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Runway Exit Design Tool and Landing Events Database Seminar

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Runway Exit Design Tool and Landing Events Database Seminar

- **Tentative Agenda**
- 1:00 to 1:10 PM Introduction (Kent Duffy and Lauren)
- 1:10 to 2:10 PM Explanations of Landing Events Database and Runway Exit design Model
  - New features of the Runway Exit Model and LED
- 2:10 to 2:30 PM Questions and answers
- 2:30 to 3:00 User feedback section

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 Phases and Model Development

Phase	Objectives
1	• Process Airport Surface Equipment data (37 airports and data for years 2015 and 2016) • Develop a Windows-based version of the Runway Exit Optimization Model developed in 1994 • Created Landing Event Database accessible through a computer client program
2	• Process Airport Surface Equipment data (43 airports and years 2017-2020) • Improve the Runway Exit Optimization Model developed in Phase 1 (pilot motivational practice, updates to aircraft database) • Load the new airport data into the Landing Event Database (ASSC data for years 2017-2020)

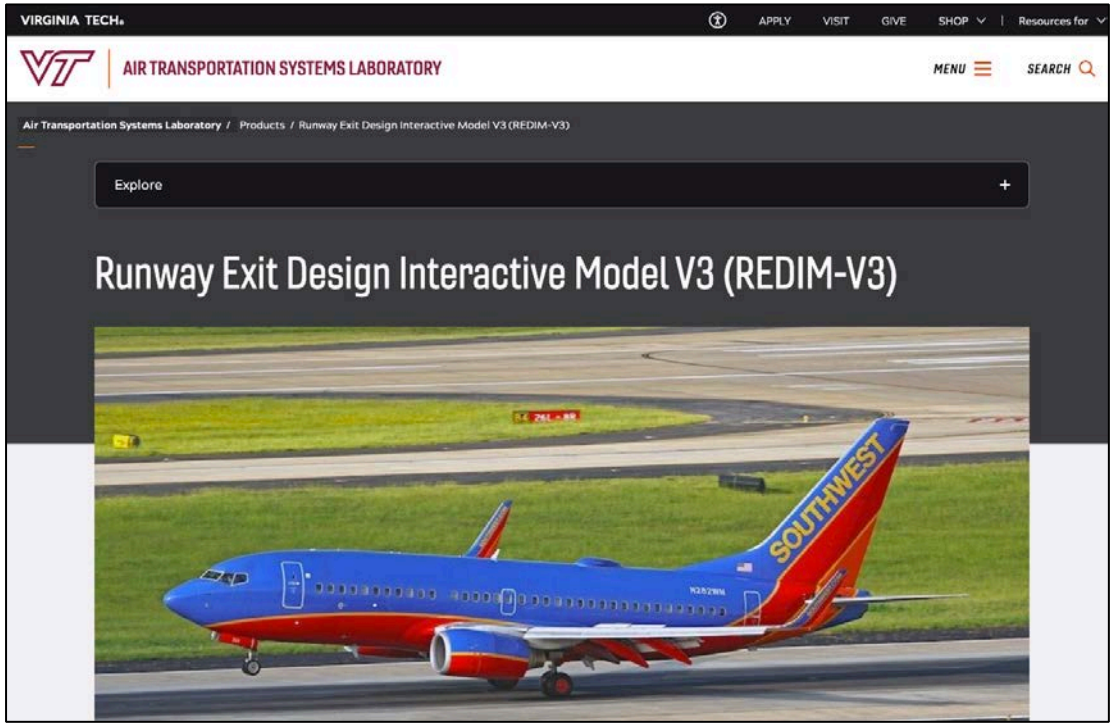
Phase 1 Project Outcomes

- **Landing Events Database** archives 11.8 million landing records from ASDE-X data (all landing operations at 37 U.S. airports during 2015 and 2016)
  - Stand-alone product (client software)
- Tabular and graphical data on runway exit utilization at 37 U.S. airports
- **Updated Runway Exit Design Tool (REDIM 3 model)**
  - Windows-based computer model to estimate the best location of runway exits (stand-alone software)
  - Uses individual aircraft Kernel distributions collected in the **Landing Events Database** to model landing performance
- Developed guidance for updated to Table 4-13 in AC 150/5300-13A, Airport Design

Task 3: REDIM Model Updates/Improvements

- **Version 3.09 - released on January 27, 2021**
  - Fixed custom exit geometries parameters not saved properly in "Runway Evaluation" mode.
- **Version 3.0.8 - released on January 7, 2021**
  - Added runway occupancy time based on aircraft clearing the holdbar
  - Added ability to save and load aircraft mix
  - Added ability to export all the raw data
  - Improvements to memory management

Site to Obtain the Landing Events Database and Runway Exit Design Model



https://atsl.cee.vt.edu/products/runway-exit-design-interactive-model--redim-.html

Download REDIM 3

- REDIM 3.0.9 - Windows Installer
- User Group
- User Manual
- FAQs
- Change Log

Download Landing Events Database

- Landing Events Database 1.2.4 - Windows Installer
- User Manual

Download REDIM 2

- REDIM 2.1

Detailed Documentation for REDIM 3

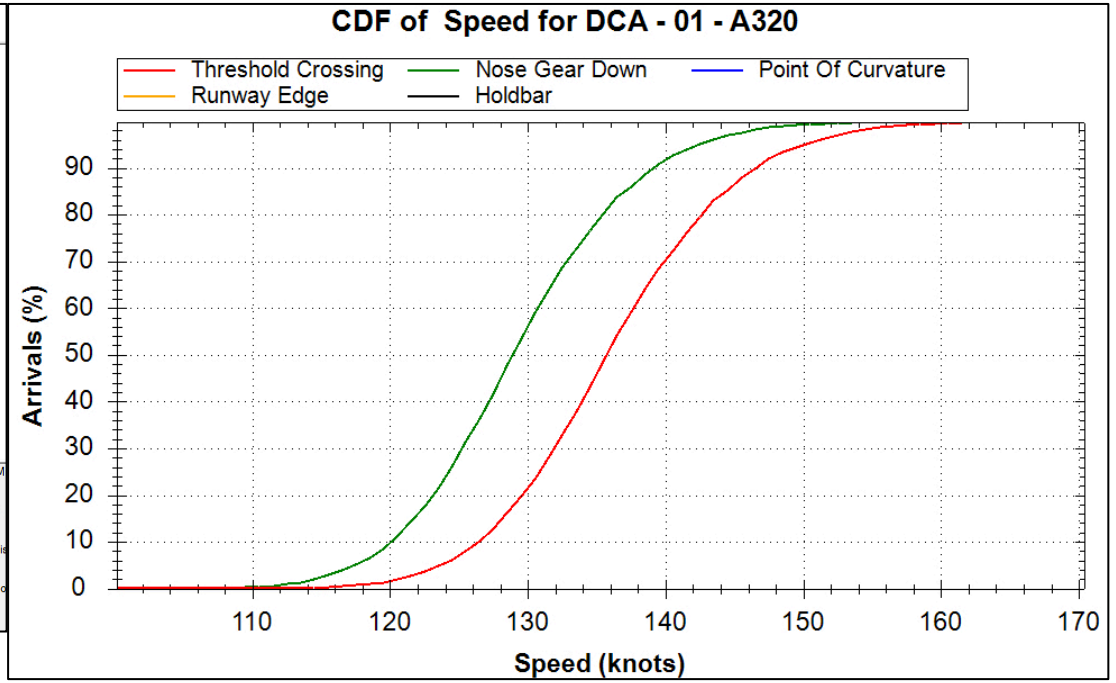
- Aircraft Database
- Runway Clusters
- Exit Clusters (Plots)
- Distributions:
  - Threshold Crossing Speeds: Aircraft - AAC
  - Nose Gear Down Distances: Aircraft - AAC
  - Nominal Decelerations: Aircraft - AAC
  - Point Of Curvature (PC) Speeds: Aircraft - AAC

Landing Events Database

Landing Events Database Updates/Improvements

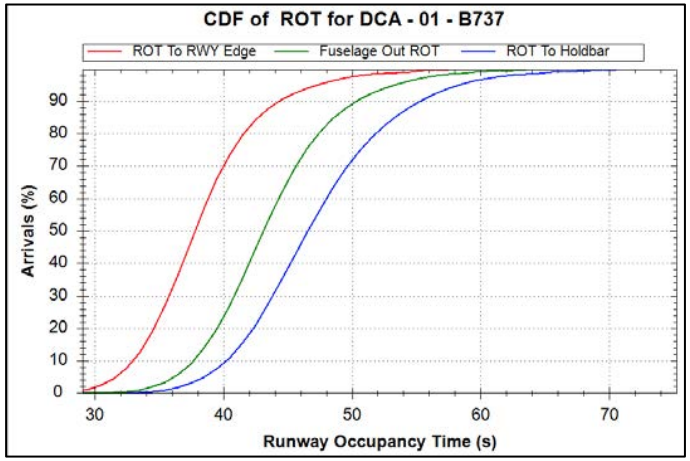
- **Version 1.2.3 - released on February 10, 2021**
- **Version 1.2.4 - released on April 15, 2021**
  - Allow queries by date ranges in the RawData viewer
  - This should facilitate the runway auditing process investigations
  - Additional features added to the “Statistics” section
  - Reports can now be done by runway and exit
  - Provides quick synopsis of operations by runway and runway exit

Landing Event Database Tool Version 1.2.4

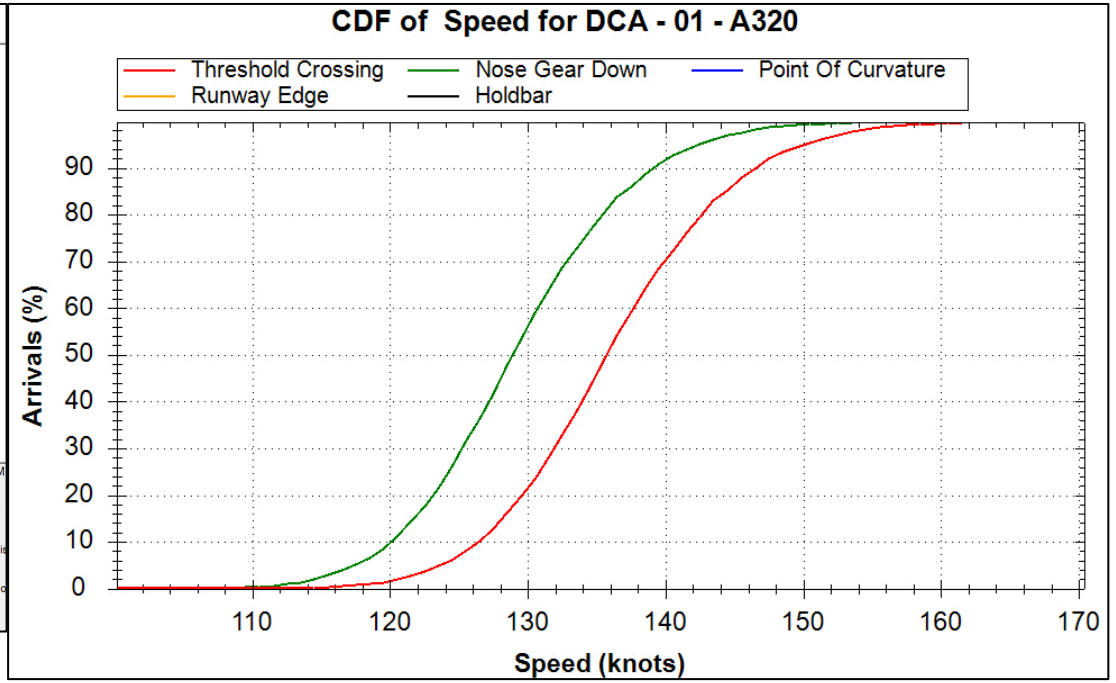


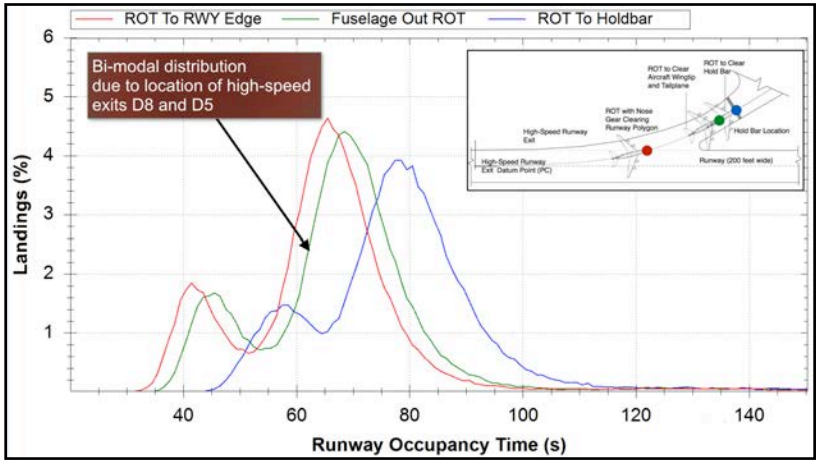
Landing database client can be downloaded at:

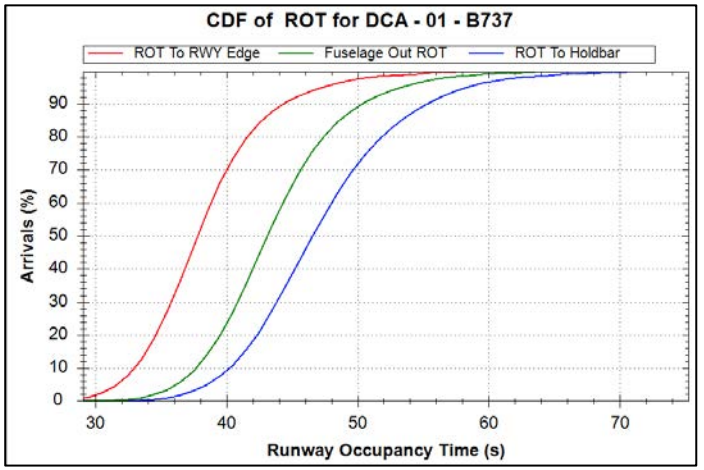
https://atsl.cee.vt.edu/products/runway-exit-design-interactive-model--redim-.html



Landing Event Database Tool Version 1.2.4

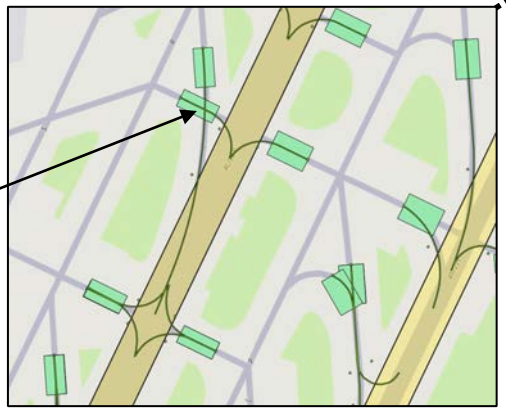






Landing Events Database : Data Collection

- ASDE-X data
  - 11.8 million landings (12 TB data)
  - Years 2015 and 2016
- Runway exit geometry information for 3,385 runway exits at 292 runways (top 37 airports)
- One and 5-minute weather data for all 37 airports
- Video data to validate the aircraft touchdown location algorithms



Runway exit polygons at EWR airport

Newark International Airport Runway Exit Data

Phase 2 Runway Auditing Effort

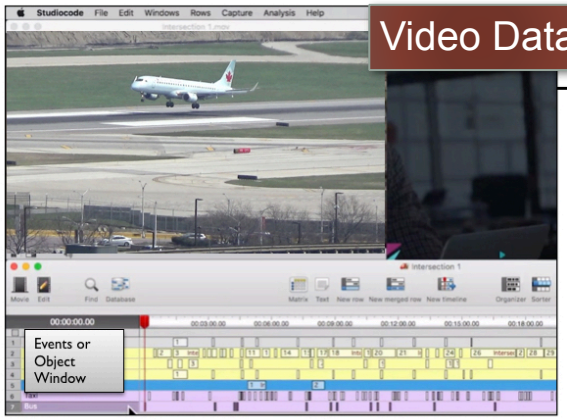
- Completed updates to all runways and runway exits at 37 airports in the landing events database (see table below)
- Adding six new airports to the database: 39 runway ends and 349 runway exits

	No. Audited	No. Geometry Changes Required	No. Geometry Changes Updated
Runways	320	24	24
Exits	3567	244	244

Snapshot		
	No.	No. Geometry Changes Completed
Runways	39	39
Exits	349	123

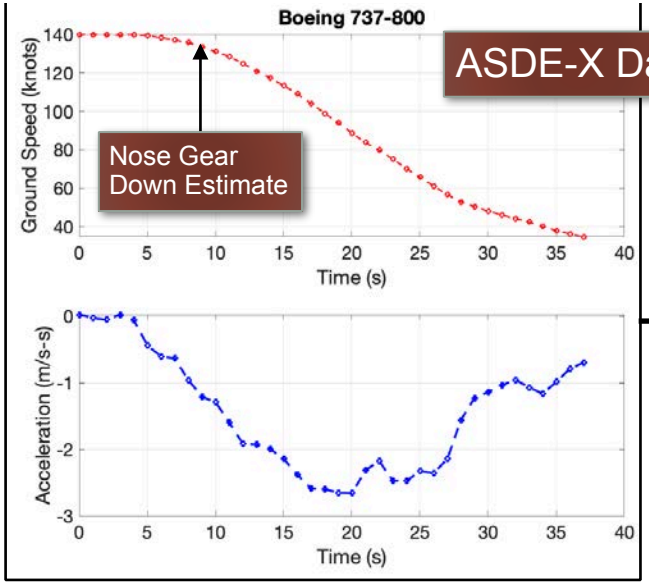
Airport ID	No. Runway Geoms.	No. Exit Geoms.	Runway Geom. Status	Exit Geom. Status
ANC	6	55	✓	✓
MCI	6	55	✓	✓
MSY	4	24	✓	✓ (13 of 24 Complete)
PDX	6	52	✓	×
PIT	8	80	✓	×
CVG	8	83	✓	×

Validation of Landing Parameters using Video Data Collected at 3 Airports



Database of Landing Events

Matlab Parser of Landing Events



Aircraft Type	DCA Video Data Collection			
	Main Gear Touchdown Distance (m)	Touchdown Distance STD (m)	Runway Occupancy Time (s)	Time Between Main gear and Nose Gear Touchdown (s)
Boeing 737-800	390	65	44.9	2.7
Embraer 170	384	69	44.7	3.2
Embraer 145	343	80	44.1	3.3

Main and Nose Gear Touchdown Location Estimates

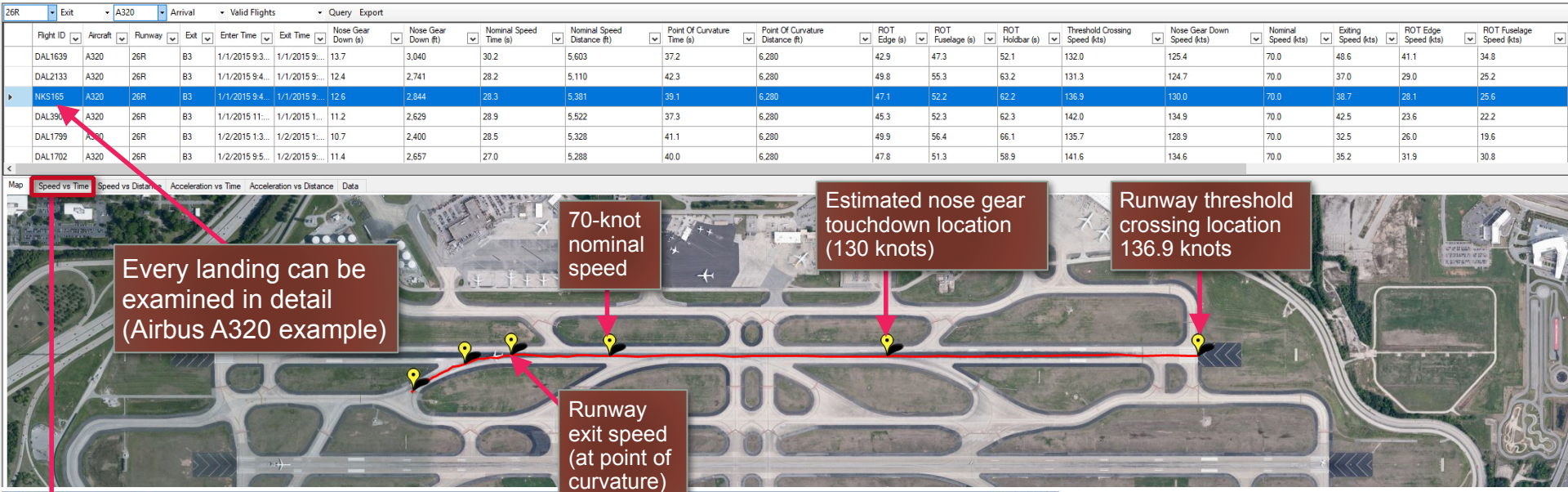
Landing Event Database Tool (1)

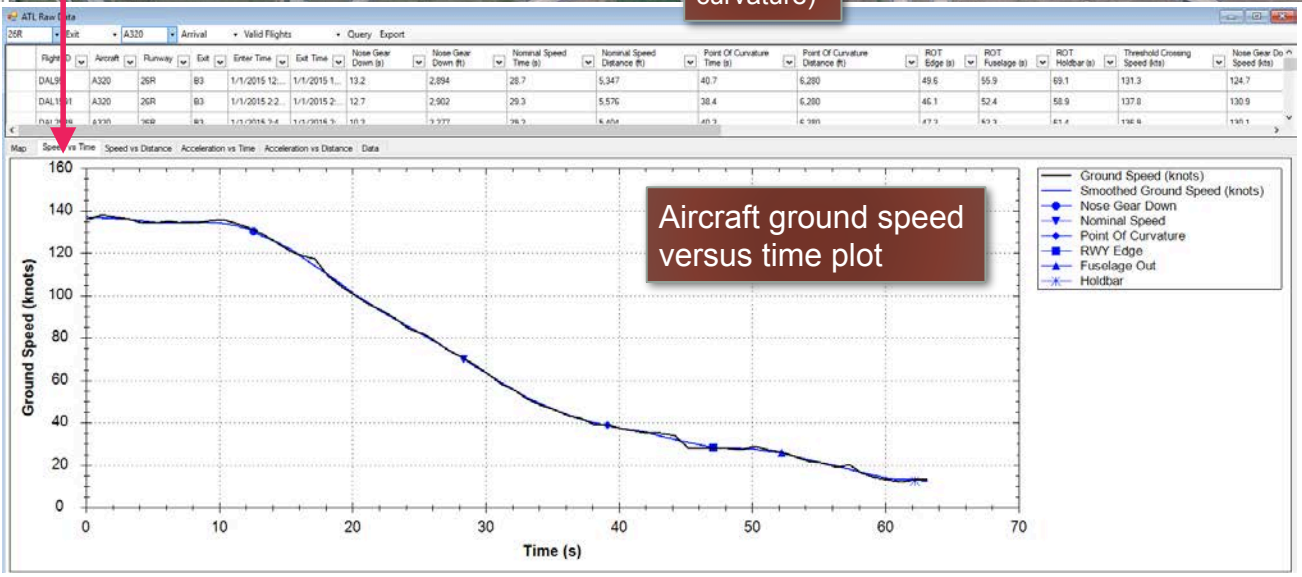
Analysis	Purpose	Metrics and Ready-Made Query Options
Aircraft Mix	Provides an overview of aircraft fleet mix in the form of a pie chart with the top 10 aircraft in the fleet mix presented.	By runway By runway exit
Runway Occupancy Time	Provides three values of runway occupancy time measured at three locations: 1. Runway edge 2. Fuselage out 3. At hold bar	1. Average ROT (in seconds) by runway, runway exit and aircraft 2. Median ROT (in seconds) by runway, runway exit and aircraft 3. Probability Density Function (PDF) of ROT (dim) by runway, runway exit and aircraft 4. Cumulative density function of ROT by runway, runway exit and aircraft 5. Runway exit utilization (percentage) by runway exit and aircraft
Speed	Provides information about five aircraft ground speeds at different locations of the landing profile: 1. Threshold 2. Nose gear down 3. Point of curvature 4. Runway edge 5. Hold bar	1. Average ROT (in seconds) by runway, runway exit and aircraft 2. Median ROT (in seconds) by runway, runway exit and aircraft 3. Probability Density Function (PDF) of ROT (dim) by runway, runway exit and aircraft 4. Cumulative density function of ROT by runway, runway exit and aircraft 5. Detailed speed profiles as a function of distance by aircraft, runway and runway exit 6. Detailed speed profiles as a function of time by aircraft, runway and runway exit
Nose Gear Location	Provides estimates of nose gear distance. The nose gear distance is estimated in the landing algorithm to initiate the nominal deceleration.	1. Nose gear distance from runway landing threshold by runway, aircraft and runway exit 2. Probability Density Function (PDF) of nose gear distance (feet or meters) by runway, runway exit and aircraft 3. Cumulative density function of nose gear distance (feet or meters) by runway, runway exit and aircraft

