



# Runway Exit Design Tool (REDIM 3 Model)

## Example Computer Model that Uses Monte Carlo Simulation



**A. Trani, N. Hinze, N. Mirmohammadsadeghi, H. Swingle**  
**September 21, 2020**





# Acknowledgments

- **Project supported by the Federal Aviation Administration (FAA)**
- **FAA Project Technical Monitors: Kent Duffy and Lauren Vitagliano**
- Project of the National Center of Excellence for Aviation Operations Research (NEXTOR 2)
  
- Special thanks to:
  - Tom Tessitore (FAA)
  - Chicago Department of Aviation (Ginger Evans)
  - Charlotte-Douglas International Airport (Jack Christine)
  - Metropolitan Washington Airports Authority (Jennifer Dermody)



# 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)

REDIM - [REDIM]

File Window Help

## REDIM

Version 3.0.0

**Virginia Tech - Air Transportation Systems Lab**

Dr. Antonio Trani (Team Leader)	Mani Bhargava Reddy Bollempalli
Nicolas Hinze (Team Co-Leader)	Mihir Rimjha
Navid Mirmohammadsadeghi	Arman Izadi

**FAA - Project Sponsors**

Kent Duffy	FAA Airports Planning and Environmental Division (APP-400)
Lauren Vitagliano	FAA William J. Hughes Technical Center



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### Runway Exit Design Interactive Model (REDIM)



REDIM is a computer model developed to locate and design high-speed runway exits at airports. The model uses kinematic equations to characterize the aircraft landing dynamics and a polynomial-time dynamic programming algorithm to find the optimal locations of the high-speed exits. The objective of the optimization algorithm is to minimize the weighted average runway occupancy time (ROT) of an aircraft mix selected by the user. A database of aircraft characteristics for four terminal Aircraft Approach Categories (AAC) has been included in the model to facilitate its use in a large variety of airport environments and conditions. The database file relieves the user's data-input burden, specially when the aircraft mix consists of many different types of aircraft. The program is developed to be used as a design and a planning instrument by engineers. Hence, considerable effort has been devoted to user interface such as menu system, interactive data editing, and graphical and tabular outputs.

**Download REDIM 3**

- [REDIM 3.0.1](#) - Windows Installer
- [User Manual](#)

**Download Landing Events Database**

- [Landing Events Database 1.2.2](#) - Windows Installer
- [User Manual](#)

**Download REDIM 2**

- [REDIM 2.1](#)

The Runway Exit Design Tool can be downloaded at:

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



# Runway Exit Design Tool Objectives

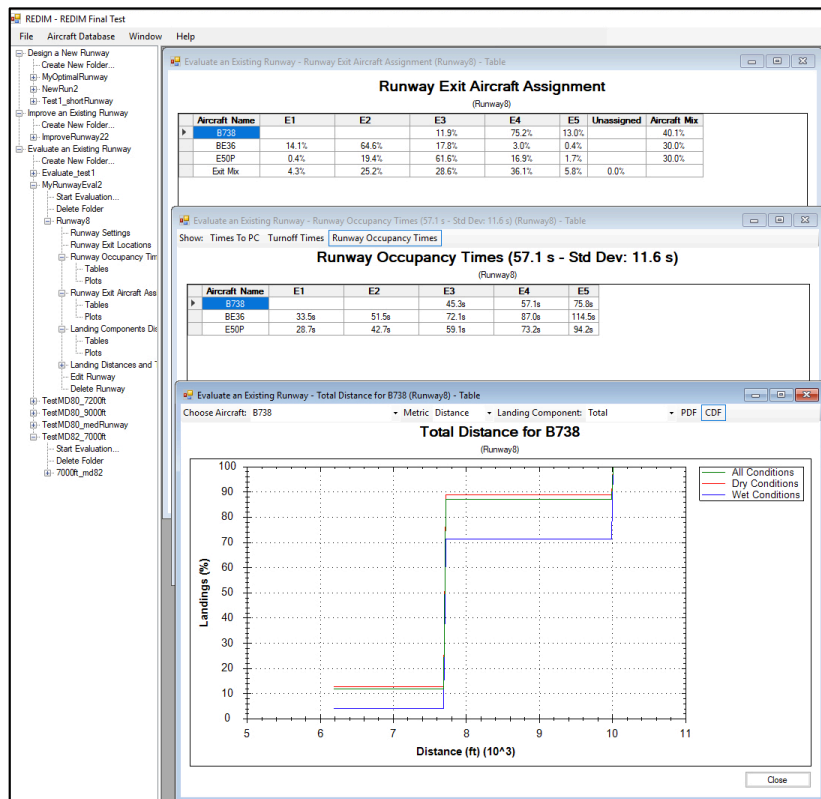
- Predict runway occupancy times at any airport given a fleet mix , runway length, runway exits and airport environmental conditions
- Help airport designers locate new runway exits to reduce runway occupancy time





# 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
<b>Aircraft Mix</b>	Provides an overview of aircraft fleet mix	Percent of aircraft types simulated in the analysis
<b>Runway Occupancy Time</b>	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)
<b>Runway Exit Utilization</b>	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
<b>Aircraft Landing Performance</b>	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



# 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

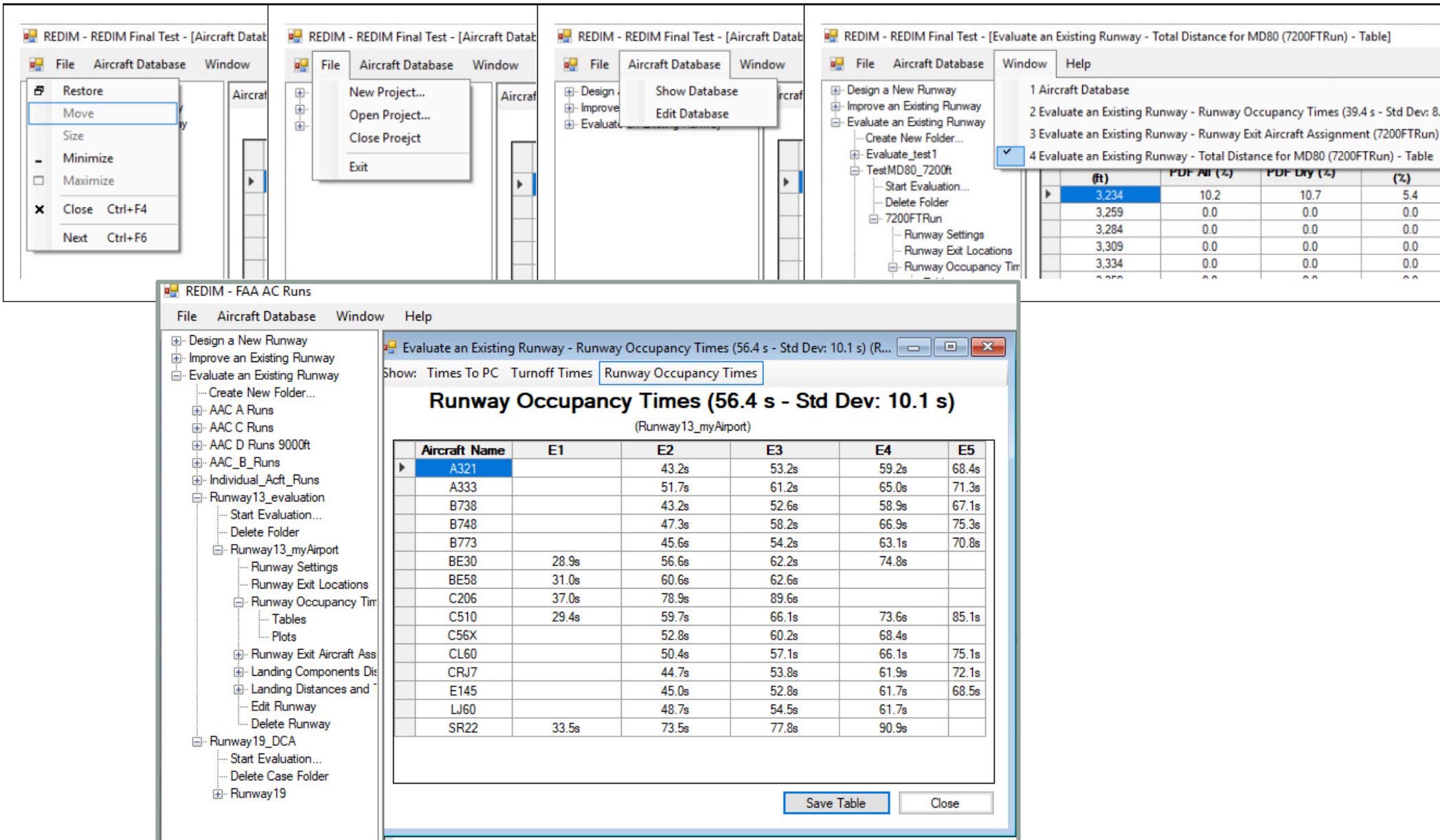
Aircraft Design Group (ADG): I

**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



The screenshot displays the REDIM 3 software interface with several windows open. The main window shows a project tree on the left and a data table on the right. The table displays runway occupancy times for various aircraft types across five evaluation points (E1 to E5).

