Runway Exit Design Tool (REDIM 3 Model)

Example Computer Model that Uses Monte Carlo Simulation

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Acknowledgments

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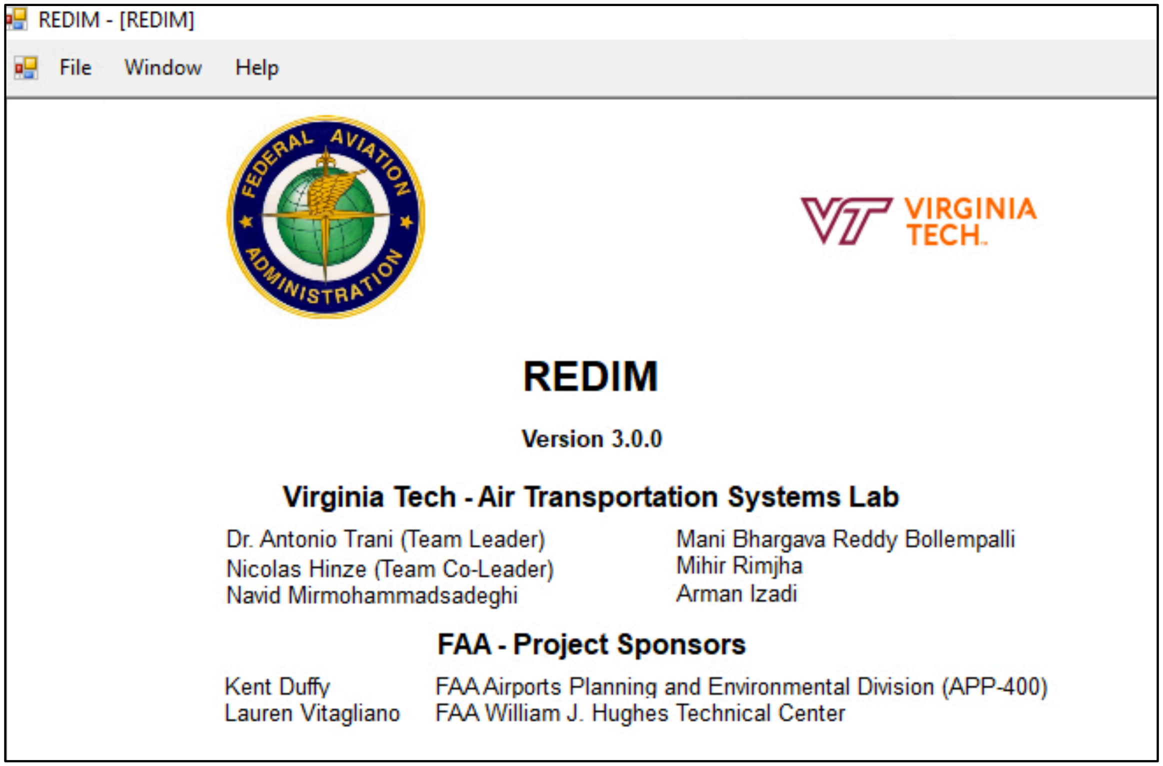
Project Outcomes

- **Landing Events Database** containing 12 million landing records from ASDE-X data (all landings at 37 US airport during 2015 and 2016)
  - Stand-alone product (client software)
- Development of tabular and graphical data on runway exit utilization at 37 airports
- **Updated Runway Exit Design Tool (REDIM 3 model)**
  - Windows-based computer model for evaluating the best location of runway exits (stand-alone software)
  - Considers observed aircraft landing performance and runway exit probabilities

Runway Exit Design Tool

Runway Exit Design Tool (REDIM 3 model)



The Runway Exit Design Tool can be downloaded at:

https://www.atsl.cee.vt.edu/products/redim.html

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Runway Exit Design Tool Objectives

- Predict runway occupancy times at any airport given a fleet mix , runway length, runway exits and airport environmental conditions
- Help airport designers locate new runway exits to reduce runway occupancy time

Runway with ROT > 50 seconds
All right angle runway exits

Runway with ROT < 50 seconds
Two high-speed runway exits

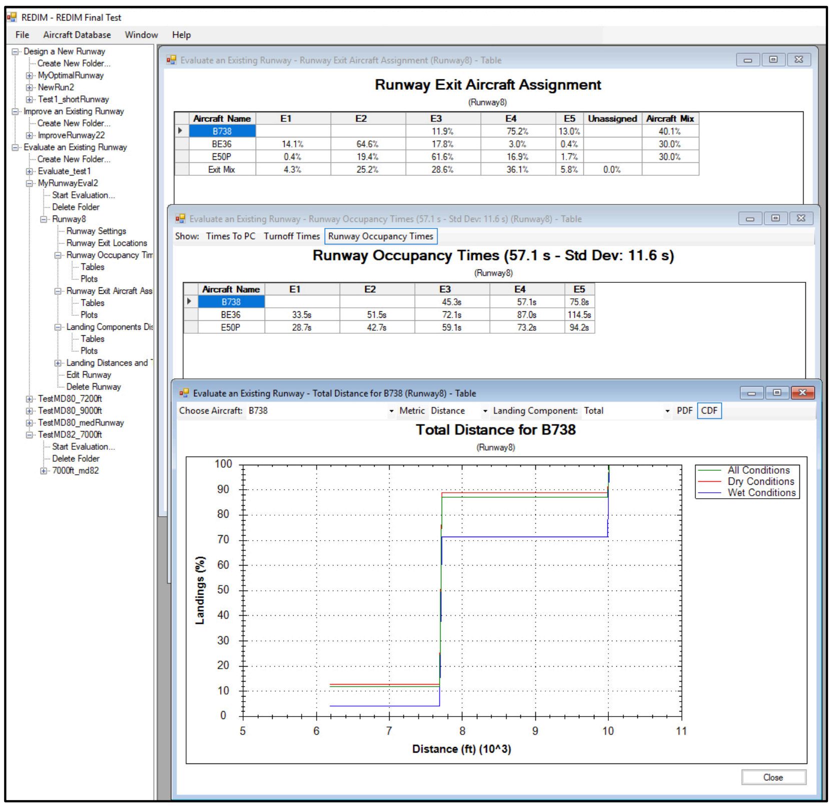
General Information About the Model

- Model has three analysis modules:

a) Evaluation of an existing runway

b) Improvements to an existing runway

c) Design optimal locations for a new runway



- Stand-alone Windows application
- Requires ~1.8 Gb of hard disk space
- New runway clustering
- Improvements to landing roll profile calculations

Model predicts the weighted average Runway Occupancy Time (ROT)

Runway Exit Design Tool Outputs

Analysis	Purpose	Outputs Produced
Aircraft Mix	Provides an overview of aircraft fleet mix	Percent of aircraft types simulated in the analysis
Runway Occupancy Time	Provides three values of runway occupancy time measured at two locations: 1.Fuselage out 2.At hold bar	1.Average ROT (in seconds) by runway exit and aircraft (table format) 2.Average ROT (in seconds) by runway exit and aircraft (graphical format) 3. Weighted average ROT for the complete aircraft mix using the runway 4. Standard deviation of ROT for the complete fleet mix 5. Individual landing roll times for every aircraft simulated by the model (~50,000 landings per aircraft)
Runway Exit Utilization	Provides information about aircraft assigned to each exit	1. Percent of individual aircraft assigned to each runway exit 2. Individual ROT by aircraft and runway exit
Aircraft Landing Performance	Provides individual landing event information (REDIM uses a Monte Carlo Simulation Process)	1. Landing roll distributions (CDF and PDF) by runway condition (wet or dry) in table format 2. Landing roll distributions (CDF and PDF) by runway condition (wet or dry) in graphical form 3. Landing roll distances and times by aircraft and runway pavement condition (wet or dry) a) Air distance and air time (time to nose gear touchdown) b) Nominal braking distance and time c) Extra roll distance and time d) Turnoff distance and time

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REDIM 3 Aircraft Database

- The model contains data for 298 aircraft
  - 134 turbofan aircraft
  - 105 piston aircraft
  - 59 turboprop aircraft

REDIM - FAA AC Runs - [Aircraft Database]