Landing Event Database Tool (2)

Analysis	Purpose	Metrics and Ready-Made Query Options
Deceleration	Provides two values of aircraft deceleration on the runway: Nominal Nominal location to point of curvature (Nominal to PC)	Average deceleration (in m/s2) by runway, runway exit and aircraft Median deceleration (in m/s2) by runway, runway exit and aircraft Probability Density Function (PDF) of deceleration (in m/s2) by runway, runway exit and aircraft (both average and median values can be plotted) Cumulative density function of aircraft deceleration (in m/s2) by runway, runway exit and aircraft (both average and median values can be plotted)
Raw Data	Provides detailed information (in a table) on 30 key parameters for every landing contained in the Landing Events Database. Provides graphical information of every landing in the database. Provides a graphical depiction of individual landings in a Microsoft NAVTEQ map layer (bottom viewport)	30 key parameters defining the landing profile of each landing operation. Parameters include: flight ID, aircraft type, runway, runway exit use, time of operation, nose gear touchdown distance and time, nominal deceleration, deceleration from nominal point to PC, exit speed, and airport wind conditions. Speed-distance profile of each landing event Speed-time profile of each landing event Acceleration-time profile of each landing event Acceleration-distance profile of each landing event Processed numerical data with speed, acceleration, distance and time for individual landings.
Statistics	Summarizes the landing statistics processed by airport by month.	Total landing records Valid records Number of records with missing parameters Number of records with unreasonable parameters Records with no associated runway Go-around records

Landing Database Raw Data Viewer





Spirit Airlines Airbus A320

Landing Database Raw Data Viewer

26R | Exit | A320 | Arrival | Valid Flights | Query | Export

Flight ID	Aircraft	Runway	Exit	Enter Time	Exit Time	Nose Gear Down (s)	Nose Gear Down (ft)	Nominal Speed Time (s)	Nominal Speed Distance (ft)	Point Of Curvature Time (s)	Point Of Curvature Distance (ft)	ROT Edge (s)	ROT Fuselage (s)	ROT Holdbar (s)	Threshold Crossing Speed (kts)	Nose Gear Down Speed (kts)	Nominal Speed (kts)	Exiting Speed (kts)	ROT Edge Speed (kts)	ROT Fuselage Speed (kts)
DAL1639	A320	26R	B3	1/1/2015 9:3...	1/1/2015 9:...	13.7	3,040	30.2	5,603	37.2	6,280	42.9	47.3	52.1	132.0	125.4	70.0	48.6	41.1	34.8
DAL2133	A320	26R	B3	1/1/2015 9:4...	1/1/2015 9:...	12.4	2,741	28.2	5,110	42.3	6,280	49.8	55.3	63.2	131.3	124.7	70.0	37.0	29.0	25.2
NKS165	A320	26R	B3	1/1/2015 9:4...	1/1/2015 9:...	12.6	2,844	28.3	5,381	39.1	6,280	47.1	52.2	62.2	136.9	130.0	70.0	38.7	28.1	25.6
DAL390	A320	26R	B3	1/1/2015 11:...	1/1/2015 1...	11.2	2,629	28.9	5,522	37.3	6,280	45.3	52.3	62.3	142.0	134.9	70.0	42.5	23.6	22.2
DAL1799	A320	26R	B3	1/2/2015 1:3...	1/2/2015 1:...	10.7	2,400	28.5	5,328	41.1	6,280	49.9	56.4	66.1	135.7	128.9	70.0	32.5	26.0	19.6
DAL1702	A320	26R	B3	1/2/2015 9:5...	1/2/2015 9:...	11.4	2,657	27.0	5,288	40.0	6,280	47.8	51.3	58.9	141.6	134.6	70.0	35.2	31.9	30.8

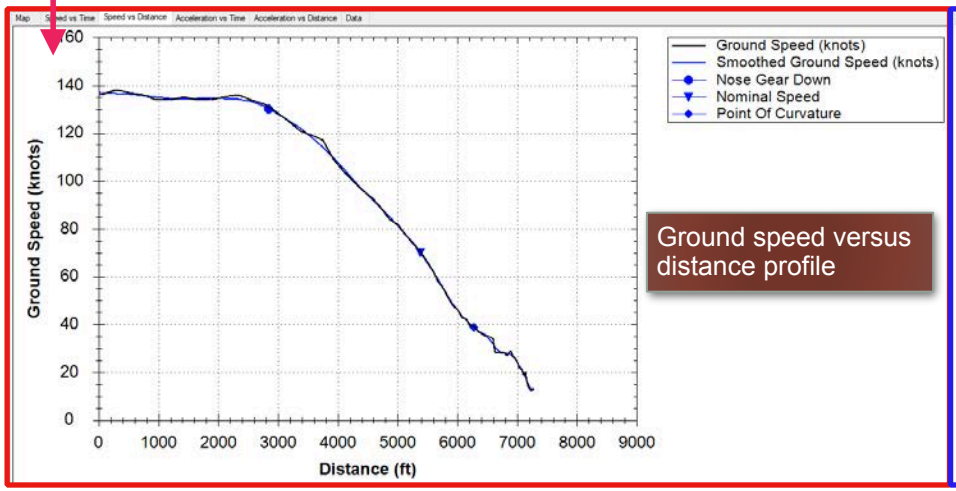
Map | Speed vs Time | Speed vs Distance | Acceleration vs Time | Acceleration vs Distance | Data

Every landing can be examined in detail (Airbus A320 example)

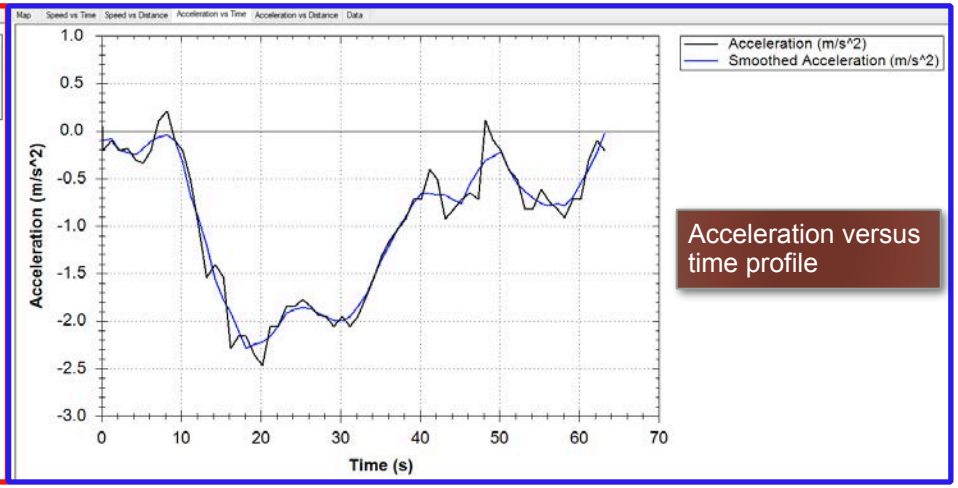
70-knot nominal speed

Estimated nose gear touchdown location

Runway threshold crossing location

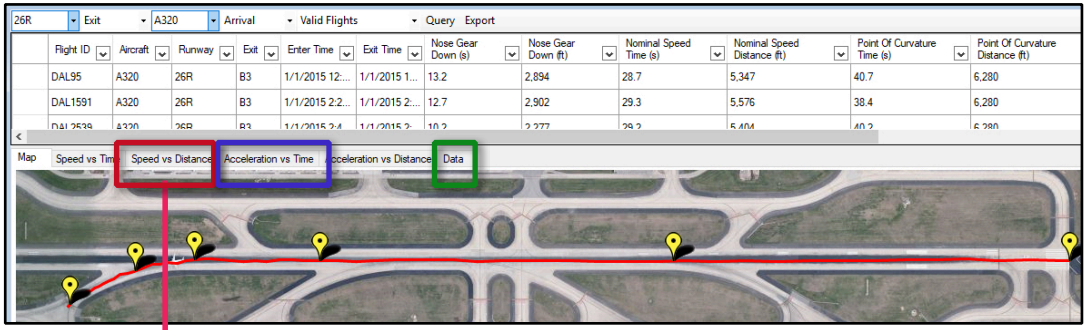


Ground speed versus distance profile

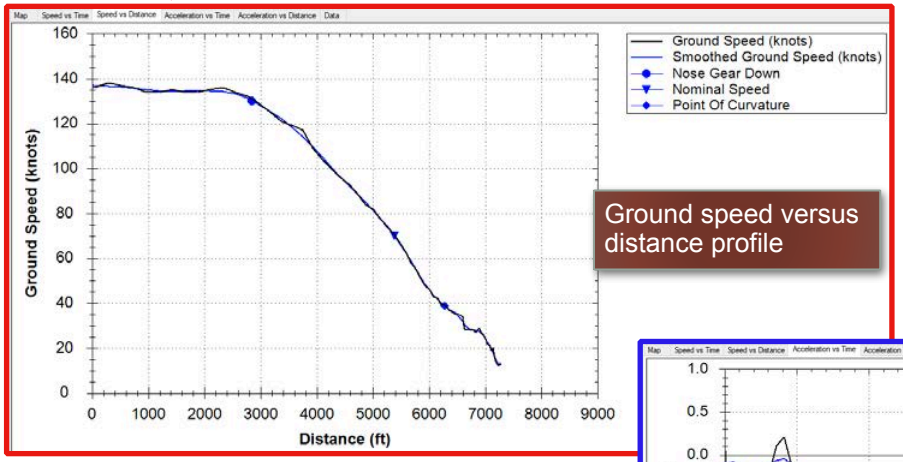


Acceleration versus time profile

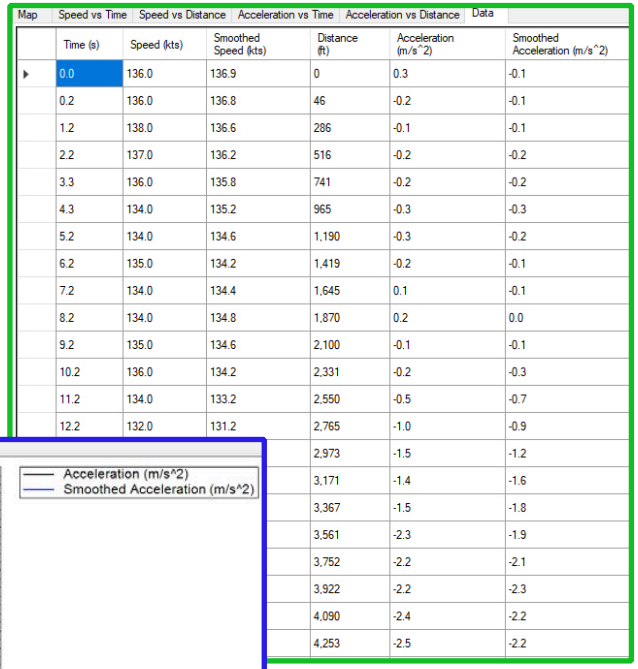
Landing Database Raw Data Viewer (2)



Spirit Airlines Airbus A320

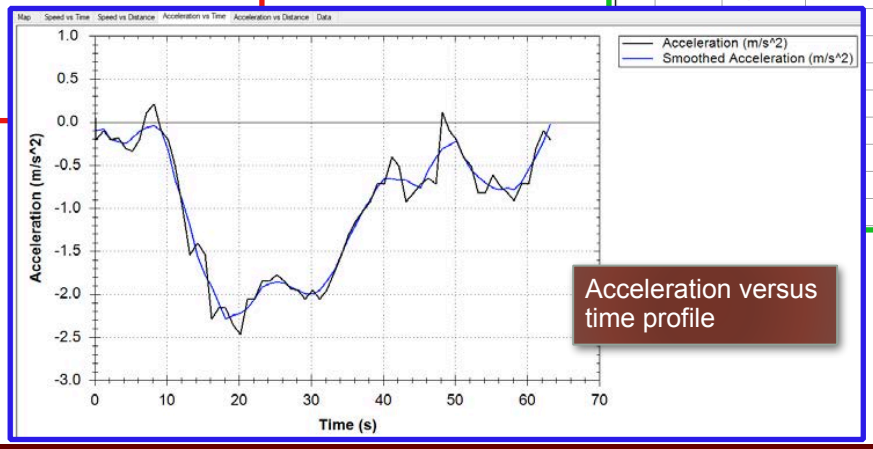


Ground speed versus distance profile



Time (s)	Speed (kts)	Smoothed Speed (kts)	Distance (ft)	Acceleration (m/s^2)	Smoothed Acceleration (m/s^2)
0.0	136.0	136.9	0	0.3	-0.1
0.2	136.0	136.8	46	-0.2	-0.1
1.2	138.0	136.6	286	-0.1	-0.1
2.2	137.0	136.2	516	-0.2	-0.2
3.3	136.0	135.8	741	-0.2	-0.2
4.3	134.0	135.2	965	-0.3	-0.3
5.2	134.0	134.6	1,190	-0.3	-0.2
6.2	135.0	134.2	1,419	-0.2	-0.1
7.2	134.0	134.4	1,645	0.1	-0.1
8.2	134.0	134.8	1,870	0.2	0.0
9.2	135.0	134.6	2,100	-0.1	-0.1
10.2	136.0	134.2	2,331	-0.2	-0.3
11.2	134.0	133.2	2,550	-0.5	-0.7
12.2	132.0	131.2	2,765	-1.0	-0.9
			2,973	-1.5	-1.2
			3,171	-1.4	-1.6
			3,367	-1.5	-1.8
			3,561	-2.3	-1.9
			3,752	-2.2	-2.1
			3,922	-2.2	-2.3
			4,090	-2.4	-2.2
			4,253	-2.5	-2.2

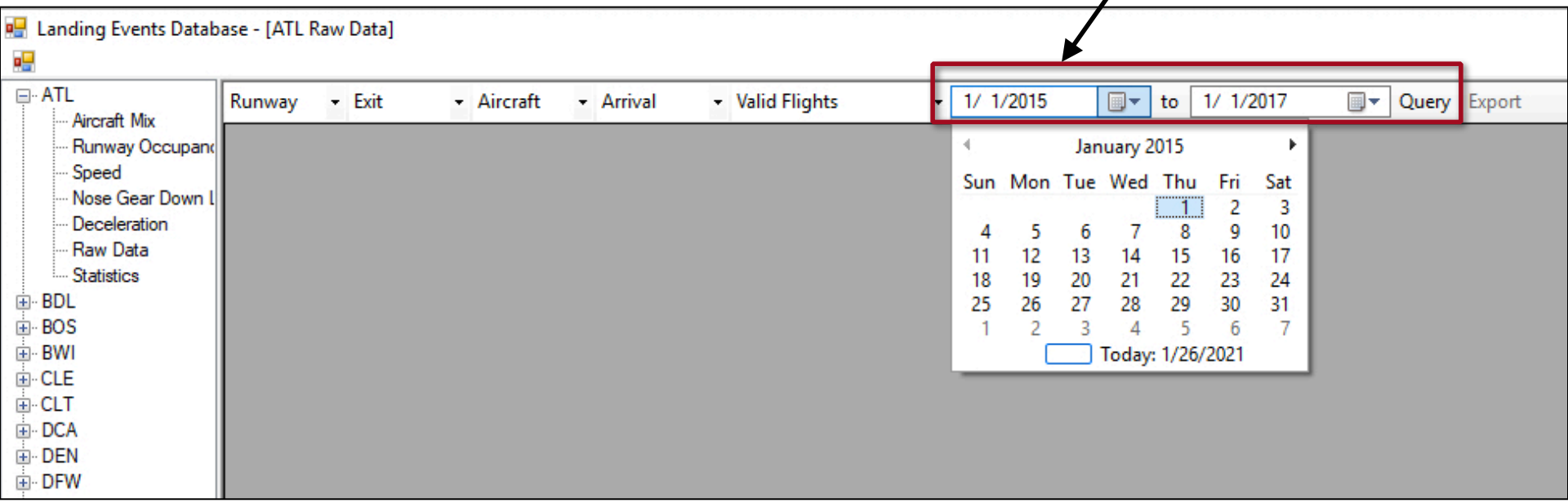
Every landing can be examined in detail (Airbus A320 example)



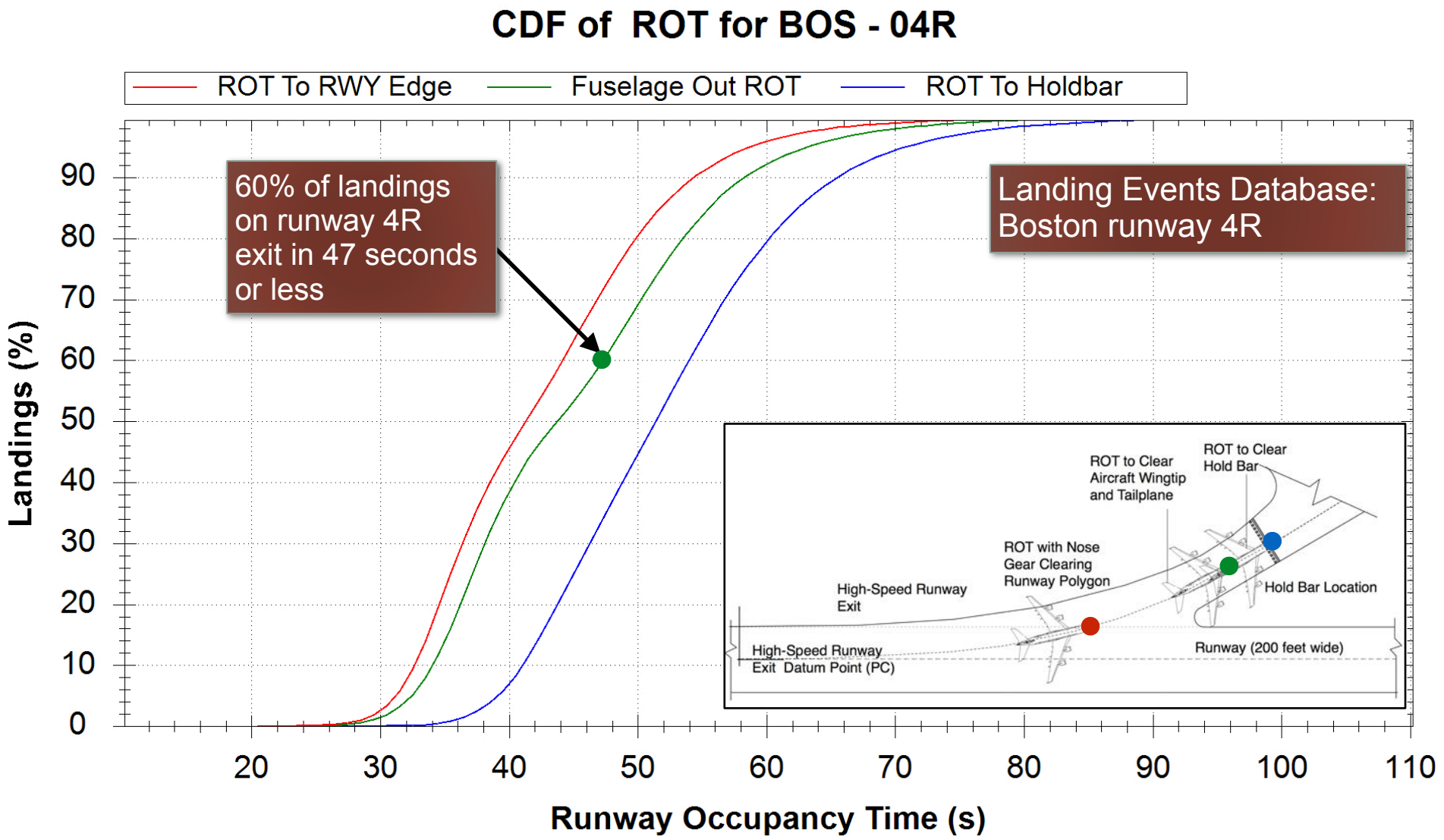
Acceleration versus time profile

Landing Events Database Date Range Query in Raw Data Viewer

- Allow queries by date ranges in the RawData viewer
  - Facilitates the runway auditing process investigations