**Runway Occupancy Times (56.4 s - Std Dev: 10.1 s)**  
(Runway13\_myAirport)

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

**Runway Exit Aircraft Assignment**  
(Runway8)

Aircraft Name	E1	E2	E3	E4	E5	Unassigned	Aircraft Mix
B738			11.9%	75.2%	13.0%		40.1%
BE36	14.1%	64.6%	17.8%	3.0%	0.4%		30.0%
E50P	0.4%	19.4%	61.6%	16.9%	1.7%		30.0%
Exit Mix	4.3%	25.2%	28.6%	36.1%	5.8%	0.0%	

**Runway Exit Locations**  
(Runway8)

Exit	Exit Status	Exit Type	Location (ft)
E1	Open	90°	2,500
E2	Open	90°	3,999
E3	Open	30° (with 1,500 ft circular arc)	5,499
E4	Open	90°	7,500
E5	Open	90°	9,800

**Runway Occupancy Times (57.1 s - Std Dev: 11.6 s)**  
(Runway8)

Aircraft Name	E1	E2	E3	E4	E5
B738			45.3s	57.1s	75.8s
BE36	33.5s	51.5s	72.1s	87.0s	114.5s
E50P	28.7s	42.7s	59.1s	73.2s	94.2s

**Total Distance for B738**  
(Runway8)

**Runway Occupancy Times (57.1 s - Std Dev: 11.6 s)**  
(Runway8)

Exit	BE36 (s)	E50P (s)	B738 (s)
E1	33.5	28.7	
E2	51.5	42.7	
E3	72.1	59.1	45.3
E4	87.0	73.2	57.1
E5	114.5	94.2	75.8



# Interface and Panels in the Runway Exit Design Model

The screenshot displays the REDIM - FAA AC Runs software interface. On the left is a navigation tree with various project folders and sub-items. The main window shows two panels: a table of Runway Occupancy Times and a corresponding bar chart.

**Table: Runway Occupancy Times (33.7 s - Std Dev: 4.4 s)**

Aircraft Name	e1	e2	e3	e4	e5	e6	e7
BE33		21.8s	24.7s	27.4s	30.3s	33.2s	36.0s
BE35		21.4s	24.6s	27.7s	30.6s	33.3s	36.2s
BE36		21.2s	24.1s	26.6s	29.7s	32.5s	35.6s
C152			25.3s	28.6s	31.7s	34.7s	38.1s
C172			25.4s	28.5s	31.7s		
C177		21.2s	24.6s	27.5s	30.8s		
C182		21.2s	24.3s	27.5s	30.5s		
C206	17.5s	21.0s	24.5s	27.1s	30.3s		
C208	18.6s	21.7s	24.6s	27.4s	30.1s		
C210	18.0s	20.4s	24.4s	27.0s	30.1s		
COL4		20.1s	24.6s	26.6s	29.5s		
DA40		21.6s	23.8s	27.1s	30.3s	33.4s	36.7s
M20P	18.1s	21.2s	23.7s	26.7s	29.6s	32.5s	35.8s
P28A	18.4s	21.5s	24.4s	27.6s	30.5s	33.6s	36.9s
P32R	18.0s	21.0s	23.9s	26.4s	29.0s	31.9s	34.2s

**Bar Chart: Runway Occupancy Times (33.7 s - Std Dev: 4.4 s)**

The bar chart displays Runway Occupancy Time (s) on the y-axis (0 to 50) against Exit (e1 to e7) on the x-axis. A legend on the right identifies the aircraft types: BE33 (red), BE35 (blue), BE36 (green), C152 (purple), C172 (cyan), C177 (pink), C182 (light blue), C206 (grey), C208 (dark green), C210 (yellow), COL4 (orange), DA40 (dark blue), M20P (light green), P28A (purple), and P32R (cyan). The chart shows that occupancy times generally increase from e1 to e7, with a notable peak at e7 for several aircraft types.

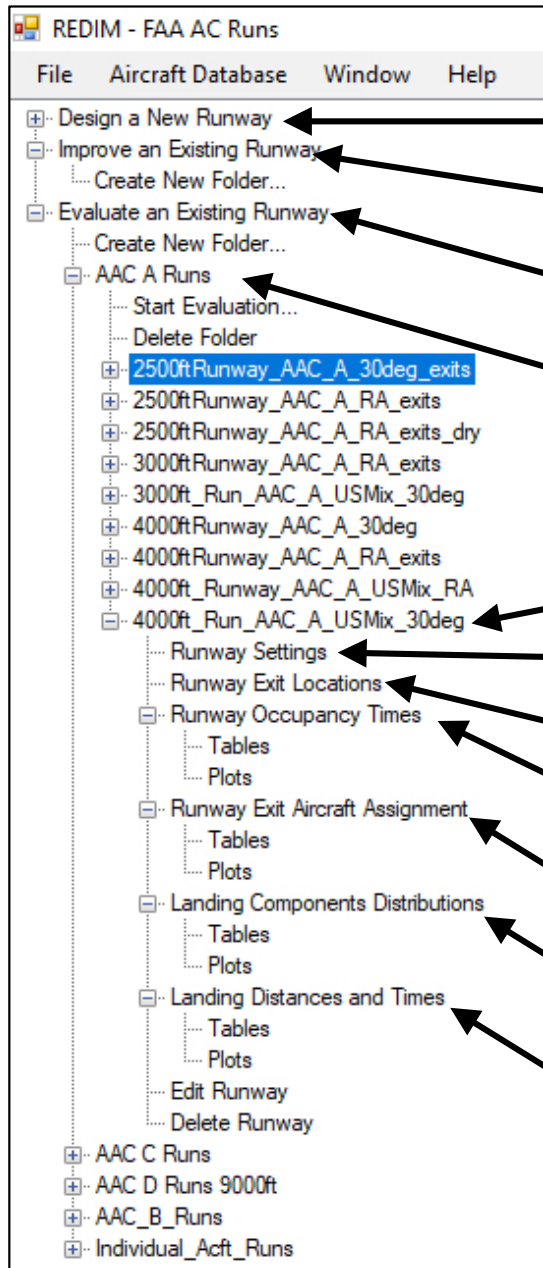
Tables with relevant model results

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)

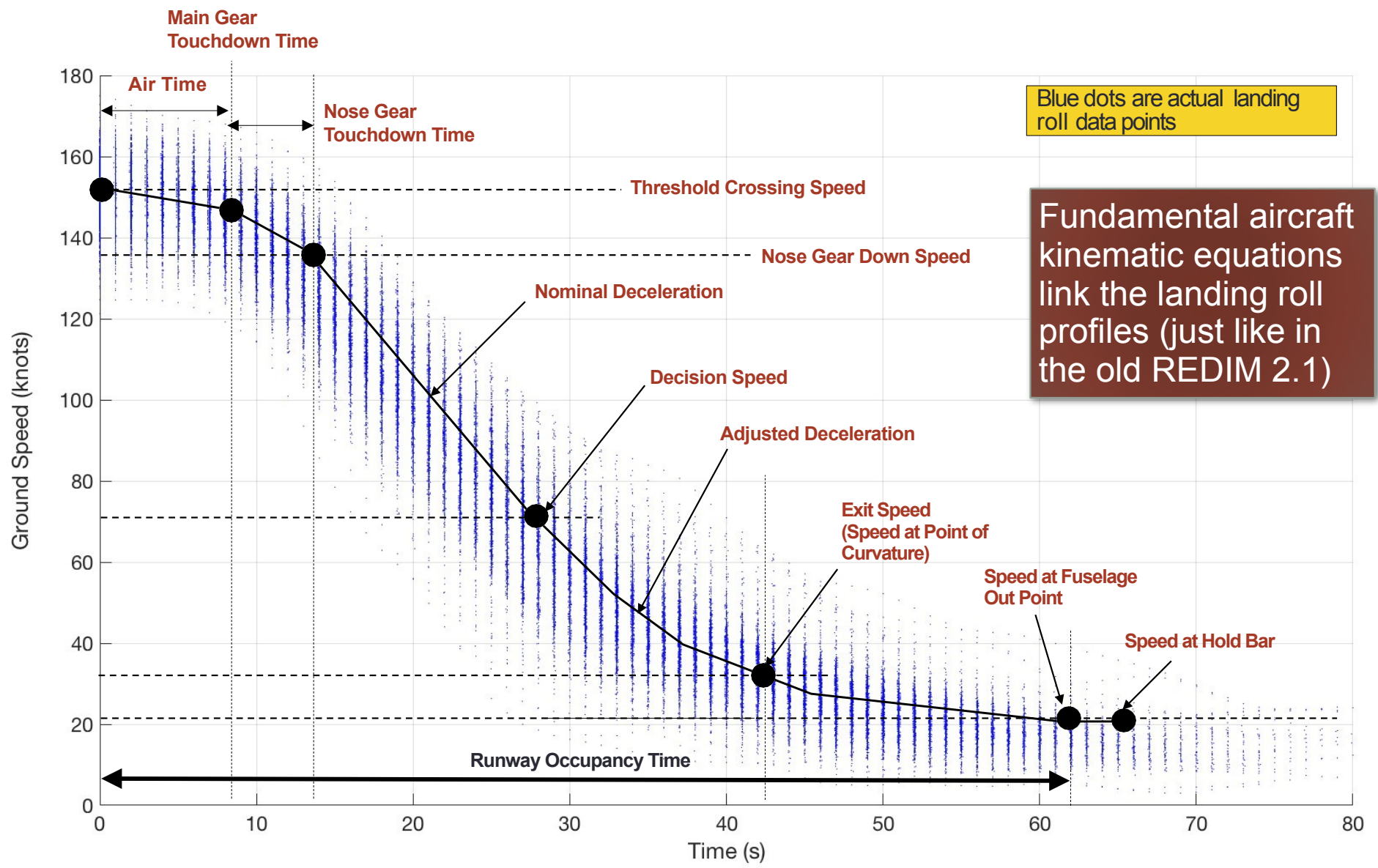
Aircraft landing distributions (tables and plots)