File Aircraft Database Window Help

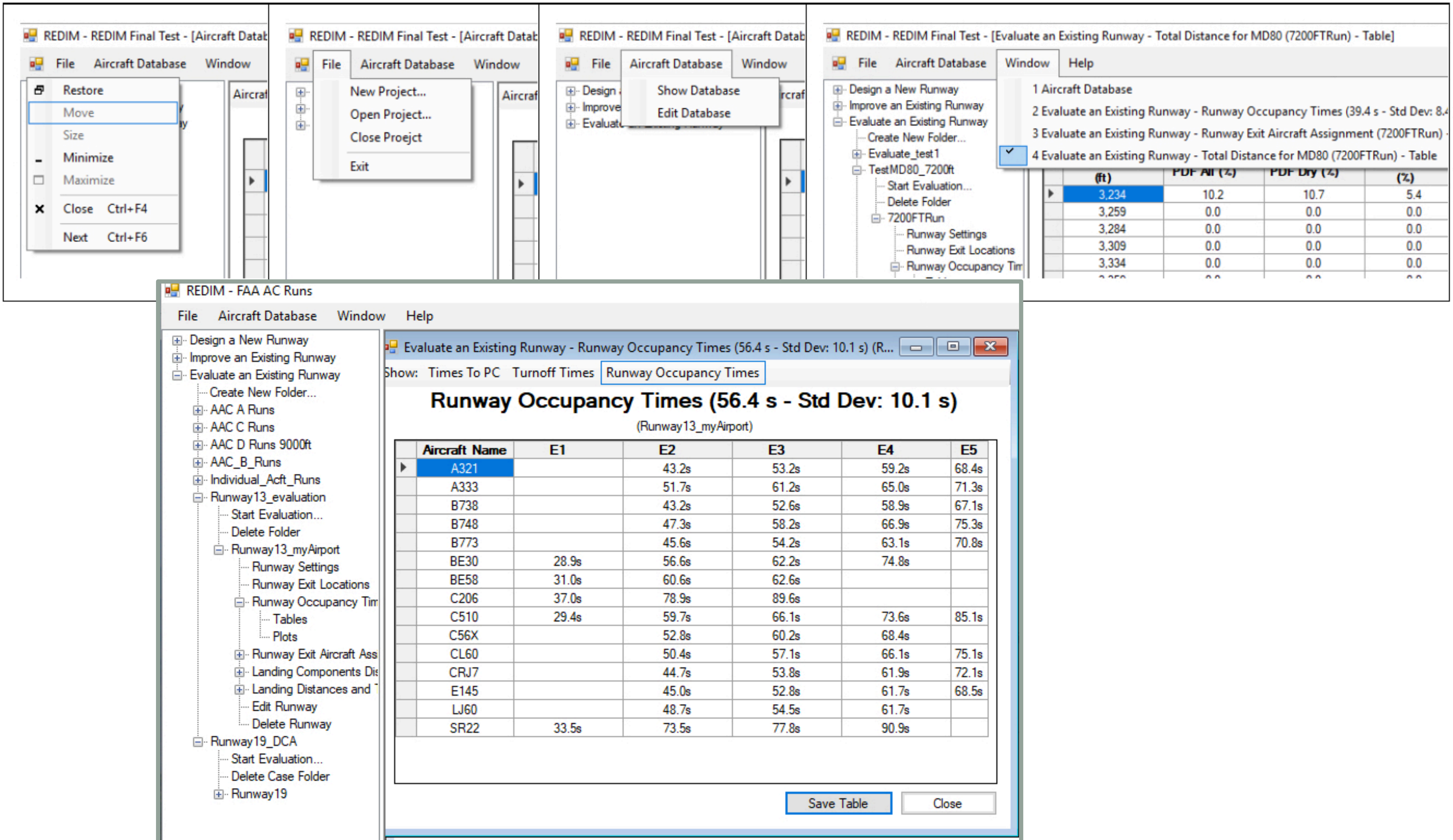
- Design a New Runway
- Improve an Existing Runway
- Evaluate an Existing Runway
  - Create New Folder...
  - AAC A Runs
  - AAC C Runs
  - AAC D Runs 9000ft
  - AAC_B_Runs
  - Individual_Acft_Runs

Aircraft Design Group (ADG): I

ADG I Aircraft

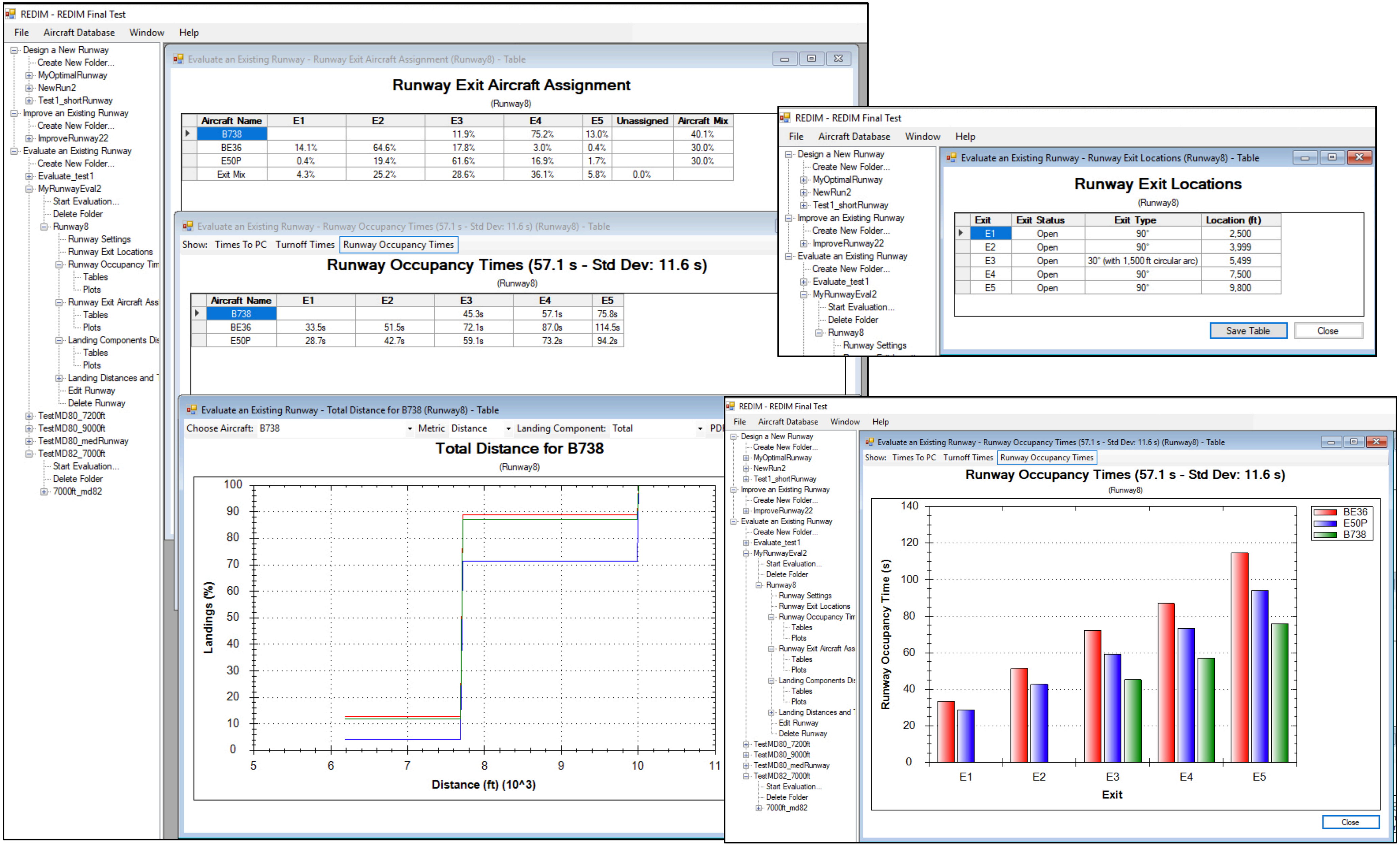
Aircraft ID	Aircraft Name	Engine Type	Aircraft Design Group	Aircraft Approach Category	Nose Gear to Main Gear (m)	Nose Gear to Tail (m)	Wing Tip Radius (m)	Full Length (m)
AA1	Grumman American AA1	Piston	I	A	1.48	5.14	3.78	5.87
AA5	Grumman American AA5	Piston	I	A	1.66	5.65	4.92	6.71
AC11	Rockwell Commander 112	Piston	I	A	2.15	6.65	5	7.63
AC50	Aero Commander 500	Piston	I	A	4.27	10.95	7.49	11.2
AC90	Turbo Commander 690	Turboprop	I	B	5.1	12.89	7.16	13.5
AEST	Piper Aerostar	Piston	I	B	3.43	8.91	5.2	10.6
B36T	Beechcraft Bonanza 36	Piston	I	A	3.19	6.99	5.89	8.5
BE10	Beechcraft B100 King Air	Turboprop	I	B	4.43	11.67	7.02	12.2
BE23	Beechcraft 23 Musketeer	Piston	I	A	1.89	7.12	5.02	8.2
BE24	Beechcraft 24 Sierra	Piston	I	A	1.96	6.85	5.04	7.9
BE33	Beechcraft F33 Bonanza	Piston	I	A	2.24	7.19	5.17	7.7
BE35	Beechcraft V35 Bonanza	Piston	I	A	2.2	7.87	5.76	8.6
BE36	Beechcraft 36 Bonanza	Piston	I	A	2.47	7.63	5.18	8.1
BE40	Beechcraft 400 Hawker	Jet	I	B	5.88	13.39	6.86	14.8
BE50	Beechcraft 50 Twin Bonanza	Piston	I	A	1.14	8.18	7.1	9.6
BE55	Beechcraft 55 Baron	Piston	I	B	2.2	7.87	5.76	8.6