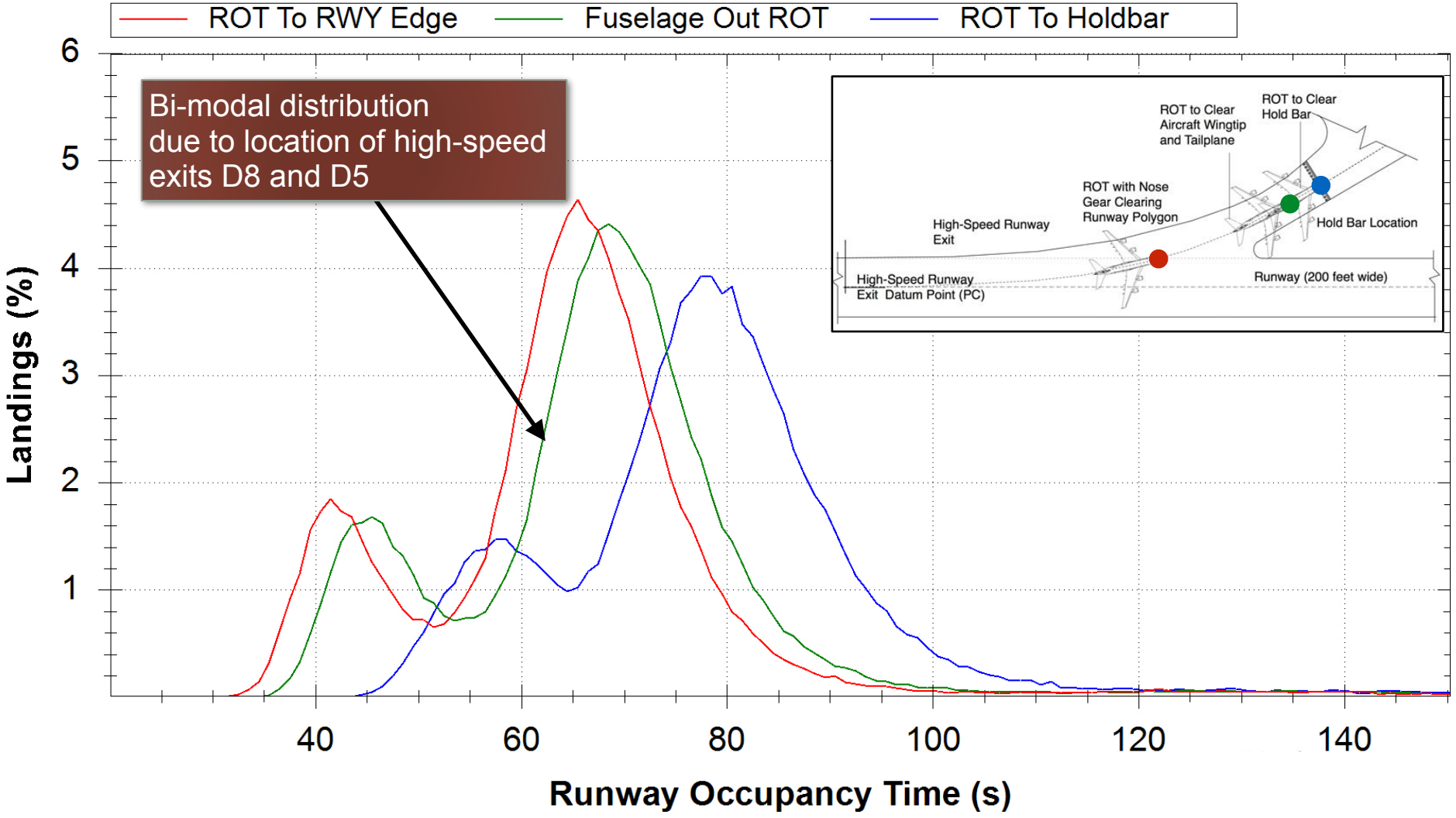


Three Definitions of Runway Occupancy Time

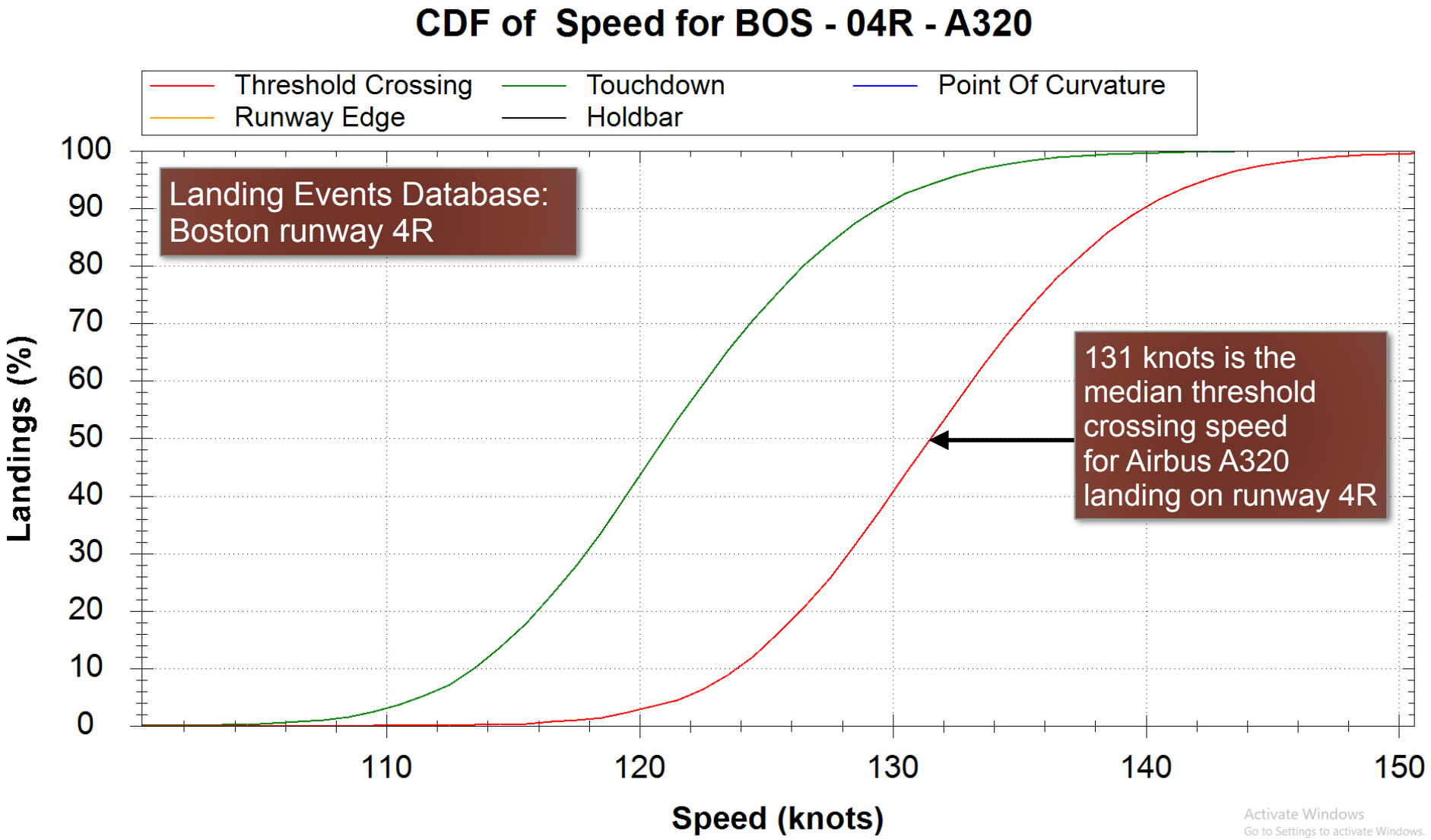


Distribution of Runway Occupancy Times

PDF of ROT for DEN - 16R



Ground Speed Distribution Over Runway Threshold



Runway Occupancy Time Tables

Step 1
Runway Occupancy Time

Step 2
Select runway

Step 3
Select ROT Table
1) ROT to runway edge
2) ROT to clear runway
3) ROT to hold bar

Step 4
Plot (query)

Landing Events Database

- ATL
  - Aircraft Mix
  - Runway Occupancy Time
  - Speed
  - Nose Gear Down Location
  - Deceleration
  - Raw Data
  - Statistics
- BDL
- BOS
- DFW
- DTW
- EWR
- FLL
- HNL
- HOU
- MSP
- ORD
- PHL
- PHX
- PVD
- SAN
- SDF
- SEA
- SFO
- SLC
- SNA
- STL

ATL - Runway Occupancy Time (ROT) Analysis

Runway: 08L | ROT Type: Fuselage Out | Query

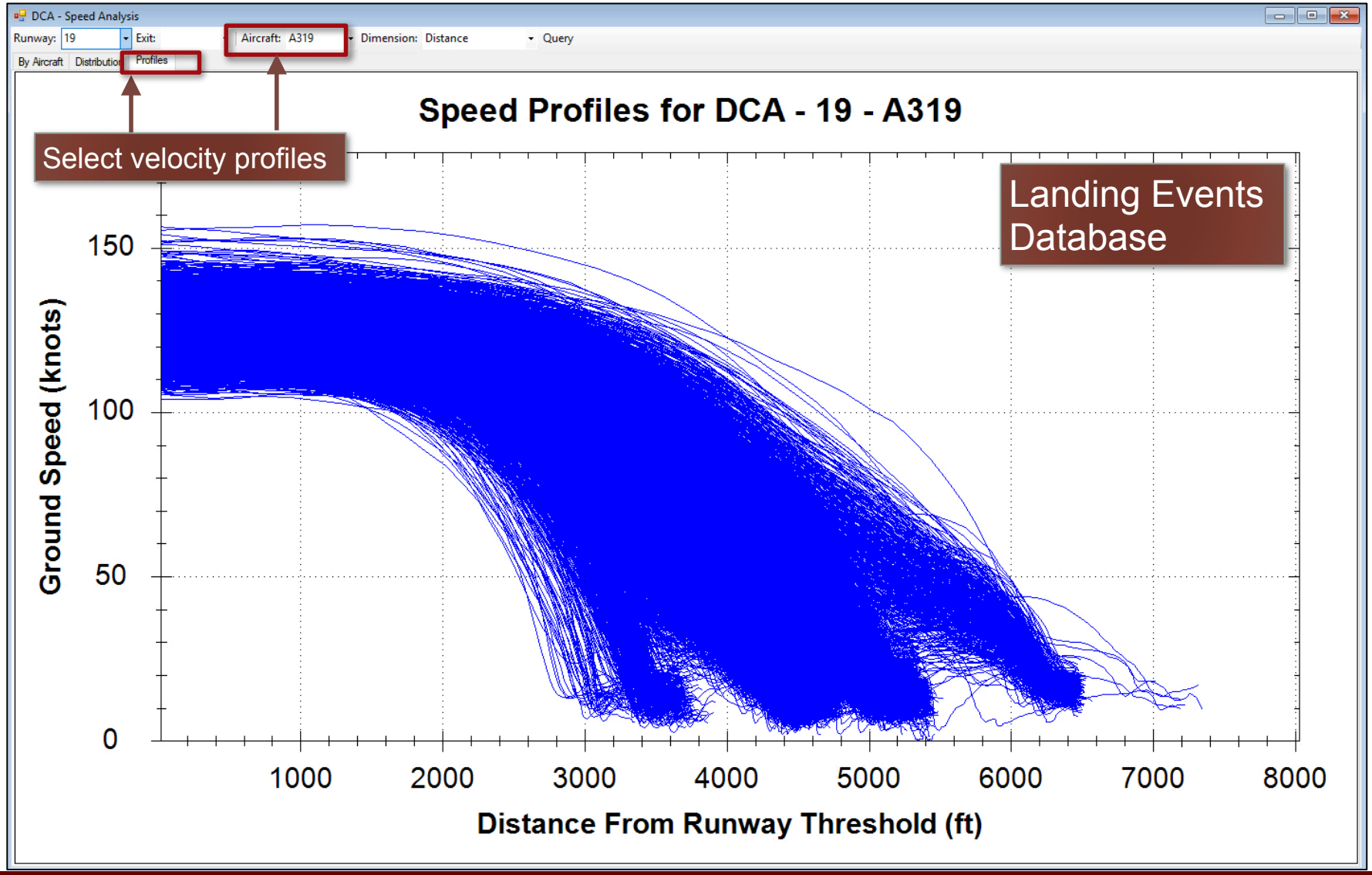
By Aircraft | Distribution | Table

Fuselage Out ROT for ATL - 08L

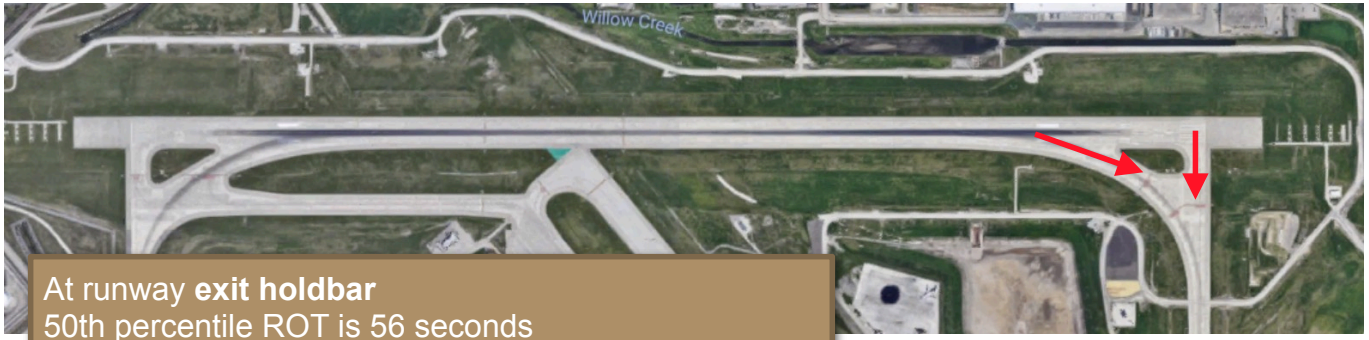
Aircraft	A	A4	A6-1	A6-2	B11	B13	B15	B5	B7	C-L	C-R	D-L	D-R	Average
A124						114.2s 100.0%								114.2s
A306	90.0s 3.0%		62.2s 33.3%	61.8s 53.3%	44.5s 0.3%					47.6s 2.0%		52.7s 8.1%		61.7s
A310			62.5s 45.5%	60.6s 34.1%						49 2.				
A319	75.6s 0.0%			59.8s 0.2%	50.5s 77.3%	71.2s 1.2%	78.7s 0.0%	36.2s 0.0%	41.3s 14.9%	47 0.				
A320	81.9s 0.0%			54.4s 0.1%	48.7s 89.4%	70.3s 3.1%	69.3s 0.1%		40.6s 5.0%					
A321	83.0s 0.1%		57.3s 0.1%	53.8s 0.3%	47.8s 81.3%	69.4s 14.2%	75.7s 0.4%		39.8s 3.0%					
A332					56.2s 77.8%	78.3s 20.4%	72.1s 1.9%							
A333					54.0s 81.1%	75.0s 16.3%	80.8s 1.1%		48.4s 0.8%					
A343					56.3s 67.1%	79.1s 30.4%	82.1s 1.3%		49.8s 1.3%					
A346					54.5s 71.6%	80.0s 28.4%								
AC50										55 10				
AC90										46 10				
AC95										59 60				
AEST				68.3s 16.7%						70.3s 33.3%		69.8s 50.0%		69.7s
ASTR				53.1s 31.3%						43.4s 18.8%		45.8s 50.0%		47.6s
AT43		34.1s 16.7%								47.1s 16.7%		51.8s 66.7%		48.1s
AT72										44.1s 50.0%		49.0s 50.0%		46.5s
B190				61.1s 0.4%						47.2s 53.6%		50.2s 45.9%		48.7s
B350		38.0s 8.8%								50.5s 59.3%		53.5s 31.9%		50.3s
B712	72.0s 0.0%			48.1s 0.1%	46.3s 94.6%	66.6s 0.8%	65.9s 0.0%		38.8s 3.7%		40.6s 0.2%		42.8s 0.6%	46.2s
B732				51.1s 100.0%										51.1s
B733				53.9s 0.1%	47.7s 68.9%	67.7s 0.4%			39.5s 20.7%		41.6s 3.1%	45.8s 0.1%	43.0s 6.8%	45.6s
B734	70.6s 5.1%			52.2s 79.5%	51.5s 1.7%	71.7s 0.9%	78.3s 0.9%			43.2s 3.4%		45.8s 8.5%		52.7s
B735				55.6s 33.3%	48.6s 33.3%								43.1s 33.3%	49.1s

Cells in table show:
1) Average runway occupancy time by runway exit at the selected runway
2) Percent of aircraft using each runway exit

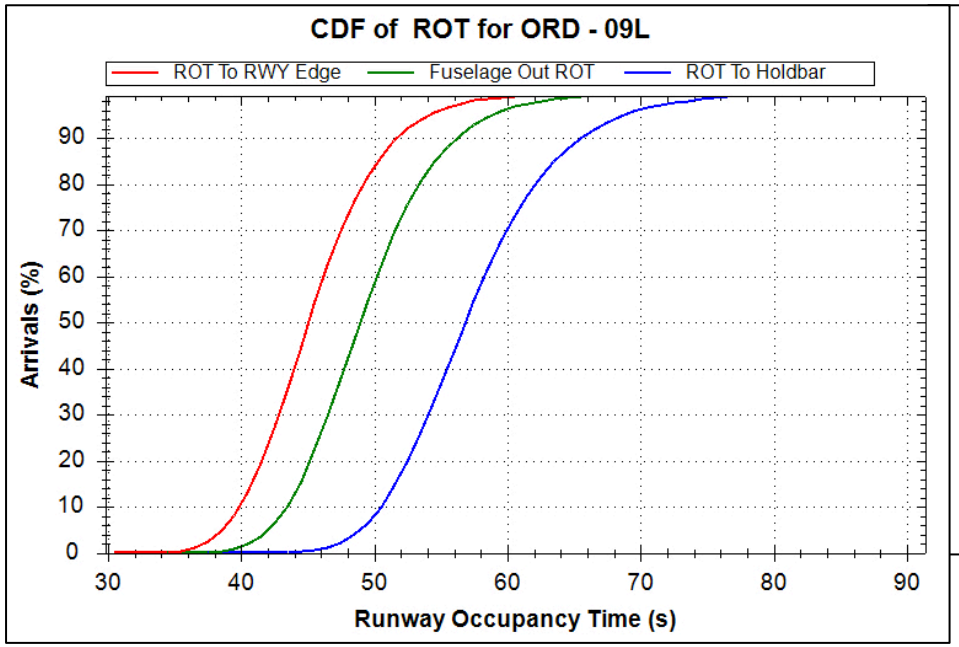
Aircraft Velocity Profiles : Airbus A319 at DCA Runway 19

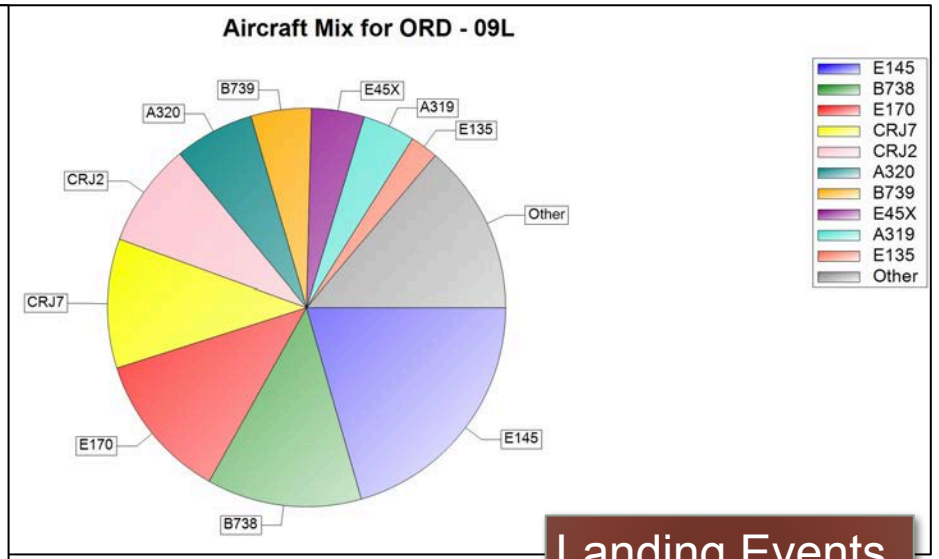


ORD Airport Runway 9L (Two Usable Exits)



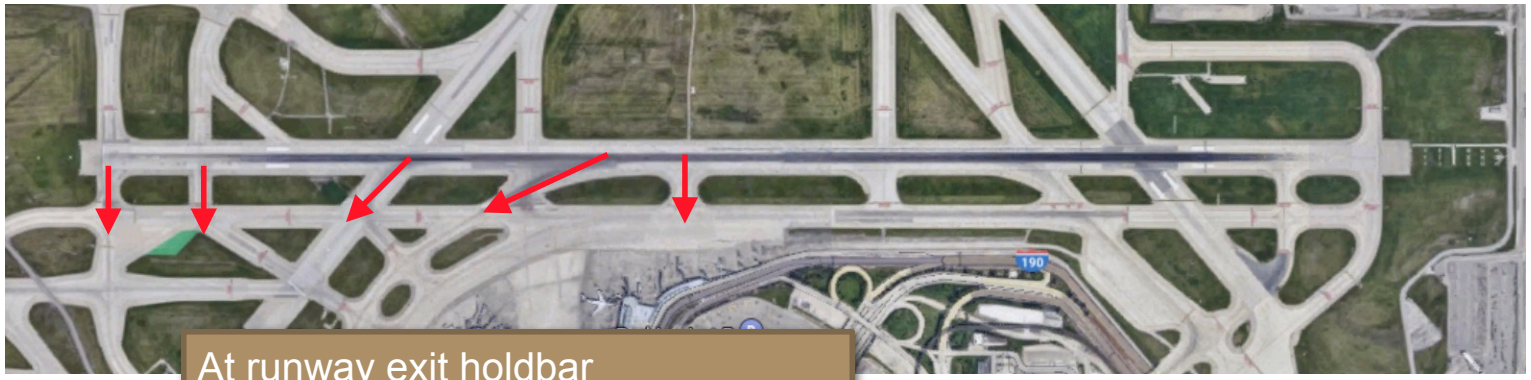
At runway **exit holdbar**
50th percentile ROT is 56 seconds
95th percentile ROT is 71 seconds
Relatively high ROT value due to few runway exits



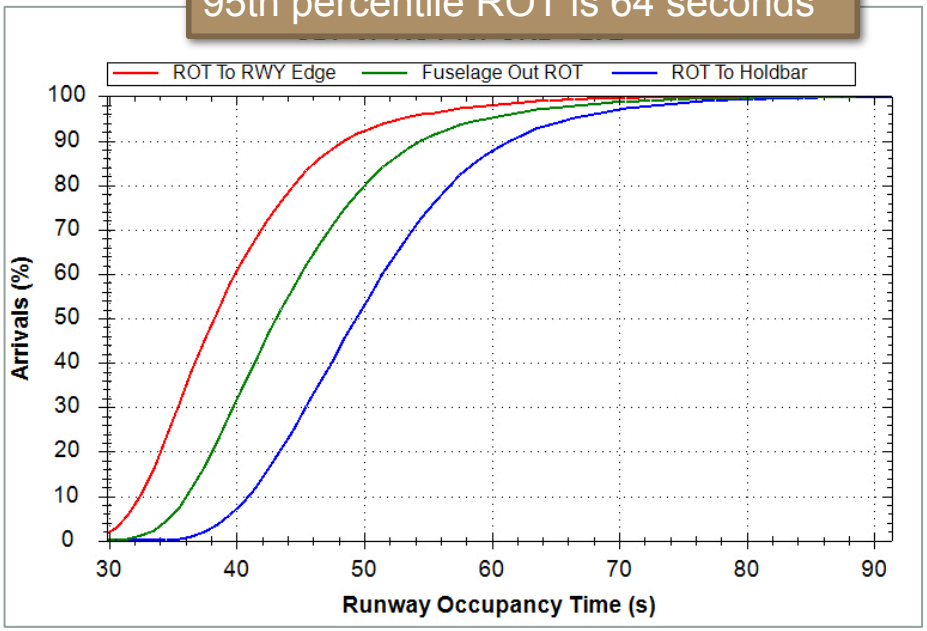


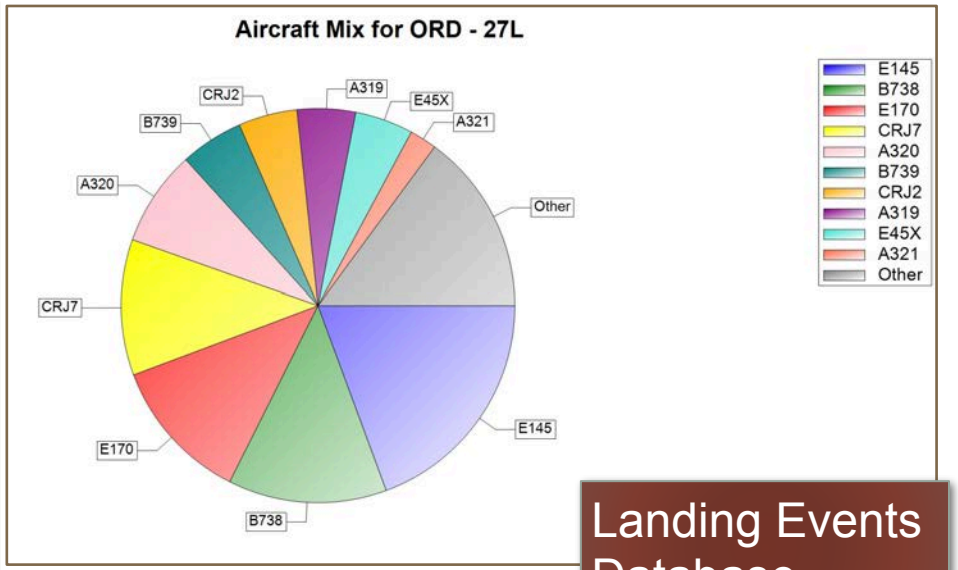
Landing Events Database

ORD Airport Runway 27L (Five Usable Exits)



At runway exit holdbar
50th percentile ROT is 49 seconds
95th percentile ROT is 64 seconds