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

Cluster #	Runway Length (ft)		Number Of Runways
	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	
18	10950	11145	
15	11377	11553	
4	11863	12293	
2	12962	13436	10
12	16020	16020	2
<b>Total</b>			<b>292</b>

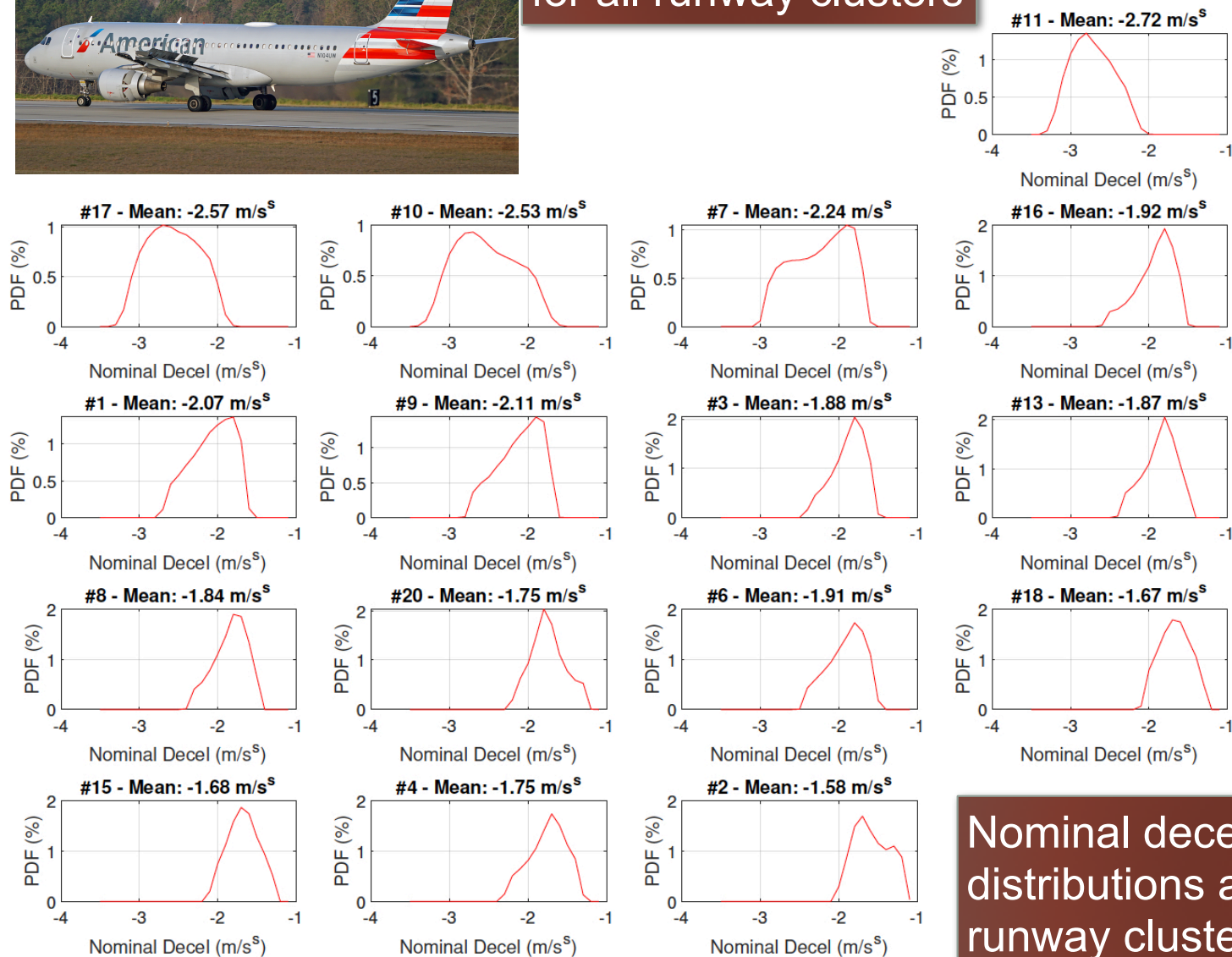
Runway clusters influence the landing roll behavior