REDIM 3 Menu Structure

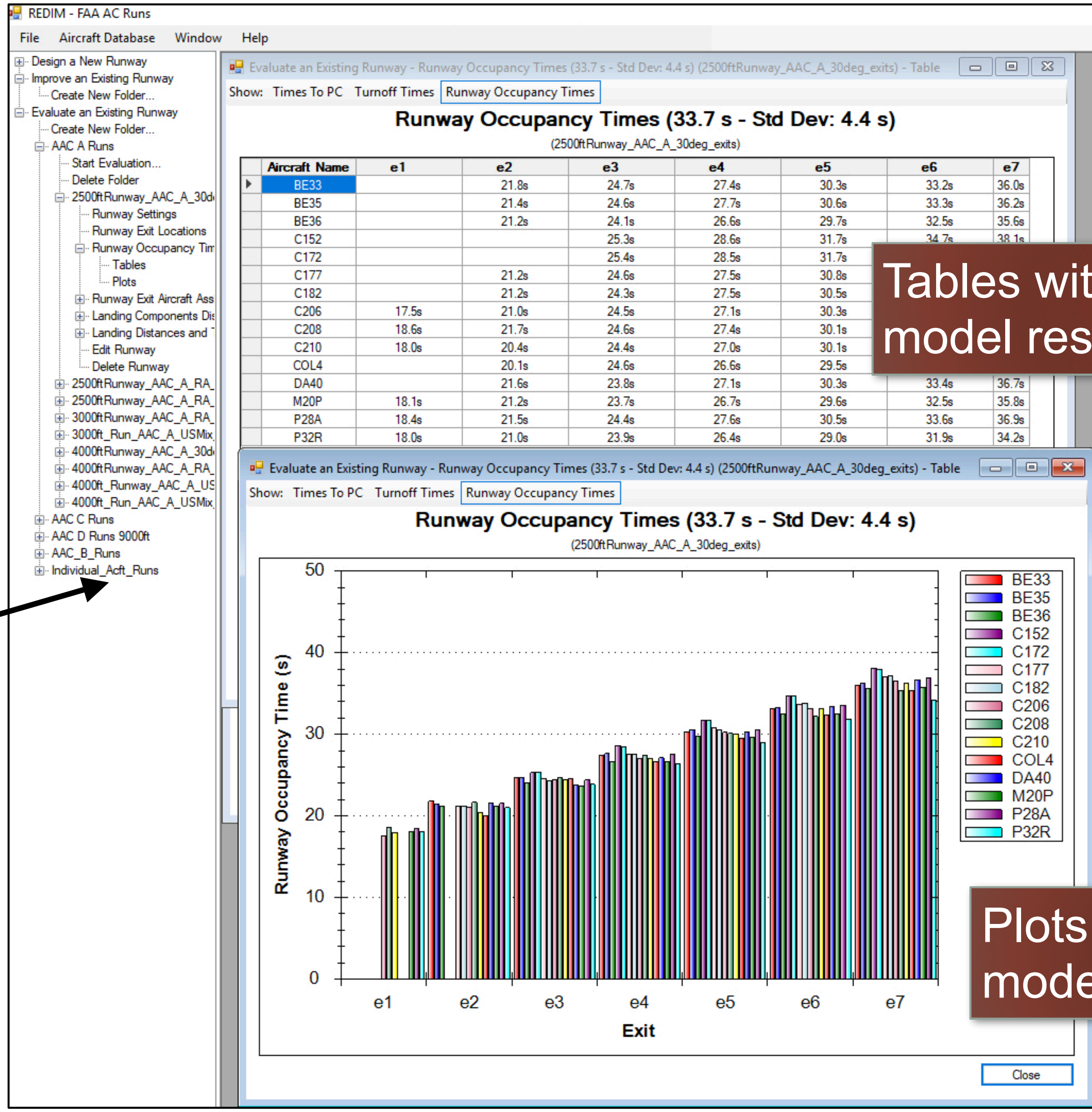


Aircraft Name	E1	E2	E3	E4	E5
A321		43.2s	53.2s	59.2s	68.4s
A333		51.7s	61.2s	65.0s	71.3s
B738		43.2s	52.6s	58.9s	67.1s
B748		47.3s	58.2s	66.9s	75.3s
B773		45.6s	54.2s	63.1s	70.8s
BE30	28.9s	56.6s	62.2s	74.8s	
BE58	31.0s	60.6s	62.6s		
C206	37.0s	78.9s	89.6s		
C510	29.4s	59.7s	66.1s	73.6s	85.1s
C56X		52.8s	60.2s	68.4s	
CL60		50.4s	57.1s	66.1s	75.1s
CRJ7		44.7s	53.8s	61.9s	72.1s
E145		45.0s	52.8s	61.7s	68.5s
LJ60		48.7s	54.5s	61.7s	
SR22	33.5s	73.5s	77.8s	90.9s	

Sample Screens of Runway Exit Design Tool



Interface and Panels in the Runway Exit Design Model

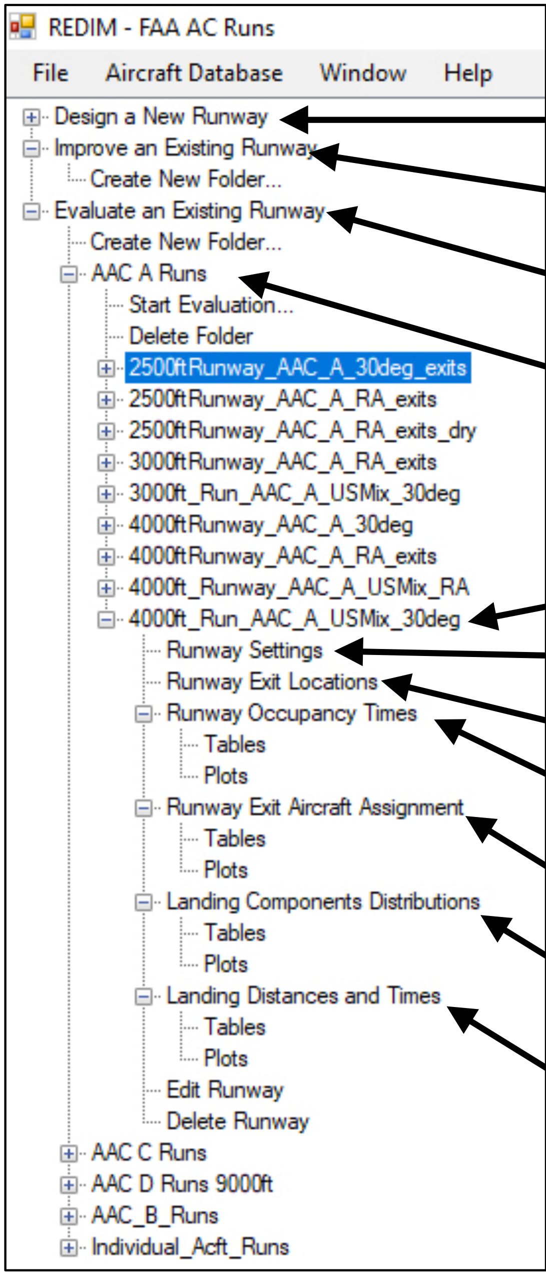


Tables with relevant model results

Navigation and project panel with information and results

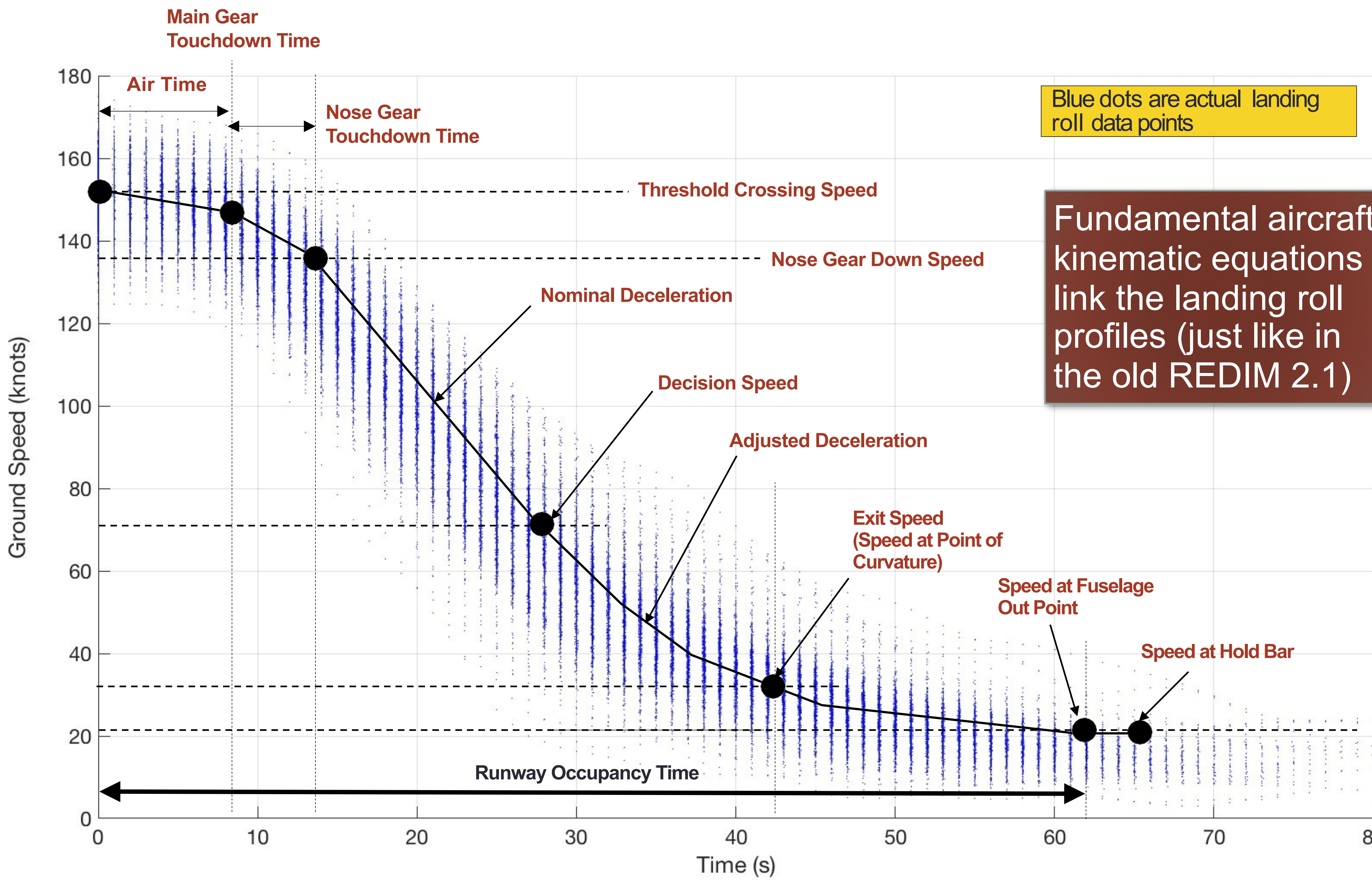
Plots of relevant model results

Navigation/Project Panel Hierarchy



- Design a new runway
- Improve an existing runway
- Evaluate an existing runway
- Project folder
- Scenarios inside project folder
- Scenario settings
- Runway exit locations
- Runway occupancy times (tables and plots)
- Runway exit assignment (tables and plots)
- Aircraft landing distributions (tables and plots)
- Aircraft landing distances and times (tables and plots)

Runway Exit Model Landing Roll Profile Phases Modeled



Fundamental aircraft kinematic equations link the landing roll profiles (just like in the old REDIM 2.1)

