Runway Exit Design Tool and Landing Events Database Seminar

N. Hinze, O. Afshin, A. Zolfaghari, and A. Trani

March 16, 2022

Runway Exit Design Tool and Landing Events Database Seminar

- Tentative Agenda
- 3:00 to 3:10 PM Introduction (Kent Duffy and Lauren)
- 3:10 to 4:10 PM Explanations of Landing Events Database and Runway Exit design Model
  - New features of the Runway Exit Model 4 and LED 1.3.5
- 4:10 to 4:30 PM Questions and answers
- 4:30 to 5:00 User feedback section

Acknowledgments

- **Project supported by the Federal Aviation Administration (FAA)**
- **FAA Project Technical Monitors: Kent Duffy, Lauren Vitagliano, and Christina Nutting (for Integration of ACD)**
- **Project of the National Center of Excellence for Aviation Operations Research (NEXTOR 3)**

- 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 2015-2020)* • *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 2015-2020)* • *Integrate the FAA Aircraft Characteristics Database into the Runway Exit Model and Landing Events Database*

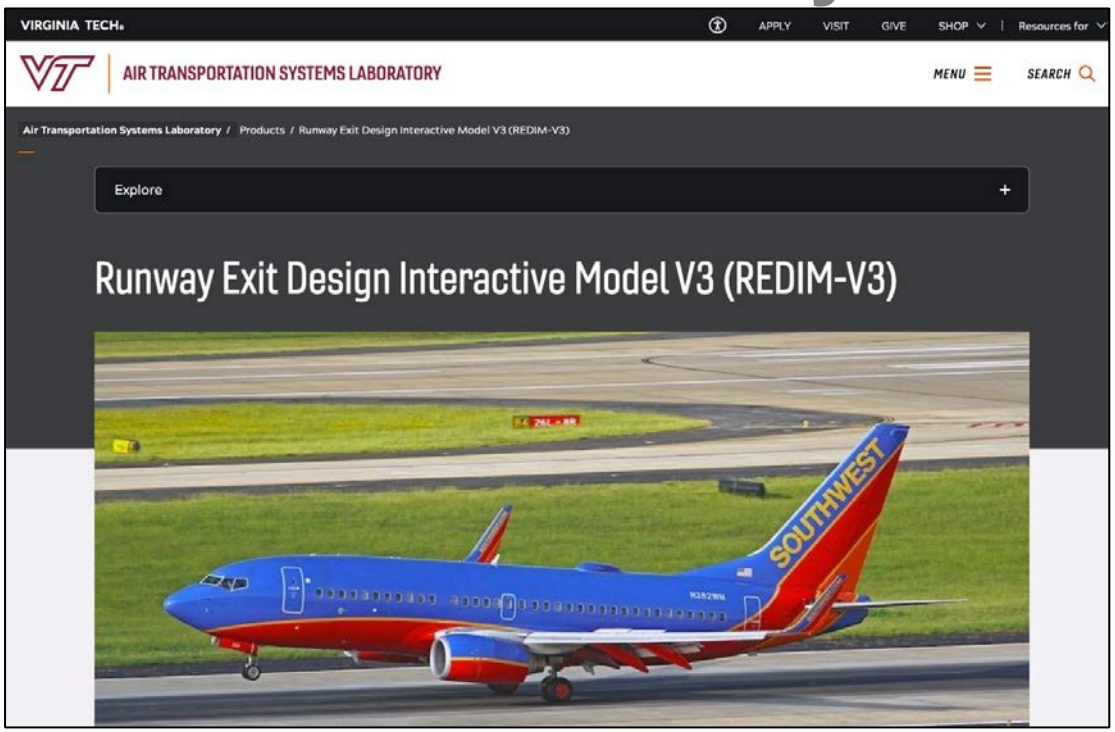
Project Outcomes

- **Landing Events Database** archives 32 million landing records from ASSC data (landing operations at 43 U.S. airports between 2015 and 2020)
  - Stand-alone product (client software)
  - Version 1.3.6 is the current version of the database
- **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 landing distributions collected in the Landing Events Database to model landing performance
  - 330 aircraft modeled in REDIM 4.0 (in testing phase)
  - Developed guidance for updated to Table 4-13 in AC 150/5300-13A, Airport Design

Task 3: REDIM Model Updates/Improvements

- **Version 3.0.10 - released on October 19, 2021**
  - Fixed issue with path length (English units) of new exit would be locked to metric units
  -
- **Version 4.0 – in testing**
  - ASDE-X data from 43 airports collected between 2015 and 2020
  - Support for 330 aircraft types
  - Nose Gear Down Location and Nominal Deceleration is now a function of runway length instead of clusters
  - Turnoff times are now calculated using PC to RWY Edge, RWY Edge to Fuselage Out, and Fuselage Out to hold bar decelerations.
  - Exact exit geometries are supported using cartesian coordinates.
  - Runway Threshold to last Point Of Curvature is now used instead of Runway Length. runway occupancy time based on aircraft clearing the hold bar

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 3.0.10 - Windows Installer
- User Group
- User Manual
- FAQs
- Change Log

Download Landing Events Database

- Landing Events Database 1.3.6 - Windows Installer
- User Manual

Download REDIM 2

- REDIM 2.1

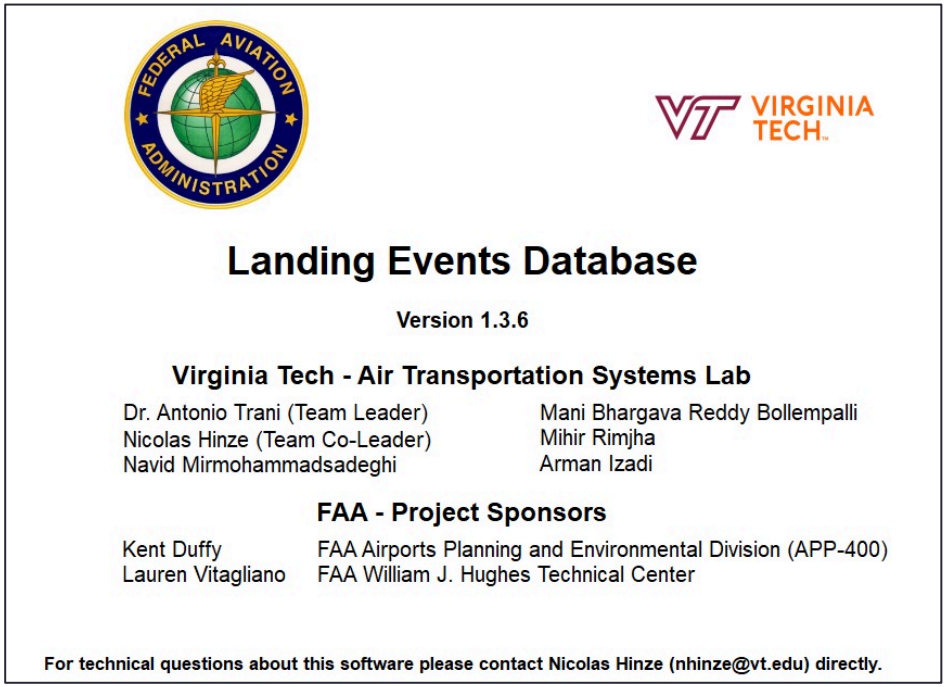
Detailed Documentation for REDIM 3

- 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
  - PC to Fuselage Out Decelerations: Aircraft - AAC
  - PC to Hold Bar Decelerations: Aircraft - AAC

Landing Events Database

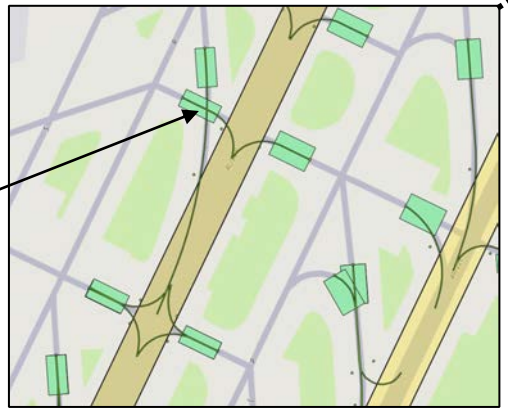
Landing Events Database Updates/Improvements

- **Version 1.3.6 - released on March 15, 2022**
  - Summary of landing records with 180-degree turns on the runway
- **Version 1.3.5 - released on November 19, 2021**
  - Filter results by airline (suggested at the last industry meeting)
  - Landing track follows the aircraft up to the last position reported (near the gate location)
  - Gate location from landing threshold
  - Moved data to a new AWS service framework



Landing Events Database : Data Collection

- ASDE-X data
  - More than 32 million landing events
  - Years 2015-2020
- Runway exit geometry information for 4,806 runway exits at 313 runways (top 43 airports)
- One and 5-minute weather data for all 43 airports



Runway exit polygons at EWR airport

Newark International Airport Runway Exit Data

Landing Event Database Tool Version 1.3.6

Landing Events Database

Version 1.3.6

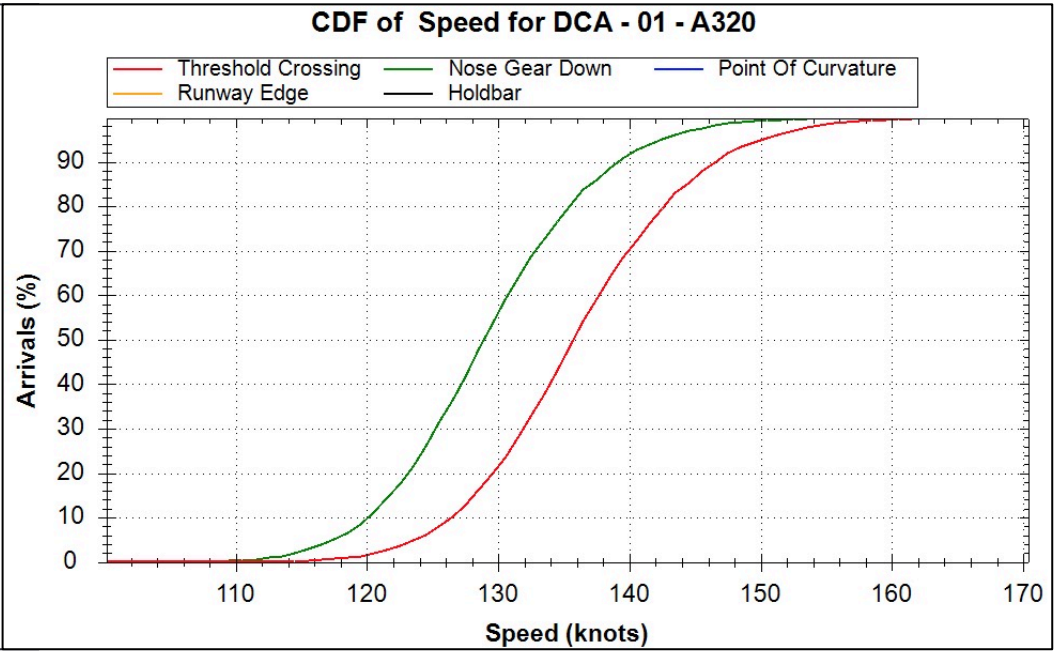
Virginia Tech - Air Transportation Systems Lab

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

FAA - Project Sponsors

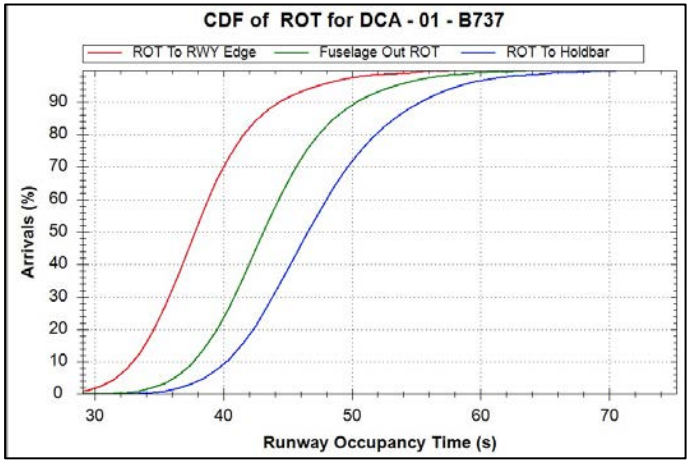
Kent Duffy — FAA Airports Planning and Environmental Division (APP-400)
Lauren Vitagliano — FAA William J. Hughes Technical Center

For technical questions about this software please contact Nicolas Hinze (nhinze@vt.edu) directly.

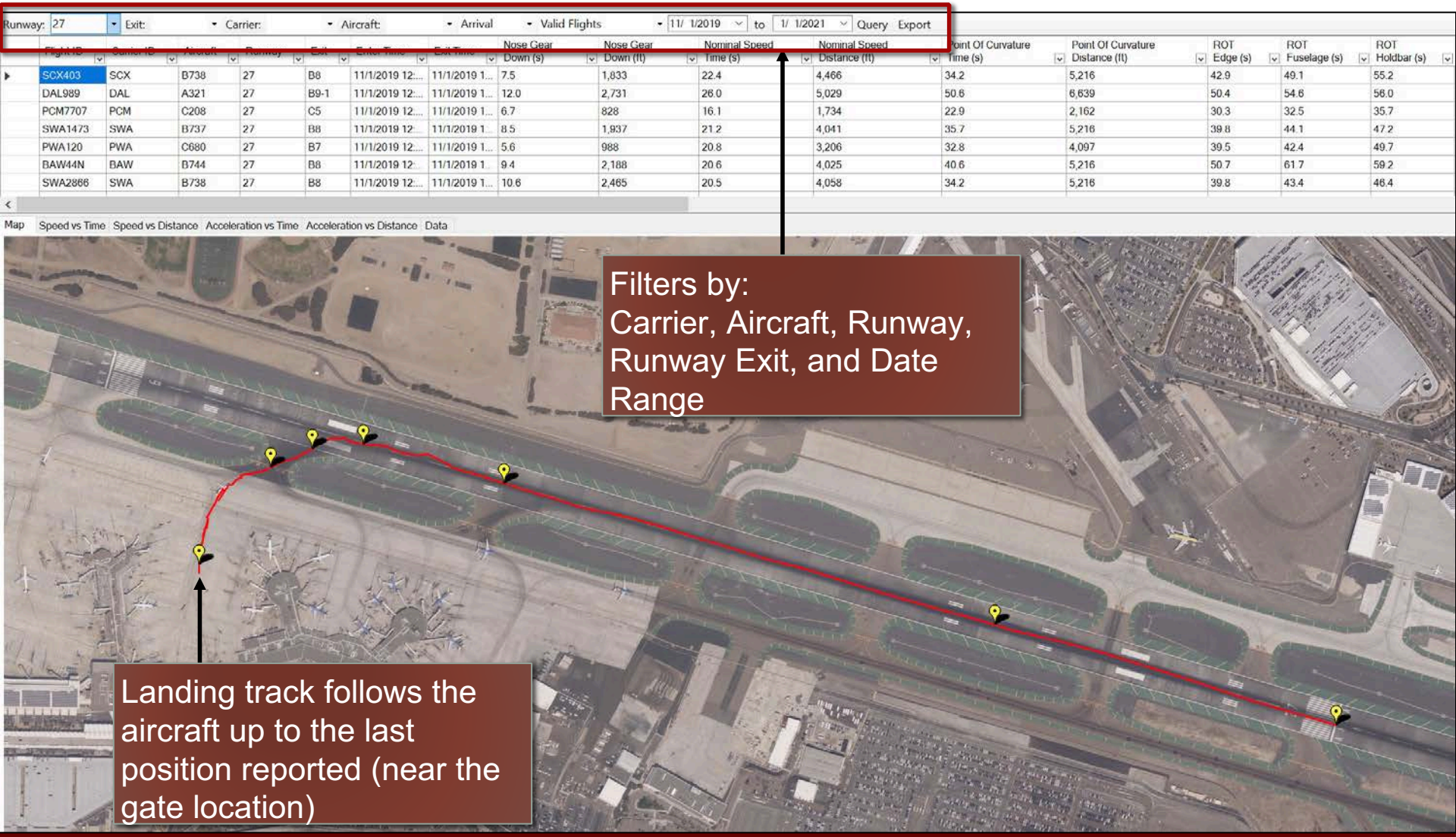


Landing database client can be downloaded at:

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



Landing Event Database Tool Version 1.3.6



Flight ID	Carrier 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)
SCX403	SCX	B738	27	B8	11/1/2019 12:...	11/1/2019 1...	7.5	1,833	22.4	4,466	34.2	5,216	42.9	49.1	55.2
DAL989	DAL	A321	27	B9-1	11/1/2019 12:...	11/1/2019 1...	12.0	2,731	26.0	5,029	50.6	6,639	50.4	54.6	58.0
PCM7707	PCM	C208	27	C5	11/1/2019 12:...	11/1/2019 1...	6.7	828	16.1	1,734	22.9	2,162	30.3	32.5	35.7
SWA1473	SWA	B737	27	B8	11/1/2019 12:...	11/1/2019 1...	8.5	1,937	21.2	4,041	35.7	5,216	39.8	44.1	47.2
PWA120	PWA	C680	27	B7	11/1/2019 12:...	11/1/2019 1...	5.6	988	20.8	3,206	32.8	4,097	39.5	42.4	49.7
BAW44N	BAW	B744	27	B8	11/1/2019 12:...	11/1/2019 1...	9.4	2,188	20.6	4,025	40.6	5,216	50.7	61.7	59.2
SWA2866	SWA	B738	27	B8	11/1/2019 12:...	11/1/2019 1...	10.6	2,465	20.5	4,058	34.2	5,216	39.8	43.4	46.4

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 Bing 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

Runway: 08L Exit: Carrier: DAL Aircraft: A319 Arrival Valid Flights 12/ 1/2019 to 1/ 1/2021 Query Export

Flight ID	Carrier 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)
DAL1351	DAL	A319	08L	B11	12/6/2019 2:2...	12/6/2019 2...	11.0	2,390	25.4	4,650	39.8	5,965	47.9	52.0	58.1
DAL796	DAL	A319	08L	B11	12/7/2019 1:3...	12/7/2019 1...	14.0	2,959	27.1	4,924	38.9	5,965	47.2	51.1	55.5
DAL1351	DAL	A319	08L	B11	12/7/2019 2:2...	12/7/2019 2...	12.2	2,756	28.2	5,289	35.4	5,965	44.4	48.4	56.4
DAL796	DAL	A319	08L	B11	12/9/2019 1:3	12/9/2			27.7	4,961		5,965		48.7	54.0

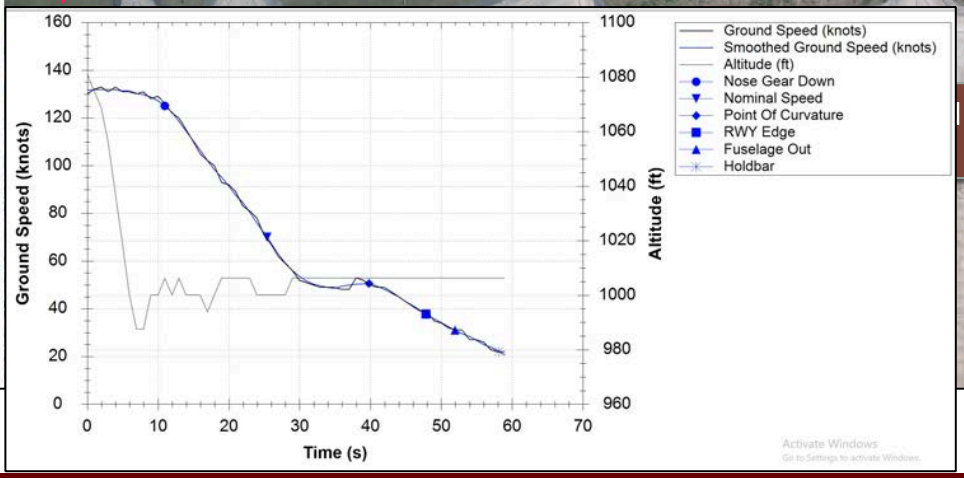
Map | Speed vs Time | Speed vs Distance | Acceleration vs Time | Acceleration vs Distance | Data

Estimated nose gear touchdown location (125 knots)

70-knot nominal speed

Runway exit speed 50.6 knots

Every landing can be examined in detail (Airbus A319 example)