# Model Uses Individual Aircraft Data



Airbus A320 Data  
for all runway clusters

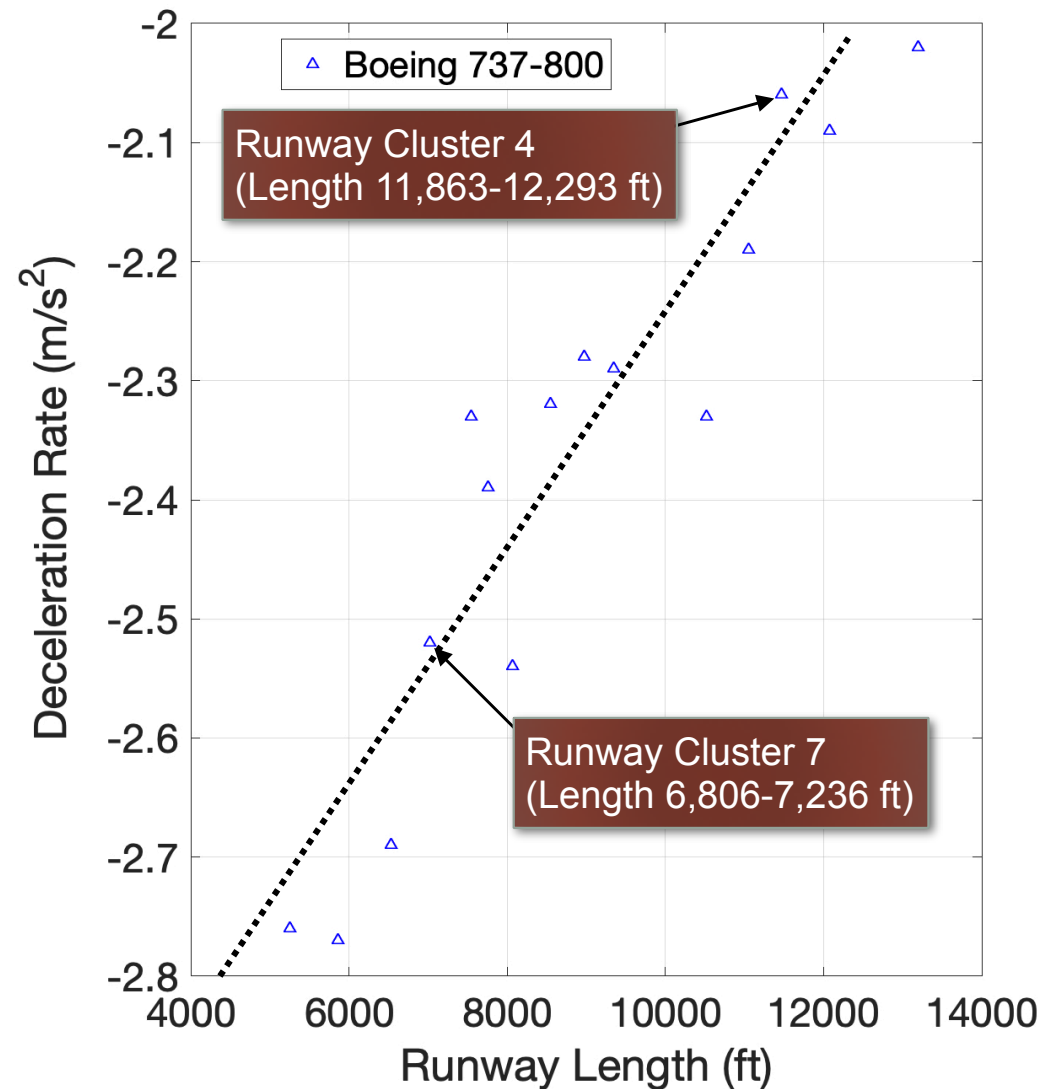
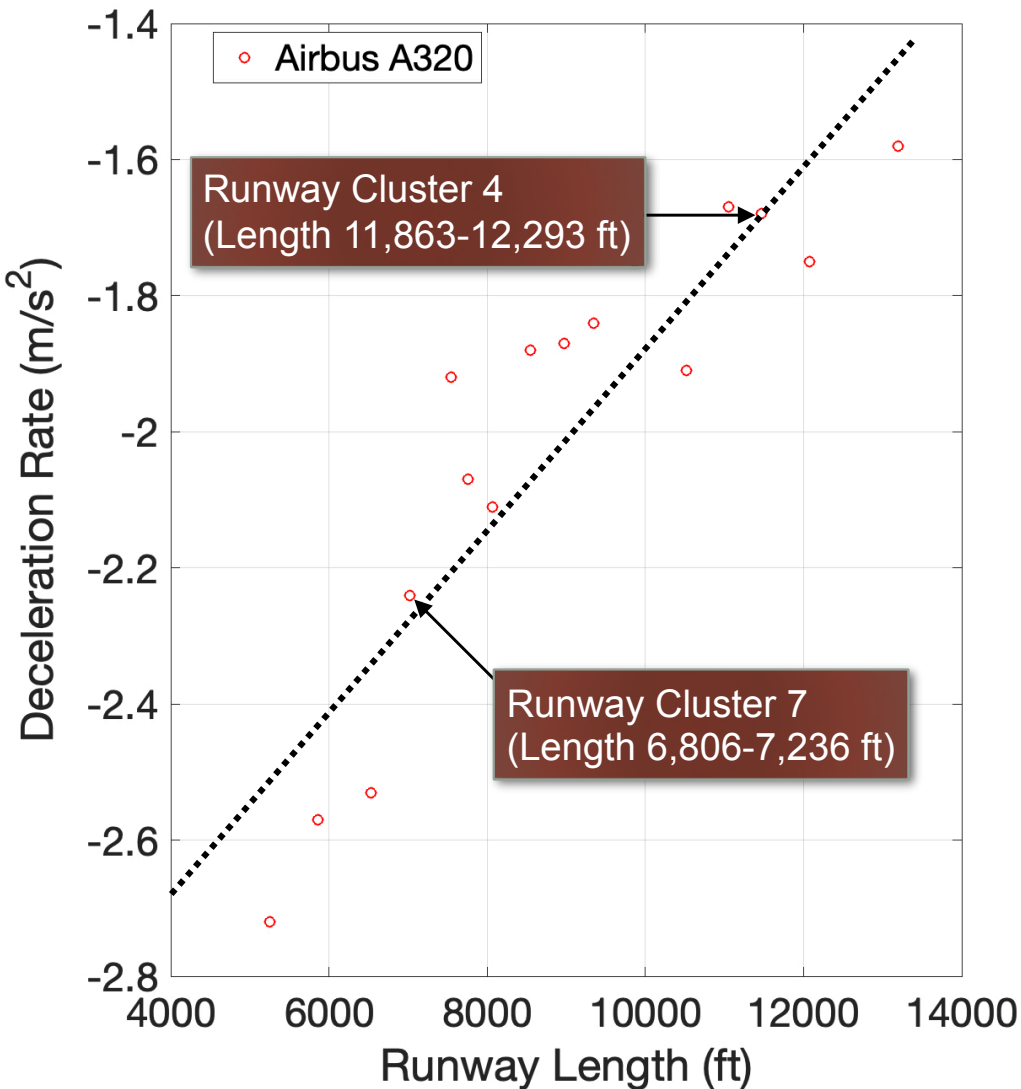


Nominal decelerations and their distributions are different for every runway cluster (i.e., runway length)



# Runway Cluster Affects Landing Roll Profile

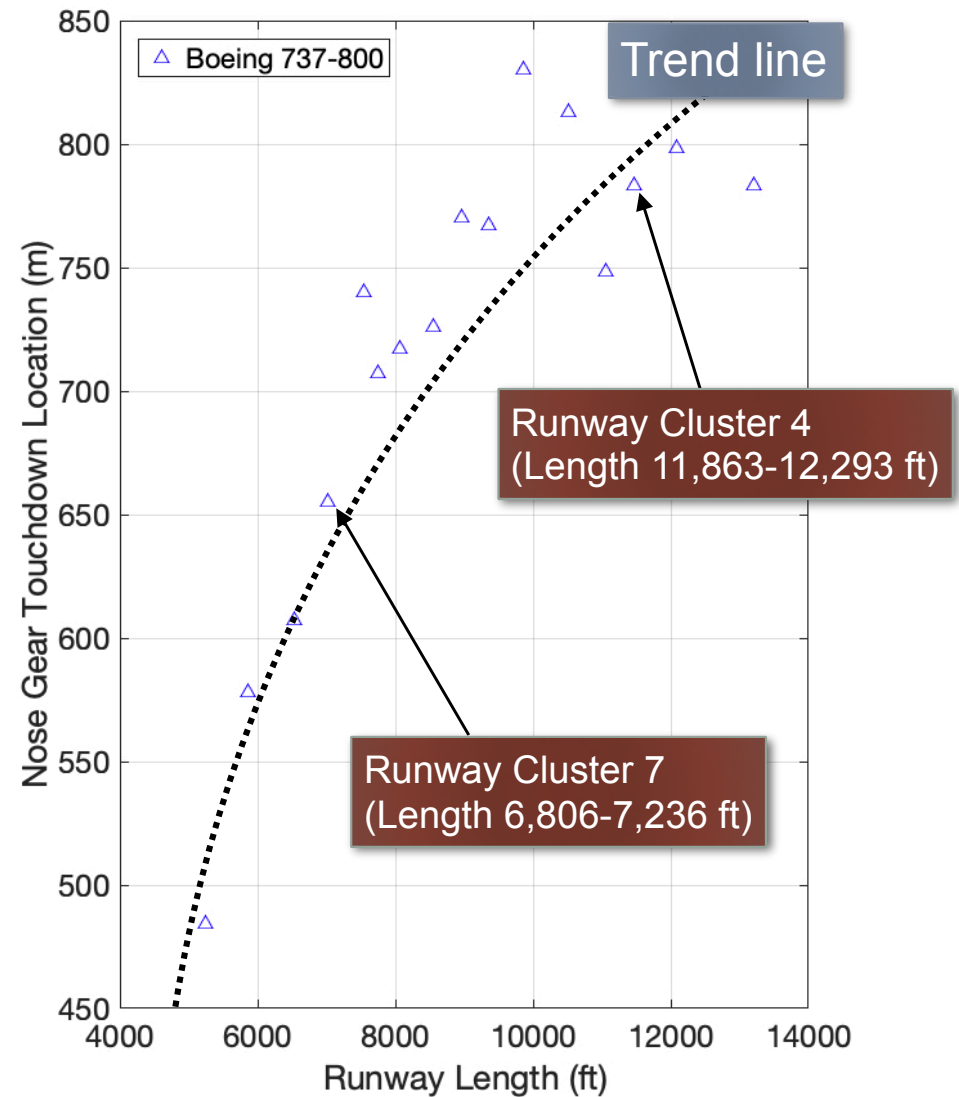
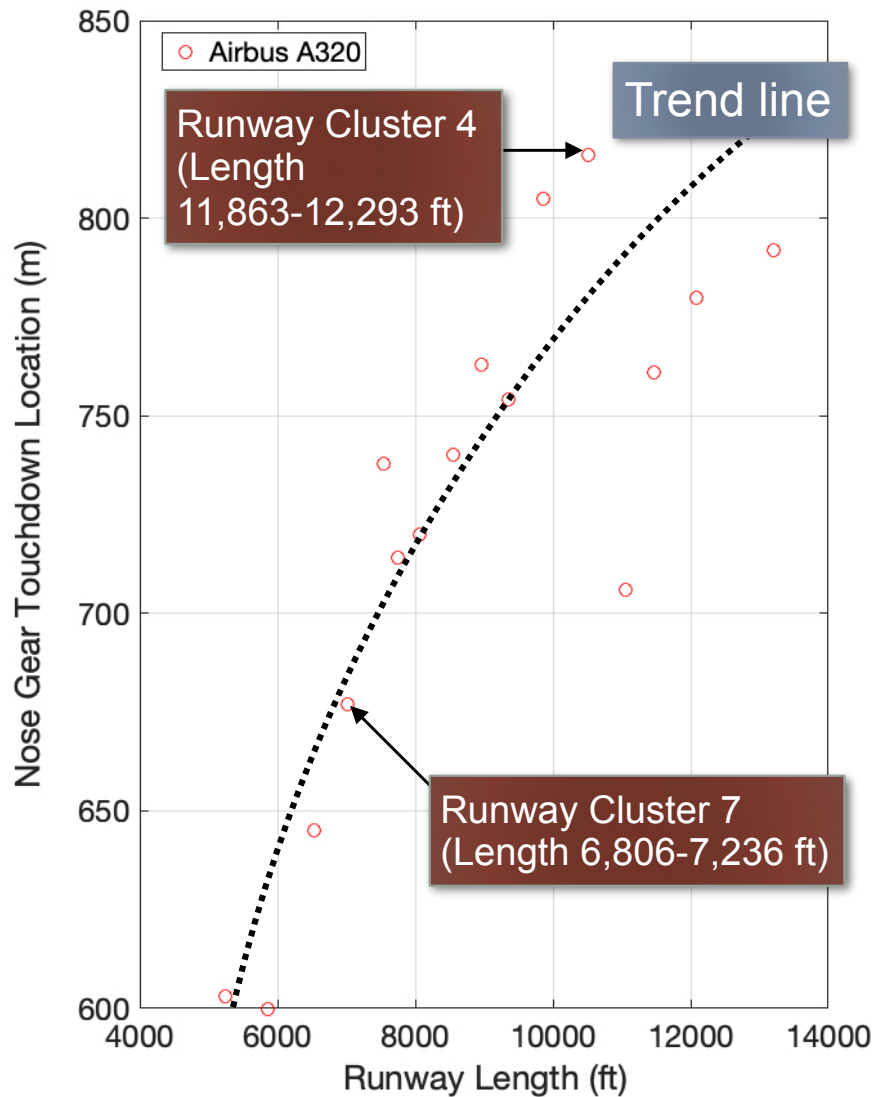
## Mean Deceleration Rates for Narrow Body Aircraft