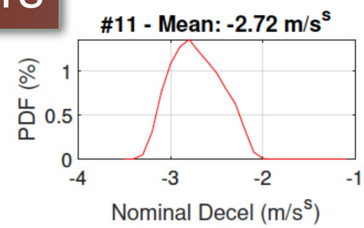
Runway Clusters in REDIM 3

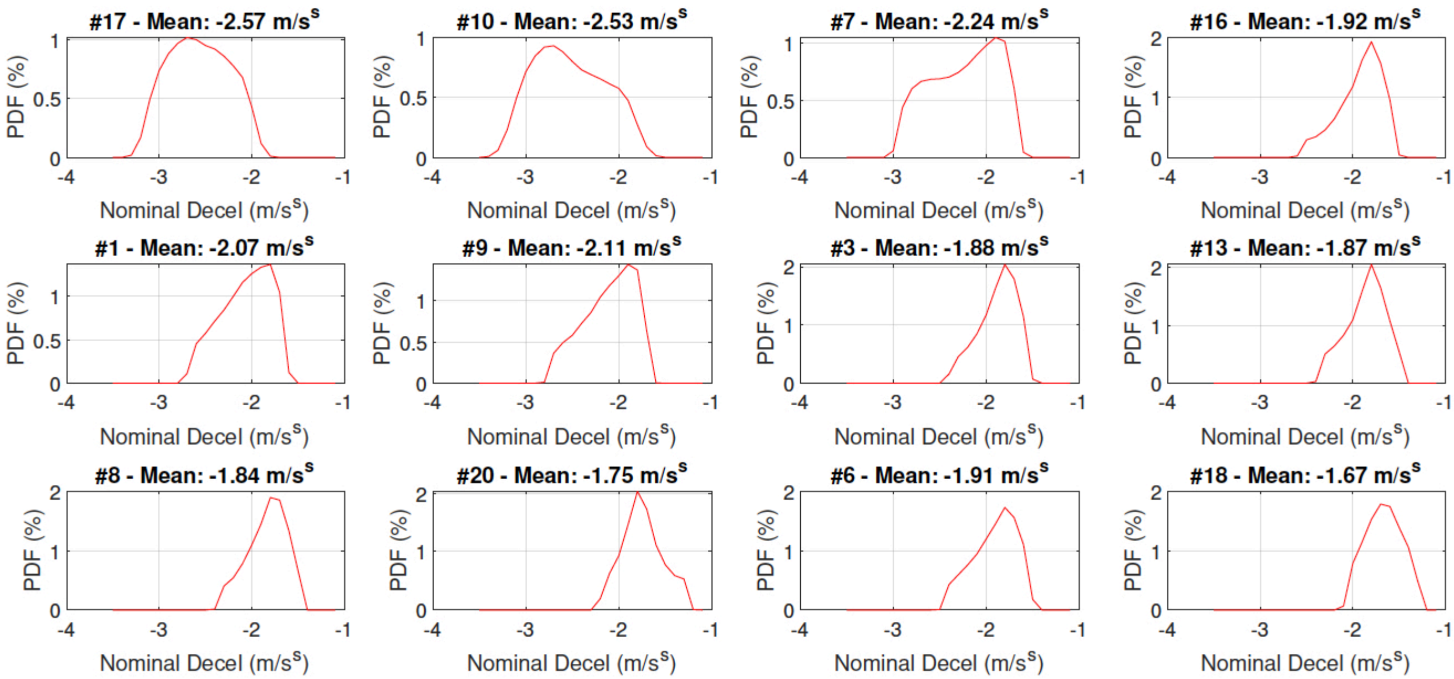
	Runway Length (ft)		Number Of Runways
Cluster #	**Min**	**Max**	
14	2555	2890	4
19	3796	4385	10
5	4588	4894	8
11	4989	5515	16
17	5709	6019	6
10	6486	6570	6
7	6806	7236	26
16	7479	7607	12
1	7657	7849	10
9	7946	8197	18
3	8375	8710	30
13	8907	9032	28
8	9190	9503	22
20	9691	10038	20
6	10277	10768	[illegible]
18	10950	11145	[illegible]
15	11377	11553	[illegible]
4	11863	12293	[illegible]
2	12962	13436	10
12	16020	16020	2
Total			292

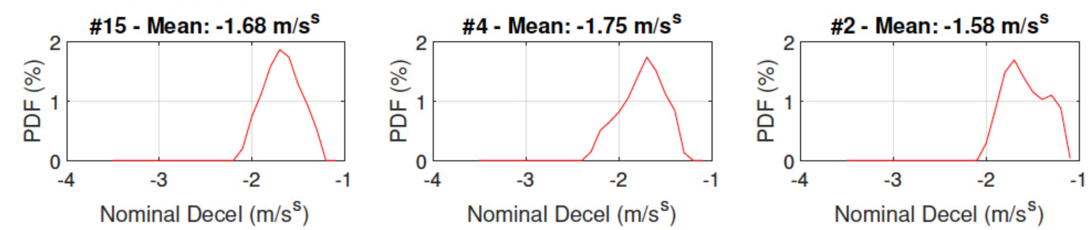
Runway clusters influence the landing roll behavior