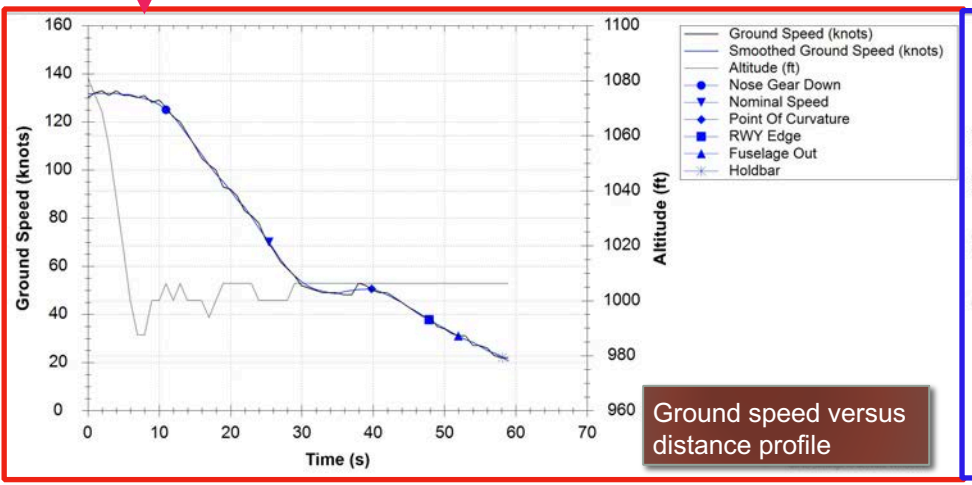


Landing Database Raw Data Viewer

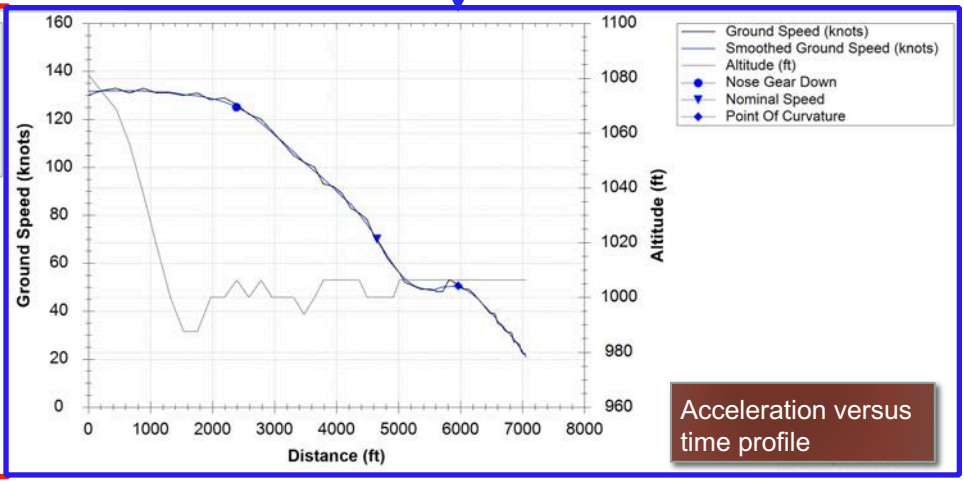
Runway: 08L | Exit: | Carrier: DAL | Aircraft: A319 | Arrival | Valid Flights | 12/ 1/2019 to 1/ 1/2021 | Query | Export

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)
2,390	25.4	4,650	39.8	5,965	47.9	52.0	58.1	131.6
2,959	27.1	4,924	38.9	5,965	47.2	51.1	55.5	125.8
2,756	28.2	5,289	35.4	5,965	44.4	48.4	56.4	135.9
2,589	27.7	4,961	37.4	5,965	44.8	48.7	54.0	128.4

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



Ground speed versus distance profile



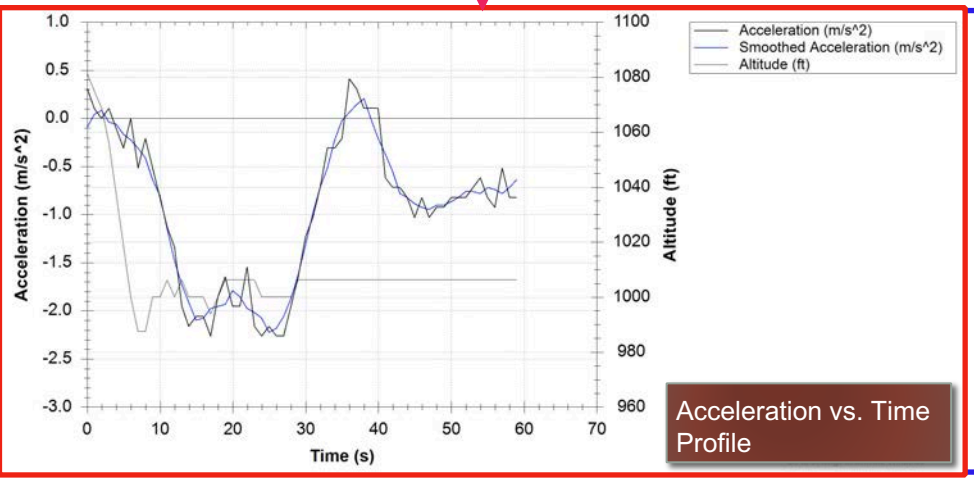
Acceleration versus time profile

Landing Database Raw Data Viewer

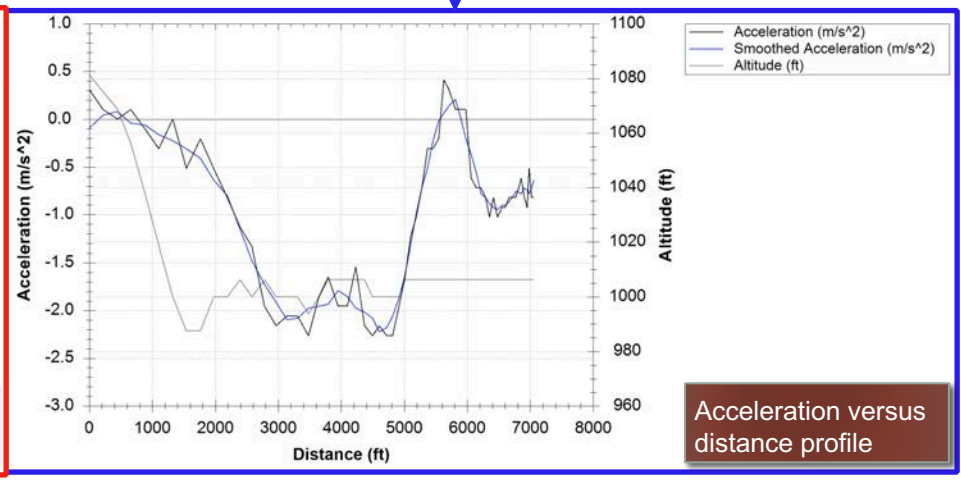
Runway: 08L Exit: Carrier: DAL Aircraft: A319 Arrival Valid Flights 12/ 1/2019 to 1/ 1/2021 Query Export

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)
2,390	25.4	4,650	39.8	5,965	47.9	52.0	58.1	131.6
2,959	27.1	4,924	38.9	5,965	47.2	51.1	55.5	125.8
2,756	28.2	5,289	35.4	5,965	44.4	48.4	56.4	135.9
2,589	27.7	4,961	37.4	5,965	44.8	48.7	54.0	128.4

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



Acceleration vs. Time Profile



Acceleration versus distance profile

Landing Database Raw Data Viewer

Runway: 08L | Exit: | Carrier: DAL | Aircraft: A319 | Arrival | Valid Flights | 12/ 1/2019 to 1/ 1/2021 | Query | Export

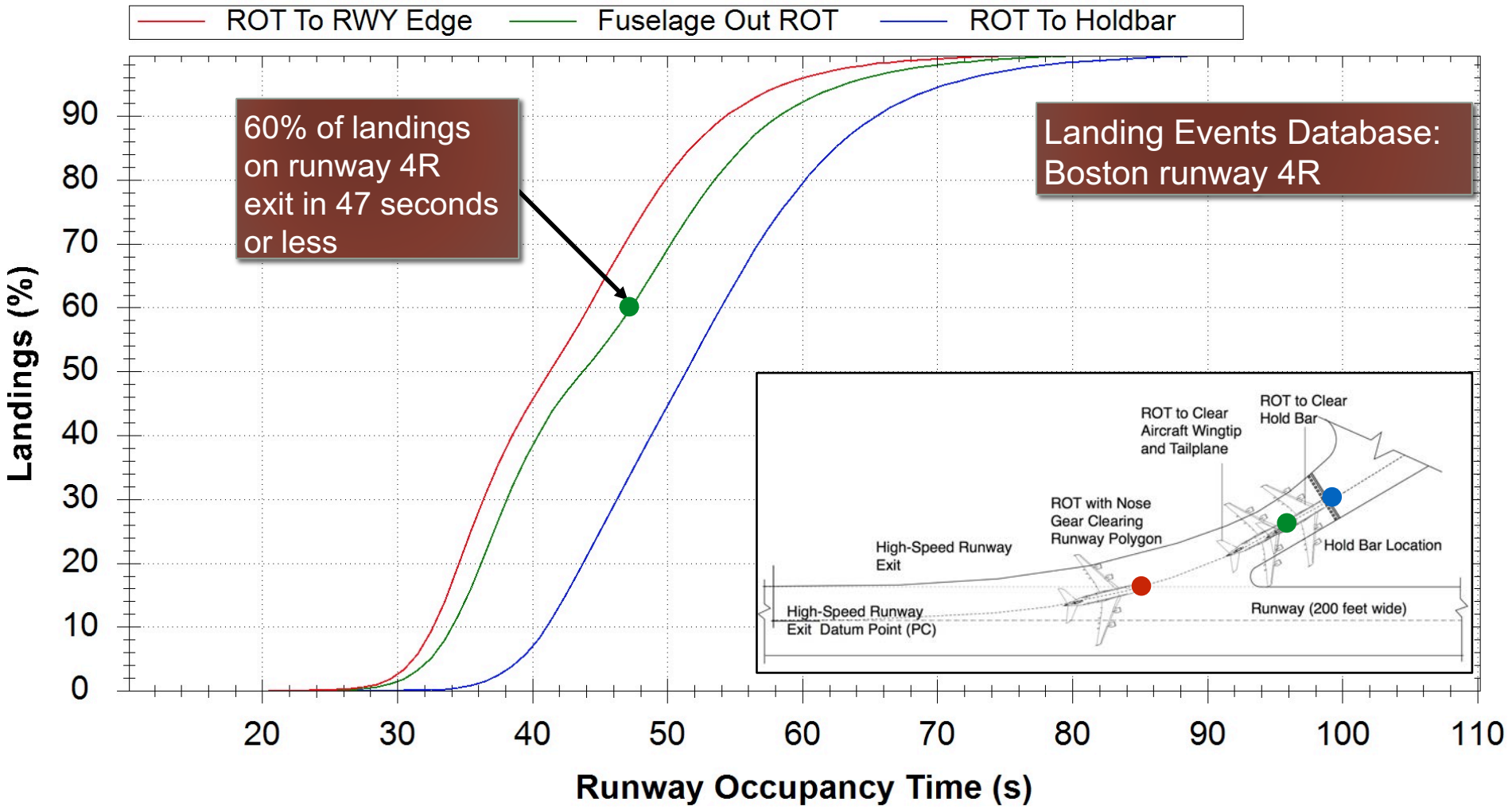
Nose Gear Down (ft)	Nominal Speed Time (s)	Nominal Speed Distance (ft)	Point Of Curvature Time (s)	Point Of Curvature Distance (ft)	ROT Edge (s)	ROT Fuselage (s)	ROT Holdbar (s)	Threshold Crossing Speed (kts)
2,390	25.4	4,650	39.8	5,965	47.9	52.0	58.1	131.6
2,959	27.1	4,924	38.9	5,965	47.2	51.1	55.5	125.8
2,756	28.2	5,289	35.4	5,965	44.4	48.4	56.4	135.9
2,589	27.7	4,961	37.4	5,965	44.8	48.7	54.0	128.4

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

All data

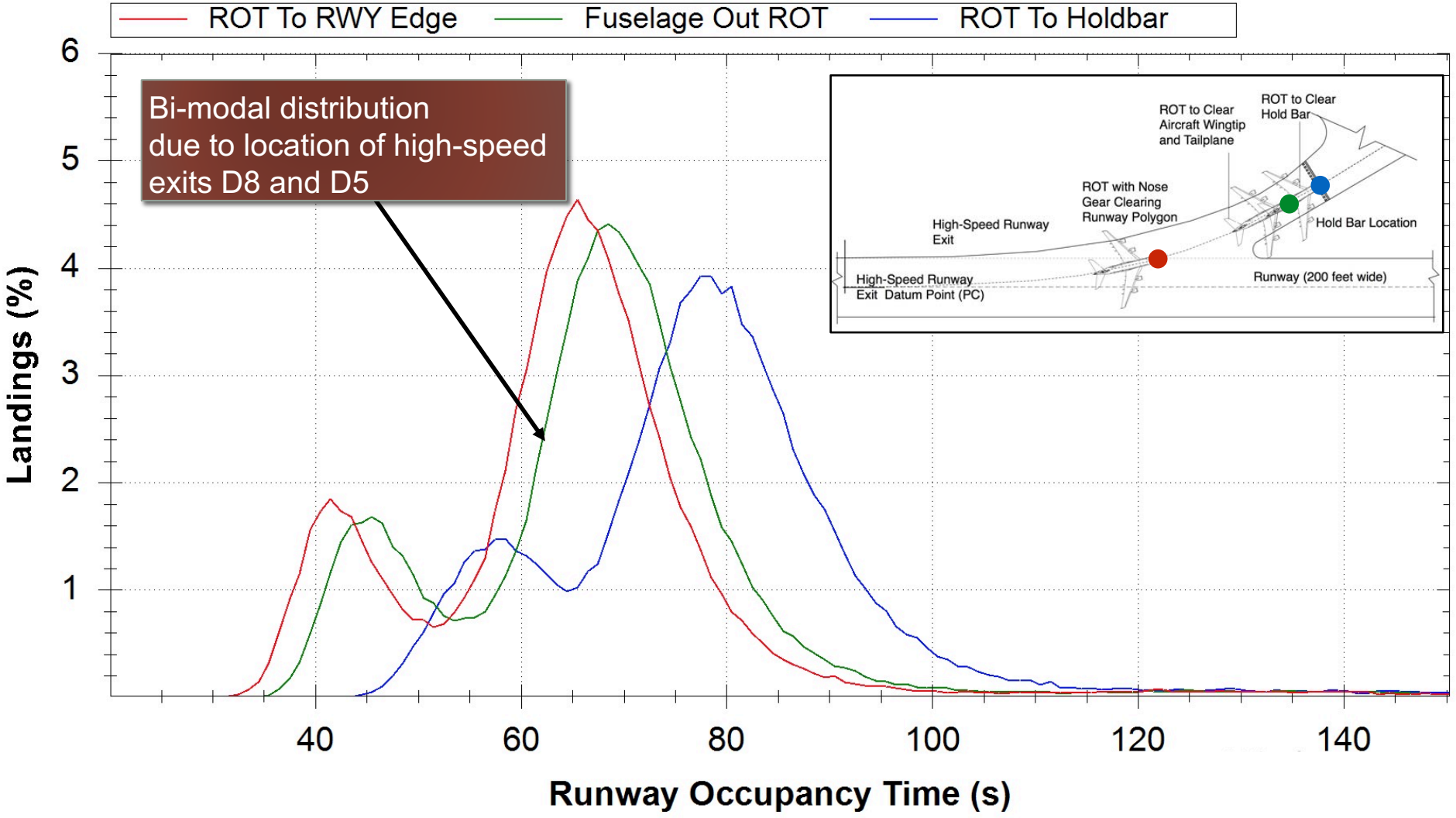
Time (s)	Speed (kts)	Smoothed Speed (kts)	Distance (ft)	Acceleration (m/s^2)	Smoothed Acceleration (m/s^2)	Altitude (ft)	Point ID
0.0	130.1	131.6	0	0.3	-0.1	1,081	192
1.0	132.0	131.8	219	0.1	0.0	1,075	193
2.0	133.0	131.8	447	0.0	0.1	1,069	194
3.0	131.0	132.0	660	0.1	0.0	1,056	195
4.0	133.0	131.8	887	-0.1	-0.1	1,038	196
5.0	131.0	131.2	1,105	-0.3	-0.2	1,019	197
6.0	131.0	131.2	1,325	0.0	-0.2	1,000	198
7.0	130.0	130.2	1,539	-0.5	-0.3	988	199
8.0	131.0	129.8	1,761	-0.2	-0.4	988	200
9.0	128.0	128.8	1,971	-0.5	-0.6	1,000	201
10.0	129.0	127.2	2,192	-0.8	-0.8	1,000	202
11.0	126.0	125.0	2,393	-1.1	-1.2	1,006	203
12.0	122.0	122.4	2,587	-1.3	-1.5	1,000	204
13.0	120.0	118.6	2,784	-2.0	-1.7	1,006	205
14.0	115.0	114.4	2,965	-2.2	-1.9	1,000	206
15.0	110.0	110.4	3,139	-2.1	-2.1	1,000	207
16.0	105.0	106.4	3,310	-2.1	-2.1	1,000	208
17.0	102.0	102.0	3,479	-2.3	-2.0	994	209
18.0	100.0	98.4	3,647	-1.9	-2.0	1,000	210
19.0	93.0	95.2	3,793	-1.6	-1.9	1,006	211

Runway Occupancy Time Outputs

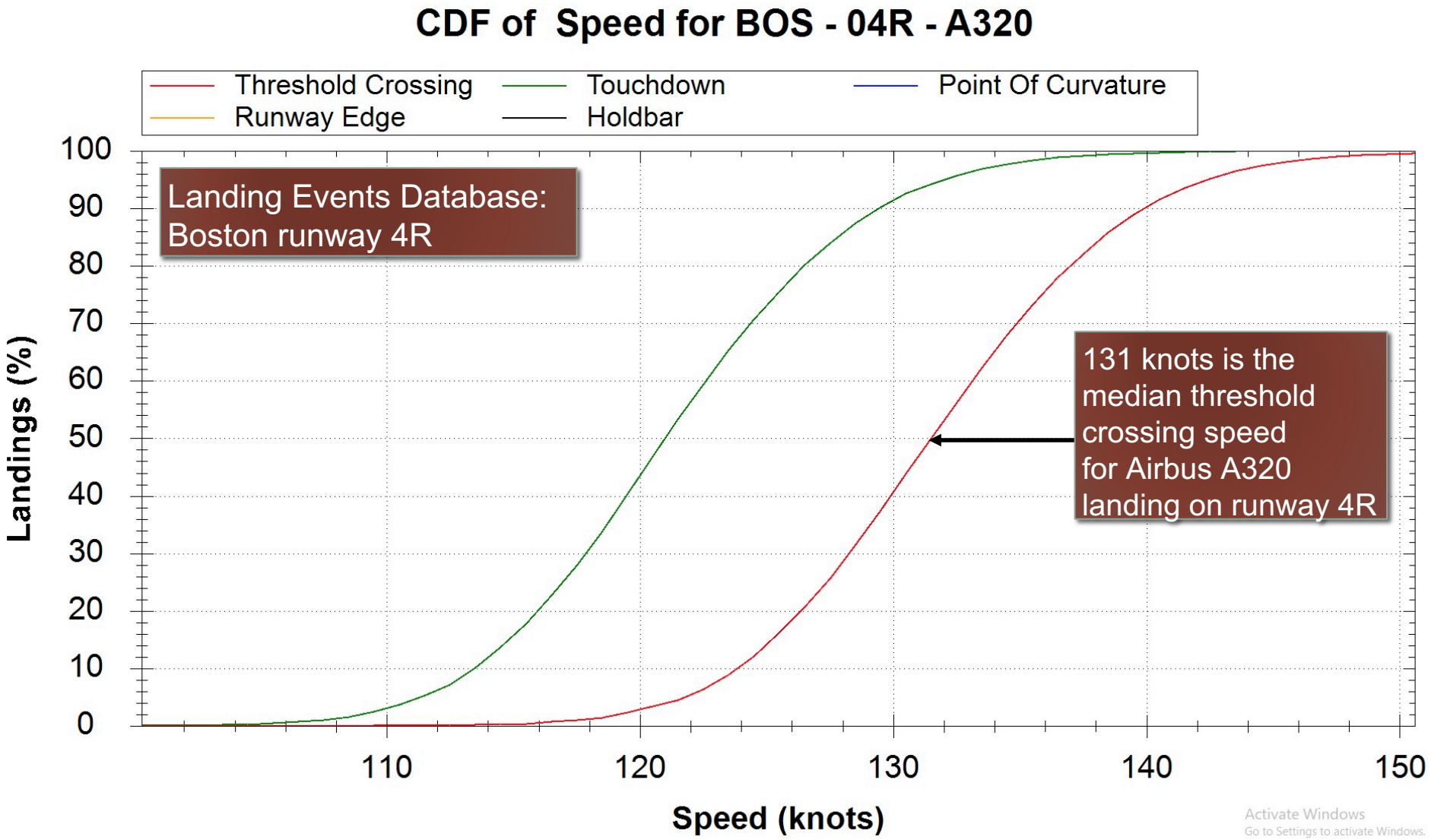


Distribution of Runway Occupancy Times

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 0.9%					
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 A321 at CLT Runway 36C