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

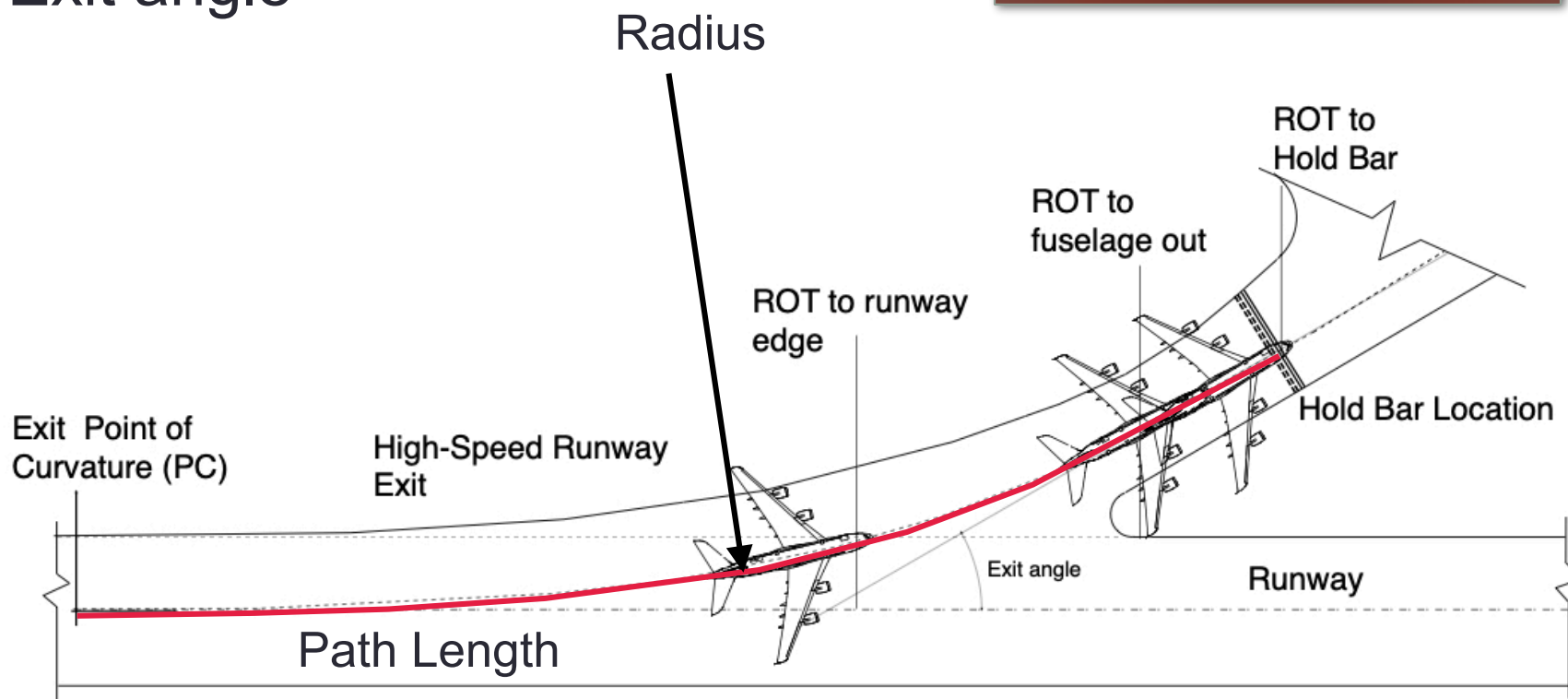




# Runway Exit Clusters and Geometry

- 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

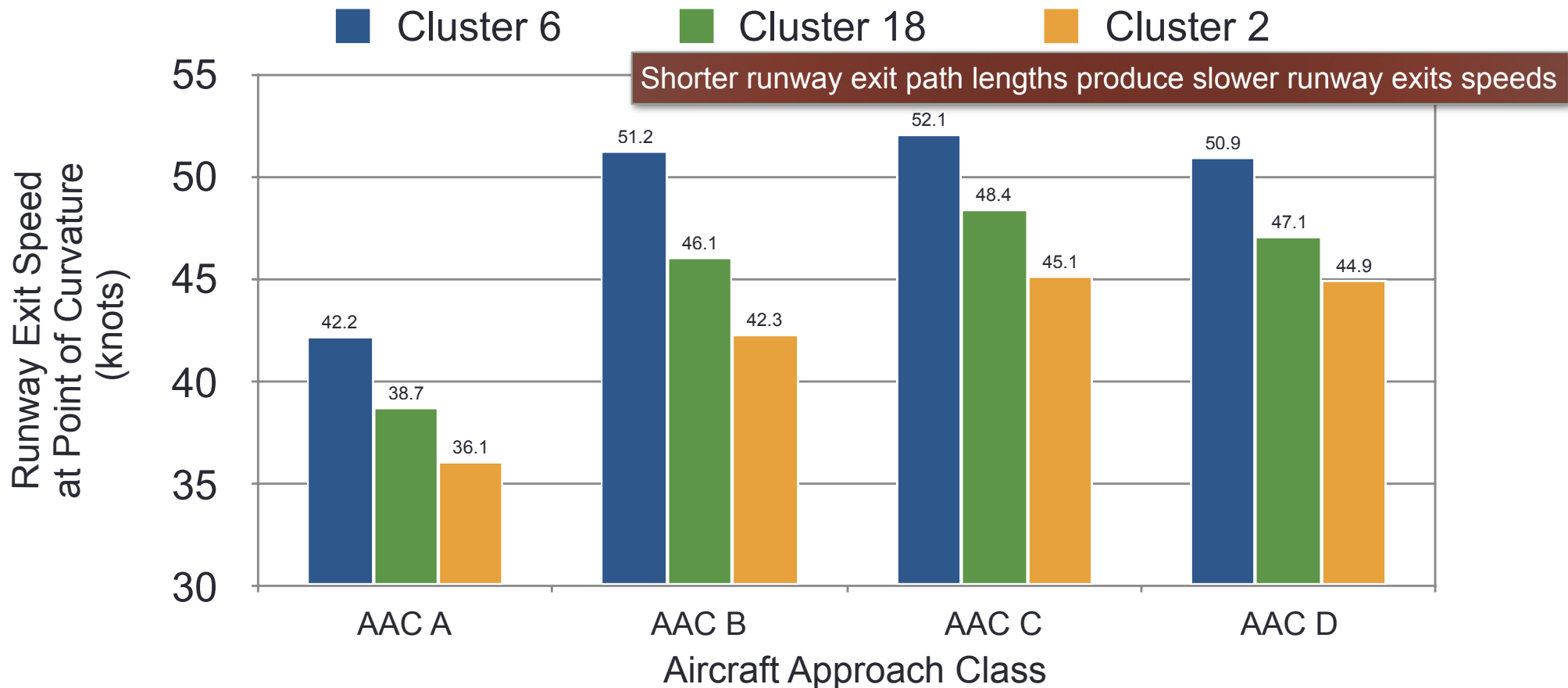
Cluster #	Angle (deg)		Radius (ft)		Path Length (ft)		Number Of Exits	Type of Runway
	Min	Max	Min	Max	Min	Max		Exit
7	50	76	150	590	426	696	55	Intermediate angle, midsize path length
4	25	53	150	600	494	708	59	Acute angle, modest radius, midsize path length
16	30	70	400	900	966	1158	58	Intermediate angle, 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 length