Model Uses Individual Aircraft Data

Airbus A320 Data for all runway clusters

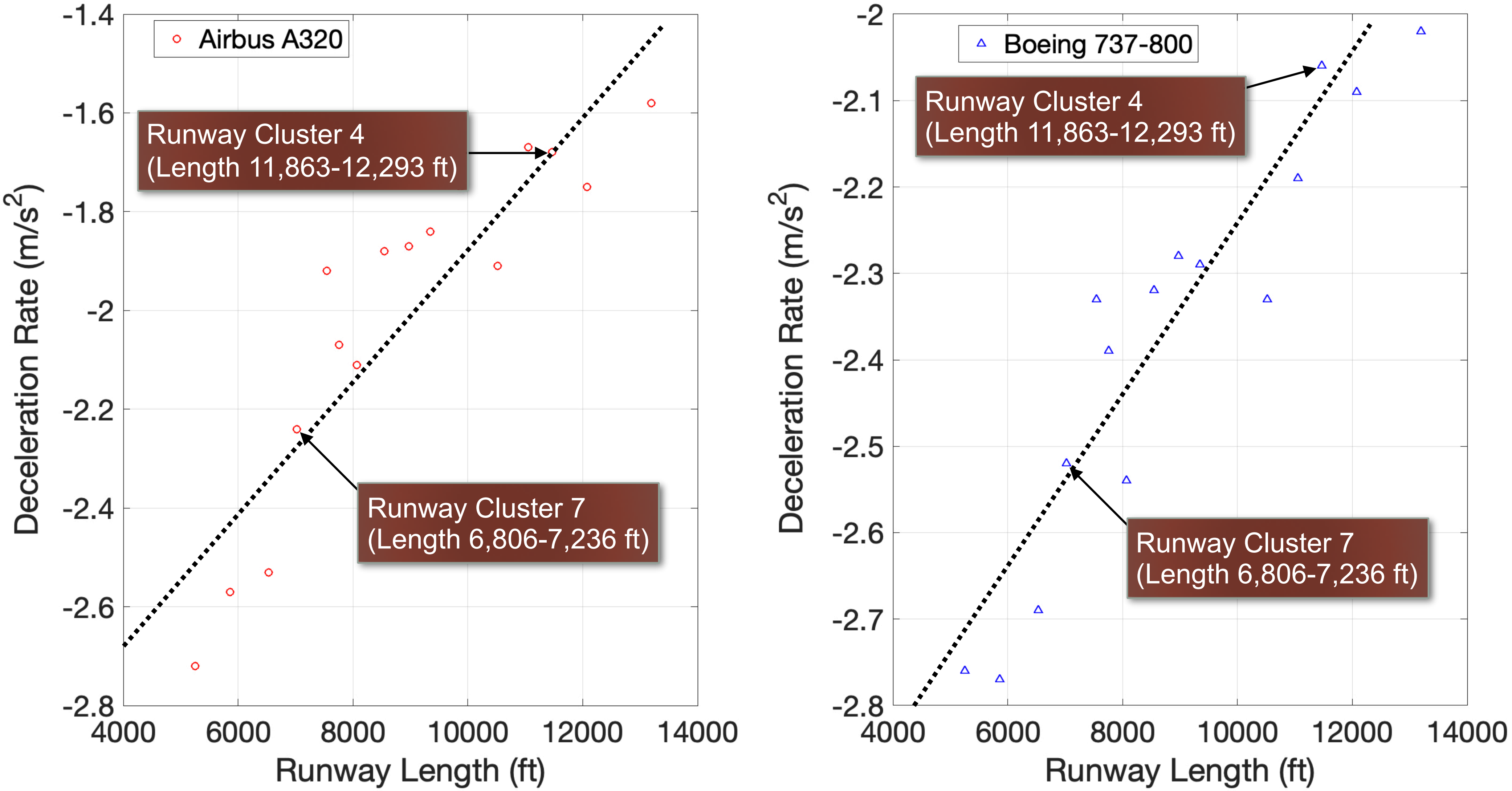




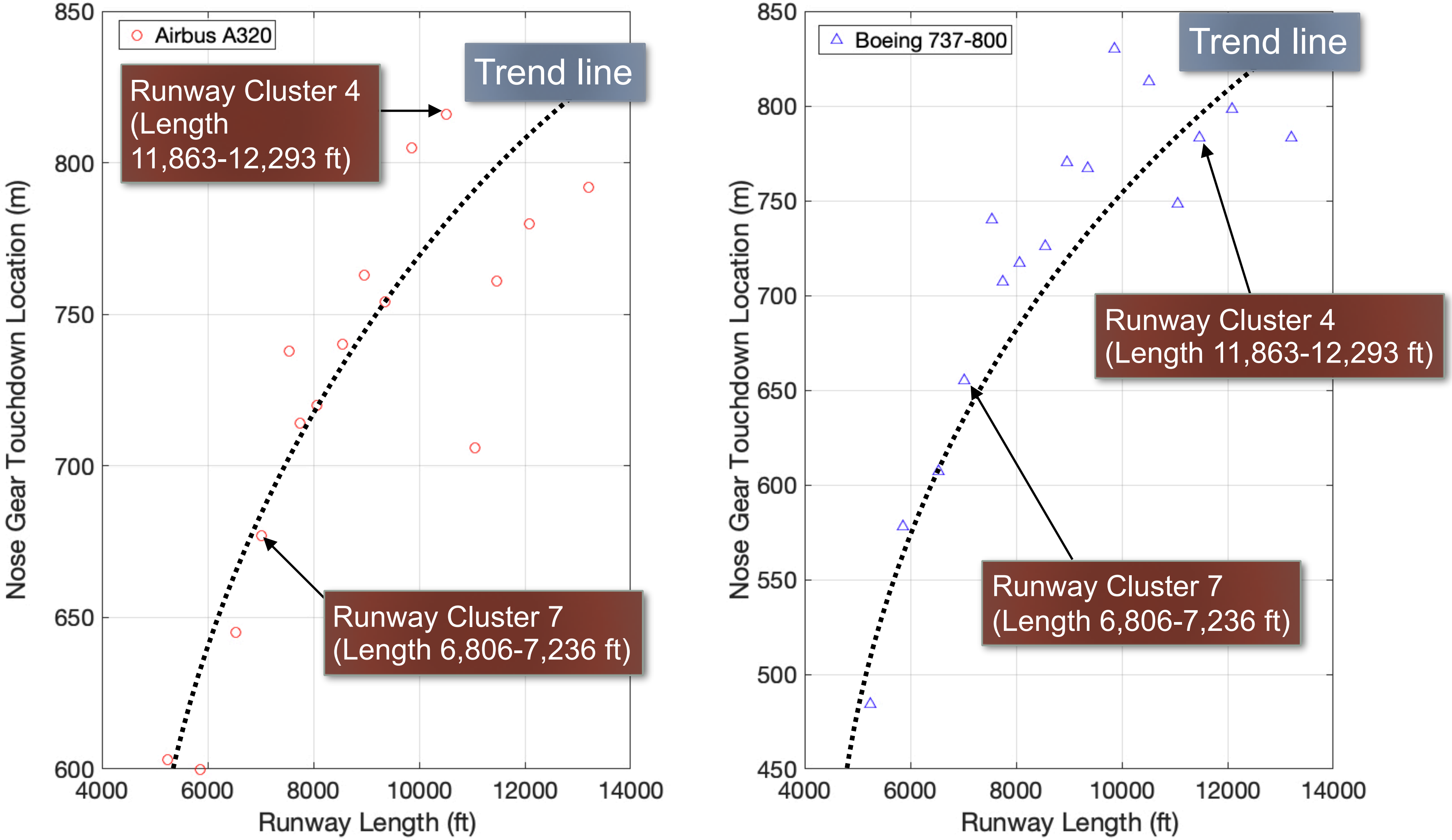


Nominal decelerations and their distributions are different for every runway cluster (i.e., runway length)

Runway Cluster Affects Landing Roll Profile
Mean Deceleration Rates for Narrow Body Aircraft



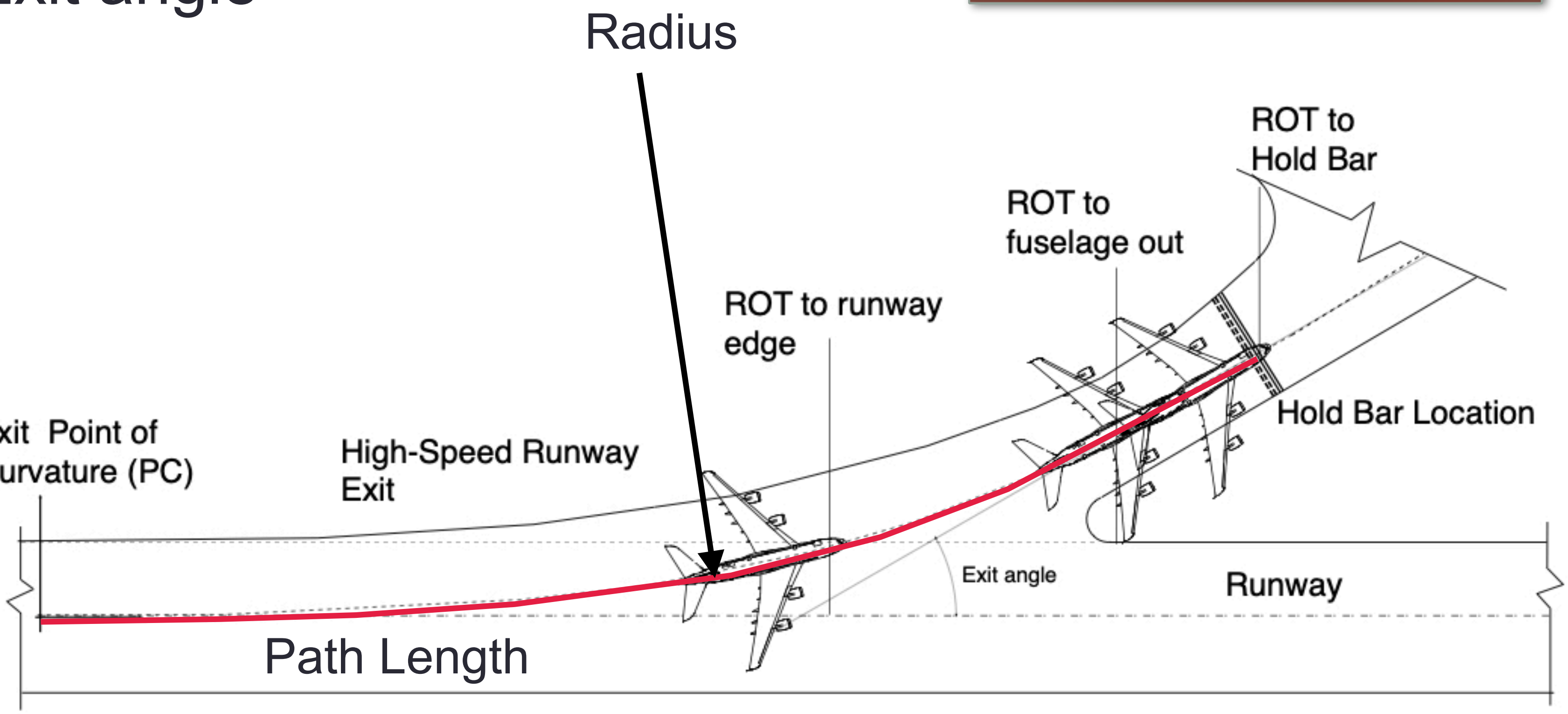
Runway Cluster Effect on Nose Gear Touchdown Locations (Narrow Body Aircraft)



Runway Exit Clusters and Geometry

- Three parameters define the **runway exit cluster**:
  - Radius
  - Path length to hold bar
  - Exit angle

Each runway exit cluster has a distinct aircraft speed behavior



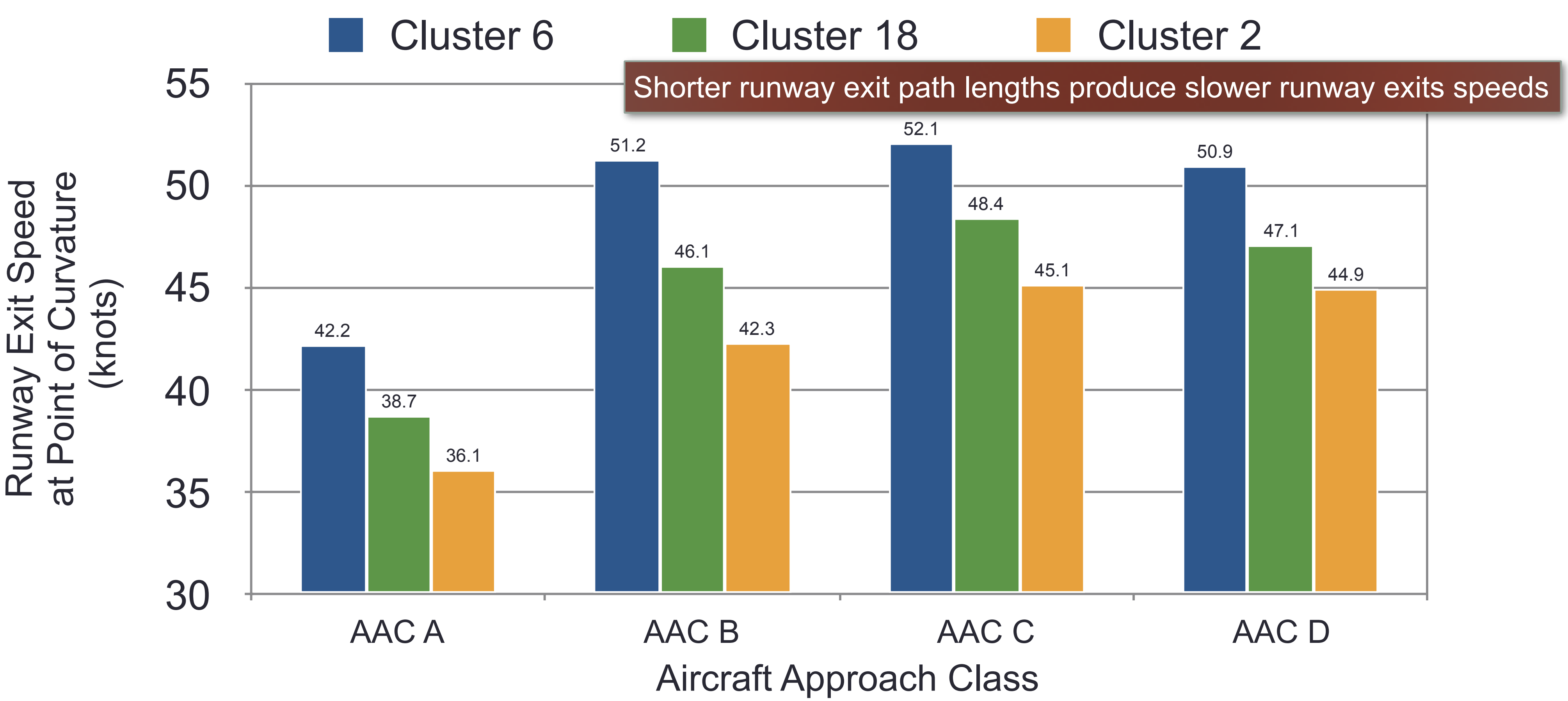
Runway Exit Clusters in REDIM 3

	Angle (deg)		Radius (ft)		Path Length (ft)		Number Of Exits	Type of Runway
Cluster #	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**		Exit
7	50	76	150	590	426	696	55	Intermediate angle, midsize path length
4	25	53	150	600	494	708	59	Acute angle, modest radius, midsize path length
16	30	70	400	900	966	1158	58	Intermediate angle, long path length
17	21	61	300	900	715	956	28	Acute angle, midsize radius, long path length
5	23	53	500	1000	1130	1546	13	Acute angle, midsize radius, long path length
13	28	65	675	1400	584	872	66	Acute angle, long radius, midsize path length
12	30	52	1200	1503	761	1108	37	Acute angle, midsize radius, long path length
2	30	57	1800	1800	677	1043	96	Acute angle, long radius, midsize path length
6	20	30	1400	1800	1233	1684	63	Acute angle, long radius, long path length
18	20	35	1800	1800	1047	1224	95	Acute angle, long radius, long path