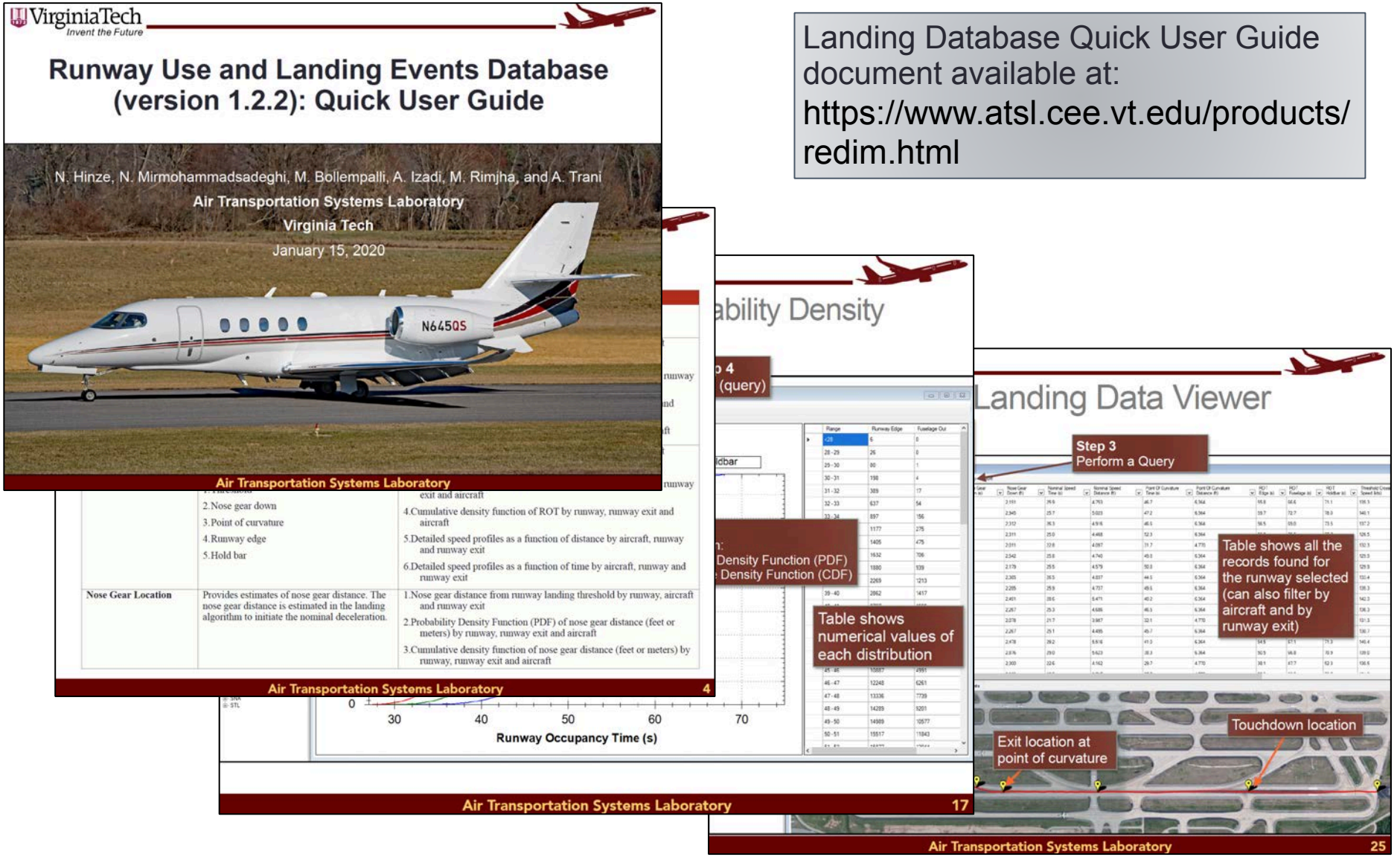




Landing Events Database

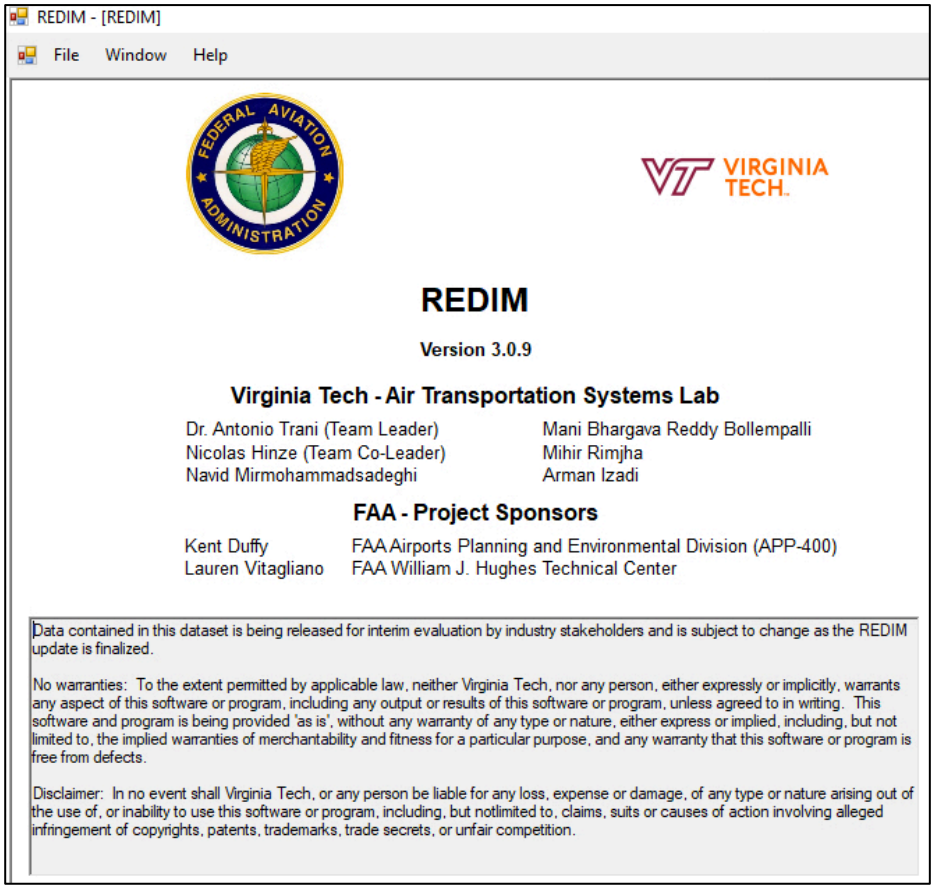
Landing Event Database Quick User Guide

Landing Database Quick User Guide document available at: https://www.atsl.cee.vt.edu/products/redim.html



Runway Exit Design Tool

Updated Runway Exit Design Tool (REDIM 3 Model)



The Runway Exit Design Tool can be downloaded at:

https://atsl.cee.vt.edu/products/runway-exit-design-interactive-model--redim-.html

Download REDIM 3

- REDIM 3.0.9 - Windows Installer
- User Group
- User Manual
- FAQs
- Change Log

Download Landing Events Database

- Landing Events Database 1.2.4 - Windows Installer
- User Manual

Download REDIM 2

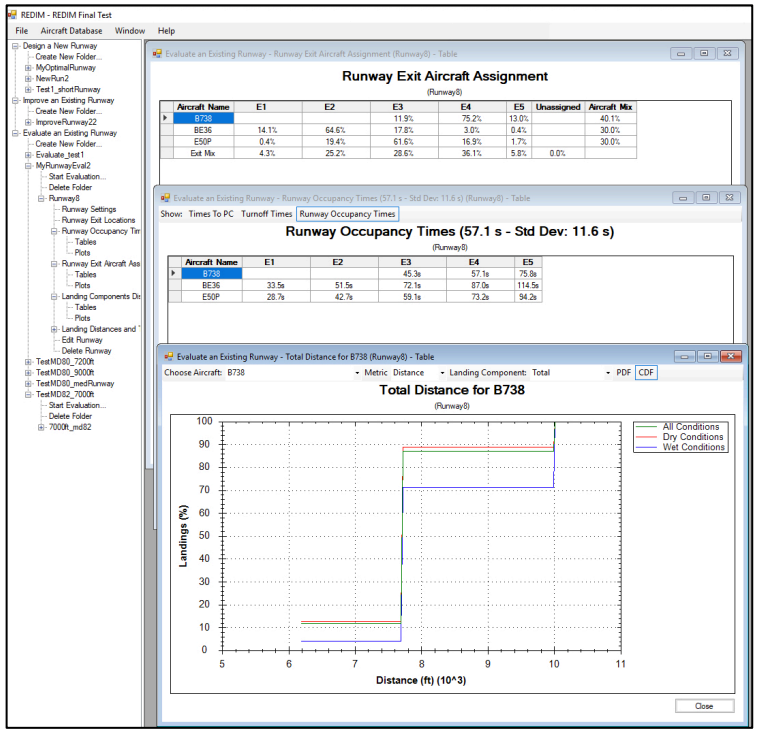
- REDIM 2.1

Detailed Documentation for REDIM 3

- Aircraft Database
- Runway Clusters
- Exit Clusters (Plots)
- Distributions:
  - Threshold Crossing Speeds: Aircraft - AAC
  - Nose Gear Down Distances: Aircraft - AAC
  - Nominal Decelerations: Aircraft - AAC
  - Point Of Curvature (PC) Speeds: Aircraft - AAC

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**

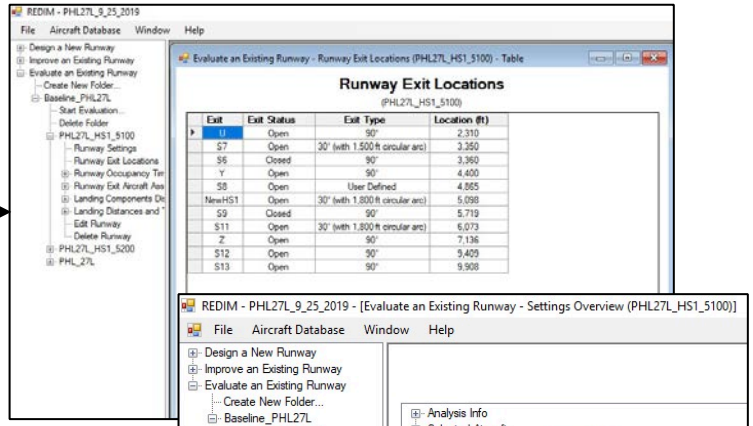


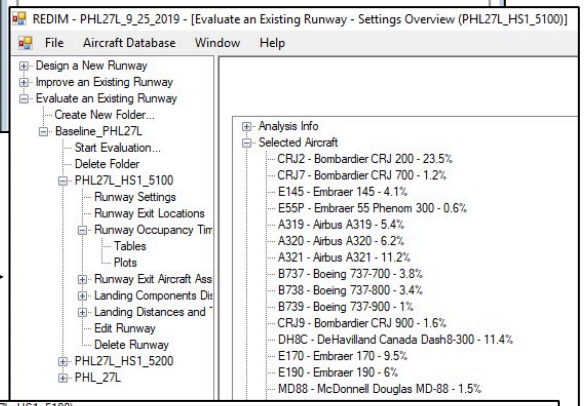
Model uses Monte Carlo Simulation to predict aircraft landing roll performance

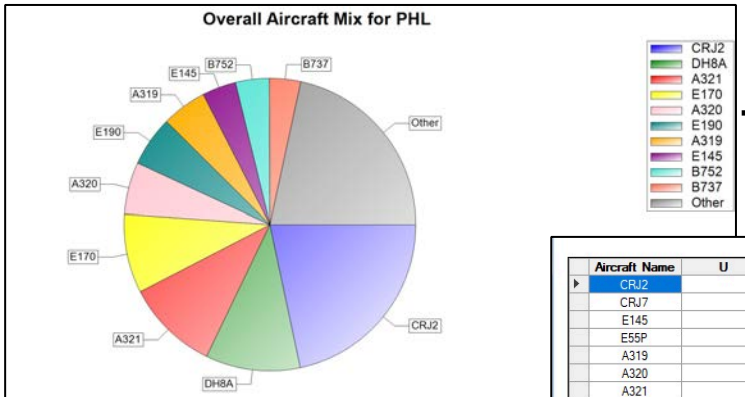
- Stand-alone Windows application
- Requires ~1.8 Gb of hard disk space
- New runway clustering
- Improvements to landing roll profile calculations

Runway Exit Design Model (a Computer Tool)

Runway Exit Locations and Geometry







Aircraft Fleet Mix

Runway Occupancy Table

(PHL27L_HS1_5100)

Aircraft Name	U	S7	S6	Y	S8	NewHS1	S9	S11	Z
CRJ2		31.2s		36.8s	39.6s	41.3s		47.9s	56.9s
CRJ7		33.9s		37.3s	39.9s	41.5s		48.4s	57.6s
E145		33.6s		37.1s	38.9s	40.7s		47.1s	55.6s
E55P		38.2s		45.0s	47.7s	49.2s		56.1s	65.2s
A319		31.0s		38.1s	41.3s	44.3s		51.3s	58.8s
A320				36.7s	40.3s	42.2s		49.0s	56.4s
A321				35.6s	39.2s	40.7s		47.1s	52.8s
B737									57.1s
B738								3s	53.0s
B739								1s	53.5s
CRJ9		28.0s						7s	55.9s
DH8C		34.6s						9s	60.3s
E170		32.1s		36.7s	40.2s	42.4s		49.1s	56.1s
E190		32.5s		36.1s	37.6s	42.3s		49.3s	55.6s
MD88				35.6s	40.7s	39.9s		46.0s	53.4s
MD90				35.4s	39.0s	39.7s		45.7s	52.7s
B752		35.2s		41.1s	44.5s	45.8s		52.5s	60.8s
B763				39.0s	43.2s	44.2s		50.8s	57.5s
MD11				36.2s	42.3s	43.0s		49.4s	53.9s
A332				40.8s	46.6s	46.9s		53.6s	58.8s
A333					47.2s	46.1s		53.1s	57.1s
B772					46.4s	45.4s		53.7s	58.8s

Save Table
Close

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

Differences with Previous Runway Exit Model

Item	Older Model (REDIM 2.1)	New Model (REDIM 3)
Wind information	Single wind speed and direction Airports have complex wind patterns	Landing observations are effected by local wind conditions Landing events database has wind speed and direction for each landing REDIM 3 designs for average wind conditions included in the landing speed distributions collected at 37 ASDE-X airports
Runway gradient	Ten values of local gradients along the runway Model will calculate the average gradient and apply a very small correction factor	Runways designed for commercial operations have limited gradients by regulation (0.8% in first quarter of runway and a maximum of 1.5%) The correction factor for such runways is very small We plan to investigate this issue in the future
Pavement conditions	50/50 wet dry default condition Wet pavement conditions reduce nominal deceleration	10/90 default condition in new model Rainfall data collected at selected airports provided the basis for the new default Wet pavement conditions reduce nominal deceleration
Safety factor	Turnoff safety factor (user defined)	The new model is based on extensive runway and runway exit data Observed runway exit speeds in the new model make the use of a safety factor in the turning maneuver unnecessary
Aircraft fleet	5 aircraft modeled directly (Douglas DC9-30, McDonnell Douglas MD-80, Boeing 727-200, Boeing 737-300 and Boeing 757-200) 70+ aircraft modeled indirectly based on landing distance parameters adjusted for airport elevation Aircraft performance adjusted for airport elevation and temperature Model assumed all landing roll distributions to be normally distributed truncated to 2.5 sigma	298 aircraft modeled Aircraft performance adjusted for airport elevation and temperature Landing roll distributions use Kernel Density Functions (KDE) for individual aircraft (functions of runway length and runway exit types) Model defaults to Aircraft Approach Group (AAC) category if a Kernel distribution does not exists for the aircraft in question

REDIM 3 Aircraft Database

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

New aircraft identified in Phase 2 dataset (see next page)

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

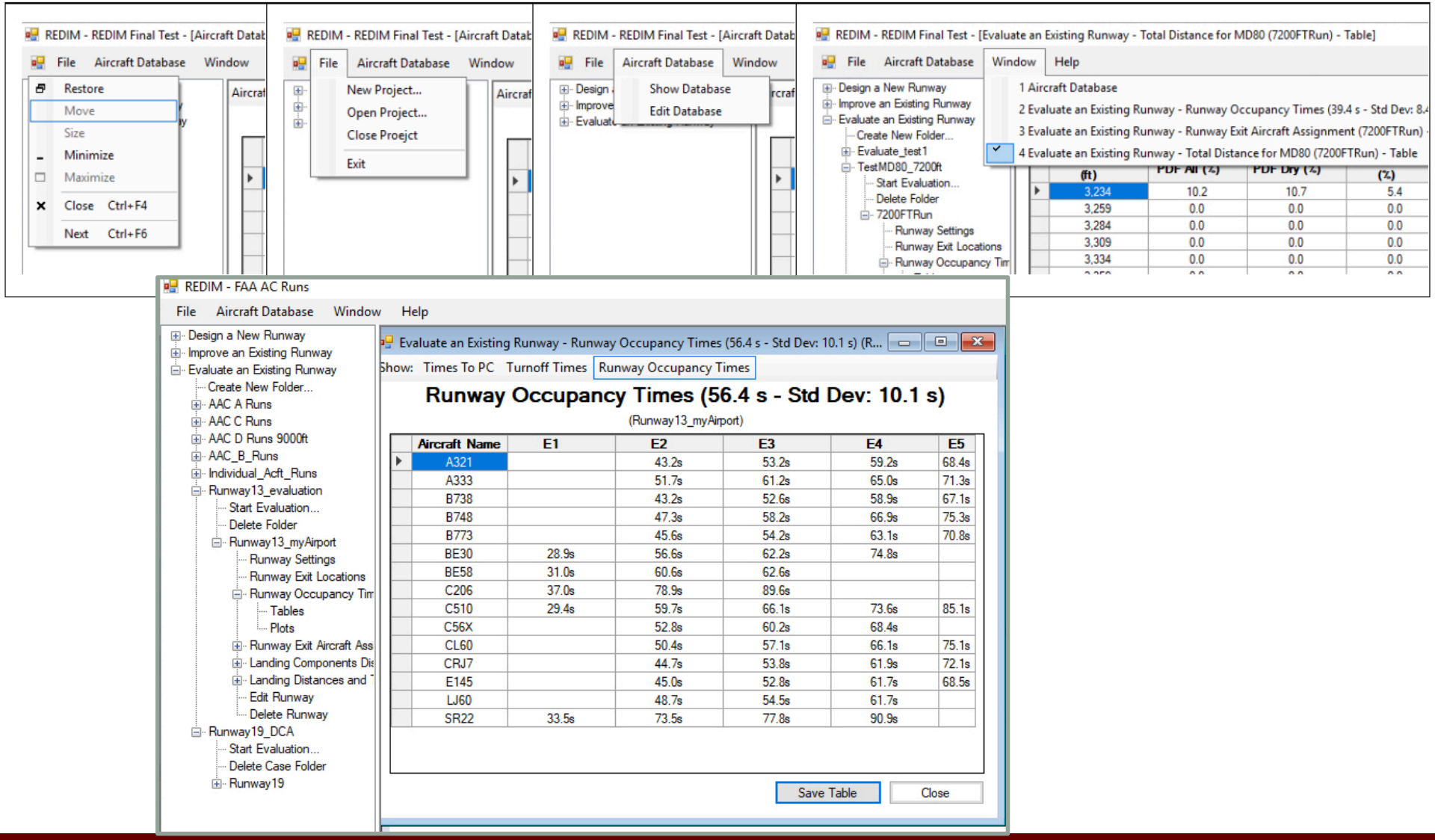
Aircraft ID	Aircraft Name	Engine Type	Aircraft Design Group	Aircraft Approach Category	Nose Gear to Main Gear (m)	Nose Gear to Tail (m)	Wing Tip Radius (m)	Full Length (m)
AA1	Grumman American AA1	Piston	I	A	1.48	5.14	3.78	5.87
AA5	Grumman American AA5	Piston	I	A	1.66	5.65	4.92	6.71
AC11	Rockwell Commander 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

Expanding REDIM 3 Aircraft Database

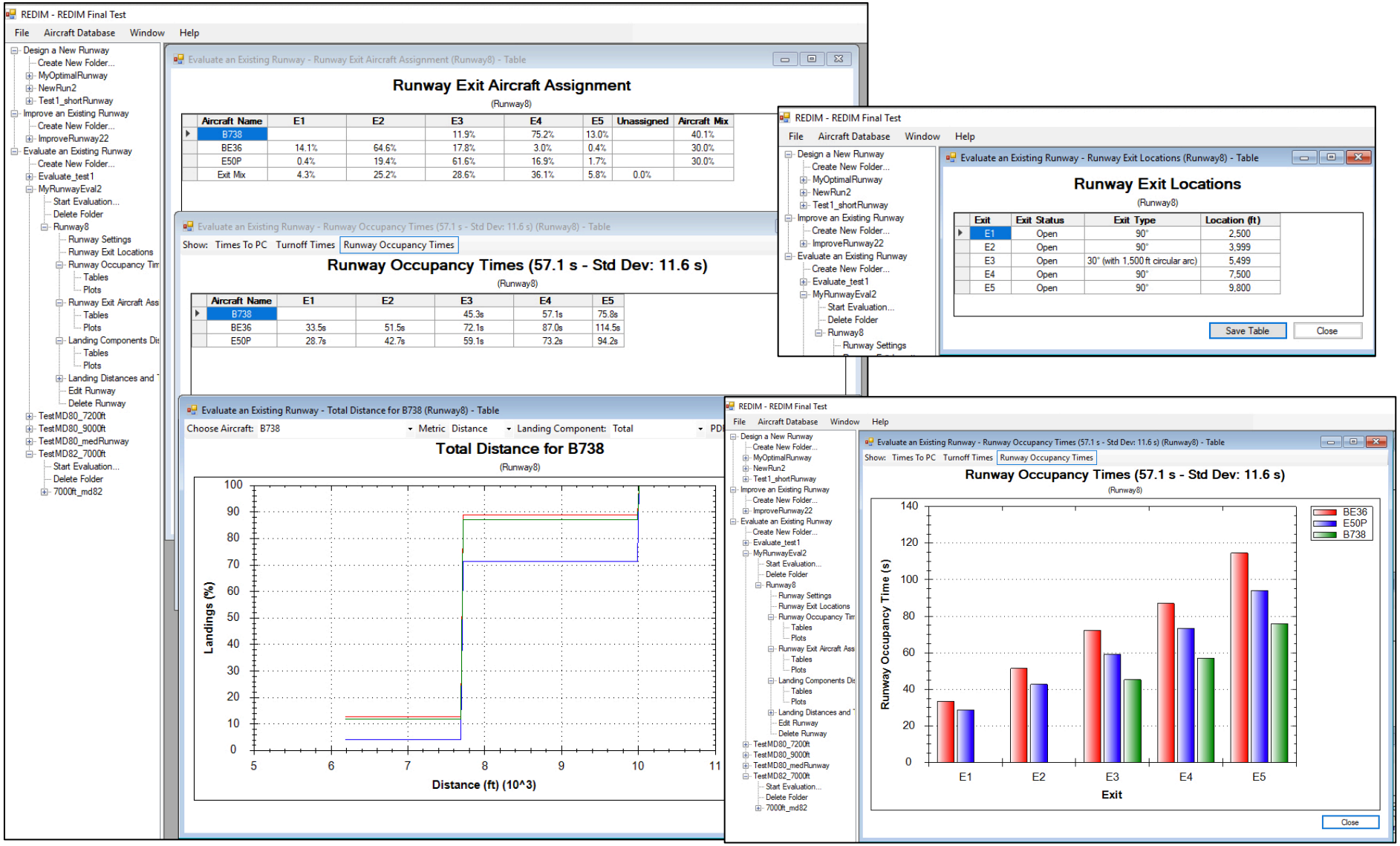
- New airport data (2017-2020) at 43 ASSC airports has operational data on new aircraft

Aircraft Class	*Types*	
AAC A	Piper Cherokee Arrow	
AAC B	Pilatus PC-24 Cirrus Vision SF50 Piper Seneca PA34 Lockheed C-130 Hercules	Cessna Citation Longitude Cessna Citation Bravo Cessna Citation M2 Dassault Falcon 8X Bombardier Global Express 7500
AAC C	Airbus A319 neo Airbus A320 neo Airbus A321 neo Boeing 737-7 Max Embraer 195	Embraer 175-E2 Embraer 190-E2 Embraer 195-E2 Gulfstream G500 Gulfstream G600
AAC D	Boeing 737-8 Max Boeing 737-9 Max Boeing 777-8 Boeing 777-9 Boeing 787-10	Airbus A330-800 Airbus A330-900 Airbus A350-1000