CLT - Speed Analysis

Runway: 36L | Exit: | Carrier AAL | Aircraft: A321 | Dimension: Distance | 1/ 1/2020 | Query

By Aircraft | Distribution | Profiles

Select velocity profiles

Speed Profiles for CLT - 36L - A321 - AAL - 2020-01-01

Ground Speed (knots)

160
140
120
100
80
60
40
20
0

Landing Events Database 1.3.6

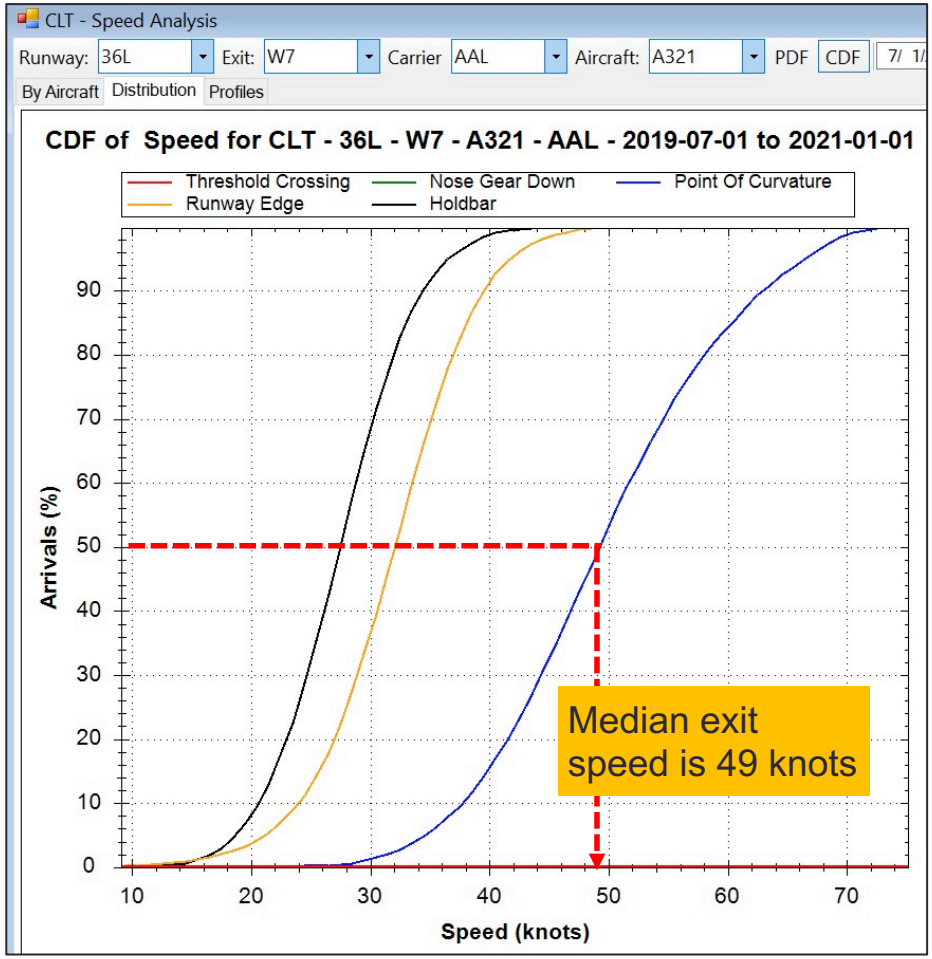
Exit W7

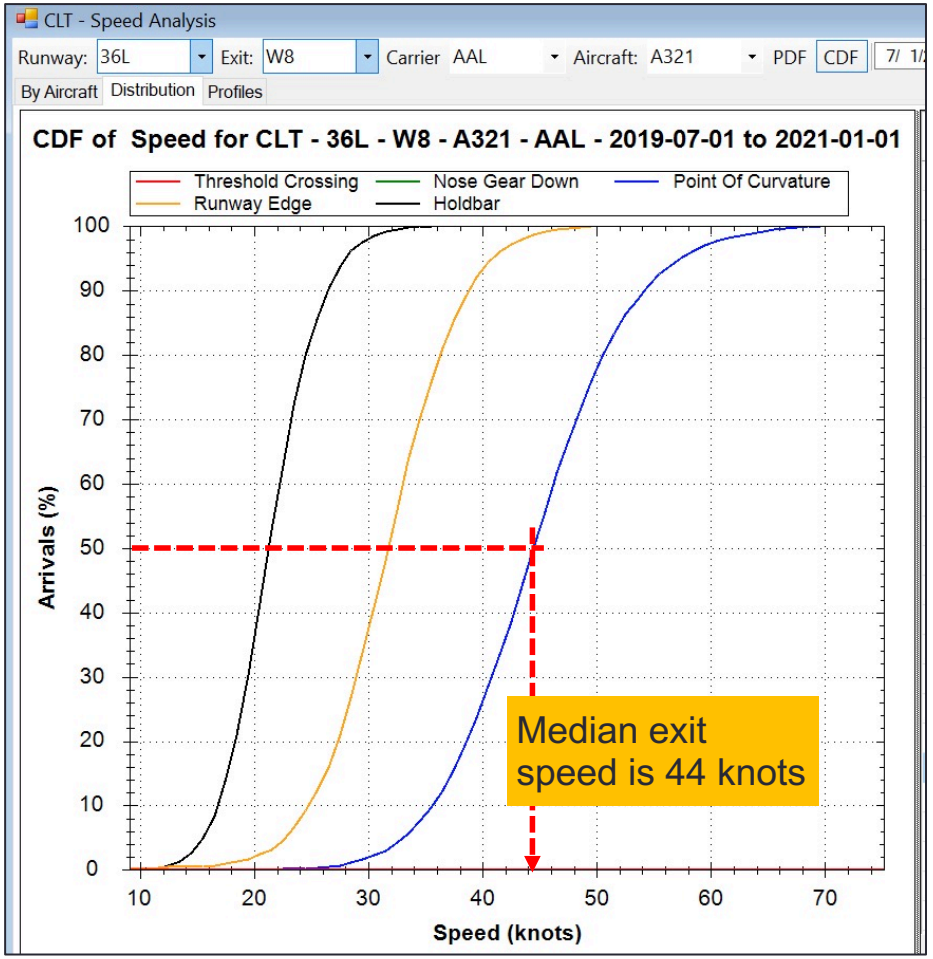
Exit W8

0 1000 2000 3000 4000 5000 6000 7000 8000 9000

Distance From Runway Threshold (ft)

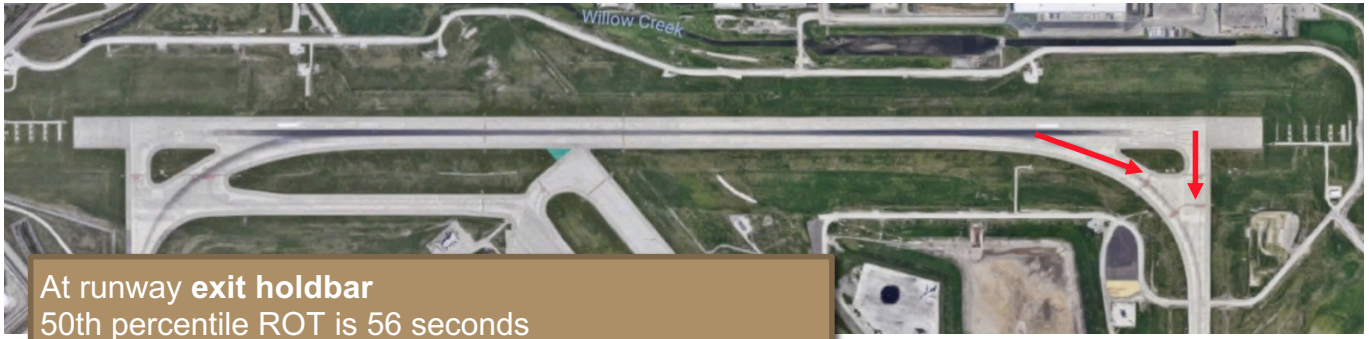
Exit Speed Distributions at CLT Runway 36C



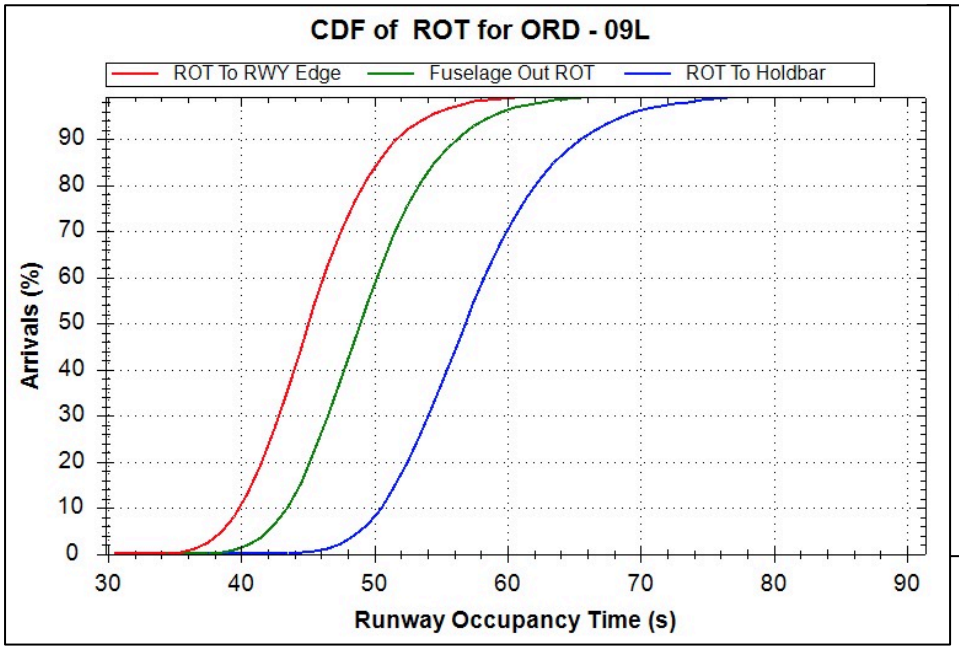


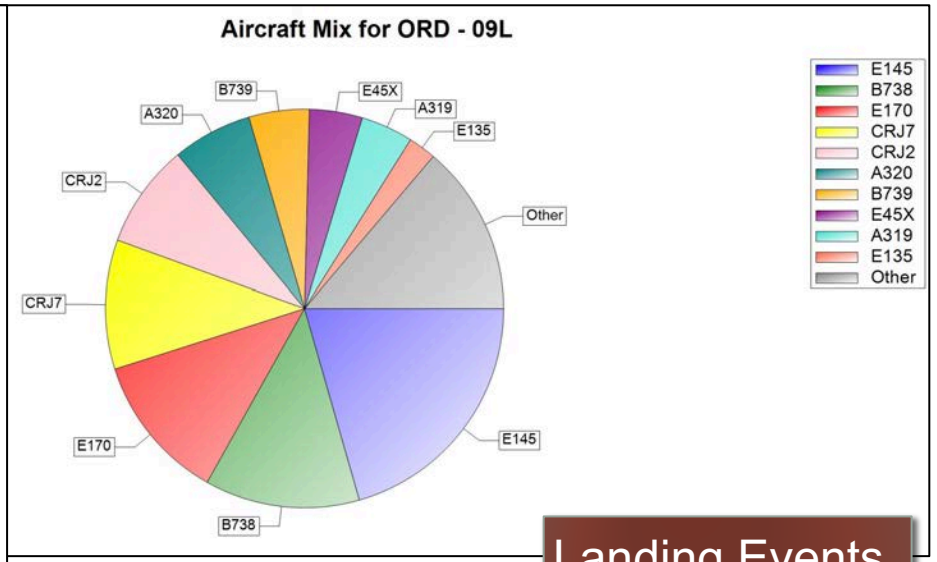
High-speed exits W7 and W8
Radius of curve = 1,800 feet
Exit angle = 30 degrees
Path length = 1050 feet

ORD Airport Runway 9L (Two Usable Exits)



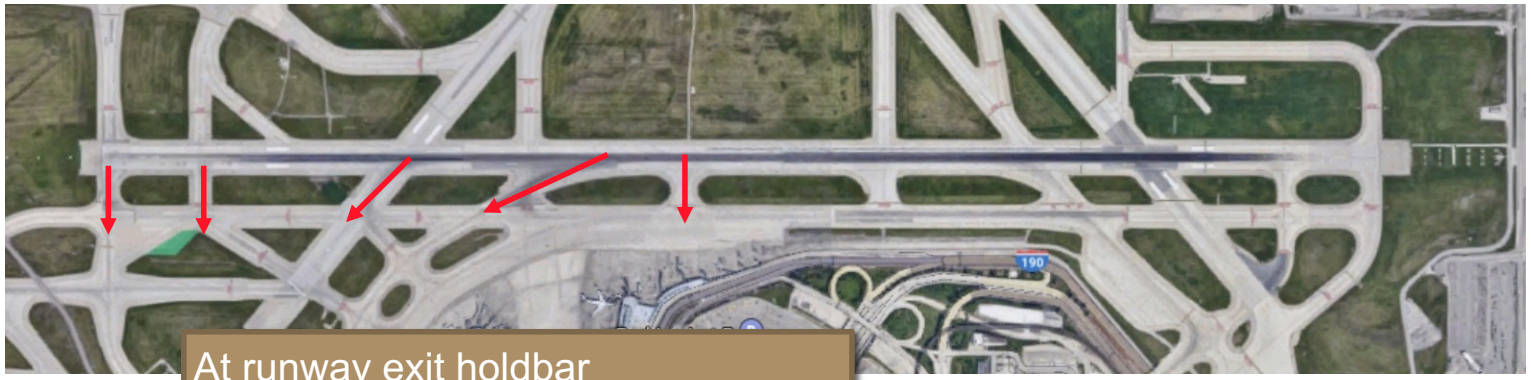
At runway **exit holdbar**
50th percentile ROT is 56 seconds
95th percentile ROT is 71 seconds
Relatively high ROT value due to few runway exits



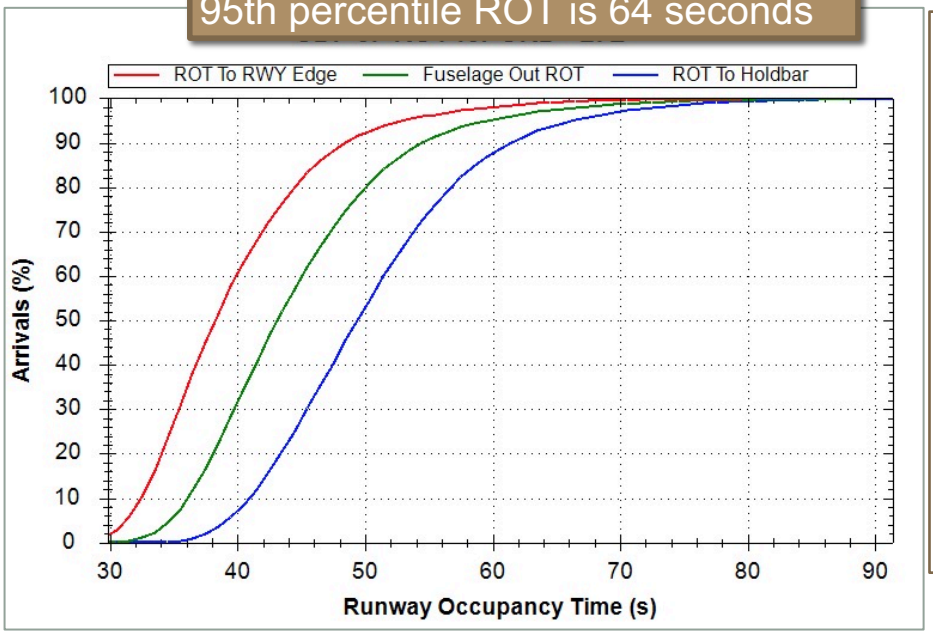


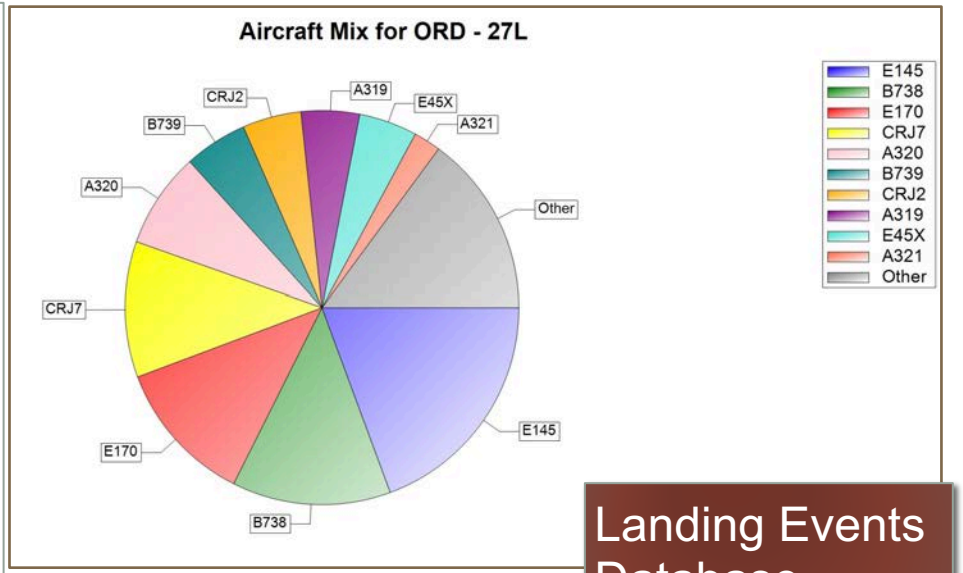
Landing Events Database

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

Runway Exit Design Tool

Runway Exit Design Tool (REDIM 3 Model)

REDIM

Version 3.0.10

Virginia Tech - Air Transportation Systems Lab

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

FAA - Project Sponsors

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

Download REDIM 3

- REDIM 3.0.10 - Windows Installer
- User Group
- User Manual
- FAQs
- Change Log

Download Landing Events Database

- Landing Events Database 1.3.5 - 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
  - PC to Fuselage Out Decelerations: Aircraft - AAC
  - PC to Hold Bar Decelerations: Aircraft - AAC

The Runway Exit Design Tool can be downloaded at:

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

New version REDIM 4.0

REDIM

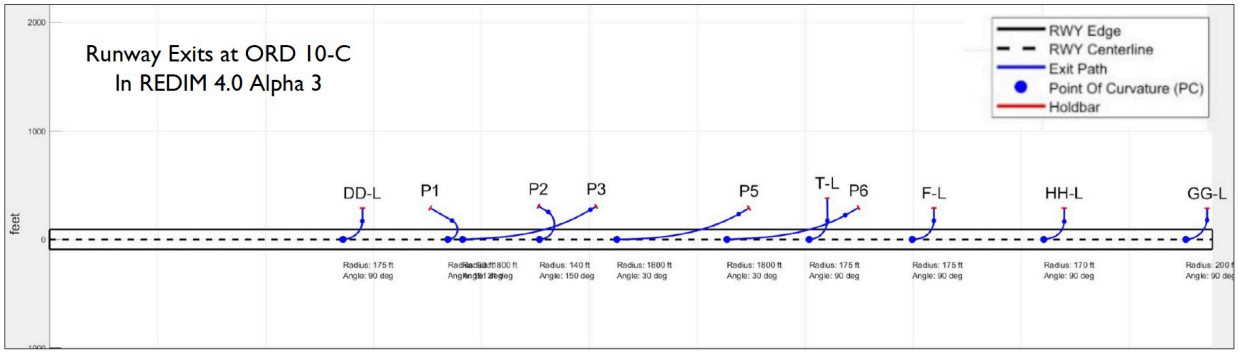
Version 4.0.0.alpha2 - Date: 02/22/2022

Virginia Tech - Air Transportation Systems Lab

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

FAA - Project Sponsors

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



- Uses **six years of data** to calibrate individual aircraft landing roll behavior
- Deceleration rate and touchdown distances are estimated from data but **monotonic with runway length to reduce bias** observed in some runway clusters
- Improvements to runway exit logic and runway exit definition (runway exit libraries)