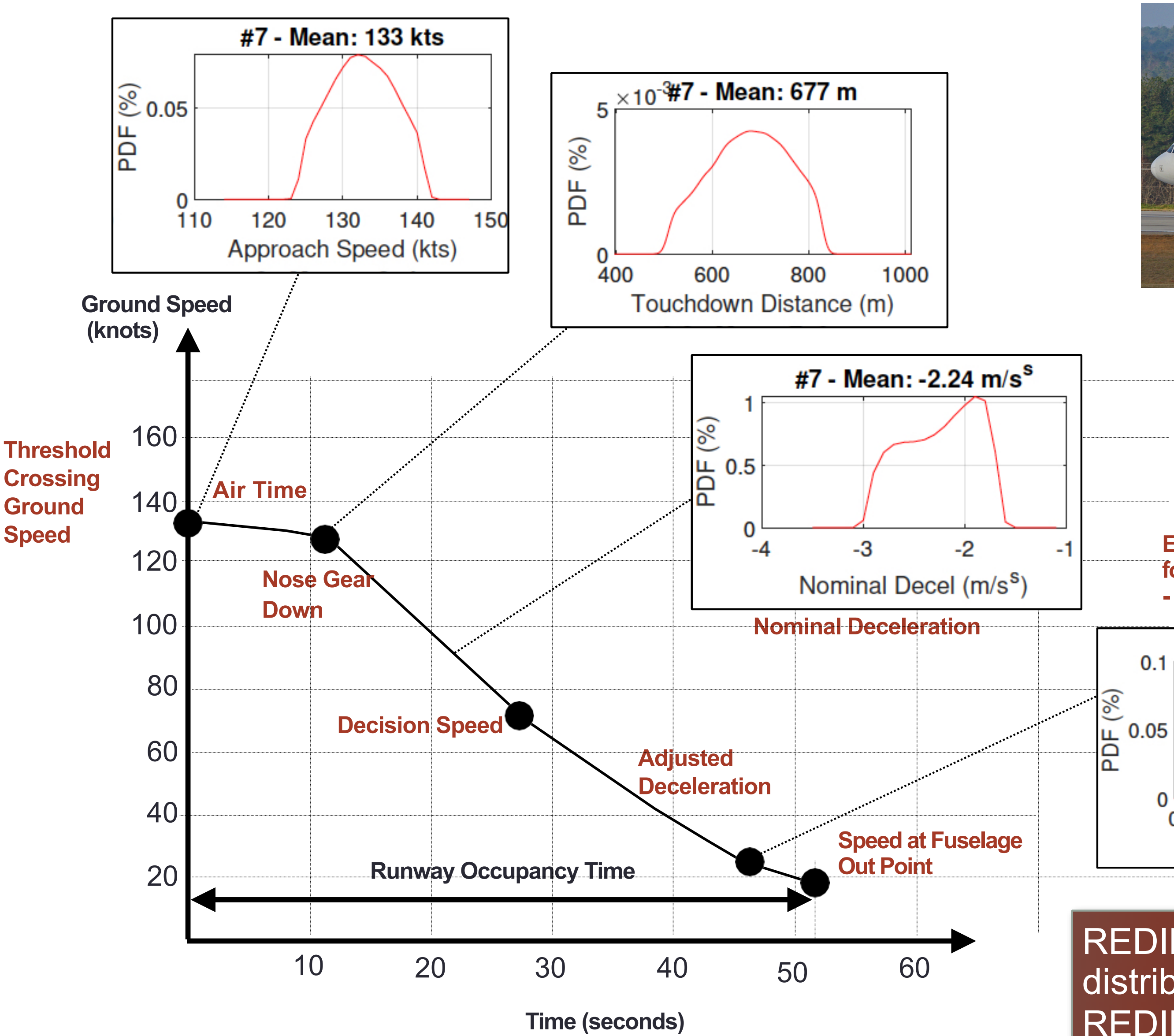
Model uses 20 runway exit clusters to differentiate runway exit characteristics

Effect of Runway Exit Cluster on Exit Speed

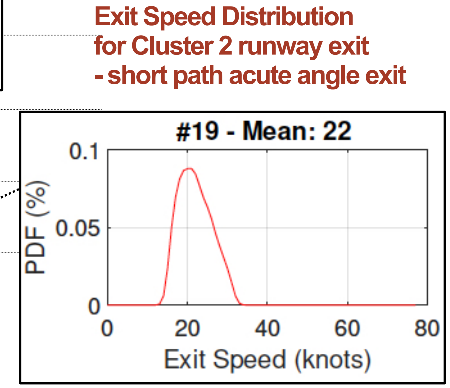
	Angle (deg)		Radius (ft)		Path Length (ft)		Number Of Exits	Type of Runway
Cluster #	Min	Max	Min	Max	Min	Max		Exit
2	30	57	1800	1800	677	1043	96	Acute angle, long radius, midsize path length
6	20	30	1400	1800	1233	1684	63	Acute angle, long radius, long path length
18	20	35	1800	1800	1047	1224	95	Acute angle, long radius, long path length



Monte Carlo Simulation in REDIM 3



Typical distributions for an Airbus A320 landing on a 7,100 ft runway



REDIM 2.1 assumed normally distributed random variables
REDIM 3 uses actual distribution from data collected

REDIM 3 Output (Tabular Form)

- sign a New Runway
- prove an Existing Runway
- aluate an Existing Runway
  - Create New Folder...
  - AAC A Runs
  - AAC C Runs
  - AAC D Runs 9000ft
  - AAC_B_Runs
  - Individual_Acft_Runs
  - Runway13_evaluation
  - Runway19_DCA
    - Start Evaluation...
    - Delete Case Folder
    - Runway19
      - Runway Settings
      - Runway Exit Locations
      - Runway Occupancy Tim
        - Tables
        - Plots
      - Runway Exit Aircraft Ass
      - Landing Components Dis
      - Landing Distances and
        - Tables
        - Plots
      - Edit Runway
      - Delete Runway

Choose Aircraft: A320 | Distances | Times | Speeds & Decelerations

Landing Number	Wet Conditions	Exit	Air Distance (ft)	Braking Distance (ft)	Extra Roll Distance (ft)	Turnoff Distance (ft)	Total Distance (ft)
1		A	2,447	2,154	1,452	258	6,311
2		E-22	2,001	1,963	737	259	4,961
3		E-22	2,000	1,825	877	257	4,958
4		A	2,426	2,596	1,031	260	6,313
5		A	1,846	2,234	1,973	258	6,311
6		Last	2,504	3,216	1,130	258	7,108
7		A	2,366	2,087	1,600	259	6,312
8		A	1,999	2,341	1,713	259	6,312
9		E-22	2,624	1,506	572	259	4,960
10		F_L	2,049	1,655	716	259	4,678
11		A	2,191	2,153	1,709	258	6,311
12		A	2,159	2,010	1,884	259	6,312
13		A	2,247	1,894	1,912	259	6,312
14		E-22	2,054	1,920	727	260	4,961
15	Yes	A	2,232	1,986	1,835	259	6,316
16		A	2,141	2,195	1,717	260	6,313
17		F_L	1,700	1,763	956	258	4,677
18							
19							
20							

Evaluate an Existing Runway - Landing Speeds & Decelerations for A320 (Runway19) - Table

Choose Aircraft: A320 | Distances | Times | Speeds & Decelerations

Landing Speeds Decelerations for A320

(Runway19)

Landing Number	Wet Conditions	Exit	Threshold Crossing Speed (knots)	Touchdown Speed (knots)	Nominal Speed (knots)	Speed at PC (knots)	Nominal Deceleration (m/s^2)	Deceleration to PC (m/s^2)	Deceleration after PC (m/s^2)	Touchdown Speed Coefficient
1		A	132	125	70	16	-2.17	-1.38	-0.34	0.95
2		E-22	132	125	70	22	-2.37	-2.61	-0.34	0.95
3		E-22	129	122	70	23	-2.39	-2.16	-0.34	0.95
4		A	129	122	70	23	-1.69	-1.84	-0.34	0.95
5		A	138	131	70	23	-2.40	-0.96	-0.34	0.95
6		Last	141	134	70	21	-1.77	-1.71	-0.34	0.95
7		A	135	128	70	25	-2.41	-1.17	-0.34	0.95
8		A	130	123	70	24	-1.91	-1.09	-0.34	0.95
9		E-22	127	121	70	28	-2.80	-3.13	-0.34	0.95
10		F_L	131	124	70	22	-2.77	-2.68	-0.34	0.95
11		A	134	127	70	18	-2.29	-1.16	-0.34	0.95
12		A	128	122	70	17	-2.14	-1.06	-0.34	0.95
13		A	126	119	70	20	-2.15	-1.02	-0.34	0.95
14		E-22	140	133	70	24	-2.91	-2.58	-0.34	0.95
15	Yes	A	131	124	70	28	-2.29	-0.97	-0.34	0.95
Average			133	126	70	24	-2.21	-1.62	-0.34	0.95