Model uses 20 runway exit clusters to differentiate runway exit characteristics



# Effect of Runway Exit Cluster on Exit Speed

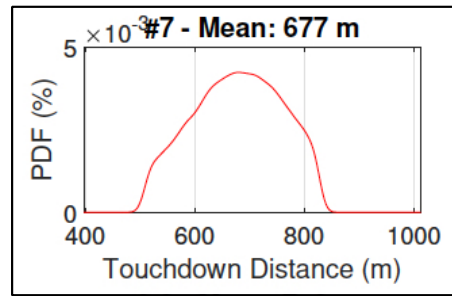
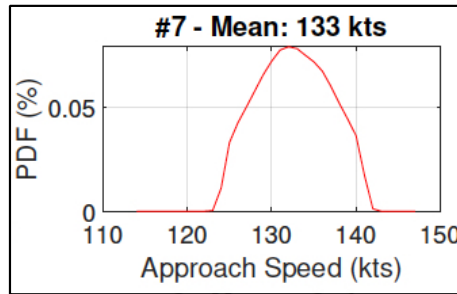
Cluster #	Angle (deg)		Radius (ft)		Path Length (ft)		Number Of Exits	Type of Runway Exit
	Min	Max	Min	Max	Min	Max		
2	30	57	1800	1800	677	1043	96	Acute angle, long radius, midsize path length
6	20	30	1400	1800	1233	1684	63	Acute angle, long radius, long path length
18	20	35	1800	1800	1047	1224	95	Acute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



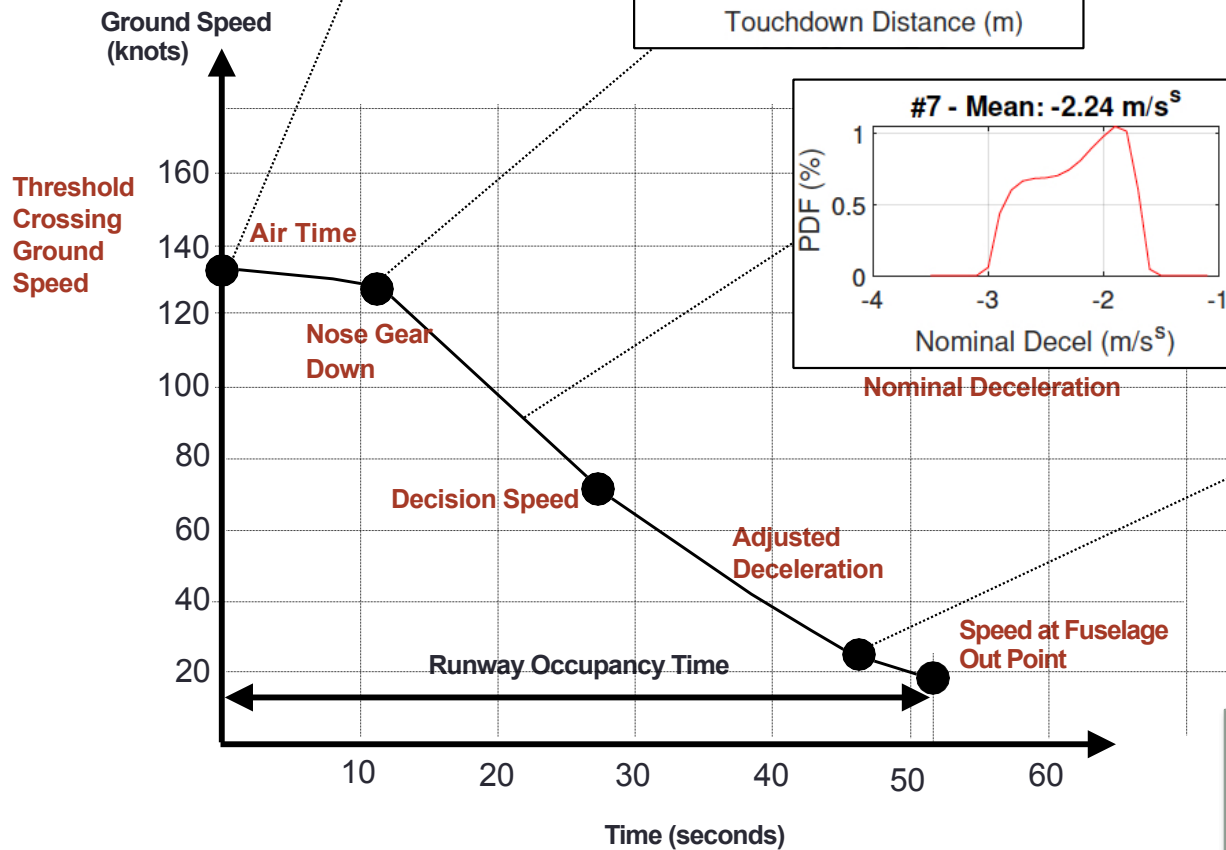




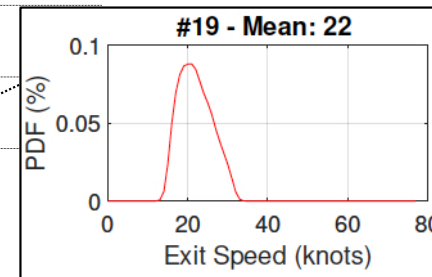
# Monte Carlo Simulation in REDIM 3



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



Exit Speed Distribution for Cluster 2 runway exit - short path acute angle exit



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



# REDIM 3 Output (Tabular Form)

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							

Landing events with a wet runway

Every landing simulated in REDIM 3 is reported in tables

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 <sup>2</sup> )	Deceleration to PC (m/s <sup>2</sup> )	Deceleration after PC (m/s <sup>2</sup> )	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