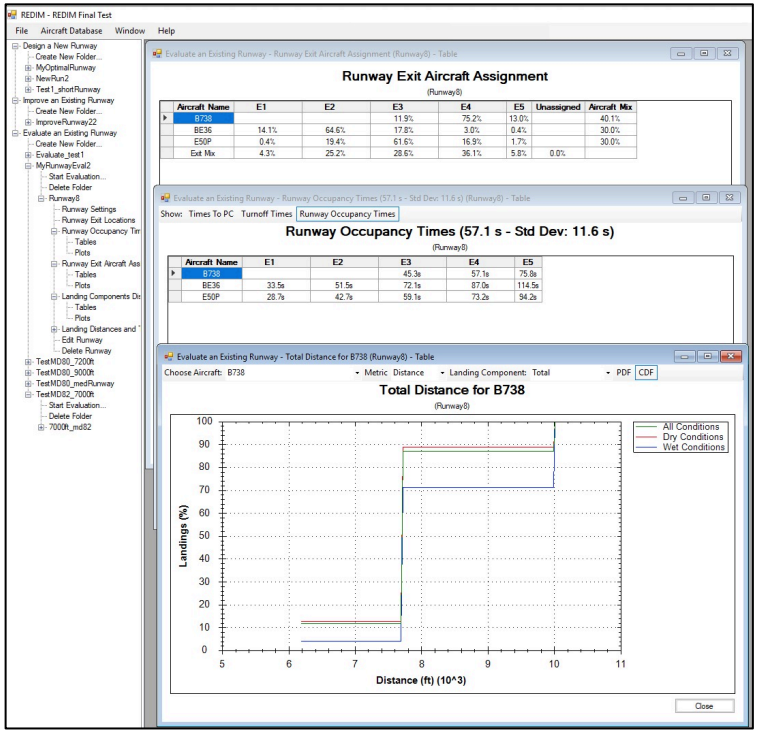
General Information About the Model

- 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

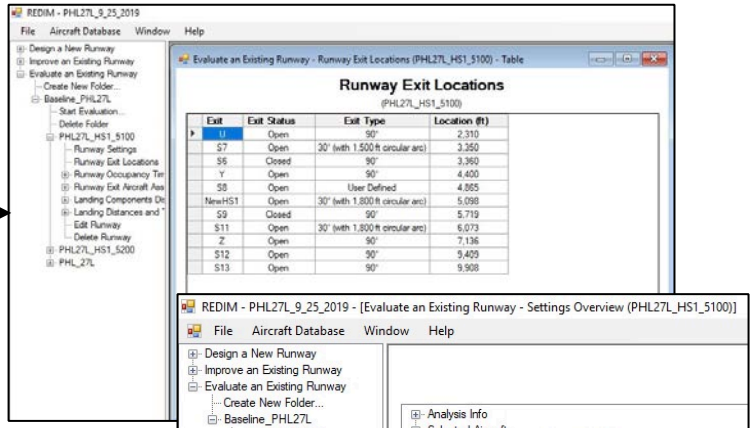


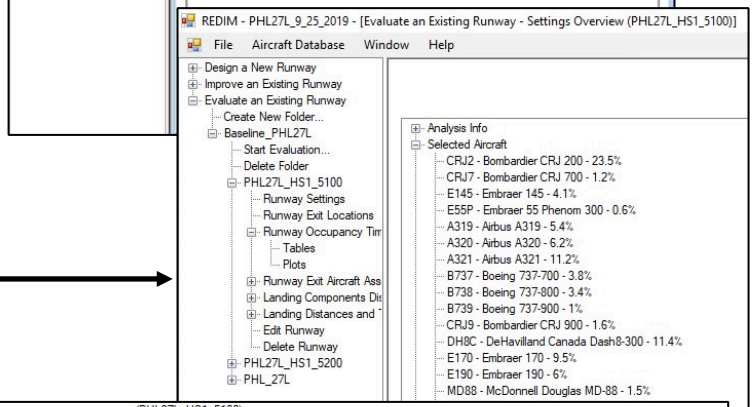
Model uses Monte Carlo Simulation to predict aircraft landing roll performance

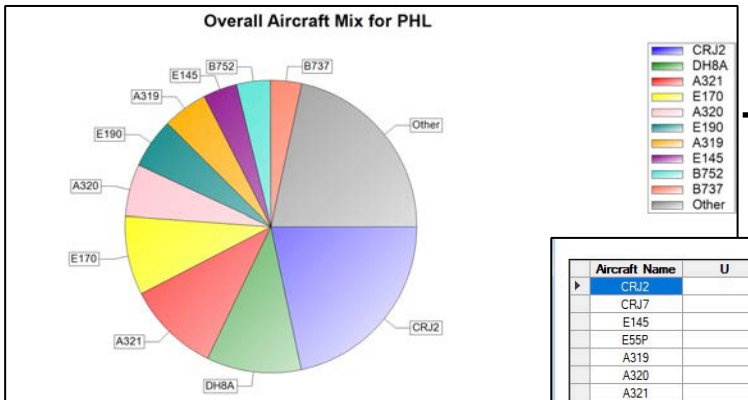
- Stand-alone Windows application
- Requires ~1.8 Gb of hard disk space
- Version 4 improvements will be explained in the slides that follow

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									53.0s
B739									53.5s
CRJ9		28.0s							55.9s
DH8C		34.6s							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 3.Fuselage past 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

REDIM 3 and 4 Aircraft Databases

- REDIM 3.0.10 contains data for 298 aircraft
  - 134 turbofan aircraft
  - 105 piston aircraft
  - 59 turboprop aircraft

REDIM 4 increases the number of aircraft to 330

Aircraft Design Group (ADG): III

ADG III Aircraft

Aircraft ID	Aircraft Name	Engine Type	Aircraft Design Group	Aircraft Approach Category	Nose Gear to Main Gear (m)
A19N	Airbus A319 Neo	Jet	III	C	11.04
A20N	Airbus A320 Neo	Jet	III	C	12.64
A21N	Airbus A321 Neo	Jet	III	C	16.9
A318	Airbus A318	Jet	III	C	11.04
A319	Airbus A319	Jet	III	C	11.04
A320	Airbus A320	Jet	III	C	12.64
B37M	Boeing 737 MAX 7	Jet	III	C	13.36
B38M	Boeing 737 MAX 8	Jet	III	D	15.6
B39M	Boeing 737 MAX 9	Jet	III	D	17.17
B712	Boeing 717-200	Jet	III	C	17.6
B717	Boeing 717-200	Jet	III	C	17.6
B77W	Boeing 777-300ER	Jet	V	D	31.22	67.97
B788	Boeing 787-8	Jet	V	D	22.78	51.31
B789	Boeing 787-9	Jet	V	D	25.83	57.4

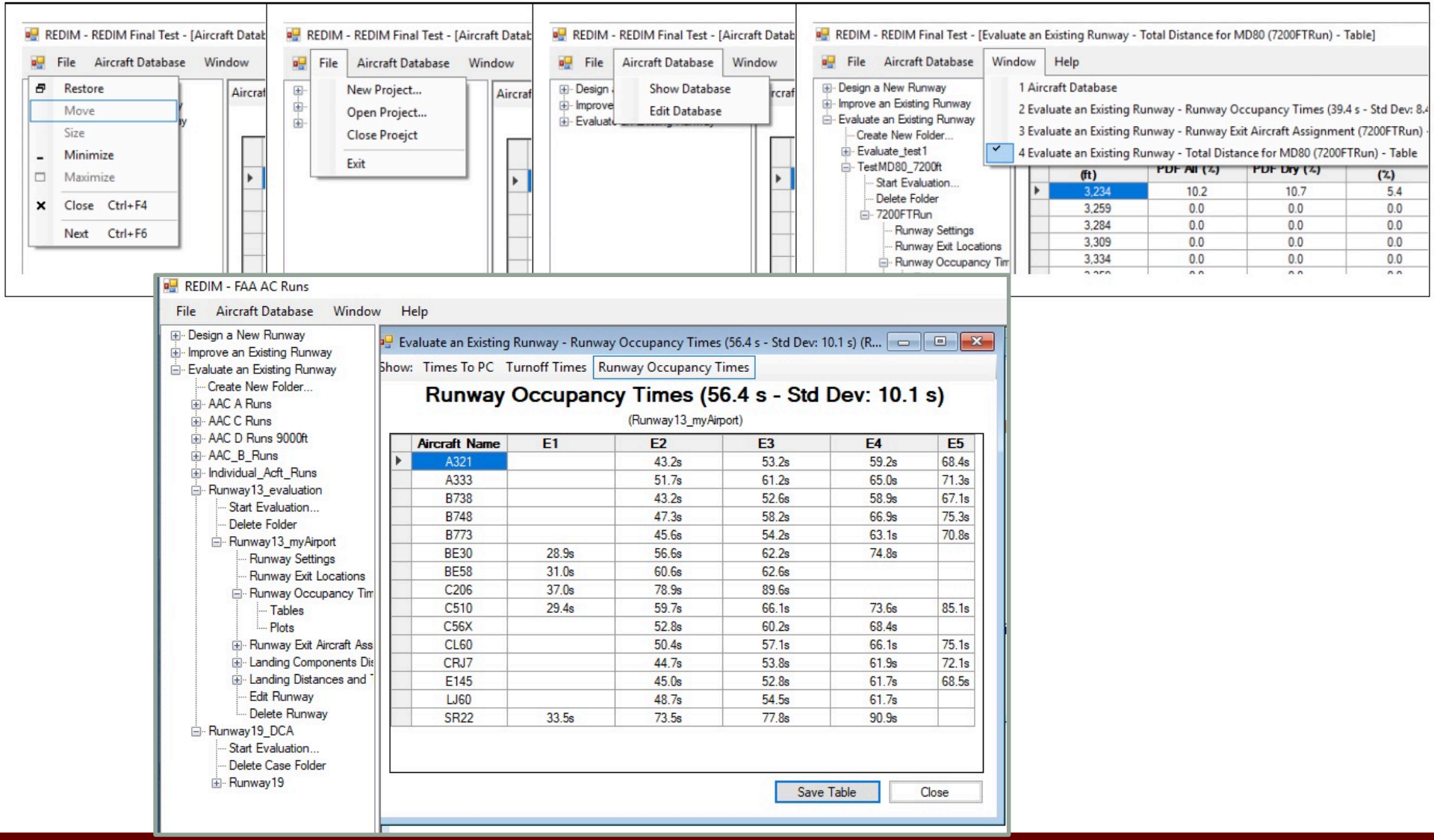
REDIM 3 and 4 Aircraft Databases

- REDIM 3.0.10 contains data for 298 aircraft
  - 134 turbofan aircraft
  - 105 piston aircraft
  - 59 turboprop aircraft
- New aircraft added since version 3.0.10 (see table below)

REDIM 4 increases the number of aircraft to 330

Aircraft Class	Types	
AAC A	Piper Cherokee Arrow	
AAC B	Pilatus PC-24 Cirrus Vision SF50 Piper Seneca PA34 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 and 4 Menu Structure



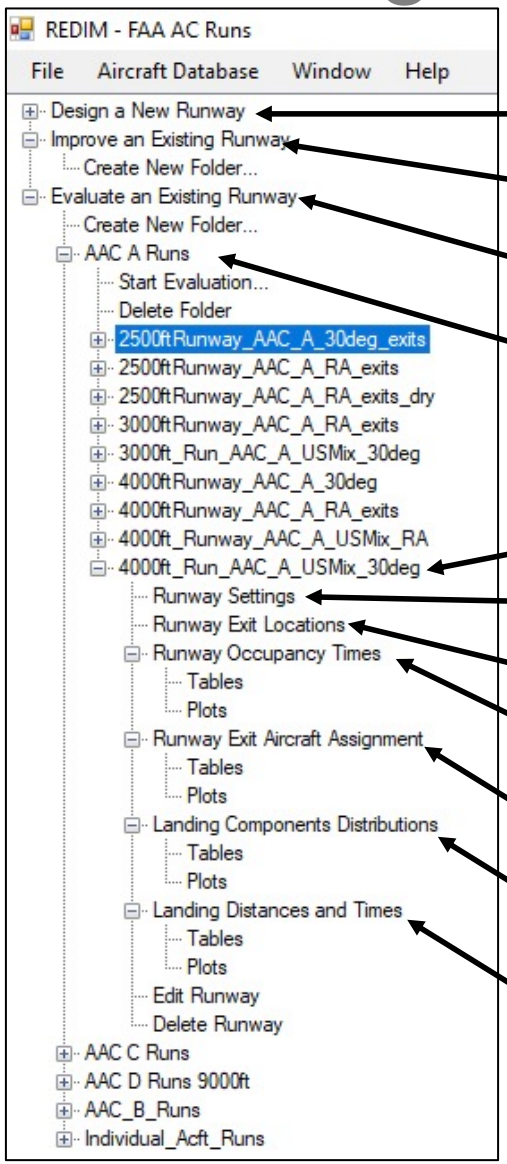
Sample Screens of Runway Exit Design Tool

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

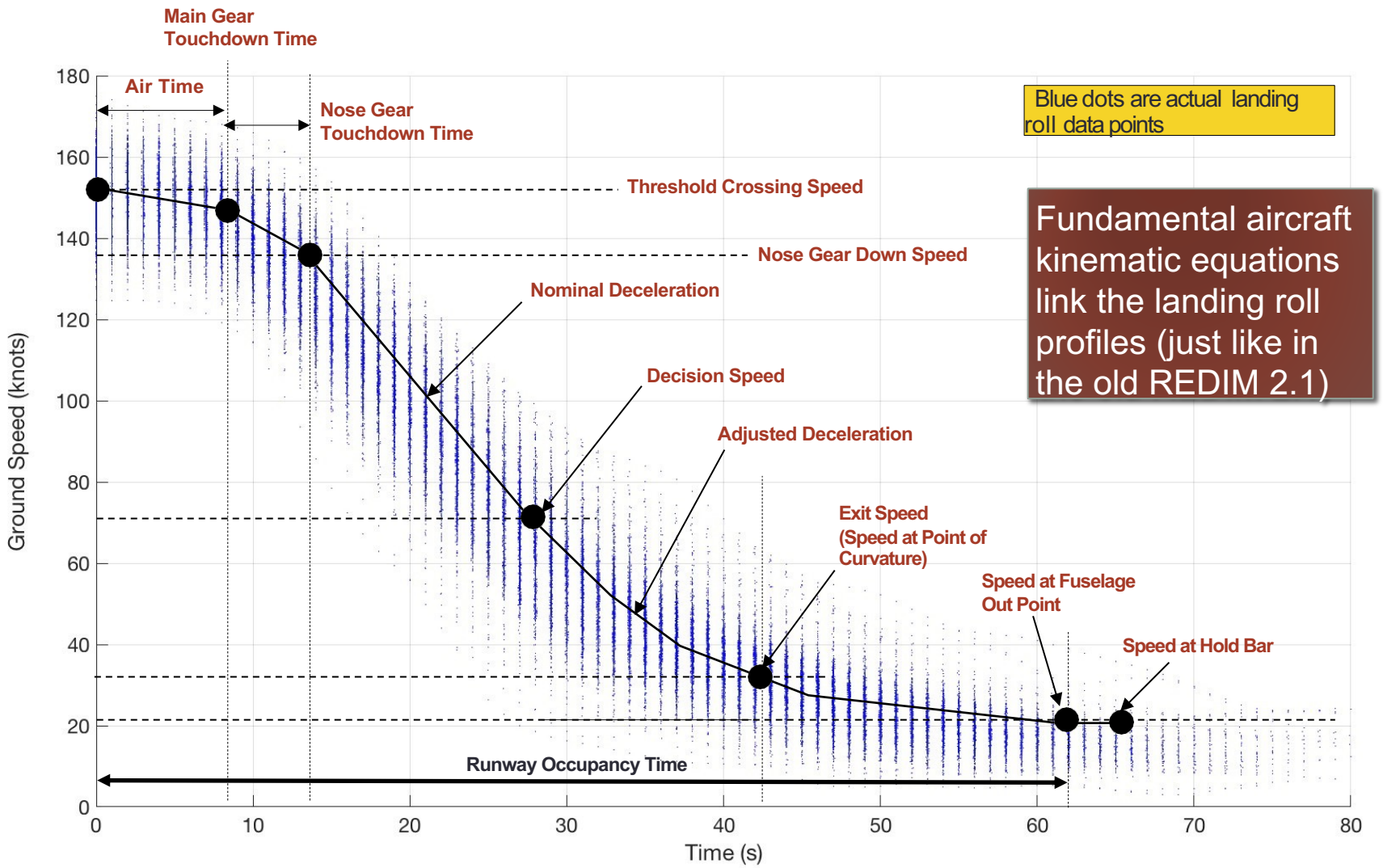
Runway occupancy times (tables and plots)

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

REDIM 3 Individual Aircraft Deceleration Model

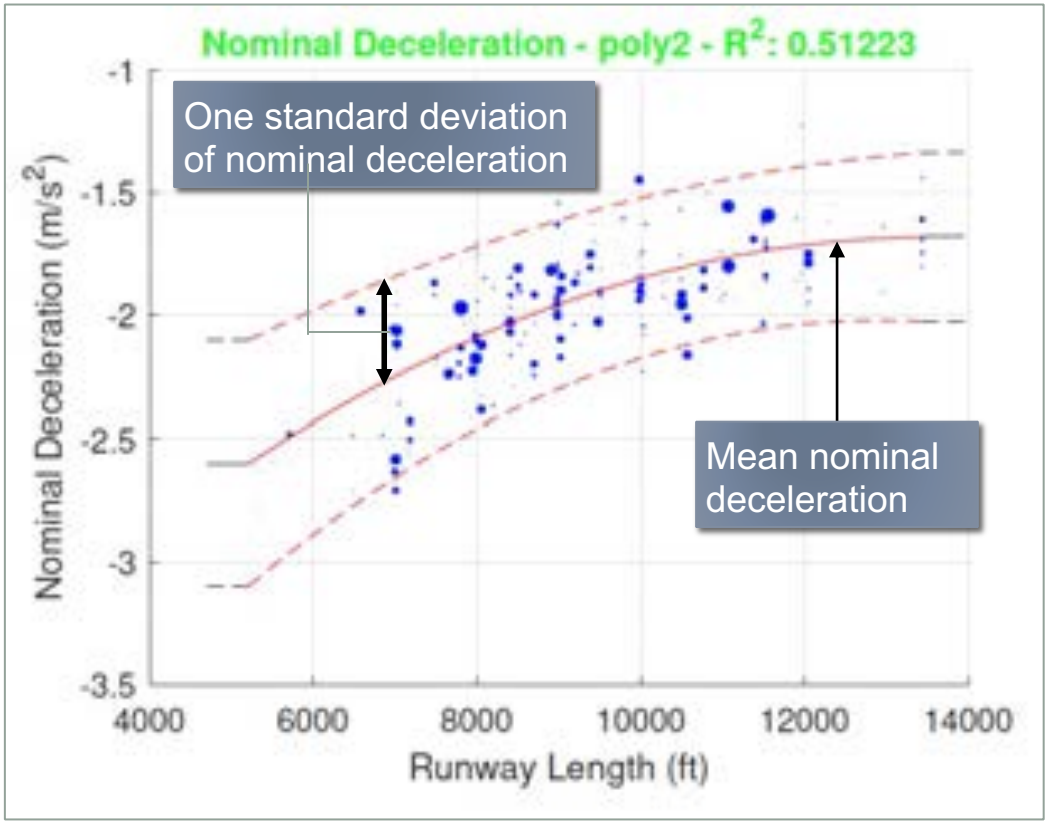
Airbus A320 Data
for all runway clusters

Issue: Some runway clusters are dominated by runways with few exits and produce atypical deceleration behavior