Save Table | Close

Landing events with a wet runway

Every landing simulated in REDIM 3 is reported in tables

Application of Runway Exit Design Tool to Selected US Airports

Application of the Runway Exit Design Tool to Four Airports

Runway Exit Study
High-Speed Runway Exits at PHL Runway 27L

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Runway Exit Study
Charles B. Wheeler Downtown Airport (MKC)

VirginiaTech
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Runway Exit Analysis of Boston Logan Airport

Air Transportation Systems Laboratory

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Runway Exit Analysis of Denver International Airport

Air Transportation Systems Laboratory

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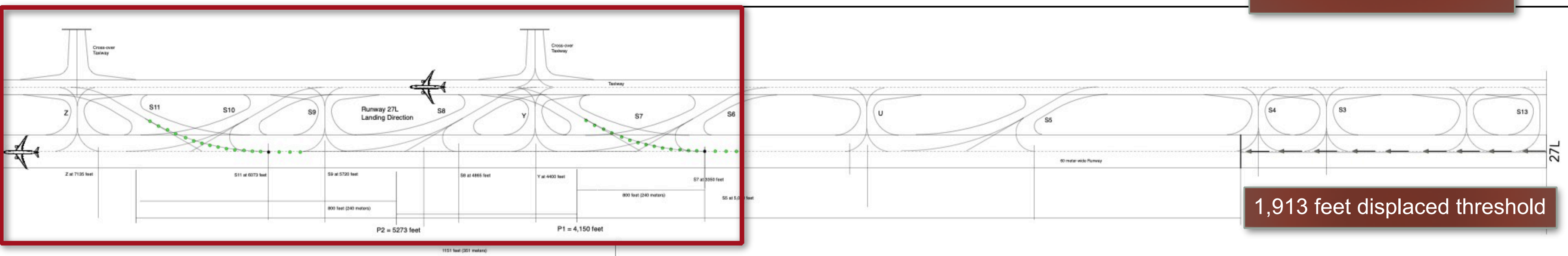
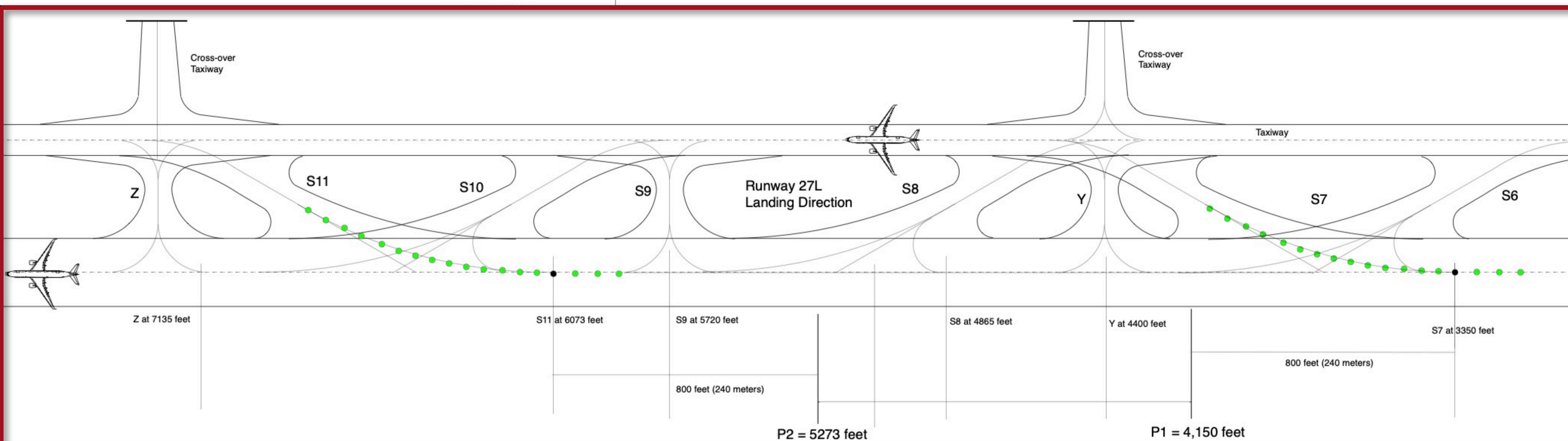
PHL Runway 27L

- S7 located at 3,350 feet from threshold
- S11 located at 6,073 feet from threshold
- Earliest PC of new high-speed runway exit ~ 4150 feet
- Furthest PC of new high-speed runway exit ~ 5273 feet

If 800 feet is the minimum distance to locate two high-speed exits

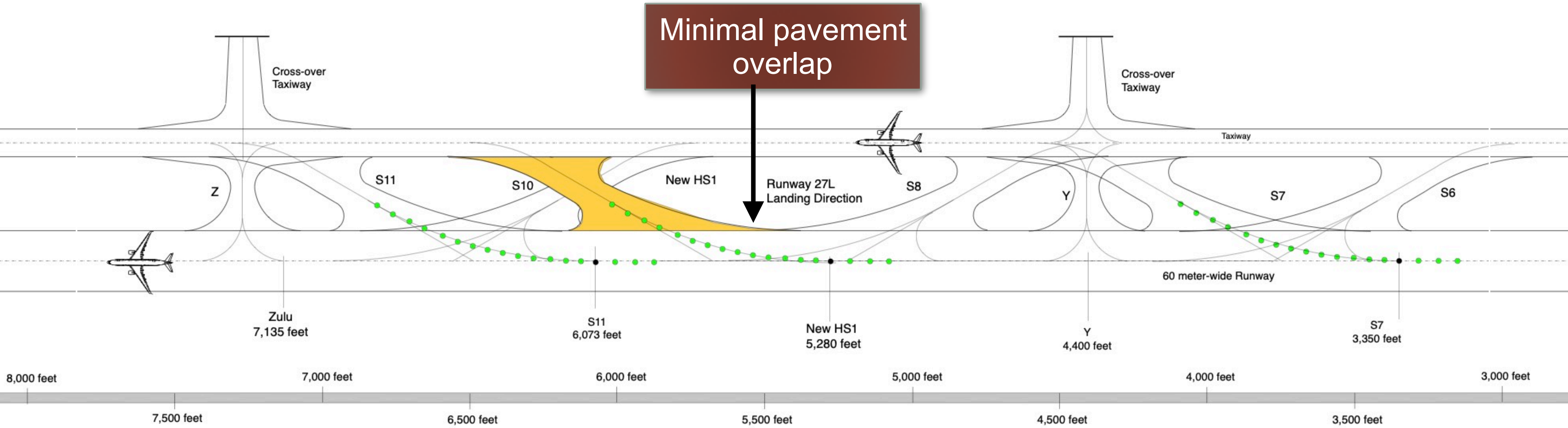




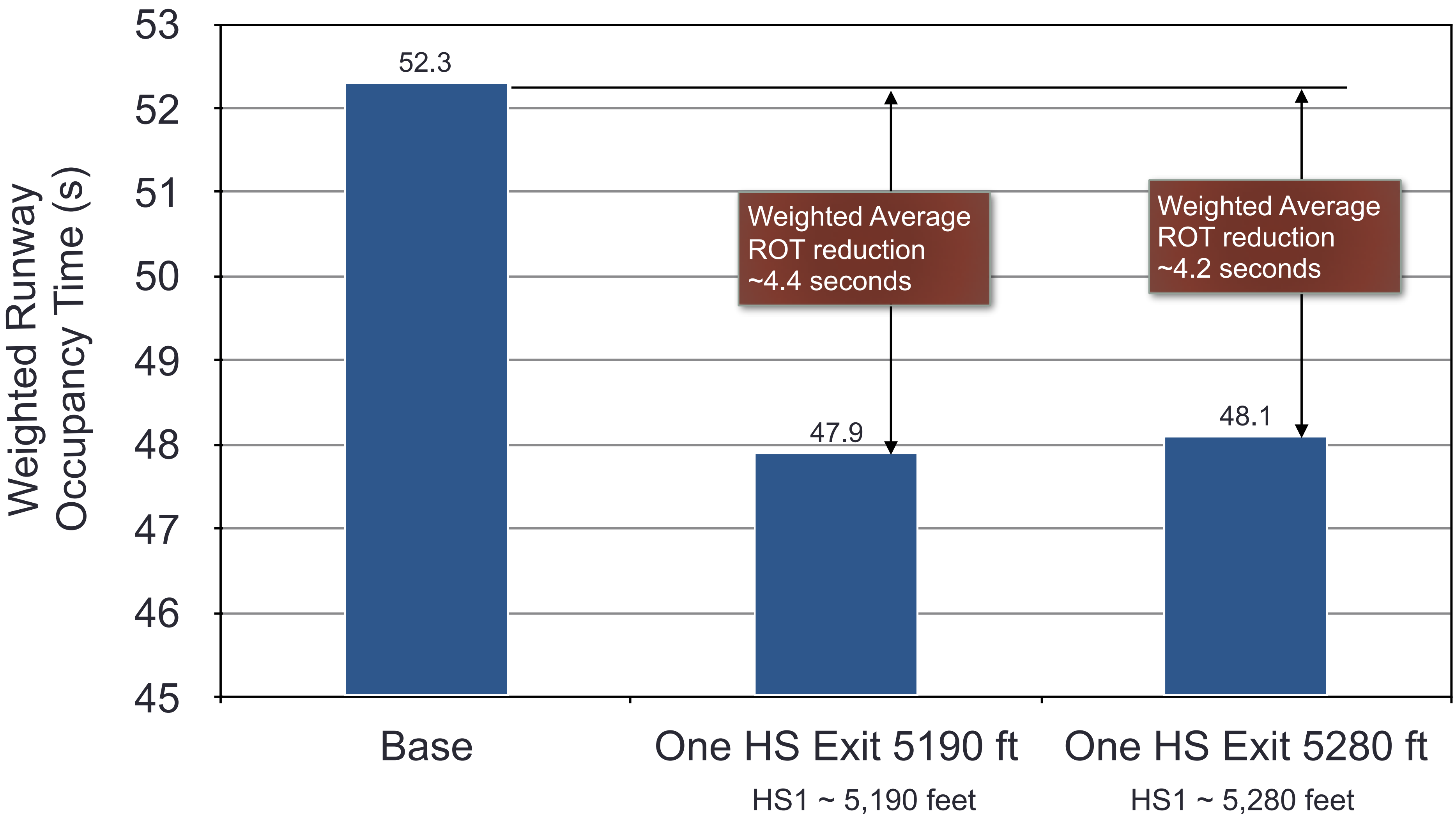
Case: One New High-Speed Runway Exit, 20/80 (wet/dry pavement design)