# 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



N. Mirmohammadsadeghi, N. Hinze and A. Trani  
November 7, 2019



## Runway Exit Analysis of Boston Logan Airport



N. Mirmohammadsadeghi, N. Hinze and A. Trani  
November 15, 2019



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



A. Trani, N. Hinze and N. Mirmohammadsadeghi  
November 15, 2019



## Runway Exit Analysis of Denver International Airport



Virginia Tech REDIM Team  
December 9, 2019

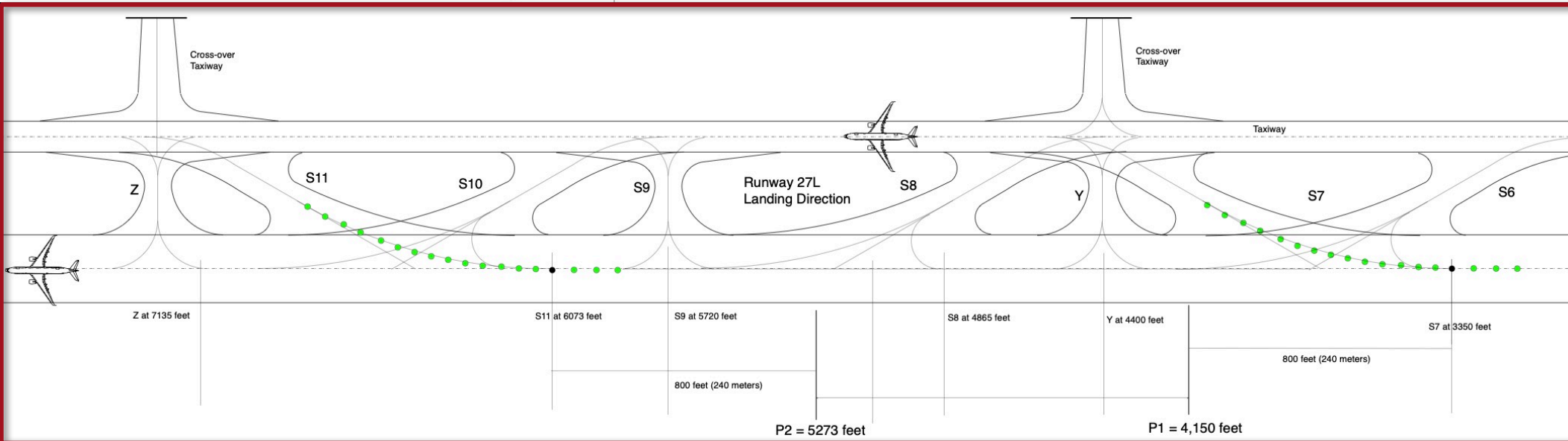
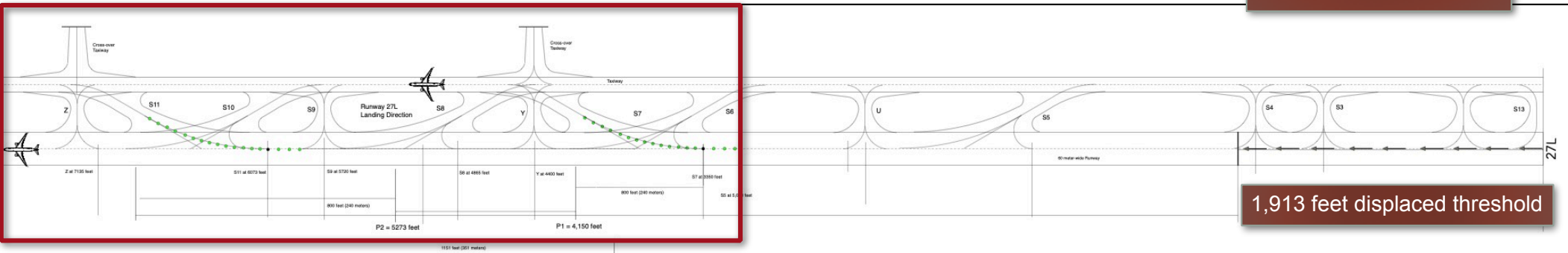




# PHL Runway 27L

- 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

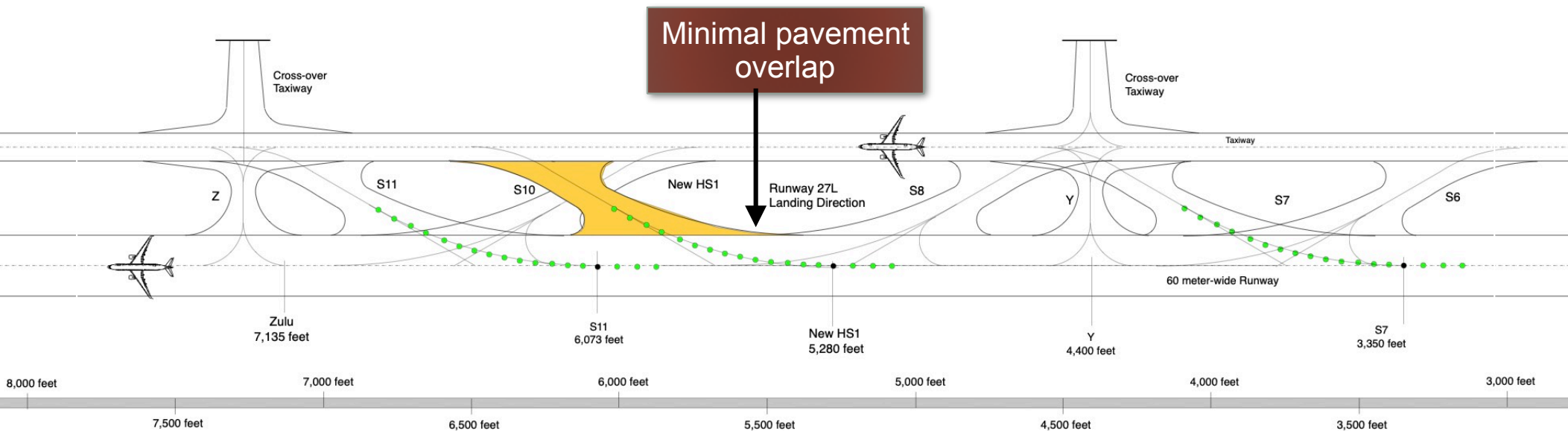
If 800 feet is the minimum distance to locate two high-speed exits





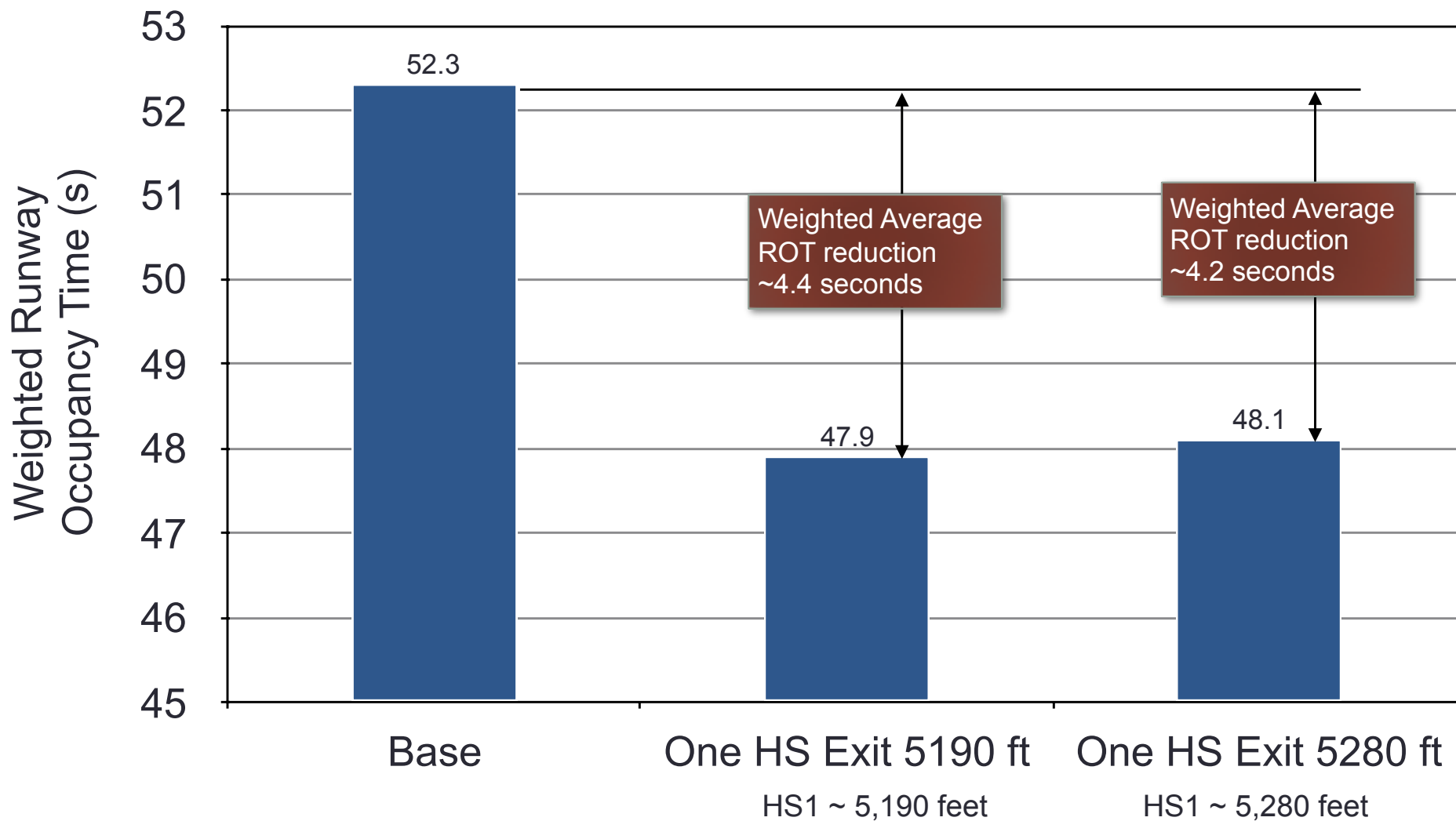
## Case: One New High-Speed Runway Exit, 20/80 (wet/dry pavement design)