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

REDIM 4 Individual Aircraft Deceleration Model

Airbus A320 Data

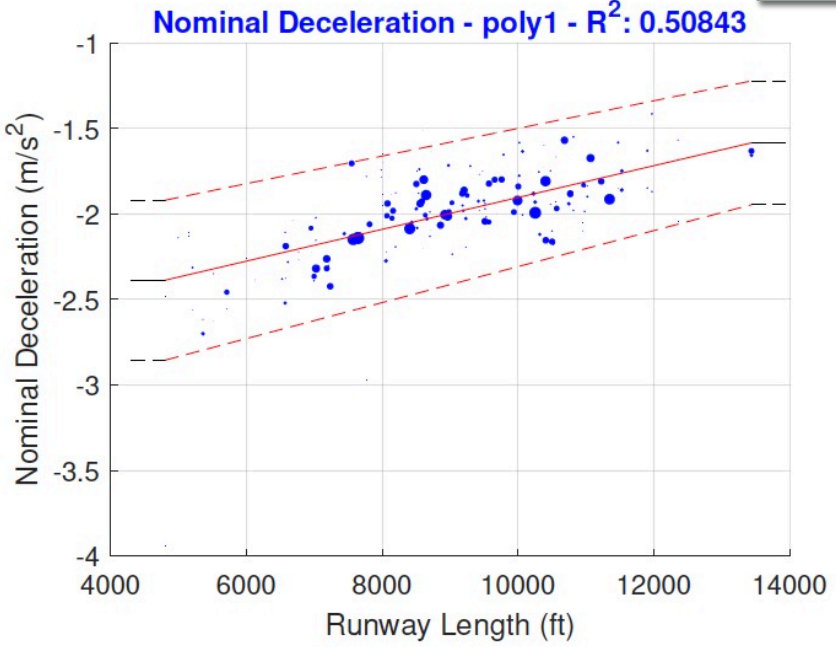


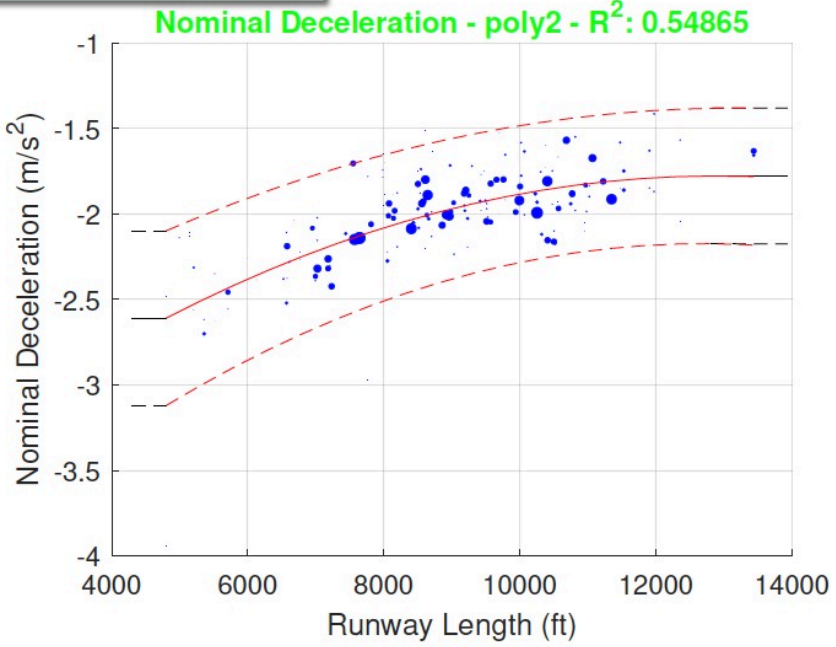
- Model selects the best polynomial fit of nominal deceleration as a function of runway length
- Deceleration data is monotonic
- Each dot is a runway end of data collected at 43 airports
- Each dot is weighted by the number of operations at every airport

Runway Landing Behavior Changes: Nominal Deceleration Rate Model

- Developed statistical models (using linear and second order polynomials) to relate nominal deceleration rate and runway length
- Derived models for 300+ aircraft and also for AAC groups (used as defaults when the number of landing events is not sufficient to create a statistically valid model)

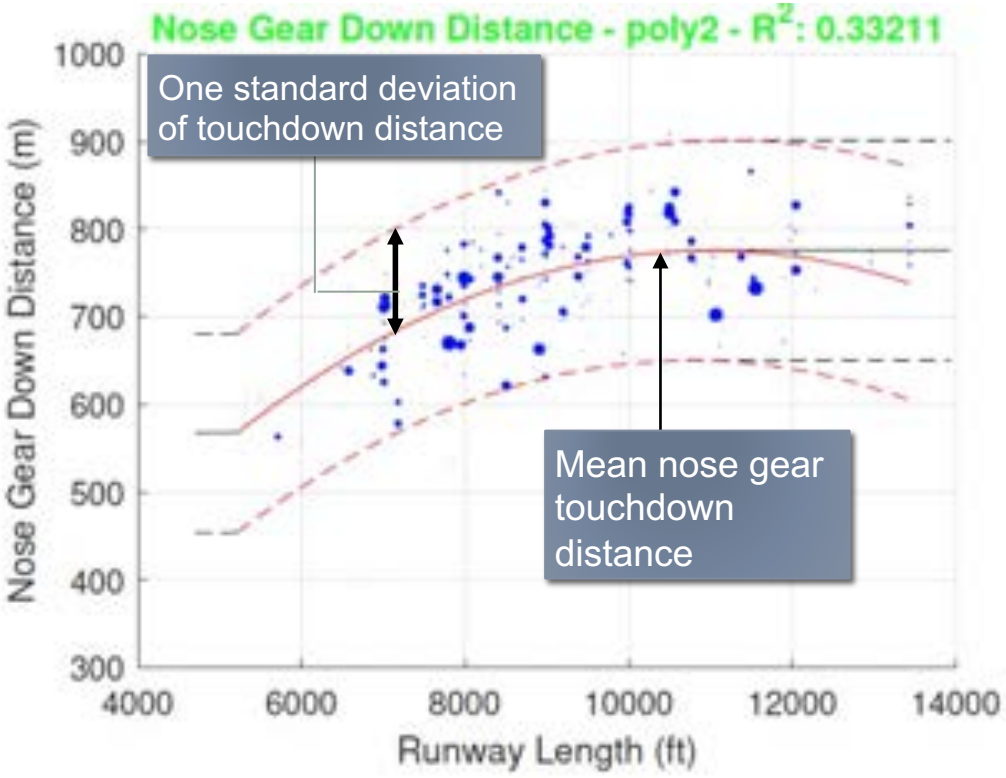
AAC Group C Model





REDIM 4 Individual Aircraft Touchdown Model

Airbus A320 Data

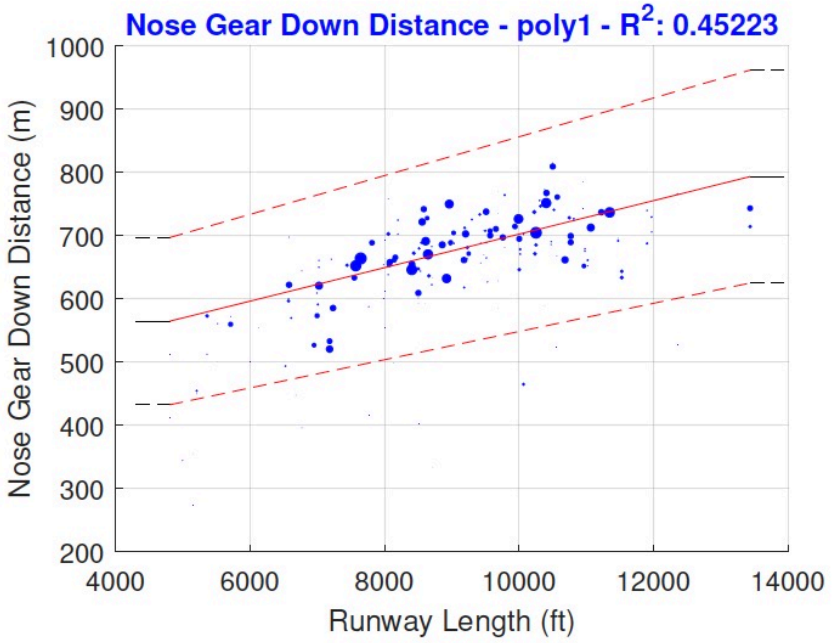


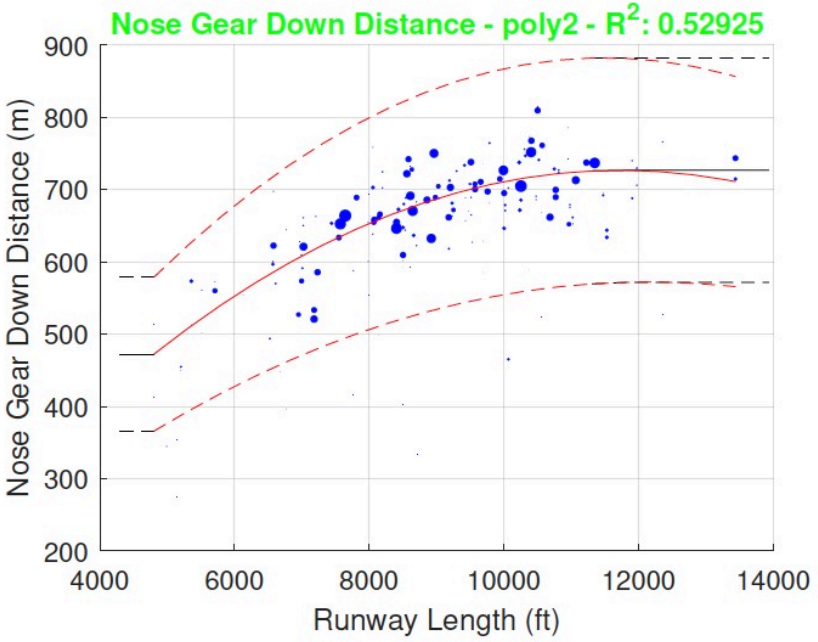
- Model selects the best polynomial fit of the touchdown location as a function of runway length
- Touchdown data is monotonic
- Each dot is a runway end of data collected at 43 airports
- Each dot is weighted by the number of operations at every airport

Runway Landing Behavior Changes: Touchdown Location Model (AAC Group Model)

- Developed statistical models (using linear and second order polynomials) to relate touchdown location (nose gear) and runway length
- Standard deviation metrics are also available in the analysis

AAC C - All - Mean & +/- 1 StdDev - Weighted

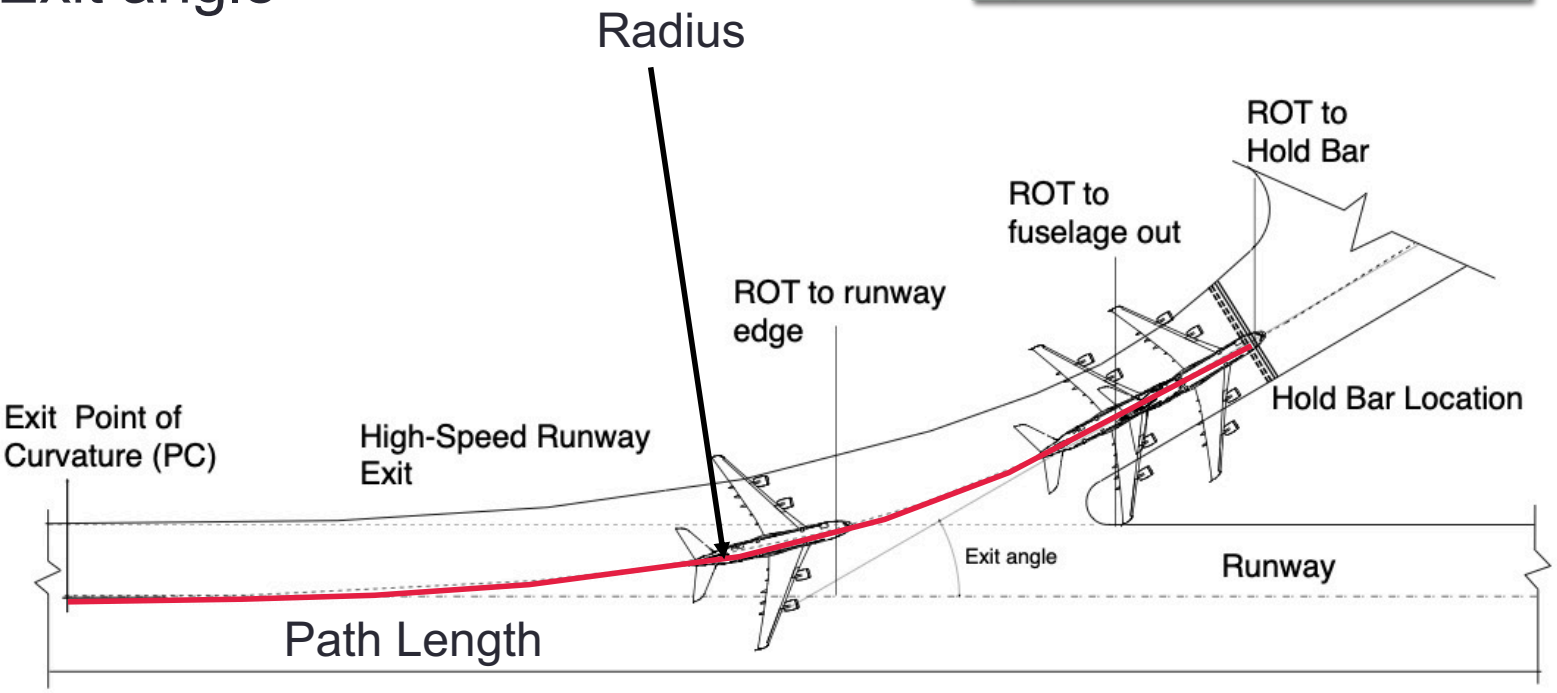




Runway Exit Clusters and Geometry

- 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



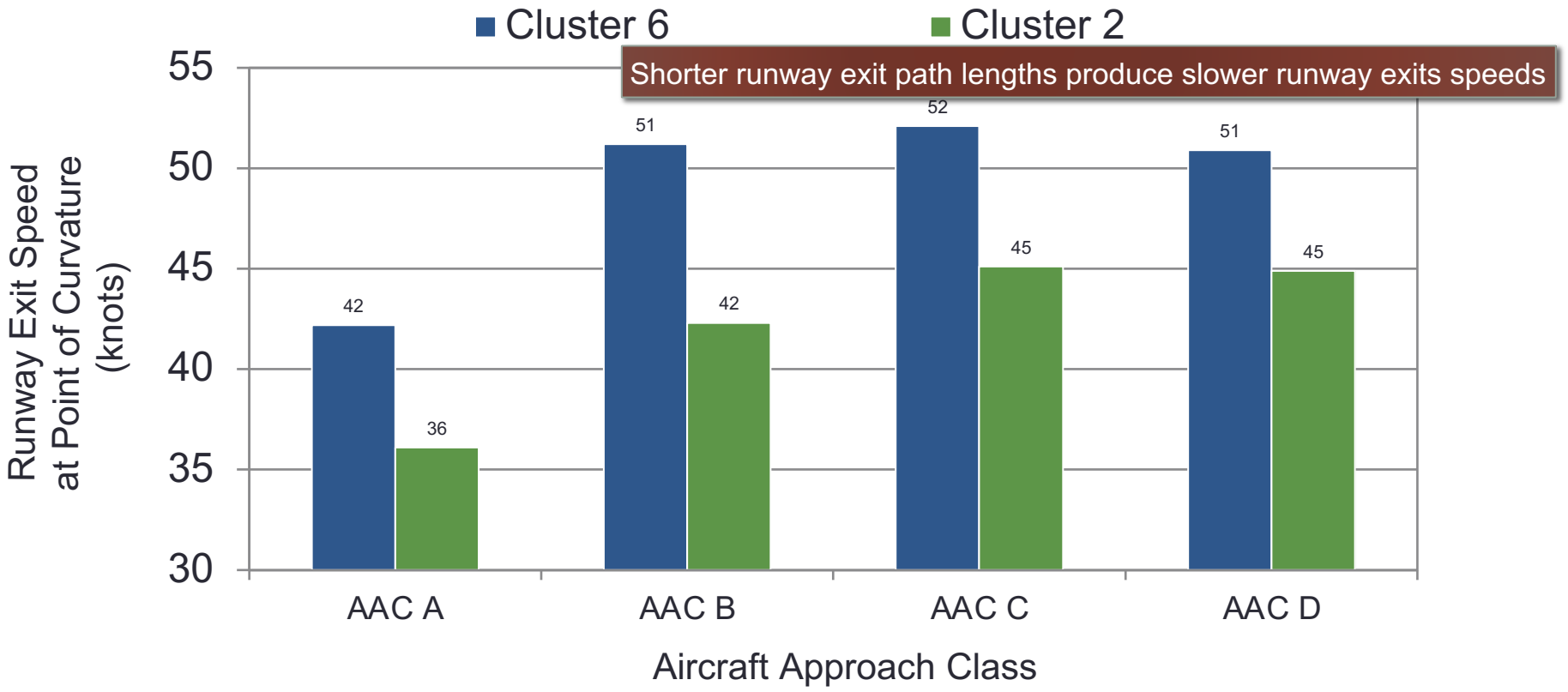
Runway Exit Clusters in REDIM 3

	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 length

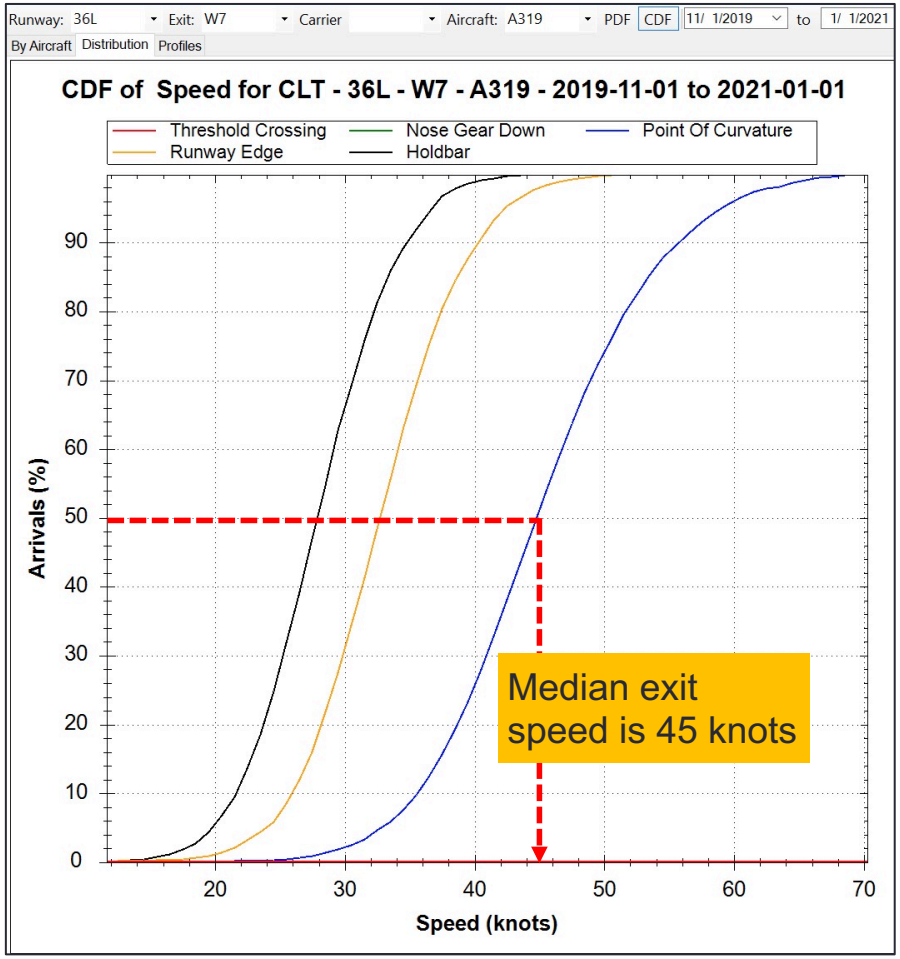
Model uses 20 runway exit clusters to differentiate runway exit characteristics

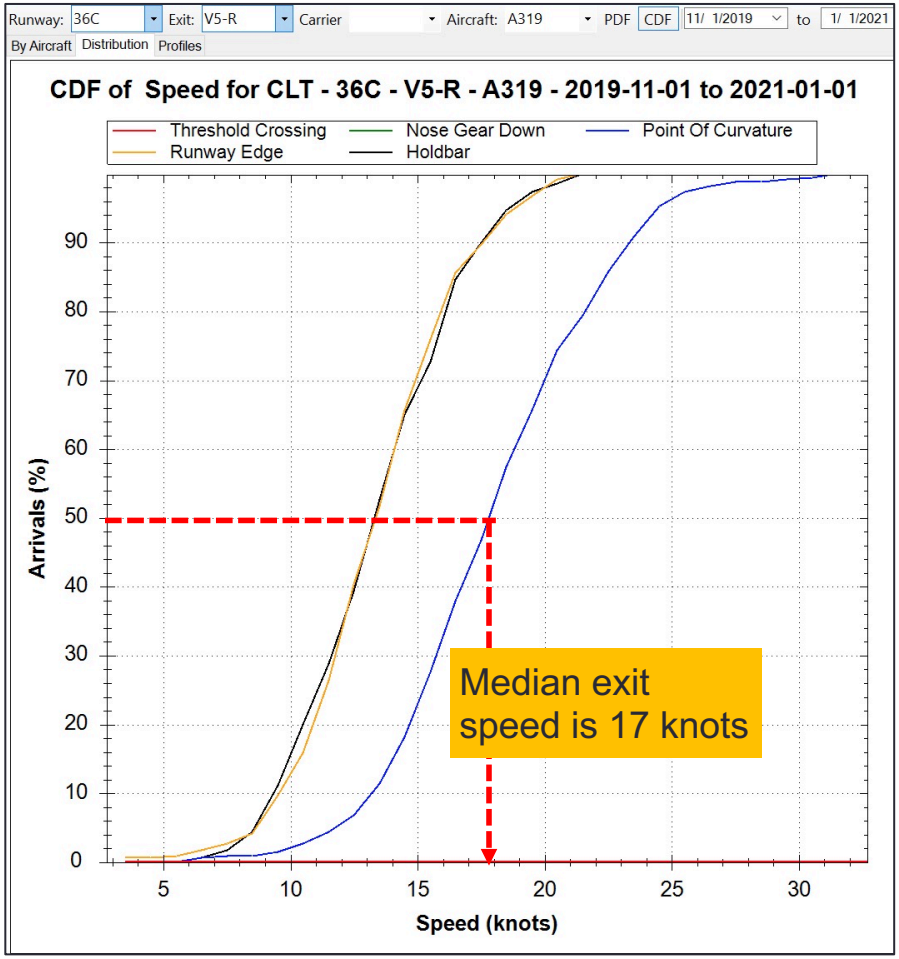
Effect of Runway Exit Cluster on Exit Speed