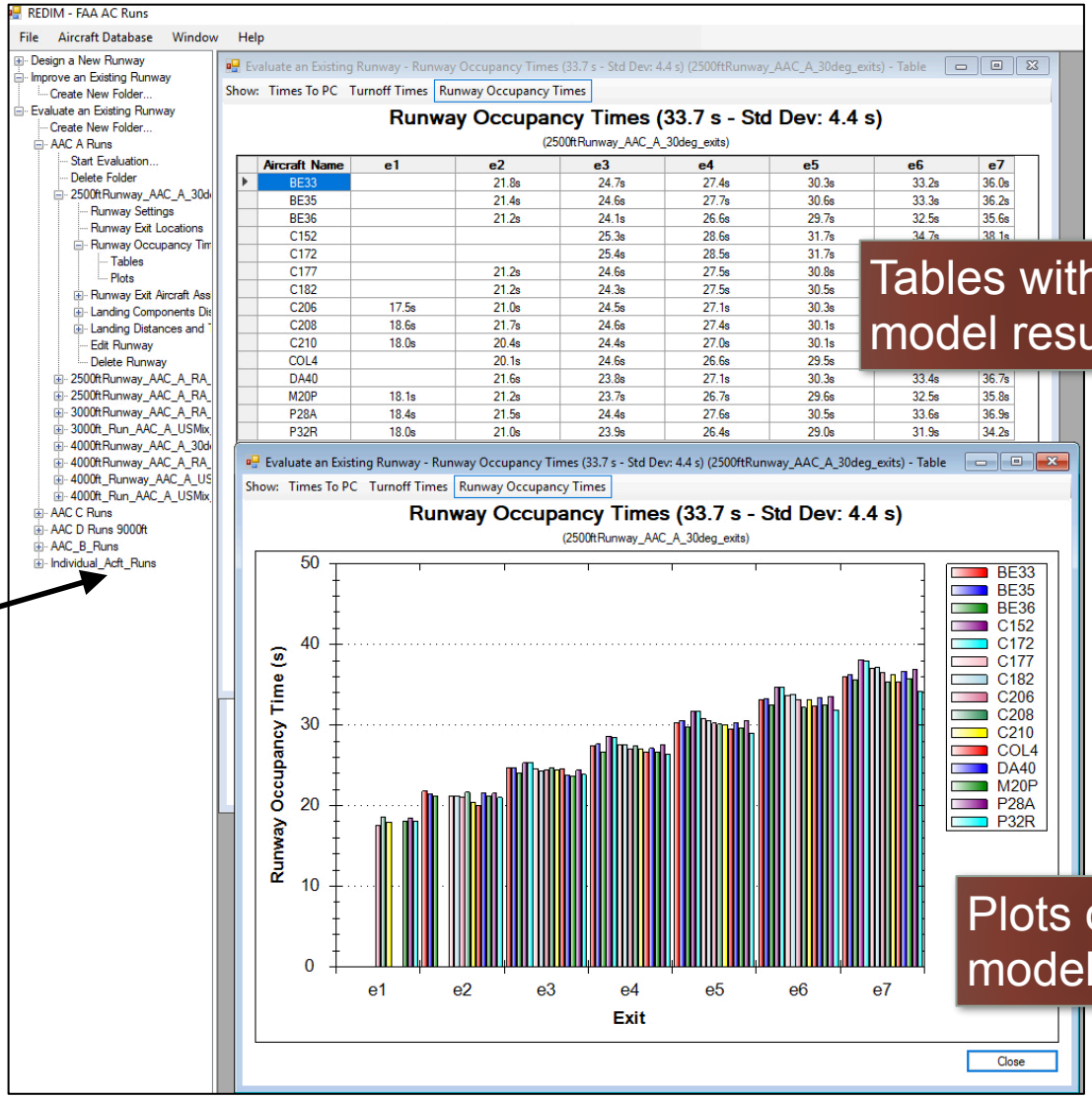
REDIM 3 Menu Structure



Sample Screens of Runway Exit Design Tool



Interface and Panels in the Runway Exit Design Model

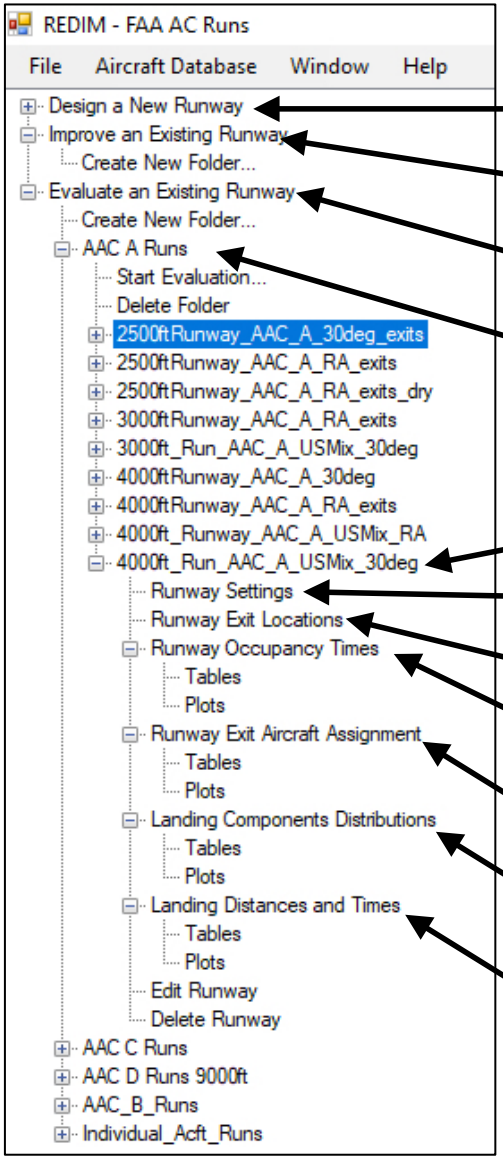


Tables with relevant model results

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

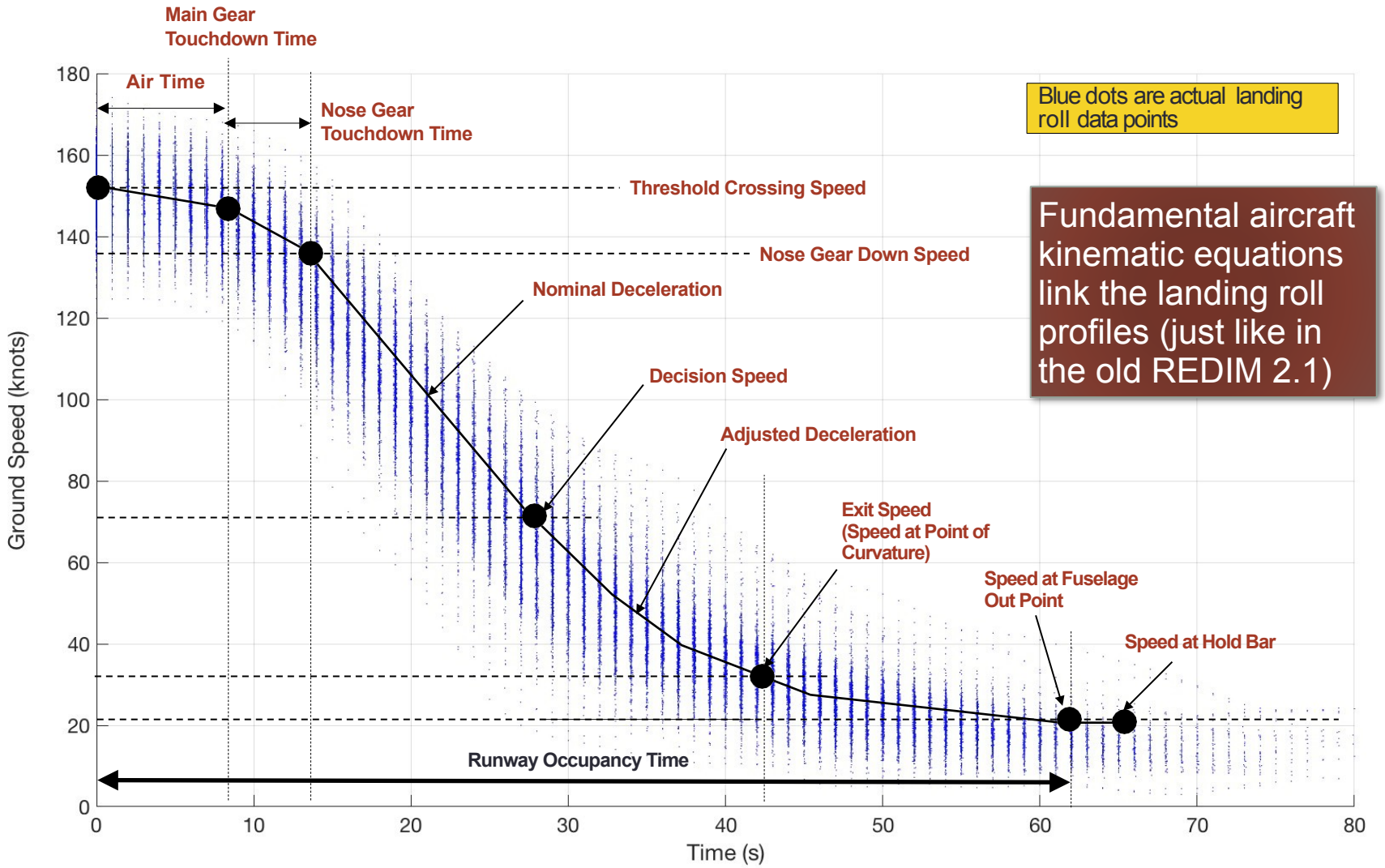
Runway occupancy times (tables and plots)

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	
18	10950	11145	
15	11377	11553	
4	11863	12293	
2	12962	13436	10
12	16020	16020	2
Total			292

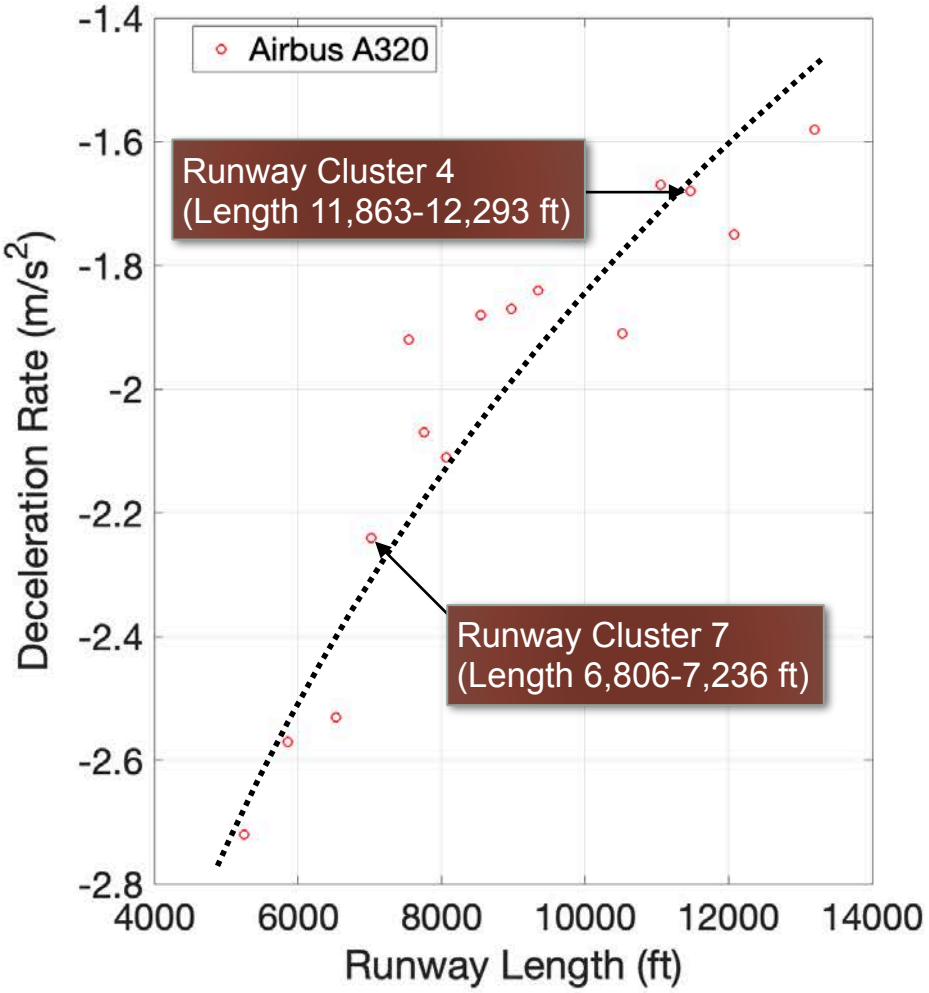
Runway clusters influence the landing roll behavior

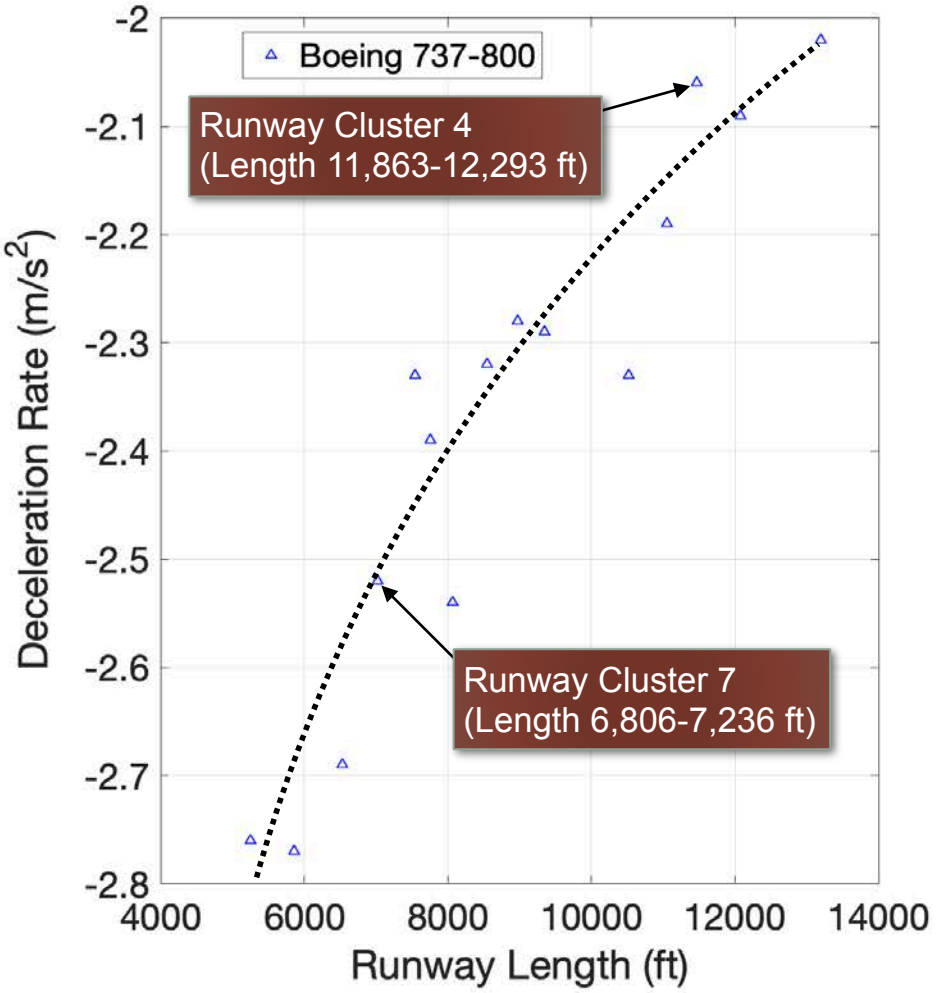
Model Uses Individual Aircraft Data

Airbus A320 Data
for all runway clusters

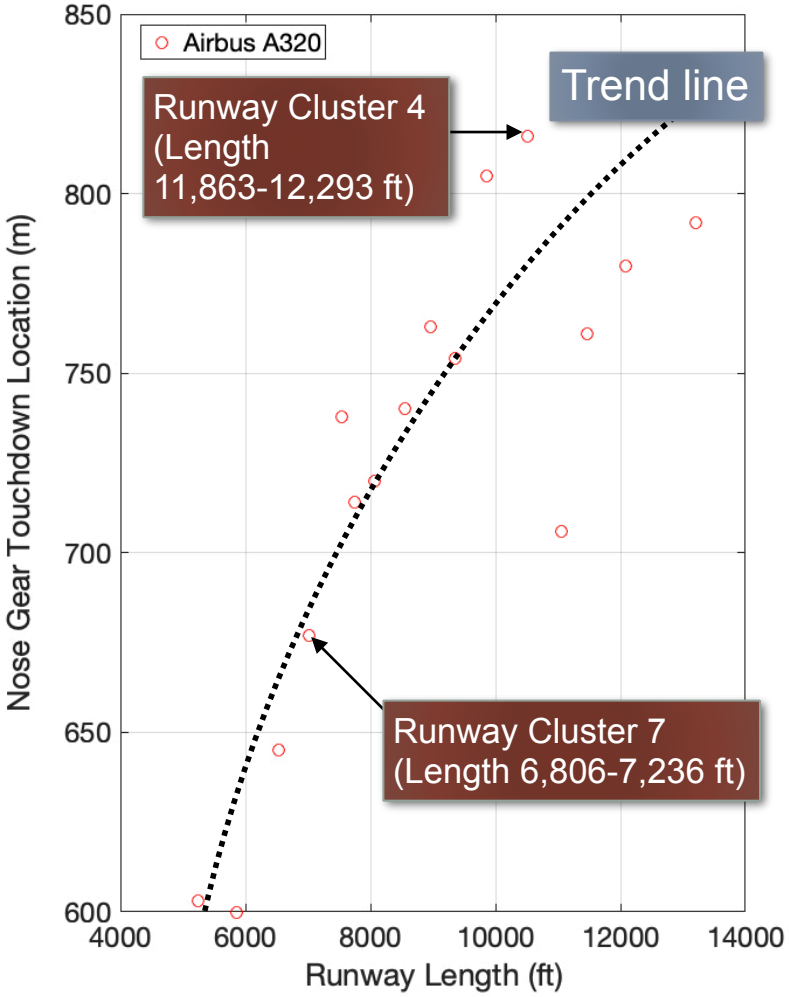
Aircraft nominal deceleration distributions are different for every runway cluster (i.e., runway length)

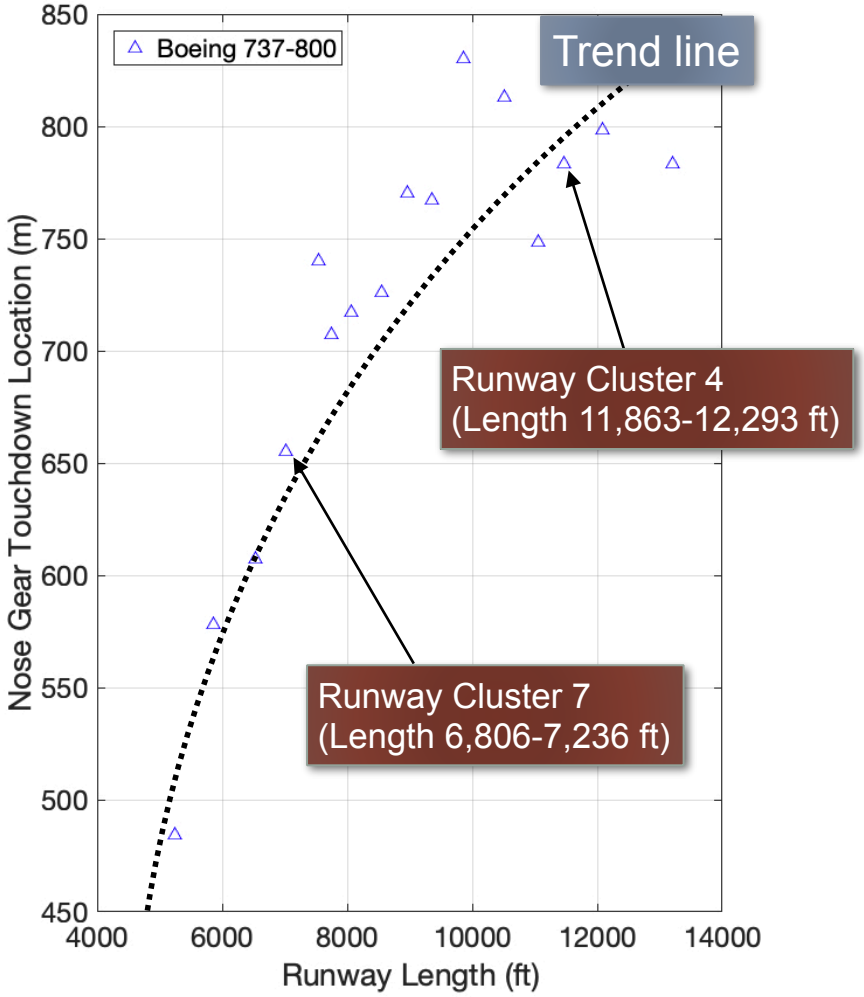
Runway Cluster Affects Landing Roll Profile
Mean Deceleration Rates for Narrow Body Aircraft