- 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

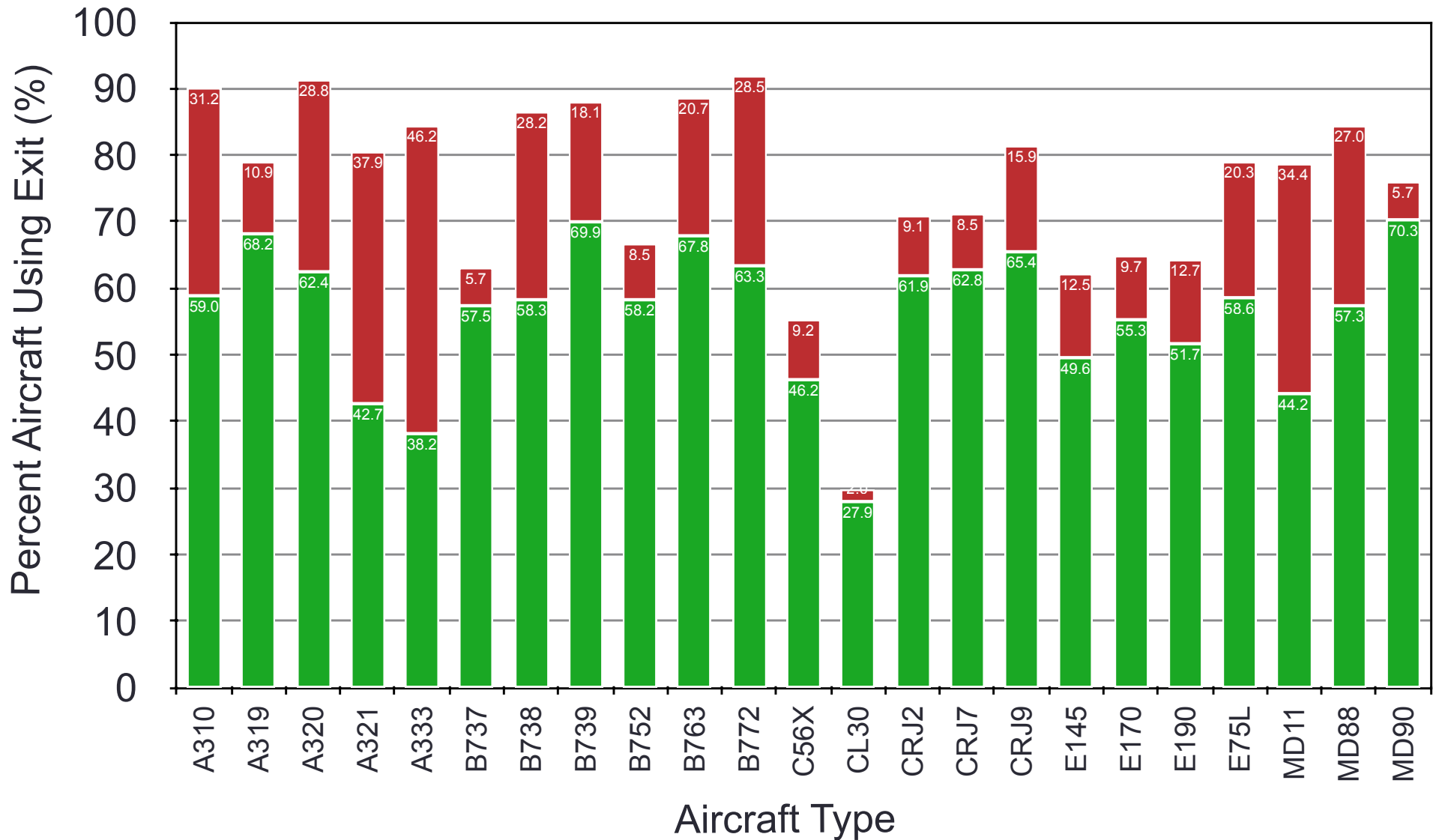


PHL Fleet Mix (Jan/2018 to Aug/2019) provided by FAA



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

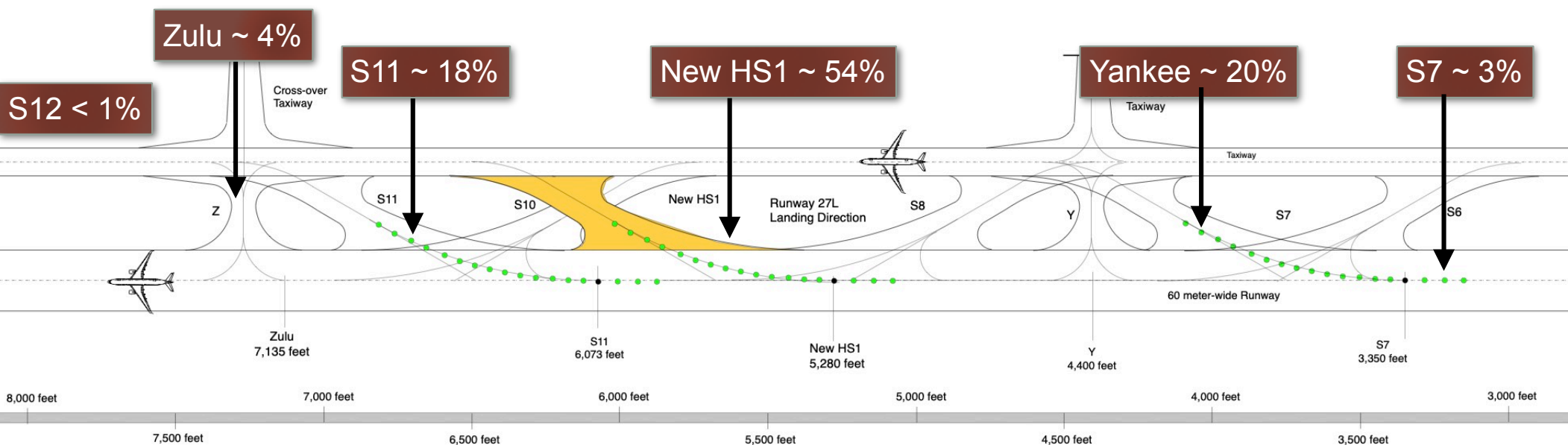
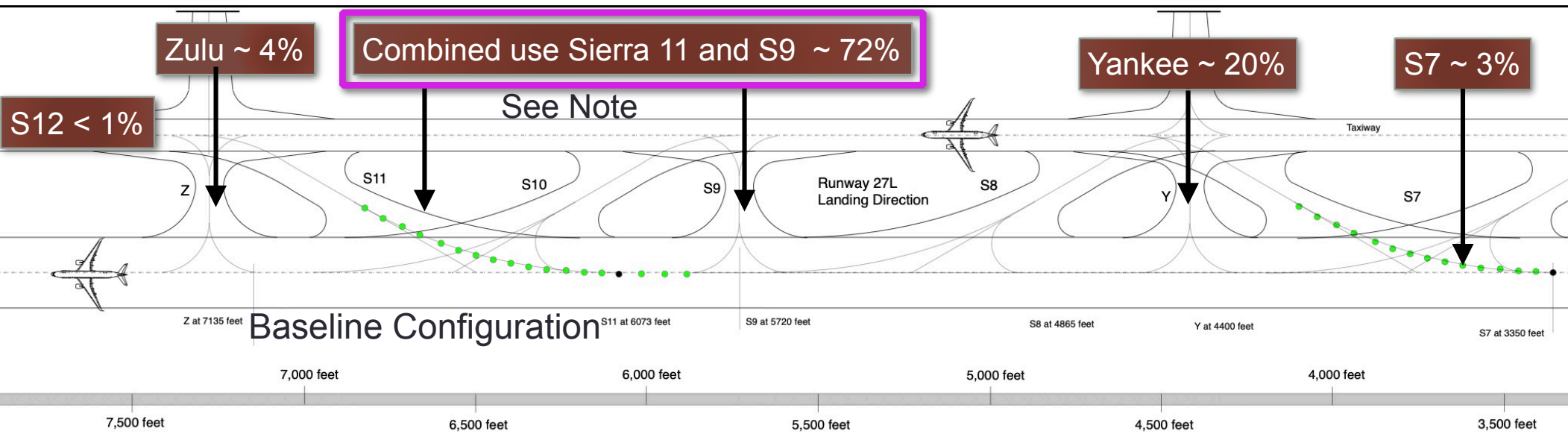
■ New HS Exit (5280 feet)
 ■ High-Speed Exit Sierra 11 (6073 feet)







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



Optimal High-Speed Exit at 5,280 feet



# Contact Information

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