	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



Exit Speed for Different Runway Exits (CLT)

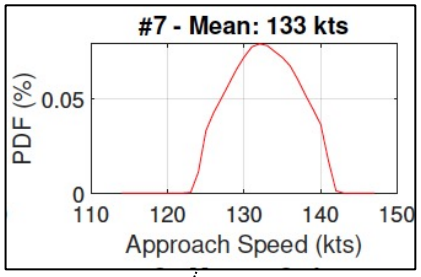


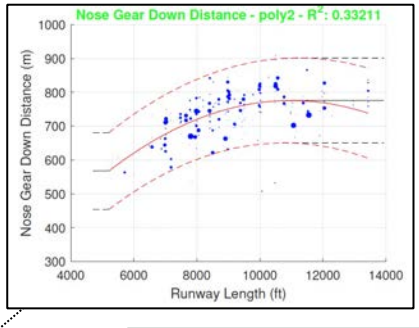


High-speed exit W7
Radius of curve = 1,800 feet
Exit angle = 30 degrees
Path length = 1050 feet

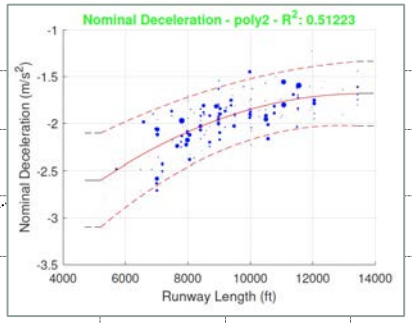
Right angle exit V5
Radius of curve = 150 feet
Exit angle = 90 degrees
Path length = 370 feet

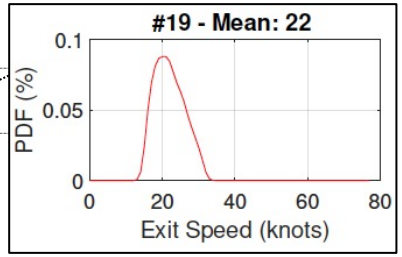
Monte Carlo Simulation in REDIM 4





Typical distributions for an Airbus A320 landing

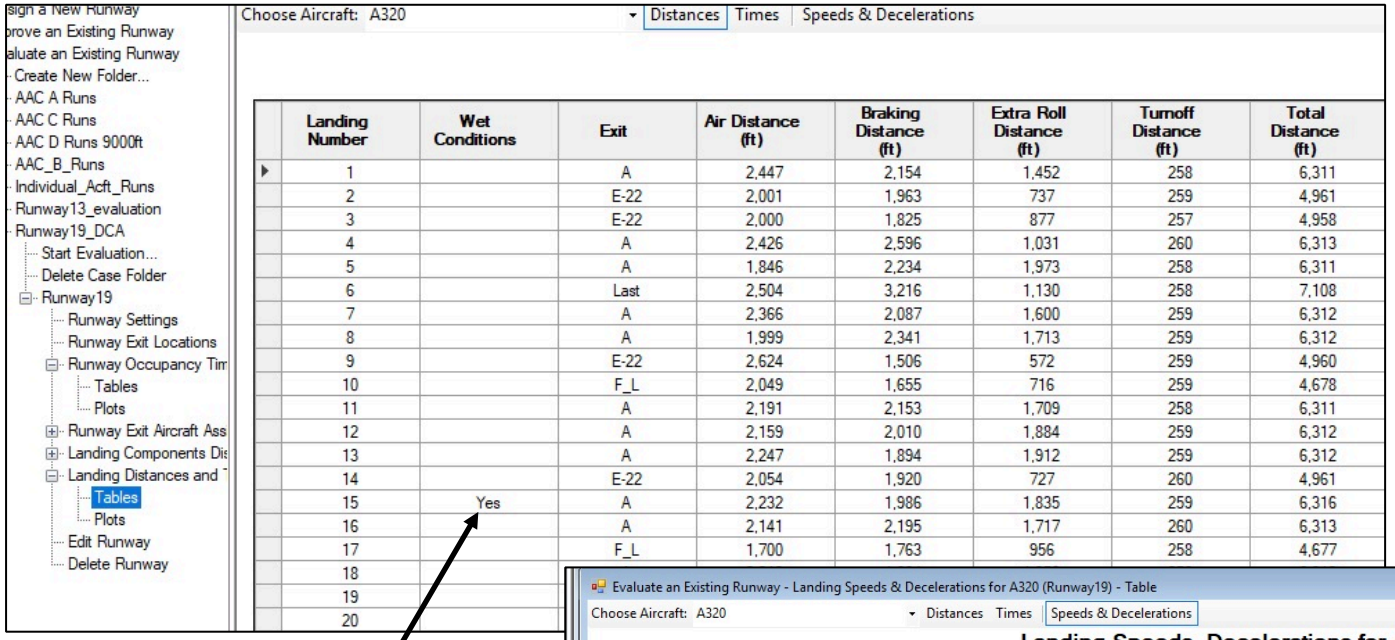




Exit Speed Distribution for Cluster 2 runway exit - right angle runway exit

REDIM 4 uses the new polynomial distributions for nominal deceleration rate and nose gear down location

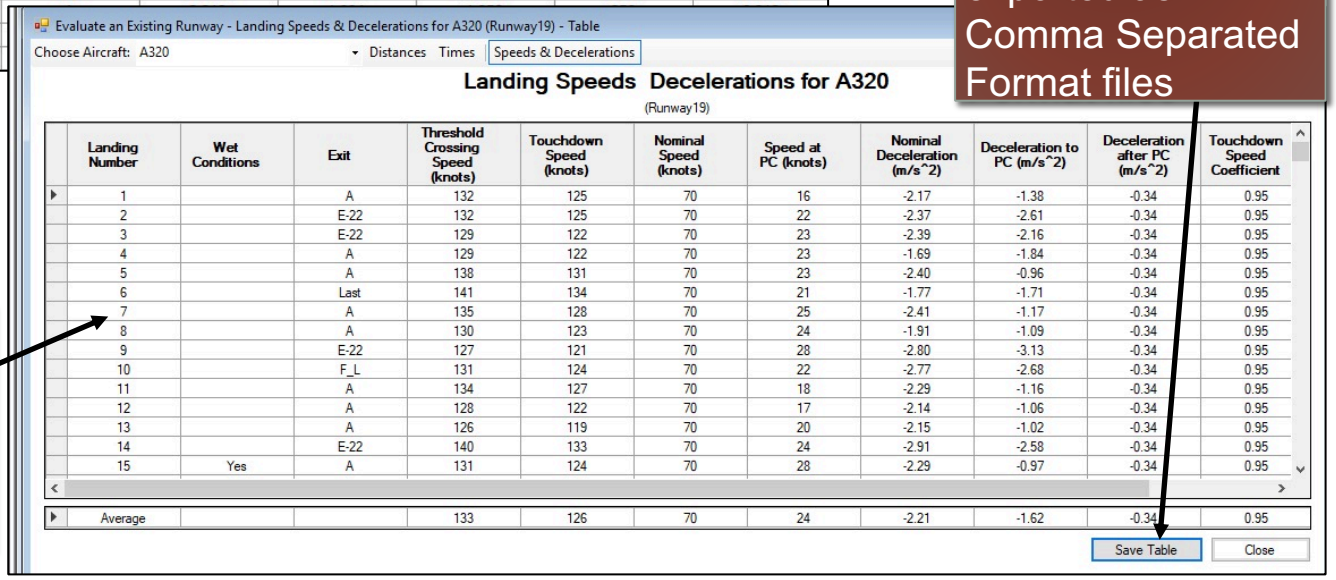
REDIM 3/4 Output (Tabular Form)



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



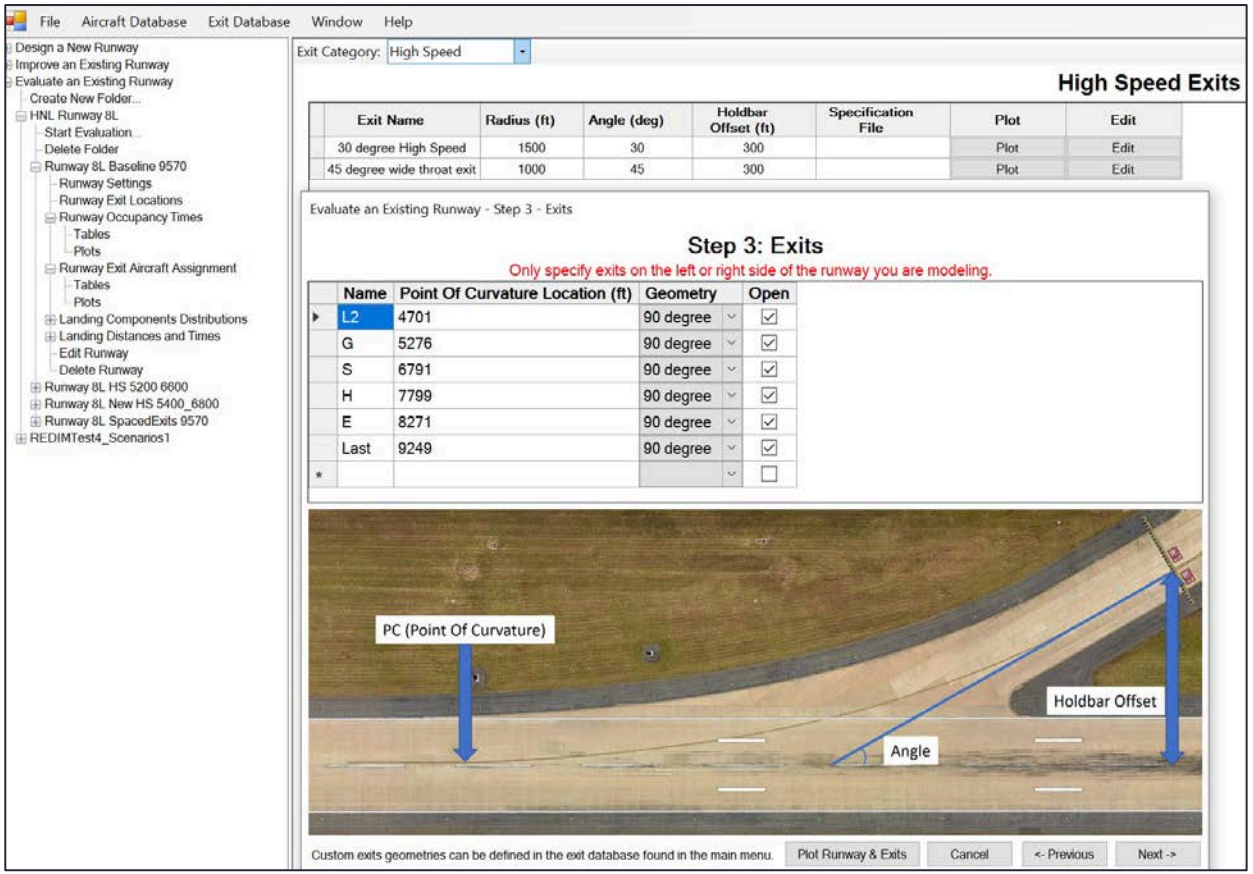
Landing Number	Wet Conditions	Exit	Threshold Crossing Speed (knots)	Touchdown Speed (knots)	Nominal Speed (knots)	Speed at PC (knots)	Nominal Deceleration (m/s^2)	Deceleration to PC (m/s^2)	Deceleration after PC (m/s^2)	Touchdown Speed Coefficient
1		A	132	125	70	16	-2.17	-1.38	-0.34	0.95
2		E-22	132	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	-0.34	0.95

Save Table | Close

All output tables can be exported as Comma Separated Format files

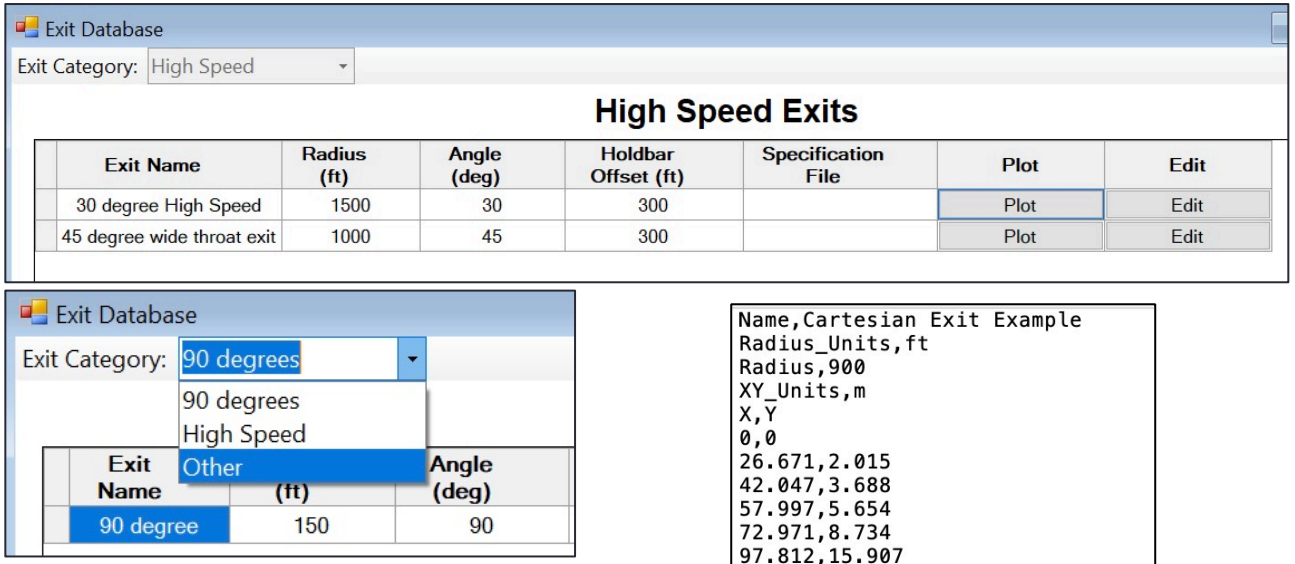
Runway Exit Design Library and Improved Turnoff Simulation

- Purpose is to handle more efficiently how users define runway exits in the model
- A library allows a user to specify either standard or custom exits and just place them along the runway
- User-defined runway exits using simple parameters employing cartesian or absolute latitude and longitude coordinates

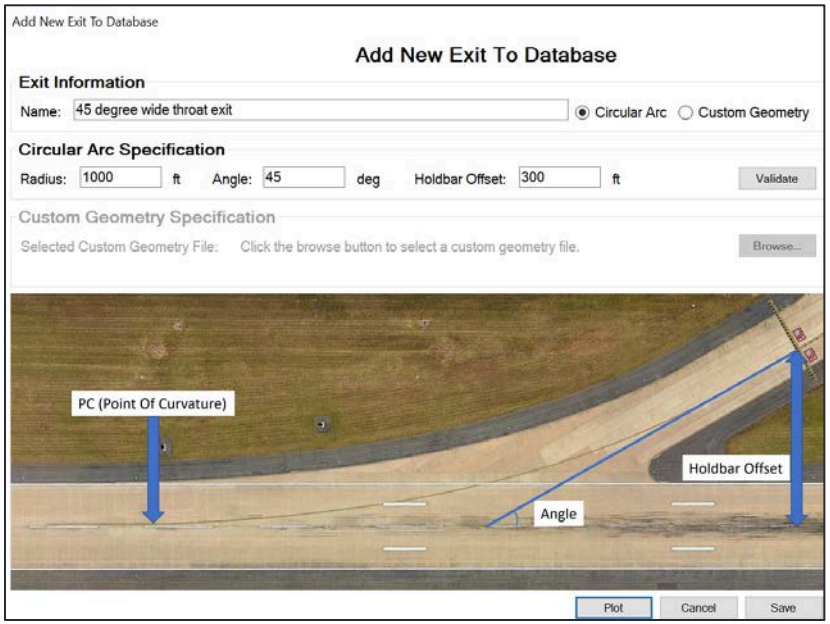


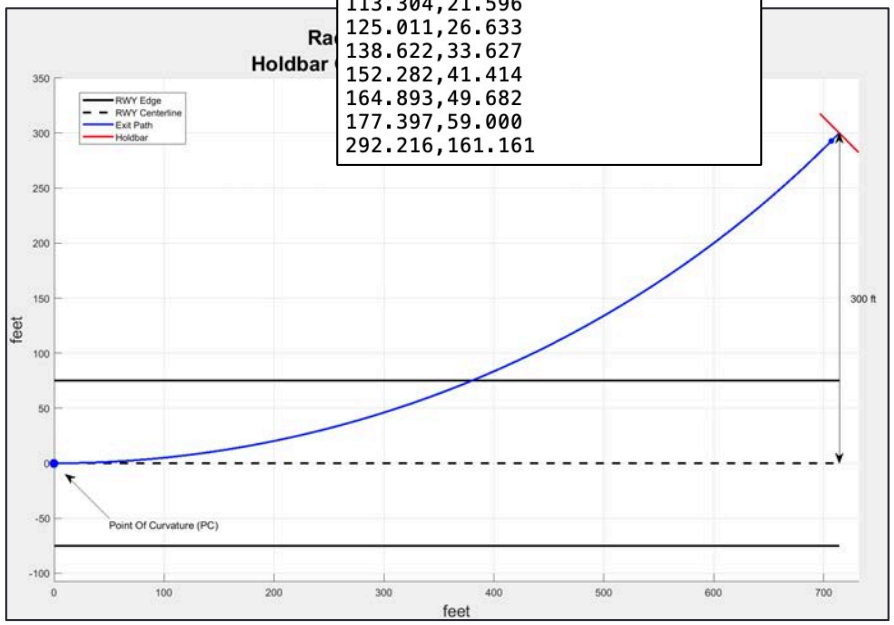
Adding a Runway Exit to the Runway Exit Database

- Define runway parameters
- Validate the parameters
- Plot the runway exit geometry



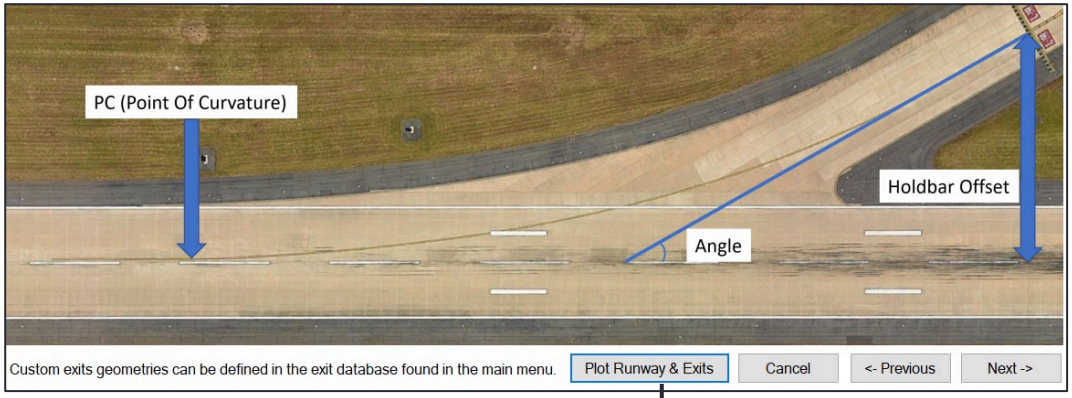

```
Name,Cartesian Exit Example
Radius_Units,ft
Radius,900
XY_Units,m
X,Y
0,0
26.671,2.015
42.047,3.688
57.997,5.654
72.971,8.734
97.812,15.907
113.304,21.596
125.011,26.633
138.622,33.627
152.282,41.414
164.893,49.682
177.397,59.000
292.216,161.161
```