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

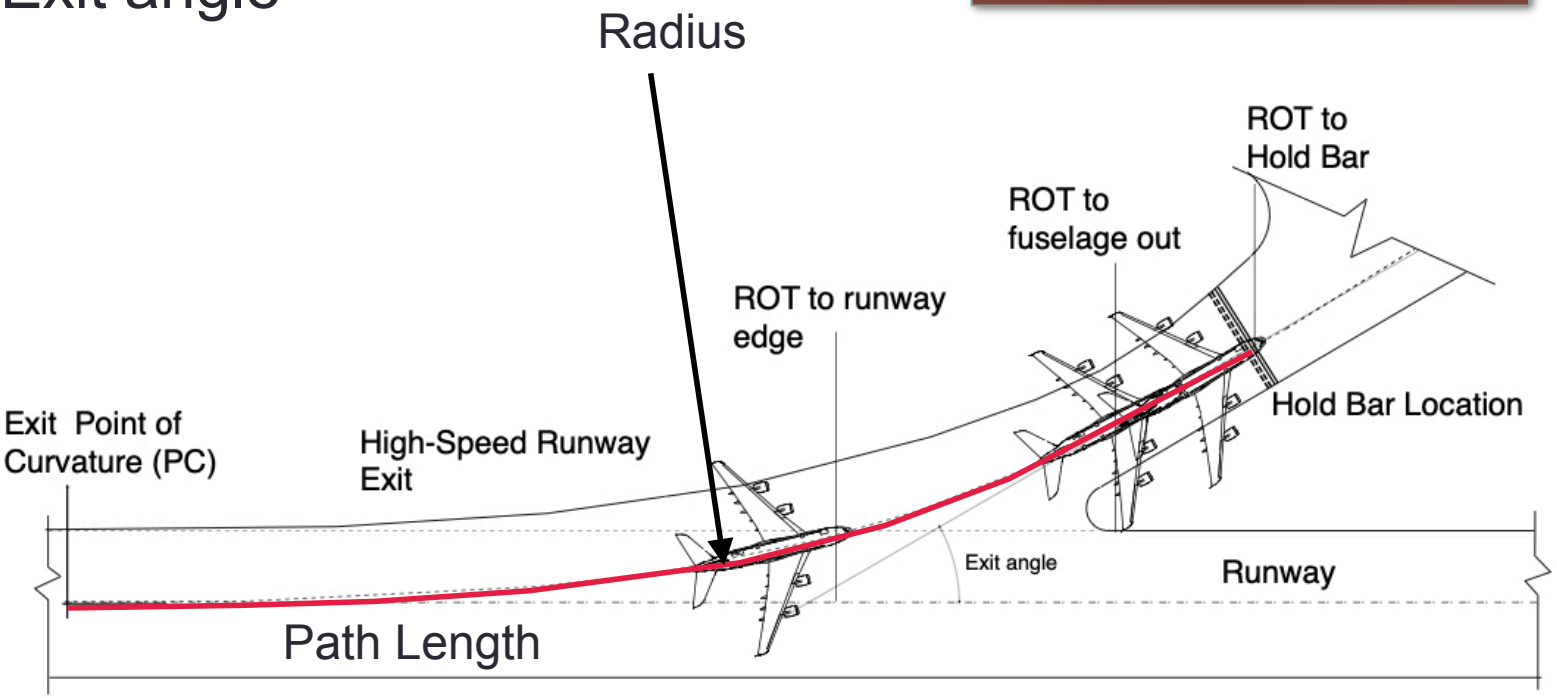




Runway Exit Clusters and Geometry

- 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



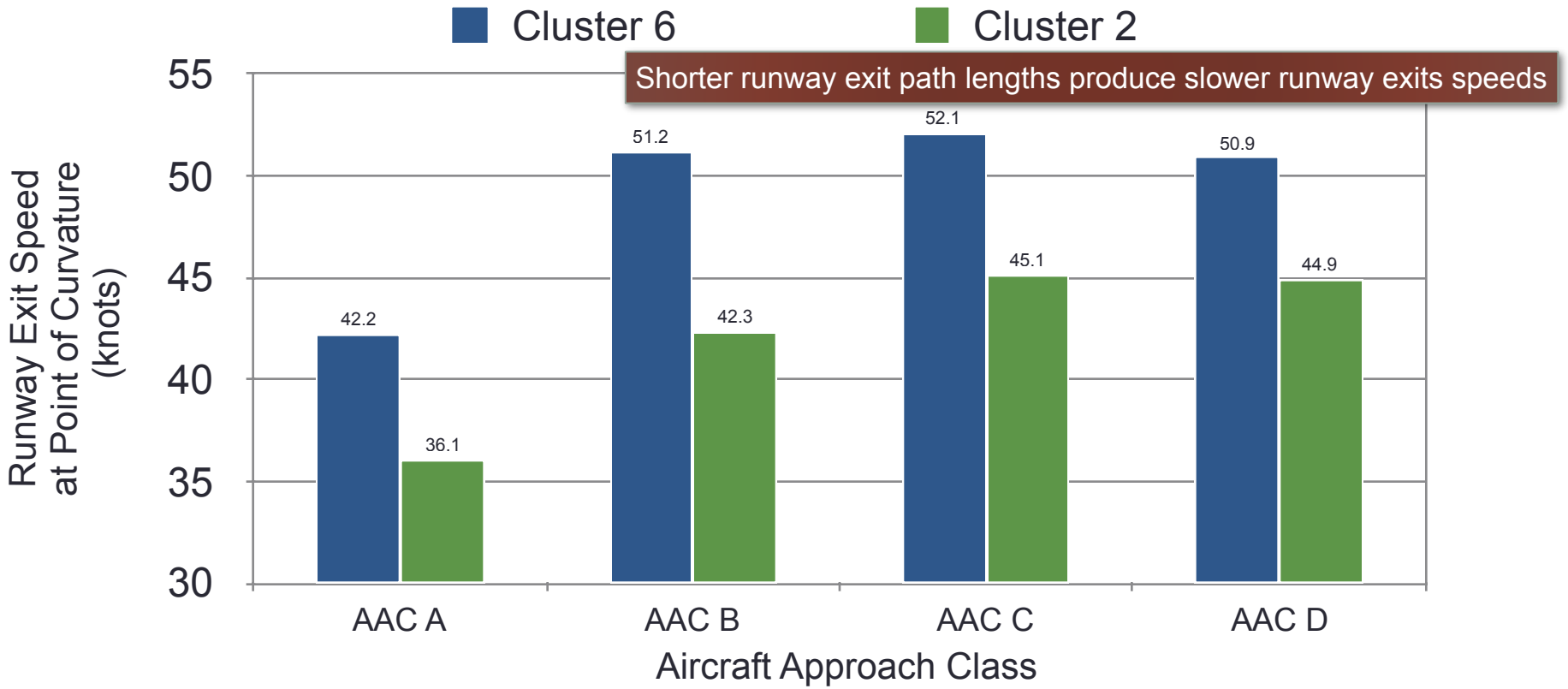
Runway Exit Clusters in REDIM 3

	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

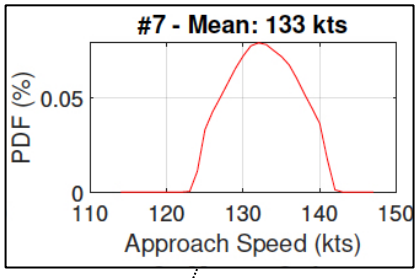
Effect of Runway Exit Cluster on Exit Speed

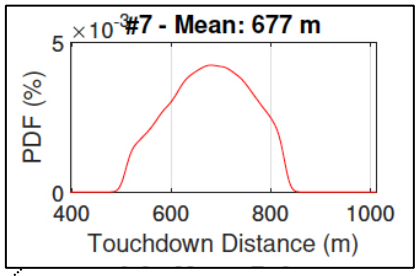
	Angle (deg)		Radius (ft)		Path Length (ft)		Number Of Exits	Type of Runway
Cluster #	Min	Max	Min	Max	Min	Max		Exit
2	30	57	1800	1800	677	1043	96	Acute angle, long radius, midsize path length
6	20	30	1400	1800	1233	1684	63	Acute angle, long radius, long path length

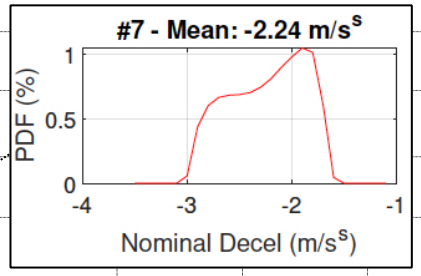


Monte Carlo Simulation in REDIM 3

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

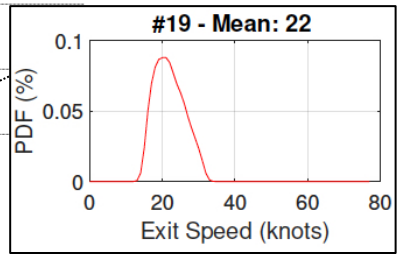






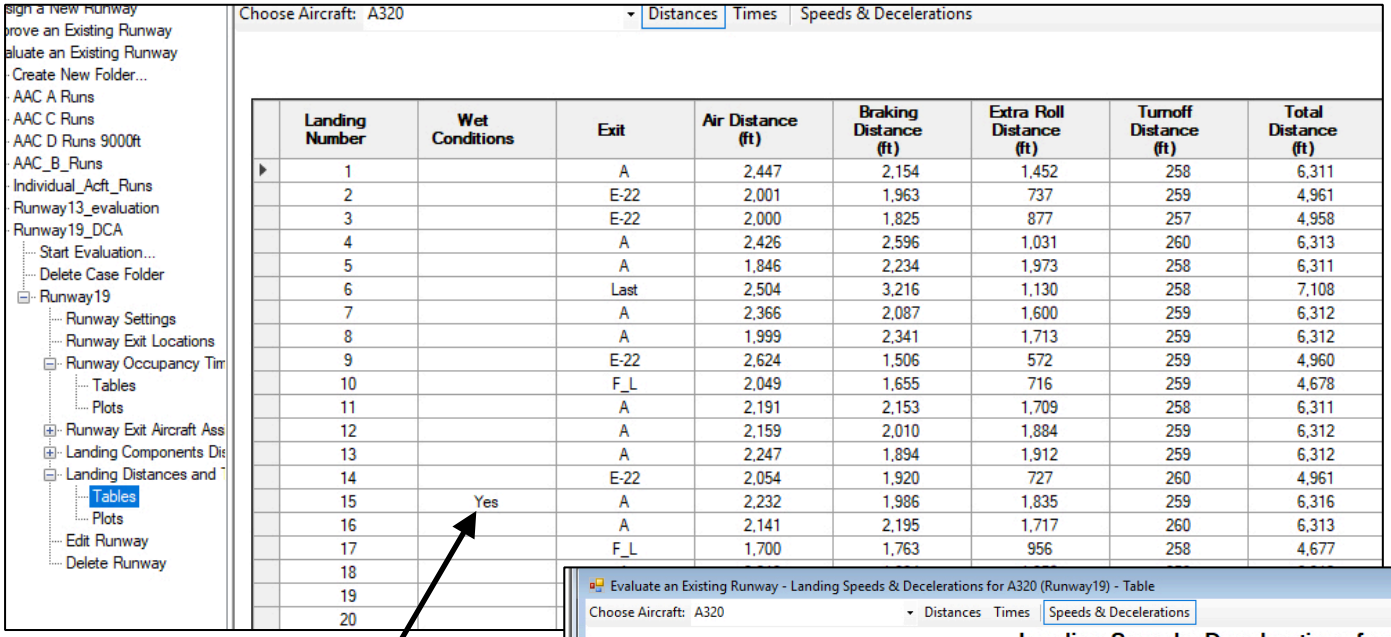
Nominal Deceleration

Exit Speed Distribution for Cluster 2 runway exit - right angle runway exit



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

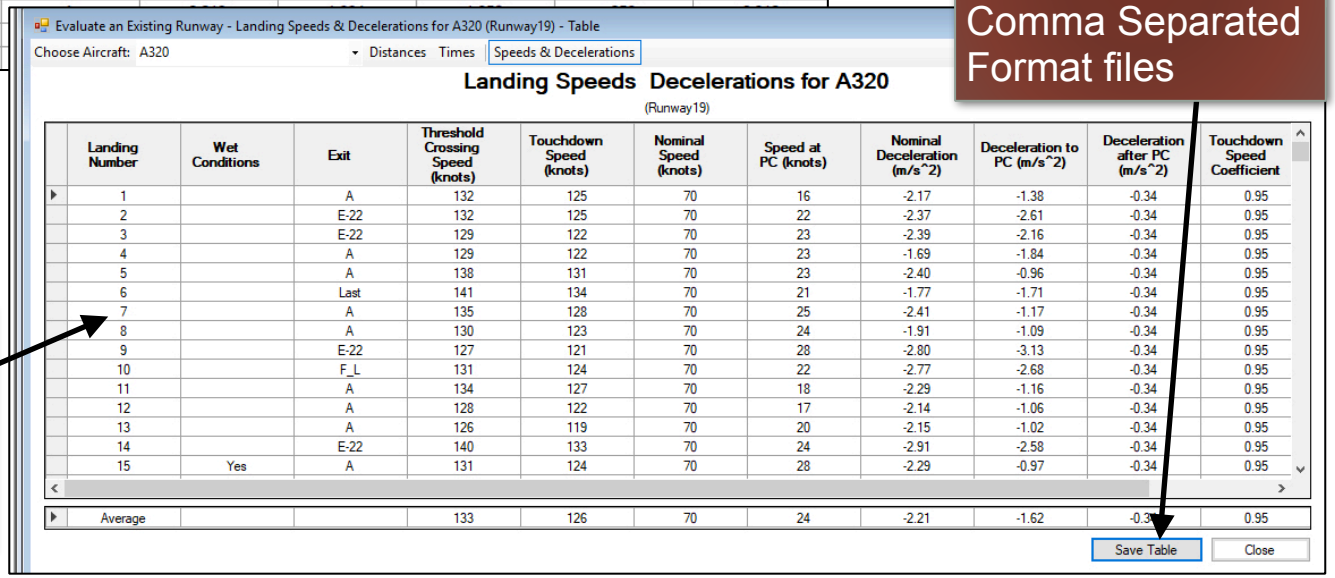
REDIM 3 Output (Tabular Form)



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



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	-0.3	0.95

All output tables can be exported as Comma Separated Format files

Application of Runway Exit Design Tool to Selected US Airports

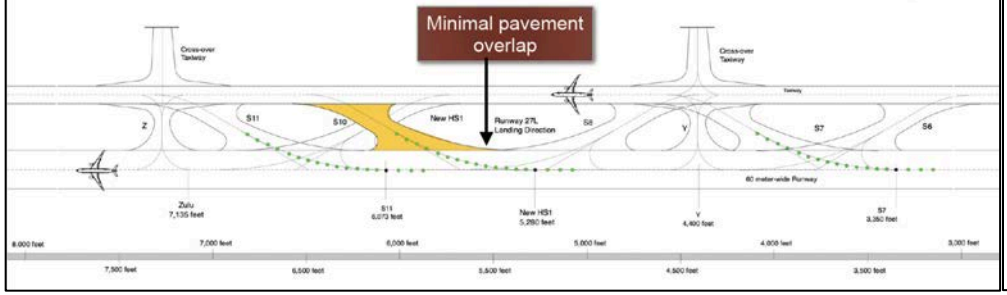
Application of the Runway Exit Design Tool to Four Airports

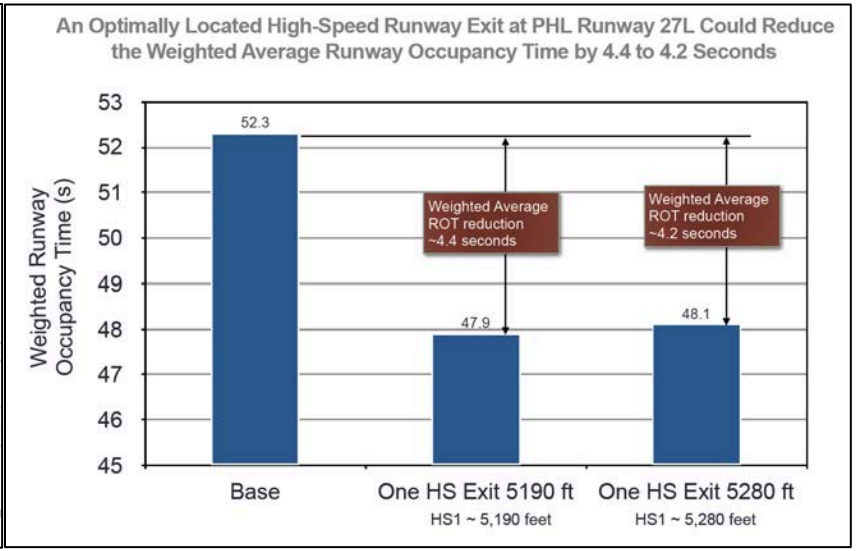
Application of the Runway Exit Design Tool to PHL

Scenario	Location of New Optimal High-Speed Exit (ft)	Wet/Dry Mix (%/%)	Remarks
Baseline	Not applicable	10/90	Open exits: U, S7, Y, S9, S11, S12 and S13
One High-Speed Runway Exit, 10/90	5,190	10/90	Open exits: U, S7, Y, NewHS1, S11, S12 and S13
One High-Speed Runway Exit, 20/80	5,280	20/80	Open exits: U, S7, Y, NewHS1, S11, S12 and S13

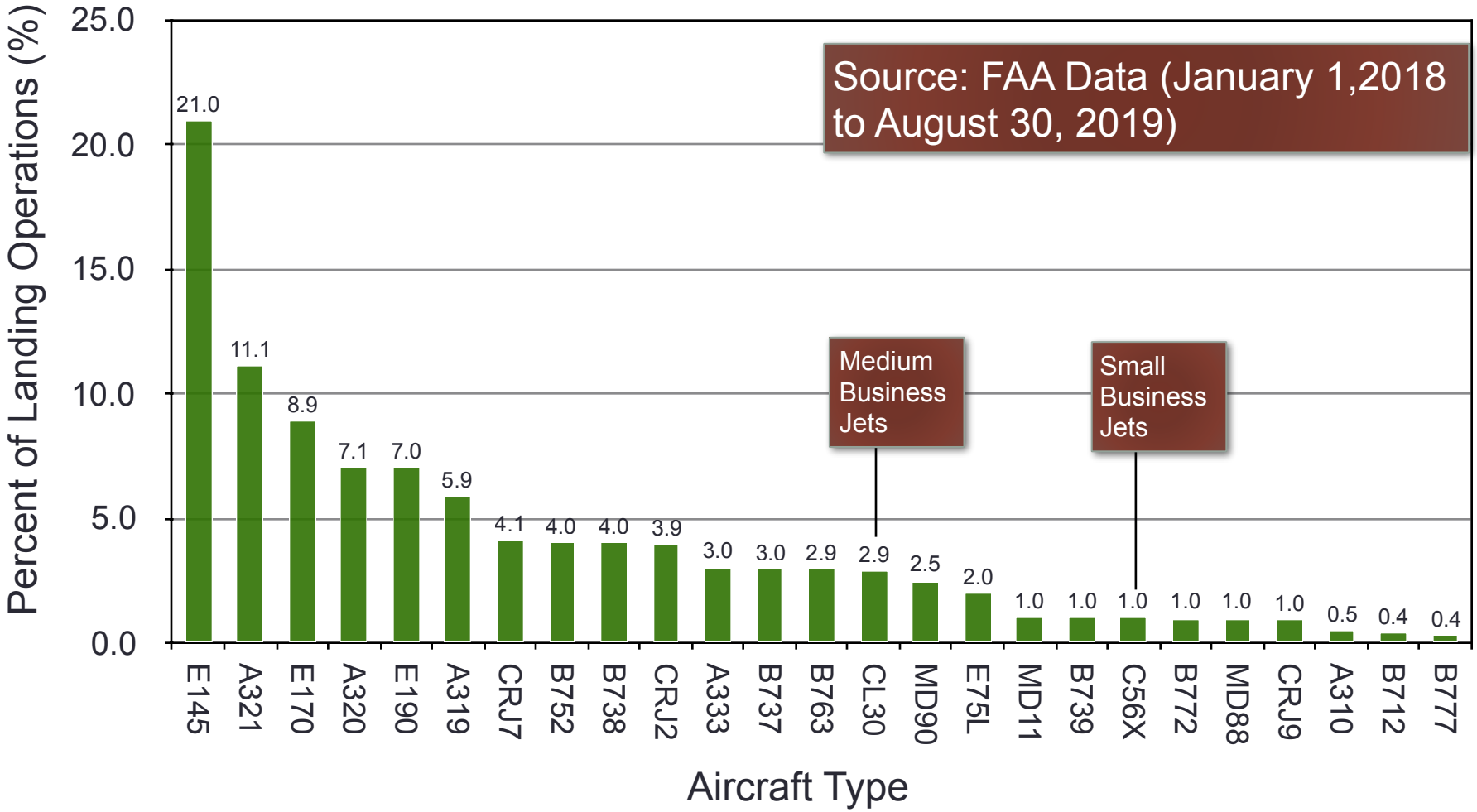
- Optimal location of a **new High-Speed Runway exit** designed for 20/80% wet/dry pavement conditions is **5,280 feet** (point of curvature)
- Runway exit Sierra-9 is eliminated
- **793 feet** - distance between new exit high-speed exit HS2 and Sierra-11

Optimally located runway exit in yellow





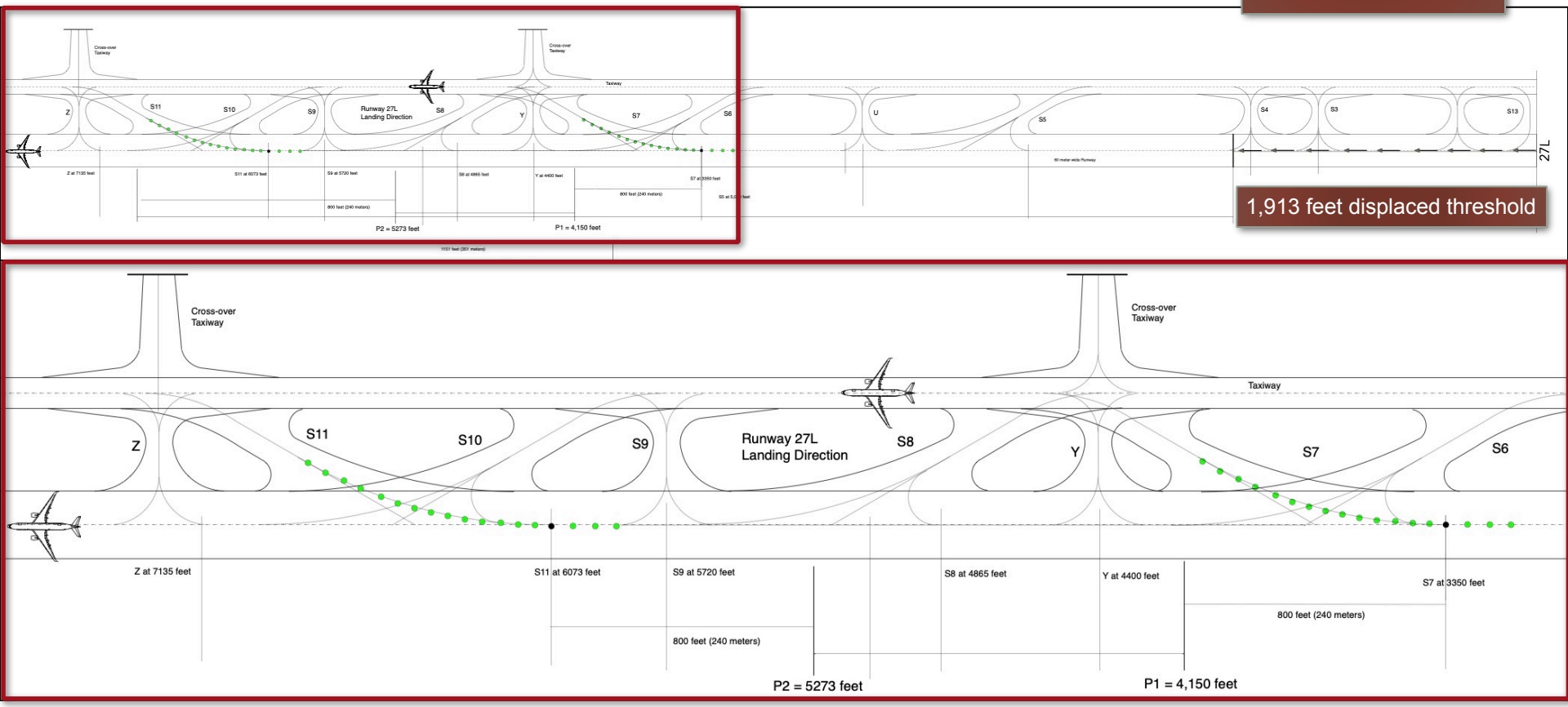
Airport Fleet Mix Used in the Analysis of Runway 27L



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



Scenarios Studied with New PHL Fleet Mix

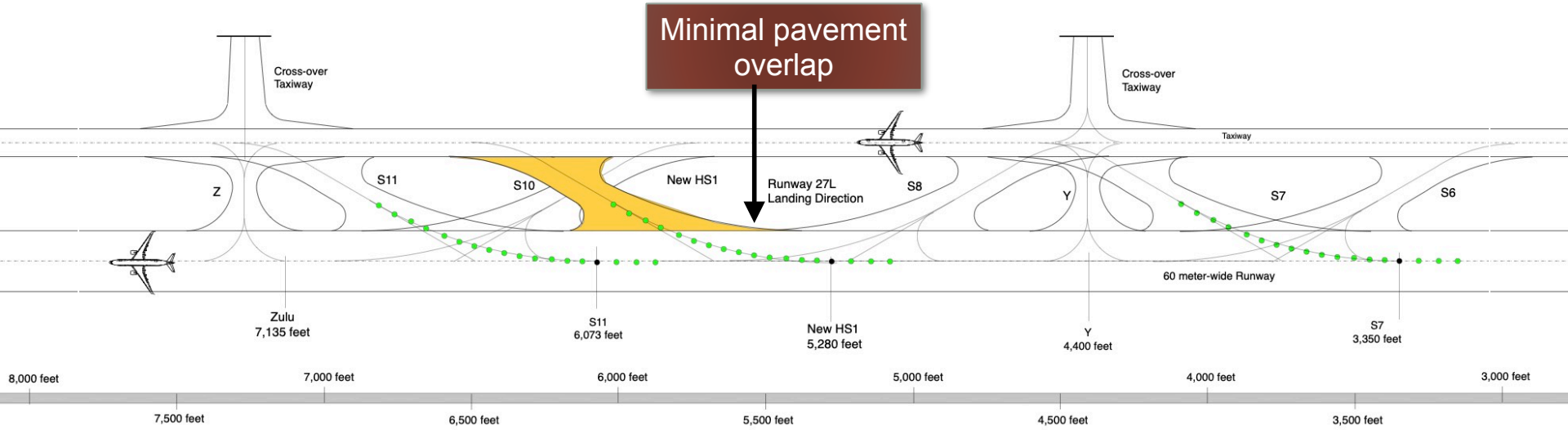
Scenario	Location of New Optimal High-Speed Exit (ft)	Wet/Dry Mix (%/%)	Remarks
Baseline	Not applicable	10/90	Open exits: U, S7, Y, S9, S11, S12 and S13
One High-Speed Runway Exit, 10/90	5,190	10/90	Open exits: U, S7, Y, NewHS1, S11, S12 and S13
One High-Speed Runway Exit, 20/80	5,280	20/80	Open exits: U, S7, Y, NewHS1, S11, S12 and S13

