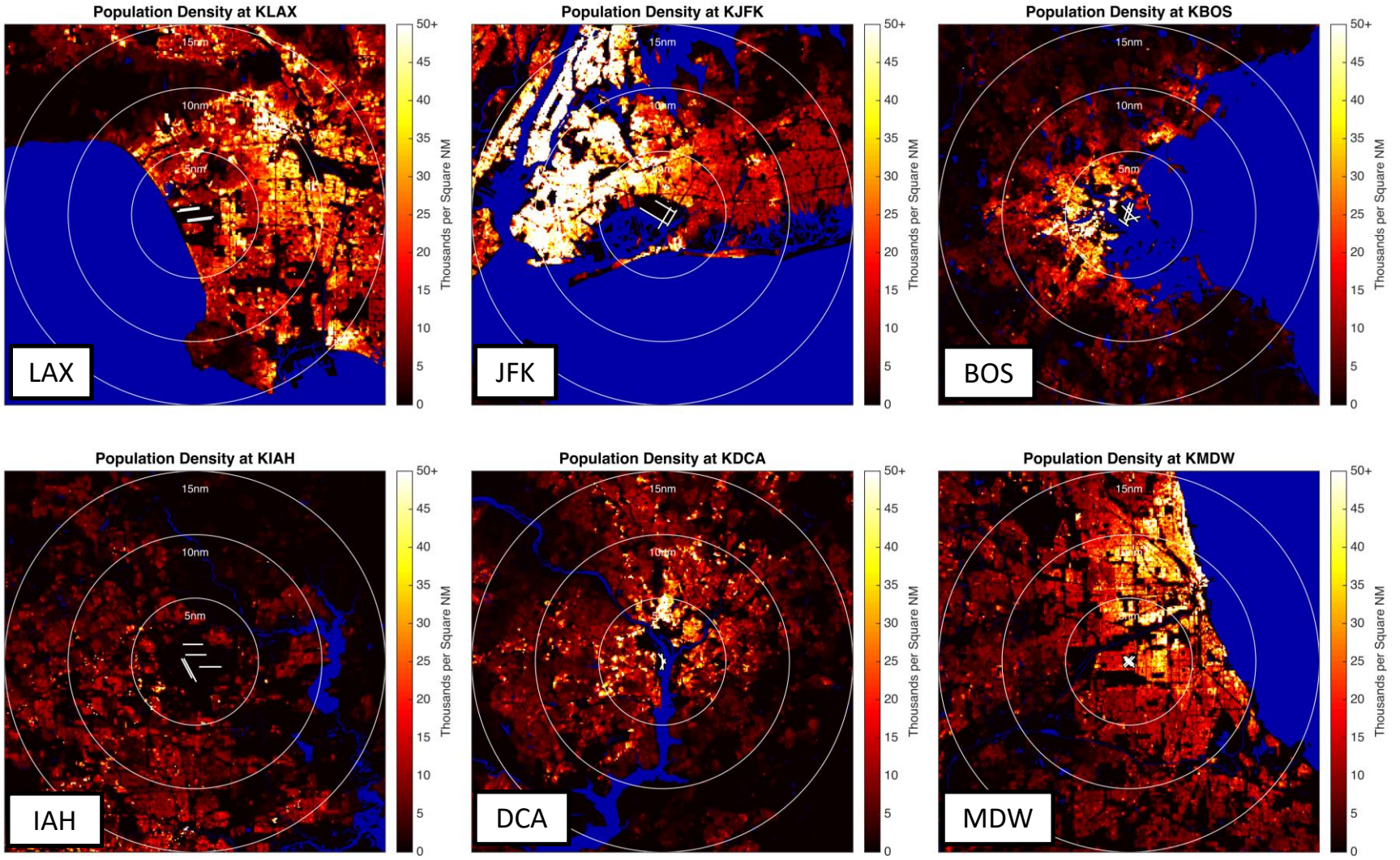
Contour Source: 2013 SEA 14 CFR Part 150 Environmental Assessment

Model Framework



Population Exposure Calculation

Block-level 2010 US Census data re-gridded to 0.1nm square spacing for each OEP35 airport (same grid as noise results allowing rapid impact calculation)



Summary

- Rapid modeling approaches provide new options for policymaking and operational evaluation
- Next steps
  - Develop efficient method to represent non-standard procedures
    - Selectively avoid straight-in and straight-out assumption
    - Capture effects of flight track dispersion
  - Extend system-level analysis to include more aircraft types and procedure permutations
- Key challenges
  - Addressing dimensionality of aviation environmental analysis
    - Identifying classes of problems that should be analyzed using rapid approaches vs. direct high-fidelity assessment, particularly with noise analysis