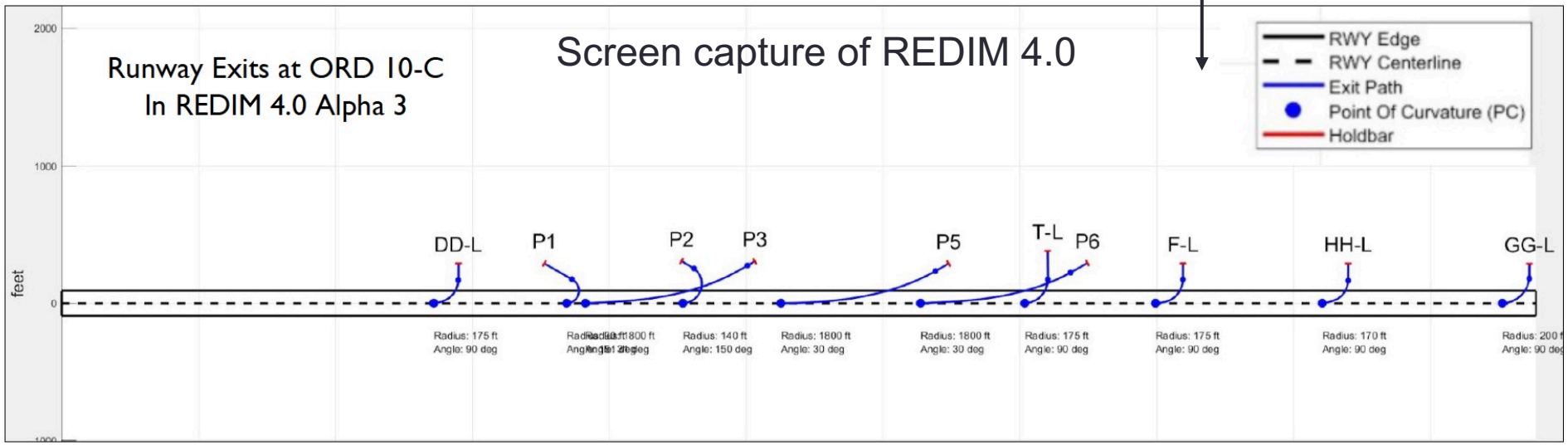


Runway Exits along a Runway (REDIM 4)

- Provides a view of runway exit geometries along the runway for a given scenario
- Centerline geometries are plotted to scale (see figure below)
- Overlaps between adjacent runway exits can be easily detected

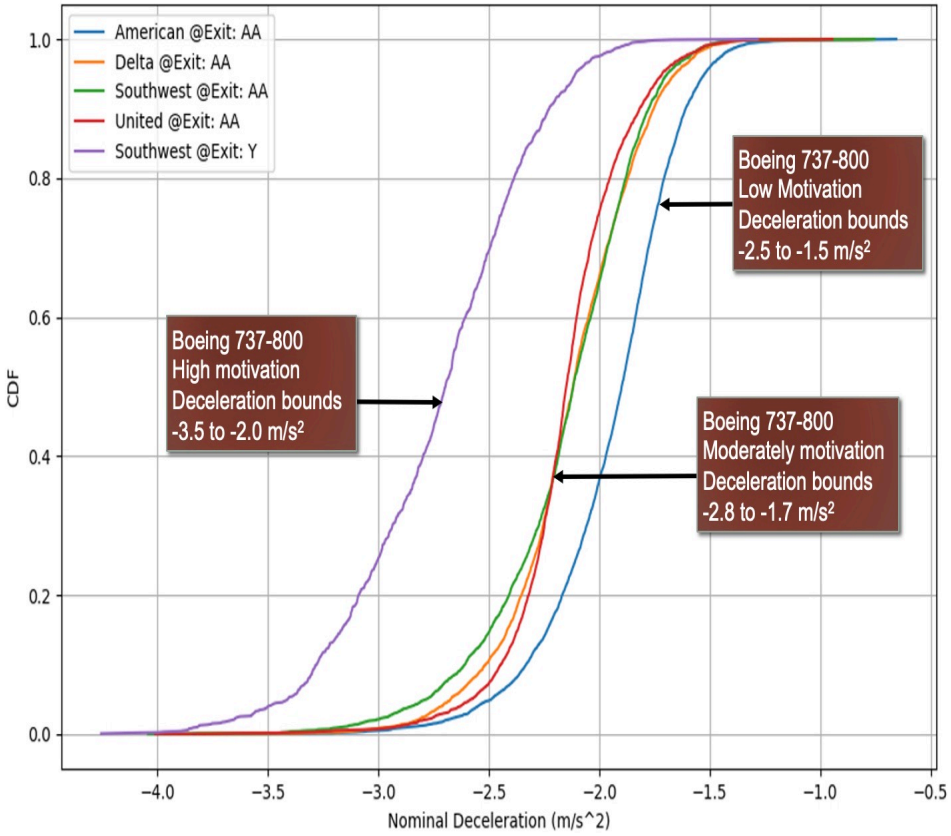


Screen capture of REDIM 4.0



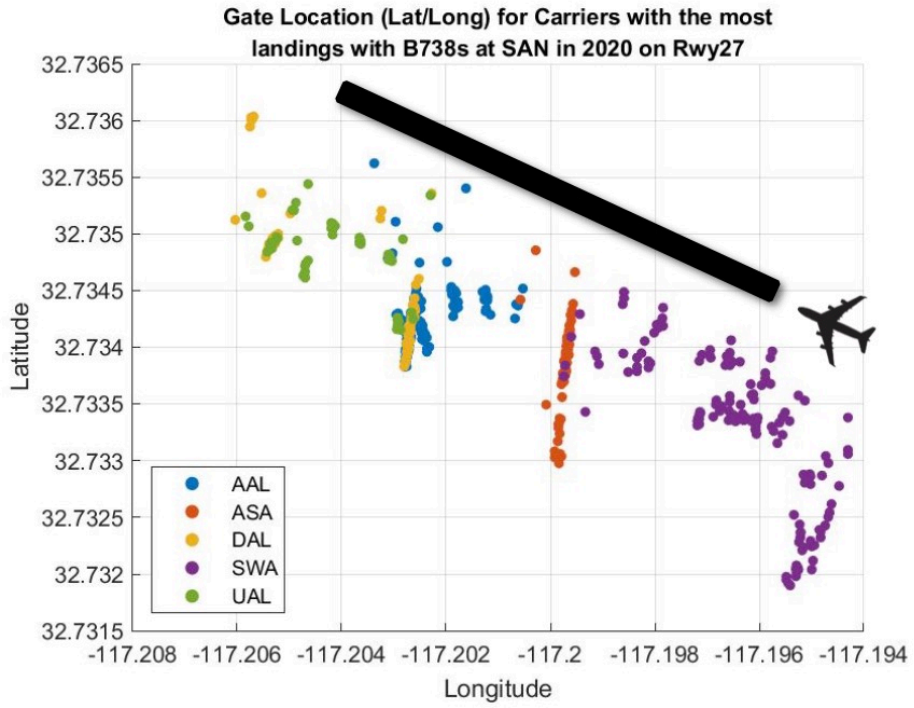
Pilot Motivation Analysis

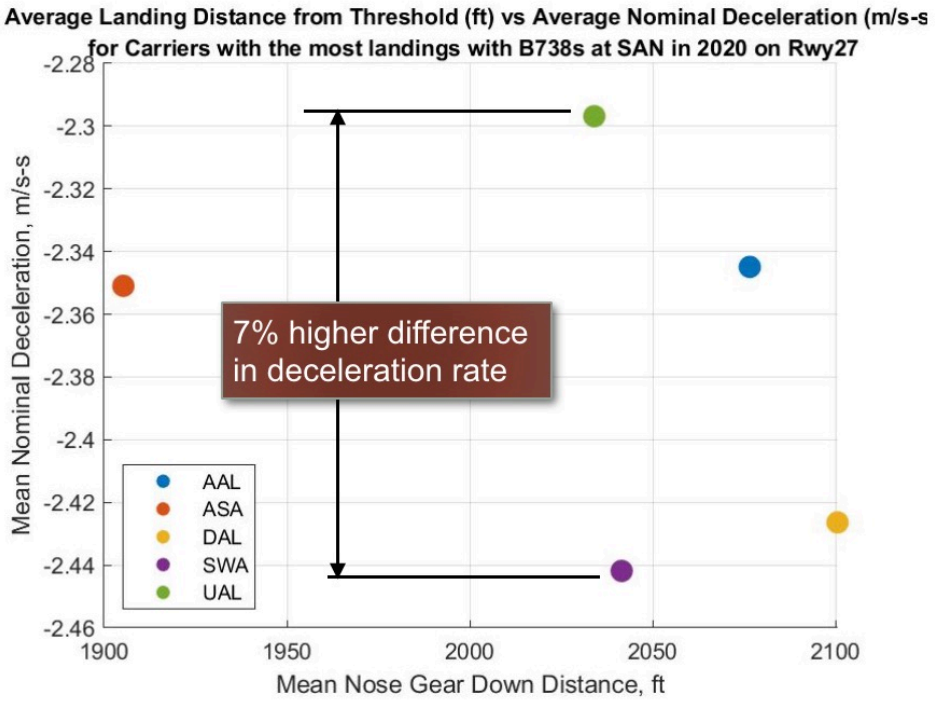
- Examined conditions at various airports to identify pilot motivation
- Identified landing parameters that can be used to identify pilot motivation (or lack of motivation)
  - Nominal deceleration rate
  - Touchdown location
- Investigated differences in critical pilot motivation parameters by aircraft type and runway length



Pilot Motivation Analysis: San Diego

- Touchdown distance and deceleration rate can be used to assess pilot motivational practices
- Example: SWA pilots tend to decelerate more aggressively while landing at SAN runway 27 due to the location of gates for SWA

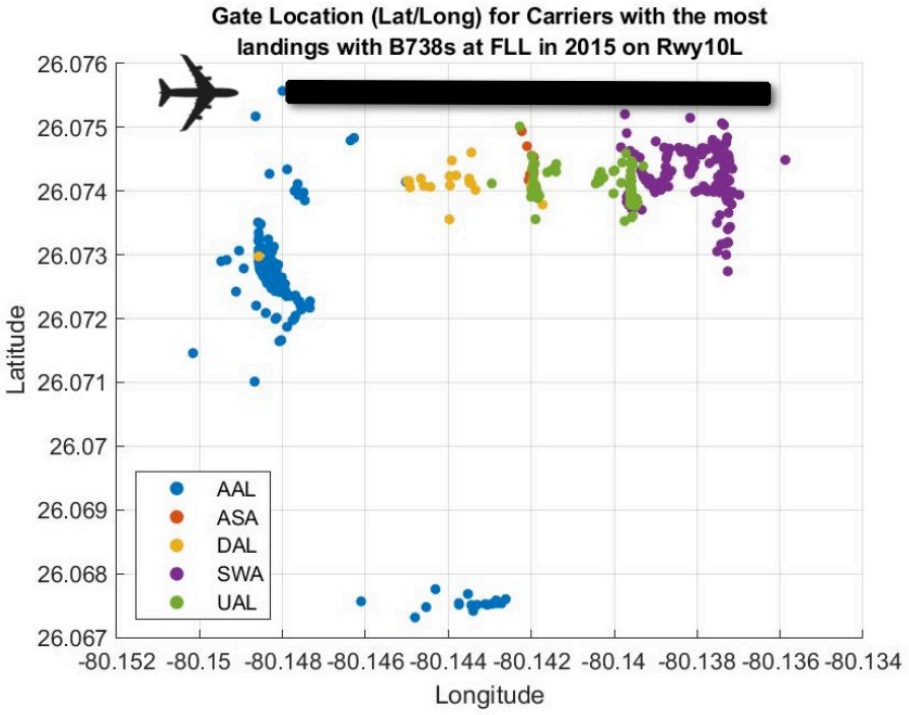


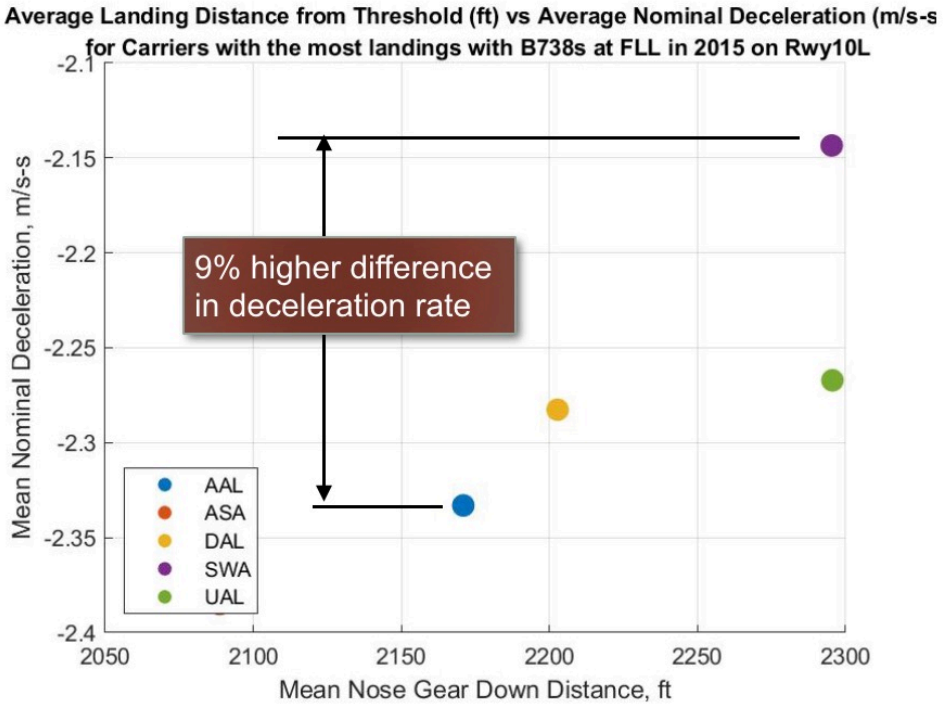


San Diego International Airport Runway 27 (LDA = 7,591 ft)

Pilot Motivation Analysis: Fort Lauderdale

- Touchdown distance and deceleration rate can be used to assess pilot motivational practices
- Example: SWA pilots tend to decelerate more aggressively while landing at SAN runway 27 due to the location of gates for SWA





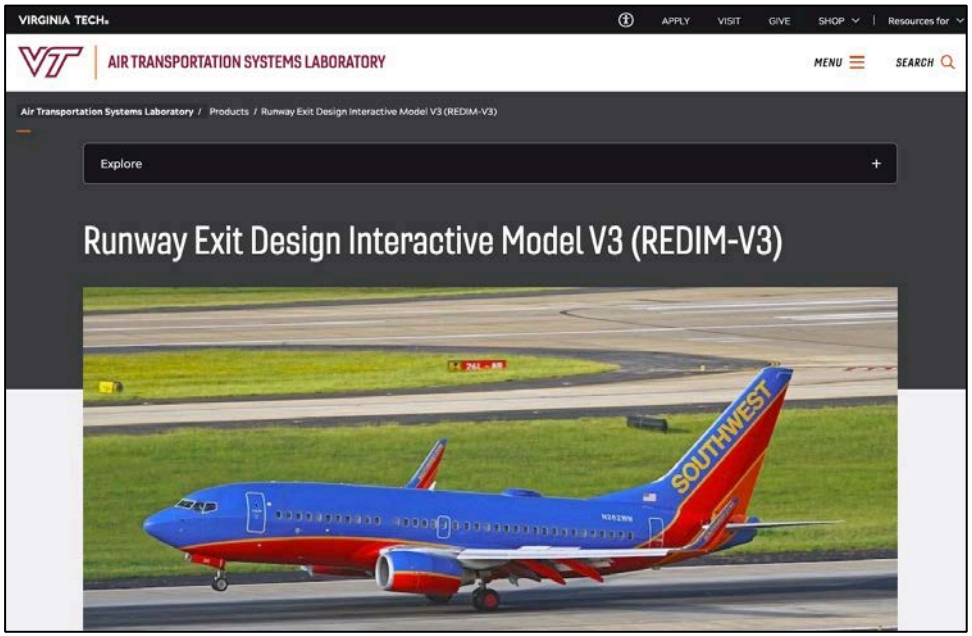
Fort Lauderdale International Airport Runway 10L (LDA = 8,424 ft)

Aircraft Characteristics Database

- Review and Validation of FAA Aircraft Characteristics Database
  - Review the information of the existing Aircraft Characteristics Database (ACD) to identify the aircraft characteristics to be included in ACD
  - Review the accuracy of the information (data validation)
- Integration of FAA ACD into REDIM and Landing Events Database

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

Application of Runway Exit Design Tool to Selected US Airports

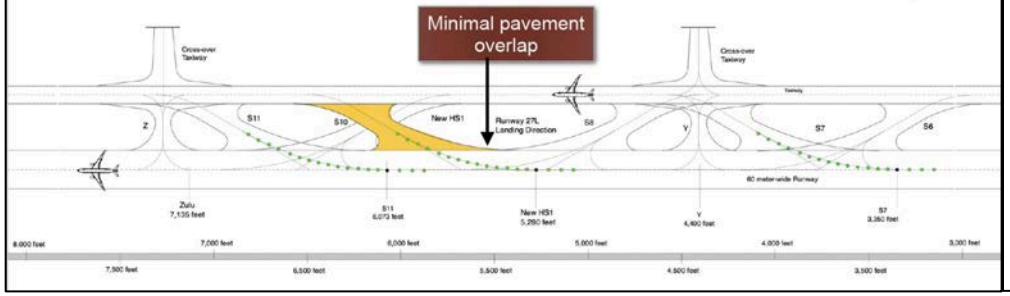
Application of the Runway Exit Design Tool to Four Airports

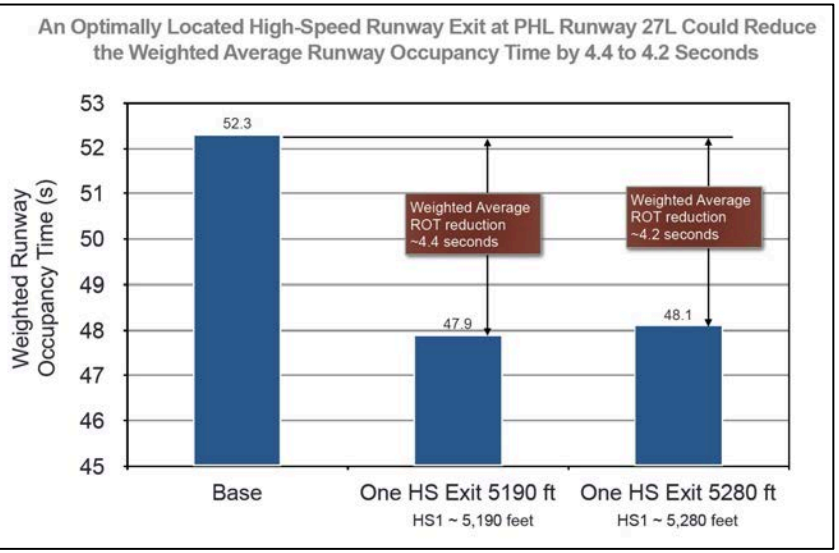
Application of the Runway Exit Design Tool to PHL