Optimal locations found using REDIM 3 dynamic programming algorithm
The backup slides contain probabilities of precipitation at PHL

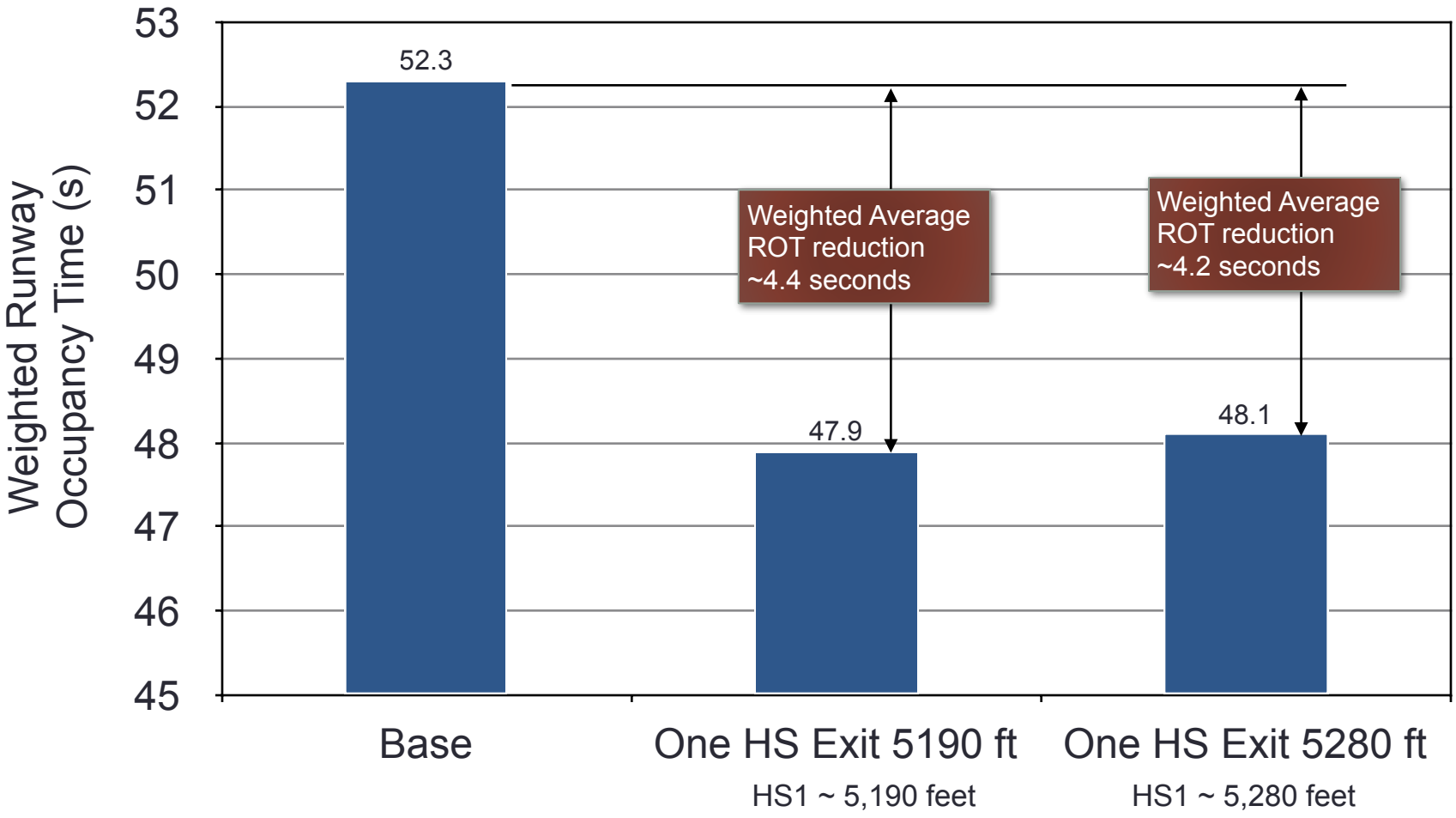
Case: One New High-Speed Runway Exit, 20/80 (wet/dry pavement design)

- 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

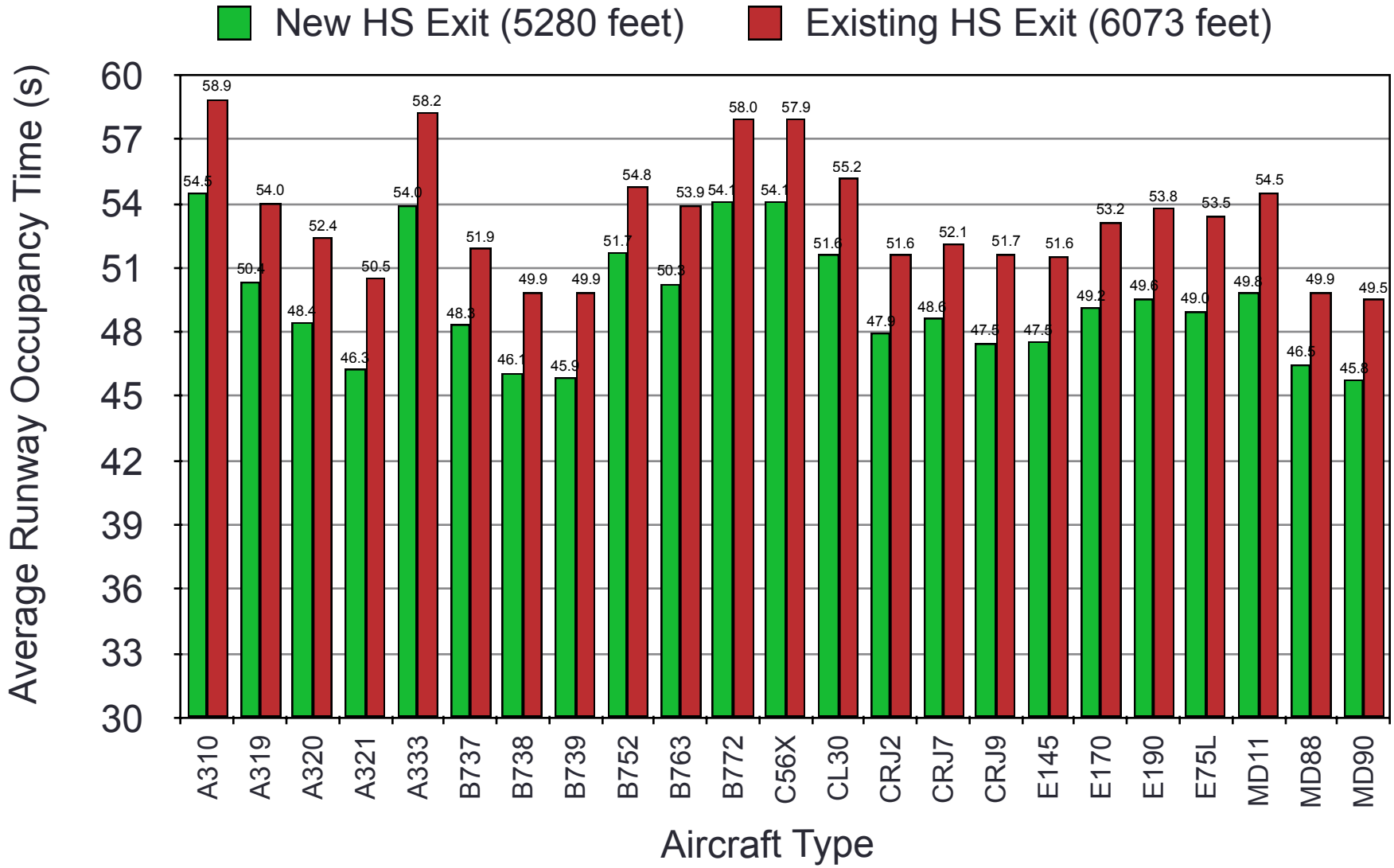


An Optimally Located High-Speed Runway Exit at PHL Runway 27L Could Reduce the Weighted Average Runway Occupancy Time by 4.4 to 4.2 Seconds

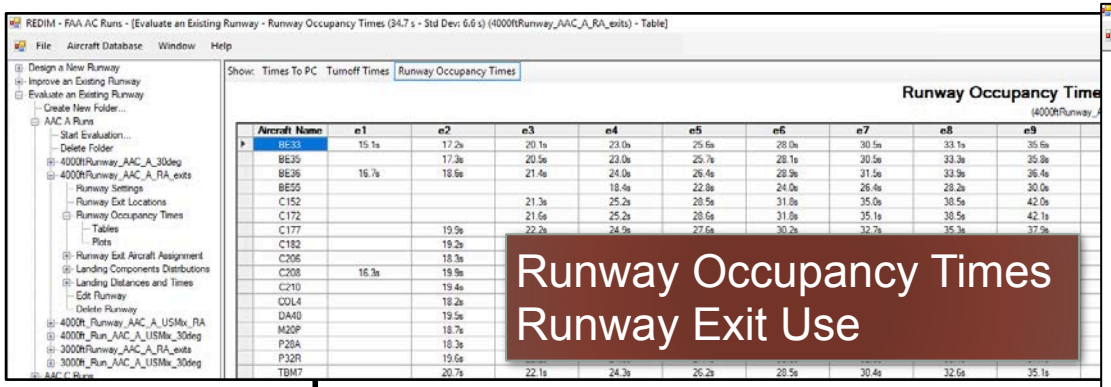


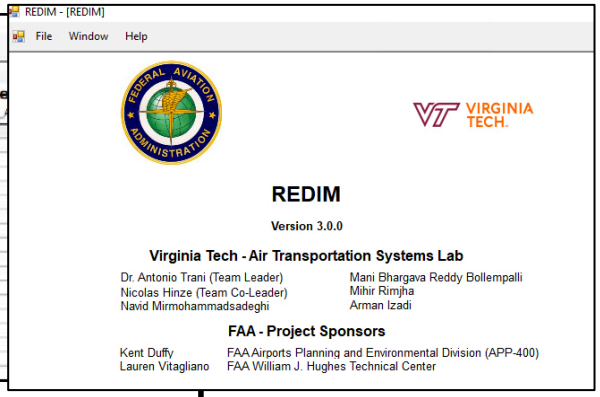
PHL Fleet Mix (Jan/2018 to Aug/2019) provided by FAA

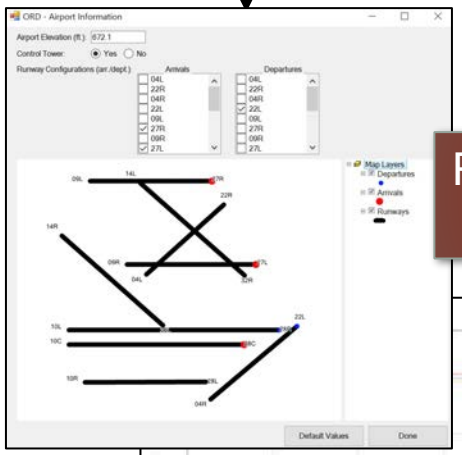
Aircraft Using the New High-Speed Exit at 5,280 feet could Save 3.5-4.7 seconds Compared to Using HS Exit Sierra-11 (6073 ft)

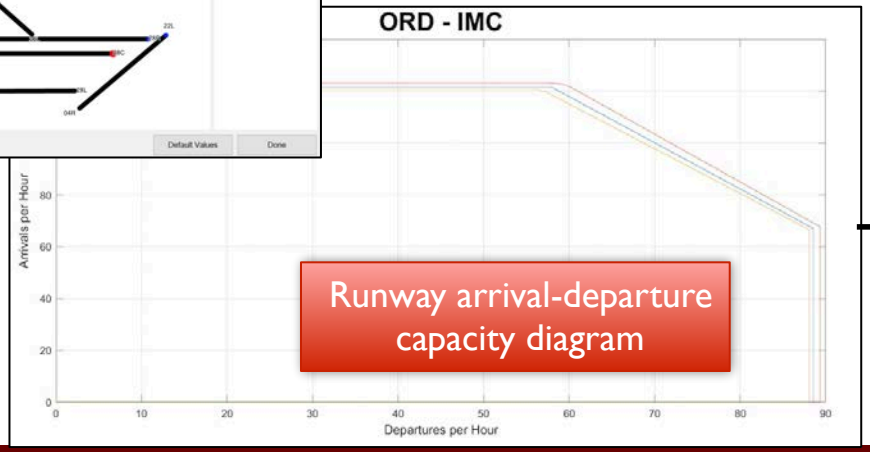


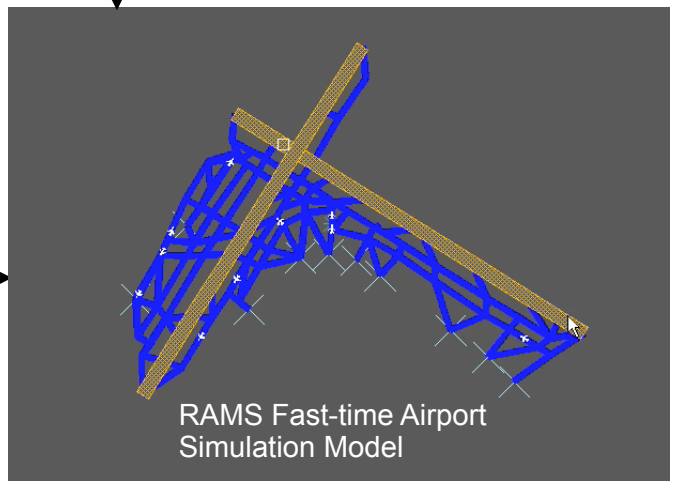
Typical Use of the REDIM Model





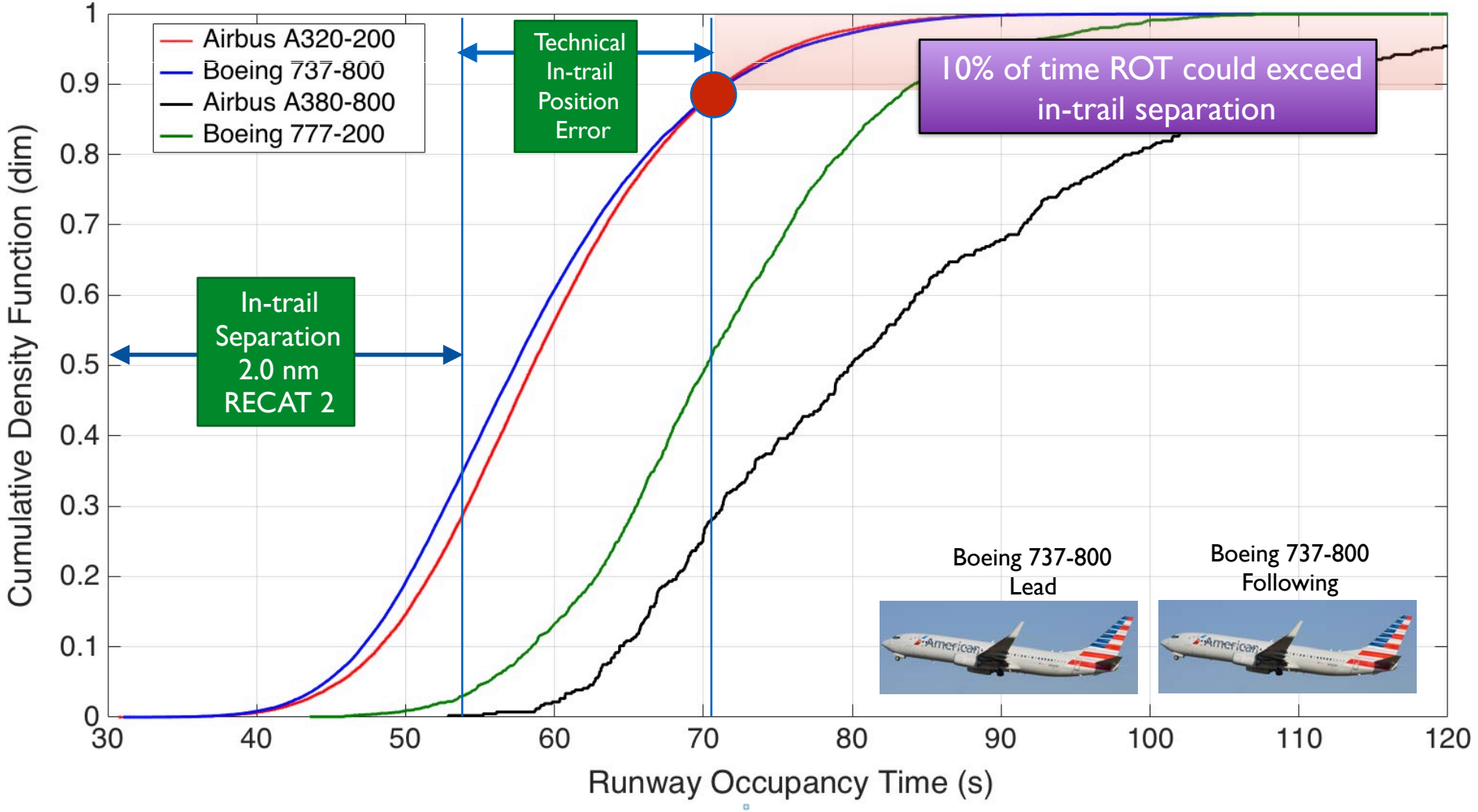






Challenges Ahead with Reduced In-Trail Separations

- Runway occupancy times may take an important role in runway throughput



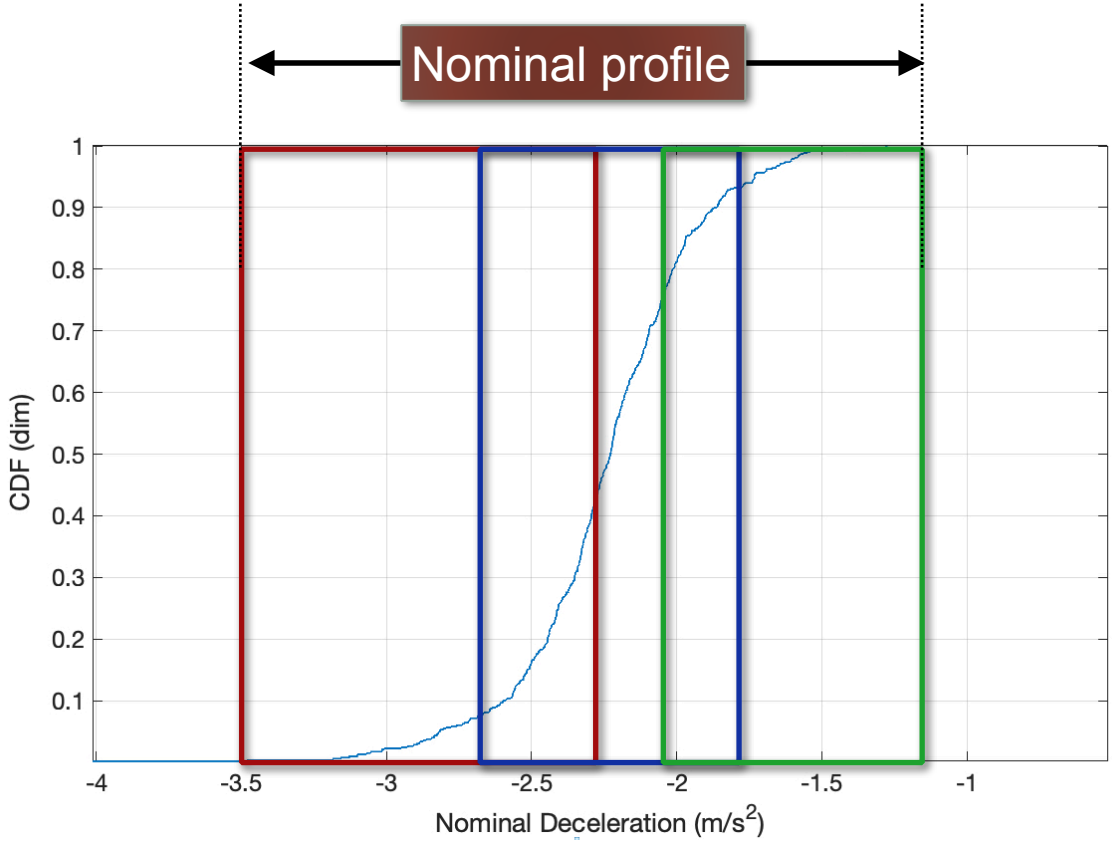
source of data: ASDE-X (37,383 Boeing 737-800 operations at 20 US airports)

New Features of Runway Exit Model

- Pilot motivational practice
- Expanded aircraft database (28-30 new aircraft)
- Improved algorithms to predict runway exit use for small, single-engine aircraft

Pilot Motivation Procedure

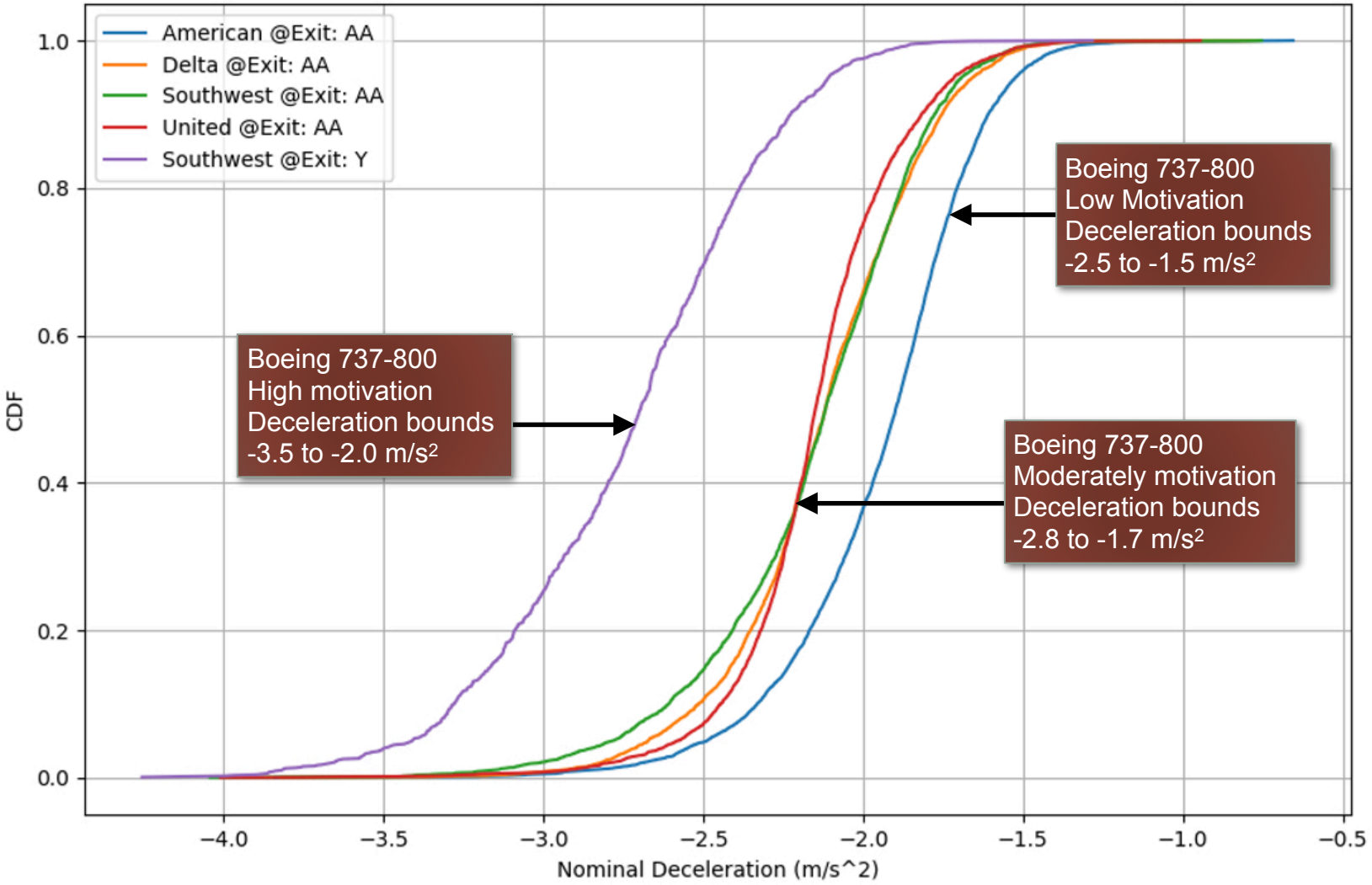
- User provides a **qualitative motivational factor** (i.e., low, medium, or high)
- Requires information on fleet and fraction of the fleet that has motivation
- Default is always the existing procedure (no additional input)