- Optimal location of a **new High-Speed Runway exit** designed for 20/80% wet/dry pavement conditions is **5,280 feet** (point of curvature)
- Runway exit Sierra-9 is eliminated
- **793 feet** - distance between new exit high-speed exit HS2 and Sierra-11

Optimally located runway exit in yellow

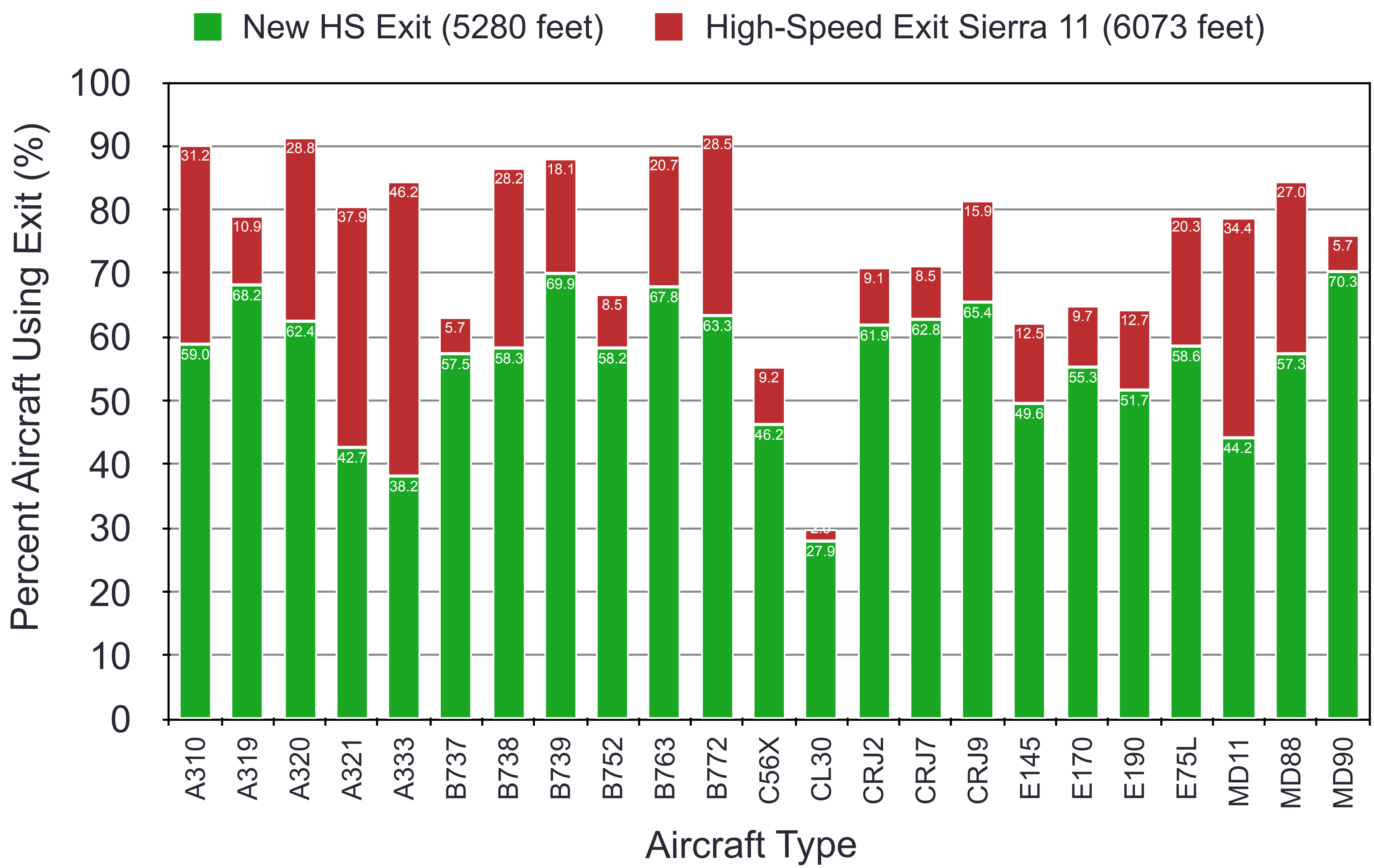


An Optimally Located High-Speed Runway Exit at PHL Runway 27L Could Reduce the Weighted Average Runway Occupancy Time by 4.4 to 4.2 Seconds

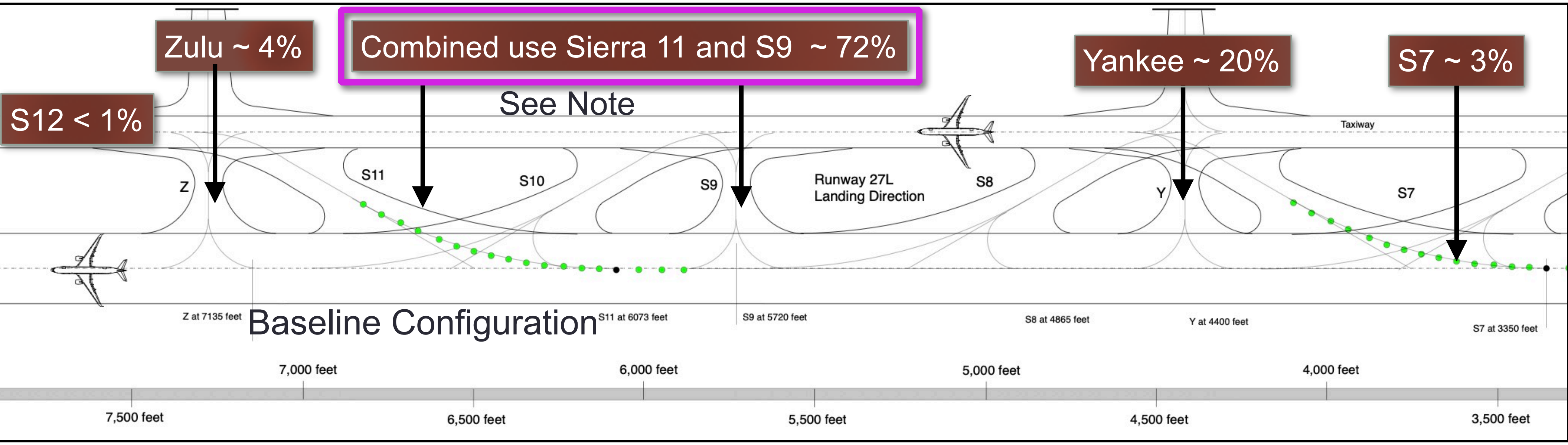


PHL Fleet Mix (Jan/2018 to Aug/2019) provided by FAA

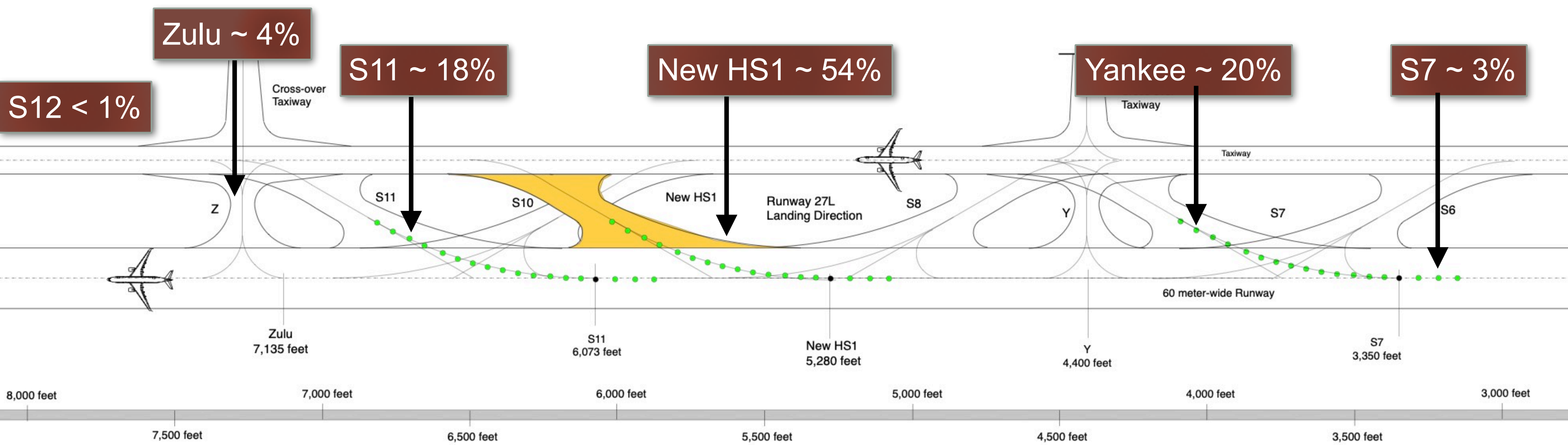
54% of Landings on Runway 27L Could Use the New High-Speed Exit at 5,280 feet (20/80 wet/dry Design Scenario)



Runway Exit Use with High-Speed Runway at PHL 27L



Baseline Configuration



Optimal High-Speed Exit at 5,280 feet

Contact Information

- For more information or questions about the tools presented you can contact us:
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- Nick Hinze (nhinze@vt.edu)