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

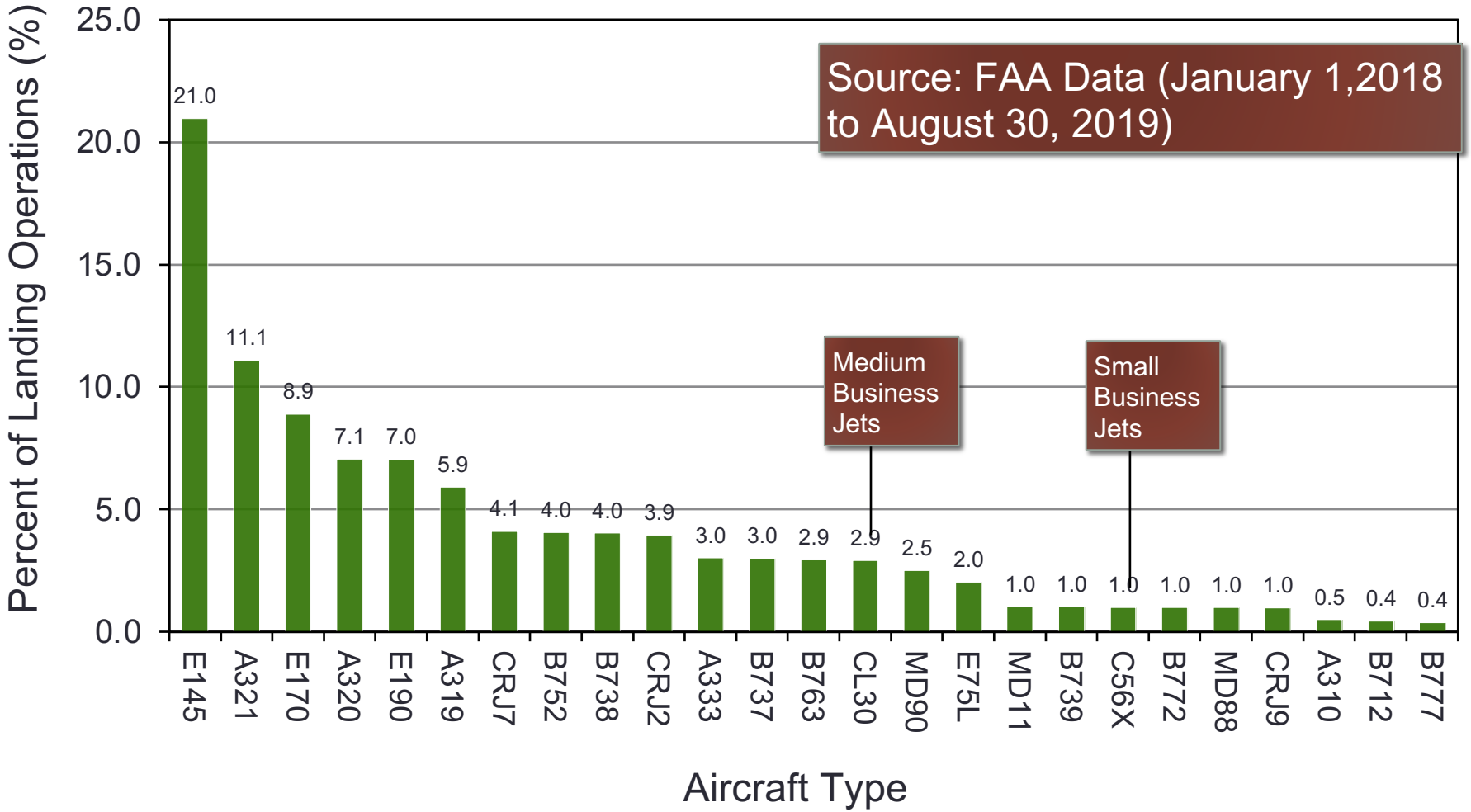
- Optimal location of a **new High-Speed Runway exit** designed for 20/80% wet/dry pavement conditions is **5,280 feet** (point of curvature)
- Runway exit Sierra-9 is eliminated
- **793 feet** - distance between new exit high-speed exit HS2 and Sierra-11

Optimally located runway exit in yellow





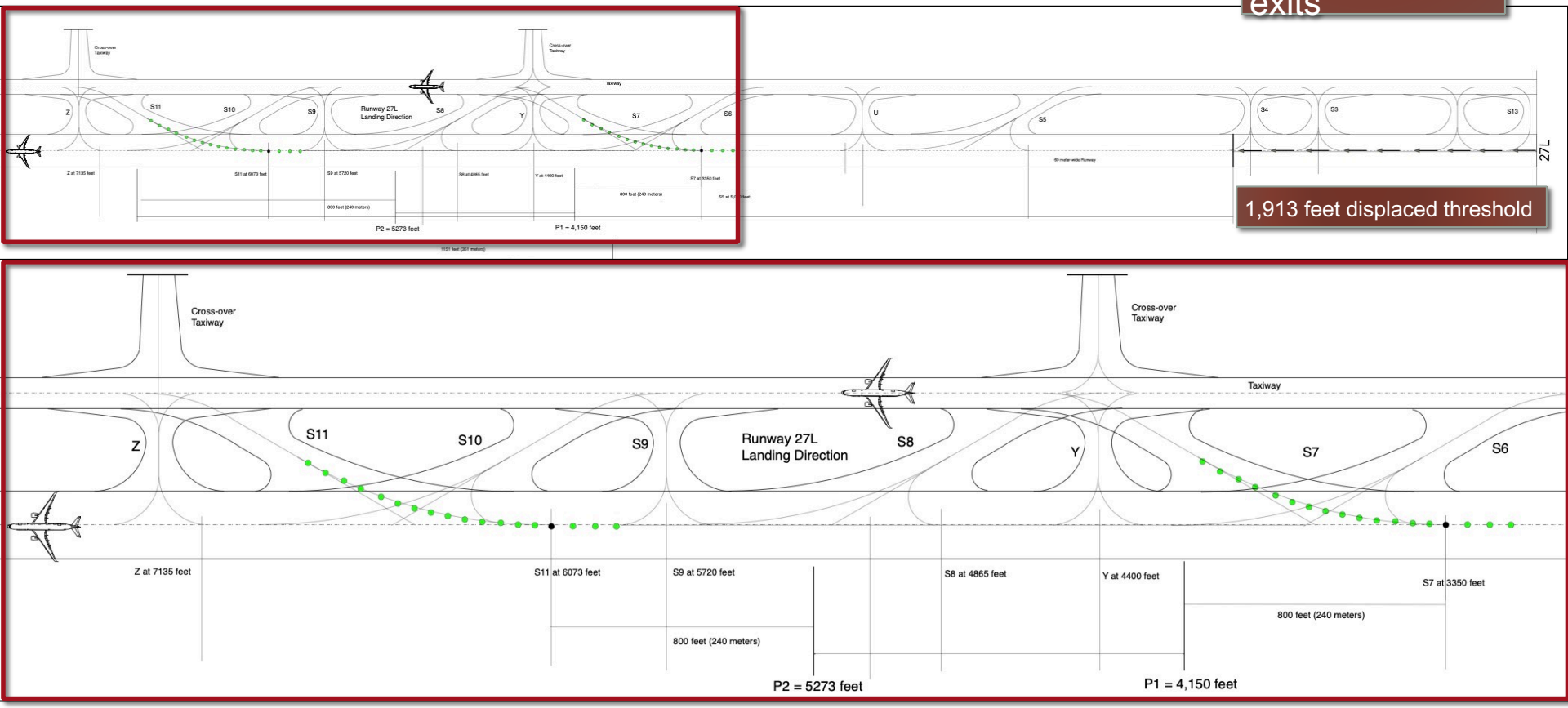
Airport Fleet Mix Used in the Analysis of Runway 27L



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

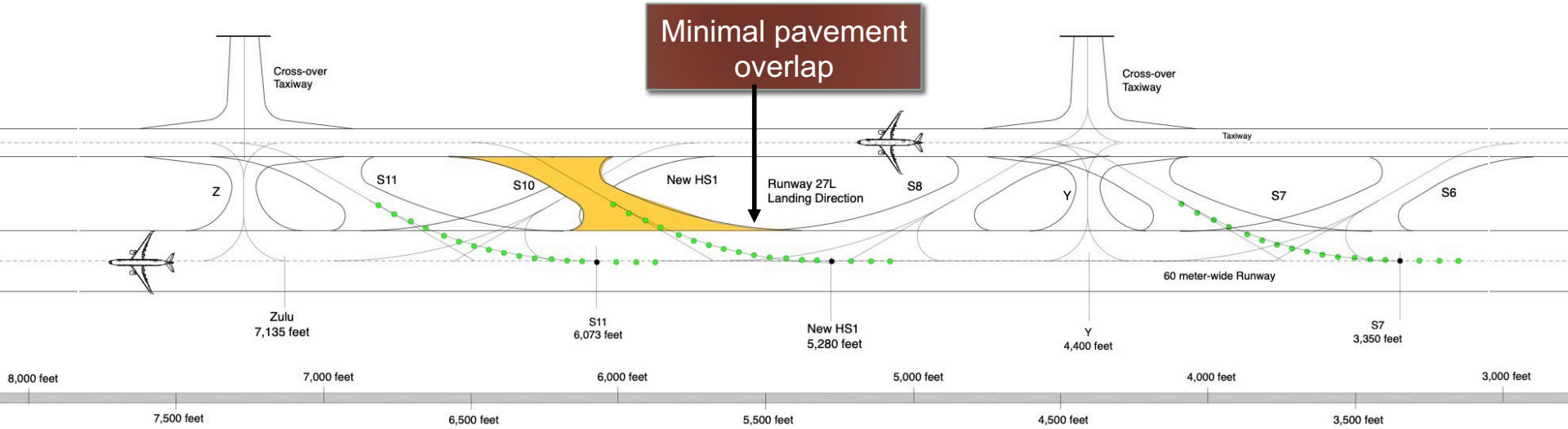
Scenario	Location of New Optimal High-Speed Exit (ft)	Wet/Dry Mix (%/%)	Remarks
Baseline	Not applicable	10/90	Open exits: U, S7, Y, S9, S11, S12 and S13
One High-Speed Runway Exit, 10/90	5,190	10/90	Open exits: U, S7, Y, NewHS1, S11, S12 and S13
One High-Speed Runway Exit, 20/80	5,280	20/80	Open exits: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

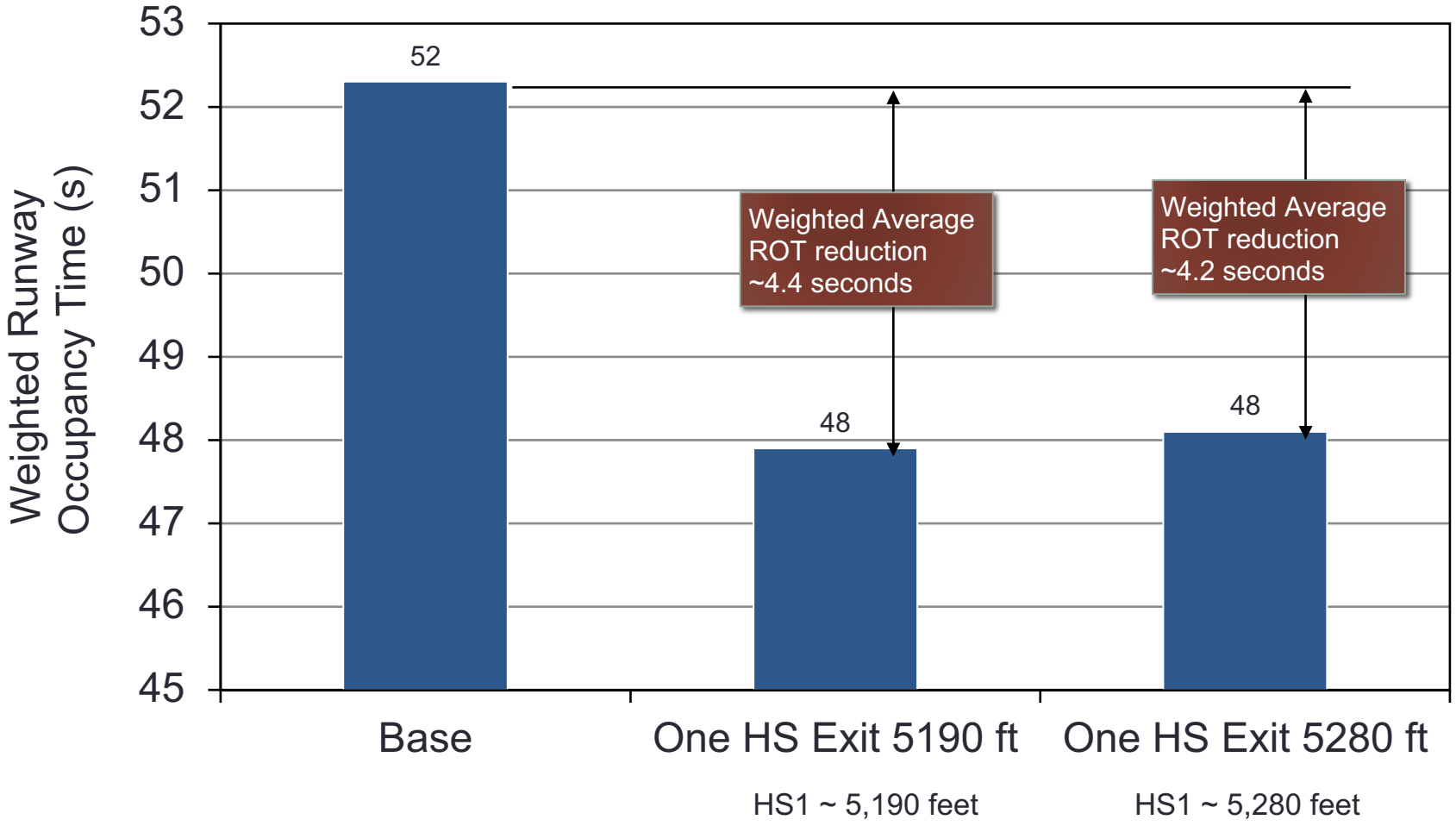
Case: One New High-Speed Runway Exit, 20/80 (wet/dry pavement design)

- 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

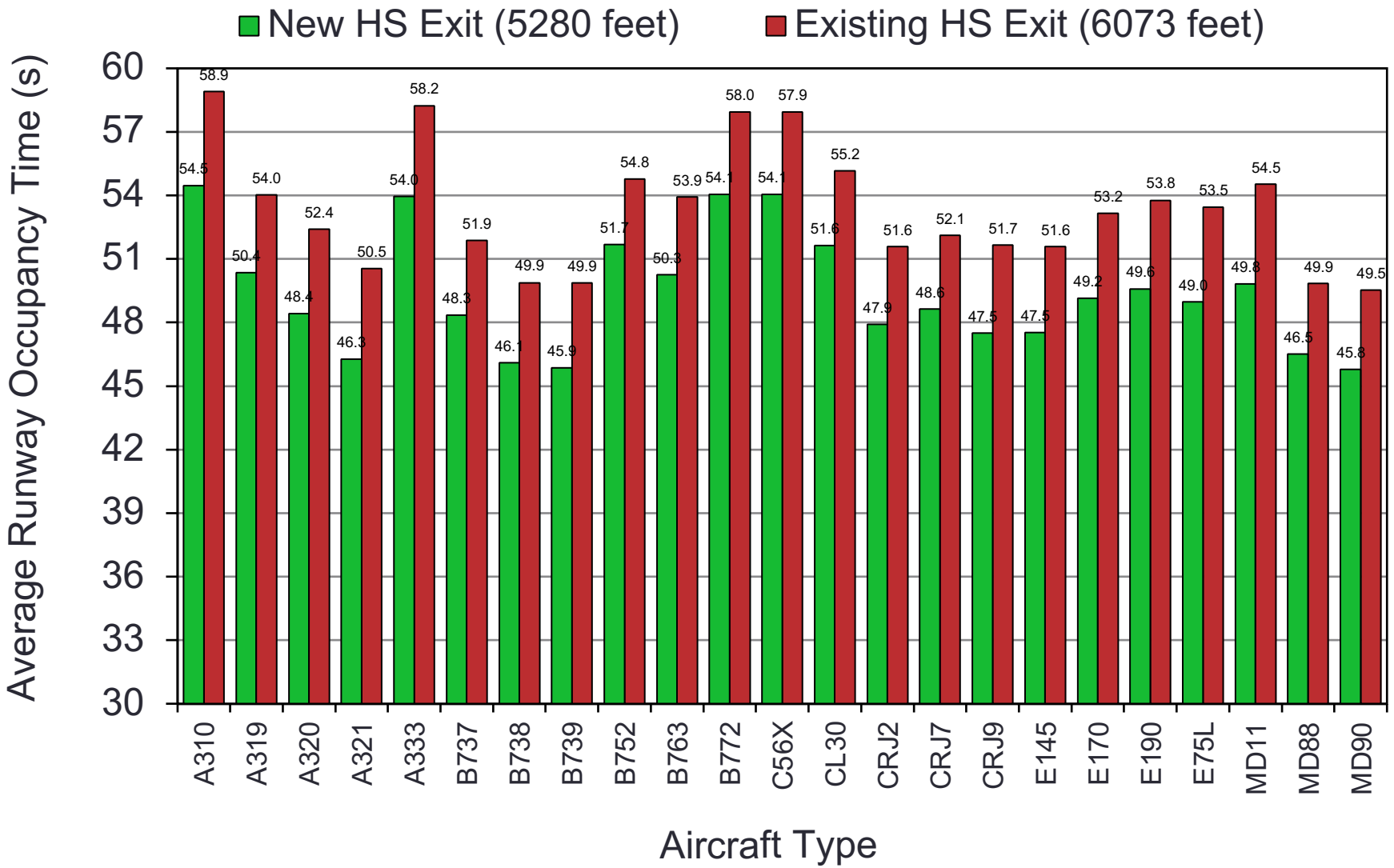


An Optimally Located High-Speed Runway Exit at PHL Runway 27L Could Reduce the Weighted Average Runway Occupancy Time by 4.4 to 4.2 Seconds

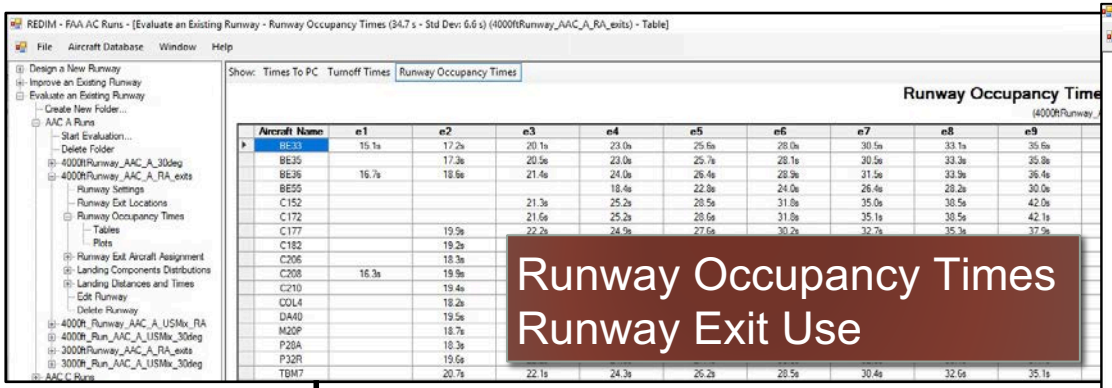


PHL Fleet Mix (Jan/2018 to Aug/2019) provided by FAA

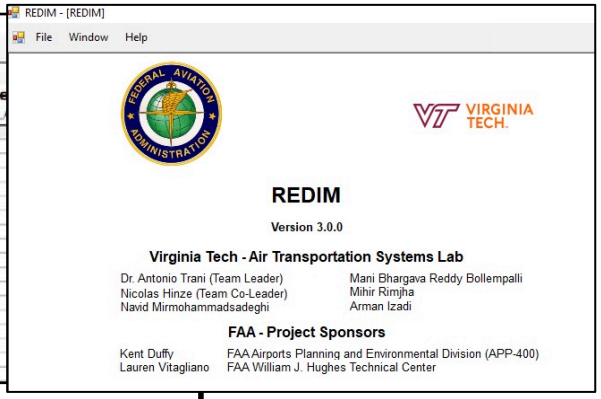
Aircraft Using the New High-Speed Exit at 5,280 feet could Save 3.5-4.7 seconds Compared to Using HS Exit Sierra-11 (6073 ft)

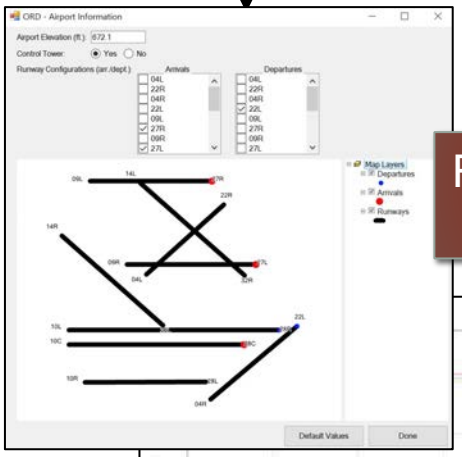


Typical Use of the REDIM Model

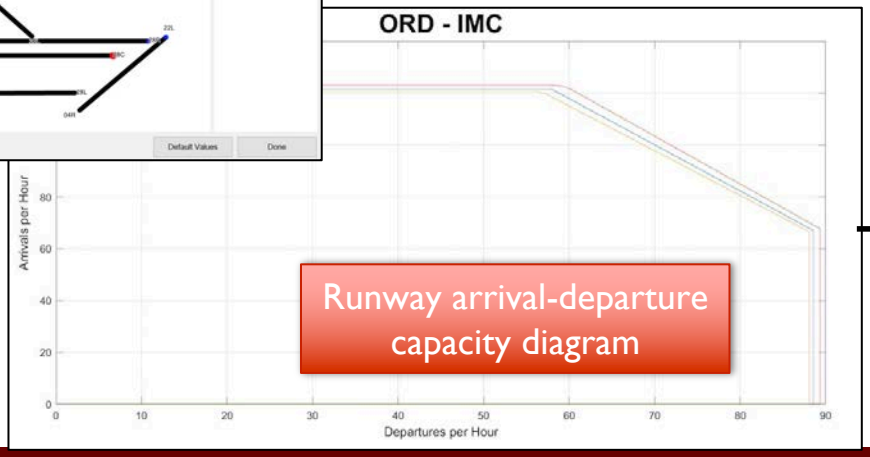


Runway Occupancy Times
Runway Exit Use





Runway Capacity Model



Runway arrival-departure capacity diagram

Fast-time Airport Simulation Model