Red = high motivation
Blue = medium motivation
Green = low motivation

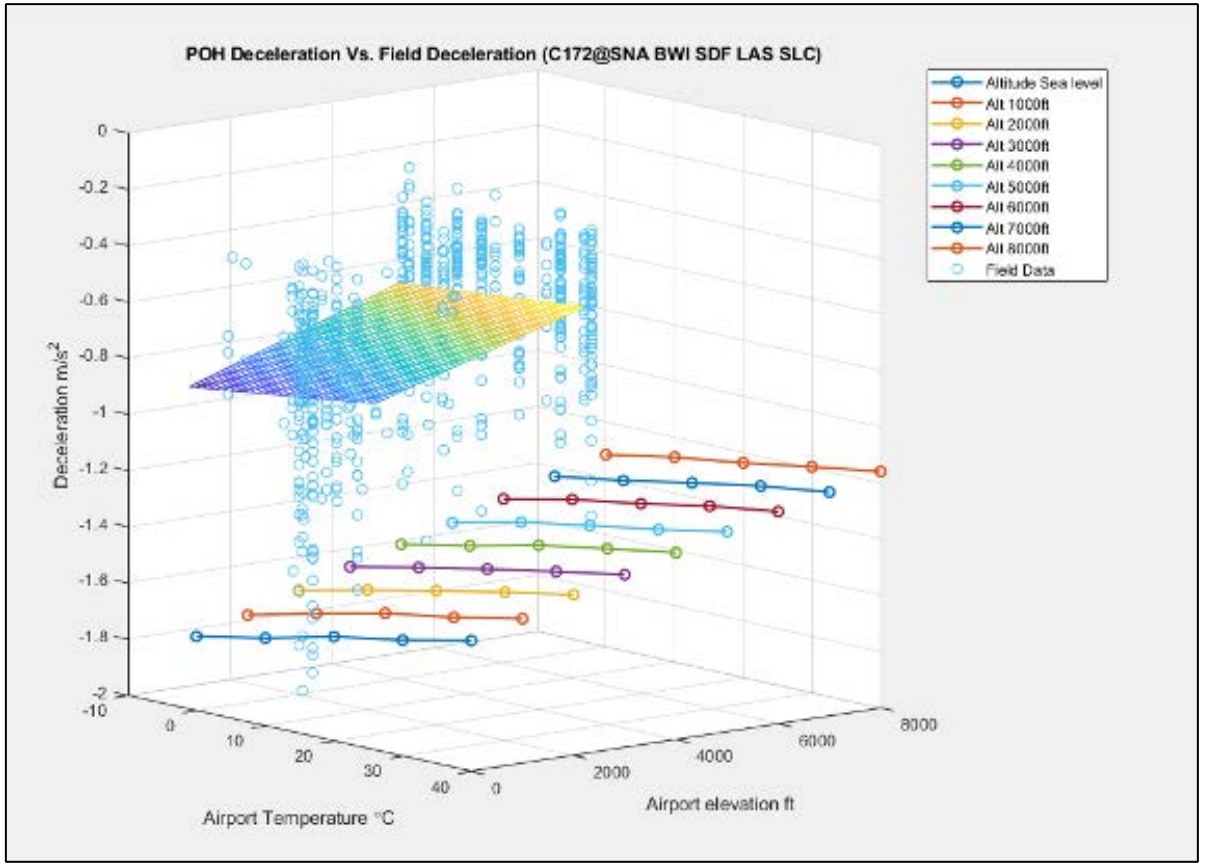
Deceleration rates are still evaluated as a function of runway clusters

Examples of Pilot Motivational Practice: Los Angeles Airport



Small Aircraft Runway Exit Use Improvements

- Goal is to improve the runway exit use prediction for small, single engine aircraft
- Current recommendation in using REDIM 3 to model small single engines piston powered aircraft to employ high performance aircraft in the database such as Piper PA-34 and Beechcraft Bonanza A36



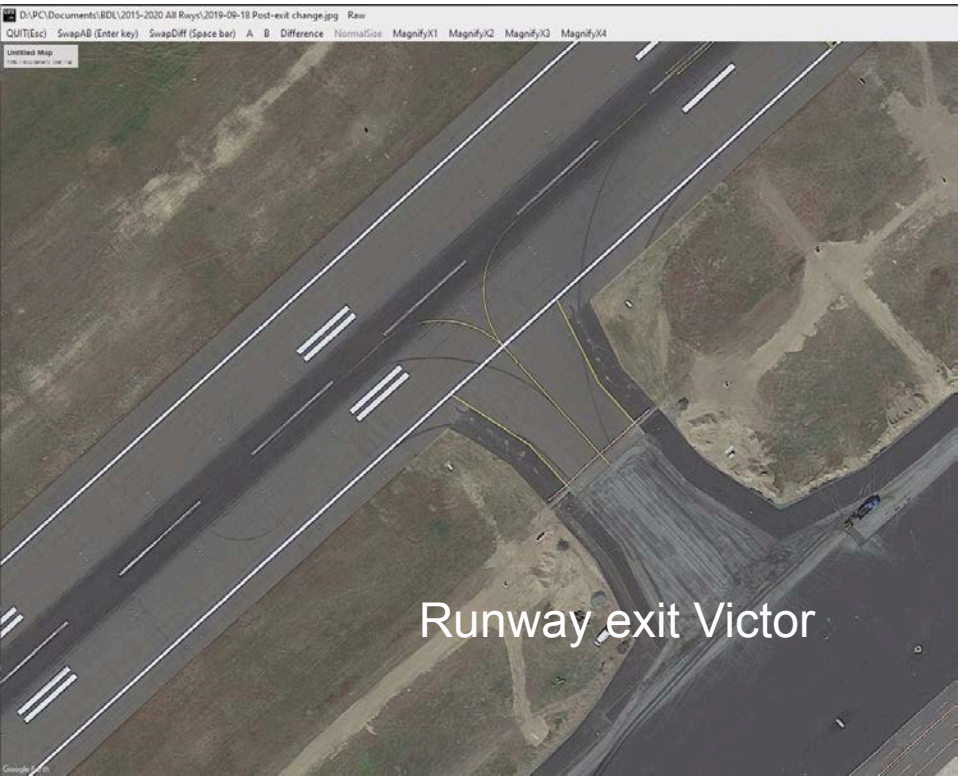
Deceleration rates for Cessna 172 landing operations versus Pilot Operating Handbook data

New Features of the Landing Events Database

- 43 airports (versus 37 in version 1.2.4)
- Updated runway and exit clusters based on four years of additional data
- 28 new additional aircraft including new generation commercial aircraft (Airbus A320 neo class and Boeing 737-8 Max class)
- Others suggested by users

Updated Runway Database and Runway Exits

- More than 3500 runway exits have been audited
- Geometric design features identified and updated



Expanding REDIM 3 Aircraft Database

- New airport data (2017-2020) at 43 ASSC airports has operational data on new aircraft

Aircraft Class	*Types*	
AAC A	Piper Cherokee Arrow	
AAC B	Pilatus PC-24 Cirrus Vision SF50 Piper Seneca PA34 Lockheed C-130 Hercules	Cessna Citation Longitude Cessna Citation Bravo Cessna Citation M2 Dassault Falcon 8X Bombardier Global Express 7500
AAC C	Airbus A319 neo Airbus A320 neo Airbus A321 neo Boeing 737-7 Max Embraer 195	Embraer 175-E2 Embraer 190-E2 Embraer 195-E2 Gulfstream G500 Gulfstream G600
AAC D	Boeing 737-8 Max Boeing 737-9 Max Boeing 777-8 Boeing 777-9 Boeing 787-10	Airbus A330-800 Airbus A330-900 Airbus A350-1000

Runway Exit Design Guidance

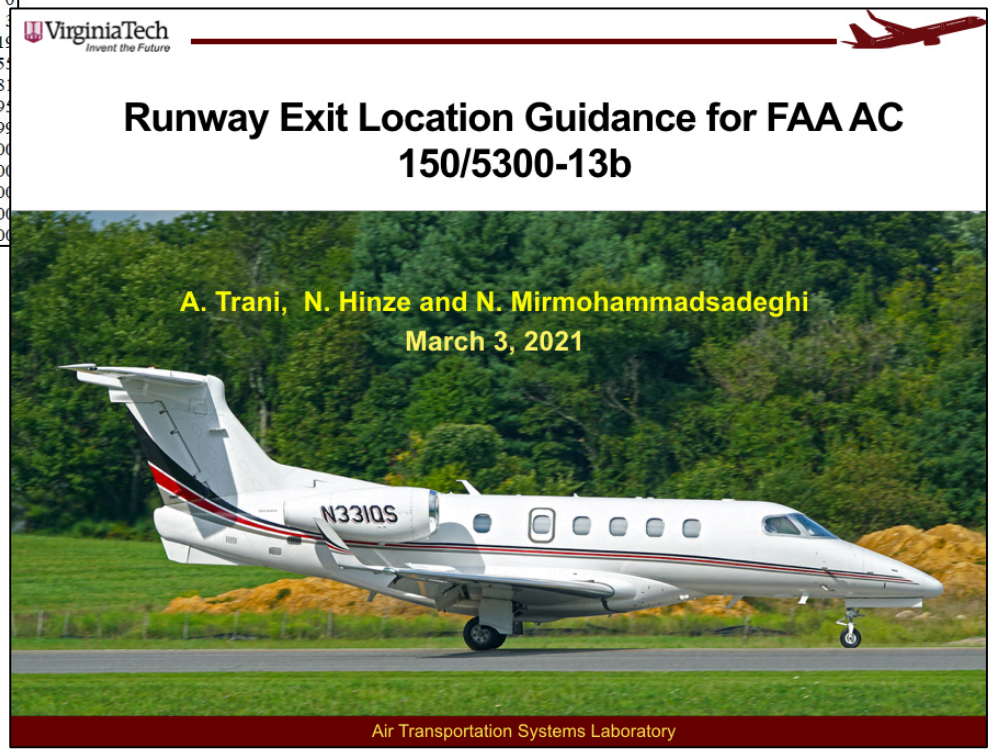
FAA AC 150/5300-13 Runway Location Guidance

Table 4-9. Exit taxiway cumulative utilization percentages

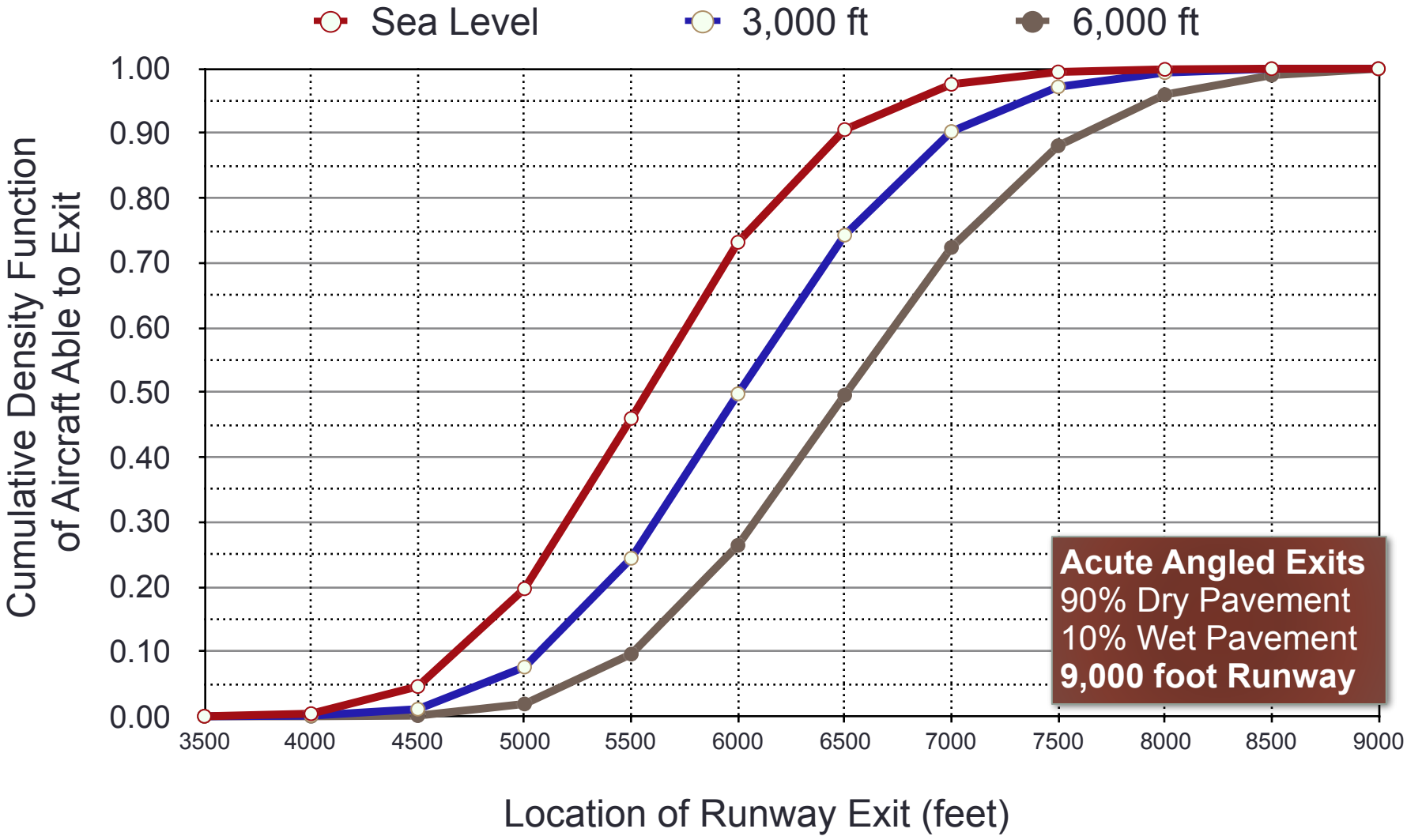
DISTANCE THRESHOLD TO EXIT	WET RUNWAYS				DRY RUNWAYS							
	RIGHT & ACUTE ANGLED EXITS				RIGHT ANGLED EXITS				ACUTE ANGLED EXITS			
	S	T	L	H	S	T	L	H	S	T	L	H
0 ft (0 m)	0	0	0	0	0	0	0	0	0	0	0	0
500 ft (152 m)	0	0	0	0	0	0	0	0	1	0	0	0
1000 ft (305 m)	4	0	0	0	6	0	0	0	13	0	0	0
1500 ft (457 m)	23	0	0	0	39	0	0	0	53	0	0	0
2000 ft (610 m)	60	0	0	0	84	1	0	0	90	1	0	0
2500 ft (762 m)	84	1	0	0	99	10	0	0	99	10	0	0
3000 ft (914 m)	96	10	0	0	100	39	0	0	100	40	0	0
3500 ft (1067 m)	99	41	0	0	100	81	2	0	100	82	9	0
4000 ft (1219 m)	100	80	1	0	100	98	8	0	100	98	26	
4500 ft (1372 m)	100	97	4	0	100	100	24	2	100	100	51	1
5000 ft (1524 m)	100	100	12	0	100	100	49	9	100	100	76	5
5500 ft (1676 m)	100	100	27	0	100	100	75	24	100	100	92	8
6000 ft (1829 m)	100	100	48	10	100	100	92	71	100	100	98	9
6500 ft (1981 m)	100	100	71	35	100	100	98	90	100	100	100	9
7000 ft (2134 m)	100	100	88	64	100	100	100	98	100	100	100	10
7500 ft (2286 m)	100	100	97	84	100	100	100	100	100	100	100	10
8000 ft (2438 m)	100	100	100	93	100	100	100	100	100	100	100	10
8500 ft (2591 m)	100	100	100	99	100	100	100	100	100	100	100	10
9000 ft (2743 m)	100	100	100	100	100	100	100	100	100	100	100	10

Notes:

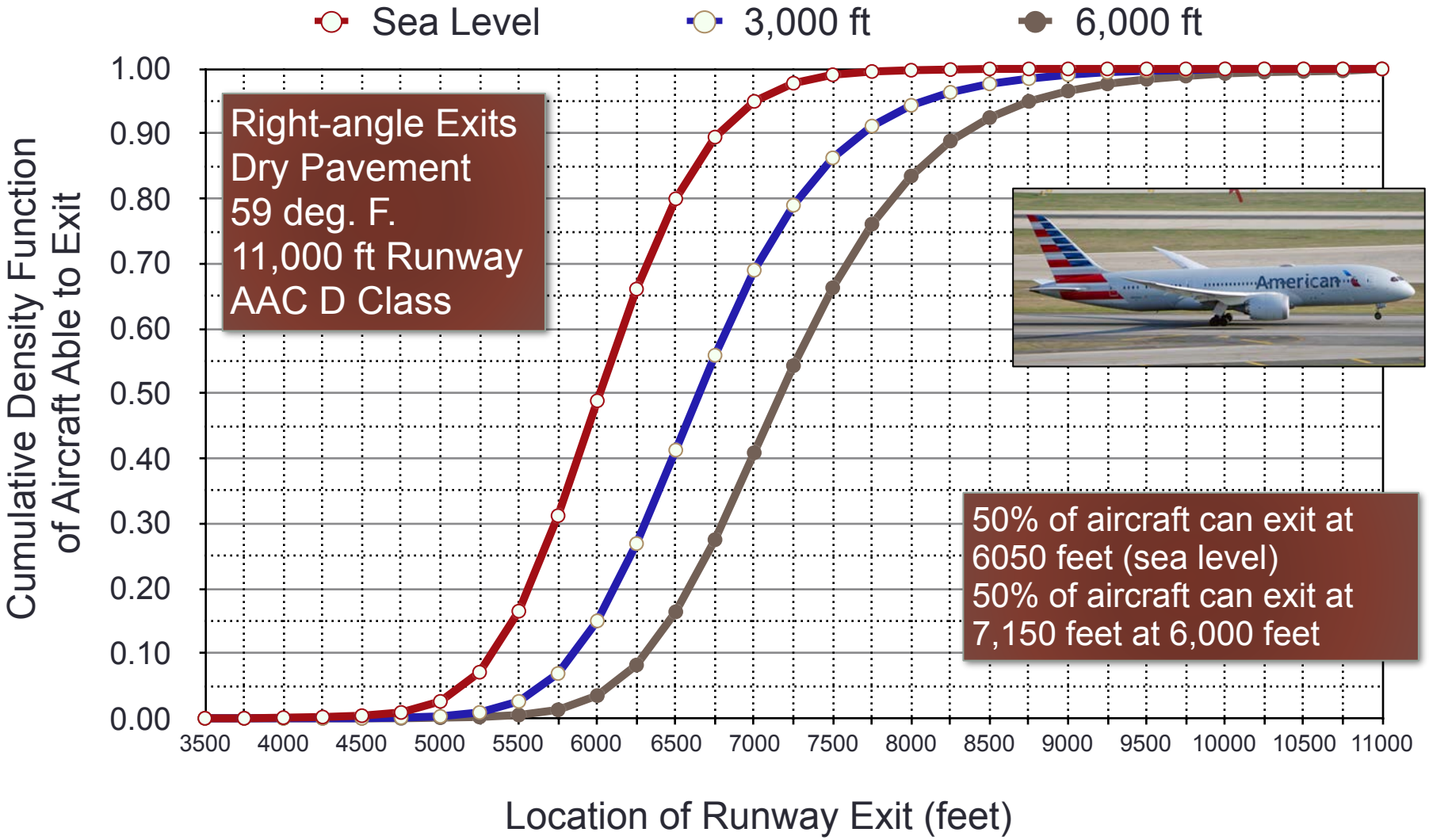
S - Small, single engine	12,500 lbs (5670 kg) or less
T - Small, twin engine	12,500 lbs (5670 kg) or less
L - Large	12,500 lbs (5670 kg) to 300,000 lbs (136080 kg)
H - Heavy	300,000 lbs



For Typical Acute Angle Exit Locations, Increase Runway Exit Location by 150 feet for Every 1,000 ft Airfield Elevation Change

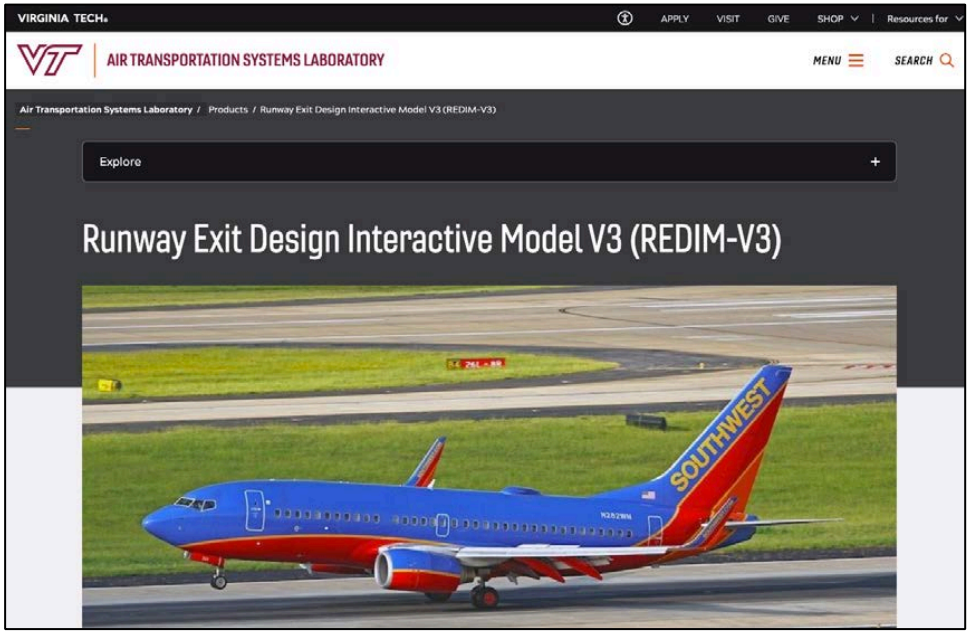


Increase Runway Exit Location by 185 feet for Each 1,000 ft Airfield Elevation



Contact Information and Web Site

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



https://atsl.cee.vt.edu/products/runway-exit-design-interactive-model--redim-.html